

POWER Vector Library Manual

1.0.4

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Chapter 1

POWER Vector Library (pveclib)

A library of useful vector functions for POWER. This library fills in the gap between the instructions defined in the POWER Instruction Set Architecture (**PowerISA**) and higher level library APIs. The intent is to improve the productivity of application developers who need to optimize their applications or dependent libraries for POWER.

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1.2 Rationale

The C/C++ language compilers (that support PowerISA) may implement vector intrinsic functions (compiler built-ins as embodied by `altivec.h`). These vector intrinsics offer an alternative to assembler programming, but do little to reduce the complexity of the underlying PowerISA. Higher level vector intrinsic operations are needed to improve productivity and encourage developers to optimize their applications for PowerISA. Another key goal is to smooth over the complexity of the evolving PowerISA and compiler support.

For example: the PowerISA 2.07 (POWER8) provides population count and count leading zero operations on vectors of byte, halfword, word, and doubleword elements but not on the whole vector as a `__int128` value. Before PowerISA 2.07, neither operation was supported, for any element size.

Another example: The original **Altivec** (AKA Vector Multimedia Extension (**VMX**)) provided Vector Multiply Odd / Even operations for signed / unsigned byte and halfword elements. The PowerISA 2.07 added Vector Multiply Even/Odd operations for signed / unsigned word elements. This release also added a Vector Multiply Unsigned Word Modulo operation. This was important to allow auto vectorization of C loops using 32-bit (int) multiply.

But PowerISA 2.07 did not add support for doubleword or quadword (`__int128`) multiply directly. Nor did it fill in the missing multiply modulo operations for byte and halfword. However it did add support for doubleword and quadword add / subtract modulo. This can be helpful, if you are willing to apply grade school arithmetic (add, carry the 1) to vector elements.

PowerISA 3.0 (POWER9) did add a Vector Multiply-Sum Unsigned Doubleword Modulo operation. With this instruction (and a generated vector of zeros as input) you can effectively implement the simple doubleword integer multiply modulo operation in a few instructions. Similarly for Vector Multiply-Sum Unsigned Halfword Modulo. But this may not be obvious.

This history embodies a set of trade-offs negotiated between the Software and Processor design architects at specific points in time. But most programmers would prefer to use a set of operators applied across the supported element types and sizes.

1.2.1 POWER Vector Library Goals

Obviously many useful operations can be constructed from existing PowerISA operations and GCC `<altivec.h>` built-ins but the implementation may not be obvious. The optimum sequence will vary across the PowerISA levels as new instructions are added. And finally the compiler's built-in support for new PowerISA instructions evolves with the compiler's release cycle.

So the goal of this project is to provide well crafted implementations of useful vector and large number operations.

- Provide equivalent functions across versions of the PowerISA. This includes some of the most useful vector instructions added to POWER9 (PowerISA 3.0B). Many of these operations can be implemented as inline function in a few vector instructions on earlier PowerISA versions.
- Provide equivalent functions across versions of the compiler. For example built-ins provided in later versions of the compiler can be implemented as inline functions with inline asm in earlier compiler versions.
- Provide complete arithmetic operations across supported C types. For example multiply modulo and even/odd for `int`, `long`, and `__int128`.
- Provide complete extended arithmetic (carry / extend / multiple high) operations across supported C types. For example add / subtract with carry and extend for `int`, `long`, and `__int128`.
- Provide higher order functions not provided directly by the PowerISA. For example vector SIMD implementation for ASCII `__isalpha`, etc. As another example full `__int128` implementations of Count Leading Zeros, Population Count, Shift left/right immediate, and large integer multiply/divide.
- Most implementations should be small enough to inline and allow the compiler opportunity to apply common optimization techniques.
- Larger Implementations should be built into platform specific object archives and dynamic shared objects. Shared objects should use **IFUNC resolvers** to bind the dynamic symbol to best implementation for the platform (see [Putting the Library into PVECLIB](#)).

1.2.1.1 POWER Vector Library Intrinsic headers

The POWER Vector Library will be primarily delivered as C language inline functions in headers files.

- [vec_common_ppc.h](#) Typedefs and helper macros
- [vec_int512_ppc.h](#) Operations on multiple precision integer values
- [vec_int128_ppc.h](#) Operations on vector `__int128` values
- [vec_int64_ppc.h](#) Operations on vector long int (64-bit) values
- [vec_int32_ppc.h](#) Operations on vector int (32-bit) values
- [vec_int16_ppc.h](#) Operations on vector short int (16-bit) values
- [vec_char_ppc.h](#) Operations on vector char (values) values
- [vec_bcd_ppc.h](#) Operations on vectors of Binary Code Decimal and Zoned Decimal values
- [vec_f128_ppc.h](#) Operations on vector `_Float128` values
- [vec_f64_ppc.h](#) Operations on vector double values
- [vec_f32_ppc.h](#) Operations on vector float values

Note

The list above is complete in the current public github as a first pass. A backlog of functions remain to be implemented across these headers. Development continues while we work on the backlog listed in: [Issue #13](#)
[TODOs](#)

The goal is to provide high quality implementations that adapt to the specifics of the compile target (-mcpu=) and compiler (<altivec.h>) version you are using. Initially pveclib will focus on the GCC compiler and -mcpu=[power7|power8|power9] for Linux. Testing will focus on Little Endian (**powerpc64le** for power8 and power9 targets. Any testing for Big Endian (**powerpc64** will be initially restricted to power7 and power8 targets.

Expanding pveclib support beyond this list to include:

- additional compilers (ie Clang)
- additional PPC platforms (970, power6, ...)
- Larger functions that just happen to use vector registers (Checksum, Crypto, compress/decompress, lower precision neural networks, ...)

will largely depend on additional skilled practitioners joining this project and contributing (code and platform testing) on a sustained basis.

1.2.2 How pveclib is different from compiler vector built-ins

The PowerPC vector built-ins evolved from the original [AltiVec \(TM\) Technology Programming Interface Manual](#) (PIM). The PIM defined the minimal extensions to the application binary interface (ABI) required to support the Vector Facility. This included new keywords (vector, pixel, bool) for defining new vector types, and new operators (built-in functions) required for any supporting and compliant C language compiler.

The vector built-in function support included:

- generic AltiVec operations, like `vec_add()`
- specific AltiVec operations (instructions, like `vec_vaddubm()`)
- predicates computed from AltiVec operations, like `vec_all_eq()` which are also generic

See [Background on the evolution of <altivec.h>](#) for more details.

There are clear advantages with the compiler implementing the vector operations as built-ins:

- The compiler can access the C language type information and vector extensions to implement the function overloading required to process generic operations.
- Built-ins can be generated inline, which eliminates function call overhead and allows more compact code generation.
- The compiler can then apply higher order optimization across built-ins including: Local and global register allocation. Global common subexpression elimination. Loop-invariant code motion.

- The compiler can automatically select the best instructions for the *target* processor ISA level (from the `-mcpu` compiler option).

While this is an improvement over writing assembler code, it does not provide much function beyond the specific operations specified in the PowerISA. As a result the generic operations were not uniformly applied across vector element types. And this situation often persisted long after the PowerISA added instructions for wider elements. Some examples:

- Initially `vec_add` / `vec_sub` applied to float, int, short and char.
- Later compilers added support for double (with POWER7 and the Vector Scalar Extensions (VSX) facility)
- Later still, integer long (64-bit) and `__int128` support (with POWER8 and PowerISA 2.07B).

But `vec_mul` / `vec_div` did not:

- Initially `vec_mul` applied to vector float only. Later vector double was supported for POWER7 VSX. Much later integer multiply modulo under the generic `vec_mul` intrinsic.
- `vec_mule` / `vec_mulo` (Multiply even / odd elements) applied to [signed | unsigned] integer short and char. Later compilers added support for vector int after POWER8 added vector multiply word instructions.
- `vec_div` was not included in the original PIM as AltiVec (VMX) only included vector reciprocal estimate for float and no vector integer divide for any size. Later compilers added support for `vec_div` float / double after POWER7 (VSX) added vector divide single/double-precision instructions.

Note

While the processor you (plan to) use, may support the specific instructions you want to exploit, the compiler you are using may not support, the generic or specific vector operations, for the element size/types, you want to use. This is common for GCC versions installed by "Enterprise Linux" distributions. They tend to freeze the GCC version early and maintain that GCC version for long term stability. One solution is to use the [IBM Advance toolchain for Linux on Power \(AT\)](#). AT is free for download and new AT versions are released yearly (usually in August) with the latest stable GCC from that spring.

This can be a frustrating situation unless you are familiar with:

- the PowerISA and how it has evolved.
- the history and philosophy behind the implementation of `<altivec.h>`.
- The specific level of support provided by the compiler(s) you are using.

And to be fair, this author believes, this too much to ask from your average library or application developer. A higher level and more intuitive API is needed.

1.2.2.1 What can we do about this?

A lot can be done to improve this situation. For older compilers we substitute inline assembler for missing `<altivec.h>` operations. For older processors we can substitute short instruction sequences as equivalents for new instructions. And useful higher level (and more intuitive) operations can be written and shared. All can be collected and provided in headers and libraries.

1.2.2.1.1 Use inline assembler carefully

First the Binutils assembler is usually updated within weeks of the public release of the PowerISA document. So while your compiler may not support the latest vector operations as built-in operations, an older compiler with an updated assembler, may support the instructions as inline assembler.

Sequences of inline assembler instructions can be wrapped within C language static inline functions and placed in a header files for shared use. If you are careful with the input / output register *constraints* the GCC compiler can provide local register allocation and minimize parameter marshaling overhead. This is very close (in function) to a specific AltiVec (built-in) operation.

Note

Using GCC's inline assembler can be challenging even for the experienced programmer. The register constraints have grown in complexity as new facilities and categories were added. The fact that some (VMX) instructions are restricted to the original 32 Vector Registers (**VRs**) (the high half of the Vector-Scalar Registers **VSRs**), while others (Binary and Decimal Floating-Point) are restricted to the original 32 Floating-Point Registers (**FPRs** (overlapping the low half of the VSRs), and the new VSX instructions can access all 64 VSRs, is just one source of complexity. So it is very important to get your input/output constraints correct if you want inline assembler code to work correctly.

In-line assembler should be reserved for the first implementation using the latest PowerISA. Where possible you should use existing vector built-ins to implement specific operations for wider element types, support older hardware, or higher order operations. Again wrapping these implementations in static inline functions for collection in header files for reuse and distribution is recommended.

1.2.2.1.2 Define multi-instruction sequences to fill in gaps

The PowerISA vector facility has all the instructions you need to implement extended precision operations for add, subtract, and multiply. Add / subtract with carry-out and permute or double vector shift and grade-school arithmetic is all you need.

For example the Vector Add Unsigned Quadword Modulo introduced in POWER8 (PowerISA 2.07B) can be implemented for POWER7 and earlier machines in 10-11 instructions. This uses a combination of Vector Add Unsigned Word Modulo (`vadduwm`), Vector Add and Write Carry-Out Unsigned Word (`vaddcuw`), and Vector Shift Left Double by Octet Immediate (`vsldoi`), to propagate the word carries through the quadword.

For POWER8 and later, C vector integer (modulo) multiply can be implemented in a single Vector Unsigned Word Modulo (`vmuluwm`) instruction. This was added explicitly to address vectorizing loops using int multiply in C language code. And some newer compilers do support generic `vec_mul()` for vector int. But this is not documented. Similarly for char (byte) and short (halfword) elements.

POWER8 also introduced Vector Multiply Even Signed|Unsigned Word (`vmulesw|vmuleuw`) and Vector Multiply Odd Signed|Unsigned Word (`vmulosw|vmulouw`) instructions. So you would expect the generic `vec_mule` and `vec_mulo` operations to be extended to support *vector int*, as these operations have long been supported for char and short. Sadly this is not supported as of GCC 7.3 and inline assembler is required for this case. This support was added for GCC 8.

So what will the compiler do for vector multiply int (modulo, even, or odd) for targeting power7? Older compilers will reject this as a *invalid parameter combination* A newer compiler may implement the equivalent function in a short sequence of VMX instructions from PowerISA 2.06 or earlier. And GCC 7.3 does support `vec_mul` (modulo) for element types char, short, and int. These sequences are in the 2-7 instruction range depending on the operation and element type. This includes some constant loads and permute control vectors that can be factored and reused across operations. See [vec_muluwm\(\)](#) code for details.

1.2.2.1.3 Define new and useful operations

Once the pattern is understood it is not hard to write equivalent sequences using operations from the original `<altivec.h>`. With a little care these sequences will be compatible with older compilers and older PowerISA versions. These concepts can be extended to operations that PowerISA and the compiler does not support yet. For example; a processor that may not have multiply even/odd/modulo of the required width (word, doubleword, or quadword). This might take 10-12 instructions to implement the next element size bigger than the current processor. A full 128-bit by 128-bit multiply with 256-bit result only requires 36 instructions on POWER8 (using multiple word even/odd) and 15 instructions on POWER9 (using `vmsumudm`).

1.2.2.1.4 Leverage other PowerISA facilities

Also many of the operations missing from the vector facility, exist in the Fixed-point, Floating-point, or Decimal Floating-point scalar facilities. There will be some loss of efficiency in the data transfer but compared to a complex operation like divide or decimal conversions, this can be a workable solution. On older POWER processors (before power7/8) transfers between register banks (GPR, FPR, VR) had to go through memory. But with the VSX facility (POWER7) FPRs and VRs overlap with the lower and upper halves of the 64 VSR registers. So FPR \leftrightarrow VSR transfer are 0-2 cycles latency. And with power8 we have direct transfer (GPR \leftrightarrow FPR | VR | VSR) instructions in the 4-5 cycle latency range.

For example POWER8 added Decimal (BCD) Add/Subtract Modulo (`bcdadd`, `bcdsub`) instructions for signed 31 digit vector values. POWER9 added Decimal Convert From/To Signed Quadword (`bcdcfq`, `bcdctsq`) instructions. So far vector unit does not support BCD multiply / divide. But the Decimal Floating-Point (DFP) facility (introduced with PowerISA 2.05 and Power6) supports up to 34-digit (`__Decimal128`) precision and all the expected (add/subtract/multiply/divide/...) arithmetic operations. DFP also supports conversion to/from 31-digit BCD and `__Decimal128` precision. This is all supported with a hardware Decimal Floating-Point Unit (DFU).

So we can implement `vec_bcdadd()` and `vec_bcdsub()` with single instructions on POWER8, and 10-11 instructions for Power6/7. This count include the VSR \leftrightarrow FPRp transfers, BCD \leftrightarrow DFP conversions, and DFP add/sub. Similarly for `vec_bcdcfq()` and `vec_bcdctsq()`. The POWER8 and earlier implementations are a bit bigger (83 and 32 instruction respectively) but even the POWER9 hardware implementation runs 37 and 23 cycles (respectively).

The `vec_bcddiv()` and `vec_bcdmul()` operations are implement by transfer/conversion to `__Decimal128` and execute in the DFU. This is slightly complicated by the requirement to preserve correct fix-point alignment/truncation in the floating-point format. The operation timing runs \sim 100-200 cycles mostly driven the DFP multiply/divide and the number of digits involved.

Note

So why does anybody care about BCD and DFP? Sometimes you get large numbers in decimal that you need converted to binary for extended computation. Sometimes you need to display the results of your extended binary computation in decimal. The multiply by 10 and BCD vector operations help simplify and speed-up these conversions.

1.2.2.1.5 Use clever tricks

And finally: Henry S. Warren's wonderful book *Hacker's Delight* provides inspiration for SIMD versions of; count leading zeros, population count, parity, etc.

1.2.2.2 So what can the Power Vector Library project do?

Clearly the PowerISA provides multiple, extensive, and powerful computational facilities that continue to evolve and grow. But the best instruction sequence for a specific computation depends on which POWER processor(s) you have or plan to support. It can also depend on the specific compiler version you use, unless you are willing to write some of your application code in assembler. Even then you need to be aware of the PowerISA versions and when specific instructions were introduced. This can be frustrating if you just want to port your application to POWER for a quick evaluation.

So you would like to start evaluating how to leverage this power for key algorithms at the heart of your application.

- But you are working with an older POWER processor (until the latest POWER box is delivered).
- Or the latest POWER machine just arrived at your site (or cloud) but you are stuck using an older/stable Linux distro version (with an older distro compiler).
- Or you need extended precision multiply for your crypto code but you are not really an assembler level programmer (or don't want to be).
- Or you would like to program with higher level operations to improve your own productivity.

Someone with the right background (knowledge of the PowerISA, assembler level programming, compilers and the vector built-ins, ...) can solve any of the issues described above. But you don't have time for this.

There should be an easier way to exploit the POWER vector hardware without getting lost in the details. And this extends beyond classical vector (Single Instruction Multiple Data (SIMD)) programming to exploiting larger data width (128-bit and beyond), and larger register space (64 x 128 Vector Scalar Registers)

1.2.2.2.1 Vector Add Unsigned Quadword Modulo example

Here is an example of what can be done:

```
static inline vui128_t
vec_adduqm (vui128_t a, vui128_t b)
{
    vui32_t t;
#ifdef _ARCH_PWR8
#ifdef vec_vadduqm
    __asm__(
        "vadduqm %0,%1,%2;"
        : "=v" (t)
        : "v" (a),
        "v" (b)
        : );
#else
    t = (vui32_t) vec_vadduqm (a, b);
#endif
#else
    vui32_t c, c2;
    vui32_t z = { 0,0,0,0};

    c = vec_vaddcuw ((vui32_t)a, (vui32_t)b);
    t = vec_vadduwm ((vui32_t)a, (vui32_t)b);
    c = vec_sld (c, z, 4);
    c2 = vec_vaddcuw (t, c);
    t = vec_vadduwm (t, c);
    c = vec_sld (c2, z, 4);
    c2 = vec_vaddcuw (t, c);
    t = vec_vadduwm (t, c);
    c = vec_sld (c2, z, 4);
    t = vec_vadduwm (t, c);
#endif
    return ((vui128_t) t);
}
```


The `_ARCH_PWR8` macro is defined by the compiler when it targets POWER8 (PowerISA 2.07) or later. This is the first processor and PowerISA level to support vector quadword add/subtract. Otherwise we need to use the vector word add modulo and vector word add and write carry-out word, to add 32-bit chunks and propagate the carries through the quadword.

One little detail remains. Support for `vec_vadduqm` was added to GCC in March of 2014, after GCC 4.8 was released and GCC 4.9's feature freeze. So the only guarantee is that this feature is in GCC 5.0 and later. At some point this change was backported to GCC 4.8 and 4.9 as it is included in the current GCC 4.8/4.9 documentation. When or if these backports were propagated to a specific Linux Distro version or update is difficult to determine. So support for this vector built-in depends on the specific version of the GCC compiler, or if specific Distro update includes these specific backports for the GCC 4.8/4.9 compiler they support. The:

```
#ifndef vec_vadduqm
```

C preprocessor conditional checks if the `vec_vadduqm` is defined in `<altivec.h>`. If defined we can assume that the compiler implements `__builtin_vec_vadduqm` and that `<altivec.h>` includes the macro definition:

```
#define vec_vadduqm __builtin_vec_vadduqm
```

For `_ARCH_PWR7` and earlier we need a little grade school arithmetic using Vector Add Unsigned Word Modulo (**vadduwm**) and Vector Add and Write Carry-Out Unsigned Word (**vaddcuw**). This treats the vector `__int128` as 4 32-bit binary digits. The first instruction sums each (32-bit digit) column and the second records the carry out of the high order bit of each word. This leaves the carry bit in the original (word) column, so a shift left 32-bits is needed to line up the carries with the next higher word.

To propagate any carries across all 4 (word) digits, repeat this (add / carry / shift) sequence three times. Then a final add modulo word to complete the 128-bit add. This sequence requires 10-11 instructions. The 11th instruction is a vector splat word 0 immediate, which is needed in the shift left (`vsldoi`) instructions. This is common in vector codes and the compiler can usually reuse this register across several blocks of code and inline functions.

For POWER7/8 these instructions are all 2 cycle latency and 2 per cycle throughput. The `vadduwm` / `vaddcuw` instruction pairs should issue in the same cycle and execute in parallel. So the expected latency for this sequence is 14 cycles. For POWER8 the `vadduqm` instruction has a 4 cycle latency.

Similarly for the carry / extend forms which can be combined to support wider (256, 512, 1024, ...) extended arithmetic.

See also

[vec_addcuq](#), [vec_addeuqm](#), and [vec_addecuq](#)

1.2.2.2.2 Vector Multiply-by-10 Unsigned Quadword example

PowerISA 3.0 (POWER9) added this instruction and its extend / carry forms to speed up decimal to binary conversion for large numbers. But this operation is generally useful and not that hard to implement for earlier processors.

```

static inline vui128_t
vec_mull10uq (vui128_t a)
{
    vui32_t t;
#ifdef _ARCH_PWR9
    __asm__(
        "vmull0uq %0,%1;\n"
        : "=v" (t)
        : "v" (a)
        : );
#else
    vui16_t ts = (vui16_t) a;
    vui16_t t10;
    vui32_t t_odd, t_even;
    vui32_t z = { 0, 0, 0, 0 };
    t10 = vec_splat_u16(10);
    if __BYTE_ORDER__ == __ORDER_LITTLE_ENDIAN__
        t_even = vec_vmulouh (ts, t10);
        t_odd = vec_vmuleuh (ts, t10);
    else
        t_even = vec_vmuleuh(ts, t10);
        t_odd = vec_vmulouh(ts, t10);
    #endif
    t_even = vec_sld (t_even, z, 2);
#ifdef _ARCH_PWR8
    t = (vui32_t) vec_vadduqm ((vui128_t) t_even, (vui128_t) t_odd);
#else
    t = (vui32_t) vec_vadduqm ((vui128_t) t_even, (vui128_t) t_odd);
#endif
    #endif
    return ((vui128_t) t);
}

```

Notice that under the **_ARCH_PWR9** conditional, there is no check for the specific **vec_vmul10uq** built-in. As of this writing **vec_vmul10uq** is not included in the *OpenPOWER ELF2 ABI* documentation nor in the latest GCC trunk source code.

Note

The *OpenPOWER ELF2 ABI* does define **bcd_mul10** which (from the description) will actually generate Decimal Shift (**bcds**). This instruction shifts 4-bit nibbles (BCD digits) left or right while preserving the BCD sign nibble in bits 124-127. While this is a handy instruction to have, it is not the same operation as **vec_vmul10uq**, which is a true 128-bit binary multiply by 10. As of this writing **bcd_mul10** support is not included in the latest GCC trunk source code.

For **_ARCH_PWR8** and earlier we need a little grade school arithmetic using **Vector Multiply Even/Odd Unsigned Halfword**. This treats the vector **__int128** as 8 16-bit binary digits. We multiply each of these 16-bit digits by 10, which is done in two (even and odd) parts. The result is 4 32-bit (2 16-bit digits) partial products for the even digits and 4 32-bit products for the odd digits. The vector register (independent of endian); the even product elements are higher order and odd product elements are lower order.

The even digit partial products are offset right by 16-bits in the register. If we shift the even products left 1 (16-bit) digit, the even digits are lined up in columns with the odd digits. Now we can sum across partial products to get the final 128 bit product.

Notice also the conditional code for endian around the **vec_vmulouh** and **vec_vmuleuh** built-ins:

```

#if __BYTE_ORDER__ == __ORDER_LITTLE_ENDIAN__

```

Little endian (**LE**) changes the element numbering. This also changes the meaning of even / odd and this effects the code generated by compilers. But the relationship of high and low order bytes, within multiplication products, is defined by the hardware and does not change. (See: [General Endian Issues](#)) So the pveclib implementation needs to pre-swap

the even/odd partial product multiplies for LE. This in effect nullifies the even / odd swap hidden in the compilers **LE** code generation and the resulting code gives the correct results.

Now we are ready to sum the partial product *digits* while propagating the digit carries across the 128-bit product. For **_ARCH_PWR8** we can use **Vector Add Unsigned Quadword Modulo** which handles all the internal carries in hardware. Before **_ARCH_PWR8** we only have **Vector Add Unsigned Word Modulo** and **Vector Add and Write Carry-Out Unsigned Word**.

We see these instructions used in the **else** leg of the pveclib **vec_adduqm** implementation above. We can assume that this implementation is correct and tested for supported platforms. So here we use another pveclib function to complete the implementation of **Vector Multiply-by-10 Unsigned Quadword**.

Again similarly for the carry / extend forms which can be combined to support wider (256, 512, 1024, ...) extended decimal to binary conversions.

See also

[vec_mul10cuq](#), [vec_mul10euq](#), and [vec_mul10ecuq](#)

And similarly for full 128-bit x 128-bit multiply which combined with the add quadword carry / extended forms above can be used to implement wider (256, 512, 1024, ...) multiply operations.

See also

[vec_mulluq](#) and [vec_muluq](#)
[Vector Merge Algebraic High Word example](#)
[Vector Multiply High Unsigned Word example](#)

1.2.2.3 pveclib is not a matrix math library

The pveclib does not implement general purpose matrix math operations. These should continue to be developed and improved within existing projects (ie LAPACK, OpenBLAS, ATLAS, etc). We believe that pveclib will be helpful to implementors of matrix math libraries by providing a higher level, more portable, and more consistent vector interface for the PowerISA.

The decision is still pending on: extended arithmetic, cryptographic, compression/decompression, pattern matching / search and small vector libraries (libmvec). This author believes that the small vector math implementation should be part of GLIBC (libmvec). But the lack of optimized implementations or even good documentation and examples for these topics is a concern. This may be something that PVECLIB can address by providing enabling kernels or examples.

1.2.3 Practical considerations.

1.2.3.1 General Endian Issues

For POWER8, IBM made the explicit decision to support Little Endian (**LE**) data format in the Linux ecosystem. The goal was to enhance application code portability across Linux platforms. This goal was integrated into the OpenPOWER ELF V2 Application Binary Interface **ABI** specification.

The POWER8 processor architecturally supports an *Endian Mode* and supports both BE and LE storage access in hardware. However, register to register operations are not effected by endian mode. The ABI extends the LE storage format to vector register (logical) element numbering. See OpenPOWER ABI specification [Chapter 6. Vector Programming Interfaces](#) for details.

This has no effect for most `altivec.h` operations where the input elements and the results "stay in their lanes". For operations of the form $(T[n] = A[n] \text{ op } B[n])$, it does not matter if elements are numbered $[0, 1, 2, 3]$ or $[3, 2, 1, 0]$.

But there are cases where element renumbering can change the results. Changing element numbering does change the even / odd relationship for merge and integer multiply. For **LE** targets, operations accessing even vector elements are implemented using the equivalent odd instruction (and visa versa) and inputs are swapped. Similarly for high and low merges. Inputs are also swapped for Pack, Unpack, and Permute operations and the permute select vector is inverted. The above is just a sampling of a larger list of *LE transforms*. The OpenPOWER ABI specification provides a helpful table of [Endian-Sensitive Operations](#).

Note

This means that the vector built-ins provided by `altivec.h` may not generate the instructions you expect.

This does matter when doing extended precision arithmetic. Here we need to maintain most-to-least significant byte order and align "digit" columns for summing partial products. Many of these operations were defined long before Little Endian was seriously considered and are decidedly Big Endian in register format. Basically, any operation where the element changes size (truncated, extended, converted, subsetting) from input to output is suspect for **LE** targets.

The coding for these higher level operations is complicated by *Little Endian* (LE) support as specified in the OpenPOWER ABI and as implemented in the compilers. Little Endian changes the effective vector element numbering and the location of even and odd elements.

This is a general problem for using vectors to implement extended precision arithmetic. The multiply even/odd operations being the primary example. The products are double-wide and in BE order in the vector register. This is reinforced by the Vector Add/Subtract Unsigned Doubleword/Quadword instructions. And the products from multiply even instructions are always *numerically* higher digits than multiply odd products. The pack, unpack, and sum operations have similar issues.

This matters when you need to align (shift) the partial products or select the *numerically* high or lower portion of the products. The (high to low) order of elements for the multiply has to match the order of the largest element size used in accumulating partial sums. This is normally a quadword (`vadduqm` instruction).

So the element order is fixed while the element numbering and the partial products (between even and odd) will change between BE and LE. This effects splatting and octet shift operations required to align partial product for summing. These are the places where careful programming is required, to nullify the compiler's LE transforms, so we will get the correct numerical answer.

So what can the Power Vector Library do to help?

- Be aware of these mandated LE transforms and if required provide compliant inline assembler implementations for LE.
- Where required for correctness provide LE specific implementations that have the effect of nullifying the unwanted transforms.
- Provide higher level operations that help pveclib and applications code in an endian neutral way and get correct results.

See also

[Endian problems with word operations](#)
[Vector Multiply-by-10 Unsigned Quadword example](#)

1.2.3.2 Returning extended quadword results.

Extended quadword add, subtract and multiply results can exceed the width of a single 128-bit vector. A 128-bit add can produce 129-bit results. A unsigned 128-bit by 128-bit multiply result can produce 256-bit results. This is simplified for the *modulo* case where any result bits above the low order 128 can be discarded. But extended arithmetic requires returning the full precision result. Returning double wide quadword results are a complication for both RISC processor and C language library design.

1.2.3.2.1 PowerISA and Implementation.

For a RISC processor, encoding multiple return registers forces hard trade-offs in a fixed sized instruction format. Also building a vector register file that can support at least one (or more) double wide register writes per cycle is challenging. For a super-scalar machine with multiple vector execution pipelines, the processor can issue and complete multiple instructions per cycle. As most operations return single vector results, this is a higher priority than optimizing for double wide results.

The PowerISA addresses this by splitting these operations into two instructions that execute independently. Here independent means that given the same inputs, one instruction does not depend on the result of the other. Independent instructions can execute out-of-order, or if the processor has multiple vector execution pipelines, can execute (issue and complete) concurrently.

The original VMX implementation had Vector Add/Subtract Unsigned Word Modulo (**vadduwm** / **vsubuwm**), paired with Vector Add/Subtract and Write Carry-out Unsigned Word (**vaddcuw** / **vsubcuw**). Most usage ignores the carry-out and only uses the add/sub modulo instructions. Applications requiring extended precision, pair the add/sub modulo with add/sub write carry-out, to capture the carry and propagate it to higher order bits.

The (four word) carries are generated into the same *word lane* as the source addends and modulo result. Propagating the carries require a separate shift (to align the carry-out with the low order (carry-in) bit of the next higher word) and another add word modulo.

POWER8 (PowerISA 2.07B) added full Vector Add/Subtract Unsigned Quadword Modulo (**vadduqm** / **vsubuqm**) instructions, paired with corresponding Write Carry-out instructions. (**vaddcuq** / **vsubcuq**). A further improvement over the word instructions was the addition of three operand *Extend* forms which combine add/subtract with carry-in (**vaddeuqm**, **vsubeuqm**, **vaddecuq** and **vsubecuq**). This simplifies propagating the carry-out into higher quadword operations.

See also

[vec_adduqm](#), [vec_addcuq](#), [vec_addeuqm](#), [vec_addecuq](#)

POWER9 (PowerISA 3.0B) added Vector Multiply-by-10 Unsigned Quadword (Modulo is implied), paired with Vector Multiply-by-10 and Write Carry-out Unsigned Quadword (**vmul10uq** / **vmul10cuq**). And the *Extend* forms (**vmul10euq** / **vmul10ecuq**) simplifies the digit (0-9) carry-in for extended precision decimal to binary conversions.

See also

[vec_mul10uq](#), [vec_mul10cuq](#), [vec_mul10euq](#), [vec_mul10ecuq](#)

The VMX integer multiply operations are split into multiply even/odd instructions by element size. The product requires the next larger element size (twice as many bits). So a vector multiply byte would generate 16 halfword products (256-bits in total). Requiring separate even and odd multiply instructions cuts the total generated product bits (per instruction) in half. It also simplifies the hardware design by keeping the generated product in adjacent element lanes. So each vector multiply even or odd byte operation generates 8 halfword products (128-bits) per instruction.

This multiply even/odd technique applies to most element sizes from byte up to doubleword. The original VMX supports multiply even/odd byte and halfword operations. In the original VMX, arithmetic operations were restricted to byte, halfword, and word elements. Multiply halfword products fit within the integer word element. No multiply byte/halfword modulo instructions were provided, but could be implemented via a vmule, vmulo, vperm sequence.

POWER8 (PowerISA 2.07B) added multiply even/odd word and multiply modulo word instructions.

See also

[vec_muleuw](#), [vec_mulouw](#), [vec_muluwm](#)

The latest PowerISA (3.0B for POWER9) does add a doubleword integer multiply via **Vector Multiply-Sum unsigned Doubleword Modulo**. This is a departure from the Multiply even/odd byte/halfword/word instructions available in earlier Power processors. But careful conditioning of the inputs can generate the equivalent of multiply even/odd unsigned doubleword.

See also

[vec_msumudm](#), [vec_muleud](#), [vec_muloud](#)

This (multiply even/odd) technique breaks down when the input element size is quadword or larger. A quadword integer multiply forces a different split. The easiest next step would be a high/low split (like the Fixed-point integer multiply). A multiply low (modulo) quadword would be a useful function. Paired with multiply high quadword provides the double quadword product. This would provide the basis for higher (multi-quadword) precision multiplies.

See also

[vec_mulluq](#), [vec_muludq](#)

1.2.3.2.2 C Language restrictions.

The Power Vector Library is implemented using C language (inline) functions and this imposes its own restrictions. Standard C language allows an arbitrary number of formal parameters and one return value per function. Parameters and return values with simple C types are normally transferred (passed / returned) efficiently in local (high performance) hardware registers. Aggregate types (struct, union, and arrays of arbitrary size) are normally handled by pointer indirection. The details are defined in the appropriate Application Binary Interface (ABI) documentation.

The POWER processor provides lots of registers (96) so we want to use registers wherever possible. Especially when our application is composed of collections of small functions. And more especially when these functions are small enough to inline and we want the compiler to perform local register allocation and common subexpression elimination optimizations across these functions. The PowerISA defines 3 kinds of registers;

- General Purpose Registers (GPRs),
- Floating-point Registers (FPRs),
- Vector registers (VRs),

with 32 of each kind. We will ignore the various special registers for now.

The PowerPC64 64-bit ELF (and OpenPOWER ELF V2) ABIs normally pass simple arguments and return values in a single register (of the appropriate kind) per value. Arguments of aggregate types are passed as storage pointers in General Purpose Registers (GPRs).

The language specification, the language implementation, and the ABI provide some exceptions. The C99 language adds `_Complex` floating types which are composed of real and imaginary parts. GCC adds `_Complex` integer types. For PowerPC ABIs complex values are held in a pair of registers of the appropriate kind. C99 also adds double word integers as the *long long int* type. This only matters for PowerPC 32-bit ABIs. For PowerPC64 ABIs *long long* and *long* are both 64-bit integers and are held in 64-bit GPRs.

GCC also adds the `__int128` type for some targets including the PowerPC64 ABIs. Values of `__int128` type are held (for operations, parameter passing and function return) in 64-bit GPR pairs. Starting with version 4.9 GCC supports the vector signed/unsigned `__int128` type. This is passed and returned as a single vector register and should be used for all 128-bit integer types (bool/signed/unsigned).

GCC supports `__ibm128` and `_Decimal128` floating point types which are held in Floating-point Registers pairs. These are distinct types from vector double and oriented differently in the VXS register file. But the doubleword halves can be moved between types using the VSX permute double word immediate instructions (xxpermdi). This useful for type conversions and implementing some vector BCD operations.

GCC recently added the `__float128` floating point type which are held in single vector register. The compiler considers this to be floating scalar and is not cast compatible with any vector type. To access the `__float128` value as a vector it must be passed through a union.

Note

The implementation will need to provide transfer functions between vectors and other 128-bit types.

GCC defines Generic Vector Extensions that allow typedefs for vectors of various element sizes/types and generic SIMD (arithmetic, logical, and element indexing) operations. For PowerPC64 ABIs this is currently restricted to 16-byte vectors as defined in `<altivec.h>`. For currently available compilers attempts to define vector types with larger (32 or 64 byte) *vector_size* values are treated as arrays of scalar elements. Only *vector_size*(16) variables are passed and returned in vector registers.

The OpenPOWER 64-Bit ELF V2 ABI Specification makes specific provisions for passing/returning *homogeneous aggregates* of multiple like (scalar/vector) data types. Such aggregates can be passed/returned as up to eight floating-point or vector registers. A parameter list may include multiple *homogeneous aggregates* with up to a total of twelve parameter registers.

This is defined for the Little Endian ELF V2 ABI and is not applicable to Big Endian ELF V1 targets. Also GCC versions before GCC8, do not fully implement this ABI feature, and revert to old ABI structure passing (passing through storage).

Passing large *homogeneous aggregates* becomes the preferred solution as PVECLIB starts to address wider (256 and 512-bit) vector operations. For example the ABI allows passing up to 3 512-bit parameters and return a 1024-bit result in vector registers (as in `vec_madd512x512a512_inline()`). For large multi-quadword precision operations the only practical solution uses reference parameters to arrays or structs in storage (as in `vec_mul2048x2048()`). See `vec_int512_ppc.h` for more examples.

So we have shown that there are mechanisms for functions to return multiple vector register values.

1.2.3.2.3 Subsetting the problem.

We can simplify this problem by remembering that:

- Only a subset of the pveclib functions need to return more than one 128-bit vector.
- The PowerISA normally splits these cases into multiple instructions anyway.
- Most of these functions are small and fully inlined.
- The exception will be the multiple quadword precision arithmetic operations.

So we have two (or three) options given the current state of GCC compilers in common use:

- Mimic the PowerISA and split the operation into two functions, where each function only returns (up to) 128-bits of the result.
- Use pointer parameters to return a second vector value in addition to the function return.
- Support both options above and let the user decide which works best.
- With a availability of GCC 8/9 compilers, pass/return 256, 512 and 1024-bit vectors as *homogeneous aggregates*.

The add/subtract quadword operations provide good examples. For example adding two 256-bit unsigned integer values and returning the 257-bit (the high / low sum and the carry) result looks like this:

```
s1 = vec_vadduqm (a1, b1); // sum low 128-bits a1+b1
c1 = vec_vaddcuq (a1, b1); // write-carry from low a1+b1
s0 = vec_vaddeuqm (a0, b0, c1); // Add-extend high 128-bits a0+b0+c1
c0 = vec_vaddecuq (a0, b0, c1); // write-carry from high a0+b0+c1
```

This sequence uses the built-ins from `<altivec.h>` and generates instructions that will execute on POWER8 and POWER9. The compiler must target POWER8 (`-mcpu=power8`) or higher. In fact the compile will fail if the target is POWER7.

Now let's look at the pveclib version of these operations from `<vec_int128_ppc.h>`:

```
s1 = vec_adduqm (a1, b1); // sum low 128-bits a1+b1
c1 = vec_addcuq (a1, b1); // write-carry from low a1+b1
s0 = vec_addeuqm (a0, b0, c1); // Add-extend high 128-bits a0+b0+c1
c0 = vec_addecuq (a0, b0, c1); // write-carry from high a0+b0+c1
```

Looks almost the same but the operations do not use the 'v' prefix on the operation name. This sequence generates the same instructions for (`-mcpu=power8`) as the `<altivec.h>` version above. It will also generate a different (slightly longer) instruction sequence for (`-mcpu=power7`) which is functionally equivalent.

The pveclib `<vec_int128_ppc.h>` header also provides a coding style alternative:

```
s1 = vec_addcq (&c1, a1, b1);
s0 = vec_addeq (&c0, a0, b0, c1);
```

Here `vec_addcq` combines the `adduqm/addcuq` operations into a *add and carry quadword* operation. The first parameter is a pointer to vector to receive the carry-out while the 128-bit modulo sum is the function return value. Similarly `vec_addeq` combines the `addeuqm/addecuq` operations into a *add with extend and carry quadword* operation.

As these functions are inlined by the compiler the implied store / reload of the carry can be converted into a simple register assignment. For (`-mcpu=power8`) the compiler should generate the same instruction sequence as the two previous examples.

For (`-mcpu=power7`) these functions will expand into a different (slightly longer) instruction sequence which is functionally equivalent to the instruction sequence generated for (`-mcpu=power8`).

For older processors (power7 and earlier) and under some circumstances instructions generated for this "combined form" may perform better than the "split form" equivalent from the second example. Here the compiler may not recognize all the common subexpressions, as the "split forms" are expanded before optimization.

1.3 Background on the evolution of <altivec.h>

The original **Altivec (TM) Technology Programming Interface Manual** defined the minimal vector extensions to the application binary interface (ABI), new keywords (vector, pixel, bool) for defining new vector types, and new operators (built-in functions).

- generic Altivec operations, like `vec_add()`
- specific Altivec operations (instructions, like `vec_addubm()`)
- predicates computed from a Altivec operation like `vec_all_eq()`

A generic operation generates specific instructions based on the types of the actual parameters. So a generic `vec_add` operation, with vector char parameters, will generate the (specific) vector add unsigned byte modulo (`vaddubm`) instruction. Predicates are used within if statement conditional clauses to access the condition code from vector operations that set Condition Register 6 (vector SIMD compares and Decimal Integer arithmetic and format conversions).

The PIM defined a set of compiler built-ins for vector instructions (see section "4.4 Generic and Specific Altivec Operations") that compilers should support. The document suggests that any required typedefs and supporting macro definitions be collected into an include file named <altivec.h>.

The built-ins defined by the PIM closely match the vector instructions of the underlying PowerISA. For example: `vec_mul`, `vec_mule` / `vec_mulo`, and `vec_muleub` / `vec_muloub`.

- `vec_mul` is defined for float and double and will (usually) generate a single instruction for the type. This is a simpler case as floating point operations usually stay in their lanes (result elements are the same size as the input operand elements).
- `vec_mule` / `vec_mulo` (multiply even / odd) are defined for integer multiply as integer products require twice as many bits as the inputs (the results don't stay in their lane).

The RISC philosophy resists and POWER Architecture avoids instructions that write to more than one register. So the hardware and PowerISA vector integer multiply generate even and odd product results (from even and odd input elements) from two instructions executing separately. The PIM defines and compiler supports these operations as overloaded built-ins and selects the specific instructions based on the operand (char or short) type.

As the PowerISA evolved adding new vector (VMX) instructions, new facilities (Vector Scalar Extended (VSX)), and specialized vector categories (little endian, AES, SHA2, RAID), some of these new operators were added to <altivec.h>. This included some new specific and generic operations and additional vector element types (long (64-bit) int, `__int128`, double and quad precision (`__Float128` float)). This support was *staged* across multiple compiler releases in response to perceived need and stake-holder requests.

The result was a patchwork of <altivec.h> built-ins support versus new instructions in the PowerISA and shipped hardware. The original Altivec (VMX) provided Vector Multiply (Even / Odd) operations for byte (char) and halfword (short) integers. Vector Multiply Even / Odd Word (int) instructions were not introduced until PowerISA V2.07 (POWER8) under the generic built-ins `vec_mule`, `vec_mulo`. PowerISA 2.07 also introduced Vector Multiply Word Modulo under the generic built-in `vec_mul`. Both were first available in GCC 8. Specific built-in forms (`vec_vmuleuw`, `vec_vmulouw`, `vec_vmuluwm`) were not provided. PowerISA V3.0 (POWER9) added Multiply-Sum Unsigned Doubleword Modulo but neither generic (`vec_msum`) or specific (`vec_msumudm`) forms have been provided (so far as of GCC 9).

However the original PIM documents were primarily focused on embedded processors and were not updated to include the vector extensions implemented by the server processors. So any documentation for new vector operations were relegated to the various compilers. This was a haphazard process and some divergence in operation naming did occur between compilers.

In the run up to the POWER8 launch and the OpenPOWER initiative it was recognized that switching to Little Endian would require and new and well documented Application Binary Interface (**ABI**). It was also recognized that new <altivec.h> extensions needed to be documented in a common place so the various compilers could implement a common vector built-in API. So ...

1.3.1 The ABI is evolving

The [OpenPOWER ELF V2 application binary interface \(ABI\)](#): Chapter 6. **Vector Programming Interfaces** and **Appendix A. Predefined Functions for Vector Programming** document the current and proposed vector built-ins we expect all C/C++ compilers to implement for the PowerISA.

The ABI defined generic operations as overloaded built-in functions. Here the ABI suggests a specific PowerISA implementation based on the operand (vector element) types. The ABI also defines the (big/little) endian behavior and the ABI may suggest different instructions based on the endianness of the target.

This is an important point as the vector element numbering changes between big and little endian, and so does the meaning of even and odd. Both affect what the compiler supports and the instruction sequence generated.

- **vec_mule** and **vec_mulo** (multiply even / odd are examples of generic built-ins defined by the ABI. One would assume these built-ins will generate the matching instruction based only on the input vector type, however the GCC compiler will adjust the generated instruction based on the target endianness (reversing even / odd for little endian).
- Similarly for the merge (even/odd high/low) operations. For little endian the compiler reverses even/odd (high/low) and swaps operands as well.
- See **Table 6.1. Endian-Sensitive Operations** for details.

The many existing specific built-ins (where the name includes explicit type and signed/unsigned notation) are included in the ABI but listed as deprecated. Specifically the **Appendix A.6. Deprecated Compatibility Functions** and **Table A.8. Functions Provided for Compatibility**.

This reflects an explicit decision by the ABI and compiler maintainers that a generic only interface would be smaller/easier to implement and document as the PowerISA evolves.

Certainly the addition of VSX to POWER7 and the many vector extensions added to POWER8 and POWER9 added hundreds of vector instructions. Many of these new instructions needed built-ins to:

- Enable early library exploitations. For example new floating point element sizes (double and Float128).
- Support specialized operations not generally supported in the language. For example detecting Not-a-Number and Infinities without triggering exceptions. These are needed in the POSIX library implementation.
- Supporting wider integer element sizes can result in large multiples of specific built-ins if you include variants for:
 - signed and unsigned
 - saturated
 - even, odd, modulo, write-carry, and extend
 - high and low
 - and additional associated merge, pack, unpack, splat, operations

So implementing new instructions as generic built-ins first, and delaying the specific built-in permutations, is a wonderful simplification. This moves naturally from tactical to strategy to plan quickly. Dropping the specific built-ins for new instructions and deprecating the existing specific built-ins saves a lot of work.

As the ABI places more emphasis on generic built-in operations, we are seeing more cases where the compiler generates multiple instruction sequences. The first example was **vec_abs** (vector absolute value) from the original AltiVec PIM. There was no vector absolute instruction for any of the supported types (including vector float at the time). But this could be implemented in a 3 instruction sequence. This generic operation was extended to vector double for VSX (PowerISA 2.06) which introduced hardware instructions for absolute value of single and double precision vectors. But **vec_abs** remains a multiple instruction sequence for integer elements.

Another example is **vec_mul**. POWER8 (PowerISA 2.07) introduced Vector Multiply Unsigned Word Modulo (**vmulwmm**). This was included in the ISA as it simplified vectorizing C language (int) loops. This also allowed a single instruction implementation for **vec_mul** for vector (signed/unsigned) int. The PowerISA does not provide direct vector multiply modulo instructions for char, short, or long. Again this requires a multiple-instruction sequence to implement.

1.3.2 The current <altivec.h> is a mixture

The current vector ABI implementation in the compiler and <altivec.h> is mixture of old and new.

- Many new instruction (since PowerISA 2.06) are supported only under existing built-ins (with new element types; `vec_mul`, `vec_mule`, `vec_mulo`). Or as newly defined generic built-ins (`vec_eqv`, `vec_nand`, `vec_orc`).
 - Specific types/element sizes under these generic built-ins may be marked *phased in*.
- Some new instructions are supported with both generic (`vec_popcnt`) and specific built-ins (`vec_vpopcntb`, `vec_vpopcntd`, `vec_vpopcnth`, `vec_vpopcntw`).
- Other new instructions are only supported with specific built-ins (`vec_vaddcuq`, `vec_vaddecuq`, `vec_vaddeuqm`, `vec_vsubcuq`, `vec_vsubecuq`, `vec_vsubeuqm`). To be fair only the quadword element supports the write-carry and extend variants.
- Endian sensitivity may be applied in surprising ways.
 - **`vec_muleub`** and **`vec_muloub`** (multiply even / odd unsigned byte) are examples of non-overloaded built-ins provided by the GCC compiler but not defined in the ABI. One would assume these built-ins will generate the matching instruction, however the GCC compiler will adjust the generated instruction based on the target endianness (even / odd is reversed for little endian).
 - **`vec_sld`**, **`vec_sldw`**, **`vec_sll`**, and **`vec_slo`** (vector shift left) are **not** endian sensitive. Historically, these built-ins are often used to shift by amounts not a multiple of the element size, across types.
- A number of built-ins are defined in the ABI and marked (all or in part) as *phased in*. This implies that compilers **shall** implement these built-ins (eventually) in <altivec.h>. However the specific compiler version you are using may not have implemented it yet.

1.3.3 Best practices

This is a small sample of the complexity we encounter programming at this low level (vector intrinsic) API. This is also an opportunity for a project like the Power Vector Library (PVECLIB) to smooth off the rough edges and simplify software development for the OpenPOWER ecosystem.

If the generic vector built-in operation you need:

- is defined in the ABI, and
- defined in the PowerISA across the processor versions you need to support, and
- defined in <altivec.h> for the compilers and compiler versions you expect to use, and
- implemented for the vector types/element sizes you need for the compilers and compiler versions you expect to use.

Then use the generic vector built-in from <altivec.h> in your application/library.

Otherwise if the specific vector built-in operation you need is defined in <altivec.h>:

- For the vector types/element sizes you need, and
- defined in the PowerISA across the processor versions you need to support, and

- implemented for the compilers and compiler versions you expect to use.

Then use the specific vector built-in from `<altivec.h>` in your application/library.

Otherwise if the vector operation you need is defined in PVECLIB.

- For the vector types/element sizes you need.

Then use the vector operation from PVECLIB in your application/library.

Otherwise

- Check on <https://github.com/open-power-sdk/pveclib> and see if there is newer version of PVECLIB.
- Open an issue on <https://github.com/open-power-sdk/pveclib/issues> for the operation you would like to see.
- Look at source for PVECLIB for examples similar to what you are trying to do.

1.4 Putting the Library into PVECLIB

Until recently (as of v1.0.3) PVECLIB operations were **static inline** only. This was reasonable as most operations were small (one to a few vector instructions). This offered the compiler opportunity for:

- Better register allocation.
- Identifying common subexpressions and factoring them across operation instances.
- Better instruction scheduling across operations.

Even then, a few operations (quadword multiply, BCD multiply, BCD \leftrightarrow binary conversions, and some POWER8/7 implementations of POWER9 instructions) were getting uncomfortably large (10s of instructions). But it was the multiple quadword precision operations that forced the issue as they can run to 100s and sometimes 1000s of instructions. So, we need to build some functions from pveclib into a static archive and/or a dynamic library (DSO).

1.4.1 Building Multi-target Libraries

Building libraries of compiled binaries is not that difficult. The challenge is effectively supporting multiple processor (POWER7/8/9) targets, as many PVECLIB operations have different implementations for each target. This is especially evident on the multiply integer word, doubleword, and quadword operations (see; [vec_muludq\(\)](#), [vec_mulhuq\(\)](#), [vec_↔mulluq\(\)](#), [vec_vmuleud\(\)](#), [vec_vmuloud\(\)](#), [vec_msumudm\(\)](#), [vec_muleuw\(\)](#), [vec_mulouw\(\)](#)).

This is dictated by both changes in the PowerISA and in the micro-architecture as it evolved across processor generations. So an implementation to run on a POWER7 is necessarily restricted to the instructions of PowerISA 2.06. But if we are running on a POWER9, leveraging new instructions from PowerISA 3.0 can yield better performance than the POWER7 compatible implementation. When we are dealing with larger operations (10s and 100s of instructions) the compiler can schedule instruction sequences based on the platform (`-mtune=`) for better performance.

So, we need to deliver multiple implementations for some operations and we need to provide mechanisms to select a specific target implementation statically at compile/build or dynamically at runtime. First we need to compile multiple version of these operations, as unique functions, each with a different effective compile target (`-mcpu=` options).

Obviously, creating multiple source files implementing the same large operation, each supporting a different specific target platform, is a possibility. However, this could cause maintenance problems where changes to a operation must be coordinated across multiple source files. This is also inconsistent with the current PVECLIB coding style where a file contains an operation's complete implementation, including documentation and target specific implementation variants.

The current PVECLIB implementation makes extensive use of C Preprocessor (**CPP**) conditional source code. These includes testing for; compiler version, target endianness, and current target processor, then selects the appropriate source code snippet ([So what can the Power Vector Library project do?](#)). This was intended to simplify the application/library developer's life were they could use the PVECLIB API and not worry about these details.

So far, this works as intended (single vector source for multiple PowerISA VMX/VSX targets) when the entire application is compiled for a single target. However, this dependence on CPP conditionals is mixed blessing then the application needs to support multiple platforms in a single package.

1.4.1.1 The mechanisms available

The compiler and ABI offer options that at first glance seem to allow multiple target specific binaries from a single source. Besides the compiler's command level target options a number of source level mechanisms to change the target. These include:

- `__attribute__((target("cpu=power8")))`
- `__attribute__((target_clones("cpu=power9,default")))`
- `#pragma GCC target("cpu=power8")`
- multiple compiles with different command line options (i.e. `-mcpu=`)

The `target` and `target_clones` attributes are function attributes (apply to single function). The `target` attribute overrides the command line `-mcpu=` option. However it is not clear which version of GCC added explicit support for `(target("cpu="))`. This was not explicitly documented until GCC 5. The `target_clones` attribute will cause GCC will create two (or more) function clones, one (or more) compiled with the specified `cpu=` target and another with the default (or command line `-mcpu=`) target. It also creates a resolver function that dynamically selects a clone implementation suitable for current platform architecture. This PowerPC specific variant was not explicitly documented until GCC 8.

There are a few issues with function attributes:

- The Doxygen preprocessor can not parse function attributes without a lot of intervention.
- The availability of these attributes seems to be limited to the latest GCC compilers.

Note

The Clang/LLVM compilers don't provide equivalents to `attribute (target)` or `#pragma target`.

But there is a deeper problem related to the usage of CPP conditionals. Many PVECLIB operation implementations depend on GCC/compiler predefined macros including:

- `__GNUC__`
- `__GNUC_MINOR__`
- `__BYTE_ORDER__`
- `__ORDER_LITTLE_ENDIAN__`
- `__ORDER_BIG_ENDIAN__`

PVECLIB also depends on many system-specific predefined macros including:

- `__ALTIVEC__`
- `__VSX__`
- `__FLOAT128__`
- `_ARCH_PWR9`
- `_ARCH_PWR8`
- `_ARCH_PWR7`

PVECLIB also depends on the `<altivec.h>` include file which provides the mapping between the ABI defined intrinsics and compiler defined built-ins. In some places PVECLIB conditionally tests if specific built-in is defined and substitutes an in-line assembler implementation if not. `Altivec.h` also depends on system-specific predefined macros to enable/disable blocks of intrinsic built-ins based on PowerISA level of the compile target.

1.4.1.2 Some things just do not work

This issue is the compiler (GCC at least) only expands the compiler and system-specific predefined macros once per source file. The preprocessed source does not change due to embedded function attributes that change the target. So the following does not work as expected.

```
#include <altivec.h>
#include <pveclib/vec_int128_ppc.h>
#include <pveclib/vec_int512_ppc.h>

// Defined in vec_int512_ppc.h but included here for clarity.
static inline __VEC_U_256
vec_mul128x128_inline (vu128_t a, vu128_t b)
{
    __VEC_U_256 result;
    // vec_muludq is defined in vec_int128_ppc.h
    result.vx0 = vec_muludq (&result.vx1, a, b);
    return result;
}

__VEC_U_256 __attribute__((target ("cpu=power7")))
vec_mul128x128_PWR7 (vu128_t m11, vu128_t m21)
```

```

{
    return vec_mul128x128_inline (m1l, m2l);
}

__VEC_U_256 __attribute__((target ("cpu=power8")))
vec_mul128x128_PWR8 (vuil28_t m1l, vuil28_t m2l)
{
    return vec_mul128x128_inline (m1l, m2l);
}

__VEC_U_256 __attribute__((target ("cpu=power9")))
vec_mul128x128_PWR9 (vuil28_t m1l, vuil28_t m2l)
{
    return vec_mul128x128_inline (m1l, m2l);
}

```

For example if we assume that the compiler default is (or the command line specifies) `-mcpu=power8` the compiler will use this to generate the system-specific predefined macros. This is done before the first include file is processed. In this case `<altivec.h>`, `vec_int128_ppc.h`, and `vec_int512_ppc.h` source will be expanded for power8 (PowerISA-2.07). The result is the `vec_muludq` and `vec_muludq` inline source implementations will be the power8 specific version.

This will all be established before the compiler starts to parse and generate code for `vec_mul128x128_PWR7`. This compile is likely to fail because we are trying to compile code containing power8 instructions for a `-mcpu=power7` target.

The compilation of `vec_mul128x128_PWR8` should work as we are compiling power8 code with a `-mcpu=power8` target. The compilation of `vec_mul128x128_PWR9` will compile without error but will generate essentially the same code as `vec_mul128x128_PWR8`. The `target("cpu=power9")` allows that compiler to use power9 instructions but the expanded source coded from `vec_muludq` and `vec_mul128x128_inline` will not contain any power9 intrinsic built-ins.

Note

The GCC attribute **`target_clone`** has the same issue.

Pragma GCC target has a similar issue if you try to change the target multiple times within the same source file.

```

#include <altivec.h>
#include <pveclib/vec_int128_ppc.h>
#include <pveclib/vec_int512_ppc.h>

// Defined in vec_int512_ppc.h but included here for clarity.
static inline __VEC_U_256
vec_mul128x128_inline (vuil28_t a, vuil28_t b)
{
    __VEC_U_256 result;
    // vec_muludq is defined in vec_int128_ppc.h
    result.vx0 = vec_muludq (&result.vx1, a, b);
    return result;
}

#pragma GCC push_options
#pragma GCC target ("cpu=power7")

__VEC_U_256
vec_mul128x128_PWR7 (vuil28_t m1l, vuil28_t m2l)
{
    return vec_mul128x128_inline (m1l, m2l);
}

#pragma GCC pop_options
#pragma GCC push_options
#pragma GCC target ("cpu=power8")

__VEC_U_256
vec_mul128x128_PWR8 (vuil28_t m1l, vuil28_t m2l)
{
    return vec_mul128x128_inline (m1l, m2l);
}

```

```
#pragma GCC pop_options
#pragma GCC push_options
#pragma GCC target ("cpu=power9")

__VEC_U_256
vec_mul128x128_PWR9 (vu128_t m11, vu128_t m21)
{
    return vec_mul128x128_inline (m11, m21);
}
```

This has the same issues as the target attribute example above. However you can use #pragma GCC target if;

- it proceeds the first #include in the source file.
- there is only one target #pragma in the file.

For example:

```
#pragma GCC target ("cpu=power9")
#include <altivec.h>
#include <pveclib/vec_int128_ppc.h>
#include <pveclib/vec_int512_ppc.h>

// vec_mul128x128_inline is defined in vec_int512_ppc.h
__VEC_U_256
vec_mul128x128_PWR9 (vu128_t m11, vu128_t m21)
{
    return vec_mul128x128_inline (m11, m21);
}
```

In this case the cpu=power9 option is applied before the compiler reads the first include file and initializes the system-specific predefined macros. So the CPP source expansion reflects the power9 target.

Note

So far the techniques described only work reliably for C/C++ codes, compiled with GCC, that don't use <altivec.h> intrinsics or use CPP conditionals.

The implication is we need a build system that allows source files to be compiled multiple times, each with different compile targets.

1.4.1.3 Some tricks to build targeted runtime objects.

We need a unique compiled object implementation for each target processor. We still prefer a single file implementation for each function to improve maintenance. So we need a way to separate setting the platform target from the implementation source. Also we need to provide a unique external symbol for each target specific implementation of a function.

This can be handled with a simple macro to append a suffix based on system-specific predefined macro settings.

```
#ifdef _ARCH_PWR9
#define __VEC_PWR_IMP(FNAME) FNAME ## _PWR9
#else
#ifdef _ARCH_PWR8
#define __VEC_PWR_IMP(FNAME) FNAME ## _PWR8
#else
#define __VEC_PWR_IMP(FNAME) FNAME ## _PWR7
#endif
#endif
```


Then use `__VEC_PWR_IMP()` as function name wrapper in the implementation source file.

```
//
// \file vec_int512_runtime.c
//

#include <altivec.h>
#include <pveclib/vec_int128_ppc.h>
#include <pveclib/vec_int512_ppc.h>

// vec_mul128x128_inline is defined in vec_int512_ppc.h
__VEC_U_256
__VEC_PWR_IMP (vec_mul128x128) (vui128_t m1, vui128_t m2l)
{
    return vec_mul128x128_inline (m1, m2l);
}
```

Then the use `__VEC_PWR_IMP()` function wrapper for any calling function that is linked statically to that library function.

```
__VEC_U_1024
__VEC_PWR_IMP (vec_mul512x512) (__VEC_U_512 m1,
    __VEC_U_512 m2)
{
    __VEC_U_1024 result;
    __VEC_U_512x1 mp3, mp2, mp1, mp0;

    mp0.x640 = __VEC_PWR_IMP (vec_mul512x128) (m1, m2.vx0);
    result.vx0 = mp0.x3.v1x128;
    mp1.x640 = __VEC_PWR_IMP (vec_madd512x128a512) (m1, m2.vx1, mp0.x3.v0x512);
    ;
    result.vx1 = mp1.x3.v1x128;
    mp2.x640 = __VEC_PWR_IMP (vec_madd512x128a512) (m1, m2.vx2, mp1.x3.v0x512);
    ;
    result.vx2 = mp2.x3.v1x128;
    mp3.x640 = __VEC_PWR_IMP (vec_madd512x128a512) (m1, m2.vx3, mp2.x3.v0x512);
    ;
    result.vx3 = mp3.x3.v1x128;
    result.vx4 = mp3.x3.v0x512.vx0;
    result.vx5 = mp3.x3.v0x512.vx1;
    result.vx6 = mp3.x3.v0x512.vx2;
    result.vx7 = mp3.x3.v0x512.vx3;
    return result;
}
```

The **runtime** library implementation is in a separate file from the **inline** implementation. The `vec_int512_ppc.h` file contains:

- static inline implementations and associated doxygen interface descriptions. These are still small enough to used directly by application codes and as building blocks for larger library implementations.
- extern function declarations and associated doxygen interface descriptions. These names are for the dynamic shared object (**DSO**) function implementations. The functions are not qualified with inline or target suffixes. The expectation is the dynamic linker mechanism with bind to the appropriate implementation.
- extern function declarations qualified with a target suffix. These names are for the statically linked (**archive**) function implementations. The suffix is applied by the `__VEC_PWR_IMP()` macro for the current (default) target processor. These have no doxygen descriptions as using the `__VEC_PWR_IMP()` macro interferes with the doxygen scanner. But the interface is the same as the unqualified extern for the DSO implementation of the same name.

The runtime source file (for example `vec_int512_runtime.c`) contains the common implementations for all the target qualified static interfaces.

- Again the function names are target qualified via the `__VEC_PWR_IMP()` macro.
- The runtime implementation can use any of the PVECLIB inline operations (see: `vec_mul128x128()` and `vec_mul256x256()`) as well as other function implementations from the same file (see: `vec_mul512x512()` and `vec_mul2048x2048()`).
- At the -O3 optimization level the compiler will attempt to inline functions referenced from the same file. Compiler heuristics will limit this based on estimates for the final generated object size. GCC also supports the function attribute `__flatten__` which overrides the in-lining size heuristics.
- These implementations can also use target specific CPP conditional codes to manually tweak code optimization or generated code size for specific targets.

This simple strategy allows the collection of the larger function implementations into a single source file and build object files for multiple platform targets. For example collect all the multiple precision quadword implementations into a source file named `vec_int512_runtime.c`.

1.4.2 Building static runtime libraries

This source file can be compiled multiple times for different platform targets. The resulting object files have unique function symbols due to the platform specific suffix provided by the `__VEC_PWR_IMP()` macro. There are a number of build strategies for this.

For example, create a small source file named `vec_runtime_PWR8.c` that starts with the target pragma and includes the multi-platform source file.

```
// \file vec_runtime_PWR8.c
#pragma GCC target ("cpu=power8")
#include "vec_int512_runtime.c"
```

Similarly for `vec_runtime_PWR7.c`, `vec_runtime_PWR9.c` with appropriate changes for "cpu=". Additional runtime source files can be included as needed. Other multiple precision functions supporting BCD and BCD <-> binary conversions are likely candidates.

Note

Current Clang compilers silently ignore "#pragma GCC target". This causes all such targeted runtimes to revert to the compiler default target or configure CFLAGS "-mcpu=". In this case the `__VEC_PWR_IMP()` macro will apply the same suffix to all functions across the targeted runtime builds. As a result linking these targeted runtime objects into the DSO will fail with duplicate symbols.

Projects using autotools (like PVECLIB) can use Makefile.am rules to associate runtime source files with a library. For example:

```
libpvec_la_SOURCES = vec_runtime_PWR9.c \
    vec_runtime_PWR8.c \
    vec_runtime_PWR7.c
```

If compiling with GCC this is sufficient for automake to generate Makefiles to compile each of the runtime sources and combine them into a single static archive named libpvec.a. However it is not that simple, especially if the build uses a different compiler.

We would like to use Makefile.am rules to specify different -mcpu= compile options. This eliminates the #pragma GCC target and simplifies the platform source files too something like:

```
//
// \file vec_runtime_PWR8.c
//
#include "vec_int512_runtime.c"
```

This requires splitting the target specific runtimes into distinct automake libraries.

```
libpveccommon_la_SOURCES = tipowof10.c decpowof2.c
libpvecPWR9_la_SOURCES = vec_runtime_PWR9.c
libpvecPWR8_la_SOURCES = vec_runtime_PWR8.c
libpvecPWR7_la_SOURCES = vec_runtime_PWR7.c
```

Then add the -mcpu compile option to runtime library CFLAGS

```
libpvecPWR9_la_CFLAGS = -mcpu=power9
libpvecPWR8_la_CFLAGS = -mcpu=power8
libpvecPWR7_la_CFLAGS = -mcpu=power7
```

Then use additional automake rules to combine these targeted runtimes into a single static archive library.

```
libpvecstatic_la_LIBADD = libpveccommon.la
libpvecstatic_la_LIBADD += libpvecPWR9.la
libpvecstatic_la_LIBADD += libpvecPWR8.la
libpvecstatic_la_LIBADD += libpvecPWR7.la
```

However this does not work if the user (build configure) specifies flag variables (i.e. CFLAGS) containing -mcpu= options internal use of target options.

Note

Automake/libtool will always apply the user CFLAGS after any AM_CFLAGS or yourlib_la_CFLAGS (See [Automake documentation: Flag Variables Ordering](#)) and the last -mcpu option always wins. This has the same affect as the compiler ignoring the #pragma GCC target options described above.

1.4.2.1 A deeper look at library Makefiles

This requires a deeper dive into the black arts of automake and libtools. In this case the libtool macro LTCOMPILE expands the various flag variables in a specific order (with \$CFLAGS last) for all `--tag=CC --mode=compile` commands. In this case we need to either:

- locally edit CFLAGS to eliminates any `-mcpu=` (or `-O`) options so that our internal build targets are applied.
- provide our own alternative to the LTCOMPILE macro and use our own explicit make rules. (See `./pveclib/src/Makefile.am` for examples.)

So lets take a look at LTCOMPILE:

```
LTCOMPILE = $(LIBTOOL) $(AM_V_lt) --tag=CC $(AM_LIBTOOLFLAGS) \
             $(LIBTOOLFLAGS) --mode=compile $(CC) $(DEFS) \
             $(DEFAULT_INCLUDES) $(INCLUDES) $(AM_CPPFLAGS) $(CPPFLAGS) \
             $(AM_CFLAGS) $(CFLAGS)
```

Note

"\$(CFLAGS)" is always applied after all other *FLAGS*.

The generated Makefile.in includes rules that depend on LTCOMPILE. For example the general rule for compile `.c` source to `.lo` objects.

```
.c.lo:
@am__fastdepCC_TRUE@    $(AM_V_CC) depbase='echo $@ | sed 's|[/]*$$|$(DEPDIR)/&|;s|\.lo$$$|'`; \
@am__fastdepCC_TRUE@    $(LTCOMPILE) -MT $@ -MD -MP -MF $$depbase.Tpo -c -o $@ $< && \
@am__fastdepCC_TRUE@    $(am__mv) $$depbase.Tpo $$depbase.Plo
@AMDEP_TRUE@@am__fastdepCC_FALSE@    $(AM_V_CC) source='$<' object='$@' libtool=yes @AMDEPBACKSLASH@
@AMDEP_TRUE@@am__fastdepCC_FALSE@    DEPDIR=$(DEPDIR) $(CCDEPMODE) $(depcomp) @AMDEPBACKSLASH@
@am__fastdepCC_FALSE@    $(AM_V_CC@am__nodep@) $(LTCOMPILE) -c -o $@ $<
```

Or the more specific rule to compile the `vec_runtime_PWR9.c` for the `-mcpu=power9` target:

```
libpvecPWR9_la-vec_runtime_PWR9.lo: vec_runtime_PWR9.c
@am__fastdepCC_TRUE@    $(AM_V_CC) $(LIBTOOL) $(AM_V_lt) --tag=CC $(AM_LIBTOOLFLAGS) \
$(LIBTOOLFLAGS) --mode=compile $(CC) $(DEFS) $(DEFAULT_INCLUDES) $(INCLUDES) \
$(AM_CPPFLAGS) $(CPPFLAGS) $(libpvecPWR9_la_CFLAGS) $(CFLAGS) \
-MT libpvecPWR9_la-vec_runtime_PWR9.lo -MD -MP -MF \
$(DEPDIR)/libpvecPWR9_la-vec_runtime_PWR9.Tpo -c -o libpvecPWR9_la-vec_runtime_PWR9.lo \
`test -f 'vec_runtime_PWR9.c' || echo '$(srcdir)/'`vec_runtime_PWR9.c
@am__fastdepCC_TRUE@    $(AM_V_at) $(am__mv) $(DEPDIR)/libpvecPWR9_la-vec_runtime_PWR9.Tpo \
$(DEPDIR)/libpvecPWR9_la-vec_runtime_PWR9.Plo
@AMDEP_TRUE@@am__fastdepCC_FALSE@    $(AM_V_CC) source='vec_runtime_PWR9.c' \
object='libpvecPWR9_la-vec_runtime_PWR9.lo' libtool=yes @AMDEPBACKSLASH@
@AMDEP_TRUE@@am__fastdepCC_FALSE@    DEPDIR=$(DEPDIR) $(CCDEPMODE) \
$(depcomp) @AMDEPBACKSLASH@
@am__fastdepCC_FALSE@    $(AM_V_CC@am__nodep@) $(LIBTOOL) $(AM_V_lt) --tag=CC \
$(AM_LIBTOOLFLAGS) $(LIBTOOLFLAGS) --mode=compile $(CC) $(DEFS) $(DEFAULT_INCLUDES) \
$(INCLUDES) $(AM_CPPFLAGS) $(CPPFLAGS) $(libpvecPWR9_la_CFLAGS) $(CFLAGS) -c \
-o libpvecPWR9_la-vec_runtime_PWR9.lo `test -f 'vec_runtime_PWR9.c' \
|| echo '$(srcdir)/'`vec_runtime_PWR9.c
```

Which is eventually generated into the Makefile as:

```
libpvecPWR9_la-vec_runtime_PWR9.lo: vec_runtime_PWR9.c
$(AM_V_CC) $(LIBTOOL) $(AM_V_lt) --tag=CC $(AM_LIBTOOLFLAGS) $(LIBTOOLFLAGS) \
--mode=compile $(CC) $(DEFS) $(DEFAULT_INCLUDES) $(INCLUDES) $(AM_CPPFLAGS) \
$(CPPFLAGS) $(libpvecPWR9_la_CFLAGS) $(CFLAGS) -MT libpvecPWR9_la-vec_runtime_PWR9.lo \
-MD -MP -MF $(DEPDIR)/libpvecPWR9_la-vec_runtime_PWR9.Tpo -c -o \
libpvecPWR9_la-vec_runtime_PWR9.lo `test -f 'vec_runtime_PWR9.c' || \
echo '$(srcdir)/'`vec_runtime_PWR9.c
$(AM_V_at) $(am__mv) $(DEPDIR)/libpvecPWR9_la-vec_runtime_PWR9.Tpo \
$(DEPDIR)/libpvecPWR9_la-vec_runtime_PWR9.Plo
# $(AM_V_CC) source='vec_runtime_PWR9.c' object='libpvecPWR9_la-vec_runtime_PWR9.lo' \
# libtool=yes DEPDIR=$(DEPDIR) $(CCDEPMODE) $(depcomp) \
# $(AM_V_CC_no) $(LIBTOOL) $(AM_V_lt) --tag=CC $(AM_LIBTOOLFLAGS) $(LIBTOOLFLAGS) \
# --mode=compile $(CC) $(DEFS) $(DEFAULT_INCLUDES) $(INCLUDES) $(AM_CPPFLAGS) \
# $(CPPFLAGS) $(libpvecPWR9_la_CFLAGS) $(CFLAGS) -c -o libpvecPWR9_la-vec_runtime_PWR9.lo \
# `test -f 'vec_runtime_PWR9.c' || echo '$(srcdir)/'`vec_runtime_PWR9.c
```

Somehow in the internal struggle for the dark soul of automake/libtools, the `@am__fastdepCC_TRUE@` conditional wins out over `@AMDEP_TRUE@@am__fastdepCC_FALSE@`, and the alternate rule was commented out as the Makefile was generated.

However this still leaves a problem. While we see that `$(libpvecPWR9_la_CFLAGS)` applies the `"-mcpu=power9"` target option, it is immediately followed by `$(CFLAGS)`. And if `CFLAGS` contains any `"-mcpu="` option the last `"-mcpu="` option always wins. The result will be broken library archives with duplicate symbols.

Note

The techniques described work reliably for most codes and compilers as long as the user does not override target `(-mcpu=)` with `CFLAGS` on configure.

1.4.2.2 Adding our own Makefile magic

Todo Is there a way for automake to compile `vec_int512_runtime.c` with `-mcpu=power9` and `-o vec_runtime_PWR9.o`? And similarly for `PWR7/PWR8`.

Once we get a glimpse of the underlying automake/libtool rule generation we have a template for how to solve this problem. However while we need to workaround some automake/libtool constraints we also want to fit into overall flow.

First we need an alternative to **LTCOMPILE** where we can bypass user provided **CFLAGS**. For example:

```
PVECCOMPILE = $(LIBTOOL) $(AM_V_lt) --tag=CC $(AM_LIBTOOLFLAGS) \
$(LIBTOOLFLAGS) --mode=compile $(CC) $(DEFS) \
$(DEFAULT_INCLUDES) $(INCLUDES) $(AM_CPPFLAGS) $(CPPFLAGS) \
$(AM_CFLAGS)
```

In this variant (**PVECCOMPILE**) we simply leave `$(CFLAGS)` off the end of the macro.

Now we can use the generated rule above as an example to provide our own Makefile rules. These rules will be passed directly to the generated Makefile. For example:

```
vec_staticrt_PWR9.lo: vec_runtime_PWR9.c $(pveclibinclude_HEADERS)
if am__fastdepCC
$(PVECCOMPILE) $(PVECLIB_POWER9_CFLAGS) -MT $@ -MD -MP -MF \
$(DEPDIR)/$*.Tpo -c -o $@ $(srcdir)/vec_runtime_PWR9.c
mv -f $(DEPDIR)/$*.Tpo $(DEPDIR)/$*.Plo
else
if AMDEP
source='vec_runtime_PWR9.c' object='$@' libtool=yes @AMDEPBACKSLASH@
DEPDIR=$(DEPDIR) $(CCDEPMODE) $(depcomp) @AMDEPBACKSLASH@
endif
$(PVECCOMPILE) $(PVECLIB_POWER9_CFLAGS) -c -o $@ $(srcdir)/vec_runtime_PWR9.c
endif
```

We change the target (`vec_staticrt_PWR9.lo`) of the rule to indicate that this object is intended for a *static* runtime archive. And we list prerequisites `vec_runtime_PWR9.c` and `$(pveclibinclude_HEADERS)`

For the recipe we expand both clauses (`am__fastdepCC` and `AMDEP`) from the example. We don't know exactly what they represent or do, but assume they both are needed for some configurations. We use the alternative `PVECCOMPIL` to provide all the libtool commands and options we need without the `CFLAGS`. We use new `PVECLIB_POWER9_CFL`↔`AGS` macro to provide all the platform specific target options we need. The automatic variable `$@` provides the file name of the target object (`vec_staticrt_PWR9.lo`). And we specify the `$(srcdir)` qualified source file (`vec_runtime_PWR9.c`) as input to the compile. We can provide similar rules for the other processor targets (`PWR8/PWR7`).

With this technique we control the compilation of specific targets without requiring unique `LTLIBRARIES`. This was only required before so libtool would allow target specific `CFLAGS`. So we can eliminate `libpvecPWR9.la`, `libpvecPWR8.la`, and `libpvecPWR7.la` from `lib_LTLIBRARIES`.

Continuing the theme of separating the static archive elements from DSO elements we rename `libpveccommon.la` to `libpvecstatic.la`. We can add the common (none target specific) source files and `CFLAGS` to *libpvecstatic.la*.

```
libpvecstatic_la_SOURCES = tipowof10.c decpowof2.c

libpvecstatic_la_CFLAGS = $(AM_CPPFLAGS) $(PVECLIB_DEFAULT_CFLAGS) $(AM_CFLAGS)
```

We still need to add the target specific objects generated by the rules above to the `libpvecstatic.a` archive.

```
# libpvecstatic_la already includes tipowof10.c decpowof2.c.
# Now add the name qualified -mcpu= target runtimes.
libpvecstatic_la_LIBADD = vec_staticrt_PWR9.lo
libpvecstatic_la_LIBADD += vec_staticrt_PWR8.lo
libpvecstatic_la_LIBADD += vec_staticrt_PWR7.lo
```

Note

the `libpvecstatic` archive will contain 2 or 3 implementations of each target specific function (i.e. the function `vec_mul128x128()` will have implementations `vec_mul128x128_PWR7()` and `vec_mul128x128_PWR8()`, `vec_`↔`mul128x128_PWR9()`). This OK because because the target suffix insures the name is unique within the archive. When an application calls function with the appropriate target suffix (using the `__VEC_PWR_IMP()` wrapper macro) and links to `libpvecstatic`, the linker will extract only the matching implementations and include them in the static program image.

1.4.3 Building dynamic runtime libraries

Building objects for dynamic runtime libraries is a bit more complicated than building static archives. For one dynamic libraries requires position independent code (**PIC**) while static code does not. Second we want to leverage the Dynamic Linker/Loader's GNU Indirect Function (See: [What is an indirect function \(IFUNC\)?](#)) binding mechanism.

PIC functions require a more complicated call linkage or function prologue. This usually requires the `-fpic` compiler option. This is the case for the OpenPOWER ELF V2 ABI. Any PIC function must assume that the caller may be from an different execution unit (library or main executable). So the called function needs to establish the Table of Contents (**TOC**) base address for itself. This is the case if the called function needs to reference static or const storage variables or calls to functions in other dynamic libraries. So it is normal to compile library runtime codes separately for static archives and DSOs.

Note

The details of how the **TOC** is established differs between the ELF V1 ABI (Big Endian POWER) and the ELF V2 ABI (Little Endian POWER). This should not be an issue if compile options (-fpic) are used correctly.

There are additional differences associated with dynamic selection of function Implementations for different processor targets. The Linux dynamic linker/loader (ld64.so) provides general mechanism for target specific binding of function call linkage.

The dynamic linker employs a user supplied resolver mechanism as function calls are dynamically bound to to an implementation. The DSO exports function symbols that externally look like a normal *extern*. For example:

```
extern __VEC_U_256
vec_mul128x128 (vui128_t, vui128_t);
```

This symbol's implementation has a special **STT_GNU_IFUNC** attribute recognized by the dynamic linker which associates this symbol with the corresponding runtime resolver function. So in addition to any platform specific implementations we need to provide the resolver function referenced by the *IFUNC* symbol. For example:

```
//
// \file vec_runtime_DYN.c
//
extern __VEC_U_256
vec_mul128x128_PWR7 (vui128_t, vui128_t);

extern __VEC_U_256
vec_mul128x128_PWR8 (vui128_t, vui128_t);

extern __VEC_U_256
vec_mul128x128_PWR9 (vui128_t, vui128_t);

static
__VEC_U_256
(*resolve_vec_mul128x128 (void)) (vui128_t, vui128_t)
{
#ifdef __BUILTIN_CPU_SUPPORTS__
    if (__builtin_cpu_is ("power9"))
        return vec_mul128x128_PWR9;
    else
    {
        if (__builtin_cpu_is ("power8"))
            return vec_mul128x128_PWR8;
        else
            return vec_mul128x128_PWR7;
    }
#else // ! __BUILTIN_CPU_SUPPORTS__
    return vec_mul128x128_PWR7;
#endif
}

__VEC_U_256
vec_mul128x128 (vui128_t, vui128_t)
__attribute__ ((ifunc ("resolve_vec_mul128x128"));
```

For convince we collect the:

- IFUNC symbols
- corresponding resolver functions
- and externs to target specific implementations

into one or more source files (For example: `vec_runtime_DYN.c`).

On the program's first call to an *IFUNC* symbol, the dynamic linker calls the resolver function associated with that symbol. The resolver function performs a runtime check to determine the platform, selects the (closest) matching platform specific function, then returns that function pointer to the dynamic linker.

The dynamic linker stores this function pointer in the callers Procedure Linkage Tables (PLT) before forwarding the call to the resolved implementation. Any subsequent calls to this function symbol branch (via the PLT) directly to the appropriate platform specific implementation.

Note

The platform specific implementations we use here are compiled from the same source files we used to build the static library archive.

Like the static libraries we need to build multiple target specific implementations of the functions. So we can leverage the example of explicit Makefile rules we used for the static archive but with some minor differences. For example:

```
vec_dynrt_PWR9.lo: vec_runtime_PWR9.c $(pveclibinclude_HEADERS)
if am__fastdepCC
    $(PVECCOMPILER) -fpic $(PVECLIB_POWER9_CFLAGS) -MT $@ -MD -MP -MF \
    $(DEPDIR)/$*.Tpo -c -o $@ $(srcdir)/vec_runtime_PWR9.c
    mv -f $(DEPDIR)/$*.Tpo $(DEPDIR)/$*.Plo
else
if AMDEP
    source='vec_runtime_PWR9.c' object='$@' libtool=yes @AMDEPBACKSLASH@
    DEPDIR=$(DEPDIR) $(CCDEPMODE) $(depcomp) @AMDEPBACKSLASH@
endif
    $(PVECCOMPILER) -fpic $(PVECLIB_POWER9_CFLAGS) -c -o $@ \
    $(srcdir)/vec_runtime_PWR9.c
endif
```

Again we change the rule target (`vec_dynrt_PWR9.lo`) of the rule to indicate that this object is intended for a *DSO* runtime. And we list the same prerequisites `vec_runtime_PWR9.c` and `$(pveclibinclude_HEADERS)`

For the recipe we expand both clauses (`am__fastdepCC` and `AMDEP`) from the example. We use the alternative `PVECCOMPILER` to provide all the libtool commands and options we need without the `CFLAGS`. But we insert the `-fpic` option so the compiler will generate position independent code. We use a new `PVECLIB_POWER9_CFLAGS` macro to provide all the platform specific target options we need. The automatic variable `$@` provides the file name of the target object (`vec_dynrt_PWR9.lo`). And we specify the same `$(srcdir)` qualified source file (`vec_runtime_PWR9.c`) we used for the static library. We can provide similar rules for the other processor targets (`PWR8/PWR7`). We also build an `-fpic` version of `vec_runtime_common.c`.

Continuing the theme of separating the static archive elements from *DSO* elements, we use `libpvec.la` as the libtool name for `libpvec.so`. Here we add the source files for the *IFUNC* resolvers and add `-fpic` as library specific `CFLAGS` to `libpvec.la`.

```
libpvec_la_SOURCES = vec_runtime_DYN.c

libpvec_la_CFLAGS = $(AM_CPPFLAGS) -fpic $(PVECLIB_DEFAULT_CFLAGS) $(AM_CFLAGS)
```

We still need to add the target specific and common objects generated by the rules above to the `libpvec` library.

```
# libpvec_la already includes vec_runtime_DYN.c compiled with -fpic
# for IFUNC resolvers.
# Now adding the -fpic -mcpu= target built runtimes.
libpvec_la_LDFLAGS = -version-info $(PVECLIB_SO_VERSION)
libpvec_la_LIBADD = vec_dynrt_PWR9.lo
libpvec_la_LIBADD += vec_dynrt_PWR8.lo
libpvec_la_LIBADD += vec_dynrt_PWR7.lo
libpvec_la_LIBADD += vec_dynrt_common.lo
libpvec_la_LIBADD += -lc
```


1.4.4 Calling Multi-platform functions

The next step is to provide mechanisms for applications to call these functions via static or dynamic linkage. For static linkage the application needs to reference a specific platform variant of the functions name. For dynamic linkage we will use **STT_GNU_IFUNC** symbol resolution (a symbol type extension to the ELF standard).

1.4.4.1 Static linkage to platform specific functions

For static linkage the application is compiled for a specific platform target (via `-mcpu=`). So function calls should be bound to the matching platform specific implementations. The application may select the platform specific function directly by defining a *extern* and invoking the platform qualified function.

Or simply use the `__VEC_PWR_IMP()` macro as wrapper for the function name in the application. This selects the appropriate platform specific implementation based on the `-mcpu=` specified for the application compile. For example.

```
k = __VEC_PWR_IMP (vec_mul128x128) (i, j);
```

The `vec_int512_ppc.h` header provides the default platform qualified *extern* declarations for this and related functions based on the `-mcpu=` specified for the compile of application including this header. For example.

```
extern __VEC_U_256
__VEC_PWR_IMP (vec_mul128x128) (vui128_t,
                               vui128_t);
```

For example if the applications calling `vec_mul128x128()` is itself compiled with `-mcpu=power8`, then the `__VEC_PWR_IMP()` will insure that:

- The `vec_int512_ppc.h` header will define an extern for `vec_mul128x128_PWR8`.
- That application's calls to `__VEC_PWR_IMP (vec_mul128x128)` will reference `vec_mul128x128_PWR8`.

The application should then link to the `libpvecstatic.a` archive. Where the application references PVECLIB functions with the appropriate target suffix, the linker will extract only the matching implementations and include them in the program image.

1.4.4.2 Dynamic linkage to platform specific functions

Applications using dynamic linkage will call the unqualified function symbol. For example:

```
extern __VEC_U_256
vec_mul128x128 (vui128_t, vui128_t);
```

This symbol's implementation (in `libpvec.so`) has a special **STT_GNU_IFUNC** attribute recognized by the dynamic linker which associates this symbol with the corresponding runtime resolver function. The application simply calls the (unqualified) function and the dynamic linker (with the help of PVECLIB's IFUNC resolvers) handles the details.

1.5 Performance data.

It is useful to provide basic performance data for each pveclib function. This is challenging as these functions are small and intended to be in-lined within larger functions (algorithms). As such they are subject to both the compiler's instruction scheduling and common subexpression optimizations plus the processors super-scalar and out-of-order execution design features.

As pveclib functions are normally only a few instructions, the actual timing will depend on the context it is in (the instructions that it depends on for data and instructions that proceed them in the pipelines).

The simplest approach is to use the same performance metrics as the Power Processor Users Manuals Performance Profile. This is normally per instruction latency in cycles and throughput in instructions issued per cycle. There may also be additional information for special conditions that may apply.

For example the vector float absolute value function. For recent PowerISA implementations this a single (VSX **xvabssp**) instruction which we can look up in the POWER8 / POWER9 Processor User's Manuals (**UM**).

processor	Latency	Throughput
power8	6-7	2/cycle
power9	2	2/cycle

The POWER8 UM specifies a latency of *"6 cycles to FPU (+1 cycle to other VSU ops"* for this class of VSX single precision FPU instructions. So the minimum latency is 6 cycles if the register result is input to another VSX single precision FPU instruction. Otherwise if the result is input to a VSU logical or integer instruction then the latency is 7 cycles. The POWER9 UM shows the pipeline improvement of 2 cycles latency for simple FPU instructions like this. Both processors support dual pipelines for a 2/cycle throughput capability.

A more complicated example:

```
static inline vb32_t
vec_isnanf32 (vf32_t vf32)
{
    vui32_t tmp2;
    const vui32_t expmask = CONST_VINT128_W(0x7f800000, 0x7f800000, 0x7f800000,
                                              0x7f800000);
    #if _ARCH_PWR9
    // P9 has a 2 cycle xvabssp and eliminates a const load.
    tmp2 = (vui32_t) vec_abs (vf32);
    #else
    const vui32_t signmask = CONST_VINT128_W(0x80000000, 0x80000000, 0x80000000,
                                              0x80000000);
    tmp2 = vec_andc ((vui32_t)vf32, signmask);
    #endif
    return vec_cmpgt (tmp2, expmask);
}
```

Here we want to test for *Not A Number* without triggering any of the associate floating-point exceptions (VXSNAN or VXVC). For this test the sign bit does not effect the result so we need to zero the sign bit before the actual test. The vector abs would work for this, but we know from the example above that this instruction has a high latency as we are definitely passing the result to a non-FPU instruction (vector compare greater than unsigned word).

So the code needs to load two constant vectors masks, then vector and-compliment to clear the sign-bit, before comparing each word for greater than infinity. The generated code should look something like this:

```

addis    r9,r2,.rodata.cst16+0x10@ha
addis    r10,r2,.rodata.cst16+0x20@ha
addi     r9,r9,.rodata.cst16+0x10@l
addi     r10,r10,.rodata.cst16+0x20@l
lvx      v0,0,r10 # load vector const signmask
lvx      v12,0,r9 # load vector const expmask
xxlandc  vs34,vs34,vs32
vcmpgtuw v2,v2,v12

```

So six instructions to load the const masks and two instructions for the actual `vec_isnanf32` function. The first six instructions are only needed once for each containing function, can be hoisted out of loops and into the function prologue, can be *commoned* with the same constant for other pveclib functions, or executed out-of-order and early by the processor.

Most of the time, constant setup does not contribute measurably to the over all performance of `vec_isnanf32`. When it does it is limited by the longest (in cycles latency) of the various independent paths that load constants. In this case the const load sequence is composed of three pairs of instructions that can issue and execute in parallel. The `addis/addi` FXU instructions supports throughput of 6/cycle and the `lvx` load supports 2/cycle. So the two vector constant load sequences can execute in parallel and the latency is same as a single const load.

For POWER8 it appears to be (2+2+5=) 9 cycles latency for the const load. While the core `vec_isnanf32` function (`xxlandc/vcmpgtuw`) is a dependent sequence and runs (2+2) 4 cycles latency. Similar analysis for POWER9 where the `addis/addi/lvx` sequence is still listed as (2+2+5) 9 cycles latency. While the `xxlandc/vcmpgtuw` sequence increases to (2+3) 5 cycles.

The next interesting question is what can we say about throughput (if anything) for this example. The thought experiment is "what would happen if?";

- two or more instances of `vec_isnanf32` are used within a single function,
- in close proximity in the code,
- with independent data as input,

could the generated instructions execute in parallel and to what extent. This illustrated by the following (contrived) example:

```

int
test512_all_f32_nan (vf32_t val0, vf32_t val1, vf32_t val2,
                    vf32_t val3)
{
    const vb32_t alltrue = { -1, -1, -1, -1 };
    vb32_t nan0, nan1, nan2, nan3;

    nan0 = vec_isnanf32 (val0);
    nan1 = vec_isnanf32 (val1);
    nan2 = vec_isnanf32 (val2);
    nan3 = vec_isnanf32 (val3);

    nan0 = vec_and (nan0, nan1);
    nan2 = vec_and (nan2, nan3);
    nan0 = vec_and (nan2, nan0);

    return vec_all_eq(nan0, alltrue);
}

```

which tests 4 X vector float (16 X float) values and returns true if all 16 floats are NaN. Recent compilers will generates something like the following PowerISA code:

```

addis    r9,r2,-2
addis    r10,r2,-2
vspltisw vl3,-1      # load vector const alltrue
addi     r9,r9,21184
addi     r10,r10,-13760
lvx      v0,0,r9      # load vector const signmask
lvx      v1,0,r10     # load vector const expmask
xxlandc  vs35,vs35,vs32
xxlandc  vs34,vs34,vs32
xxlandc  vs37,vs37,vs32
xxlandc  vs36,vs36,vs32
vcmpgtuw v3,v3,v1     # nan1 = vec_isnanf32 (val1);
vcmpgtuw v2,v2,v1     # nan0 = vec_isnanf32 (val0);
vcmpgtuw v5,v5,v1     # nan3 = vec_isnanf32 (val3);
vcmpgtuw v4,v4,v1     # nan2 = vec_isnanf32 (val2);
xxland   vs35,vs35,vs34 # nan0 = vec_and (nan0, nan1);
xxland   vs36,vs37,vs36 # nan2 = vec_and (nan2, nan3);
xxland   vs36,vs35,vs36 # nan0 = vec_and (nan2, nan0);
vcmpqeuw v4,v4,v13    # vec_all_eq(nan0, alltrue);
...

```

first the generated code loading the vector constants for signmask, expmask, and alltrue. We see that the code is generated only once for each constant. Then the compiler generate the core `vec_isnanf32` function four times and interleaves the instructions. This enables parallel pipeline execution where conditions allow. Finally the 16X isnan results are reduced to 8X, then 4X, then to a single condition code.

For this exercise we will ignore the constant load as in any realistic usage it will be *commoned* across several pveclib functions and hoisted out of any loops. The reduction code is not part of the `vec_isnanf32` implementation and also ignored. The sequence of 4X `xxlandc` and 4X `vcmpgtuw` in the middle it the interesting part.

For POWER8 both `xxlandc` and `vcmpgtuw` are listed as 2 cycles latency and throughput of 2 per cycle. So we can assume that (only) the first two `xxlandc` will issue in the same cycle (assuming the input vectors are ready). The issue of the next two `xxlandc` instructions will be delay by 1 cycle. The following `vcmpgtuw` instruction are dependent on the `xxlandc` results and will not execute until their input vectors are ready. The first two `vcmpgtuw` instruction will execute 2 cycles (latency) after the first two `xxlandc` instructions execute. Execution of the second two `vcmpgtuw` instructions will be delayed 1 cycle due to the issue delay in the second pair of `xxlandc` instructions.

So at least for this example and this set of simplifying assumptions we suggest that the throughput metric for `vec_isnanf32` is 2/cycle. For latency metric we offer the range with the latency for the core function (without and constant load overhead) first. Followed by the total latency (the sum of the constant load and core function latency). For the `vec_isnanf32` example the metrics are:

processor	Latency	Throughput
power8	4-13	2/cycle
power9	5-14	2/cycle

Looking at a slightly more complicated example where core functions implementation can execute more then one instruction per cycle. Consider:

```

static inline vb32_t
vec_isnormalf32 (vf32_t vf32)
{
    vui32_t tmp, tmp2;
    const vui32_t expmask = CONST_VINT128_W(0x7f800000, 0x7f800000, 0x7f800000,
                                              0x7f800000);
    const vui32_t minnorm = CONST_VINT128_W(0x00800000, 0x00800000, 0x00800000,
                                              0x00800000);

    #if _ARCH_PWR9
    // P9 has a 2 cycle xwabssp and eliminates a const load.
    tmp2 = (vui32_t) vec_abs (vf32);
    #else

```

```

const vui32_t signmask = CONST_VINT128_W(0x80000000, 0x80000000, 0x80000000,
                                           0x80000000);
tmp2 = vec_andc ((vui32_t)vf32, signmask);
#endif
tmp = vec_and ((vui32_t) vf32, expmask);
tmp2 = (vui32_t) vec_cmplt (tmp2, minnorm);
tmp = (vui32_t) vec_cmpeq (tmp, expmask);

return (vb32_t)vec_nor (tmp, tmp2);
}

```

which requires two (independent) masking operations (sign and exponent), two (independent) compares that are dependent on the masking operations, and a final *not OR* operation dependent on the compare results.

The generated POWER8 code looks like this:

```

addis    r10,r2,-2
addis    r8,r2,-2
addi     r10,r10,21184
addi     r8,r8,-13760
addis    r9,r2,-2
lvx      v13,0,r8
addi     r9,r9,21200
lvx      v1,0,r10
lvx      v0,0,r9
xxland   vs33,vs33,vs34
xxlandc  vs34,vs45,vs34
vcmpgtuw v0,v0,v1
vcmpequw v2,v2,v13
xxlnor   vs34,vs32,vs34

```

Note this this sequence needs to load 3 vector constants. In previous examples we have noted that POWER8 `lvx` supports 2/cycle throughput. But with good scheduling, the 3rd vector constant load, will only add 1 additional cycle to the timing (10 cycles).

Once the constant masks are loaded the `xxland/xxlandc` instructions can execute in parallel. The `vcmpgtuw/vcmpequw` can also execute in parallel but are delayed waiting for the results of masking operations. Finally the `xxnor` is dependent on the data from both compare instructions.

For POWER8 the latencies are 2 cycles each, and assuming parallel execution of `xxland/xxlandc` and `vcmpgtuw/vcmpequw` we can assume (2+2+2=) 6 cycles minimum latency and another 10 cycles for the constant loads (if needed).

While the POWER8 core has ample resources (10 issue ports across 16 execution units), this specific sequence is restricted to the two *issue ports and VMX execution units* for this class of (simple vector integer and logical) instructions. For `vec_isnormalf32` this allows for a lower latency (6 cycles vs the expected 10, over 5 instructions), it also implies that both of the POWER8 cores *VMX execution units* are busy for 2 out of the 6 cycles.

So while the individual instructions have can have a throughput of 2/cycle, `vec_isnormalf32` can not. It is plausible for two executions of `vec_isnormalf32` to interleave with a delay of 1 cycle for the second sequence. To keep the table information simple for now, just say the throughput of `vec_isnormalf32` is 1/cycle.

After that it gets complicated. For example after the first two instances of `vec_isnormalf32` are issued, both *VMX execution units* are busy for 4 cycles. So either the first instructions of the third `vec_isnormalf32` will be delayed until the fifth cycle. Or the compiler scheduler will interleave instructions across the instances of `vec_isnormalf32` and the latencies of individual `vec_isnormalf32` results will increase. This is too complicated to put in a simple table.

For POWER9 the sequence is slightly different

```

addis    r10,r2,-2
addis    r9,r2,-2
xvabssp  vs45,vs34
addi     r10,r10,-14016
addi     r9,r9,-13920
lvx      v1,0,r10
lvx      v0,0,r9
xxland   vs34,vs34,vs33
vcmpgtuw v0,v0,v13
vcmpquw  v2,v2,v1
xxlnor   vs34,vs32,vs34

```

We use `vec_abs` (`xvabssp`) to replace the `sigmask` and `vec_andc` and so only need to load two vector constants. So the constant load overhead is reduced to 9 cycles. However the the vector compares are now 3 cycles for $(2+3+2=)$ 7 cycles for the core sequence. The final table for `vec_isnormalf32`:

processor	Latency	Throughput
power8	6-16	1/cycle
power9	7-16	1/cycle

1.5.1 Additional analysis and tools.

The overview above is simplified analysis based on the instruction latency and throughput numbers published in the Processor User's Manuals (see [Reference Documentation](#)). These values are *best case* (input data is ready, SMT1 mode, no cache misses, mispredicted branches, or other hazards) for each instruction in isolation.

Note

This information is intended as a guide for compiler and application developers wishing to optimize for the platform. Any performance tables provided for pveclib functions are in this spirit.

Of course the actual performance is complicated by the overall environment and how the pveclib functions are used. It would be unusual for pveclib functions to be used in isolation. The compiler will in-line pveclib functions and look for sub-expressions it can hoist out of loops or share across pveclib function instances. The compiler will also model the processor and schedule instructions across the larger containing function. So in actual use the instruction sequences for the examples above are likely to be interleaved with instructions from other pveclib functions and user written code.

Larger functions that use pveclib and even some of the more complicated pveclib functions (like `vec_muludq`) defy simple analysis. For these cases it is better to use POWER specific analysis tools. To understand the overall pipeline flows and identify hazards the instruction trace driven performance simulator is recommended.

The [IBM Advance Toolchain](#) includes an updated (POWER enabled) Valgrind tool and instruction trace plug-in (`itrace`). The `itrace` tool (`-tool=itrace`) collects instruction traces for the whole program or specific functions (via `-fname=option`).

Note

The Valgrind package provided by the Linux Distro may not be enabled for the latest POWER processor. Nor will it include the `itrace` plug-in or the associated `vgi2qt` conversion tool.

Instruction trace files are processed by the [Performance Simulator](#) (`sim_ppc`) models. Performance simulators are specific to each processor generation (POWER7-9) and provides a cycle accurate modeling for instruction trace streams. The results of the model (a pipe file) can viewed via one the interactive display tools (`scrollpv`, `jviewer`) or passed to an analysis tool like `pipestat`.

Chapter 2

Todo List

page [POWER Vector Library \(pveclib\)](#)

Is there a way for automake to compile `vec_int512_runtime.c` with `-mcpu=power9` and `-o vec_runtime_PWR9.o`? And similarly for PWR7/PWR8.

File [vec_bcd_ppc.h](#)

The BCD add/subtract extend/carry story is not complete. The carry extend operations based only on the **OV** condition codes only works as expected for `bcdadd` operands with the same sign and `bcdsub` with different signs. See [vec_bcdaddcsq\(\)](#) and [vec_bcdaddecscq\(\)](#). Extended BCD difference (or subtract the same sign or add with different signs) is more complicated. See [vec_bcdsubcsq\(\)](#) and [vec_bcdsubecscq\(\)](#). Generating a true borrow seems to require looking one (31-digit) column ahead or behind. The first attempt at generating correct borrowing is implemented in [vec_cbcdaddcsq\(\)](#) and [vec_cbcdaddecscq\(\)](#). There are still cases where these operation will generate a borrow and invert (10s complement) incorrectly. The net seems to be that for BCD multiple precision difference to work correctly, the larger magnitude must be the first operand.

File [vec_int128_ppc.h](#)

The implementation above gives correct results for all the cases tested for divide by constants 10^{31} and 10^{32}). This is not a mathematical proof of correctness, just an observation. Anyone who finds a counter example or offers a mathematical proof should submit a bug report.

File [vec_int512_ppc.h](#)

Currently the dynamic resolvers and *IFUNC* symbols for `vec_int512_runtime.c` are contained within `vec_runtime↔_DYN.c`. As the list of runtime operations expands to other element sizes/types, `vec_runtime_DYN.c` should be refactored into multiple files.

Chapter 3

Deprecated List

Member `vec_slq4` (`vui128_t vra`)

Vector Shift Left 4-bits Quadword. Replaced by `vec_slqi` with `shb param = 4`.

Member `vec_slq5` (`vui128_t vra`)

Vector Shift Left 5-bits Quadword. Replaced by `vec_slqi` with `shb param = 5`.

Member `vec_spltd` (`vui64_t vra, const int ctl`)

Vector splat doubleword. Duplicate the selected doubleword element across the doubleword elements of the result.

Member `vec_srq4` (`vui128_t vra`)

Vector Shift right 4-bits Quadword. Replaced by `vec_srq` with `shb param = 4`.

Member `vec_srq5` (`vui128_t vra`)

Vector Shift right 5-bits Quadword. Replaced by `vec_srq` with `shb param = 5`.

Chapter 4

Class Index

4.1 Class List

Here are the classes, structs, unions and interfaces with brief descriptions:

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__VEC_U_1024x512	A vector representation of a 1024-bit unsigned integer as two 512-bit fields	47
__VEC_U_1152	A vector representation of a 1152-bit unsigned integer	48
__VEC_U_128	Union used to transfer 128-bit data between vector and non-vector types	49
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Chapter 5

File Index

5.1 File List

Here is a list of all documented files with brief descriptions:

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src/pveclib/ vec_char_ppc.h Header package containing a collection of 128-bit SIMD operations over 8-bit integer (char) elements	126
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Chapter 6

Class Documentation

6.1 `__VEC_U_1024` Struct Reference

A vector representation of a 1024-bit unsigned integer.

```
#include <vec_int512_ppc.h>
```

6.1.1 Detailed Description

A vector representation of a 1024-bit unsigned integer.

A homogeneous aggregate of 8 x 128-bit unsigned integer fields. The low order field is named vx0, progressing to the high order field vx7.

The documentation for this struct was generated from the following file:

- src/pveclib/[vec_int512_ppc.h](#)

6.2 `__VEC_U_1024x512` Union Reference

A vector representation of a 1024-bit unsigned integer as two 512-bit fields.

```
#include <vec_int512_ppc.h>
```

6.2.1 Detailed Description

A vector representation of a 1024-bit unsigned integer as two 512-bit fields.

A union of:

- homogeneous aggregate of 1024-bit unsigned integer.
- struct of:
 - two x homogeneous aggregate of 512-bit unsigned integers.

Note

Useful for summing partial products based on a 512x512-bit multiply.

The documentation for this union was generated from the following file:

- [src/pveclib/vec_int512_ppc.h](#)

6.3 __VEC_U_1152 Struct Reference

A vector representation of a 1152-bit unsigned integer.

```
#include <vec_int512_ppc.h>
```

6.3.1 Detailed Description

A vector representation of a 1152-bit unsigned integer.

A homogeneous aggregate of 9 x 128-bit unsigned integer fields. The low order field is named vx0, progressing to the high order field vx8.

Note

Useful for returning the result of a 1024x128-bit multiply.

This structure does not qualify for parameter passing in registers (more than 8 registers are required) and will be passed in memory.

The documentation for this struct was generated from the following file:

- [src/pveclib/vec_int512_ppc.h](#)

6.4 __VEC_U_128 Union Reference

Union used to transfer 128-bit data between vector and non-vector types.

```
#include <vec_common_ppc.h>
```

Public Attributes

- unsigned __int128 [i128](#)
Signed 128-bit integer from pair of 64-bit GPRs.
- unsigned __int128 [ui128](#)
Unsigned 128-bit integer from pair of 64-bit GPRs.
- _Decimal128 [dpd128](#)
128 bit Decimal Float from pair of double float registers.
- long double [ldbl128](#)
IBM long double float from pair of double float registers.
- [vui8_t vx16](#)
128 bit Vector of 16 unsigned char elements.
- [vui16_t vx8](#)
128 bit Vector of 8 unsigned short int elements.
- [vui32_t vx4](#)
128 bit Vector of 4 unsigned int elements.
- [vui64_t vx2](#)
128 bit Vector of 2 unsigned long int (64-bit) elements.
- [vui128_t vx1](#)
128 bit Vector of 1 unsigned __int128 element.
- [vf64_t vf2](#)
128 bit Vector of 2 double float elements.
- ```
struct {
 uint64_t lower
 uint64_t upper
} ulong
```

*Struct of two unsigned long int (64-bit GPR) fields.*

### 6.4.1 Detailed Description

Union used to transfer 128-bit data between vector and non-vector types.

The documentation for this union was generated from the following file:

- src/pveclib/[vec\\_common\\_ppc.h](#)

## 6.5 \_\_VEC\_U\_2048 Struct Reference

A vector representation of a 2048-bit unsigned integer.

```
#include <vec_int512_ppc.h>
```

### 6.5.1 Detailed Description

A vector representation of a 2048-bit unsigned integer.

A homogeneous aggregate of 16 x 128-bit unsigned integer fields. The low order field is named vx0, progressing to the high order field vx15.

#### Note

This structure does not qualify for parameter passing in registers (more than 8 registers are required) and will be passed in memory.

The documentation for this struct was generated from the following file:

- [src/pveclib/vec\\_int512\\_ppc.h](#)

## 6.6 \_\_VEC\_U\_2048x512 Union Reference

A vector representation of a 2048-bit unsigned integer as 4 x 512-bit integer fields.

```
#include <vec_int512_ppc.h>
```

### 6.6.1 Detailed Description

A vector representation of a 2048-bit unsigned integer as 4 x 512-bit integer fields.

A union of:

- homogeneous aggregate of 2048-bit unsigned integer.
- struct of:
  - 4 x homogeneous aggregate of 512-bit unsigned integers.

#### Note

Useful to access 512-bit blocks to pass to a 512x512-bit multiplies. These can be used as partial products in a larger 2048x2048-bit multiply.

This structure does not qualify for parameter passing in registers (more than 8 registers are required) and will be passed in memory.

The documentation for this union was generated from the following file:

- [src/pveclib/vec\\_int512\\_ppc.h](#)

## 6.7 \_\_VEC\_U\_2176 Struct Reference

A vector representation of a 2176-bit unsigned integer.

```
#include <vec_int512_ppc.h>
```

### 6.7.1 Detailed Description

A vector representation of a 2176-bit unsigned integer.

A homogeneous aggregate of 17 x 128-bit unsigned integer fields. The low order field is named vx0, progressing to the high order field vx16.

#### Note

Useful for returning the result of a 2048x128-bit multiply.

This structure does not qualify for parameter passing in registers (more than 8 registers are required) and will be passed in memory.

The documentation for this struct was generated from the following file:

- [src/pveclib/vec\\_int512\\_ppc.h](#)

## 6.8 \_\_VEC\_U\_256 Struct Reference

A vector representation of a 256-bit unsigned integer.

```
#include <vec_int512_ppc.h>
```

### 6.8.1 Detailed Description

A vector representation of a 256-bit unsigned integer.

A homogeneous aggregate of 2 x 128-bit unsigned integer fields. The low order field is named vx0, progressing to the high order field vx1.

The documentation for this struct was generated from the following file:

- [src/pveclib/vec\\_int512\\_ppc.h](#)

## 6.9 \_\_VEC\_U\_4096 Struct Reference

A vector representation of a 4096-bit unsigned integer.

```
#include <vec_int512_ppc.h>
```

### 6.9.1 Detailed Description

A vector representation of a 4096-bit unsigned integer.

A homogeneous aggregate of 32 x 128-bit unsigned integer fields. The low order field is named vx0, progressing to the high order field vx31.

#### Note

This structure does not qualify for parameter passing in registers (more than 8 registers are required) and will be passed in memory.

The documentation for this struct was generated from the following file:

- [src/pveclib/vec\\_int512\\_ppc.h](#)

## 6.10 \_\_VEC\_U\_4096x512 Union Reference

A vector representation of a 4096-bit unsigned integer as 8 x 512-bit integer fields.

```
#include <vec_int512_ppc.h>
```

### 6.10.1 Detailed Description

A vector representation of a 4096-bit unsigned integer as 8 x 512-bit integer fields.

A union of:

- homogeneous aggregate of 4096-bit unsigned integer.
- struct of:
  - 8 x homogeneous aggregate of 512-bit unsigned integers.

#### Note

Useful to access 512-bit blocks to pass to a 512x512-bit multiplies. These can be used as partial products in a larger 2048x2048-bit multiply.

This structure does not qualify for parameter passing in registers (more than 8 registers are required) and will be passed in memory.

The documentation for this union was generated from the following file:

- [src/pveclib/vec\\_int512\\_ppc.h](#)

## 6.11 \_\_VEC\_U\_512 Struct Reference

A vector representation of a 512-bit unsigned integer.

```
#include <vec_int512_ppc.h>
```

### 6.11.1 Detailed Description

A vector representation of a 512-bit unsigned integer.

A homogeneous aggregate of 4 x 128-bit unsigned integer fields. The low order field is named vx0, progressing to the high order field vx3.

The documentation for this struct was generated from the following file:

- src/pveclib/[vec\\_int512\\_ppc.h](#)

## 6.12 \_\_VEC\_U\_512x1 Union Reference

A vector representation of a 512-bit unsigned integer and a 128-bit carry-out.

```
#include <vec_int512_ppc.h>
```

### 6.12.1 Detailed Description

A vector representation of a 512-bit unsigned integer and a 128-bit carry-out.

A union of:

- homogeneous aggregate of 640-bit unsigned integer.
- struct of:
  - homogeneous aggregate of 512-bit unsigned integer.
  - vector representation of the carry out of 512-bit add.
- The Carry out vector overlays the high-order 128-bits of the 640-bit vector.

#### Note

Useful for passing the carry-out of a 512-bit add into the carry-in of an extended add.

The documentation for this union was generated from the following file:

- src/pveclib/[vec\\_int512\\_ppc.h](#)

## 6.13 \_\_VEC\_U\_640 Struct Reference

A vector representation of a 640-bit unsigned integer.

```
#include <vec_int512_ppc.h>
```

### 6.13.1 Detailed Description

A vector representation of a 640-bit unsigned integer.

A homogeneous aggregate of 5 x 128-bit unsigned integer fields. The low order field is named vx0, progressing to the high order field vx4.

#### Note

Useful for returning the result of a 512x128-bit multiply.

The documentation for this struct was generated from the following file:

- [src/pveclib/vec\\_int512\\_ppc.h](#)

## 6.14 \_\_VF\_128 Union Reference

Union used to transfer 128-bit data between vector and \_\_float128 types.

```
#include <vec_f128_ppc.h>
```

### Public Attributes

- [vui8\\_t vx16](#)  
*union field of vector unsigned char elements.*
- [vui16\\_t vx8](#)  
*union field of vector unsigned short elements.*
- [vui32\\_t vx4](#)  
*union field of vector unsigned int elements.*
- [vui64\\_t vx2](#)  
*union field of vector unsigned long long elements.*
- [vui128\\_t vx1](#)  
*union field of vector unsigned \_\_int128 elements.*
- [vb128\\_t vbool1](#)  
*union field of vector \_\_bool \_\_int128 elements.*
- [\\_\\_binary128 vf1](#)  
*union field of \_\_float128 elements.*

### 6.14.1 Detailed Description

Union used to transfer 128-bit data between vector and \_\_float128 types.

The documentation for this union was generated from the following file:

- [src/pveclib/vec\\_f128\\_ppc.h](#)

## Chapter 7

# File Documentation

### 7.1 src/pveclib/vec\_bcd\_ppc.h File Reference

Header package containing a collection of Binary Coded Decimal (**BCD**) computation and Zoned Character conversion operations on vector registers.

```
#include <pveclib/vec_common_ppc.h>
#include <pveclib/vec_char_ppc.h>
#include <pveclib/vec_int128_ppc.h>
```

#### Macros

- `#define vBCD_t vui32_t`  
*vector signed BCD integer of up to 31 decimal digits.*
- `#define vbBCD_t vb32_t`  
*vector vector bool from 128-bit signed BCD integer.*
- `#define _BCD_CONST_PLUS_NINES ((vBCD_t) CONST_VINT128_DW128(0x9999999999999999, 0x999999999999999c))`  
*vector signed BCD constant +9s.*
- `#define _BCD_CONST_PLUS_ONE ((vBCD_t) CONST_VINT128_DW128(0, 0x1c))`  
*vector signed BCD constant +1.*
- `#define _BCD_CONST_MINUS_ONE ((vBCD_t) CONST_VINT128_DW128(0, 0x1d))`  
*vector signed BCD constant -1.*
- `#define _BCD_CONST_ZERO ((vBCD_t) CONST_VINT128_DW128(0, 0x0c))`  
*vector signed BCD constant +0.*
- `#define _BCD_CONST_SIGN_MASK ((vBCD_t) CONST_VINT128_DW128(0, 0xf))`  
*vector BCD sign mask in bits 124:127.*

## Functions

- static `vui64_t vec_BCD2BIN` (`vBCD_t` val)  
*Convert vector of 2 x unsigned 16-digit BCD values to vector 2 x doubleword binary values.*
- static `_Decimal128 vec_BCD2DFP` (`vBCD_t` val)  
*Convert a Vector Signed BCD value to \_\_Decimal128.*
- static `vBCD_t vec_BIN2BCD` (`vui64_t` val)  
*Convert vector unsigned doubleword binary values to Vector unsigned 16-digit BCD values.*
- static `vBCD_t vec_DFP2BCD` (`_Decimal128` val)  
*Convert a \_\_Decimal128 value to Vector BCD.*
- static `vBCD_t vec_bcdadd` (`vBCD_t` a, `vBCD_t` b)  
*Decimal Add Signed Modulo Quadword.*
- static `vBCD_t vec_bcdaddcsq` (`vBCD_t` a, `vBCD_t` b)  
*Decimal Add & write Carry Signed Quadword.*
- static `vBCD_t vec_bcdaddecq` (`vBCD_t` a, `vBCD_t` b, `vBCD_t` c)  
*Decimal Add Extended & write Carry Signed Quadword.*
- static `vBCD_t vec_bcdaddesqm` (`vBCD_t` a, `vBCD_t` b, `vBCD_t` c)  
*Decimal Add Extended Signed Modulo Quadword.*
- static `vBCD_t vec_bcdcfsq` (`vi128_t` vrb)  
*Vector Decimal Convert From Signed Quadword returning up to 31 BCD digits.*
- static `vBCD_t vec_bcdcfud` (`vui64_t` vrb)  
*Vector Decimal Convert From Unsigned doubleword returning up to 2x16 BCD digits.*
- static `vBCD_t vec_bcdcfuq` (`vui128_t` vra)  
*Vector Decimal Convert From Unsigned Quadword returning up to 32 BCD digits.*
- static `vBCD_t vec_bcdcfz` (`vui8_t` vrb)  
*Vector Decimal Convert From Zoned.*
- static `vbBCD_t vec_bcdcmp_eqsq` (`vBCD_t` vra, `vBCD_t` vrb)  
*Vector Compare Signed BCD Quadword for equal.*
- static `vbBCD_t vec_bcdcmp_gesq` (`vBCD_t` vra, `vBCD_t` vrb)  
*Vector Compare Signed BCD Quadword for greater than or equal.*
- static `vbBCD_t vec_bcdcmp_gtsq` (`vBCD_t` vra, `vBCD_t` vrb)  
*Vector Compare Signed BCD Quadword for greater than.*
- static `vbBCD_t vec_bcdcmp_lesq` (`vBCD_t` vra, `vBCD_t` vrb)  
*Vector Compare Signed BCD Quadword for less than or equal.*
- static `vbBCD_t vec_bcdcmp_ltsq` (`vBCD_t` vra, `vBCD_t` vrb)  
*Vector Compare Signed BCD Quadword for less than.*
- static `vbBCD_t vec_bcdcmp_nesq` (`vBCD_t` vra, `vBCD_t` vrb)  
*Vector Compare Signed BCD Quadword for not equal.*
- static `int vec_bcdcmpeq` (`vBCD_t` vra, `vBCD_t` vrb)  
*Vector Compare Signed BCD Quadword for equal.*
- static `int vec_bcdcmpge` (`vBCD_t` vra, `vBCD_t` vrb)  
*Vector Compare Signed BCD Quadword for greater than or equal.*
- static `int vec_bcdcmpgt` (`vBCD_t` vra, `vBCD_t` vrb)  
*Vector Compare Signed BCD Quadword for greater than.*
- static `int vec_bcdcmple` (`vBCD_t` vra, `vBCD_t` vrb)  
*Vector Compare Signed BCD Quadword for less than or equal.*
- static `int vec_bcdcmplt` (`vBCD_t` vra, `vBCD_t` vrb)



- Vector Compare Signed BCD Quadword for less than.*
- static int [vec\\_bcdcmpne](#) ([vBCD\\_t](#) vra, [vBCD\\_t](#) vrb)
- Vector Compare Signed BCD Quadword for not equal.*
- static [vBCD\\_t](#) [vec\\_bcdcpsgn](#) ([vBCD\\_t](#) vra, [vBCD\\_t](#) vrb)
- Vector copy sign BCD.*
- static [vi128\\_t](#) [vec\\_bcdctsq](#) ([vBCD\\_t](#) vra)
- Vector Decimal Convert to Signed Quadword.*
- static [vui8\\_t](#) [vec\\_bcdctub](#) ([vBCD\\_t](#) vra)
- Vector Decimal Convert Binary Coded Decimal (BCD) digit pairs to binary unsigned bytes .*
- static [vui16\\_t](#) [vec\\_bcdctuh](#) ([vBCD\\_t](#) vra)
- Vector Decimal Convert groups of 4 BCD digits to binary unsigned halfwords.*
- static [vui32\\_t](#) [vec\\_bcdctuw](#) ([vBCD\\_t](#) vra)
- Vector Decimal Convert groups of 8 BCD digits to binary unsigned words.*
- static [vui64\\_t](#) [vec\\_bcdctud](#) ([vBCD\\_t](#) vra)
- Vector Decimal Convert groups of 16 BCD digits to binary unsigned doublewords.*
- static [vui128\\_t](#) [vec\\_bcdctuq](#) ([vBCD\\_t](#) vra)
- Vector Decimal Convert groups of 32 BCD digits to binary unsigned quadword.*
- static [vui8\\_t](#) [vec\\_bcdctz](#) ([vBCD\\_t](#) vrb)
- Vector Decimal Convert To Zoned.*
- static [vBCD\\_t](#) [vec\\_bcddiv](#) ([vBCD\\_t](#) a, [vBCD\\_t](#) b)
- Divide a Vector Signed BCD 31 digit value by another BCD value.*
- static [vBCD\\_t](#) [vec\\_bcddiv](#) ([vBCD\\_t](#) a, [vBCD\\_t](#) b)
- Decimal Divide Extended.*
- static [vBCD\\_t](#) [vec\\_bcdmul](#) ([vBCD\\_t](#) a, [vBCD\\_t](#) b)
- Multiply two Vector Signed BCD 31 digit values.*
- static [vBCD\\_t](#) [vec\\_bcdmulh](#) ([vBCD\\_t](#) a, [vBCD\\_t](#) b)
- Vector Signed BCD Multiply High.*
- static [vBCD\\_t](#) [vec\\_bcds](#) ([vBCD\\_t](#) vra, [vi8\\_t](#) vrb)
- Decimal Shift. Shift a vector signed BCD value, left or right a variable amount of digits (nibbles). The sign nibble is preserved.*
- static [vBCD\\_t](#) [vec\\_bcdsetsgn](#) ([vBCD\\_t](#) vrb)
- Vector Set preferred BCD Sign.*
- static [vBCD\\_t](#) [vec\\_bcdslqi](#) ([vBCD\\_t](#) vra, const unsigned int \_N)
- Vector BCD Shift Right Signed Quadword.*
- static [vBCD\\_t](#) [vec\\_bcdsluqi](#) ([vBCD\\_t](#) vra, const unsigned int \_N)
- Vector BCD Shift Right unsigned Quadword.*
- static [vBCD\\_t](#) [vec\\_bcdsr](#) ([vBCD\\_t](#) vra, [vi8\\_t](#) vrb)
- Decimal Shift and Round. Shift a vector signed BCD value, left or right a variable amount of digits (nibbles). The sign nibble is preserved. If byte element 7 of the shift count is negative (right shift), and the last digit shifted out is greater then or equal to 5, then increment the shifted magnitude by 1.*
- static [vBCD\\_t](#) [vec\\_bcdsrqi](#) ([vBCD\\_t](#) vra, const unsigned int \_N)
- Vector BCD Shift Right Signed Quadword Immediate.*
- static [vBCD\\_t](#) [vec\\_bcdsrrqi](#) ([vBCD\\_t](#) vra, const unsigned int \_N)
- Vector BCD Shift Right and Round Signed Quadword Immediate.*
- static [vBCD\\_t](#) [vec\\_bcdsruqi](#) ([vBCD\\_t](#) vra, const unsigned int \_N)
- Vector BCD Shift Right Unsigned Quadword immediate.*
- static [vBCD\\_t](#) [vec\\_bcdsub](#) ([vBCD\\_t](#) a, [vBCD\\_t](#) b)
- Subtract two Vector Signed BCD 31 digit values.*

- static `vBCD_t vec_bcdsubcsq` (`vBCD_t a`, `vBCD_t b`)  
*Decimal Subtract & write Carry Signed Quadword.*
- static `vBCD_t vec_bcdsubecsqs` (`vBCD_t a`, `vBCD_t b`, `vBCD_t c`)  
*Decimal Add Extended & write Carry Signed Quadword.*
- static `vBCD_t vec_bcdsubesqm` (`vBCD_t a`, `vBCD_t b`, `vBCD_t c`)  
*Decimal Subtract Extended Signed Modulo Quadword.*
- static `vBCD_t vec_bcdtrunc` (`vBCD_t vra`, `vui16_t vrb`)  
*Decimal Truncate. Truncate a vector signed BCD value vra to N-digits, where N is the unsigned integer value in bits 48-63 of vrb. The first 31-N digits are set to 0 and the result returned.*
- static `vBCD_t vec_bcdtruncqi` (`vBCD_t vra`, `const unsigned short _N`)  
*Decimal Truncate Quadword Immediate. Truncate a vector signed BCD value vra to N-digits, where N is a unsigned short integer constant. The first 31-N digits are set to 0 and the result returned.*
- static `vBCD_t vec_bcdus` (`vBCD_t vra`, `vui8_t vrb`)  
*Decimal Unsigned Shift. Shift a vector unsigned BCD value, left or right a variable amount of digits (nibbles).*
- static `vBCD_t vec_bcduttrunc` (`vBCD_t vra`, `vui16_t vrb`)  
*Decimal Unsigned Truncate. Truncate a vector unsigned BCD value vra to N-digits, where N is the unsigned integer value in bits 48-63 of vrb. The first 32-N digits are set to 0 and the result returned.*
- static `vBCD_t vec_bcduttruncqi` (`vBCD_t vra`, `const unsigned short _N`)  
*Decimal Unsigned Truncate Quadword Immediate. Truncate a vector unsigned BCD value vra to N-digits, where N is a unsigned short integer constant. The first 32-N digits are set to 0 and the result returned.*
- static `vBCD_t vec_cbcdaddcsq` (`vBCD_t *cout`, `vBCD_t a`, `vBCD_t b`)  
*Combined Decimal Add & Write Carry Signed Quadword.*
- static `vBCD_t vec_cbcdaddecqs` (`vBCD_t *cout`, `vBCD_t a`, `vBCD_t b`, `vBCD_t cin`)  
*Combined Decimal Add Extended & write Carry Signed Quadword.*
- static `vBCD_t vec_cbcdmul` (`vBCD_t *p_high`, `vBCD_t a`, `vBCD_t b`)  
*Combined Vector Signed BCD Multiply High/Low.*
- static `vBCD_t vec_cbcdsubcsq` (`vBCD_t *cout`, `vBCD_t a`, `vBCD_t b`)  
*Combined Decimal Subtract & Write Carry Signed Quadword.*
- static `vui64_t vec_pack_Decimal128` (`_Decimal128 lval`)  
*Pack a FPR pair (\_Decimal128) to a doubleword vector (vector double).*
- static `_Decimal128 vec_quantize0_Decimal128` (`_Decimal128 val`)  
*Quantize (truncate) a \_Decimal128 value before convert to BCD.*
- static `vui8_t vec_rdxcf100b` (`vui8_t vra`)  
*Vector Decimal Convert Binary Coded Decimal (BCD) digit pairs from radix 100 binary integer bytes.*
- static `vui8_t vec_rdxcf10kh` (`vui16_t vra`)  
*Vector Decimal Convert radix 10,000 Binary halfwords to pairs of radix 100 binary bytes.*
- static `vui16_t vec_rdxcf100mw` (`vui32_t vra`)  
*Vector Decimal Convert radix 10\*\*8 Binary words to pairs of radix 10,000 binary halfwords.*
- static `vui32_t vec_rdxcf10E16d` (`vui64_t vra`)  
*Vector Decimal Convert radix 10\*\*16 Binary doublewords to pairs of radix 10\*\*8 binary words.*
- static `vui64_t vec_rdxcf10e32q` (`vui128_t vra`)  
*Vector Decimal Convert radix 10\*\*32 Binary quadword to pairs of radix 10\*\*16 binary doublewords.*
- static `vui8_t vec_rdxcfzt100b` (`vui8_t zone00`, `vui8_t zone16`)  
*Vector Decimal Convert Zoned Decimal digit pairs to to radix 100 binary integer bytes..*
- static `vui8_t vec_rdxct100b` (`vui8_t vra`)  
*Vector Decimal Convert Binary Coded Decimal (BCD) digit pairs to radix 100 binary integer bytes.*
- static `vui16_t vec_rdxct10kh` (`vui8_t vra`)  
*Vector Decimal Convert radix 100 digit pairs to radix 10,000 binary integer halfwords.*

- static `vui32_t vec_rdxct100mw` (`vui16_t` vra)  
*Vector Decimal Convert radix 10,000 digit halfword pairs to radix 100,000,000 binary integer words.*
- static `vui64_t vec_rdxct10E16d` (`vui32_t` vra)  
*Vector Decimal Convert radix 100,000,000 digit word pairs to radix 10E16 binary integer doublewords.*
- static `vui128_t vec_rdxct10e32q` (`vui64_t` vra)  
*Vector Decimal Convert radix 10E16 digit pairs to radix 10E32 \_\_int128 quadwords.*
- static `vb128_t vec_setbool_bcdinv` (`vBCD_t` vra)  
*Vector Set Bool from Signed BCD Quadword if invalid.*
- static `vb128_t vec_setbool_bcdsq` (`vBCD_t` vra)  
*Vector Set Bool from Signed BCD Quadword.*
- static `int vec_signbit_bcdsq` (`vBCD_t` vra)  
*Vector Sign bit from Signed BCD Quadword.*
- static `_Decimal128 vec_unpack_Decimal128` (`vf64_t` lval)  
*Unpack a doubleword vector (vector double) into a FPR pair. (\_Decimal128).*
- static `vui128_t vec_zndctuq` (`vui8_t` zone00, `vui8_t` zone16)  
*Vector Zoned Decimal Convert 32 digits to binary unsigned quadword.*

### 7.1.1 Detailed Description

Header package containing a collection of Binary Coded Decimal (**BCD**) computation and Zoned Character conversion operations on vector registers.

Many of these operations are implemented in a single VMX or DFP instruction on newer (POWER8/POWER9) processors. This header serves to fill in functional gaps for older (POWER7, POWER8) processors (using existing VMX, VSX, and DFP instructions) and provides in-line assembler implementations for older compilers that do not provide the built-ins.

Starting with POWER6 introduced a Decimal Floating-point (*DFP*) Facility implementing the [IEEE 754-2008 revision](#) standard. This is implemented in hardware as an independent Decimal Floating-point Unit (*DFU*). This is supported with ISO C/C++ language bindings and runtime libraries.

The DFP Facility supports a different data format [Densely packed decimal](#) (*DPD*) and a more extensive set of operations than BCD or Zoned. So DFP and the comprehensive C language and runtime library support makes it a better target for new business oriented applications. As the DFP Facility supports conversions between DPD and BCD, existing DFP operations can be used to emulate BCD operations on older processors and fill in operational gaps in the vector BCD instruction set.

As DFP is supported directly in the hardware and has extensive language and runtime support, there is little that PVECLIB can contribute to general decimal radix computation. However the vector unit and recent BCD and Zoned extensions can still be useful in areas include large order multiple precision computation and conversions between binary and decimal radix. Both are required to convert large decimal numeric or floating-point values with extreme exponents for input or print.

So what operations are needed, what does the PowerISA provide, and what does the ABI and/or compiler provide. Some useful operations include:

- conversions between BCD and \_\_int128
  - As intermediate step between external decimal/\_Decimal128 and \_Float128

- Conversions between BCD and Zoned (character)
- Conversions between BCD and DFP
- BCD add/subtract with carry/extend
- BCD compare equal, greater than, less than
- BCD copy sign and set bool from sign
- BCD digit shift left/right
- BCD multiply/divide

The original VMX (AKA Altivec) only defined a few instructions that operated on the 128-bit vector as a whole. This included the vector shifts by bit and octet, and generalized vector permute, general binary integer add, subtract and multiply for byte/halfword/word. But no BCD or decimal character operations.

POWER6 introduced the Decimal Floating-point Facility. DFP provides a robust set of operations with 7 (`_Decimal32`), 16 (`_Decimal64`), and 34 (`_Decimal128`) digit precision. Arithmetic operations include add, subtract, multiply, divide, and compare. Special operations insert/extract exponent, quantize, and digit shift. Conversions to and from signed (31-digits) and unsigned (32-digit) BCD. And conversions to and from binary signed long (64-bit) integer. DFP operations use the existing floating-point registers (FPRs). The 128-bit DFP (quadword) instructions operate on even/odd 64-bit Floating-point register pairs (FPRp).

POWER6 also implemented the Vector Facility (VMX) instructions. No additional vectors operations were added and the Vector Registers (VRs) were separate from the GRPs and FPRs. The only transfer data path between register sets is via storage. So while the DFP Facility could be used for BCD operations and conversions, there was little synergy with the vector unit, in POWER6.

POWER7 introduced the VSX facility providing 64x128-bit Vector Scalar Registers (VSRs) that overlaid both the FPRs (VSRs 0-31) and VRs (VSRs 32-63). It also added useful doubleword permute immediate (`xxpermdi`) and logical/select operations with access to all 64 VSRs. This greatly simplifies data transfers between VRs and FPRs (FPRps) (see [vec\\_pack\\_Decimal128\(\)](#), [vec\\_unpack\\_Decimal128\(\)](#)). This makes it more practical to transfer vector contents to the DFP Facility for processing (see [vec\\_BCD2DFP\(\)](#) and [vec\\_DFP2BCD\(\)](#)).

#### Note

All the BCD instructions and the quadword binary add/subtract are defined as vector class and can only access vector registers (VSRs 32-63). The DFP instructions can only access FPRs (VSRs 0-31). So only a VSX instruction (like `xxpermdi`) can perform the transfer without going through storage.

POWER8 added vector add/subtract modulo/carry/extend unsigned quadword for binary integer (vector [unsigned]  $\leftrightarrow$  `_int128`). This combined with the wider (word) multiply greatly enhances multiple precision operations on large (> 128-bit) binary numbers. POWER8 also added signed BCD add/subtract instructions with up to 31-digits. While the PowerISA did not provide carry/extend forms of `bcdadd/bcdsub`, it does set a condition code with bits for GT/LT/EQ/OV. This allows for implementations of BCD compare and the overflow (OVF) bit supports carry/extend operations. Also the lack of BCD multiply/divide in the vector unit is not a problem because we can leverage DFP (see [vec\\_bcdmul\(\)](#), [vec\\_bcddiv\(\)](#)).

POWER9 (PowerISA 3.0B) adds BCD copy sign, set sign, shift, round, and truncate instructions. There are also unsigned (32-digit) forms of the shift and truncate instructions. And instructions to convert between signed BCD and quadword (`_int128`) and signed BCD and Zoned. POWER9 also added quadword binary multiply 10 with carry extend forms that can also help with decimal to binary conversion.

The [OpenPOWER ABI](#) does have an *Appendix B. Binary-Coded Decimal Built-In Functions* and proposes that compilers provide a `bcd.h` header file. At this time no compiler provides this header. GCC does provide compiler built-ins to generate the `bcdadd/bcdsub` instructions and access the associated condition codes in *if* statements. GCC also provides built-ins to generate the DFP instruction encode/decode to and from BCD.

**Note**

The compiler disables built-ins if the **mcpu** target does not enable the specific instruction. For example if you compile with **-mcpu=power7**, `__builtin_bcdadd` and `__builtin_bcdsub` are not supported. But `vec_bcdadd()` is always defined in this header, will generate the minimum code, appropriate for the target, and produce correct results.

This header covers operations that are either:

- Operations implemented in hardware instructions for later processors and useful to programmers, on slightly older processors, even if the equivalent function requires more instructions. Examples include quadword BCD add and subtract.
- Defined in the OpenPOWER ABI but *not* yet defined in `<altivec.h>` or `<bcd.h>` provided by available compilers in common use. Examples include `bcd_add`, `bcd_cmpg` and `bcd_mul`.
- Commonly used operations, not covered by the ABI or `<altivec.h>`, and require multiple instructions or are not obvious. Examples include `vec_pack_Decimal128()` and `vec_unpack_Decimal128()`.

See [Returning extended quadword results](#). for more background on extended quadword computation.

### 7.1.2 Endian problems with quadword implementations

Technically, operations on quadword elements should not require any endian specific transformation. There is only one element so there can be no confusion about element numbering or order. However some of the more complex quadword operations are constructed from operations on smaller elements. And those operations as provided by `<altivec.h>` are required by the OpenPOWER ABI to be endian sensitive. See [Endian problems with doubleword operations](#) for a more detailed discussion.

In any case, the arithmetic (high to low) order of digit nibbles in BCD or characters in Zoned are defined in the PowerPC ISA. In the vector register, high order digits are on the left while low order digits and the sign are on the right. (See `vec_bcdadd()` and `vec_bcdsub()`). So pveclib implementations will need to either:

- Nullify little endian transforms of `<altivec.h>` operations. The `<altivec.h>` built-ins `vec_mule()`, `vec_mulo()`, and `vec_pack()` are endian sensitive and often require nullification that restores the original operation.
- Use new operations that are specifically defined to be stable across BE/LE implementations. The pveclib operations; `vec_vmuleud()` and `vec_mulubm()` are defined to be endian stable.

### 7.1.3 Some details of BCD computation

**Binary-coded decimal** (Also called *packed decimal*) and the related *Zoned Decimal* are common representations of signed decimal radix (base 10) numbers. BCD is more compact and usually faster than zoned. Zoned format is more closely aligned with human readable and printable character formats. In both formats the sign indicator is associated (in the same character or byte) with the low order digit.

BCD and Zoned formats and operations were implemented for some of the earliest computers. Then circuitry was costly and arithmetic was often implemented as a digit (or bit) serial operation. Modern computers have more circuitry with

wider data paths and more complex arithmetic/logic units. The current trend is for each processor core implementation to include multiple computational units that can operate in parallel.

For POWER server class processors separate and multiple Fixed-Point Units (FXU), (binary) Floating-point Units (FPU), and Vector Processing Units (VPU) are the norm. POWER6 introduced a Decimal Floating-point (DFP) Facility implementing the IEEE 754-2008 revision standard. This is implemented in hardware as an independent Decimal Floating-point Unit (DFU). This is supported with ISO C/C++ language bindings and runtime libraries.

The DFU supports a different data format *Densely packed decimal* (DPD) and a more extensive set of operations than BCD or Zoned. So hardware DFP and the comprehensive C language and runtime library support makes it a better target for new business oriented applications. As DFP is supported directly in the hardware and has extensive language and runtime support, there is little that PVECLIB can contribute to general decimal radix computation.

#### Note

BCD and DFP support requires at least PowerISA 2.05 (POWER6) or later server level processor support.

However the vector unit and recent BCD and Zoned extensions can still be useful in areas including large order multiple precision computation and conversions between binary and decimal radix. Both are required to convert large decimal numeric or floating-point values with extreme exponents for input or print. And conversions between `_Float128` and `_Decimal128` types is even more challenging. Basically both POSIX and IEEE 754-2008 require that it possible to convert floating-point values to an external character decimal representation, with the specified rounding, and back recovering the original value. This always requires more precision for the conversion than is available in the given format and size.

#### 7.1.3.1 Preferred sign, zone, and zero.

BCD and Zoned Decimal have a long history with multiple computer manufacturers, and this is reflected as multiple encodings of the same basic concept. This is in turn reflected in the PowerISA as Preferred Sign **PS** immediate operand on BCD instructions.

This header implementation assumes that users of PVECLIB are not interested in this detail and just want access to BCD computation with consistent results. So PVECLIB does not expose preferred sign at the API and provides reasonable defaults in the implementation.

PVECLIB is targeted at the Linux ecosystem with ASCII character encoding, so the implementation defaults for:

- preferred zone nibble 0x3. ASCII encodes decimal characters as 0x30 - 0x39.
- preferred sign code nibbles 0xC and 0xD. Historically accounting refers to *Credit* as positive and *Dedit* for negative.

The PowerISA implementation is permissive of sign encoding of input values and will accept four (0xA, 0xC, 0xE, 0xF) encodings of positive and two (0xB, 0xD) for negative. But the sign code of the result is always set to the preferred sign.

The BCD encoding allows for signed zeros (-0, +0) but the PowerISA implementation prefers the positive encoding for zero results. Again the implementation is permissive of both encodings for input operands. Usually this is not an issue but can be when dealing with conversions from other formats (DFP also allows signed 0.0) and implementations of BCD operations for older (POWER7/8) processors.

This is most likely to effect user code in comparisons of BCD values for 0. One might expect the following vector binary word compare all

```
if (vec_all_eq((vui32_t) t, (vui32_t) _BCD_CONST_ZERO))
```

to give the same result as

```
if (vec_bcdcmpeq (t, _BCD_CONST_ZERO))
```

The vector binary compare is likely to have lower latency (on POWER7/8), but will miss compare on -0. The BCD compare operation (i.e. `vec_bcdcmpeq` ()) is recommended, unless the programs knows the details for the source operands generation, and have good (performance and latency) reasons to to use the alternative compare. Pveclib strives to provide correct preferred zeros results in its implementation of BCD operations.

### 7.1.3.2 Extended Precision computation with BCD

Extended precision requires carry and extend forms of bcdadd/sub. Also BCD multiply with multiply high and double quadword (62-digit) forms. The vector unit does not support BCD multiply so pveclib leverages the DFP Facility to implement these operations. Finally algorithms and extended precision conversions require BCD divide and divide extended. Again leveraging the DPU to implement these operations.

#### 7.1.3.2.1 Vector Add/Subtrace with Carry/Extend example

The PowerISA does not provide the extend and write-carry forms of the bcdadd/sub instructions. But bcdadd/sub instructions do post status to CR field 6 which includes:

- Result is less than zero (CR.bit[56])
- Result is greater than zero (CR.bit[57])
- Result is equal to zero (CR.bit[58])
- Result overflowed (CR.bit[59])

which provides a basis for BCD comparison and the overflow may be used for carry/extend logic. The GCC compiler provides built-ins to generate the bcdadd/sub and test the resulting CR bits in if statements.

Unfortunately, the Overflow flag generated by bcdadd/bcdsub is not a true carry/borrow. If the operands have the same sign for bcdadd (different sign for bcdsub) and there is a carry out of the high order digit, then:

- The sum is truncated to the low order 31 digits
- The sum's sign matches the operands signs
- The overflow flag (CR.bit[59]) is set.

#### Note

overflow is only set in conjunction with greater than zero (positive) or less than zero (negative) results. This implies that BCD carries are tri-state; +1, 0, or -1.

This can be used to simulate a **Add and Write-Carry** operation. However if the operands have different signs the bcdadd (same sign for bcdsub) the operation does the following:

- The smaller magnitude is subtracted from the larger magnitude.
- The sign matches the sign of the larger magnitude.
- The ox\_flag (CR.bit[59]) is NOT set.

For a simple BCD add this is the desired result (overflow is avoided and the borrow is recorded in the sign). But for multiple precision BCD operation, this will delay propagation of borrows to the higher order digits and the result is a mixture of signs across elements of the larger multiple precision value. This would have to be corrected at some later stage. For example the sum of 32 digits:









## 7.1.3.2.2 Vector BCD Multiply/Divide Quadword example

BCD multiply and divide operations are not directly supported in the current PowerISA. Decimal multiply and divide are supported in the Decimal Floating-point (DFP) Facility, as well as conversion to and from signed (unsigned) BCD.

So BCD multiply and divide operations can be routed through the DFP Facility with a few caveats.

- DFP Extended format supports up to 34 digits precision
- DFP significand represent digits to the *left* of the implied decimal point.
- DFP finite number are not normalized.

This allows DFP to represent decimal integer and fixed point decimal values with a preferred exponent of 0. The DFP Facility will maintain this preferred exponent for DFP arithmetic operations until:

- An arithmetic operation involves a operand with a non-zero exponent.
- A divide operation generates a result with fractional digits
- A multiply operation generates a result that exceeds 34 digits.

The implementation can insure that input operands are derived from 31-digit BCD values. The results of any divide operations can be truncated back to decimal integer with the preferred 0 exponent. This can be achieved with the DFP Quantize Immediate instruction, specifying the ideal exponent of 0 and a rounding mode of *round toward 0* (see [vec\\_quantize0\\_Decimal128\(\)](#)). This allows the following implementation:

```
static inline vBCD_t
vec_bcddiv (vBCD_t a, vBCD_t b)
{
 vBCD_t t;
 _Decimal128 d_t, d_a, d_b;
 d_a = vec_BCD2DFP (a);
 d_b = vec_BCD2DFP (b);
 d_t = vec_quantize0_Decimal128 (d_a / d_b);
 t = vec_DFP2BCD (d_t);
 return (t);
}
```

The multiply case is bit more complicated as we need to produce up to 62 digit results without losing precision and DFP only supports 34 digits. This requires splitting the input operands into groups of digits where partial products of any combination of these groups is guaranteed not exceed 34 digits.

One way to do this is split each 31-digit operand into two 16-digit chunks (actually 15 and 16-digits). These chunks are converted to DFP extended format and multiplied to produce four 32-digit partial products. These partial products can be aligned and summed to produce the high and low 31-digits of the full 62-digit product. This is the basis for [vec\\_bcd\\_mul\(\)](#), [vec\\_bcdmulh\(\)](#), and [vec\\_cbcdmul\(\)](#).

A simple [vec\\_and\(\)](#) can be used to isolate the low order 16 BCD digits. It is simple at this point to detect if both operands are 16-digits or less by comparing the original operand to the isolate value. In this case the product can not exceed 32 digits and we can short circuit the product to a single multiply. Here we can safely use binary compare all.

```

const vBCD_t dword_mask = (vBCD_t) CONST_VINT128_DW(15, -1);
vBCD_t t, low_a, low_b, high_a, high_b;
_Decimal128 d_p, d_t, d_a, d_b;

low_a = vec_and (a, dword_mask);
low_b = vec_and (b, dword_mask);
d_a = vec_BCD2DFP (low_a);
d_b = vec_BCD2DFP (low_b);
d_p = d_a * d_b;
if (__builtin_expect ((vec_cmpuq_all_eq ((vui128_t) low_a, (
 vui128_t) a)
 && vec_cmpuq_all_eq ((vui128_t) low_b, (vui128_t) b)), 1))
{
 d_t = d_p;
}
else
{
 ...
}
t = vec_DFP2BCD (d_t);

```

This is a case where negative 0 can be generated in the DFP multiply and converted unchanged to BCD. This is handled with the following fix up code:

```

// Minus zero
const vui32_t mz = CONST_VINT128_W (0, 0, 0, 0x0000000d);
...
#ifdef _ARCH_PWR9
t = vec_bcdadd (t, _BCD_CONST_ZERO);
#else
if (vec_all_eq((vui32_t) t, mz))
t = _BCD_CONST_ZERO;
#endif
return t;

```

From here the code diverges for multiply low and multiply high (and full combined multiply). Multiply low only needs the 3 lower order partial products. The highest order partial product does not impact the lower order 31-digits and is not needed. Multiply high requires the generation and summation of all 4 partial products. Following code completes the implementation of BCD multiply low:

```

...
else
{
 _Decimal128 d_ah, d_bh, d_hl, d_lh, d_h;

 high_a = vec_bcdsrqi (a, 16);
 high_b = vec_bcdsrqi (b, 16);

 d_ah = vec_BCD2DFP (high_a);
 d_bh = vec_BCD2DFP (high_b);

 d_hl = d_ah * d_b;
 d_lh = d_a * d_bh;

 d_h = d_hl + d_lh;
 d_h = __builtin_dscliq (d_h, 17);
 d_h = __builtin_dscriq (d_h, 1);

 d_t = d_p + d_h;
}

```

Here we know that there are higher order digits in one or both operands. First use `vec_bcdsrqi()` to isolate the high 15-digits of operands a and b. Both Vector unit and DFP Facility have decimal shift operations, but the vector shift operation is faster.

Then convert to DFP and multiply ( $\text{high\_a} * \text{low\_b}$  and  $\text{high\_b} * \text{low\_a}$ ) for the two middle order partial products which are summed. This sum represents the high 32-digits (the 31-digit sum can carry) of a 48-digit product. Only the lower

16-digits of this sum is needed for the final sum and this needs to be aligned with the high 16 digits of the original lower order partial product.

For this case use **DFP Shift Significand Left Immediate** and **DFP Shift Significand Right Immediate**. All the data is in the DFP Facility and the high cost of the DFP Facility shift is offset by avoiding extra format conversions. We use shift left 17 followed by shift right 1 to clear the highest order DFP digit and avoid any overflow. A final DFP add produces the low order 32 digits of the product which will be truncated to 31-digits in the conversion to BCD.

How we can look at the BCD multiply high (generate the full 62-digit product returning the high 31 digits) and point out the differences. Multiply high also starts by isolating the low order 16 BCD digits, performing the low order multiply ( $\text{low\_a} * \text{low\_b}$ ), and testing for the short circuit (all higher order digits are 0). The first difference (from multiply low) is that in this case only the high digit of the potential 32-digit product is returned.

```
const vBCD_t dword_mask = (vBCD_t) CONST_VINT128_DW(15, -1);
vBCD_t t, low_a, low_b, high_a, high_b;
_Decimal128 d_p, d_t, d_a, d_b;

low_a = vec_and(a, dword_mask);
low_b = vec_and(b, dword_mask);
d_a = vec_BCD2DFP(low_a);
d_b = vec_BCD2DFP(low_b);
d_p = d_a * d_b;
if (__builtin_expect((vec_cmpuq_all_eq((vui128_t) low_a, (
 vui128_t) a)
 && vec_cmpuq_all_eq((vui128_t) low_b, (vui128_t) b)), 1))
{
 d_t = __builtin_dscrlq(d_p, 31);
}
else
{
 ...
}
t = vec_DFP2BCD(d_t);
```

So the short circuit code shifts the low partial product right 31 digits and returns that value.

If we can not short circuit, Multiply high requires the generation and summation of all four partial products. Following code completes the implementation of BCD multiply high:

```
...
else
{
 _Decimal128 d_ah, d_bh, d_hl, d_lh, d_h, d_ll, d_m;

 high_a = vec_bcdsrqi(a, 16);
 high_b = vec_bcdsrqi(b, 16);
 d_ah = vec_BCD2DFP(high_a);
 d_bh = vec_BCD2DFP(high_b);

 d_hl = d_ah * d_bl;
 d_lh = d_al * d_bh;
 d_ll = __builtin_dscrlq(d_p, 16);

 d_m = d_hl + d_lh + d_ll;
 d_m = __builtin_dscrlq(d_m, 15);

 d_h = d_ah * d_bh;
 d_h = __builtin_dsclq(d_h, 1);
 d_t = d_m + d_h;
}
```

Again we know that there are higher order digits in one or both operands and use `vec_bcdsrqi()` to isolate the high 15-digits of operands a and b. Then convert to DFP and multiply ( $\text{high\_a} * \text{low\_b}$  and  $\text{high\_b} * \text{low\_a}$ ) for the two middle order partial products ( $\text{d\_hl}$  and  $\text{d\_lh}$ ).

The low order partial product (`d_p`) was generated above but we need only the high order 15 digits for summation. Shift the low partial product right 16 digits then sum (`d_hl + d_lh + d_ll`) the low and middle order partial products. This produces the high 32 digits of the lower 48 digit partial sum. Shift this right 15 digits to align with the high order 31 digits for the product.

Then multiply (`high_a * high_b`) to generate the high order partial product. This represents the high 30 digits of a 62 digits. Shift this left 1 digit to correct the alignment. The sum of the adjusted high and middle order partials gives the high order 31 digits of the 62-digit product.

#### 7.1.3.2.3 Vector BCD to/from Binary conversion

Conversions between Decimal (BCD, Zoned, or string) and binary is another topic which is more complicated than it first appears. Everyone that takes computer science should have learned about *atoi* and *itoa* for conversions between strings of decimal character and binary integers.

ASCII to integer is basically;

- initialize a integer accumulator to 0
- loop
  - multiply the accumulator by 10
  - load the next character and convert to a binary decimal digit
  - Add this digit to the accumulator
- repeat until end of string.

Integer to ASCII is basically;

- initialize a temp variable with the integer number
- loop
  - compute the remainder/modulo of temp by 10
  - convert this binary digit to a character and store as the next char
  - divide temp by 10 and use that for the next iteration
- repeat until temp is zero.

You may have noticed that the algorithms above are not exactly vector ready. Both are serialized on expensive multiply and divide operations. This is not so bad for 9 digit (32-bit) integers but will be noticeable when converting between 128-bit binary and 31-digit BCD.

For the vector BCD equivalent of *atoi* we could use the PVECLIB implementation of **Vector Multiply by 10 Extended Unsigned Quadword**. For POWER8, `vec_mul10euq()` uses; multiple even/odd, a couple of shift left octet immediates, and add quadword. This sequence runs 5-7 instructions and has a minimum latency of 13 cycles. To convert from BCD to binary we need to shift and isolate, one BCD digit at a time, then feed that into `vec_mul10euq()`. Ignoring for now the latency associated with shifting the BCD digits, we can quickly estimate  $13 * 32 = 416$  cycles to convert 32 digits.

For the vector BCD equivalent of *itoa* we could use the POWER8 **Decimal Add Modulo** instruction. For POWER8 `vec_bcdadd()` has a latency of 13 cycles. But the conversion would be one bit at a time. Use `vec_bcdadd()` to multiply by 2 then shift / isolate a bit from the binary value, format / convert that bit to BCD 0/1. and `vec_bcdadd()` again. So a quick estimate for this conversion is  $13 * 2 * 128 = 3328$  cycles.



## Note

Actually  $10^{**}32$  can be represented in 107 bits, but who is counting.

Actually, it is a little more complicated than multiply and add. The digits of the digit pair must be isolated and shifted into alignment before the multiply and add. Looking something like this:

```
vui8_t
test_vec_rdxct100b_0 (vui8_t vra)
{
 vui8_t x10, c10, high_digit, low_digit;
 // Isolate the low_digit
 low_digit = vec_slbi (vra, 4);
 low_digit = vec_srbi (low_digit, 4);
 // Shift the high digit into the units position
 high_digit = vec_srbi (vra, 4);
 // multiply the high digit by 10
 c10 = vec_splats ((unsigned char) 10);
 x10 = vec_mulubm (high_digit, c10);
 // add the low_digit to high_digit * 10.
 return vec_add (x10, low_digit);
}
```

The PowerISA does not provide general *nibble* arithmetic, only byte. So the first operations involve isolating each nibble into separate (high\_digit and low\_digit) bytes. The high\_digit shift also aligns the binary for the multiply and add.

The Multiply Unsigned Byte Modulo ([vec\\_mulubm\(\)](#)) generates vmuleub/vmuloub then loads a permute control vector and permutes the low order bytes of the halfword (even/odd) products into a single vector. Finally, add the x10 product and low\_digit to get the binary value in the range 0-99.

This sequence runs 6-10 instructions and 13-22 cycles latency. The lower values assume the shift control and permute control vectors are commoned with other operations.

This is a case where the process on paper is much simpler than the reality of programming computers. The operation is actually  $(bcd\_byte / 16 * 10) + (bcd\_byte * 16 / 16)$  where 16 is the *alignment* radix and 10 is the *decimal* radix at this step. The alignment radix operations are (fortunately) strength reduced to vector byte shift left/right.

Let's use a little algebra to eliminate some of these steps. One approach is to generate a correction factor from the high\_digit and the difference between the *alignment* and decimal radix. This correction factor is subtracted directly from the original BCD byte and reduces the operation to  $(bcd\_byte - ((bcd\_byte / 16) * (16 - 10)))$  Which looks something like:

```
vui8_t
test_vec_rdxct100b_1 (vui8_t vra)
{
 vui8_t x6, c6, high_digit;
 // Compute the high digit correction factor. For BCD to binary 100s
 // this is the isolated high digit multiplied by the radix difference
 // in binary. For this stage we use $0x10 - 10 = 6$.
 high_digit = vec_srbi (vra, 4);
 c6 = vec_splats ((unsigned char) (16-10));
 x6 = vec_mulubm (high_digit, c6);
 // Subtract the high digit correction bytes from the original
 // BCD bytes in binary. This reduces byte range to 0-99.
 return vec_sub (vra, x6);
}
```

Another opportunity is to let the compiler strength reduce the multiply to shift and add. Newer versions of GCC will perform this optimization when using the generic vec\_mul built-in for vector integer elements.



**Note**

Previous to GCC 8, `vec_mul()` was only supported for vector float and double.

```
#if (__GNUC__ > 7)
 x6 = vec_mul (high_digit, c6);
#else
 x6 = vec_mulubm (high_digit, c6);
#endif
```

This eliminates vector multiply even/odd, the permute, and the load associated with the permute. The final sequence runs 5-7 instructions and 10-12 cycles latency and looks something like this:

```
vspltisb v1,4
vspltisb v13,1
vsrb v1,v2,v1
vslb v0,v1,v13
vaddubm v0,v0,v1
vslb v0,v0,v13
vsububm v2,v2,v0
```

The next step converts adjacent byte pairs to halfwords. We use the same basic formula but adjust the radix constants to;  $(rdx\_hword - ((rdx\_hword / 256) \times (256 - 100)))$ . Here we need a byte multiply producing a halfword correction factor. No shifts are needed as the `vmuleub` multiply will access the high byte of each halfword directly.

```
static inline vui16_t
vec_rdxct10kh (vui8_t vra)
{
 vui8_t c156;
 vui16_t x156;
 // Compute the high digit correction factor. For 100s to binary 10ks
 // this is the isolated high digit multiplied by the radix difference
 // in binary. For this stage we use 256 - 100 = 156.
 c156 = vec_splats ((unsigned char) 156);
 #if __BYTE_ORDER__ == __ORDER_LITTLE_ENDIAN__
 x156 = vec_mulo ((vui8_t) vra, c156);
 #else
 x156 = vec_mule ((vui8_t) vra, c156);
 #endif
 // Subtract the high digit correction halfword from the original
 // 100s byte pair in binary. This reduces the range to 0-9999.
 return vec_sub ((vui16_t) vra, x156);
}
```

This requires: a constant load, a multiply even byte and subtract halfword. The final sequence runs 2-5 instructions and 9-18 cycles latency and looks something like this:

```
addis r9,r2,.rodata.cst16+0x90@ha
addi r9,r9,.rodata.cst16+0x90@l
lvx v0,0,r9
vmuleub v0,v2,v0
vsubuhm v2,v2,v0
```

This pattern continues for converting halfwords to words, words to doublewords, and doublewords to quadwords. For POWER8 the first 4 steps are supported by vector multiply and subtract instructions. The last step requires a `vec_↔_vmuleud()` operation implemented in `vec_int128_ppc.h`, based on `vec_muleuw()`, `vec_mulouw()` and `vec_adduqm()`. The `vec_adduqm()` operation is single instruction for POWER8. For POWER7 we will need to leverage more operations implemented in `vec_int64_ppc.h` and `vec_int128_ppc.h` for the last two steps.

The complete set of steps for converting 32 BCD digits to quadword `__int128` binary looks like this:

```

vui128_t
example_vec_bcdctuq (vBCD_t vra)
{
 vui8_t d100;
 vui16_t d10k;
 vui32_t d100m;
 vui64_t d10e;
 vui128_t result;

 d100 = vec_rdxct100b ((vui8_t) vra);
 d10k = vec_rdxct10kh (d100);
 d100m = vec_rdxct100mw (d10k);
 d10e = vec_rdxct10E16d (d100m);
 result = vec_rdxct10e32q (d10e);

 return result;
}

```

For POWER8 the whole sequence runs 24-36 instructions and 65-78 cycles latency. For POWER9 the whole sequence runs 17-26 instructions and 52-65 cycles latency.

#### Note

POWER9 has a Decimal Convert to Signed Quadword instruction, but no unsigned (32-digit) convert.

However we can leverage the POWER9 **Vector Multiply by 10 Extended Unsigned Quadword** instruction to extend the 31-digit convert to a full 32-digits. Basically use the **bcdctsq** to convert the high 31-digits and then multiply by 10 and add the last digit. See example below:

```

vui128_t
example_vec_bcdctuq_2 (vBCD_t vra)
{
 vui128_t vrt;
#ifdef _ARCH_PWR9
 const vui32_t bcd_one = (vui32_t) _BCD_CONST_PLUS_ONE;
 const vui32_t sign_mask = (vui32_t) _BCD_CONST_SIGN_MASK;
 vui128_t vrd;
 vBCD_t sbcd;
 // Need to convert BCD unsigned to signed for bcdctsq
 // But can't use bcdcpnsgn as the unit digit is not a sign code
 // So use vec_and/sel to extract unit digit and insert sign
 vrd = (vui128_t) vec_and ((vui32_t) vra, sign_mask);
 sbcd = (vBCD_t) vec_sel ((vui32_t) vra, bcd_one, sign_mask);
 // Convert top 31 digits to binary
 vrt = (vui128_t) vec_bcdctsq (sbcd);
 // Then X 10 plus the unit digit to complete 32-digit convert
 vrt = vec_mull0euq (vrt, vrd);
#else
 // P7/P8 implementation as above
#endif
 return vrt;
}

```

This adds a few more cycles to split the high digits from the low digit and insert a positive sign code. This requires loading some vector constants which may be commoned with loads from other operations. This adds 2-11 cycles. The **mul10euq** only adds 3 cycles latency to complete the BCD to Binary conversion. This adds only a 21% to 60% latency over the base **bcdctsq** instruction.

#### Note

This process can be extended to 256, 512, 1024-bits, etc by widening the BCD to binary conversion appropriately to blocks of 31 or 32 digits. Then use the basic *atoi* algorithm using extended quadword multiply / add operations from [vec\\_int128\\_ppc.h](#) (Multiple precision BCD to/from Binary conversion).

## 7.1.3.2.3.3 Vector Parallel quadword to BCD conversion

## Note

Binary to BCD conversions are challenging in a number of ways. First any conversion requires division by non powers of 2. Second, for the same element size binary representation holds more equivalent decimal digits than BCD. If the binary value is too large for the BCD target's element size, the results are often undefined. For example [vec\\_bcdcsq\(\)](#). So it is important to constrain the magnitude of the binary to fit the BCD target before conversion. See [Converting Vector \\_\\_int128 values to BCD](#) for details.

In most senses, binary to BCD is the reverse of BCD to binary. The radix number in the conversion formula exchange places and the conversion starts with the largest element size (quadword) and works its way down to the smallest (4-bit nibble).

Let's take a look at the conversion formula. For BCD to Binary we used:

- `bin_byte <- (bcd_byte - ((bcd_byte / 16) x (16 - 10)))`
- `bin_byte <- (bcd_byte - ((bcd_byte >> 4) x 6)`

So after swapping the conversion (to / from) radix constants we see:

- `bcd_byte <- (bin_byte - ((bin_byte / 10) x (10 - 16)))`
- `bcd_byte <- (bin_byte - ((bin_byte / 10) x (-6)))`
- `bcd_byte <- (bin_byte + ((bin_byte / 10) x 6))`

The effect is to divide vector elements of  $4 \times 2N$  bits by  $10 \times N$  and return the quotient in the high half of the element (in  $4 \times N$  bits), and the remainder of this divide in the low half of the element (in  $4 \times N$  bits), Where  $N$  is a power of  $2^n$  and  $n$  ranges from 0 to 4 (5 steps again).

## Note

So why doesn't PVECLIB provide these steps as operations. For example: divide a vector unsigned `__int128` by  $10^{16}$  and return the quotient in the high doubleword and the remainder in the low doubleword of a vector unsigned long? Because if the input quadword is not less than  $10^{32}$  the result is undefined (the quotient will overflow).

This is good news and bad news. It is good that the correction subtract became a simple add. This allows the uses of multiply sum instruction (where PowerISA has such instructions for the element size). The bad news is that the radix divisor is not a power of two. And since the PowerISA does not have vector integer divide instructions, we use the multiplicative inverse. So in effect, each step of the binary to BCD conversion requires, two multiplies and an add.

So let's look at the first and last step of the conversion (the two extremes). The first step (after verifying that the quadword value is less than  $10^{32}-1$ ) looks like this:

```

static inline vui64_t
vec_rdxcf10e32q (vui128_t vra)
{
 // Compute the high digit correction factor. For binary 10**32 to
 // 10**16, this is 0x10000000000000000 - 10000000000000000
 // = 18436744073709551616.
 const vui64_t c = CONST_VINT128_DW (0, 18436744073709551616UL);

 // Magic numbers for multiplicative inverse to divide by 10**16
 // are 76624777043294442917917351357515459181, no corrective add,
 // and shift right 51 bits.
 const vui128_t mul_invs_ten16 = (vui128_t) CONST_VINT128_DW(
 0x39a5652fb1137856UL, 0xd30baf9ale626a6dUL);
 const int shift_ten16 = 51;

 vui64_t result;
 vui128_t x, high_digit;

 // high_digit = vra / 10000000000000000;
 high_digit = vec_mulhuq (vra, mul_invs_ten16);
 high_digit = vec_srqi (high_digit, shift_ten16);

 // multiply high_digit by the radix difference c and add vra
 // This separates the high/low 16 digits into doublewords.
#ifdef _ARCH_PWR9
 // 0 in the high dword of const c reduces vmsumudm to vmuloud
 // but with a qword add included.
 result = (vui64_t) vec_msumudm ((vui64_t) high_digit, c, vra);
#else
 x = vec_vmuloud ((vui64_t) high_digit, c);
 result = (vui64_t) vec_adduqm (vra, x);
#endif
 return result;
}

```

The first multiply is an expensive (40 to 60 cycles) operation as it requires a full Multiply High Unsigned Quadword. The next operation requires a Multiply Odd Unsigned Doubleword then Add Unsigned Quadword Modulo. For POWER9 we can replace these two operations with a single Multiply Sum Unsigned Doubleword Modulo. The latency of this single step is in the same order at the complete BCD to Binary conversion ([vec\\_bcdctug\(\)](#)).

The conversion steps continue with doubleword to word, word to halfword, halfword to byte, byte to BCD (nibbles). The final step is simple by comparison to the first step.

```

static inline vui8_t
vec_rdxcf100b (vui8_t vra)
{
 vui8_t x6, c6, high_digit;
 // Let the compiler generate the multiplicative inverse code
 high_digit = vra / 10;
 // This separates two digit values into BCD Nibbles.
 // multiply high_digit by the radix difference c and
 x6 = high_digit * 6;
 // add bytes the high digit correction to the original
 // (radix 100) bytes in binary.
 return (vra + x6);
}

```

The GCC vector extensions support dividing a vector char / short / int by a constant. So we can let the compiler generate the multiplicative inverse code for the last three steps. This is not supported (yet) for long and \_\_int128 so the first two steps must explicitly code the multiplicative inverse.

Using GCC vector extensions for the following multiply and add works well in this case as it allows the compiler to perform strength reduction. It is not as useful in the other steps as the programmer knows more about the value ranges than the compiler can or should assume. We know the the quotient and corrective constant always fit into the lower half of the element. This allows the use of the half sized vector multiply odd unsigned while compiler will assume it needs to generate a multiply modulo for the full element size.

For example the third step (word to halfword) we can use Multiply Sum Unsigned Halfword Modulo to replace the multiply odd and add. This is similar to the multiply sum usage in the first step and it is a case not recognized by the compiler.

The full binary to BCD conversion requires all 5 steps to complete the operations and this adds up to 200+ cycles. So this is worth another look.

Initially using the DFP Facility for this binary to BCD conversion was rejected because:

- The DFP Facility only supports signed fixed doubleword conversions (no fixed quadword conversion)
- Fixed binary to DFP conversions are expensive operations
  - For POWER8, 32 cycles latency and 1 per 19 cycles throughput
- The DFP Facility does support DFP to BCD conversions for double and quadword
  - For POWER8, 13 cycle latency and 1 per cycle throughput

Perhaps we can use the `vec_rdxcf10e32q()` operation we defined above as the first step (factoring quadwords into the 16 digit doublewords). Then use the DFP Facility to convert binary doublewords to BCD. In this case we are not concerned with signed conversion as  $10 \times 16$  fits in 54-bits binary and guarantees positive binary values. We still have to deal with the VR to/from FPR transfers but that mechanism is already defined and at a reasonable cost (2-4 cycles each way).

```
static inline vBCD_t
vec_BIN2BCD (vui64_t val)
{
#ifdef _ARCH_PWR6
 vBCD_t t;
 _Decimal128 x, y, z;
 // unpack the vector into a FPRp
 z = vec_unpack_Decimal128 ((vf64_t) val);
 // Convert 2 long int values into 2 _Decimal64 values
 // Then convert each _Decimal64 value into 16-digit BCD
 __asm__(
 "dcffix %1,%2;\n"
 "dcffix %L1,%L2;\n"
 "ddedpd 0,%0,%1;\n"
 "ddedpd 0,%L0,%L1;\n"
 : "=d" (x),
 "=&d" (y)
 : "d" (z)
 :);
 // Pack the FPRp back into a vector
 t = (vBCD_t) vec_pack_Decimal128 (x);
 return (t);
#else
 // no solution before P6
#endif
}
```

If we assume that the second Decimal Convert From Fixed (dcffix) is independent and issues 19 cycles after the first, we get  $32+19 = 51$  cycles to complete. Then another  $13+1$  cycles to convert back to BCD. Add a few cycles for the unpack and pack operations and we estimate 69 cycles for POWER8 and 58 cycles for POWER9. The totals for `vec_rdxcf10e32q()` plus `vec_BIN2BCD()` come to 154-164 for POWER8 and 114-124 for POWER9. This is a 30-60% improvement over the previous (all vector) attempt. So the final unsigned binary to BCD conversion looks like this:

```
static inline vBCD_t
vec_bcdcfuq (vui128_t vra)
{
 vui64_t d10e;
 d10e = vec_rdxcf10e32q (vra);
#ifdef _ARCH_PWR7
 return (vBCD_t) vec_BIN2BCD (d10e);
#else

```

```

vui8_t d100;
vui16_t d10k;
vui32_t d100m;
d100m = vec_rdxcf10E16d (d10e);
d10k = vec_rdxcf100mw (d100m);
d100 = vec_rdxcf10kh (d10k);
return (vBCD_t) vec_rdxcf100b (d10e);
#endif
}

```

#### Note

This process can be extended to 256, 512, 1024-bits, etc by widening the first 5 steps appropriately and adding steps using extended quadword multiply and add operations from [vec\\_int128\\_ppc.h](#) (Quadword Long Division).

#### 7.1.3.2.4 Multiple precision BCD to/from Binary conversion

The simplest case is converting a vector unsigned `__int128` to BCD. This requires up to 39 digits across two vectors. This can either be split into 8 and 31 digits for signed conversion or 7 and 32 for unsigned. Signed conversion is preferred where extended BCD result will be input to additional BCD arithmetic. Unsigned is preferred for conversion to Zoned characters for decimal display.

From [Converting Vector `\_\_int128` values to BCD](#) we see the divide / modulo quadword by constant operations which can be used to factor binary quadwords into high and low digit groups for conversion. For example:

```

q = vec_divuq_10e32 (a);
r = vec_moduq_10e32 (a, q);
// high 7 digits
dh = vec_bcdcfuq (q);
// lower 32 digits
dl = vec_bcdcfuq (r);

printf ("%07lld%016lld%016lld", (vui64_t) dh[VEC_DW_L],
 (vui64_t) dl[VEC_DW_H], (vui64_t) dl[VEC_DW_L]);

```

##### 7.1.3.2.4.1 Multiple precision BCD from Binary conversion

The general multiple precision binary to BCD conversion requires quadword long division as described in [Quadword Long Division](#). After each long division the remainder is in a range for conversion to BCD. In the example below the remainder is converted to 32 digit BCD as the last step.

```

// Convert extended quadword binary to BCD 32-digits at a time.
vBCD_t
example_longbcdcf_10e32 (vui128_t *q, vui128_t *d, long int _N)
{
 vui128_t dn, qh, ql, rh;
 long int i;

 // init step for the top digits
 dn = d[0];
 qh = vec_divuq_10e32 (dn);
 rh = vec_moduq_10e32 (dn, qh);
 q[0] = qh;

 // now we know the remainder is less than the divisor.
 for (i=1; i<_N; i++)
 {
 dn = d[i];
 ql = vec_divudq_10e32 (&qh, rh, dn);
 rh = vec_modudq_10e32 (rh, dn, &ql);
 q[i] = ql;
 }
 // convert to BCD and return the remainder for this step
 return vec_bcdcfuq (rh);
}

```

Each call to `example_longbcdcf_10e32 ()` produces the next 32-digit group. Repeated calls where the previous iterations quotient is passed as the dividend to the next step, produce additional 32-digit groups. This continues until the quotient is less than the divisor (in this case  $10^{32}$ ). This final quadword quotient provides the highest order 32-digit group for the conversion. The digit groups are produced in order from lowest to highest significance.

As the conversion process continues the number of quadwords in the extended dividend/quotient shrinks. The divide / modulo quadword by constant operations test for leading zeros and skip over them.

#### 7.1.3.2.4.2 Multiple precision BCD to Binary conversion

The general multiple precision binary from BCD conversion only requires extended quadword multiply as described in [Extended Quadword multiply](#). Starting with the high order BCD (32 or 31) digit group, multiply by  $10^{32}$  (or  $10^{31}$ ) then add the next digit group to the extended product. Continue until the low order digit group is added. For example:

```
// Convert extended quadword BCD to binary 32-digits at a time.
long int
example_longbcdct_10e32 (vu128_t *d, vBCD_t decimal,
 long int _C , long int _N)
{
 // ten32 = +100000000000000000000000000000000000UQ
 const vu128_t ten32 = (vu128_t)
 { (__int128) 100000000000000000000000000000000000UL * (__int128) 100000000000000000000000000000000000UL };
 const vu128_t zero = (vu128_t) { (__int128) 0UL };
 vu128_t dn, ph, pl, cn, c;
 long int i, cnt;

 cnt = _C;

 dn = zero;
 cn = zero;
 // case _C == 0 is the initialization step and no multiply required
 if (cnt == 0)
 {
 // if the decimal is 0, no conversion is required
 if (vec_cmpuq_all_ne ((vu128_t) decimal, zero))
 {
 cnt++;
 dn = vec_bcdctuq (decimal);
 }
 // But it is a good time to initialize d[]
 for (i = 0; i < (_N - 1); i++)
 {
 d[i] = zero;
 }
 d[_N - cnt] = dn;
 }
 else // case _C > 0
 {
 // convert decimal group to binary.
 if (vec_cmpuq_all_ne ((vu128_t) decimal, zero))
 {
 dn = vec_bcdctuq (decimal);
 }
 // Compute extended product, plus the decimal group
 for (i = (_N - 1); i >= (_N - cnt); i--)
 {
 pl = vec_muludq (&ph, d[i], ten32);

 c = vec_addecuq (pl, dn, cn);
 d[i] = vec_addeuqm (pl, dn, cn);
 cn = c;
 dn = ph;
 }
 // If the product exceeds the current quadword count, extend
 if (vec_cmpuq_all_ne (dn, zero) || vec_cmpuq_all_ne (cn, zero))
 {
 cnt++;
 dn = vec_adduqm (dn, cn);
 d[_N - cnt] = dn;
 }
 }

 return cnt;
}
```

This process starts with a single quadword (the converted high order digit group). As additional digit groups are converted, the extended binary value is multiplied by  $10^{32}$  before adding the converted digit group. The number of quadwords in the array *d[]* expand as needed to hold the binary value.

The interface includes:

- A pointer to an array of quadwords which accumulates the converted binary value.
- A BCD decimal value to be converted and added to the accumulated binary.
- A current quadword count. The number of nonzero quadwords accumulated so far. Should be 0 on the initial call.
- A maximum quadword count.
- Return the updated quadword count. Passed back as current quadword count on the next iteration.

#### 7.1.4 Performance data.

High level performance estimates are provided as an aid to function selection when evaluating algorithms. For background on how *Latency* and *Throughput* are derived see: [Performance data](#).

#### 7.1.5 Macro Definition Documentation

##### 7.1.5.1 vBCD\_t

```
#define vBCD_t vui32_t
```

vector signed BCD integer of up to 31 decimal digits.

##### Note

Currently the GCC implementation and the [OpenPOWER ELF V2 ABI](#) disagree on the vector type (vector `__int128` vs vector unsigned char) used (parameters and return values) by the BCD built-ins. Using `vBCD_t` insulates `pveclib` and applications while this is worked out.

#### 7.1.6 Function Documentation

##### 7.1.6.1 vec\_BCD2BIN()

```
static vui64_t vec_BCD2BIN (
 vBCD_t val) [inline], [static]
```

Convert vector of 2 x unsigned 16-digit BCD values to vector 2 x doubleword binary values.

Convert a vector of 16-digit unsigned BCD doublewords to a vector of unsigned long int doublewords. The vector unsigned long int doublewords are in the range 0-9999999999999999.



| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 55      | 1/51 cycle |
| power9    | 59      | 1/53 cycle |

**Parameters**

|            |                                                    |
|------------|----------------------------------------------------|
| <i>val</i> | a vector treated a 2 unsigned BCD 16 digit values. |
|------------|----------------------------------------------------|

**Returns**

a 128-bit vector unsigned long int.

**7.1.6.2 vec\_BCD2DFP()**

```
static __Decimal128 vec_BCD2DFP (
 vBCD_t val) [inline], [static]
```

Convert a Vector Signed BCD value to \_\_Decimal128.

The BCD vector is permuted into a double float pair before conversion to DPD format via the DFP Encode BCD To DPD Quad instruction.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 17      | 1/cycle    |
| power9    | 15      | 1/cycle    |

**Parameters**

|            |                                                          |
|------------|----------------------------------------------------------|
| <i>val</i> | a 128-bit vector treated as a signed BCD 31 digit value. |
|------------|----------------------------------------------------------|

**Returns**

a \_\_Decimal128 in a double float pair.

**7.1.6.3 vec\_bcdadd()**

```
static vBCD_t vec_bcdadd (
 vBCD_t a,
 vBCD_t b) [inline], [static]
```

Decimal Add Signed Modulo Quadword.

Two Signed 31 digit values are added and lower 31 digits of the sum are returned. Overflow (carry-out) is ignored.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 13      | 1/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|          |                                                          |
|----------|----------------------------------------------------------|
| <i>a</i> | a 128-bit vector treated as a signed BCD 31 digit value. |
| <i>b</i> | a 128-bit vector treated as a signed BCD 31 digit value. |

#### Returns

a 128-bit vector which is the lower 31 digits of (a + b).

#### 7.1.6.4 `vec_bcdaddcsq()`

```
static vBCD_t vec_bcdaddcsq (
 vBCD_t a,
 vBCD_t b) [inline], [static]
```

Decimal Add & write Carry Signed Quadword.

Two Signed 31 digit BCD values are added, and the carry-out (the high order 32nd digit) of the sum is returned.

#### Note

This operation will only detect overflows where the operand signs match. It will not detect a borrow if the signs differ. So this operation should only be used if matching signs are guaranteed. Otherwise `vec_cbcdaddcsq()` should be used.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 15-21   | 1/cycle    |
| power9    | 6-18    | 2/cycle    |

#### Parameters

|          |                                                          |
|----------|----------------------------------------------------------|
| <i>a</i> | a 128-bit vector treated as a signed BCD 31 digit value. |
| <i>b</i> | a 128-bit vector treated as a signed BCD 31 digit value. |

#### Returns

a 128-bit vector with the carry digit. Values are -1, 0, and +1.

7.1.6.5 `vec_bcdaddecsg()`

```
static vBCD_t vec_bcdaddecsg (
 vBCD_t a,
 vBCD_t b,
 vBCD_t c) [inline], [static]
```

Decimal Add Extended & write Carry Signed Quadword.

Two Signed 31 digit values and a signed carry-in are added together and the carry-out (the high order 32nd digit) of the sum is returned.

**Note**

This operation will only detect overflows where the operand signs match. It will not detect a borrow if the signs differ. So this operation should only be used if matching signs are guaranteed. Otherwise [vec\\_cbcdaddecsg\(\)](#) should be used.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 28-37   | 1/cycle    |
| power9    | 9-21    | 2/cycle    |

**Parameters**

|          |                                                                          |
|----------|--------------------------------------------------------------------------|
| <i>a</i> | a 128-bit vector treated as a signed BCD 31 digit value.                 |
| <i>b</i> | a 128-bit vector treated as a signed BCD 31 digit value.                 |
| <i>c</i> | a 128-bit vector treated as a signed BCD carry with values -1, 0, or +1. |

**Returns**

a 128-bit vector with the carry digit from the sum ( $a + b + c$ ). Carry values are -1, 0, and +1.

7.1.6.6 `vec_bcdaddesqm()`

```
static vBCD_t vec_bcdaddesqm (
 vBCD_t a,
 vBCD_t b,
 vBCD_t c) [inline], [static]
```

Decimal Add Extended Signed Modulo Quadword.

Two Signed 31 digit values and a signed carry-in are added together and lower 31 digits of the sum are returned. Overflow (carry-out) is ignored.



```
static vBCD_t vec_bcdcfud (
 vui64_t vrb) [inline], [static]
```

Vector convert doubleword containing a unsigned long int each in the range 0-9999999999999999 to the equivalent unsigned BCD doubleword value each up to 16 digits.

If either doubleword of `vrB` is greater than  $10 \times 16 - 1$  the result is too large for the BCD format and the result is undefined.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 69      | 1/19 cycle |
| power9    | 58      | 1/21 cycle |

|             |                                                                                      |
|-------------|--------------------------------------------------------------------------------------|
| <i>vrbl</i> | a 128-bit vector of unsigned long int numbers, each in the range 0-9999999999999999. |
|-------------|--------------------------------------------------------------------------------------|

128-bit vector doublewords of unsigned BCD values each in the range 0-9999999999999999.

```
static vBCD_t vec_bcdcfuq (
 vuil28_t vra) [inline], [static]
```

Vector convert a quadword containing a unsigned \_\_int128 in the range 0-99999999999999999999999999999999 to the equivalent unsigned BCD value with up to 32 digits.

If the value of `vrh` is greater than `10**32-1` the result is too large for the unsigned BCD format and the result is undefined. See [Converting Vector int128 values to BCD](#) for details.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 154-164 | 1/19 cycle |
| power9    | 117-128 | 1/21 cycle |



## 7.1.6.11 vec\_bcdcmp\_eqsq()

```
static vbBCD_t vec_bcdcmp_eqsq (
 vBCD_t vra,
 vBCD_t vrb) [inline], [static]
```

Vector Compare Signed BCD Quadword for equal.

Compare vector signed BCD values and return vector bool true if vra and vrb are equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 15-17   | 1/cycle    |
| power9    | 6-9     | 2/cycle    |

## Parameters

|            |                                                                 |
|------------|-----------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector signed BCD (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector signed BCD (qword) element. |

## Returns

128-bit vector boolean reflecting vector signed BCD compare equal.

## 7.1.6.12 vec\_bcdcmp\_gesq()

```
static vbBCD_t vec_bcdcmp_gesq (
 vBCD_t vra,
 vBCD_t vrb) [inline], [static]
```

Vector Compare Signed BCD Quadword for greater than or equal.

Compare vector signed BCD values and return vector bool true if vra and vrb are greater than or equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 15-17   | 1/cycle    |
| power9    | 6-9     | 2/cycle    |

## Parameters

|            |                                                                 |
|------------|-----------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector signed BCD (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector signed BCD (qword) element. |

**Returns**

128-bit vector boolean reflecting vector signed BCD compare greater than or equal.

**7.1.6.13 vec\_bcdcmp\_gtsq()**

```
static vbBCD_t vec_bcdcmp_gtsq (
 vBCD_t vra,
 vBCD_t vrb) [inline], [static]
```

Vector Compare Signed BCD Quadword for greater than.

Compare vector signed BCD values and return vector bool true if vra and vrb are greater than.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 15-17   | 1/cycle    |
| power9    | 6-9     | 2/cycle    |

**Parameters**

|            |                                                                 |
|------------|-----------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector signed BCD (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector signed BCD (qword) element. |

**Returns**

128-bit vector boolean reflecting vector signed BCD compare greater than.

**7.1.6.14 vec\_bcdcmp\_lesq()**

```
static vbBCD_t vec_bcdcmp_lesq (
 vBCD_t vra,
 vBCD_t vrb) [inline], [static]
```

Vector Compare Signed BCD Quadword for less than or equal.

Compare vector signed BCD values and return vector bool true if vra and vrb are less than or equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 15-17   | 1/cycle    |
| power9    | 6-9     | 2/cycle    |



## Parameters

|            |                                                                 |
|------------|-----------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector signed BCD (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector signed BCD (qword) element. |

## Returns

128-bit vector boolean reflecting vector signed BCD compare less than or equal.

7.1.6.15 `vec_bcdcmp_ltsq()`

```
static vbBCD_t vec_bcdcmp_ltsq (
 vBCD_t vra,
 vBCD_t vrb) [inline], [static]
```

Vector Compare Signed BCD Quadword for less than.

Compare vector signed BCD values and return vector bool true if *vra* and *vrb* are less than.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 15-17   | 1/cycle    |
| power9    | 6-9     | 2/cycle    |

## Parameters

|            |                                                                 |
|------------|-----------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector signed BCD (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector signed BCD (qword) element. |

## Returns

128-bit vector boolean reflecting vector signed BCD compare less than.

7.1.6.16 `vec_bcdcmp_nesq()`

```
static vbBCD_t vec_bcdcmp_nesq (
 vBCD_t vra,
 vBCD_t vrb) [inline], [static]
```

Vector Compare Signed BCD Quadword for not equal.

Compare vector signed BCD values and return vector bool true if *vra* and *vrb* are not equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 15-17   | 1/cycle    |
| power9    | 6-9     | 2/cycle    |

#### Parameters

|            |                                                                 |
|------------|-----------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector signed BCD (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector signed BCD (qword) element. |

#### Returns

128-bit vector boolean reflecting vector signed BCD compare not equal.

#### 7.1.6.17 `vec_bcdcmpeq()`

```
static int vec_bcdcmpeq (
 vBCD_t vra,
 vBCD_t vrb) [inline], [static]
```

Vector Compare Signed BCD Quadword for equal.

Compare vector signed BCD values and return boolean true if vra and vrb are equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 13      | 1/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|            |                                                                 |
|------------|-----------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector signed BCD (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector signed BCD (qword) element. |

#### Returns

boolean int for BCD compare, true if equal, false otherwise.

#### 7.1.6.18 `vec_bcdcmpge()`

```
static int vec_bcdcmpge (
 vBCD_t vra,
 vBCD_t vrb) [inline], [static]
```

Vector Compare Signed BCD Quadword for greater than or equal.

Compare vector signed BCD values and return boolean true if vra and vrb are greater than or equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 13      | 1/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|                    |                                                                 |
|--------------------|-----------------------------------------------------------------|
| <i>vra</i>         | 128-bit vector treated as an vector signed BCD (qword) element. |
| <i>vr</i> <i>b</i> | 128-bit vector treated as an vector signed BCD (qword) element. |

#### Returns

boolean int for BCD compare, true if greater than or equal, false otherwise.

#### 7.1.6.19 vec\_bcdcmpgt()

```
static int vec_bcdcmpgt (
 vBCD_t vra,
 vBCD_t vrb) [inline], [static]
```

Vector Compare Signed BCD Quadword for greater than.

Compare vector signed BCD values and return boolean true if vra and vrb are greater than.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 13      | 1/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|                    |                                                                 |
|--------------------|-----------------------------------------------------------------|
| <i>vra</i>         | 128-bit vector treated as an vector signed BCD (qword) element. |
| <i>vr</i> <i>b</i> | 128-bit vector treated as an vector signed BCD (qword) element. |

#### Returns

boolean int for BCD compare, true if greater than, false otherwise.

7.1.6.20 `vec_bcdcmple()`

```
static int vec_bcdcmple (
 vBCD_t vra,
 vBCD_t vrb) [inline], [static]
```

Vector Compare Signed BCD Quadword for less than or equal.

Compare vector signed BCD values and return boolean true if vra and vrb are less than or equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 13      | 1/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|            |                                                                 |
|------------|-----------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector signed BCD (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector signed BCD (qword) element. |

## Returns

boolean int for BCD compare, true if less than or equal, false otherwise.

7.1.6.21 `vec_bcdcmplt()`

```
static int vec_bcdcmplt (
 vBCD_t vra,
 vBCD_t vrb) [inline], [static]
```

Vector Compare Signed BCD Quadword for less than.

Compare vector signed BCD values and return boolean true if vra and vrb are less than.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 13      | 1/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|            |                                                                 |
|------------|-----------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector signed BCD (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector signed BCD (qword) element. |

**Returns**

boolean int for BCD compare, true if less than, false otherwise.

**7.1.6.22 vec\_bcdcmpne()**

```
static int vec_bcdcmpne (
 vBCD_t vra,
 vBCD_t vrb) [inline], [static]
```

Vector Compare Signed BCD Quadword for not equal.

Compare vector signed BCD values and return boolean true if vra and vrb are not equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 13      | 1/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|            |                                                                 |
|------------|-----------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector signed BCD (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector signed BCD (qword) element. |

**Returns**

boolean int for BCD compare, true if not equal, false otherwise.

**7.1.6.23 vec\_bcdcpsgn()**

```
static vBCD_t vec_bcdcpsgn (
 vBCD_t vra,
 vBCD_t vrb) [inline], [static]
```

Vector copy sign BCD.

Given Two Signed BCD 31 digit values vra and vrb, return the magnitude from vra (bits 0:123) and the sign (bits 124:127) from vrb.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-11    | 1/cycle    |
| power9    | 3       | 2/cycle    |



| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 13-22   | 1/cycle    |
| power9    | 14-23   | 1/cycle    |

**Parameters**

|            |                                                              |
|------------|--------------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as 16 unsigned 2-digit BCD numbers. |
|------------|--------------------------------------------------------------|

**Returns**

128-bit vector unsigned char, For each byte in the range 0-99.

**7.1.6.26 vec\_bcdctud()**

```
static vui64_t vec_bcdctud (
 vBCD_t vra) [inline], [static]
```

Vector Decimal Convert groups of 16 BCD digits to binary unsigned doublewords.

Vector convert 2 doublewords each containing 16 BCD digits to the equivalent unsigned long int, in the range 0-9999999999999999. Input values should be valid 16 x BCD nibbles in the range 0-9.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 40-51   | 1/cycle    |
| power9    | 41-52   | 1/cycle    |

**Parameters**

|            |                                                              |
|------------|--------------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as 2 unsigned 16-digit BCD numbers. |
|------------|--------------------------------------------------------------|

**Returns**

128-bit vector unsigned long int, For each doubleword in the range 0-9999999999999999.

**7.1.6.27 vec\_bcdctuh()**

```
static vui16_t vec_bcdctuh (
 vBCD_t vra) [inline], [static]
```

Vector Decimal Convert groups of 4 BCD digits to binary unsigned halfwords.

Vector convert 8 halfwords each containing 4 BCD digits to the equivalent unsigned short, in the range 0-9999. Input values should be valid 4 x BCD nibbles in the range 0-9.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 22-31   | 1/cycle    |
| power9    | 23-32   | 1/cycle    |

**Parameters**

|            |                                                             |
|------------|-------------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as 8 unsigned 4-digit BCD numbers. |
|------------|-------------------------------------------------------------|

**Returns**

128-bit vector unsigned short, For each halfword in the range 0-9999.

**7.1.6.28 vec\_bcdctuq()**

```
static vui128_t vec_bcdctuq (
 vBCD_t vra) [inline], [static]
```

Vector Decimal Convert groups of 32 BCD digits to binary unsigned quadword.

Vector convert a quadword containing 32 BCD digits to the equivalent unsigned \_\_int128, in the range 0-99999999999999999999999999999999. Input values should be valid 32 x BCD nibbles in the range 0-9.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 65-78   | 1/cycle    |
| power9    | 28-37   | 1/12 cycle |

**Parameters**

|            |                                                              |
|------------|--------------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as an unsigned 32-digit BCD number. |
|------------|--------------------------------------------------------------|

**Returns**

128-bit vector unsigned \_\_int128 in the range 0-99999999999999999999999999999999.

**7.1.6.29 vec\_bcdctuw()**

```
static vui32_t vec_bcdctuw (
 vBCD_t vra) [inline], [static]
```

Vector Decimal Convert groups of 8 BCD digits to binary unsigned words.

Vector convert 4 words each containing 8 BCD digits to the equivalent unsigned int, in the range 0-99999999. Input values should be valid 8 x BCD nibbles in the range 0-9.



| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 31-42   | 1/cycle    |
| power9    | 32-43   | 1/cycle    |

**Parameters**

|            |                                                             |
|------------|-------------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as 4 unsigned 8-digit BCD numbers. |
|------------|-------------------------------------------------------------|

**Returns**

128-bit vector unsigned int, For each word in the range 0-99999999.

**7.1.6.30 vec\_bcdctz()**

```
static vui8_t vec_bcdctz (
 vBCD_t vrb) [inline], [static]
```

Vector Decimal Convert To Zoned.

Given a Signed 16-digit signed BCD value vrb, return equivalent Signed Zoned value. For Zoned (PS=0) the sign code is in bits 0:3 of byte 15.

- Positive sign Zone is: 0x30.
- Negative sign Zone is: 0x70.

The resulting Zone value will up to 16 digits magnitude and set to the preferred Zoned sign codes (0x30 or 0x70).

**Note**

The POWER9 bcdctz instruction gives undefined results if given invalid input. In this implementation for older processors there is no checking for BCD digit (bits 4:7) range.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 14-27   | 1/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|            |                                                          |
|------------|----------------------------------------------------------|
| <i>vrb</i> | a 128-bit vector treated as a signed BCD 16 digit value. |
|------------|----------------------------------------------------------|

**Returns**

a 128-bit Zoned value with the magnitude (low order 16-digits) and sign from the value in vrb.

**7.1.6.31 vec\_bcddiv()**

```
static vBCD_t vec_bcddiv (
 vBCD_t a,
 vBCD_t b) [inline], [static]
```

Divide a Vector Signed BCD 31 digit value by another BCD value.

One Signed 31 digit value is divided by a second 31 digit value and the quotient is returned.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 102-238 | 1/cycle    |
| power9    | 96-228  | 1/cycle    |

**Parameters**

|          |                                                          |
|----------|----------------------------------------------------------|
| <i>a</i> | a 128-bit vector treated as a signed BCD 31 digit value. |
| <i>b</i> | a 128-bit vector treated as a signed BCD 31 digit value. |

**Returns**

a 128-bit vector which is the lower 31 digits of (a / b).

**7.1.6.32 vec\_bcddivd()**

```
static vBCD_t vec_bcddivd (
 vBCD_t a,
 vBCD_t b) [inline], [static]
```

Decimal Divide Extended.

The dividend *a* is a Signed BCD 31 digit value extended to right internally with 31 decimal 0s. The divisor *b* is Signed BCD 31 digit value. The quotient of  $a \parallel 0^{31} / b$  is truncated to a Decimal integer and returned in Signed BCD format.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 102-238 | 1/cycle    |
| power9    | 96-228  | 1/cycle    |

## Parameters

|          |                                                                                       |
|----------|---------------------------------------------------------------------------------------|
| <i>a</i> | a 128-bit vector treated as the high 31-digits of a 62-digit value extended with 0's. |
| <i>b</i> | a 128-bit vector treated as a signed BCD 31 digit value.                              |

## Returns

a 128-bit vector quotient of (*a* / *b*).

## 7.1.6.33 vec\_bcdmul()

```
static vBCD_t vec_bcdmul (
 vBCD_t a,
 vBCD_t b) [inline], [static]
```

Multiply two Vector Signed BCD 31 digit values.

Two Signed 31 digit values are multiplied and the lower 31 digits of the product are returned. Overflow is ignored.

The vector unit does not have a BCD multiply, so we convert the operands to `_Decimal128` format and use the DFP quadword multiply. This gets tricky as the product can be up to 62 digits, and `_Decimal128` format can only hold 34 digits.

To avoid overflow in the DFP Facility, we split each BCD operand into 15 upper and 16 lower digit halves. This requires up to four decimal multiplies and produces up to four 30-32 digit partial products. These are aligned appropriately (via DFP decimal shift) and summed (via DFP Decimal add) to generate the high and low (31-digit) parts of the 62 digit product.

In this case we only need the lower 31-digits of the product. So only 3 (not 4) DFP multiplies are required. Also we can discard any high digits above 31.

## Note

There is early exit case if both operands are 16-digits or less. Here the product can not exceed 32-digits and requires only a single DFP multiply. The DFP2BCD conversion will discard any extra (32th) digit.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 94-194  | 1/cycle    |
| power9    | 88-227  | 1/cycle    |

## Parameters

|          |                                                          |
|----------|----------------------------------------------------------|
| <i>a</i> | a 128-bit vector treated as a signed BCD 31 digit value. |
| <i>b</i> | a 128-bit vector treated as a signed BCD 31 digit value. |

**Returns**

a 128-bit vector which is the lower 31 digits of (a \* b).

**7.1.6.34 vec\_bcdmulh()**

```
static vBCD_t vec_bcdmulh (
 vBCD_t a,
 vBCD_t b) [inline], [static]
```

Vector Signed BCD Multiply High.

Two Signed 31 digit values are multiplied and the higher 31 digits of the product are returned.

The vector unit does not have a BCD multiply, so we convert the operands to \_Decimal128 format and use the DFP quadword multiply. This gets tricky as the product can be up to 62 digits, and \_Decimal128 format can only hold 34 digits.

To avoid overflow in the DFP Facility, we split each BCD operand into 15 upper and 16 lower digit halves. This requires up four decimal multiplies and produces four 30-32 digit partial products. These are aligned appropriately (via DFP decimal shift) and summed (via DFP Decimal add) to generate the high and low (31-digit) parts of the 62 digit product.

In this case we only need the upper 31-digits of the product. The lower 31-digits are discarded.

**Note**

There is early exit case if both operands are 16-digits or less. Here the product can not exceed 32-digits and requires only a single DFP multiply. We use the DFP Decimal shift to discard the lower 31-digits and return the single (32nd) digit.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 106-361 | 1/cycle    |
| power9    | 99-271  | 1/cycle    |

**Parameters**

|          |                                                          |
|----------|----------------------------------------------------------|
| <i>a</i> | a 128-bit vector treated as a signed BCD 31 digit value. |
| <i>b</i> | a 128-bit vector treated as a signed BCD 31 digit value. |

**Returns**

a 128-bit vector which is the higher 31 digits of (a \* b).

## 7.1.6.35 vec\_bcds()

```
static vBCD_t vec_bcds (
 vBCD_t vra,
 vi8_t vrb) [inline], [static]
```

Decimal Shift. Shift a vector signed BCD value, left or right a variable amount of digits (nibbles). The sign nibble is preserved.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 14-25   | 1/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|            |                                                        |
|------------|--------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as a signed BCD 31 digit value. |
| <i>vrb</i> | Digit shift count in vector byte 7.                    |

## Returns

a 128-bit vector BCD value shifted right digits.

## 7.1.6.36 vec\_bcdsetsgn()

```
static vBCD_t vec_bcdsetsgn (
 vBCD_t vrb) [inline], [static]
```

Vector Set preferred BCD Sign.

Given a Signed BCD 31 digit value vrb, return the magnitude from vrb (bits 0:123) and the sign (bits 124:127) set to the preferred sign (0xc or 0xd). Valid positive sign codes are; 0xA, 0xC, 0xE, or 0xF. Valid negative sign codes are; 0xB or 0xD.

## Note

The POWER9 bcdsetsgn instruction gives undefined results if given invalid input. In this implementation for older processors only the sign code is checked. In this case, if the sign code is invalid the vrb input value is returned unchanged.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-26    | 1/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|            |                                                          |
|------------|----------------------------------------------------------|
| <i>vrb</i> | a 128-bit vector treated as a signed BCD 31 digit value. |
|------------|----------------------------------------------------------|

**Returns**

a 128-bit BCD value with the magnitude from *vra* and the sign copied from *vrb*.

**7.1.6.37 vec\_bcdslqi()**

```
static vBCD_t vec_bcdslqi (
 vBCD_t vra,
 const unsigned int _N) [inline], [static]
```

Vector BCD Shift Right Signed Quadword.

Shift a vector signed BCD value right *\_N* digits.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-15    | 2/cycle    |
| power9    | 3-6     | 2/cycle    |

**Parameters**

|                                          |                                                       |
|------------------------------------------|-------------------------------------------------------|
| <i>vra</i>                               | 128-bit vector signed BCD 31 digit value.             |
| $\leftarrow$<br>$\leftarrow$<br><i>N</i> | int constant for the number of digits to shift right. |

**Returns**

a 128-bit vector BCD value shifted right *\_N* digits.

**7.1.6.38 vec\_bcdsluqi()**

```
static vBCD_t vec_bcdsluqi (
 vBCD_t vra,
 const unsigned int _N) [inline], [static]
```

Vector BCD Shift Right unsigned Quadword.

Shift a vector unsigned BCD value right *\_N* digits.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-15    | 2/cycle    |
| power9    | 3-6     | 2/cycle    |

**Parameters**

|                                          |                                                       |
|------------------------------------------|-------------------------------------------------------|
| <i>vra</i>                               | 128-bit vector unsigned BCD 32 digit value.           |
| $\leftarrow$<br>$\leftarrow$<br><i>N</i> | int constant for the number of digits to shift right. |

**Returns**

a 128-bit vector BCD value shifted right *\_N* digits.

**7.1.6.39 vec\_bcdsr()**

```
static vBCD_t vec_bcdsr (
 vBCD_t vra,
 vi8_t vrb) [inline], [static]
```

Decimal Shift and Round. Shift a vector signed BCD value, left or right a variable amount of digits (nibbles). The sign nibble is preserved. If byte element 7 of the shift count is negative (right shift), and the last digit shifted out is greater than or equal to 5, then increment the shifted magnitude by 1.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 14-25   | 1/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|            |                                                        |
|------------|--------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as a signed BCD 31 digit value. |
| <i>vrb</i> | Digit shift count in vector byte 7.                    |

**Returns**

a 128-bit vector BCD value shifted right digits.

7.1.6.40 `vec_bcdsrqi()`

```
static vBCD_t vec_bcdsrqi (
 vBCD_t vra,
 const unsigned int _N) [inline], [static]
```

Vector BCD Shift Right Signed Quadword Immediate.

Shift a vector signed BCD value right `_N` digits.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-15    | 2/cycle    |
| power9    | 3-6     | 2/cycle    |

## Parameters

|                                   |                                                       |
|-----------------------------------|-------------------------------------------------------|
| <code>vra</code>                  | 128-bit vector signed BCD 31 digit value.             |
| <code>↔</code><br><code>_N</code> | int constant for the number of digits to shift right. |

## Returns

a 128-bit vector BCD value shifted right `_N` digits.

7.1.6.41 `vec_bcdsrrqi()`

```
static vBCD_t vec_bcdsrrqi (
 vBCD_t vra,
 const unsigned int _N) [inline], [static]
```

Vector BCD Shift Right and Round Signed Quadword Immediate.

Shift and round a vector signed BCD value right `_N` digits.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 25-34   | 2/cycle    |
| power9    | 3-6     | 2/cycle    |

## Parameters

|                  |                                           |
|------------------|-------------------------------------------|
| <code>vra</code> | 128-bit vector signed BCD 31 digit value. |
|------------------|-------------------------------------------|



## Parameters

|                       |                                                       |
|-----------------------|-------------------------------------------------------|
| $\leftarrow$          | int constant for the number of digits to shift right. |
| $\leftarrow$<br>$\_N$ |                                                       |

## Returns

a 128-bit vector BCD value shifted right  $\_N$  digits.

## 7.1.6.42 vec\_bcdsruqi()

```
static vBCD_t vec_bcdsruqi (
 vBCD_t vra,
 const unsigned int _N) [inline], [static]
```

Vector BCD Shift Right Unsigned Quadword immediate.

Shift a vector unsigned BCD value right  $\_N$  digits.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-15    | 2/cycle    |
| power9    | 3-6     | 2/cycle    |

## Parameters

|                       |                                                       |
|-----------------------|-------------------------------------------------------|
| $vra$                 | 128-bit vector unsigned BCD 32 digit value.           |
| $\leftarrow$<br>$\_N$ | int constant for the number of digits to shift right. |

## Returns

a 128-bit vector BCD value shifted right  $\_N$  digits.

## 7.1.6.43 vec\_bcdsub()

```
static vBCD_t vec_bcdsub (
 vBCD_t a,
 vBCD_t b) [inline], [static]
```

Subtract two Vector Signed BCD 31 digit values.

Subtract Signed 31 digit values and return the lower 31 digits of of the result. Overflow (carry-out/barrow) is ignored.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 13      | 1/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|          |                                                       |
|----------|-------------------------------------------------------|
| <i>a</i> | a 128-bit vector treated a signed BCD 31 digit value. |
| <i>b</i> | a 128-bit vector treated a signed BCD 31 digit value. |

#### Returns

a 128-bit vector which is the lower 31 digits of (a - b).

#### 7.1.6.44 `vec_bcdsubcsq()`

```
static vBCD_t vec_bcdsubcsq (
 vBCD_t a,
 vBCD_t b) [inline], [static]
```

Decimal Subtract & write Carry Signed Quadword.

Two Signed 31 digit BCD values are subtracted, and the carry-out (the high order 32nd digit) of the difference is returned.

#### Note

This operation will only detect overflows where the operand signs differ. It will not detect a borrow if the signs match. So this operation should only be used if differing signs are guaranteed.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 15-21   | 1/cycle    |
| power9    | 6-18    | 2/cycle    |

#### Parameters

|          |                                                          |
|----------|----------------------------------------------------------|
| <i>a</i> | a 128-bit vector treated as a signed BCD 31 digit value. |
| <i>b</i> | a 128-bit vector treated as a signed BCD 31 digit value. |

#### Returns

a 128-bit vector with the carry digit. Values are -1, 0, and +1.

## 7.1.6.45 vec\_bcdsubecsqr()

```
static vBCD_t vec_bcdsubecsqr (
 vBCD_t a,
 vBCD_t b,
 vBCD_t c) [inline], [static]
```

Decimal Add Extended & write Carry Signed Quadword.

Two Signed 31 digit values and a signed carry-in are added together and the carry-out (the high order 32nd digit) of the sum is returned.

## Note

This operation will only detect overflows where the operand signs differ. It will not detect a borrow if the signs match. So this operation should only be used if differing signs are guaranteed.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 28-37   | 1/cycle    |
| power9    | 9-21    | 2/cycle    |

## Parameters

|          |                                                                          |
|----------|--------------------------------------------------------------------------|
| <i>a</i> | a 128-bit vector treated as a signed BCD 31 digit value.                 |
| <i>b</i> | a 128-bit vector treated as a signed BCD 31 digit value.                 |
| <i>c</i> | a 128-bit vector treated as a signed BCD carry with values -1, 0, or +1. |

## Returns

a 128-bit vector with the carry digit from the sum ( $a + b + c$ ). Carry values are -1, 0, and +1.

## 7.1.6.46 vec\_bcdsubesqr()

```
static vBCD_t vec_bcdsubesqr (
 vBCD_t a,
 vBCD_t b,
 vBCD_t c) [inline], [static]
```

Decimal Subtract Extended Signed Modulo Quadword.

Two Signed 31 digit values and a signed carry-in are subtracted ( $a - b - c$ ) and lower 31 digits of the subtraction is returned. Overflow (carry-out) is ignored.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 26      | 1/cycle    |
| power9    | 6       | 2/cycle    |

**Parameters**

|          |                                                                          |
|----------|--------------------------------------------------------------------------|
| <i>a</i> | a 128-bit vector treated as a signed BCD 31 digit value.                 |
| <i>b</i> | a 128-bit vector treated as a signed BCD 31 digit value.                 |
| <i>c</i> | a 128-bit vector treated as a signed BCD carry with values -1, 0, or +1. |

**Returns**

a 128-bit vector which is the lower 31 digits of (a + b + c).

**7.1.6.47 vec\_bcdtrunc()**

```
static vBCD_t vec_bcdtrunc (
 vBCD_t vra,
 vuil6_t vrb) [inline], [static]
```

Decimal Truncate. Truncate a vector signed BCD value *vra* to N-digits, where N is the unsigned integer value in bits 48-63 of *vrb*. The first 31-N digits are set to 0 and the result returned.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 18-27   | 1/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|            |                                                         |
|------------|---------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as a signed BCD 31 digit value.  |
| <i>vrb</i> | Digit truncate count in vector halfword 3 (bits 48:63). |

**Returns**

a 128-bit vector BCD value with the first 31-count digits set to 0.

**7.1.6.48 vec\_bcdtruncqi()**

```
static vBCD_t vec_bcdtruncqi (
 vBCD_t vra,
 const unsigned short _N) [inline], [static]
```

Decimal Truncate Quadword Immediate. Truncate a vector signed BCD value *vra* to *N*-digits, where *N* is a unsigned short integer constant. The first 31-*N* digits are set to 0 and the result returned.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-17    | 1/cycle    |
| power9    | 6       | 2/cycle    |

#### Parameters

|                                                          |                                                        |
|----------------------------------------------------------|--------------------------------------------------------|
| <i>vra</i>                                               | 128-bit vector treated as a signed BCD 31 digit value. |
| $\leftarrow$<br>$\leftarrow$<br>$\leftarrow$<br><i>N</i> | a unsigned short integer constant truncate count.      |

#### Returns

a 128-bit vector BCD value with the first 31-count digits set to 0.

#### 7.1.6.49 vec\_bcdus()

```
static vBCD_t vec_bcdus (
 vBCD_t vra,
 vi8_t vrb) [inline], [static]
```

Decimal Unsigned Shift. Shift a vector unsigned BCD value, left or right a variable amount of digits (nibbles).

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 12-14   | 1/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|            |                                                        |
|------------|--------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as a signed BCD 32 digit value. |
| <i>vrb</i> | Digit shift count in vector byte 7.                    |

#### Returns

a 128-bit vector BCD value shifted right digits.

7.1.6.50 `vec_bcdutrunc()`

```
static vBCD_t vec_bcdutrunc (
 vBCD_t vra,
 vui16_t vrb) [inline], [static]
```

Decimal Unsigned Truncate. Truncate a vector unsigned BCD value *vra* to N-digits, where N is the unsigned integer value in bits 48-63 of *vrb*. The first 32-N digits are set to 0 and the result returned.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 16-25   | 1/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|            |                                                           |
|------------|-----------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an unsigned BCD 32 digit value. |
| <i>vrb</i> | Digit truncate count in vector halfword 3 (bits 48:63).   |

## Returns

a 128-bit vector BCD value with the first 32-count digits set to 0.

7.1.6.51 `vec_bcdutruncqi()`

```
static vBCD_t vec_bcdutruncqi (
 vBCD_t vra,
 const unsigned short _N) [inline], [static]
```

Decimal Unsigned Truncate Quadword Immediate. Truncate a vector unsigned BCD value *vra* to N-digits, where N is a unsigned short integer constant. The first 32-N digits are set to 0 and the result returned.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-17    | 1/cycle    |
| power9    | 6       | 2/cycle    |

## Parameters

|                                          |                                                        |
|------------------------------------------|--------------------------------------------------------|
| <i>vra</i>                               | 128-bit vector treated as a signed BCD 31 digit value. |
| $\leftarrow$<br>$\leftarrow$<br><i>N</i> | a unsigned short integer constant truncate count.      |

**Returns**

a 128-bit vector BCD value with the first 32-count digits set to 0.

**7.1.6.52 vec\_BIN2BCD()**

```
static vBCD_t vec_BIN2BCD (
 vui64_t val) [inline], [static]
```

Convert vector unsigned doubleword binary values to Vector unsigned 16-digit BCD values.

Convert a vector of 2 unsigned long int doubleword to 2 16-digit unsigned BCD doublewords. Input doublewords should each be in the range 0-9999999999999999.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 69      | 1/19 cycle |
| power9    | 58      | 1/21 cycle |

**Parameters**

|            |                             |
|------------|-----------------------------|
| <i>val</i> | a vector unsigned long int. |
|------------|-----------------------------|

**Returns**

a 128-bit vector treated a 2 unsigned BCD 16 digit values.

**7.1.6.53 vec\_cbcdaddcsq()**

```
static vBCD_t vec_cbcdaddcsq (
 vBCD_t * cout,
 vBCD_t a,
 vBCD_t b) [inline], [static]
```

Combined Decimal Add & Write Carry Signed Quadword.

Two Signed 31 digit BCD values are added, and the carry-out (the high order 32nd digit) of the sum is generated. Alternatively if the intermediate sum changes sign we need to, borrow '1' from the magnitude of the higher BCD value and correct (invert by subtracting from 10\*\*31) the intermediate sum. Both the sum and the carry/borrow are returned.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 15-24   | 1/cycle    |
| power9    | 6-15    | 2/cycle    |

**Parameters**

|             |                                                             |
|-------------|-------------------------------------------------------------|
| <i>cout</i> | a pointer to a 128-bit vector to receive the BCD carry-out. |
| <i>a</i>    | a 128-bit vector treated as a signed BCD 31 digit value.    |
| <i>b</i>    | a 128-bit vector treated as a signed BCD 31 digit value.    |

**Returns**

a 128-bit vector with the low order 31-digits of the sum (a+b). Values are -1, 0, and +1.

**7.1.6.54 vec\_cbcddaddecsg()**

```
static vBCD_t vec_cbcddaddecsg (
 vBCD_t * cout,
 vBCD_t a,
 vBCD_t b,
 vBCD_t cin) [inline], [static]
```

Combined Decimal Add Extended & write Carry Signed Quadword.

Two Signed 31 digit values and a signed carry-in are added together and the carry-out (the high order 32nd digit) of the sum is generated. Alternatively if the intermediate sum changes sign we need to, borrow '1' from the magnitude of the next higher BCD value and correct (invert by subtracting from 10\*\*31) the intermediate sum. Both the sum and the carry/borrow are returned.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 54-63   | 1/cycle    |
| power9    | 15-24   | 2/cycle    |

**Parameters**

|             |                                                                          |
|-------------|--------------------------------------------------------------------------|
| <i>cout</i> | a pointer to a 128-bit vector to receive the BCD carry-out.              |
| <i>a</i>    | a 128-bit vector treated as a signed BCD 31 digit value.                 |
| <i>b</i>    | a 128-bit vector treated as a signed BCD 31 digit value.                 |
| <i>cin</i>  | a 128-bit vector treated as a signed BCD carry with values -1, 0, or +1. |

**Returns**

a 128-bit vector with the low order 31-digits of the sum (a+b).



## 7.1.6.55 vec\_cbcdmul()

```
static vBCD_t vec_cbcdmul (
 vBCD_t * p_high,
 vBCD_t a,
 vBCD_t b) [inline], [static]
```

Combined Vector Signed BCD Multiply High/Low.

Two Signed 31 digit values are multiplied and generates the 62 digit product.

The vector unit does not have a BCD multiply, so we convert the operands to `_Decimal128` format and use the DFP quadword multiply. This gets tricky as the product can be up to 62 digits, and `_Decimal128` format can only hold 34 digits.

To avoid overflow in the DFP Facility, we split each BCD operand into 15 upper and 16 lower digit halves. This requires up four decimal multiplies and produces four 30-32 digit partial products. These are aligned appropriately (via DFP decimal shift) and summed (via DFP Decimal add) to generate the high and low (31-digit) parts of the 62 digit product.

In this case we compute and return the whole 62-digit product split into two 31-digit BCD vectors.

## Note

There is early exit case if both operands are 16-digits or less. Here the product can not exceed 32-digits and requires only a single DFP multiply. The DFP2BCD conversion will extract the lower 31-digits. Then DFP Decimal shift will isolate the high (32nd) digit.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 107-413 | 1/cycle    |
| power9    | 115-294 | 1/cycle    |

## Parameters

|               |                                                                                                     |
|---------------|-----------------------------------------------------------------------------------------------------|
| <i>a</i>      | a 128-bit vector treated as a signed BCD 31 digit value.                                            |
| <i>b</i>      | a 128-bit vector treated as a signed BCD 31 digit value.                                            |
| <i>p_high</i> | a pointer to a 128-bit vector to receive the high 31-digits of the product ( <i>a</i> * <i>b</i> ). |

## Returns

a 128-bit vector which is the lower 31 digits of (*a* \* *b*).

## 7.1.6.56 vec\_cbcdsubcsq()

```
static vBCD_t vec_cbcdsubcsq (
 vBCD_t * cout,
```

```

vBCD_t a,
vBCD_t b) [inline], [static]

```

Combined Decimal Subtract & Write Carry Signed Quadword.

Subtract (a -b) Signed 31 digit BCD values and detect the carry/borrow (the high order 32nd digit). If the intermediate sum changes sign we need to, borrow '1' from the magnitude of the higher BCD value and correct (invert by subtracting from  $10 \times 31$ ) the intermediate sum. Both the sum and the carry/borrow are returned.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 15-24   | 1/cycle    |
| power9    | 6-15    | 2/cycle    |

#### Parameters

|             |                                                                                        |
|-------------|----------------------------------------------------------------------------------------|
| <i>cout</i> | a pointer to a 128-bit vector to receive the BCD carry-out (values are -1, 0, and +1). |
| <i>a</i>    | a 128-bit vector treated as a signed BCD 31 digit value.                               |
| <i>b</i>    | a 128-bit vector treated as a signed BCD 31 digit value.                               |

#### Returns

a 128-bit vector with the low order 31-digits of the difference (a+b).

#### 7.1.6.57 vec\_DFP2BCD()

```

static vBCD_t vec_DFP2BCD (
 __Decimal128 val) [inline], [static]

```

Convert a \_\_Decimal128 value to Vector BCD.

The \_\_Decimal128 value is converted to a signed BCD 31 digit value via "DFP Decode DPD To BCD Quad". The conversion result is still in a double float register pair and so is permuted into single vector register for use.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 17      | 1/cycle    |
| power9    | 15      | 1/cycle    |

#### Parameters

|            |                                        |
|------------|----------------------------------------|
| <i>val</i> | a __Decimal128 in a double float pair. |
|------------|----------------------------------------|

**Returns**

a 128-bit vector treated a signed BCD 31 digit value.

**7.1.6.58 vec\_pack\_Decimal128()**

```
static vf64_t vec_pack_Decimal128 (
 _Decimal128 lval) [inline], [static]
```

Pack a FPR pair (\_Decimal128) to a doubleword vector (vector double).

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|             |                                    |
|-------------|------------------------------------|
| <i>lval</i> | FPR pair containing a _Decimal128. |
|-------------|------------------------------------|

**Returns**

vector double containing the doublewords of the FPR pair.

**7.1.6.59 vec\_quantize0\_Decimal128()**

```
static _Decimal128 vec_quantize0_Decimal128 (
 _Decimal128 val) [inline], [static]
```

Quantize (truncate) a \_Decimal128 value before convert to BCD.

Truncate (round toward 0) and justify right the input \_Decimal128 value so that the unit digit is in the right most position. This supports BCD multiply and divide using DFP instructions by truncating fractional digits before conversion back to BCD.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 15      | 1/cycle    |
| power9    | 12      | 1/cycle    |

**Parameters**

|            |                      |
|------------|----------------------|
| <i>val</i> | a _Decimal128 value. |
|------------|----------------------|

**Returns**

The quantized \_\_Decimal128 value in a double float pair.

**7.1.6.60 vec\_rdxcf100b()**

```
static vui8_t vec_rdxcf100b (
 vui8_t vra) [inline], [static]
```

Vector Decimal Convert Binary Coded Decimal (BCD) digit pairs from radix 100 binary integer bytes.

Convert 16 radix 100 digits to 32 BCD Format decimal digits. Input is radix 100 digits as binary bytes in the range 0-99. Each byte converted to the equivalent BCD digit pair in adjacent nibbles.

This can be used as the last stage operation in wider binary to decimal conversions.

**Note**

the nibble high to low digit word is effectively big endian. This matches the digit order precedence of Decimal Add/Subtract.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 24-34   | 1/cycle    |
| power9    | 27-37   | 1/cycle    |

**Parameters**

|            |                                                                         |
|------------|-------------------------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector unsigned char of radix 100 digits. |
|------------|-------------------------------------------------------------------------|

**Returns**

128-bit vector unsigned char of BCD nibble pairs in the range 0-9.

**7.1.6.61 vec\_rdxcf100mw()**

```
static vui16_t vec_rdxcf100mw (
 vui32_t vra) [inline], [static]
```

Vector Decimal Convert radix 10\*\*8 Binary words to pairs of radix 10,000 binary halfwords.

Convert 4 radix 10\*\*8 digits to 8 adjacent radix 10,000 digits. Input is radix 10\*\*8 digits as binary words in the range 0-99999999. Each word converted to the equivalent radix 10,000 pair in adjacent halfword.

This can be used as a intermediate stage operation in wider binary to decimal conversions.

**Note**

The high to low digit order is effectively big endian. This matches the digit order precedence of Decimal Add/← Subtract.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 18-25   | 1/cycle    |
| power9    | 19-26   | 1/cycle    |

**Parameters**

|            |                                                                          |
|------------|--------------------------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector unsigned int of radix 10**8 digits. |
|------------|--------------------------------------------------------------------------|

**Returns**

128-bit vector unsigned short radix 10,000 pairs in the range 0-9999.

**7.1.6.62 vec\_rdxcf10E16d()**

```
static vui32_t vec_rdxcf10E16d (
 vui64_t vra) [inline], [static]
```

Vector Decimal Convert radix 10\*\*16 Binary doublewords to pairs of radix 10\*\*8 binary words.

Convert 2 radix 10\*\*16 digits to 4 adjacent radix 10\*\*8 digits. Input is radix 10\*\*16 digits as binary doublewords in the range 0-9999999999999999. Each doubleword converted to the equivalent radix 10\*\*8 pair in adjacent words.

This can be used as a intermediate stage operation in wider binary to decimal conversions.

**Note**

The high to low digit order is effectively big endian. This matches the digit order precedence of Decimal Add/← Subtract.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 51-61   | 1/cycle    |
| power9    | 30-40   | 1/cycle    |

**Parameters**

|            |                                                                            |
|------------|----------------------------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector unsigned long of radix 10**16 digits. |
|------------|----------------------------------------------------------------------------|

**Returns**

128-bit vector unsigned short radix 10\*\*8 pairs in the range 0-99999999.

**7.1.6.63 vec\_rdxcf10e32q()**

```
static vui64_t vec_rdxcf10e32q (
 vui128_t vra) [inline], [static]
```

Vector Decimal Convert radix 10\*\*32 Binary quadword to pairs of radix 10\*\*16 binary doublewords.

Convert a binary quadword to 2 adjacent radix 10\*\*16 digits. Input is a binary quadwords in the range 0-99999999999999999999999999999999. The quadword converted to the equivalent radix 10\*\*18 pair in adjacent doublewords.

This can be used as a first stage operation in binary to decimal conversions.

**Note**

Results are undefined if the input value is greater than 10\*\*32 - 1. See [Converting Vector \\_\\_int128 values to BCD](#) for details.

The high to low digit order is effectively big endian. This matches the digit order precedence of Decimal Add/↔ Subtract.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 85-95   | 1/cycle    |
| power9    | 56-66   | 1/cycle    |

**Parameters**

|            |                                                                                                         |
|------------|---------------------------------------------------------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector unsigned __int128 in the range 0-99999999999999999999999999999999. |
|------------|---------------------------------------------------------------------------------------------------------|

**Returns**

128-bit vector unsigned long radix 10\*\*16 pairs in the range 0-9999999999999999.

**7.1.6.64 vec\_rdxcf10kh()**

```
static vui8_t vec_rdxcf10kh (
 vui16_t vra) [inline], [static]
```

Vector Decimal Convert radix 10,000 Binary halfwords to pairs of radix 100 binary bytes.

Convert 8 radix 10,000 digits to 16 adjacent radix 100 digits. Input is radix 10,000 digits as binary halfwords in the range 0-9999. Each halfword converted to the equivalent radix 100 pair in adjacent bytes.

This can be used as an intermediate stage operation in wider binary to decimal conversions.

**Note**

The high to low digit order is effectively big endian. This matches the digit order precedence of Decimal Add/↔ Subtract.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 24-34   | 1/cycle    |
| power9    | 27-37   | 1/cycle    |

**Parameters**

|            |                                                                             |
|------------|-----------------------------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector unsigned short of radix 10,000 digits. |
|------------|-----------------------------------------------------------------------------|

**Returns**

128-bit vector unsigned char radix 100 pairs in the range 0-99.

**7.1.6.65 vec\_rdxcfzt100b()**

```
static vui8_t vec_rdxcfzt100b (
 vui8_t zone00,
 vui8_t zone16) [inline], [static]
```

Vector Decimal Convert Zoned Decimal digit pairs to to radix 100 binary integer bytes..

Convert 32 decimal digits from Zoned Format (one character per digit, in 2 vectors) to Binary coded century format. Century format is adjacent digit pairs converted to a binary integer in the range 0-99. Each century digit is stored in a byte. Input values should be valid decimal characters in the range 0-9.

**Note**

Zoned numbers are character strings with the high order digit on the left.

The high to low digit order is effectively big endian. This matches the digit order precedence of Decimal Add/↔ Subtract.

This can be used as the first stage operation in wider decimal to binary conversions. Basically the result of this stage are binary coded 100s "digits" that can be passed to vec\_bcdctb10ks().

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 15-17   | 1/cycle    |
| power9    | 17-20   | 1/cycle    |

**Parameters**

|               |                                                                                 |
|---------------|---------------------------------------------------------------------------------|
| <i>zone00</i> | a 128-bit vector char containing the high order 16 digits of a 32-digit number. |
| <i>zone16</i> | a 128-bit vector char containing the low order 16 digits of a 32-digit number.  |

**Returns**

128-bit vector unsigned char. For each byte, 2 adjacent zoned digits are converted to the equivalent binary representation in the range 0-99.

**7.1.6.66 vec\_rdxct100b()**

```
static vui8_t vec_rdxct100b (
 vui8_t vra) [inline], [static]
```

Vector Decimal Convert Binary Coded Decimal (BCD) digit pairs to radix 100 binary integer bytes.

Convert 32 decimal digits from BCD Format (one 4-bit nibble per digit) to Binary coded century format. Century format is adjacent digit pairs converted to a binary integer in the range 0-99. Each century digit is stored in a byte. Input values should be valid BCD nibbles in the range 0-9.

This can be used as the first stage operation in wider decimal to binary conversions. Basically the result of this stage are binary coded Century "digits" that can be passed to vec\_bcdctb10ks().

**Note**

the nibble high to low digit word is effectively big endian. This matches the digit order precedence of Decimal Add/Subtract.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 13-22   | 1/cycle    |
| power9    | 14-23   | 1/cycle    |

**Parameters**

|            |                                                                         |
|------------|-------------------------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector unsigned char of BCD nibble pairs. |
|------------|-------------------------------------------------------------------------|

**Returns**

128-bit vector unsigned char, For each byte, BCD digit pairs are converted to the equivalent binary representation in the range 0-99.



## 7.1.6.67 vec\_rdxct100mw()

```
static vui32_t vec_rdxct100mw (
 vui16_t vra) [inline], [static]
```

Vector Decimal Convert radix 10,000 digit halfword pairs to radix 100,000,000 binary integer words.

Convert from 10k digit Format (one 10k per halfword) to Binary coded 100m (one per word) format. 100m format is adjacent 10k digit pairs converted to a binary integer in the range 0-99999999. Input halfword values should be valid 10Ks in the range 0-9999. The result will be binary int values in the range 0-99999999.

This can be used as the intermediate stage operation in a wider BCD to binary conversions. Basically the result of this stage are binary coded 100,000,000s "digit" words which can be passed to vec\_bcdctb10es().

## Note

the 10k digit high to low order is effectively big endian. This matches the digit order precedence of Decimal Add/Subtract.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 9-18    | 1/cycle    |
| power9    | 9-18    | 1/cycle    |

## Parameters

|     |                                                                               |
|-----|-------------------------------------------------------------------------------|
| vra | a 128-bit vector treated as a vector unsigned short of radix 10k digit pairs. |
|-----|-------------------------------------------------------------------------------|

## Returns

128-bit vector unsigned int. For each halfword, adjacent 10k digit pairs are converted to the equivalent binary word integer representation in the range 0-99999999.

## 7.1.6.68 vec\_rdxct10E16d()

```
static vui64_t vec_rdxct10E16d (
 vui32_t vra) [inline], [static]
```

Vector Decimal Convert radix 100,000,000 digit word pairs to radix 10E16 binary integer doublewords.

Convert from 100m digit format (one 100m digit per word) to Binary coded 10p (one per doubleword) format. 10p format is adjacent 100m digit pairs converted to a binary long integer in the range 0-9999999999999999 (10 quadrillion). Input word values should be valid 100m in the range 0-99999999.

This can be used as the intermediate stage operation in a wider BCD to binary conversions. Basically the result of this stage are binary coded 10,000,000,000,000,000s "digits" doublewords which can be passed to vec\_bcdctb10e32().

## Note

the 100m digit high to low order is effectively big endian. This matches the digit order precedence of Decimal Add/Subtract.



## 7.1.6.70 vec\_rdxct10kh()

```
static vui16_t vec_rdxct10kh (
 vui8_t vra) [inline], [static]
```

Vector Decimal Convert radix 100 digit pairs to radix 10,000 binary integer halfwords.

Convert from 16 century digit Format (one century per byte) to 8 Binary coded 10k (one per halfword) format. 10K format is adjacent century digit pairs converted to a binary integer in the range 0-9999 . Input byte values should be valid 100s in the range 0-99. The result vector will be 8 short int values in the range 0-9999.

This can be used as the intermediate stage operation in wider BCD to binary conversions. Basically the result of this stage are binary coded 10,000s "digits" which can be passed to vec\_bcdctb100ms().

**Note**

the 100s digit high to low order is effectively big endian. This matches the digit order precedence of Decimal Add/Subtract.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 9-18    | 1/cycle    |
| power9    | 9-18    | 1/cycle    |

**Parameters**

|            |                                                                              |
|------------|------------------------------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector unsigned char of radix 100 digit pairs. |
|------------|------------------------------------------------------------------------------|

**Returns**

128-bit vector unsigned short. For each halfword, adjacent pairs of century digits pairs are converted to the equivalent binary halfword representation in the range 0-9999.

## 7.1.6.71 vec\_setbool\_bcdinv()

```
static vb128_t vec_setbool_bcdinv (
 vBCD_t vra) [inline], [static]
```

Vector Set Bool from Signed BCD Quadword if invalid.

If the quadword's sign nibble is 0xB, 0xD, 0xA, 0xC, 0xE, or 0xF and all 31 digit nibbles 0-9 then return a vector bool \_\_int128 that is all '0's. Otherwise return all '1's.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 15 - 39 | 1/cycle    |
| power9    | 3 - 15  | 1/cycle    |

**Parameters**

|            |                                                  |
|------------|--------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as signed BCD quadword. |
|------------|--------------------------------------------------|

**Returns**

a 128-bit vector bool of all '0's if the BCD digits and sign are valid. Otherwise all '1's.

**7.1.6.72 vec\_setbool\_bcdsq()**

```
static vb128_t vec_setbool_bcdsq (
 vBCD_t vra) [inline], [static]
```

Vector Set Bool from Signed BCD Quadword.

If the quadword's sign nibble is 0xB or 0xD then return a vector bool \_\_int128 that is all '1's. Otherwise if the sign nibble is 0xA, 0xC, 0xE, or 0xF then return all '0's.

/note For \_ARCH\_PWR7 and earlier (No vector BCD instructions),

this implementation only tests for a valid plus sign nibble. Otherwise the BCD value is assumed to be negative.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 17 - 26 | 2/cycle    |
| power9    | 5 - 14  | 2/cycle    |

**Parameters**

|            |                                                  |
|------------|--------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as signed BCD quadword. |
|------------|--------------------------------------------------|

**Returns**

a 128-bit vector bool of all '1's if the sign is negative. Otherwise all '0's.

## 7.1.6.73 vec\_signbit\_bcdsq()

```
static int vec_signbit_bcdsq (
 vBCD_t vra) [inline], [static]
```

Vector Sign bit from Signed BCD Quadword.

If the quadword's sign nibble is 0xB or 0xD then return a non-zero value. Otherwise if the sign nibble is 0xA, 0xC, 0xE, or 0xF then return all '0's.

/note For \_ARCH\_PWR7 and earlier (No vector BCD instructions), this implementation only tests for a valid minus sign nibble. Otherwise the BCD value is assumed to be positive.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 15 - 26 | 2/cycle    |
| power9    | 5 - 14  | 2/cycle    |

## Parameters

|            |                                                  |
|------------|--------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as signed BCD quadword. |
|------------|--------------------------------------------------|

## Returns

a none-zero value if the sign is negative. Otherwise return '0's.

## 7.1.6.74 vec\_unpack\_Decimal128()

```
static _Decimal128 vec_unpack_Decimal128 (
 vf64_t lval) [inline], [static]
```

Unpack a doubleword vector (vector double) into a FPR pair. (\_Decimal128).

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 1/cycle    |
| power9    | 3       | 1/cycle    |

## Parameters

|             |                                    |
|-------------|------------------------------------|
| <i>lval</i> | FPR pair containing a _Decimal128. |
|-------------|------------------------------------|

## Returns

FPR pair containing a \_Decimal128.



- Vector isdigit.*
- static `vui8_t vec_mrgahb` (`vui16_t vra`, `vui16_t vrb`)  
*Vector Merge Algebraic High Byte operation.*
- static `vui8_t vec_mrgalb` (`vui16_t vra`, `vui16_t vrb`)  
*Vector Merge Algebraic Low Byte operation.*
- static `vui8_t vec_mrgeb` (`vui8_t vra`, `vui8_t vrb`)  
*Vector Merge Even Bytes operation.*
- static `vui8_t vec_mrgob` (`vui8_t vra`, `vui8_t vrb`)  
*Vector Merge Odd Halfwords operation.*
- static `vi8_t vec_mulhsb` (`vi8_t vra`, `vi8_t vrb`)  
*Vector Multiply High Signed Bytes.*
- static `vui8_t vec_mulhub` (`vui8_t vra`, `vui8_t vrb`)  
*Vector Multiply High Unsigned Bytes.*
- static `vui8_t vec_mulubm` (`vui8_t vra`, `vui8_t vrb`)  
*Vector Multiply Unsigned Byte Modulo.*
- static `vui8_t vec_popcntb` (`vui8_t vra`)  
*Vector Population Count byte.*
- static `vui8_t vec_slbi` (`vui8_t vra`, `const unsigned int shb`)  
*Vector Shift left Byte Immediate.*
- static `vi8_t vec_srabi` (`vi8_t vra`, `const unsigned int shb`)  
*Vector Shift Right Algebraic Byte Immediate.*
- static `vui8_t vec_srbi` (`vui8_t vra`, `const unsigned int shb`)  
*Vector Shift Right Byte Immediate.*
- static `vui8_t vec_shift_leftdo` (`vui8_t vrw`, `vui8_t vrx`, `vui8_t vrb`)  
*Shift left double quadword by octet. Return a vector unsigned char that is the left most 16 chars after shifting left 0-15 octets (chars) of the 32 char double vector (vrw||vrx). The octet shift amount is from bits 121:124 of vrb.*
- static `vui8_t vec_toupper` (`vui8_t vec_str`)  
*Vector toupper.*
- static `vui8_t vec_tolower` (`vui8_t vec_str`)  
*Vector tolower.*
- static `vui8_t vec_vmrgb` (`vui8_t vra`, `vui8_t vrb`)  
*Vector Merge Even Bytes.*
- static `vui8_t vec_vmrgob` (`vui8_t vra`, `vui8_t vrb`)  
*Vector Merge Odd Byte.*

### 7.2.1 Detailed Description

Header package containing a collection of 128-bit SIMD operations over 8-bit integer (char) elements.

Most of these operations are implemented in a single VMX or VSX instruction on newer (POWER6/POWER7/POWER8/POWER9) processors. This header serves to fill in functional gaps for older (POWER7, POWER8) processors and provides in-line assembler implementations for older compilers that do not provide the build-ins.

Most vector char (8-bit integer) operations are already covered by the original VMX (AKA AltiVec) instructions. VMX intrinsic (compiler built-ins) operations are defined in `<altivec.h>` and described in the compiler documentation. PowerISA 2.07B (POWER8) added several useful byte operations (count leading zeros, population count) not included in the original VMX. PowerISA 3.0B (POWER9) adds several more (absolute difference, compare not equal, count trailing zeros, extend sign, extract/insert, and reverse bytes). Most of these intrinsic (compiler built-ins) operations are defined in `<altivec.h>` and described in the compiler documentation.

**Note**

The compiler disables associated `<altivec.h>` built-ins if the **mcpu** target does not enable the specific instruction. For example if you compile with **-mcpu=power7**, `vec_vclz` and `vec_vclzb` will not be defined. But `vec_clzb` is always defined in this header, will generate the minimum code, appropriate for the target, and produce correct results.

This header covers operations that are either:

- Implemented in later processors and useful to programmers if the same operations are available on slightly older processors. This is required even if the operation is defined in the OpenPOWER ABI or `<altivec.h>`, as the compiler disables the associated built-ins if the **mcpu** target does not enable the instruction.
- Defined in the OpenPOWER ABI but *not* yet defined in `<altivec.h>` provided by available compilers in common use. Examples include Count Leading Zeros and Population Count.
- Commonly used operations, not covered by the ABI or `<altivec.h>`, and require multiple instructions or are not obvious. Examples include the multiply high, ASCII character tests, and shift immediate operations.

## 7.2.2 Endian problems with byte operations

It would be useful to provide a vector multiply high byte (return the high order 8-bits of the 16-bit product) operation. This can be used for multiplicative inverse (effectively integer divide) operations. Neither integer multiply high nor divide are available as vector instructions. However the multiply high byte operation can be composed from the existing multiply even/odd byte operations followed by the vector merge even byte operation. Similarly a multiply low (modulo) byte operation can be composed from the existing multiply even/odd byte operations followed by the vector merge odd byte operation.

As a prerequisite we need to provide the merge even/odd byte operations. While PowerISA has added these operations for word and doubleword, instructions are not defined for byte and halfword. Fortunately vector merge operations are just a special case of vector permute. So the `vec_vmrgob()` and `vec_vmrgeb()` implementation can use `vec_perm` and appropriate selection vectors to provide these merge operations.

As described for other element sizes this is complicated by *little-endian* (LE) support as specified in the OpenPOWER ABI and as implemented in the compilers. Little-endian changes the effective vector element numbering and the location of even and odd elements. This means that the vector built-ins provided by `altivec.h` may not generate the instructions you would expect.

**See also**

[Endian problems with halfword operations](#)  
[General Endian Issues](#)

So this header defines endian independent byte operations `vec_vmrgeb()` and `vec_vmrgob()`. These operations are used in the implementation of the endian sensitive `vec_mrgeb()` and `vec_mrgob()`. These support the OpenPOWER ABI mandated merge even/odd semantic.

We also provide the merge algebraic high/low operations `vec_mrgahb()` and `vec_mrgalb()` to simplify extended precision arithmetic. These implementations use `vec_vmrgeb()` and `vec_vmrgob()` as extended precision byte order does not change with endian. These operations are used in turn to implement multiply byte high/low/modulo (`vec_mulhsb()`, `vec_mulhub()`, `vec_mulubm()`).

These operations provide a basis for using the multiplicative inverse as a alternative to integer divide.

**See also**

[Examples, Divide by integer constant](#)



### 7.2.3 Performance data.

The performance characteristics of the merge and multiply byte operations are very similar to the halfword implementations. (see [Performance data](#)).

#### 7.2.3.1 More information.

High level performance estimates are provided as an aid to function selection when evaluating algorithms. For background on how *Latency* and *Throughput* are derived see: [Performance data](#).

### 7.2.4 Function Documentation

#### 7.2.4.1 vec\_absdub()

```
static vui8_t vec_absdub (
 vui8_t vra,
 vui8_t vrb) [inline], [static]
```

Vector Absolute Difference Unsigned byte.

Compute the absolute difference for each byte. For each unsigned byte, subtract B[i] from A[i] and return the absolute value of the difference.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 1/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|                    |                             |
|--------------------|-----------------------------|
| <i>vra</i>         | vector of 16 unsigned bytes |
| <i>vr</i> <i>b</i> | vector of 16 unsigned bytes |

#### Returns

vector of the absolute difference.

#### 7.2.4.2 vec\_clzb()

```
static vui8_t vec_clzb (
 vui8_t vra) [inline], [static]
```

Count leading zeros for a vector unsigned char (byte) elements.

Count the number of leading '0' bits (0-7) within each byte element of a 128-bit vector.

For POWER8 (PowerISA 2.07B) or later use the Vector Count Leading Zeros byte instruction **vclzb**. Otherwise use sequence of pre 2.07 VMX instructions. SIMDized count leading zeros inspired by:

Warren, Henry S. Jr and *Hacker's Delight*, 2nd Edition, Addison Wesley, 2013. Chapter 5 Counting Bits, Figure 5-12.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|            |                                                               |
|------------|---------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as 16 x 8-bit integer (byte) elements. |
|------------|---------------------------------------------------------------|

#### Returns

128-bit vector with the Leading Zeros count for each byte element.

#### 7.2.4.3 vec\_isalnum()

```
static vui8_t vec_isalnum (
 vui8_t vec_str) [inline], [static]
```

Vector isalpha.

Return a vector boolean char with a true indicator for any character that is either Lower Case Alpha ASCII or Upper Case ASCII. False otherwise.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10-20   | 1/cycle    |
| power9    | 11-21   | 1/cycle    |

#### Parameters

|                |                               |
|----------------|-------------------------------|
| <i>vec_str</i> | vector of 16 ASCII characters |
|----------------|-------------------------------|

#### Returns

vector bool char of the isalpha operation applied to each character of *vec\_str*. For each byte 0xff indicates true (isalpha), 0x00 indicates false.

#### 7.2.4.4 vec\_isalpha()

```
static vui8_t vec_isalpha (
 vui8_t vec_str) [inline], [static]
```

Vector isalnum.

Return a vector boolean char with a true indicator for any character that is either Lower Case Alpha ASCII, Upper Case ASCII, or numeric ASCII. False otherwise.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 9-18    | 1/cycle    |
| power9    | 10-19   | 1/cycle    |

##### Parameters

|                |                               |
|----------------|-------------------------------|
| <i>vec_str</i> | vector of 16 ASCII characters |
|----------------|-------------------------------|

##### Returns

vector bool char of the isalnum operation applied to each character of *vec\_str*. For each byte 0xff indicates true (isalpha), 0x00 indicates false.

#### 7.2.4.5 vec\_isdigit()

```
static vui8_t vec_isdigit (
 vui8_t vec_str) [inline], [static]
```

Vector isdigit.

Return a vector boolean char with a true indicator for any character that is ASCII decimal digit. False otherwise.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-13    | 1/cycle    |
| power9    | 5-14    | 1/cycle    |

##### Parameters

|                |                               |
|----------------|-------------------------------|
| <i>vec_str</i> | vector of 16 ASCII characters |
|----------------|-------------------------------|

**Returns**

vector bool char of the isdigit operation applied to each character of vec\_str. For each byte 0xff indicates true (isdigit), 0x00 indicates false.

**7.2.4.6 vec\_mrgahb()**

```
static vui8_t vec_mrgahb (
 vui16_t vra,
 vui16_t vrb) [inline], [static]
```

Vector Merge Algebraic High Byte operation.

Merge only the high byte from 16 x Algebraic halfwords across vectors vra and vrb. This is effectively the Vector Merge Even Byte operation that is not modified for Endian.

For example merge the high 8-bits from each of 16 x 16-bit products as generated by vec\_muleub/vec\_muloub. This result is effectively a vector multiply high unsigned byte.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-13    | 2/cycle    |
| power9    | 3-14    | 2/cycle    |

**Parameters**

|            |                                |
|------------|--------------------------------|
| <i>vra</i> | 128-bit vector unsigned short. |
| <i>vrb</i> | 128-bit vector unsigned short. |

**Returns**

A vector merge from only the high bytes of the 16 x Algebraic halfwords across vra and vrb.

**7.2.4.7 vec\_mrgalb()**

```
static vui8_t vec_mrgalb (
 vui16_t vra,
 vui16_t vrb) [inline], [static]
```

Vector Merge Algebraic Low Byte operation.

Merge only the low bytes from 16 x Algebraic halfwords across vectors vra and vrb. This is effectively the Vector Merge Odd Bytes operation that is not modified for Endian.

For example merge the low 8-bits from each of 16 x 16-bit products as generated by vec\_muleub/vec\_muloub. This result is effectively a vector multiply low unsigned byte.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-13    | 2/cycle    |
| power9    | 3-14    | 2/cycle    |

## Parameters

|            |                              |
|------------|------------------------------|
| <i>vra</i> | 128-bit vector unsigned int. |
| <i>vrh</i> | 128-bit vector unsigned int. |

## Returns

A vector merge from only the high halfwords of the 8 x Algebraic words across *vra* and *vrh*.

## 7.2.4.8 vec\_mrgeb()

```
static vui8_t vec_mrgeb (
 vui8_t vra,
 vui8_t vrh) [inline], [static]
```

Vector Merge Even Bytes operation.

Merge the even byte elements from the concatenation of 2 x vectors (*vra* and *vrh*).

## Note

The element numbering changes between Big and Little Endian. So the compiler and this implementation adjusts the generated code to reflect this.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-13    | 2/cycle    |
| power9    | 3-14    | 2/cycle    |

## Parameters

|            |                               |
|------------|-------------------------------|
| <i>vra</i> | 128-bit vector unsigned char. |
| <i>vrh</i> | 128-bit vector unsigned char. |

## Returns

A vector merge from only the even bytes of *vra* and *vrh*.

#### 7.2.4.9 vec\_mrgob()

```
static vui8_t vec_mrgob (
 vui8_t vra,
 vui8_t vrb) [inline], [static]
```

Vector Merge Odd Halfwords operation.

Merge the odd halfword elements from the concatenation of 2 x vectors (vra and vrb).

##### Note

The element numbering changes between Big and Little Endian. So the compiler and this implementation adjusts the generated code to reflect this.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-13    | 2/cycle    |
| power9    | 3-14    | 2/cycle    |

##### Parameters

|            |                               |
|------------|-------------------------------|
| <i>vra</i> | 128-bit vector unsigned char. |
| <i>vrb</i> | 128-bit vector unsigned char. |

##### Returns

A vector merge from only the odd bytes of vra and vrb.

#### 7.2.4.10 vec\_mulhsb()

```
static vi8_t vec_mulhsb (
 vi8_t vra,
 vi8_t vrb) [inline], [static]
```

Vector Multiply High Signed Bytes.

Multiple the corresponding byte elements of two vector signed char values and return the high order 8-bits, for each 16-bit product element.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 9-13    | 1/cycle    |
| power9    | 10-14   | 1/cycle    |

## Parameters

|            |                             |
|------------|-----------------------------|
| <i>vra</i> | 128-bit vector signed char. |
| <i>vrb</i> | 128-bit vector signed char. |

## Returns

vector of the high order 8-bits of the product of the byte elements from *vra* and *vrb*.

## 7.2.4.11 vec\_mulhub()

```
static vui8_t vec_mulhub (
 vui8_t vra,
 vui8_t vrb) [inline], [static]
```

Vector Multiply High Unsigned Bytes.

Multiple the corresponding byte elements of two vector unsigned char values and return the high order 8-bits, for each 16-bit product element.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 9-13    | 1/cycle    |
| power9    | 10-14   | 1/cycle    |

## Parameters

|            |                               |
|------------|-------------------------------|
| <i>vra</i> | 128-bit vector unsigned char. |
| <i>vrb</i> | 128-bit vector unsigned char. |

## Returns

vector of the high order 8-bits of the product of the byte elements from *vra* and *vrb*.

## 7.2.4.12 vec\_mulubm()

```
static vui8_t vec_mulubm (
 vui8_t vra,
 vui8_t vrb) [inline], [static]
```

Vector Multiply Unsigned Byte Modulo.

Multiple the corresponding byte elements of two vector unsigned char values and return the low order 8-bits of the 16-bit product for each element.

**Note**

`vec_mulubm` can be used for unsigned or signed char integers. It is the vector equivalent of Multiply Low Byte.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 9-13    | 1/cycle    |
| power9    | 10-14   | 1/cycle    |

**Parameters**

|                    |                               |
|--------------------|-------------------------------|
| <i>vra</i>         | 128-bit vector unsigned char. |
| <i>vr</i> <i>b</i> | 128-bit vector unsigned char. |

**Returns**

vector of the low order 8-bits of the unsigned product of the byte elements from *vra* and *vr**b*.

**7.2.4.13 `vec_popcntb()`**

```
static vui8_t vec_popcntb (
 vui8_t vra) [inline], [static]
```

Vector Population Count byte.

Count the number of '1' bits (0-8) within each byte element of a 128-bit vector.

For POWER8 (PowerISA 2.07B) or later use the Vector Population Count Byte instruction. Otherwise use simple Vector (VMX) instructions to count bits in bytes in parallel. SIMDized population count inspired by:

Warren, Henry S. Jr and *Hacker's Delight*, 2nd Edition, Addison Wesley, 2013. Chapter 5 Counting Bits, Figure 5-2.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|            |                                                                |
|------------|----------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as 16 x 8-bit integers (byte) elements. |
|------------|----------------------------------------------------------------|

**Returns**

128-bit vector with the population count for each byte element.



## 7.2.4.14 vec\_shift\_leftdo()

```
static vui8_t vec_shift_leftdo (
 vui8_t vrw,
 vui8_t vrx,
 vui8_t vrb) [inline], [static]
```

Shift left double quadword by octet. Return a vector unsigned char that is the left most 16 chars after shifting left 0-15 octets (chars) of the 32 char double vector (vrw||vrx). The octet shift amount is from bits 121:124 of vrb.

This sequence can be used to align a unaligned 16 char substring based on the result of a vector count leading zero of of the compare boolean.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-8     | 1/cycle    |
| power9    | 8-9     | 1/cycle    |

## Parameters

|            |                                              |
|------------|----------------------------------------------|
| <i>vrw</i> | upper 16-bytes of the 32-byte double vector. |
| <i>vrx</i> | lower 16-bytes of the 32-byte double vector. |
| <i>vrb</i> | Shift amount in bits 121:124.                |

## Returns

upper 16-bytes of left shifted double vector.

## 7.2.4.15 vec\_slbi()

```
static vui8_t vec_slbi (
 vui8_t vra,
 const unsigned int shb) [inline], [static]
```

Vector Shift left Byte Immediate.

Shift left each byte element [0-15], 0-7 bits, as specified by an immediate value. The shift amount is a const unsigned int in the range 0-7. A shift count of 0 returns the original value of vra. Shift counts greater than 7 bits return zero.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-11    | 2/cycle    |
| power9    | 5-11    | 2/cycle    |

## Parameters

|            |                                                     |
|------------|-----------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector unsigned char. |
| <i>shb</i> | Shift amount in the range 0-7.                      |

## Returns

128-bit vector unsigned char, shifted left shb bits.

7.2.4.16 `vec_srai()`

```
static vi8_t vec_srai (
 vi8_t vra,
 const unsigned int shb) [inline], [static]
```

Vector Shift Right Algebraic Byte Immediate.

Shift right each byte element [0-15], 0-7 bits, as specified by an immediate value. The shift amount is a const unsigned int in the range 0-7. A shift count of 0 returns the original value of vra. Shift counts greater than 7 bits return the sign bit propagated to each bit of each element.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-11    | 2/cycle    |
| power9    | 5-11    | 2/cycle    |

## Parameters

|            |                                                   |
|------------|---------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector signed char. |
| <i>shb</i> | Shift amount in the range 0-7.                    |

## Returns

128-bit vector signed char, shifted right shb bits.

7.2.4.17 `vec_srbi()`

```
static vui8_t vec_srbi (
 vui8_t vra,
 const unsigned int shb) [inline], [static]
```

Vector Shift Right Byte Immediate.

Shift right each byte element [0-15], 0-7 bits, as specified by an immediate value. The shift amount is a const unsigned int in the range 0-7. A shift count of 0 returns the original value of vra. Shift counts greater than 7 bits return zero.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-11    | 2/cycle    |
| power9    | 5-11    | 2/cycle    |

**Parameters**

|            |                                                     |
|------------|-----------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector unsigned char. |
| <i>shb</i> | Shift amount in the range 0-7.                      |

**Returns**

128-bit vector unsigned char, shifted right shb bits.

**7.2.4.18 vec\_tolower()**

```
static vui8_t vec_tolower (
 vui8_t vec_str) [inline], [static]
```

Vector tolower.

Convert any Upper Case Alpha ASCII characters within a vector unsigned char into the equivalent Lower Case character. Return the result as a vector unsigned char.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8-17    | 1/cycle    |
| power9    | 9-18    | 1/cycle    |

**Parameters**

|                |                               |
|----------------|-------------------------------|
| <i>vec_str</i> | vector of 16 ASCII characters |
|----------------|-------------------------------|

**Returns**

vector char converted to lower case.

**7.2.4.19 vec\_toupper()**

```
static vui8_t vec_toupper (
 vui8_t vec_str) [inline], [static]
```

Vector toupper.

Convert any Lower Case Alpha ASCII characters within a vector unsigned char into the equivalent Upper Case character. Return the result as a vector unsigned char.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8-17    | 1/cycle    |
| power9    | 9-18    | 1/cycle    |

#### Parameters

|                |                               |
|----------------|-------------------------------|
| <i>vec_str</i> | vector of 16 ASCII characters |
|----------------|-------------------------------|

#### Returns

vector char converted to upper case.

#### 7.2.4.20 vec\_vmrgeb()

```
static vui8_t vec_vmrgeb (
 vui8_t vra,
 vui8_t vrb) [inline], [static]
```

Vector Merge Even Bytes.

Merge the even byte elements from the concatenation of 2 x vectors (vra and vrb).

#### Note

This function implements the operation of a Vector Merge Even Bytes instruction, if the PowerISA included such an instruction. This implementation is NOT Endian sensitive and the function is stable across BE/LE implementations. Using Big Endian element numbering:

- res[0] = vra[0];
- res[1] = vrb[0];
- res[2] = vra[2];
- res[3] = vrb[2];
- res[4] = vra[4];
- res[5] = vrb[4];
- res[6] = vra[6];
- res[7] = vrb[6];
- res[8] = vra[8];
- res[9] = vrb[8];
- res[10] = vra[10];
- res[11] = vrb[10];
- res[12] = vra[12];
- res[13] = vrb[12];
- res[14] = vra[14];
- res[15] = vrb[14];

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-13    | 2/cycle    |
| power9    | 3-14    | 2/cycle    |

#### Parameters

|            |                               |
|------------|-------------------------------|
| <i>vra</i> | 128-bit vector unsigned char. |
| <i>vrh</i> | 128-bit vector unsigned char. |

#### Returns

A vector merge from only the even bytes of *vra* and *vrh*.

#### 7.2.4.21 vec\_vmrgob()

```
static vui8_t vec_vmrgob (
 vui8_t vra,
 vui8_t vrh) [inline], [static]
```

Vector Merge Odd Byte.

Merge the odd byte elements from the concatenation of 2 x vectors (*vra* and *vrh*).

#### Note

This function implements the operation of a Vector Merge Odd Bytes instruction, if the PowerISA included such an instruction. This implementation is NOT Endian sensitive and the function is stable across BE/LE implementations. Using Big Endian element numbering:

- res[0] = vra[1];
- res[1] = vrh[1];
- res[2] = vra[3];
- res[3] = vrh[3];
- res[4] = vra[5];
- res[5] = vrh[5];
- res[6] = vra[7];
- res[7] = vrh[7];
- res[8] = vra[9];
- res[9] = vrh[9];
- res[10] = vra[11];
- res[11] = vrh[11];
- res[12] = vra[13];
- res[13] = vrh[13];
- res[14] = vra[15];
- res[15] = vrh[15];

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-13    | 2/cycle    |
| power9    | 3-14    | 2/cycle    |

#### Parameters

|            |                               |
|------------|-------------------------------|
| <i>vra</i> | 128-bit vector unsigned char. |
| <i>vrh</i> | 128-bit vector unsigned char. |

#### Returns

A vector merge from only the odd bytes of *vra* and *vrh*.

## 7.3 src/pveclib/vec\_common\_ppc.h File Reference

Common definitions and typedef used by the collection of Power Vector Library (pveclib) headers.

```
#include <stdint.h>
#include <altivec.h>
```

### Classes

- union [\\_\\_VEC\\_U\\_128](#)  
*Union used to transfer 128-bit data between vector and non-vector types.*

### Macros

- #define [CONST\\_VINT64\\_DW](#)(\_\_dw0, \_\_dw1) {\_\_dw1, \_\_dw0}  
*Arrange elements of dword initializer in high->low order.*
- #define [CONST\\_VINT128\\_DW](#)(\_\_dw0, \_\_dw1) ([vui64\\_t](#)){\_\_dw1, \_\_dw0}  
*Initializer for 128-bits vector, as two unsigned long long elements in high->low order. May require an explicit cast.*
- #define [CONST\\_VINT128\\_DW128](#)(\_\_dw0, \_\_dw1) ([vui128\\_t](#))([vui64\\_t](#)){\_\_dw1, \_\_dw0})  
*A vector unsigned \_\_int128 initializer, as two unsigned long long elements in high->low order.*
- #define [CONST\\_VINT128\\_W](#)(\_\_w0, \_\_w1, \_\_w2, \_\_w3) ([vui32\\_t](#)){\_\_w3, \_\_w2, \_\_w1, \_\_w0}  
*Arrange word elements of a unsigned int initializer in high->low order. May require an explicit cast.*
- #define [CONST\\_VINT32\\_W](#)(\_\_w0, \_\_w1, \_\_w2, \_\_w3) {\_\_w3, \_\_w2, \_\_w1, \_\_w0}  
*Arrange elements of word initializer in high->low order.*
- #define [CONST\\_VINT128\\_H](#)(\_\_hw0, \_\_hw1, \_\_hw2, \_\_hw3, \_\_hw4, \_\_hw5, \_\_hw6, \_\_hw7) ([vui16\\_t](#)){\_\_hw7, \_\_hw6, \_\_hw5, \_\_hw4, \_\_hw3, \_\_hw2, \_\_hw1, \_\_hw0}  
*Arrange halfword elements of a unsigned int initializer in high->low order. May require an explicit cast.*
- #define [CONST\\_VINT16\\_H](#)(\_\_hw0, \_\_hw1, \_\_hw2, \_\_hw3, \_\_hw4, \_\_hw5, \_\_hw6, \_\_hw7) {\_\_hw7, \_\_hw6, \_\_hw5, \_\_hw4, \_\_hw3, \_\_hw2, \_\_hw1, \_\_hw0}  
*Arrange elements of halfword initializer in high->low order.*

- #define `CONST_VINT128_B`(\_b0, \_b1, \_b2, \_b3, \_b4, \_b5, \_b6, \_b7, \_b8, \_b9, \_b10, \_b11, \_b12, \_b13, \_b14, \_b15) (`vui8_t`){\_b15, \_b14, \_b13, \_b12, \_b11, \_b10, \_b9, \_b8, \_b7, \_b6, \_b5, \_b4, \_b3, \_b2, \_b1, \_b0}  
*Arrange byte elements of a unsigned int initializer in high->low order. May require an explicit cast.*
- #define `CONST_VINT8_B`(\_b0, \_b1, \_b2, \_b3, \_b4, \_b5, \_b6, \_b7, \_b8, \_b9, \_b10, \_b11, \_b12, \_b13, \_b14, \_b15) {\_b15, \_b14, \_b13, \_b12, \_b11, \_b10, \_b9, \_b8, \_b7, \_b6, \_b5, \_b4, \_b3, \_b2, \_b1, \_b0}  
*Arrange elements of byte initializer in high->low order.*
- #define `VEC_DW_H` 1  
*Element index for high order dword.*
- #define `VEC_DW_L` 0  
*Element index for low order dword.*
- #define `VEC_W_H` 3  
*Element index for highest order word.*
- #define `VEC_W_L` 0  
*Element index for lowest order word.*
- #define `VEC_WE_0` 3  
*Element index for vector splat word 0.*
- #define `VEC_WE_1` 2  
*Element index for vector splat word 1.*
- #define `VEC_WE_2` 1  
*Element index for vector splat word 2.*
- #define `VEC_WE_3` 0  
*Element index for vector splat word 3.*
- #define `VEC_HW_H` 7  
*Element index for highest order hword.*
- #define `VEC_HW_L_DWH` 4  
*Element index for lowest order hword of the high dword.*
- #define `VEC_HW_L` 0  
*Element index for lowest order hword.*
- #define `VEC_BYTE_L` 0  
*Element index for lowest order byte.*
- #define `VEC_BYTE_L_DWH` 8  
*Element index for lowest order byte of the high dword.*
- #define `VEC_BYTE_L_DWL` 0  
*Element index for lowest order byte of the low dword.*
- #define `VEC_BYTE_H` 15  
*Element index for highest order byte.*
- #define `VEC_BYTE_HHW` 14  
*Element index for second lowest order byte.*

## Typedefs

- typedef \_\_vector unsigned char `vui8_t`  
*vector of 8-bit unsigned char elements.*
- typedef \_\_vector unsigned short `vui16_t`  
*vector of 16-bit unsigned short elements.*
- typedef \_\_vector unsigned int `vui32_t`

- *vector of 32-bit unsigned int elements.*
- typedef \_\_vector unsigned long long [vui64\\_t](#)  
*vector of 64-bit unsigned long long elements.*
- typedef \_\_vector signed char [vi8\\_t](#)  
*vector of 8-bit signed char elements.*
- typedef \_\_vector short [vi16\\_t](#)  
*vector of 16-bit signed short elements.*
- typedef \_\_vector int [vi32\\_t](#)  
*vector of 32-bit signed int elements.*
- typedef \_\_vector long long [vi64\\_t](#)  
*vector of 64-bit signed long long elements.*
- typedef \_\_vector float [vf32\\_t](#)  
*vector of 32-bit float elements.*
- typedef \_\_vector double [vf64\\_t](#)  
*vector of 64-bit double elements.*
- typedef \_\_vector \_\_bool char [vb8\\_t](#)  
*vector of 8-bit bool char elements.*
- typedef \_\_vector \_\_bool short [vb16\\_t](#)  
*vector of 16-bit bool short elements.*
- typedef \_\_vector \_\_bool int [vb32\\_t](#)  
*vector of 32-bit bool int elements.*
- typedef \_\_vector \_\_bool long long [vb64\\_t](#)  
*vector of 64-bit bool long long elements.*
- typedef \_\_vector \_\_int128 [vi128\\_t](#)  
*vector of one 128-bit signed \_\_int128 element.*
- typedef \_\_vector unsigned \_\_int128 [vui128\\_t](#)  
*vector of one 128-bit unsigned \_\_int128 element.*
- typedef \_\_vector \_\_bool \_\_int128 [vb128\\_t](#)  
*vector of one 128-bit bool \_\_int128 element.*

## Variables

- const [vui128\\_t](#) [vtipowof10](#) []  
*table powers of 10 [0-38] in vector \_\_int128 format.*
- const [vui128\\_t](#) [vtifrexpof10](#) []  
*table used to verify 128-bit frexp operations for powers of 10.*
- const \_Decimal128 [decpowof2](#) []  
*table powers of 2 [0-1077] in \_Decimal128 format.*

### 7.3.1 Detailed Description

Common definitions and typedef used by the collection of Power Vector Library (pveclib) headers.

This includes:

- Typedefs as short names of common vector types.
- Union used to transfer 128-bit data between vector and non-vector types.
- Helper macros that make declaring constants and accessing elements a little easier.



### 7.3.2 Consistent vector type naming

Type names should be short, concise, and consistent. The ABI defines the vector types as extensions of the existing C Language types. So while *vector unsigned long long* is consistent it is neither short or concise. Pveclib uses the following naming convention for typedefs used in its operations, function prototypes, and internal variables.

- Starting with the **v** prefix for vector.
- followed by one of the element classes:
  - **i** for signed integer.
  - **ui** for unsigned integer.
  - **f** for floating-point.
  - **b** for bool.
- followed by the element size in bits:
  - 8, 16, 32, 64, 128
- Ending with the **\_t** suffix signifying a typedef.

For example: `vi32_t` is a vector int, `vui32_t` is a vector unsigned int, `vb32_t` is a vector bool int, and `vf32_t` is vector float.

### 7.3.3 Transferring 128-bit types

The OpenPOWER ABI and the GCC compiler define a number of 128-bit scalar types that are not vector types:

- `__int128` (a general purpose register pair)
- `_Decimal128` (a floating-point even/odd register pair)
- `__ibm128` (a floating-point register pair)
- `__float128` (a vector register)

These are not cast nor assignment compatible with any vector type. However it may be useful to transfer to/from vector types for conversion or manipulation within an operation. For example:

- Conversions between `__float128` and `__int128`, `__ibm128`, and `_Decimal128` types.
- Conversions between vector BCD integers and `__int128` and `_Decimal128` types.
- Conversions between vector `__int128` and `__float128`, `__ibm128`, and `_Decimal128` types.

Here we use the `__VEC_U_128` union to affect the transfer between the various types. We assume (fervently hope) that the compiler will recognize and optimize these as registers to registers transfers using the hardware instructions provided.

The vector to/from `__float128` transfer should be the simplest as `__float128` operations are defined over the vector register set. However `__float128` types are defined in the PowerISA and OpenPOWER ABI, as scalars that just happens to use vector registers for parameter passing and operations. This distinction between scalars and vector prevents a direct cast between types. The `__VEC_U_128` union is the simplest work around but in most cases no code should be generated for this transfer. For example: `vec_xfer_bin128_2_vui128t()` and `vec_xfer_vui128t_2_bin128()`.

Any vector to/from `__int128` transfer requires a transfer between vector and general purpose registers. POWER8 (PowerISA 2.07B) added Move to/from Vector Scalar Register (`mfvsr`, `mtvsr`) instructions. Again the `__VEC_U_128` union is used to effect the transfer and the compiler should leverage the move instructions in the generated code.

Any vector to/from `__ibm128` or `_Decimal128` requires a transfer between a pair of FPRs and a Vector Scalar Register (VSR). Technically this is transfer between the upper doubleword of two VSRs in the lower bank (VSR0-31) and another VSR. POWER7 (PowerISA 2.06B) provides the Permute Doubleword Immediate (`xxpermdi`) instruction. Again the `__VEC_U_128` union is used to effect the transfer and the compiler should leverage the Permute Doubleword Immediate instructions in the generate code. For example: `vec_BCD2DFP()` and `vec_DFP2BCD()`.

### 7.3.4 Endian and vector constants

Vector constants are often needed for: masking operations, range checks, permute selection, and radix conversion. Also compiler support for large integer and floating-point constants may be limited by the compiler. For example the GCC compilers support the (vector) `__int128` type but do not directly support `__int128` (39 digit) decimal constants. Another example is `__float128` where the type and Q suffix constants are recent additions. In both cases we need to construct: large numeric constants, special values (infinity and NaN), masks for manipulating the sign bit and exponent bits. Often these values will be constructed from vectors of word or doubleword constants.

#### Note

GCC does not support expressing an integer constant of type `__int128` for targets where long long integer is less than 128 bits wide. This applies to the PowerPC target as the long long type is reserved for 64-bit integers. This was verified in GCC 8.2,

GCC `__float128` support for the PowerPC target began with GCC 6. In GCC 6 `__float128` support is off by default and has to be explicitly enabled via the `-mfloat128` option. Starting with GCC 7, `__float128` is enabled by default with VSX support.

Defining large constants for vectors is complicated by *little-endian* (LE) support as specified in the OpenPOWER ABI and as implemented in the compilers. Little-endian changes the effective vector element numbering and the order of constant elements in initializers. But the `__int128` numerical order of magnitude or floating-point format does not change in registers. The high order bits are on the left and the low order bits are on the right.

So for example:

```
const vui32_t signmask = { 0x80000000, 0, 0, 0 };
const vui32_t expmask = { 0x7fff0000, 0, 0, 0 };
```

are correct sign and exponent masks for `__float128` in big endian (BE) but would be incorrect for little endian (LE). To get correct results for both endians, one could code something like this:

```

#if __BYTE_ORDER__ == __ORDER_LITTLE_ENDIAN__
 const vui32_t signmask = { 0, 0, 0, 0x80000000 };
 const vui32_t expmask = { 0, 0, 0, 0x7fff0000 };
#else
 const vui32_t signmask = { 0x80000000, 0, 0, 0 };
 const vui32_t expmask = { 0x7fff0000, 0, 0, 0 };
#endif

```

But this gets tedious after the first dozen times. Also this can be confusing because it does not appear to match the floating-point format diagrams in the PowerISA. The sign-bit and the exponent are always on the left.

So this header provides endian sensitive macros that maintain consistent "magnitude" order. For example:

```

const vui32_t signmask = CONST_VINT128_W (0x80000000, 0, 0, 0);
const vui32_t expmask = CONST_VINT128_W (0x7fff0000, 0, 0, 0);

```

This is always correct in either endian.

Another example; the multiplicative inverse for `__int128 10**32` is 211857340822306639531405861550393824741. The GCC compiler will not accept this constant in a vector `__int128` initializer. The next best thing would be

```

// The multiplicative inverse for 1 / 10**32 is
// 211857340822306639531405861550393824741
// or 0x9f623d5a8a732974cfbc31db4b0295e5
const vui128_t mulinv_10to32 =
 (vui128_t) CONST_VINT128_DW128 (0x9f623d5a8a732974UL,
 0xcfb31db4b0295e5UL);

```

Here we use the `CONST_VINT128_DW128` macro to maintain magnitude order across endian. Again the high order bits are on the left and the low order bits are on the right.

See also

[Endian problems with word operations](#)  
[General Endian Issues](#)

## 7.4 src/pveclib/vec\_f128\_ppc.h File Reference

Header package containing a collection of 128-bit SIMD operations over Quad-Precision floating point elements.

```

#include <pveclib/vec_common_ppc.h>
#include <pveclib/vec_int128_ppc.h>
#include <pveclib/vec_f64_ppc.h>

```

### Classes

- union [\\_\\_VF\\_128](#)

*Union used to transfer 128-bit data between vector and `__float128` types.*

## Typedefs

- typedef [vui128\\_t](#) [vf128\\_t](#)  
vector of 128-bit binary128 element. Same as `__float128` for PPC.
- typedef [vf128\\_t](#) [\\_\\_Float128](#)  
Define `__Float128` if not defined by the compiler. Same as `__float128` for PPC.
- typedef [vf128\\_t](#) [\\_\\_binary128](#)  
Define `__binary128` if not defined by the compiler. Same as `__float128` for PPC.
- typedef [vf128\\_t](#) [\\_\\_float128](#)  
Define `__float128` if not defined by the compiler. Same as `__float128` for PPC.
- typedef long double [\\_\\_IBM128](#)  
Define `__IBM128` if not defined by the compiler. Same as old long double for PPC.

## Functions

- static [vui8\\_t](#) [vec\\_xfer\\_bin128\\_2\\_vui8t](#) ([\\_\\_binary128](#) f128)  
Transfer function from a `__binary128` scalar to a vector char.
- static [vui16\\_t](#) [vec\\_xfer\\_bin128\\_2\\_vui16t](#) ([\\_\\_binary128](#) f128)  
Transfer function from a `__binary128` scalar to a vector short int.
- static [vui32\\_t](#) [vec\\_xfer\\_bin128\\_2\\_vui32t](#) ([\\_\\_binary128](#) f128)  
Transfer function from a `__binary128` scalar to a vector int.
- static [vui64\\_t](#) [vec\\_xfer\\_bin128\\_2\\_vui64t](#) ([\\_\\_binary128](#) f128)  
Transfer function from a `__binary128` scalar to a vector long long int.
- static [vui128\\_t](#) [vec\\_xfer\\_bin128\\_2\\_vui128t](#) ([\\_\\_binary128](#) f128)  
Transfer function from a `__binary128` scalar to a vector `__int128`.
- static [\\_\\_binary128](#) [vec\\_xfer\\_vui8t\\_2\\_bin128](#) ([vui8\\_t](#) f128)  
Transfer a vector unsigned char to `__binary128` scalar.
- static [\\_\\_binary128](#) [vec\\_xfer\\_vui16t\\_2\\_bin128](#) ([vui16\\_t](#) f128)  
Transfer a vector unsigned short to `__binary128` scalar.
- static [\\_\\_binary128](#) [vec\\_xfer\\_vui32t\\_2\\_bin128](#) ([vui32\\_t](#) f128)  
Transfer a vector unsigned int to `__binary128` scalar.
- static [\\_\\_binary128](#) [vec\\_xfer\\_vui64t\\_2\\_bin128](#) ([vui64\\_t](#) f128)  
Transfer a vector unsigned long long to `__binary128` scalar.
- static [\\_\\_binary128](#) [vec\\_xfer\\_vui128t\\_2\\_bin128](#) ([vui128\\_t](#) f128)  
Transfer a vector unsigned `__int128` to `__binary128` scalar.
- static [\\_\\_binary128](#) [vec\\_absf128](#) ([\\_\\_binary128](#) f128)  
Clear the sign bit of `__float128` input and return the resulting positive `__float128` value.
- static int [vec\\_all\\_isfinitef128](#) ([\\_\\_binary128](#) f128)  
Return true if the `__float128` value is Finite (Not NaN nor Inf).
- static int [vec\\_all\\_isinff128](#) ([\\_\\_binary128](#) f128)  
Return true if the `__float128` value is infinity.
- static int [vec\\_all\\_isnanf128](#) ([\\_\\_binary128](#) f128)  
Return true if the `__float128` value is Not a Number (NaN).
- static int [vec\\_all\\_isnormalf128](#) ([\\_\\_binary128](#) f128)  
Return true if the `__float128` value is normal (Not NaN, Inf, denormal, or zero).
- static int [vec\\_all\\_issubnormalf128](#) ([\\_\\_binary128](#) f128)  
Return true if the `__float128` value is subnormal (denormal).

- static int `vec_all_iszerof128` (`__binary128` f128)  
*Return true if the `__float128` value is  $\pm 0.0$ .*
- static `__binary128` `vec_copysignf128` (`__binary128` f128x, `__binary128` f128y)  
*Copy the sign bit from f128y and merge with the magnitude from f128x. The merged result is returned as a `__float128` value.*
- static `__binary128` `vec_const_huge_valf128` ()  
*return a positive infinity.*
- static `__binary128` `vec_const_inff128` ()  
*return a positive infinity.*
- static `__binary128` `vec_const_nanf128` ()  
*return a quiet NaN.*
- static `__binary128` `vec_const_nansf128` ()  
*return a signaling NaN.*
- static `vb128_t` `vec_isfinitef128` (`__binary128` f128)  
*Return 128-bit vector boolean true if the `__float128` value is Finite (Not NaN nor Inf).*
- static int `vec_isinf_signf128` (`__binary128` f128)  
*Return true (nonzero) value if the `__float128` value is infinity. For infinity indicate the sign as +1 for positive infinity and -1 for negative infinity.*
- static `vb128_t` `vec_isinff128` (`__binary128` f128)  
*Return a 128-bit vector boolean true if the `__float128` value is infinity.*
- static `vb128_t` `vec_isnanf128` (`__binary128` f128)  
*Return 128-bit vector boolean true if the `__float128` value is Not a Number (NaN).*
- static `vb128_t` `vec_isnormalf128` (`__binary128` f128)  
*Return 128-bit vector boolean true if the `__float128` value is normal (Not NaN, Inf, denormal, or zero).*
- static `vb128_t` `vec_issubnormalf128` (`__binary128` f128)  
*Return 128-bit vector boolean true value, if the `__float128` value is subnormal (denormal).*
- static `vb128_t` `vec_iszerof128` (`__binary128` f128)  
*Return 128-bit vector boolean true value, if the value that is  $\pm 0.0$ .*
- static `vb128_t` `vec_setb_qp` (`__binary128` f128)  
*Vector Set Bool from Quadword Floating-point.*
- static int `vec_signbitf128` (`__binary128` f128)  
*Return int boolean true if the `__float128` value is negative (sign bit is '1').*

### 7.4.1 Detailed Description

Header package containing a collection of 128-bit SIMD operations over Quad-Precision floating point elements.

PowerISA 3.0 added Quad-Precision floating point type and operations to the Vector-Scalar Extension (VSX) facility. The first hardware implementation is available in POWER9.

While all Quad-Precision operations are on 128-bit vector registers, they are defined as scalars in the PowerISA. The OpenPOWER ABI also treats the `__float128` type as scalar that just happens to use vector registers for parameter passing and operations. As such no operations using `__float128` (`_Float128`, or `__ieee128`) as parameter or return value are defined as vector built-ins in the ABI or `<altivec.h>`.

## Note

GCC 8.2 does document some built-ins, using the *scalar* prefix (`scalar_extract_exp`, `scalar_extract_sig`, `scalar_←test_data_class`), that do accept the `__ieee128` type. This work seems to be incomplete as `scalar_exp_cmp_*` for the `__ieee128` type are not present. GCC 7.3 defines vector and scalar forms of the `extract/insert_exp` for float and double but not for `__ieee128`. These built-ins are not defined in GCC 6.4. See [compiler documentation](#). These are useful operations and can be implement in a few vector logical instruction for earlier machines. So it seems reasonable to add these to pveclib for both vector and scalar forms.

Quad-Precision is not supported in hardware until POWER9. However the compiler and runtime supports the `__float128` type and arithmetic operations via soft-float emulation for earlier processors. The soft-float implementation follows the ABI and passes `__float128` parameters and return values in vector registers.

So it is not unreasonable for this header to provide vector forms of the `__float128` classification functions (`isnormal/subnormal/finite/inf/nan/zero`, `copysign`, and `abs`). These functions can be implemented directly using (one or more) POWER9 instructions, or a few vector logical and integer compare instructions for POWER7/8. Each is comfortably small enough to be in-lined and inherently faster than the equivalent POSIX or compiler built-in runtime functions. Performing these operations in-line and directly in vector registers (VRs) avoids call/return and VR  $\leftrightarrow$  GPR transfer overhead.

## Note

The compiler disables associated `<altivec.h>` built-ins if the `mcpu` target does not enable the specific instruction. For example if you compile with `-mcpu=power8`, Quad-Precision floating-point operations useful for floating point classification are not defined. This header provides the appropriate substitutions, will generate the minimum code, appropriate for the target, and produce correct results.  
Most ppc64le compilers will default to `-mcpu=power8` if `-mcpu` is not specified.

This header covers operations that are any of the following:

- Implemented in hardware instructions in newer processors, but useful to programmers on slightly older processors (even if the equivalent function requires more instructions).
- Defined in the OpenPOWER ABI but *not* yet defined in `<altivec.h>` provided by available compilers in common use. Examples include `scalar_test_neg`, `scalar_test_data_class`, etc.
- Providing special vector float tests for special conditions without generating extraneous floating-point exceptions. This is important for implementing `__float128` forms of ISO C99 Math functions. Examples include `vector_isnan`, `isinf`, etc.
- Commonly used operations, not covered by the ABI or `<altivec.h>`, and require multiple instructions or are not obvious.

## 7.4.2 Examples

For example: using the the classification functions for implementing the math library function sine and cosine. The Posix specification requires that special input values are processed without raising extraneous floating point exceptions and return specific floating point values in response. For example the `sin()` function.

- If the input *value* is NaN then return a NaN.
- If the input *value* is  $\pm 0.0$  then return *value*.

- If the input *value* is subnormal then return *value*.
- If the input *value* is  $\pm\text{Inf}$  then return a NaN.
- Otherwise compute and return  $\sin(\text{value})$ .

The following code example uses functions from this header to address the POSIX requirements for special values input to `sinf128()`:

```
__binary128
test_sinf128 (__binary128 value)
{
 __binary128 result;

 if (vec_all_isnormalf128 (value))
 {
 // body of taylor series.
 ...
 }
 else
 {
 if (vec_all_isinff128 (value))
 result = vec_const_nanf128 ();
 else
 result = value;
 }
 return result;
}
```

For another example the `cos()` function.

- If the input *value* is NaN then return a NaN.
- If the input *value* is  $\pm 0.0$  then return *1.0*.
- If the input *value* is  $\pm\text{Inf}$  then return a NaN.
- Otherwise compute and return  $\cos(\text{value})$ .

The following code example uses functions from this header to address the Posix requirements for special values input to `cosf128()`:

```
__binary128
test_cosf128 (__binary128 value)
{
 __binary128 result;

 if (vec_all_isfinitef128 (value))
 {
 if (vec_all_iszerof128 (value))
 result = 1.0Q;
 else
 {
 // body of taylor series ...
 }
 }
 else
 {
 if (vec_all_isinff128 (value))
 result = vec_const_nanf128 ();
 else
 result = value;
 }
 return result;
}
```

Neither example raises floating point exceptions or sets **errno**, as appropriate for a vector math library.

### 7.4.3 Performance data

High level performance estimates are provided as an aid to function selection when evaluating algorithms. For background on how *Latency* and *Throughput* are derived see: [Performance data](#).

### 7.4.4 Function Documentation

#### 7.4.4.1 `vec_absf128()`

```
static __binary128 vec_absf128 (
 __binary128 f128) [inline], [static]
```

Clear the sign bit of \_\_float128 input and return the resulting positive \_\_float128 value.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-11    | 2/cycle    |
| power9    | 2       | 4/cycle    |

#### Parameters

|             |                                               |
|-------------|-----------------------------------------------|
| <i>f128</i> | a __float128 value containing a signed value. |
|-------------|-----------------------------------------------|

#### Returns

a \_\_float128 value with magnitude from f128 and a positive sign of f128.

#### 7.4.4.2 `vec_all_isfinitef128()`

```
static int vec_all_isfinitef128 (
 __binary128 f128) [inline], [static]
```

Return true if the \_\_float128 value is Finite (Not NaN nor Inf).

A IEEE Binary128 finite value has an exponent between 0x0000 and 0x7ffe (a 0x7fff indicates NaN or Inf). The significand can be any value. Using the `!vec_all_eq` compare conditional verify this condition and avoids a vector -> GPR transfer for platforms before PowerISA-2.07. The sign bit is ignored.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-20    | 2/cycle    |
| power9    | 3       | 2/cycle    |



**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal \_\_float128 compare can.

**Parameters**

|             |                               |
|-------------|-------------------------------|
| <i>f128</i> | a __float128 value in vector. |
|-------------|-------------------------------|

**Returns**

an int containing 0 or 1.

**7.4.4.3 vec\_all\_isinff128()**

```
static int vec_all_isinff128 (
 __binary128 f128) [inline], [static]
```

Return true if the \_\_float128 value is infinity.

A IEEE Binary128 infinity has a exponent of 0x7fff and significand of all zeros. Using the vec\_all\_eq compare conditional verifies both conditions and avoids a vector -> GPR transfer for platforms before PowerISA-2.07.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-20    | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal \_\_float128 compare can.

**Parameters**

|             |                               |
|-------------|-------------------------------|
| <i>f128</i> | a __float128 value in vector. |
|-------------|-------------------------------|

**Returns**

an int containing 0 or 1.

**7.4.4.4 vec\_all\_isnanf128()**

```
static int vec_all_isnanf128 (
 __binary128 f128) [inline], [static]
```

Return true if the `__float128` value is Not a Number (NaN).

A IEEE Binary128 NaN has a exponent of 0x7fff and nonzero significand. Using the combined `vec_all_eq / vec_any_gt` compare conditional verify both conditions and avoids a vector -> GPR transfer for platforms before PowerISA-2.07. The sign bit is ignored.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-29    | 1/cycle    |
| power9    | 3       | 2/cycle    |

#### Note

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal `__float128` compare can.

#### Parameters

|             |                                            |
|-------------|--------------------------------------------|
| <i>f128</i> | a <code>__float128</code> value in vector. |
|-------------|--------------------------------------------|

#### Returns

an int containing 0 or 1.

#### 7.4.4.5 `vec_all_isnormalf128()`

```
static int vec_all_isnormalf128 (
 __binary128 f128) [inline], [static]
```

Return true if the `__float128` value is normal (Not NaN, Inf, denormal, or zero).

A IEEE Binary128 normal value has an exponent between 0x0001 and 0x7ffe (a 0x7fff indicates NaN or Inf). The significand can be any value (except 0 if the exponent is zero). Using the combined `vec_all_ne` compares conditional verify both conditions and avoids a vector -> GPR transfer for platforms before PowerISA-2.07. The sign bit is ignored.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-29    | 1/cycle    |
| power9    | 3       | 2/cycle    |

#### Note

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal `__float128` compare can.

## Parameters

|             |                               |
|-------------|-------------------------------|
| <i>f128</i> | a __float128 value in vector. |
|-------------|-------------------------------|

## Returns

an int containing 0 or 1.

## 7.4.4.6 vec\_all\_issubnormalf128()

```
static int vec_all_issubnormalf128 (
 __binary128 f128) [inline], [static]
```

Return true if the \_\_float128 value is subnormal (denormal).

A IEEE Binary128 subnormal has an exponent of 0x0000 and a nonzero significand. The sign bit is ignored.

## Note

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal \_\_float128 compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8-29    | 1/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|             |                                 |
|-------------|---------------------------------|
| <i>f128</i> | a vector of __binary128 values. |
|-------------|---------------------------------|

## Returns

a boolean int, true if the \_\_float128 value is subnormal.

## 7.4.4.7 vec\_all\_iszerof128()

```
static int vec_all_iszerof128 (
 __binary128 f128) [inline], [static]
```

Return true if the \_\_float128 value is +-0.0.

A IEEE Binary128 zero has an exponent of 0x0000 and a zero significand. The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal \_\_float128 compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-20    | 1/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|             |                                |
|-------------|--------------------------------|
| <i>f128</i> | a vector of __binary64 values. |
|-------------|--------------------------------|

**Returns**

a boolean int, true if the \_\_float128 value is +/- zero.

**7.4.4.8 vec\_const\_huge\_valf128()**

```
static __binary128 vec_const_huge_valf128 () [inline], [static]
```

return a positive infinity.

**Returns**

const \_\_float128 positive infinity.

**7.4.4.9 vec\_const\_inff128()**

```
static __binary128 vec_const_inff128 () [inline], [static]
```

return a positive infinity.

**Returns**

a const \_\_float128 positive infinity.

## 7.4.4.10 vec\_const\_nanf128()

```
static __binary128 vec_const_nanf128 () [inline], [static]
```

return a quiet NaN.

## Returns

a const \_\_float128 quiet NaN.

## 7.4.4.11 vec\_const\_nansf128()

```
static __binary128 vec_const_nansf128 () [inline], [static]
```

return a signaling NaN.

## Returns

a const \_\_float128 signaling NaN.

## 7.4.4.12 vec\_copysignf128()

```
static __binary128 vec_copysignf128 (
 __binary128 f128x,
 __binary128 f128y) [inline], [static]
```

Copy the sign bit from f128y and merge with the magnitude from f128x. The merged result is returned as a \_\_float128 value.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-11    | 2/cycle    |
| power9    | 2       | 4/cycle    |

## Parameters

|              |                                              |
|--------------|----------------------------------------------|
| <i>f128x</i> | a __float128 value containing the magnitude. |
| <i>f128y</i> | a __float128 value containing the sign bit.  |

**Returns**

a `__float128` value with magnitude from `f128x` and the sign of `f128y`.

**7.4.4.13 `vec_isfinitef128()`**

```
static vb128_t vec_isfinitef128 (
 __binary128 f128) [inline], [static]
```

Return 128-bit vector boolean true if the `__float128` value is Finite (Not NaN nor Inf).

A IEEE Binary128 finite value has an exponent between 0x0000 and 0x7ffe (a 0x7fff indicates NaN or Inf). The significand can be any value. Using the `vec_cmpeq` conditional to generate the predicate mask for NaN / Inf and then invert this for the finite condition. The sign bit is ignored.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8-17    | 2/cycle    |
| power9    | 6       | 2/cycle    |

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal `__float128` compare can.

**Parameters**

|             |                                            |
|-------------|--------------------------------------------|
| <i>f128</i> | a <code>__float128</code> value in vector. |
|-------------|--------------------------------------------|

**Returns**

a vector boolean containing all 0s or 1s.

**7.4.4.14 `vec_isinf_signf128()`**

```
static int vec_isinf_signf128 (
 __binary128 f128) [inline], [static]
```

Return true (nonzero) value if the `__float128` value is infinity. For infinity indicate the sign as +1 for positive infinity and -1 for negative infinity.

A IEEE Binary128 infinity has a exponent of 0x7fff and significand of all zeros. Using the `vec_all_eq` compare conditional verifies both conditions. A subsequent `vec_any_gt` checks the sign bit and set the result appropriately. The sign bit is ignored.

This sequence avoids a vector -> GPR transfer for platforms before PowerISA-2.07.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 12-32   | 1/cycle    |
| power9    | 3-12    | 2/cycle    |

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal \_\_float128 compare can.

**Parameters**

|             |                               |
|-------------|-------------------------------|
| <i>f128</i> | a __float128 value in vector. |
|-------------|-------------------------------|

**Returns**

an int containing 0 if not infinity and +1/-1 otherwise.

**7.4.4.15 vec\_isinff128()**

```
static vb128_t vec_isinff128 (
 __binary128 f128) [inline], [static]
```

Return a 128-bit vector boolean true if the \_\_float128 value is infinity.

A IEEE Binary128 infinity has a exponent of 0x7fff and significand of all zeros. The sign bit is ignored.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8-17    | 2/cycle    |
| power9    | 6       | 2/cycle    |

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal \_\_float128 compare can.

**Parameters**

|             |                               |
|-------------|-------------------------------|
| <i>f128</i> | a __float128 value in vector. |
|-------------|-------------------------------|

**Returns**

a vector boolean containing all 0s or 1s..

#### 7.4.4.16 vec\_isnanf128()

```
static vb128_t vec_isnanf128 (
 __binary128 f128) [inline], [static]
```

Return 128-bit vector boolean true if the \_\_float128 value is Not a Number (NaN).

A IEEE Binary128 NaN has a exponent of 0x7fff and nonzero significand. This requires a combination of verifying the exponent and that any bit of the significand is nonzero. Using the combined vec\_all\_eq / vec\_any\_gt compare conditional verify both conditions before negating the result from zero to all ones.. The sign bit is ignored.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10-19   | 1/cycle    |
| power9    | 6       | 2/cycle    |

#### Note

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal \_\_float128 compare can.

#### Parameters

|             |                               |
|-------------|-------------------------------|
| <i>f128</i> | a __float128 value in vector. |
|-------------|-------------------------------|

#### Returns

a vector boolean containing all 0s or 1s.

#### 7.4.4.17 vec\_isnormalf128()

```
static vb128_t vec_isnormalf128 (
 __binary128 f128) [inline], [static]
```

Return 128-bit vector boolean true if the \_\_float128 value is normal (Not NaN, Inf, denormal, or zero).

A IEEE Binary128 normal value has an exponent between 0x0001 and 0x7ffe (a 0x7fff indicates NaN or Inf). The significand can be any value (except 0 if the exponent is zero). The sign bit is ignored.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10-19   | 2/cycle    |
| power9    | 6       | 2/cycle    |



**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal \_\_float128 compare can.

**Parameters**

|             |                               |
|-------------|-------------------------------|
| <i>f128</i> | a __float128 value in vector. |
|-------------|-------------------------------|

**Returns**

a vector boolean containing all 0s or 1s.

**7.4.4.18 vec\_issubnormalf128()**

```
static vb128_t vec_issubnormalf128 (
 __binary128 f128) [inline], [static]
```

Return 128-bit vector boolean true value, if the \_\_float128 value is subnormal (denormal).

A IEEE Binary128 subnormal has an exponent of 0x0000 and a nonzero significand. The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal \_\_float128 compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 16-25   | 1/cycle    |
| power9    | 6       | 1/cycle    |

**Parameters**

|             |                                |
|-------------|--------------------------------|
| <i>f128</i> | a vector of __binary64 values. |
|-------------|--------------------------------|

**Returns**

a vector boolean long long, each containing all 0s(false) or 1s(true).

**7.4.4.19 vec\_iszerof128()**

```
static vb128_t vec_iszerof128 (
 __binary128 f128) [inline], [static]
```

Return 128-bit vector boolean true value, if the value that is +-0.0.

A IEEE Binary64 zero has an exponent of 0x000 and a zero significand. The sign bit is ignored.

#### Note

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal `__float128` compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8-17    | 2/cycle    |
| power9    | 6       | 2/cycle    |

#### Parameters

|             |                                             |
|-------------|---------------------------------------------|
| <i>f128</i> | a vector of <code>__binary32</code> values. |
|-------------|---------------------------------------------|

#### Returns

a vector boolean int, each containing all 0s(false) or 1s(true).

#### 7.4.4.20 `vec_setb_qp()`

```
static vb128_t vec_setb_qp (
 __binary128 f128) [inline], [static]
```

Vector Set Bool from Quadword Floating-point.

If the quadword's sign bit is '1' then return a vector bool `__int128` that is all '1's. Otherwise return all '0's.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4 - 6   | 2/cycle    |
| power9    | 6       | 2/cycle    |

#### Parameters

|             |                                                           |
|-------------|-----------------------------------------------------------|
| <i>f128</i> | a 128-bit vector treated a signed <code>__int128</code> . |
|-------------|-----------------------------------------------------------|

#### Returns

a 128-bit vector bool of all '1's if the sign bit is '1'. Otherwise all '0's.

## 7.4.4.21 vec\_signbitf128()

```
static int vec_signbitf128 (
 __binary128 f128) [inline], [static]
```

Return int boolean true if the \_\_float128 value is negative (sign bit is '1').

Anding with a signmask and then vec\_all\_eq compare with that mask generates the boolean of the sign bit.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-20    | 2/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|             |                               |
|-------------|-------------------------------|
| <i>f128</i> | a __float128 value in vector. |
|-------------|-------------------------------|

## Returns

a int boolean indicating the sign bit.

## 7.4.4.22 vec\_xfer\_bin128\_2\_vui128t()

```
static vui128_t vec_xfer_bin128_2_vui128t (
 __binary128 f128) [inline], [static]
```

Transfer function from a \_\_binary128 scalar to a vector \_\_int128.

The compiler does not allow direct transfer (assignment or type cast) between \_\_binary128 (\_\_float128) scalars and vector types. This despite the fact the the ABI and ISA require \_\_binary128 in vector registers (VRs).

## Note

this function uses a union to effect the (logical) transfer. The compiler should not generate any code for this.

## Parameters

|             |                                            |
|-------------|--------------------------------------------|
| <i>f128</i> | a __binary128 floating point scalar value. |
|-------------|--------------------------------------------|

## Returns

The original value as a 128-bit vector \_\_int128.

#### 7.4.4.23 `vec_xfer_bin128_2_vui16t()`

```
static vui16_t vec_xfer_bin128_2_vui16t (
 __binary128 f128) [inline], [static]
```

Transfer function from a `__binary128` scalar to a vector short int.

The compiler does not allow direct transfer (assignment or type cast) between `__binary128` (`__float128`) scalars and vector types. This despite the fact the the ABI and ISA require `__binary128` in vector registers (VRs).

##### Note

this function uses a union to effect the (logical) transfer. The compiler should not generate any code for this.

##### Parameters

|             |                                                         |
|-------------|---------------------------------------------------------|
| <i>f128</i> | a <code>__binary128</code> floating point scalar value. |
|-------------|---------------------------------------------------------|

##### Returns

The original value as a 128-bit vector short int.

#### 7.4.4.24 `vec_xfer_bin128_2_vui32t()`

```
static vui32_t vec_xfer_bin128_2_vui32t (
 __binary128 f128) [inline], [static]
```

Transfer function from a `__binary128` scalar to a vector int.

The compiler does not allow direct transfer (assignment or type cast) between `__binary128` (`__float128`) scalars and vector types. This despite the fact the the ABI and ISA require `__binary128` in vector registers (VRs).

##### Note

this function uses a union to effect the (logical) transfer. The compiler should not generate any code for this.

##### Parameters

|             |                                                         |
|-------------|---------------------------------------------------------|
| <i>f128</i> | a <code>__binary128</code> floating point scalar value. |
|-------------|---------------------------------------------------------|

##### Returns

The original value as a 128-bit vector int.

#### 7.4.4.25 vec\_xfer\_bin128\_2\_vui64t()

```
static vui64_t vec_xfer_bin128_2_vui64t (
 __binary128 f128) [inline], [static]
```

Transfer function from a \_\_binary128 scalar to a vector long long int.

The compiler does not allow direct transfer (assignment or type cast) between \_\_binary128 (\_\_float128) scalars and vector types. This despite the fact the the ABI and ISA require \_\_binary128 in vector registers (VRs).

##### Note

this function uses a union to effect the (logical) transfer. The compiler should not generate any code for this.

##### Parameters

|             |                                            |
|-------------|--------------------------------------------|
| <i>f128</i> | a __binary128 floating point scalar value. |
|-------------|--------------------------------------------|

##### Returns

The original value as a 128-bit vector long long int.

#### 7.4.4.26 vec\_xfer\_bin128\_2\_vui8t()

```
static vui8_t vec_xfer_bin128_2_vui8t (
 __binary128 f128) [inline], [static]
```

Transfer function from a \_\_binary128 scalar to a vector char.

The compiler does not allow direct transfer (assignment or type cast) between \_\_binary128 (\_\_float128) scalars and vector types. This despite the fact the the ABI and ISA require \_\_binary128 in vector registers (VRs).

##### Note

this function uses a union to effect the (logical) transfer. The compiler should not generate any code for this.

##### Parameters

|             |                                            |
|-------------|--------------------------------------------|
| <i>f128</i> | a __binary128 floating point scalar value. |
|-------------|--------------------------------------------|

##### Returns

The original value as a 128-bit vector char.

#### 7.4.4.27 `vec_xfer_vui128t_2_bin128()`

```
static __binary128 vec_xfer_vui128t_2_bin128 (
 vui128_t f128) [inline], [static]
```

Transfer a vector unsigned `__int128` to `__binary128` scalar.

The compiler does not allow direct transfer (assignment or type cast) between `__binary128` (`__float128`) scalars and vector types. This despite the fact the the ABI and ISA require `__binary128` in vector registers (VRs).

##### Note

this function uses a union to effect the (logical) transfer. The compiler should not generate any code for this.

##### Parameters

|             |                                                |
|-------------|------------------------------------------------|
| <i>f128</i> | a vector unsigned <code>__int128</code> value. |
|-------------|------------------------------------------------|

##### Returns

The original value returned as a `__binary128` scalar.

#### 7.4.4.28 `vec_xfer_vui16t_2_bin128()`

```
static __binary128 vec_xfer_vui16t_2_bin128 (
 vui16_t f128) [inline], [static]
```

Transfer a vector unsigned short to `__binary128` scalar.

The compiler does not allow direct transfer (assignment or type cast) between `__binary128` (`__float128`) scalars and vector types. This despite the fact the the ABI and ISA require `__binary128` in vector registers (VRs).

##### Note

this function uses a union to effect the (logical) transfer. The compiler should not generate any code for this.

##### Parameters

|             |                                |
|-------------|--------------------------------|
| <i>f128</i> | a vector unsigned short value. |
|-------------|--------------------------------|

##### Returns

The original value returned as a `__binary128` scalar.

#### 7.4.4.29 vec\_xfer\_vui32t\_2\_bin128()

```
static __binary128 vec_xfer_vui32t_2_bin128 (
 vui32_t f128) [inline], [static]
```

Transfer a vector unsigned int to \_\_binary128 scalar.

The compiler does not allow direct transfer (assignment or type cast) between \_\_binary128 (\_\_float128) scalars and vector types. This despite the fact the the ABI and ISA require \_\_binary128 in vector registers (VRs).

##### Note

this function uses a union to effect the (logical) transfer. The compiler should not generate any code for this.

##### Parameters

|             |                              |
|-------------|------------------------------|
| <i>f128</i> | a vector unsigned int value. |
|-------------|------------------------------|

##### Returns

The original value returned as a \_\_binary128 scalar.

#### 7.4.4.30 vec\_xfer\_vui64t\_2\_bin128()

```
static __binary128 vec_xfer_vui64t_2_bin128 (
 vui64_t f128) [inline], [static]
```

Transfer a vector unsigned long long to \_\_binary128 scalar.

The compiler does not allow direct transfer (assignment or type cast) between \_\_binary128 (\_\_float128) scalars and vector types. This despite the fact the the ABI and ISA require \_\_binary128 in vector registers (VRs).

##### Note

this function uses a union to effect the (logical) transfer. The compiler should not generate any code for this.

##### Parameters

|             |                                    |
|-------------|------------------------------------|
| <i>f128</i> | a vector unsigned long long value. |
|-------------|------------------------------------|

##### Returns

The original value returned as a \_\_binary128 scalar.

#### 7.4.4.31 vec\_xfer\_vui8t\_2\_bin128()

```
static __binary128 vec_xfer_vui8t_2_bin128 (
 vui8_t f128) [inline], [static]
```

Transfer a vector unsigned char to \_\_binary128 scalar.

The compiler does not allow direct transfer (assignment or type cast) between \_\_binary128 (\_\_float128) scalars and vector types. This despite the fact the the ABI and ISA require \_\_binary128 in vector registers (VRs).

#### Note

this function uses a union to effect the (logical) transfer. The compiler should not generate any code for this.

#### Parameters

|             |                               |
|-------------|-------------------------------|
| <i>f128</i> | a vector unsigned char value. |
|-------------|-------------------------------|

#### Returns

The original value returned as a \_\_binary128 scalar.

## 7.5 src/pveclib/vec\_f32\_ppc.h File Reference

Header package containing a collection of 128-bit SIMD operations over 4x32-bit floating point elements.

```
#include <pveclib/vec_common_ppc.h>
```

### Typedefs

- typedef [vf32\\_t](#) [\\_\\_vbinary32](#)  
*typedef \_\_vbinary32 to vector of 4 xfloat elements.*

### Functions

- static [vf32\\_t](#) [vec\\_absf32](#) ([vf32\\_t](#) vf32x)  
*Vector float absolute value.*
- static int [vec\\_all\\_isfinitef32](#) ([vf32\\_t](#) vf32)  
*Return true if all 4x32-bit vector float values are Finite (Not NaN nor Inf).*
- static int [vec\\_all\\_isinff32](#) ([vf32\\_t](#) vf32)  
*Return true if all 4x32-bit vector float values are infinity.*
- static int [vec\\_all\\_isnanf32](#) ([vf32\\_t](#) vf32)  
*Return true if all of 4x32-bit vector float values are NaN.*



- static int [vec\\_all\\_isnormalf32](#) ([vf32\\_t](#) vf32)  
*Return true if all of 4x32-bit vector float values are normal (Not NaN, Inf, denormal, or zero).*
- static int [vec\\_all\\_issubnormalf32](#) ([vf32\\_t](#) vf32)  
*Return true if all of 4x32-bit vector float values is subnormal (denormal).*
- static int [vec\\_all\\_iszerof32](#) ([vf32\\_t](#) vf32)  
*Return true if all of 4x32-bit vector float values are +-0.0.*
- static int [vec\\_any\\_isfinitef32](#) ([vf32\\_t](#) vf32)  
*Return true if any 4x32-bit vector float values are Finite (Not NaN nor Inf).*
- static int [vec\\_any\\_isinff32](#) ([vf32\\_t](#) vf32)  
*Return true if any 4x32-bit vector float values are infinity.*
- static int [vec\\_any\\_isnanf32](#) ([vf32\\_t](#) vf32)  
*Return true if any of 4x32-bit vector float values are NaN.*
- static int [vec\\_any\\_isnormalf32](#) ([vf32\\_t](#) vf32)  
*Return true if any of 4x32-bit vector float values are normal (Not NaN, Inf, denormal, or zero).*
- static int [vec\\_any\\_issubnormalf32](#) ([vf32\\_t](#) vf32)  
*Return true if any of 4x32-bit vector float values is subnormal (denormal).*
- static int [vec\\_any\\_iszerof32](#) ([vf32\\_t](#) vf32)  
*Return true if any of 4x32-bit vector float values are +-0.0.*
- static [vf32\\_t](#) [vec\\_copysignf32](#) ([vf32\\_t](#) vf32x, [vf32\\_t](#) vf32y)  
*Copy the sign bit from vf32y merged with magnitude from vf32x and return the resulting vector float values.*
- static [vb32\\_t](#) [vec\\_isfinitef32](#) ([vf32\\_t](#) vf32)  
*Return 4x32-bit vector boolean true values for each float element that is Finite (Not NaN nor Inf).*
- static [vb32\\_t](#) [vec\\_isinff32](#) ([vf32\\_t](#) vf32)  
*Return 4x32-bit vector boolean true values for each float, if infinity.*
- static [vb32\\_t](#) [vec\\_isnanf32](#) ([vf32\\_t](#) vf32)  
*Return 4x32-bit vector boolean true values, for each float NaN value.*
- static [vb32\\_t](#) [vec\\_isnormalf32](#) ([vf32\\_t](#) vf32)  
*Return 4x32-bit vector boolean true values, for each float value, if normal (Not NaN, Inf, denormal, or zero).*
- static [vb32\\_t](#) [vec\\_issubnormalf32](#) ([vf32\\_t](#) vf32)  
*Return 4x32-bit vector boolean true values, for each float value that is subnormal (denormal).*
- static [vb32\\_t](#) [vec\\_iszerof32](#) ([vf32\\_t](#) vf32)  
*Return 4x32-bit vector boolean true values, for each float value that is +-0.0.*

### 7.5.1 Detailed Description

Header package containing a collection of 128-bit SIMD operations over 4x32-bit floating point elements.

Most vector float (32-bit float) operations are implemented with PowerISA VMX instructions either defined by the original VMX (a.k.a. Altivec) or added to later versions of the PowerISA. POWER8 added the Vector Scalar Extended (VSX) with access to additional vector registers (64 total) and operations. Most of these operations (compiler built-ins, or intrinsics) are defined in `<altivec.h>` and described in the [compiler documentation](#).

**Note**

The compiler disables associated `<altivec.h>` built-ins if the `mcpu` target does not enable the specific instruction. For example if you compile with `-mcpu=power7`, some of the wordwise pack, unpack and merge operations useful for conversions are not defined and the equivalent `vec_perm` and `permute` control must be used instead. This header will provide the appropriate substitutions, will generate the minimum code, appropriate for the target, and produce correct results.

Most ppc64le compilers will default to `-mcpu=power8` if not specified.

Most of these operations are implemented in a single instruction on newer (POWER8/POWER9) processors. This header serves to fill in functional gaps for older (POWER7, POWER8) processors and provides an inline assembler implementation for older compilers that do not provide the built-ins.

POWER9 adds useful vector float operations, including: test data class, extract exponent, extract significand, and insert exponent. These operations are common in math library implementations.

**Note**

GCC 7.3 defines vector forms of the test data class, extract significand, and extract/insert\_exp for float and double. These built-ins are not defined in GCC 6.4. See [compiler documentation](#). These are useful operations and can be implement in a few vector logical instruction for earlier machines.

So it is reasonable for this header to provide vector forms of the floating point classification functions (isnormal/subnormal/finite/inf/nan/zero, etc.). These functions can be implemented directly using (one or more) POWER9 instructions, or a few vector logical and integer compare instructions for POWER7/8. Each is comfortably small enough to be in-lined and inherently faster than the equivalent POSIX or compiler built-in runtime scalar functions.

This header covers operations that are any of the following:

- Implemented in hardware instructions in newer processors, but useful to programmers on slightly older processors (even if the equivalent function requires more instructions). Examples include the floating point test data class, extract exponent, extract significand, and insert exponent operations.
- Defined in the OpenPOWER ABI but *not* yet defined in `<altivec.h>` provided by available compilers in common use. Examples include vector float even/odd.
- Providing special vector float tests for special conditions without generating extraneous floating-point exceptions. This is important for implementing vectorized forms of ISO C99 Math functions.
- Commonly used operations, not covered by the ABI or `<altivec.h>`, and require multiple instructions or are not obvious.

## 7.5.2 Examples

For example: using the the classification functions for implementing the math library function sine and cosine. The POSIX specification requires that special input values are processed without raising extraneous floating point exceptions and return specific floating point values in response. For example the `sin()` function.

- If the input *value* is NaN then return a NaN.
- If the input *value* is `+0.0` then return *value*.

- If the input *value* is subnormal then return *value*.
- If the input *value* is  $\pm\text{Inf}$  then return a NaN.
- Otherwise compute and return  $\sin(\text{value})$ .

The following code example uses functions from this header to address the POSIX requirements for special values input to for a vectorized `sinf()`:

```
vf32_t
test_vec_sinf32 (vf32_t value)
{
 const vf32_t vec_f0 = { 0.0, 0.0, 0.0, 0.0 };
 const vui32_t vec_f32_qnan =
 { 0x7f800001, 0x7fc00000, 0x7fc00000, 0x7fc00000 };
 vf32_t result;
 vb32_t normmask, infmask;

 normmask = vec_isnormalf32 (value);
 if (vec_any_isnormalf32 (value))
 {
 // replace non-normal input values with safe values.
 vf32_t safeval = vec_sel (vec_f0, value, normmask);
 // body of vec_sin(safeval) computation elided for this example.
 }
 else
 result = value;

 // merge non-normal input values back into result
 result = vec_sel (value, result, normmask);
 // Inf input value elements return quiet-nan
 infmask = vec_isinff32 (value);
 result = vec_sel (result, (vf32_t) vec_f32_qnan, infmask);

 return result;
}
```

The code generated for this fragment runs between 24 (`-mcpu=power9`) and 40 (`-mcpu=power8`) instructions. The normal execution path is 14 to 25 instructions respectively.

Another example the `cos()` function.

- If the input *value* is NaN then return a NaN.
- If the input *value* is  $\pm 0.0$  then return *1.0*.
- If the input *value* is  $\pm\text{Inf}$  then return a NaN.
- Otherwise compute and return  $\cos(\text{value})$ .

The following code example uses functions from this header to address the POSIX requirements for special values input to vectorized `cosf()`:

```
vf32_t
test_vec_cosf32 (vf32_t value)
{
 vf32_t result;
 const vf32_t vec_f0 = { 0.0, 0.0, 0.0, 0.0 };
 const vf32_t vec_f1 = { 1.0, 1.0, 1.0, 1.0 };
 const vui32_t vec_f32_qnan =
 { 0x7f800001, 0x7fc00000, 0x7fc00000, 0x7fc00000 };
 vb32_t finitemask, infmask, zeromask;

 finitemask = vec_isfinitef32 (value);
 if (vec_any_isfinitef32 (value))
```

```

{
 // replace non-finite input values with safe values
 vf32_t safeval = vec_sel (vec_f0, value, finitemask);
 // body of vec_sin(safeval) computation elided for this example
}
else
 result = value;

// merge non-finite input values back into result
result = vec_sel (value, result, finitemask);
// Set +-0.0 input elements to exactly 1.0 in result
zeromask = vec_iszerof32 (value);
result = vec_sel (result, vec_f1, zeromask);
// Set Inf input elements to quiet-nan in result
infmask = vec_isinff32 (value);
result = vec_sel (result, (vf32_t) vec_f32_qnan, infmask);

return result;
}

```

Neither example raises floating point exceptions or sets **errno**, as appropriate for a vector math library.

### 7.5.3 Performance data.

High level performance estimates are provided as an aid to function selection when evaluating algorithms. For background on how *Latency* and *Throughput* are derived see: [Performance data](#).

### 7.5.4 Function Documentation

#### 7.5.4.1 vec\_absf32()

```

static vf32_t vec_absf32 (
 vf32_t vf32x) [inline], [static]

```

Vector float absolute value.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-7     | 2/cycle    |
| power9    | 2       | 2/cycle    |

#### Parameters

|       |                                                |
|-------|------------------------------------------------|
| vf32x | vector float values containing the magnitudes. |
|-------|------------------------------------------------|

#### Returns

vector absolute values of 4x float elements of vf32x.

## 7.5.4.2 vec\_all\_isfinitef32()

```
static int vec_all_isfinitef32 (
 vf32_t vf32) [inline], [static]
```

Return true if all 4x32-bit vector float values are Finite (Not NaN nor Inf).

A IEEE Binary32 finite value has an exponent between 0x000 and 0x7f0 (a 0x7f8 indicates NaN or Inf). The significand can be any value. The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal float compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-20    | 2/cycle    |
| power9    | 6       | 1/cycle    |

**Parameters**

|      |                                |
|------|--------------------------------|
| vf32 | a vector of __binary32 values. |
|------|--------------------------------|

**Returns**

an int containing 0 or 1.

## 7.5.4.3 vec\_all\_isinff32()

```
static int vec_all_isinff32 (
 vf32_t vf32) [inline], [static]
```

Return true if all 4x32-bit vector float values are infinity.

A IEEE Binary32 infinity has a exponent of 0x7f8 and significand of all zeros. The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal float compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-20    | 2/cycle    |
| power9    | 6       | 1/cycle    |

**Parameters**

|                   |                                             |
|-------------------|---------------------------------------------|
| <code>vf32</code> | a vector of <code>__binary32</code> values. |
|-------------------|---------------------------------------------|

**Returns**

boolean int, true if all 4 float values are infinity

**7.5.4.4 `vec_all_isnanf32()`**

```
static int vec_all_isnanf32 (
 vf32_t vf32) [inline], [static]
```

Return true if all of 4x32-bit vector float values are NaN.

A IEEE Binary32 NaN value has an exponent between 0x7f8 and the significand is nonzero. The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal float compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-20    | 2/cycle    |
| power9    | 6       | 1/cycle    |

**Parameters**

|                   |                                             |
|-------------------|---------------------------------------------|
| <code>vf32</code> | a vector of <code>__binary32</code> values. |
|-------------------|---------------------------------------------|

**Returns**

a boolean int, true if all of 4 vector float values are NaN.

**7.5.4.5 `vec_all_isnormalf32()`**

```
static int vec_all_isnormalf32 (
 vf32_t vf32) [inline], [static]
```

Return true if all of 4x32-bit vector float values are normal (Not NaN, Inf, denormal, or zero).

A IEEE Binary32 normal value has an exponent between 0x008 and 0x7f (a 0x7f8 indicates NaN or Inf). The significand can be any value (except 0 if the exponent is zero). The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal float compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-20    | 1/cycle    |
| power9    | 6       | 1/cycle    |

**Parameters**

|             |                                |
|-------------|--------------------------------|
| <b>vf32</b> | a vector of __binary32 values. |
|-------------|--------------------------------|

**Returns**

a boolean int, true if all of 4 vector float values are normal.

**7.5.4.6 vec\_all\_issubnormalf32()**

```
static int vec_all_issubnormalf32 (
 vf32_t vf32) [inline], [static]
```

Return true if all of 4x32-bit vector float values is subnormal (denormal).

A IEEE Binary32 subnormal has an exponent of 0x000 and a nonzero significand. The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal float compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10-30   | 1/cycle    |
| power9    | 6       | 1/cycle    |

**Parameters**

|             |                                |
|-------------|--------------------------------|
| <b>vf32</b> | a vector of __binary32 values. |
|-------------|--------------------------------|

**Returns**

a boolean int, true if all of 4 vector float values are subnormal.

#### 7.5.4.7 vec\_all\_iszero32()

```
static int vec_all_iszero32 (
 vf32_t vf32) [inline], [static]
```

Return true if all of 4x32-bit vector float values are +/-0.0.

A IEEE Binary32 zero has an exponent of 0x000 and a zero significand. The sign bit is ignored.

##### Note

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal float compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-20    | 2/cycle    |
| power9    | 6       | 1/cycle    |

##### Parameters

|             |                                |
|-------------|--------------------------------|
| <i>vf32</i> | a vector of __binary32 values. |
|-------------|--------------------------------|

##### Returns

a boolean int, true if all of 4 vector float values are +/- zero.

#### 7.5.4.8 vec\_any\_isfinite32()

```
static int vec_any_isfinite32 (
 vf32_t vf32) [inline], [static]
```

Return true if any 4x32-bit vector float values are Finite (Not NaN nor Inf).

A IEEE Binary32 finite value has an exponent between 0x000 and 0x7f0 (a 0x7f8 indicates NaN or Inf). The significand can be any value. The sign bit is ignored.

##### Note

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal float compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-20    | 2/cycle    |
| power9    | 6       | 1/cycle    |



**Parameters**

|             |                                |
|-------------|--------------------------------|
| <i>vf32</i> | a vector of __binary32 values. |
|-------------|--------------------------------|

**Returns**

an int containing 0 or 1.

**7.5.4.9 vec\_any\_isinff32()**

```
static int vec_any_isinff32 (
 vf32_t vf32) [inline], [static]
```

Return true if any 4x32-bit vector float values are infinity.

A IEEE Binary32 infinity has a exponent of 0x7f8 and significand of all zeros.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal float compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-20    | 2/cycle    |
| power9    | 6       | 2/cycle    |

**Parameters**

|             |                                |
|-------------|--------------------------------|
| <i>vf32</i> | a vector of __binary32 values. |
|-------------|--------------------------------|

**Returns**

boolean int, true if any of 4 float values are infinity

**7.5.4.10 vec\_any\_isnanf32()**

```
static int vec_any_isnanf32 (
 vf32_t vf32) [inline], [static]
```

Return true if any of 4x32-bit vector float values are NaN.

A IEEE Binary32 NaN value has an exponent between 0x7f8 and the significand is nonzero. The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal float compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-20    | 2/cycle    |
| power9    | 6       | 2/cycle    |

**Parameters**

|                   |                                             |
|-------------------|---------------------------------------------|
| <code>vf32</code> | a vector of <code>__binary32</code> values. |
|-------------------|---------------------------------------------|

**Returns**

a boolean int, true if any of 4 vector float values are NaN.

**7.5.4.11 `vec_any_isnormalf32()`**

```
static int vec_any_isnormalf32 (
 vf32_t vf32) [inline], [static]
```

Return true if any of 4x32-bit vector float values are normal (Not NaN, Inf, denormal, or zero).

A IEEE Binary32 normal value has an exponent between 0x008 and 0x7f (a 0x7f8 indicates NaN or Inf). The significand can be any value (except 0 if the exponent is zero). The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal float compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10-24   | 1/cycle    |
| power9    | 6       | 1/cycle    |

**Parameters**

|                   |                                             |
|-------------------|---------------------------------------------|
| <code>vf32</code> | a vector of <code>__binary32</code> values. |
|-------------------|---------------------------------------------|

**Returns**

a boolean int, true if any of 4 vector float values are normal.

#### 7.5.4.12 vec\_any\_issubnormalf32()

```
static int vec_any_issubnormalf32 (
 vf32_t vf32) [inline], [static]
```

Return true if any of 4x32-bit vector float values is subnormal (denormal).

A IEEE Binary32 subnormal has an exponent of 0x000 and a nonzero significand. The sign bit is ignored.

##### Note

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal float compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10-18   | 1/cycle    |
| power9    | 6       | 1/cycle    |

##### Parameters

|      |                                |
|------|--------------------------------|
| vf32 | a vector of __binary32 values. |
|------|--------------------------------|

##### Returns

if any of 4 vector float values are subnormal.

#### 7.5.4.13 vec\_any\_iszerof32()

```
static int vec_any_iszerof32 (
 vf32_t vf32) [inline], [static]
```

Return true if any of 4x32-bit vector float values are +/-0.0.

A IEEE Binary32 zero has an exponent of 0x000 and a zero significand. The sign bit is ignored.

##### Note

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal float compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-20    | 2/cycle    |
| power9    | 6       | 1/cycle    |

**Parameters**

|                   |                                             |
|-------------------|---------------------------------------------|
| <code>vf32</code> | a vector of <code>__binary32</code> values. |
|-------------------|---------------------------------------------|

**Returns**

a boolean int, true if any of 4 vector float values are +/- zero.

**7.5.4.14 `vec_copysignf32()`**

```
static vf32_t vec_copysignf32 (
 vf32_t vf32x,
 vf32_t vf32y) [inline], [static]
```

Copy the sign bit from vf32y merged with magnitude from vf32x and return the resulting vector float values.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-7     | 2/cycle    |
| power9    | 2       | 2/cycle    |

**Parameters**

|                    |                                                |
|--------------------|------------------------------------------------|
| <code>vf32x</code> | vector float values containing the magnitudes. |
| <code>vf32y</code> | vector float values containing the sign bits.  |

**Returns**

vector float values with magnitude from vf32x and the sign of vf32y.

**7.5.4.15 `vec_isfinitef32()`**

```
static vb32_t vec_isfinitef32 (
 vf32_t vf32) [inline], [static]
```

Return 4x32-bit vector boolean true values for each float element that is Finite (Not NaN nor Inf).

A IEEE Binary32 finite value has an exponent between 0x000 and 0x7f0 (a 0x7f8 indicates NaN or Inf). The significand can be any value. Using the `vec_cmpeq` conditional to generate the predicate mask for NaN / Inf and then invert this for the finite condition. The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal float compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-15    | 2/cycle    |
| power9    | 5       | 2/cycle    |

#### Parameters

|                   |                                             |
|-------------------|---------------------------------------------|
| <code>vf32</code> | a vector of <code>__binary32</code> values. |
|-------------------|---------------------------------------------|

#### Returns

a vector boolean int, each containing all 0s(false) or 1s(true).

#### 7.5.4.16 `vec_isinff32()`

```
static vb32_t vec_isinff32 (
 vf32_t vf32) [inline], [static]
```

Return 4x32-bit vector boolean true values for each float, if infinity.

A IEEE Binary32 infinity has a exponent of 0x7f8 and significand of all zeros.

#### Note

This function will not raise VXSNAN or VXVC (FE\_INVALID) exceptions. A normal float compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-13    | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|                   |                                             |
|-------------------|---------------------------------------------|
| <code>vf32</code> | a vector of <code>__binary32</code> values. |
|-------------------|---------------------------------------------|

#### Returns

a vector boolean int, each containing all 0s(false) or 1s(true).

#### 7.5.4.17 vec\_isnanf32()

```
static vb32_t vec_isnanf32 (
 vf32_t vf32) [inline], [static]
```

Return 4x32-bit vector boolean true values, for each float NaN value.

A IEEE Binary32 NaN value has an exponent between 0x7f8 and the significand is nonzero. The sign bit is ignored.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-13    | 2/cycle    |
| power9    | 3       | 2/cycle    |

##### Parameters

|             |                                |
|-------------|--------------------------------|
| <i>vf32</i> | a vector of __binary32 values. |
|-------------|--------------------------------|

##### Returns

a vector boolean int, each containing all 0s(false) or 1s(true).

#### 7.5.4.18 vec\_isnormalf32()

```
static vb32_t vec_isnormalf32 (
 vf32_t vf32) [inline], [static]
```

Return 4x32-bit vector boolean true values, for each float value, if normal (Not NaN, Inf, denormal, or zero).

A IEEE Binary32 normal value has an exponent between 0x008 and 0x7f (a 0x7f8 indicates NaN or Inf). The significand can be any value (except 0 if the exponent is zero). The sign bit is ignored.

##### Note

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal float compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-15    | 1/cycle    |
| power9    | 5       | 1/cycle    |

##### Parameters

|             |                                |
|-------------|--------------------------------|
| <i>vf32</i> | a vector of __binary32 values. |
|-------------|--------------------------------|

**Returns**

a vector boolean int, each containing all 0s(false) or 1s(true).

**7.5.4.19 vec\_issubnormalf32()**

```
static vb32_t vec_issubnormalf32 (
 vf32_t vf32) [inline], [static]
```

Return 4x32-bit vector boolean true values, for each float value that is subnormal (denormal).

A IEEE Binary32 subnormal has an exponent of 0x000 and a nonzero significand. The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal float compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-16    | 1/cycle    |
| power9    | 3       | 1/cycle    |

**Parameters**

|      |                                |
|------|--------------------------------|
| vf32 | a vector of __binary32 values. |
|------|--------------------------------|

**Returns**

a vector boolean int, each containing all 0s(false) or 1s(true).

**7.5.4.20 vec\_iszerof32()**

```
static vb32_t vec_iszerof32 (
 vf32_t vf32) [inline], [static]
```

Return 4x32-bit vector boolean true values, for each float value that is +-0.0.

A IEEE Binary32 zero has an exponent of 0x000 and a zero significand. The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal float compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-13    | 2/cycle    |
| power9    | 5       | 2/cycle    |

#### Parameters

|                   |                                             |
|-------------------|---------------------------------------------|
| <code>vf32</code> | a vector of <code>__binary32</code> values. |
|-------------------|---------------------------------------------|

#### Returns

a vector boolean int, each containing all 0s(false) or 1s(true).

## 7.6 src/pveclib/vec\_f64\_ppc.h File Reference

Header package containing a collection of 128-bit SIMD operations over 64-bit double-precision floating point elements.

```
#include <pveclib/vec_common_ppc.h>
#include <pveclib/vec_int128_ppc.h>
```

#### Functions

- static `vf64_t vec_absf64 (vf64_t vf64x)`  
*Vector double absolute value.*
- static int `vec_all_isfinitef64 (vf64_t vf64)`  
*Return true if all 2x64-bit vector double values are Finite (Not NaN nor Inf).*
- static int `vec_all_isinff64 (vf64_t vf64)`  
*Return true if all 2x64-bit vector double values are infinity.*
- static int `vec_all_isnanf64 (vf64_t vf64)`  
*Return true if all 2x64-bit vector double values are NaN.*
- static int `vec_all_isnormalf64 (vf64_t vf64)`  
*Return true if all 2x64-bit vector double values are normal (Not NaN, Inf, denormal, or zero).*
- static int `vec_all_issubnormalf64 (vf64_t vf64)`  
*Return true if all 2x64-bit vector double values are subnormal (denormal).*
- static int `vec_all_iszerof64 (vf64_t vf64)`  
*Return true if all 2x64-bit vector double values are +-0.0.*
- static int `vec_any_isfinitef64 (vf64_t vf64)`  
*Return true if any of 2x64-bit vector double values are Finite (Not NaN nor Inf).*
- static int `vec_any_isinff64 (vf64_t vf64)`  
*Return true if any of 2x64-bit vector double values are infinity.*
- static int `vec_any_isnanf64 (vf64_t vf64)`  
*Return true if any of 2x64-bit vector double values are NaN.*
- static int `vec_any_isnormalf64 (vf64_t vf64)`  
*Return true if any of 2x64-bit vector double values are normal (Not NaN, Inf, denormal, or zero).*



- static int [vec\\_any\\_issubnormalf64](#) ([vf64\\_t](#) vf64)  
*Return true if any of 2x64-bit vector double values is subnormal (denormal).*
- static int [vec\\_any\\_iszerof64](#) ([vf64\\_t](#) vf64)  
*Return true if any of 2x64-bit vector double values are +-0.0.*
- static [vf64\\_t](#) [vec\\_copysignf64](#) ([vf64\\_t](#) vf64x, [vf64\\_t](#) vf64y)  
*Copy the sign bit from vf64y merged with magnitude from vf64x and return the resulting vector double values.*
- static [vb64\\_t](#) [vec\\_isfinitef64](#) ([vf64\\_t](#) vf64)  
*Return 2x64-bit vector boolean true values for each double element that is Finite (Not NaN nor Inf).*
- static [vb64\\_t](#) [vec\\_isinff64](#) ([vf64\\_t](#) vf64)  
*Return 2x64-bit vector boolean true values for each double, if infinity.*
- static [vb64\\_t](#) [vec\\_isnanf64](#) ([vf64\\_t](#) vf64)  
*Return 2x64-bit vector boolean true values, for each double NaN value.*
- static [vb64\\_t](#) [vec\\_isnormalf64](#) ([vf64\\_t](#) vf64)  
*Return 2x64-bit vector boolean true values, for each double value, if normal (Not NaN, Inf, denormal, or zero).*
- static [vb64\\_t](#) [vec\\_issubnormalf64](#) ([vf64\\_t](#) vf64)  
*Return 2x64-bit vector boolean true values, for each double value that is subnormal (denormal).*
- static [vb64\\_t](#) [vec\\_iszerof64](#) ([vf64\\_t](#) vf64)  
*Return 2x64-bit vector boolean true values, for each double value that is +-0.0.*
- static long double [vec\\_pack\\_longdouble](#) ([vf64\\_t](#) lval)  
*Copy the pair of doubles from a vector to IBM long double.*
- static [vf64\\_t](#) [vec\\_unpack\\_longdouble](#) (long double lval)  
*Copy the pair of doubles from a IBM long double to a vector double.*

### 7.6.1 Detailed Description

Header package containing a collection of 128-bit SIMD operations over 64-bit double-precision floating point elements.

Many vector double-precision (64-bit float) operations are implemented with PowerISA-2.06 Vector Scalar Extended (VSX) (POWER7 and later) instructions. Most VSX instructions provide access to 64 combined scalar/vector registers. PowerISA-3.0 (POWER9) provides additional vector double operations: convert with round, convert to/from integer, insert/extract exponent and significand, and test data class. Most of these operations (compiler built-ins, or intrinsics) are defined in `<altivec.h>` and described in the [compiler documentation](#).

#### Note

The compiler disables associated `<altivec.h>` built-ins if the **mcpu** target does not enable the specific instruction. For example if you compile with **-mcpu=power8**, the double-precision vector converts, insert/extract and test data class built-ins are not defined. This header provides the appropriate substitutions, will generate the minimum code, appropriate for the target, and produce correct results.

Most ppc64le compilers will default to **-mcpu=power8** if not specified.

GCC 7.3 defines vector forms of the test data class, extract significand, and extract/insert\_exp for float and double. These built-ins are not defined in GCC 6.4. See [compiler documentation](#). These are useful operations and can be implemented in a few vector logical instructions for earlier machines.

So it is reasonable for this header to provide vector forms of the double-precision floating point classification functions (isnormal/subnormal/finite/inf/nan/zero, etc.). These functions can be implemented directly using (one or more) POWER9 instructions, or a few vector logical and integer compare instructions for POWER7/8. Each is comfortably small enough to be in-lined and inherently faster than the equivalent POSIX or compiler built-in runtime scalar functions.

Most of these operations are implemented in a few instructions on newer (POWER7/POWER8/POWER9) processors. This header serves to fill in functional gaps for older (POWER7, POWER8) processors and provides an inline assembler implementation for older compilers that do not provide the built-ins.

This header covers operations that are any of the following:

- Implemented in hardware instructions in newer processors, but useful to programmers on slightly older processors (even if the equivalent function requires more instructions).
- Defined in the OpenPOWER ABI but *not* yet defined in `<altivec.h>` provided by available compilers in common use. Examples include vector double even/odd conversions.
- Providing special vector double tests for special conditions without generating extraneous floating-point exceptions. This is important for implementing vectorized forms of ISO C99 Math functions. Examples include vector double isnan, isinf, etc.
- Commonly used operations, not covered by the ABI or `<altivec.h>`, and require multiple instructions or are not obvious. For example, converts that change element size and imply converting two vectors into one vector of smaller elements, or one vector into two vectors of larger elements. Another example is the special case of packing/unpacking an IBM long double between a pair of floating-point registers (FPRs) and a single vector register (VR).

### 7.6.2 Examples

For example: using the the classification functions for implementing the math library function sine and cosine. The POSIX specification requires that special input values are processed without raising extraneous floating point exceptions and return specific floating point values in response. For example, the `sin()` function.

- If the input *value* is NaN then return a NaN.
- If the input *value* is `+0.0` then return *value*.
- If the input *value* is subnormal then return *value*.
- If the input *value* is `+-Inf` then return a quiet-NaN.
- Otherwise compute and return `sin(value)`.

The following code example uses functions from this header to address the POSIX requirements for special values input to for a vectorized `sinf()`:

```
vf64_t
test_vec_sinf64 (vf64_t value)
{
 const vf64_t vec_f0 = { 0.0, 0.0 };
 const vui64_t vec_f64_qnan =
 { 0x7ff8000000000000, 0x7ff8000000000000 };
 vf64_t result;
 vb64_t normmask, infmask;

 normmask = vec_isnormalf64 (value);
```

```

if (vec_any_isnormalf64 (value))
{
 // replace non-normal input values with safe values.
 vf64_t safeval = vec_sel (vec_f0, value, normmask);
 // body of vec_sin(safeval) computation elided for this example.
}
else
 result = value;

// merge non-normal input values back into result
result = vec_sel (value, result, normmask);
// Inf input value elements return quiet-nan.
inffmask = vec_isinff64 (value);
result = vec_sel (result, (vf64_t) vec_f64_qnan, inffmask);

return result;
}

```

The code generated for this fragment runs between 24 (-mcpu=power9) and 40 (-mcpu=power8) instructions. The normal execution path is 14 to 25 instructions respectively.

Another example the cos() function.

- If the input *value* is NaN then return a NaN.
- If the input *value* is +-0.0 then return 1.0.
- If the input *value* is +-Inf then return a quiet-NaN.
- Otherwise compute and return cos(value).

The following code example uses functions from this header to address the POSIX requirements for special values input to vectorized cosf():

```

vf64_t
test_vec_cosf64 (vf64_t value)
{
 vf64_t result;
 const vf64_t vec_f0 = { 0.0, 0.0 };
 const vf64_t vec_f1 = { 1.0, 1.0 };
 const vui64_t vec_f64_qnan =
 { 0x7ff8000000000000, 0x7ff8000000000000 };
 vb64_t finitemask, inffmask, zeromask;

 finitemask = vec_isfinitef64 (value);
 if (vec_any_isfinitef64 (value))
 {
 // replace non-finite input values with safe values.
 vf64_t safeval = vec_sel (vec_f0, value, finitemask);
 // body of vec_sin(safeval) computation elided for this example.
 }
 else
 result = value;

 // merge non-finite input values back into result
 result = vec_sel (value, result, finitemask);
 // Set +-0.0 input elements to exactly 1.0 in result.
 zeromask = vec_iszerof64 (value);
 result = vec_sel (result, vec_f1, zeromask);
 // Set Inf input elements to quiet-nan in result.
 inffmask = vec_isinff64 (value);
 result = vec_sel (result, (vf64_t) vec_f64_qnan, inffmask);

 return result;
}

```

Neither example raises floating point exceptions or sets **errno**, as appropriate for a vector math library.

### 7.6.3 Performance data.

High level performance estimates are provided as an aid to function selection when evaluating algorithms. For background on how *Latency* and *Throughput* are derived see: [Performance data](#).

## 7.6.4 Function Documentation

### 7.6.4.1 vec\_absf64()

```
static vf64_t vec_absf64 (
 vf64_t vf64x) [inline], [static]
```

Vector double absolute value.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-7     | 2/cycle    |
| power9    | 2       | 2/cycle    |

#### Parameters

|              |                                                 |
|--------------|-------------------------------------------------|
| <i>vf64x</i> | vector double values containing the magnitudes. |
|--------------|-------------------------------------------------|

#### Returns

vector double absolute values of *vf64x*.

### 7.6.4.2 vec\_all\_isfinitef64()

```
static int vec_all_isfinitef64 (
 vf64_t vf64) [inline], [static]
```

Return true if all 2x64-bit vector double values are Finite (Not NaN nor Inf).

A IEEE Binary64 finite value has an exponent between 0x000 and 0x7fe (a 0x7ff indicates NaN or Inf). The significand can be any value. The sign bit is ignored.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-20    | 2/cycle    |
| power9    | 6       | 1/cycle    |

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal \_\_binary64 compare can.

**Parameters**

|             |                                |
|-------------|--------------------------------|
| <i>vf64</i> | a vector of __binary64 values. |
|-------------|--------------------------------|

**Returns**

an int containing 0 or 1.

**7.6.4.3 vec\_all\_isinff64()**

```
static int vec_all_isinff64 (
 vf64_t vf64) [inline], [static]
```

Return true if all 2x64-bit vector double values are infinity.

A IEEE Binary64 infinity has a exponent of 0x7ff and significand of all zeros. The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal double compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-20    | 2/cycle    |
| power9    | 6       | 1/cycle    |

**Parameters**

|             |                                |
|-------------|--------------------------------|
| <i>vf64</i> | a vector of __binary64 values. |
|-------------|--------------------------------|

**Returns**

boolean int, true if all 2 double values are infinity

**7.6.4.4 vec\_all\_isnanf64()**

```
static int vec_all_isnanf64 (
 vf64_t vf64) [inline], [static]
```

Return true if all 2x64-bit vector double values are NaN.

A IEEE Binary64 NaN value has an exponent between 0x7ff and the significand is nonzero. The sign bit is ignored.

#### Note

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal double compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-20    | 2/cycle    |
| power9    | 6       | 1/cycle    |

#### Parameters

|                   |                                             |
|-------------------|---------------------------------------------|
| <code>vf64</code> | a vector of <code>__binary64</code> values. |
|-------------------|---------------------------------------------|

#### Returns

a boolean int, true if all 2 vector double values are NaN.

#### 7.6.4.5 `vec_all_isnormalf64()`

```
static int vec_all_isnormalf64 (
 vf64_t vf64) [inline], [static]
```

Return true if all 2x64-bit vector double values are normal (Not NaN, Inf, denormal, or zero).

A IEEE Binary64 normal value has an exponent between 0x001 and 0x7fe (a 0x7ff indicates NaN or Inf). The significand can be any value (except 0 if the exponent is zero). The sign bit is ignored.

#### Note

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal double compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10-28   | 1/cycle    |
| power9    | 6       | 1/cycle    |

#### Parameters

|                   |                                             |
|-------------------|---------------------------------------------|
| <code>vf64</code> | a vector of <code>__binary64</code> values. |
|-------------------|---------------------------------------------|

**Returns**

a boolean int, true if all 2 vector double values are normal.

**7.6.4.6 vec\_all\_issubnormalf64()**

```
static int vec_all_issubnormalf64 (
 vf64_t vf64) [inline], [static]
```

Return true if all 2x64-bit vector double values are subnormal (denormal).

A IEEE Binary64 subnormal has an exponent of 0x000 and a nonzero significand. The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal double compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10-30   | 1/cycle    |
| power9    | 6       | 1/cycle    |

**Parameters**

|      |                                |
|------|--------------------------------|
| vf64 | a vector of __binary64 values. |
|------|--------------------------------|

**Returns**

a boolean int, true if all of 2 vector double values are subnormal.

**7.6.4.7 vec\_all\_iszerof64()**

```
static int vec_all_iszerof64 (
 vf64_t vf64) [inline], [static]
```

Return true if all 2x64-bit vector double values are +-0.0.

A IEEE Binary64 zero has an exponent of 0x000 and a zero significand. The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal double compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-20    | 2/cycle    |
| power9    | 6       | 1/cycle    |

**Parameters**

|             |                                |
|-------------|--------------------------------|
| <i>vf64</i> | a vector of __binary64 values. |
|-------------|--------------------------------|

**Returns**

a boolean int, true if all 2 vector double values are +/- zero.

**7.6.4.8 vec\_any\_isfinitef64()**

```
static int vec_any_isfinitef64 (
 vf64_t vf64) [inline], [static]
```

Return true if any of 2x64-bit vector double values are Finite (Not NaN nor Inf).

A IEEE Binary64 finite value has an exponent between 0x000 and 0x7fe (a 0x7ff indicates NaN or Inf). The significand can be any value. The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal double compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-20    | 2/cycle    |
| power9    | 6       | 1/cycle    |

**Parameters**

|             |                                |
|-------------|--------------------------------|
| <i>vf64</i> | a vector of __binary64 values. |
|-------------|--------------------------------|

**Returns**

an int containing 0 or 1.



#### 7.6.4.9 vec\_any\_isinff64()

```
static int vec_any_isinff64 (
 vf64_t vf64) [inline], [static]
```

Return true if any of 2x64-bit vector double values are infinity.

A IEEE Binary64 infinity has a exponent of 0x7ff and significand of all zeros.

##### Note

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal double compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-20    | 2/cycle    |
| power9    | 6       | 1/cycle    |

##### Parameters

|             |                                |
|-------------|--------------------------------|
| <i>vf64</i> | a vector of __binary32 values. |
|-------------|--------------------------------|

##### Returns

boolean int, true if any of 2 double values are infinity

#### 7.6.4.10 vec\_any\_isnanf64()

```
static int vec_any_isnanf64 (
 vf64_t vf64) [inline], [static]
```

Return true if any of 2x64-bit vector double values are NaN.

A IEEE Binary64 NaN value has an exponent between 0x7ff and the significand is nonzero. The sign bit is ignored.

##### Note

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal double compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-20    | 2/cycle    |
| power9    | 6       | 1/cycle    |

**Parameters**

|             |                                             |
|-------------|---------------------------------------------|
| <i>vf64</i> | a vector of <code>__binary64</code> values. |
|-------------|---------------------------------------------|

**Returns**

a boolean int, true if any of 2 vector double values are NaN.

**7.6.4.11 `vec_any_isnormalf64()`**

```
static int vec_any_isnormalf64 (
 vf64_t vf64) [inline], [static]
```

Return true if any of 2x64-bit vector double values are normal (Not NaN, Inf, denormal, or zero).

A IEEE Binary64 normal value has an exponent between 0x001 and 0x7fe (a 0x7ff indicates NaN or Inf). The significand can be any value (except 0 if the exponent is zero). The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal double compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-20    | 1/cycle    |
| power9    | 6       | 1/cycle    |

**Parameters**

|             |                                             |
|-------------|---------------------------------------------|
| <i>vf64</i> | a vector of <code>__binary64</code> values. |
|-------------|---------------------------------------------|

**Returns**

a boolean int, true if any of 2 vector double values are normal.

**7.6.4.12 `vec_any_issubnormalf64()`**

```
static int vec_any_issubnormalf64 (
 vf64_t vf64) [inline], [static]
```

Return true if any of 2x64-bit vector double values is subnormal (denormal).

A IEEE Binary64 subnormal has an exponent of 0x000 and a nonzero significand. The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal double compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10-18   | 1/cycle    |
| power9    | 6       | 1/cycle    |

**Parameters**

|             |                                |
|-------------|--------------------------------|
| <i>vf64</i> | a vector of __binary64 values. |
|-------------|--------------------------------|

**Returns**

true if any of 2 vector double values are subnormal.

**7.6.4.13 vec\_any\_iszerof64()**

```
static int vec_any_iszerof64 (
 vf64_t vf64) [inline], [static]
```

Return true if any of 2x64-bit vector double values are +-0.0.

A IEEE Binary64 zero has an exponent of 0x000 and a zero significand. The sign bit is ignored.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal double compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-20    | 2/cycle    |
| power9    | 6       | 1/cycle    |

**Parameters**

|             |                                |
|-------------|--------------------------------|
| <i>vf64</i> | a vector of __binary64 values. |
|-------------|--------------------------------|

**Returns**

a boolean int, true if any of 2 vector double values are +/- zero.

#### 7.6.4.14 vec\_copysignf64()

```
static vf64_t vec_copysignf64 (
 vf64_t vf64x,
 vf64_t vf64y) [inline], [static]
```

Copy the sign bit from vf64y merged with magnitude from vf64x and return the resulting vector double values.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-7     | 2/cycle    |
| power9    | 2       | 2/cycle    |

##### Parameters

|       |                                                 |
|-------|-------------------------------------------------|
| vf64x | vector double values containing the magnitudes. |
| vf64y | vector double values containing the sign bits.  |

##### Returns

vector double values with magnitude from vf64x and the sign of vf64y.

#### 7.6.4.15 vec\_isfinitef64()

```
static vb64_t vec_isfinitef64 (
 vf64_t vf64) [inline], [static]
```

Return 2x64-bit vector boolean true values for each double element that is Finite (Not NaN nor Inf).

A IEEE Binary64 finite value has an exponent between 0x000 and 0x7fe (a 0x7ff indicates NaN or Inf). The significand can be any value.

Using the vec\_cmpeq conditional to generate the predicate mask for NaN / Inf and then invert this for the finite condition. The sign bit is ignored.

##### Note

This function will not raise VXSNAN or VXVC (FE\_INVALID) exceptions. A normal double compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-15    | 2/cycle    |
| power9    | 5       | 2/cycle    |

**Parameters**

|                   |                                             |
|-------------------|---------------------------------------------|
| <code>vf64</code> | a vector of <code>__binary64</code> values. |
|-------------------|---------------------------------------------|

**Returns**

a vector boolean long, each containing all 0s(false) or 1s(true).

**7.6.4.16 vec\_isinff64()**

```
static vb64_t vec_isinff64 (
 vf64_t vf64) [inline], [static]
```

Return 2x64-bit vector boolean true values for each double, if infinity.

A IEEE Binary64 infinity has a exponent of 0x7ff and significand of all zeros.

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal double compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-13    | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|                   |                                             |
|-------------------|---------------------------------------------|
| <code>vf64</code> | a vector of <code>__binary64</code> values. |
|-------------------|---------------------------------------------|

**Returns**

a vector boolean long long, each containing all 0s(false) or 1s(true).

**7.6.4.17 vec\_isnanf64()**

```
static vb64_t vec_isnanf64 (
 vf64_t vf64) [inline], [static]
```

Return 2x64-bit vector boolean true values, for each double NaN value.

A IEEE Binary64 NaN value has an exponent between 0x7ff and the significand is nonzero. The sign bit is ignored.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-13    | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|             |                                |
|-------------|--------------------------------|
| <i>vf64</i> | a vector of __binary64 values. |
|-------------|--------------------------------|

**Returns**

a vector boolean long long, each containing all 0s(false) or 1s(true).

**7.6.4.18 vec\_isnormalf64()**

```
static vb64_t vec_isnormalf64 (
 vf64_t vf64) [inline], [static]
```

Return 2x64-bit vector boolean true values, for each double value, if normal (Not NaN, Inf, denormal, or zero).

A IEEE Binary64 normal value has an exponent between 0x001 and 0x7ffe (a 0x7ff indicates NaN or Inf). The significand can be any value (except 0 if the exponent is zero).

**Note**

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal double compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-15    | 1/cycle    |
| power9    | 5       | 1/cycle    |

**Parameters**

|             |                                |
|-------------|--------------------------------|
| <i>vf64</i> | a vector of __binary64 values. |
|-------------|--------------------------------|

**Returns**

a vector boolean long long, each containing all 0s(false) or 1s(true).

#### 7.6.4.19 vec\_issubnormalf64()

```
static vb64_t vec_issubnormalf64 (
 vf64_t vf64) [inline], [static]
```

Return 2x64-bit vector boolean true values, for each double value that is subnormal (denormal).

A IEEE Binary64 subnormal has an exponent of 0x000 and a nonzero significand. The sign bit is ignored.

##### Note

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal double compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-16    | 1/cycle    |
| power9    | 3       | 1/cycle    |

##### Parameters

|             |                                |
|-------------|--------------------------------|
| <i>vf64</i> | a vector of __binary64 values. |
|-------------|--------------------------------|

##### Returns

a vector boolean long long, each containing all 0s(false) or 1s(true).

#### 7.6.4.20 vec\_iszerof64()

```
static vb64_t vec_iszerof64 (
 vf64_t vf64) [inline], [static]
```

Return 2x64-bit vector boolean true values, for each double value that is +-0.0.

A IEEE Binary64 zero has an exponent of 0x000 and a zero significand. The sign bit is ignored.

##### Note

This function will not raise VXSNaN or VXVC (FE\_INVALID) exceptions. A normal double compare can.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-13    | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|             |                                             |
|-------------|---------------------------------------------|
| <i>vf64</i> | a vector of <code>__binary32</code> values. |
|-------------|---------------------------------------------|

**Returns**

a vector boolean int, each containing all 0s(false) or 1s(true).

**7.6.4.21 `vec_pack_longdouble()`**

```
static long double vec_pack_longdouble (
 vf64_t lval) [inline], [static]
```

Copy the pair of doubles from a vector to IBM long double.

**Parameters**

|             |                                                      |
|-------------|------------------------------------------------------|
| <i>lval</i> | vector double values containing the IBM long double. |
|-------------|------------------------------------------------------|

**Returns**

IBM long double as FPR pair.

**7.6.4.22 `vec_unpack_longdouble()`**

```
static vf64_t vec_unpack_longdouble (
 long double lval) [inline], [static]
```

Copy the pair of doubles from a IBM long double to a vector double.

**Parameters**

|             |                              |
|-------------|------------------------------|
| <i>lval</i> | IBM long double as FPR pair. |
|-------------|------------------------------|

**Returns**

vector double values containing the IBM long double.



## 7.7 src/pveclib/vec\_int128\_ppc.h File Reference

Header package containing a collection of 128-bit computation functions implemented with PowerISA VMX and VSX instructions.

```
#include <pveclib/vec_common_ppc.h>
#include <pveclib/vec_int64_ppc.h>
```

### Macros

- #define [CONST\\_VUINT128\\_QxW](#)(\_\_q0, \_\_q1, \_\_q2, \_\_q3)  
*Generate a vector unsigned \_\_int128 constant from words.*
- #define [CONST\\_VUINT128\\_QxD](#)(\_\_q0, \_\_q1)  
*Generate a vector unsigned \_\_int128 constant from doublewords.*
- #define [CONST\\_VUINT128\\_Qx19d](#)(\_\_q0, \_\_q1)  
*Generate a vector unsigned \_\_int128 constant from doublewords.*
- #define [CONST\\_VUINT128\\_Qx18d](#)(\_\_q0, \_\_q1)  
*Generate a vector unsigned \_\_int128 constant from doublewords.*
- #define [CONST\\_VUINT128\\_Qx16d](#)(\_\_q0, \_\_q1)  
*Generate a vector unsigned \_\_int128 constant from doublewords.*

### Functions

- static [vui128\\_t vec\\_absduq](#) (vui128\_t vra, vui128\_t vrb)  
*Vector Absolute Difference Unsigned Quadword.*
- static [vui128\\_t vec\\_avguq](#) (vui128\_t vra, vui128\_t vrb)  
*Vector Average Unsigned Quadword.*
- static [vui128\\_t vec\\_addcuq](#) (vui128\_t a, vui128\_t b)  
*Vector Add & write Carry Unsigned Quadword.*
- static [vui128\\_t vec\\_addecuq](#) (vui128\_t a, vui128\_t b, vui128\_t ci)  
*Vector Add Extended & write Carry Unsigned Quadword.*
- static [vui128\\_t vec\\_addeuqm](#) (vui128\_t a, vui128\_t b, vui128\_t ci)  
*Vector Add Extended Unsigned Quadword Modulo.*
- static [vui128\\_t vec\\_adduqm](#) (vui128\_t a, vui128\_t b)  
*Vector Add Unsigned Quadword Modulo.*
- static [vui128\\_t vec\\_addcq](#) (vui128\_t \*cout, vui128\_t a, vui128\_t b)  
*Vector Add with carry Unsigned Quadword.*
- static [vui128\\_t vec\\_addeq](#) (vui128\_t \*cout, vui128\_t a, vui128\_t b, vui128\_t ci)  
*Vector Add Extend with carry Unsigned Quadword.*
- static [vui128\\_t vec\\_clzq](#) (vui128\_t vra)  
*Vector Count Leading Zeros Quadword.*
- static [vui128\\_t vec\\_cmpeqsq](#) (vui128\_t vra, vui128\_t vrb)  
*Vector Compare Equal Signed Quadword.*
- static [vui128\\_t vec\\_cmpequq](#) (vui128\_t vra, vui128\_t vrb)  
*Vector Compare Equal Unsigned Quadword.*

- static `vb128_t vec_cmpgesq` (`vi128_t vra`, `vi128_t vrb`)  
*Vector Compare Greater Than or Equal Signed Quadword.*
- static `vb128_t vec_cmpgeuq` (`vui128_t vra`, `vui128_t vrb`)  
*Vector Compare Greater Than or Equal Unsigned Quadword.*
- static `vb128_t vec_cmpgtsq` (`vi128_t vra`, `vi128_t vrb`)  
*Vector Compare Greater Than Signed Quadword.*
- static `vb128_t vec_cmpgtuq` (`vui128_t vra`, `vui128_t vrb`)  
*Vector Compare Greater Than Unsigned Quadword.*
- static `vb128_t vec_cmplesq` (`vi128_t vra`, `vi128_t vrb`)  
*Vector Compare Less Than or Equal Signed Quadword.*
- static `vb128_t vec_cmpleuq` (`vui128_t vra`, `vui128_t vrb`)  
*Vector Compare Less Than or Equal Unsigned Quadword.*
- static `vb128_t vec_cmpltsq` (`vi128_t vra`, `vi128_t vrb`)  
*Vector Compare Less Than Signed Quadword.*
- static `vb128_t vec_cmpltuq` (`vui128_t vra`, `vui128_t vrb`)  
*Vector Compare Less Than Unsigned Quadword.*
- static `vb128_t vec_cmpnesq` (`vi128_t vra`, `vi128_t vrb`)  
*Vector Compare Equal Signed Quadword.*
- static `vb128_t vec_cmpneuq` (`vui128_t vra`, `vui128_t vrb`)  
*Vector Compare Not Equal Unsigned Quadword.*
- static int `vec_cmpsq_all_eq` (`vi128_t vra`, `vi128_t vrb`)  
*Vector Compare all Equal Signed Quadword.*
- static int `vec_cmpsq_all_ge` (`vi128_t vra`, `vi128_t vrb`)  
*Vector Compare any Greater Than or Equal Signed Quadword.*
- static int `vec_cmpsq_all_gt` (`vi128_t vra`, `vi128_t vrb`)  
*Vector Compare any Greater Than Signed Quadword.*
- static int `vec_cmpsq_all_le` (`vi128_t vra`, `vi128_t vrb`)  
*Vector Compare any Less Than or Equal Signed Quadword.*
- static int `vec_cmpsq_all_lt` (`vi128_t vra`, `vi128_t vrb`)  
*Vector Compare any Less Than Signed Quadword.*
- static int `vec_cmpsq_all_ne` (`vi128_t vra`, `vi128_t vrb`)  
*Vector Compare all Not Equal Signed Quadword.*
- static int `vec_cmpuq_all_eq` (`vui128_t vra`, `vui128_t vrb`)  
*Vector Compare all Equal Unsigned Quadword.*
- static int `vec_cmpuq_all_ge` (`vui128_t vra`, `vui128_t vrb`)  
*Vector Compare any Greater Than or Equal Unsigned Quadword.*
- static int `vec_cmpuq_all_gt` (`vui128_t vra`, `vui128_t vrb`)  
*Vector Compare any Greater Than Unsigned Quadword.*
- static int `vec_cmpuq_all_le` (`vui128_t vra`, `vui128_t vrb`)  
*Vector Compare any Less Than or Equal Unsigned Quadword.*
- static int `vec_cmpuq_all_lt` (`vui128_t vra`, `vui128_t vrb`)  
*Vector Compare any Less Than Unsigned Quadword.*
- static int `vec_cmpuq_all_ne` (`vui128_t vra`, `vui128_t vrb`)  
*Vector Compare all Not Equal Unsigned Quadword.*
- static `vui128_t vec_cmul10ecuq` (`vui128_t *cout`, `vui128_t a`, `vui128_t cin`)  
*Vector combined Multiply by 10 Extended & write Carry Unsigned Quadword.*
- static `vui128_t vec_cmul10cuq` (`vui128_t *cout`, `vui128_t a`)

- Vector combined Multiply by 10 & write Carry Unsigned Quadword.*

  - static `vi128_t vec_divsq_10e31` (`vi128_t` vra)
- Vector Divide by const 10e31 Signed Quadword.*

  - static `vui128_t vec_divudq_10e31` (`vui128_t` \*qh, `vui128_t` vra, `vui128_t` vrb)
- Vector Divide Unsigned Double Quadword by const 10e31.*

  - static `vui128_t vec_divudq_10e32` (`vui128_t` \*qh, `vui128_t` vra, `vui128_t` vrb)
- Vector Divide Unsigned Double Quadword by const 10e32.*

  - static `vui128_t vec_divuq_10e31` (`vui128_t` vra)
- Vector Divide by const 10e31 Unsigned Quadword.*

  - static `vui128_t vec_divuq_10e32` (`vui128_t` vra)
- Vector Divide by const 10e32 Unsigned Quadword.*

  - static `vi128_t vec_maxsq` (`vi128_t` vra, `vi128_t` vrb)
- Vector Maximum Signed Quadword.*

  - static `vui128_t vec_maxuq` (`vui128_t` vra, `vui128_t` vrb)
- Vector Maximum Unsigned Quadword.*

  - static `vi128_t vec_minsq` (`vi128_t` vra, `vi128_t` vrb)
- Vector Minimum Signed Quadword.*

  - static `vui128_t vec_minuq` (`vui128_t` vra, `vui128_t` vrb)
- Vector Minimum Unsigned Quadword.*

  - static `vi128_t vec_modsq_10e31` (`vi128_t` vra, `vi128_t` q)
- Vector Modulo by const 10e31 Signed Quadword.*

  - static `vui128_t vec_modudq_10e31` (`vui128_t` vra, `vui128_t` vrb, `vui128_t` \*ql)
- Vector Modulo Unsigned Double Quadword by const 10e31.*

  - static `vui128_t vec_modudq_10e32` (`vui128_t` vra, `vui128_t` vrb, `vui128_t` \*ql)
- Vector Modulo Unsigned Double Quadword by const 10e32.*

  - static `vui128_t vec_moduq_10e31` (`vui128_t` vra, `vui128_t` q)
- Vector Modulo by const 10e31 Unsigned Quadword.*

  - static `vui128_t vec_moduq_10e32` (`vui128_t` vra, `vui128_t` q)
- Vector Modulo by const 10e32 Unsigned Quadword.*

  - static `vui128_t vec_mul10cuq` (`vui128_t` a)
- Vector Multiply by 10 & write Carry Unsigned Quadword.*

  - static `vui128_t vec_mul10ecuq` (`vui128_t` a, `vui128_t` cin)
- Vector Multiply by 10 Extended & write Carry Unsigned Quadword.*

  - static `vui128_t vec_mul10euq` (`vui128_t` a, `vui128_t` cin)
- Vector Multiply by 10 Extended Unsigned Quadword.*

  - static `vui128_t vec_mul10uq` (`vui128_t` a)
- Vector Multiply by 10 Unsigned Quadword.*

  - static `vui128_t vec_cmul100cuq` (`vui128_t` \*cout, `vui128_t` a)
- Vector combined Multiply by 100 & write Carry Unsigned Quadword.*

  - static `vui128_t vec_cmul100ecuq` (`vui128_t` \*cout, `vui128_t` a, `vui128_t` cin)
- Vector combined Multiply by 100 Extended & write Carry Unsigned Quadword.*

  - static `vui128_t vec_msumudm` (`vui64_t` a, `vui64_t` b, `vui128_t` c)
- Vector Multiply-Sum Unsigned Doubleword Modulo.*

  - static `vui128_t vec_muleud` (`vui64_t` a, `vui64_t` b)
- Vector Multiply Even Unsigned Doublewords.*

  - static `vui64_t vec_mulhud` (`vui64_t` vra, `vui64_t` vrb)
- Vector Multiply High Unsigned Doubleword.*

- static [vui128\\_t vec\\_muloud](#) ([vui64\\_t](#) a, [vui64\\_t](#) b)  
*Vector Multiply Odd Unsigned Doublewords.*
- static [vui64\\_t vec\\_muludm](#) ([vui64\\_t](#) vra, [vui64\\_t](#) vrb)  
*Vector Multiply Unsigned Doubleword Modulo.*
- static [vui128\\_t vec\\_mulhuq](#) ([vui128\\_t](#) a, [vui128\\_t](#) b)  
*Vector Multiply High Unsigned Quadword.*
- static [vui128\\_t vec\\_mulluq](#) ([vui128\\_t](#) a, [vui128\\_t](#) b)  
*Vector Multiply Low Unsigned Quadword.*
- static [vui128\\_t vec\\_muludq](#) ([vui128\\_t](#) \*mulu, [vui128\\_t](#) a, [vui128\\_t](#) b)  
*Vector Multiply Unsigned Double Quadword.*
- static [vui128\\_t vec\\_madduq](#) ([vui128\\_t](#) \*mulu, [vui128\\_t](#) a, [vui128\\_t](#) b, [vui128\\_t](#) c)  
*Vector Multiply-Add Unsigned Quadword.*
- static [vui128\\_t vec\\_madd2uq](#) ([vui128\\_t](#) \*mulu, [vui128\\_t](#) a, [vui128\\_t](#) b, [vui128\\_t](#) c1, [vui128\\_t](#) c2)  
*Vector Multiply-Add2 Unsigned Quadword.*
- static [vui128\\_t vec\\_popcntq](#) ([vui128\\_t](#) vra)  
*Vector Population Count Quadword.*
- static [vui128\\_t vec\\_revbq](#) ([vui128\\_t](#) vra)  
*Vector Byte Reverse Quadword.*
- static [vui128\\_t vec\\_rlq](#) ([vui128\\_t](#) vra, [vui128\\_t](#) vrb)  
*Vector Rotate Left Quadword.*
- static [vui128\\_t vec\\_rlqi](#) ([vui128\\_t](#) vra, const unsigned int shb)  
*Vector Rotate Left Quadword Immediate.*
- static [vui128\\_t vec\\_setb\\_cyq](#) ([vui128\\_t](#) vcy)  
*Vector Set Bool from Quadword Carry.*
- static [vui128\\_t vec\\_setb\\_ncq](#) ([vui128\\_t](#) vcy)  
*Vector Set Bool from Quadword not Carry.*
- static [vui128\\_t vec\\_setb\\_sq](#) ([vui128\\_t](#) vra)  
*Vector Set Bool from Signed Quadword.*
- static [vui128\\_t vec\\_sldq](#) ([vui128\\_t](#) vrw, [vui128\\_t](#) vrx, [vui128\\_t](#) vrb)  
*Vector Shift Left Double Quadword.*
- static [vui128\\_t vec\\_sldqi](#) ([vui128\\_t](#) vrw, [vui128\\_t](#) vrx, const unsigned int shb)  
*Vector Shift Left Double Quadword Immediate.*
- static [vui128\\_t vec\\_slq](#) ([vui128\\_t](#) vra, [vui128\\_t](#) vrb)  
*Vector Shift Left Quadword.*
- static [vui128\\_t vec\\_slqi](#) ([vui128\\_t](#) vra, const unsigned int shb)  
*Vector Shift Left Quadword Immediate.*
- static [vui128\\_t vec\\_sraq](#) ([vui128\\_t](#) vra, [vui128\\_t](#) vrb)  
*Vector Shift Right Algebraic Quadword.*
- static [vui128\\_t vec\\_sraqi](#) ([vui128\\_t](#) vra, const unsigned int shb)  
*Vector Shift Right Algebraic Quadword Immediate.*
- static [vui128\\_t vec\\_srqi](#) ([vui128\\_t](#) vra, [vui128\\_t](#) vrb)  
*Vector Shift Right Quadword.*
- static [vui128\\_t vec\\_srqi](#) ([vui128\\_t](#) vra, const unsigned int shb)  
*Vector Shift Right Quadword Immediate.*
- static [vui128\\_t vec\\_slq4](#) ([vui128\\_t](#) vra)
- static [vui128\\_t vec\\_slq5](#) ([vui128\\_t](#) vra)
- static [vui128\\_t vec\\_sq4](#) ([vui128\\_t](#) vra)

- static `vui128_t vec_sr5` (`vui128_t vra`)
- static `vui128_t vec_subcuq` (`vui128_t vra`, `vui128_t vrb`)  
*Vector Subtract and Write Carry Unsigned Quadword.*
- static `vui128_t vec_subecuq` (`vui128_t vra`, `vui128_t vrb`, `vui128_t vrc`)  
*Vector Subtract Extended and Write Carry Unsigned Quadword.*
- static `vui128_t vec_subeuqm` (`vui128_t vra`, `vui128_t vrb`, `vui128_t vrc`)  
*Vector Subtract Extended Unsigned Quadword Modulo.*
- static `vui128_t vec_subuqm` (`vui128_t vra`, `vui128_t vrb`)  
*Vector Subtract Unsigned Quadword Modulo.*
- static `vui128_t vec_vmuleud` (`vui64_t a`, `vui64_t b`)  
*Vector Multiply Even Unsigned Doublewords.*
- static `vui128_t vec_vmaddeud` (`vui64_t a`, `vui64_t b`, `vui64_t c`)  
*Vector Multiply-Add Even Unsigned Doublewords.*
- static `vui128_t vec_vmadd2eud` (`vui64_t a`, `vui64_t b`, `vui64_t c`, `vui64_t d`)  
*Vector Multiply-Add2 Even Unsigned Doublewords.*
- static `vui128_t vec_vmuloud` (`vui64_t a`, `vui64_t b`)  
*Vector Multiply Odd Unsigned Doublewords.*
- static `vui128_t vec_vmaddoud` (`vui64_t a`, `vui64_t b`, `vui64_t c`)  
*Vector Multiply-Add Odd Unsigned Doublewords.*
- static `vui128_t vec_vmadd2oud` (`vui64_t a`, `vui64_t b`, `vui64_t c`, `vui64_t d`)  
*Vector Multiply-Add2 Odd Unsigned Doublewords.*
- static `vui128_t vec_vmsumeud` (`vui64_t a`, `vui64_t b`, `vui128_t c`)  
*Vector Multiply-Sum Even Unsigned Doublewords.*
- static `vui128_t vec_vmsumoud` (`vui64_t a`, `vui64_t b`, `vui128_t c`)  
*Vector Multiply-Sum Odd Unsigned Doublewords.*

### 7.7.1 Detailed Description

Header package containing a collection of 128-bit computation functions implemented with PowerISA VMX and VSX instructions.

Some of these operations are implemented in a single instruction on newer (POWER8/POWER9) processors. This header serves to fill in functional gaps for older (POWER7, POWER8) processors and provides a in-line assembler implementation for older compilers that do not provide the build-ins. Other operations do not exist as instructions on any current processor but are useful and should be provided. This header serves to provide these operations as inline functions using existing vector built-ins or other pveclib operations.

The original VMX (AKA AltiVec) only defined a few instructions that operated on the 128-bit vector as a whole. This included the vector shift left/right (bit), vector shift left/right by octet (byte), vector shift left double by octet (select a contiguous 16-bytes from 2 concatenated vectors) 256-bit), and generalized vector permute (select any 16-bytes from 2 concatenated vectors). Use of these instructions can be complicated when;

- the shift amount is more than 8 bits,
- the shift amount is not a multiple of 8-bits (octet),
- the shift amount is a constant and needs to be generated/loaded before use.

These instructions can be used in combination to provide generalized vector `__int128` shift/rotate operations. `pvecLib` uses these operations to provide vector `__int128` shift / rotate left, shift right and shift algebraic right operations. These operations require pre-conditions to avoid multiple instructions or require a combination of (bit and octet shift) instructions to get the quadword result. The compiler `<altivec.h>` built-ins only supports individual instructions. So using these operations quickly inspires a need for a header (like this) to contain implementations of the common operations.

The VSX facility (introduced with POWER7) did not add any integer doubleword (64-bit) or quadword (128-bit) operations. However it did add a useful doubleword permute immediate and word wise; merge, shift, and splat immediate operations. Otherwise vector `__int128` (128-bit elements) operations have to be implemented using VMX word and halfword element integer operations for POWER7.

POWER8 added multiply word operations that produce the full doubleword product and full quadword add / subtract (with carry extend). The add quadword is useful to sum the partial products for a full 128 x 128-bit multiply. The add quadword write carry and extend forms, simplify extending arithmetic to 256-bits and beyond.

While POWER8 provided quadword integer add and subtract operations, it did not provide quadword Signed/Unsigned integer compare operations. It is possible to implement quadword compare operations using existing word / doubleword compares and the new quadword subtract write-carry operation. The trick is to convert the carry into a vector bool `__int128` via the `vec_setb_ncq()` operation. This header provides easy to use quadword compare operations.

POWER9 (PowerISA 3.0B) adds the **Vector Multiply-Sum unsigned Doubleword Modulo** instruction. Aspects of this instruction mean it needs to be used carefully as part of larger quadword multiply. It performs only two of the four required doubleword multiplies. The final quadword modulo sum will discard any overflow/carry from the potential 130-bit result. With careful pre-conditioning of doubleword inputs the results are can not overflow from 128-bits. Then separate add quadword add/write carry operations can be used to complete the sum of partial products. These techniques are used in the POWER9 specific implementations of `vec_muleud`, `vec_muloud`, `vec_mulluq`, and `vec_muludq`.

PowerISA 3.0B also defined additional: Binary Coded Decimal (BCD) and Zoned character format conversions. String processing operations. Vector Parity operations. Integer Extend Sign Operations. Integer Absolute Difference Operations. All of these seem to be useful additions to `pvecLib` for older (POWER7/8) processors and across element sizes (including quadword elements).

Most of these intrinsic (compiler built-in) operations are defined in `<altivec.h>` and described in the compiler documentation. However it took several compiler releases for all the new POWER8 64-bit and 128-bit integer vector intrinsics to be added to **altivec.h**. This support started with the GCC 4.9 but was not complete across function/type and bug free until GCC 6.0.

#### Note

The compiler disables associated `<altivec.h>` built-ins if the **mcpu** target does not enable the specific instruction. For example, if you compile with **-mcpu=power7**, `vec_vadduqm` and `vec_vsubudm` will not be defined. But `vec_↵_adduqm()` and `vec_subudm()` and always be defined in this header, will generate the minimum code, appropriate for the target, and produce correct results.

Most of these operations are implemented in a single instruction on newer (POWER8/POWER9) processors. So this header serves to fill in functional gaps for older (POWER7, POWER8) processors and provides a in-line assembler implementation for older compilers that do not provide the built-ins.

This header covers operations that are either:

- Operations implemented in hardware instructions for later processors and useful to programmers, on slightly older processors, even if the equivalent function requires more instructions. Examples include quadword byte reverse, add and subtract.

- Defined in the OpenPOWER ABI but *not* yet defined in `<altivec.h>` provided by available compilers in common use. Examples include quadword byte reverse, add and subtract.
- Are commonly used operations, not covered by the ABI or `<altivec.h>`, and require multiple instructions or are not obvious. Examples include quadword Signed and Unsigned compare, shift immediate, multiply, multiply by 10 immediate, count leading zeros and population count.

#### Note

The Multiply sum/even/odd doubleword operations are currently implemented here (in `<vec_int128_ppc.h>`) which resolves a dependency on Add Quadword. These functions (`vec_msumudm`, `vec_muleud`, `vec_muloud`) all produce a quadword results and may use the `vec_adduqm` implementation to sum partial products.

See [Returning extended quadword results](#). for more background on extended quadword computation.

### 7.7.2 Endian problems with quadword implementations

Technically operations on quadword elements should not require any endian specific transformation. There is only one element so there can be no confusion about element numbering or order. However some of the more complex quadword operations are constructed from operations on smaller elements. And those operations as provided by `<altivec.h>` are required by the OpenPOWER ABI to be endian sensitive. See [Endian problems with doubleword operations](#) for a more detailed discussion.

In any case the arithmetic (high to low) order of bits in a quadword are defined in the PowerISA (See `vec_adduqm()` and `vec_subuqm()`). So pveclib implementations will need to either:

- Nullify little endian transforms of `<altivec.h>` operations. The `<altivec.h>` built-ins `vec_muleuw()`, `vec_mulouw()`, `vec_mergel()`, and `vec_mergeh()` are endian sensitive and often require nullification that restores the original operation.
- Use new operations that are specifically defined to be stable across BE/LE implementations. The pveclib operations; `vec_vmuleud()` `vec_vmuloud()`, `vec_mrgahd()`, `vec_mrgald()`. and `vec_permdi()` are defined to be endian stable.

#### 7.7.2.1 Quadword Integer Constants

The compilers may not support 128-bit integers for constants and `printf` (integer to ascii). For example GCC provides ANSI mandated constant and runtime support for integers up to long long which for PowerPC is only 64-bit.

The `__int128` type is an extension that provides basic arithmetic operations but does not compile 128-bit constants or support `printf` formatting for integers larger than long long. The following section provides examples and work around's for these restrictions.

The GCC compiler allows integer constants to be assigned/cast to `__int128` types. The support also allows `__int128` constants to be assigned/cast to vector `__int128` types. So the following are allowed:

```

const vui128_t vec128_zeros = {(vui128_t) ((unsigned __int128) 0)};
const vui128_t vec128_10 = {(vui128_t) ((unsigned __int128) 10)};
const vui128_t vec128_10to16 = {(vui128_t) ((unsigned __int128)
 100000000000000000UL)};
const vui128_t vec128_maxLong = {(vui128_t) ((unsigned __int128)
 __INT64_MAX_)};
const vui128_t vec128_max_Long = {(vui128_t) ((unsigned __int128)
 0x7fffffffffffffffffL)};
// -1 signed extended to __int128 is 0xFFFF...FFF
const vui128_t vec128_foxes = {(vui128_t) ((__int128) -1L)};

```

It gets more complicated when the constant exceeds the range of a long long value. For example the magic numbers for the multiplicative inverse described in [Printing Vector \\_\\_int128 values](#). The decimal integer constant we need for the quadword multiplier is "76624777043294442917917351357515459181" or the equivalent hexadecimal value "0x39a5652fb1137856d30baf9a1e626a6d". GCC does not allow constants this large to be expressed directly.

GCC supports aggregate initializer lists for the elements of vectors. For example:

```
vui32_t xyzw = (vector<int>) { 1, 2, 3, 4 };
```

So it is possible to compose a quadword constant by initializing a vector of word or doubleword elements then casting the result to a quadword type. For example:

```

const vui128_t invmul = (vui128_t) (vector<unsigned long long>
 { 0x39a5652fb1137856UL, 0xd30baf9a1e626a6dUL });

```

or

```

const vui128_t invmul = (vui128_t) (vector<unsigned int>
 { 0x39a5652f, 0xb1137856, 0xd30baf9a, 0x1e626a6d });

```

There is one small problem with this as element order is endian dependent, while a vector quadword integer is always big endian. So we would need to adjust the element order for endian. For example:

```

const vui128_t invmul = (vui128_t) (vector<unsigned long long>
#ifdef __BYTE_ORDER__ == __ORDER_LITTLE_ENDIAN__
 { 0xd30baf9a1e626a6dUL, 0x39a5652fb1137856UL });
#else
 { 0x39a5652fb1137856UL, 0xd30baf9a1e626a6dUL });
#endif

```

or

```

const vui128_t invmul = (vui128_t) (vector<unsigned int>
#ifdef __BYTE_ORDER__ == __ORDER_LITTLE_ENDIAN__
 { 0x1e626a6d, 0xd30baf9a, 0xb1137856, 0x39a5652f });
#else
 { 0x39a5652f, 0xb1137856, 0xd30baf9a, 0x1e626a6d });
#endif

```

Remembering to add the endian correction for constants used quadword operations is an issue and manually reversing the element order can be error prone. There should be an easier way.





### 7.7.3 Some facts about fixed precision integers

The transition from grade school math to computer programming requires the realization that computers handle numbers in fixed sized chunks. For the PowerISA these chunks are byte, halfword, word, doubleword, and quadword. While computer languages like "C" have integer types like char, short, int, long int, and `__int128`.

Happily these chunks are large enough to hold the equivalent of several decimal digits and handle most of the grotty details of multiply, divide, add, and subtract. But sometimes the chunk (used) is not large enough to hold all the digits you need. Sums may overflow and multiplies may be truncated (modulo the chunk size).

Sometimes we can simply switch to the next larger size (int to long, word to doubleword) and avoid the problem (overflow of sums or truncation of multiply). But sometimes the largest chunk the compiler or hardware supports is still not large enough for the numbers we are dealing with. This requires *multiple precision arithmetic* which works a lot like grade school arithmetic but with larger digits represented by the most convenient computer sized chunk.

Most programmers would prefer to use an existing *multiple precision arithmetic* library and move on. Existing libraries are implemented with scalar instructions and loops over storage arrays. But here we need to provide vector quadword multiply and extended quadword add/subtract operations. Any transfers between the libraries multi-precision storage arrays and vector registers are likely to exceed the timing for a direct vector implementation.

#### Note

The PowerISA 2.07 provides direct vector quadword integer add/subtract with carry/extend. PowerISA 3.0 provides unsigned doubleword multiply with quadword product. This exceeds the capability of the PowerISA 64-bit (doubleword) Fixed Point unit which requires multiple instructions to generate quadword results.

We also want to provide the basis for general *multiple quadword precision arithmetic* operations (see [vec\\_int512\\_ppc](#)[↔h](#)). And for security implementations requiring large multiply products we are motivated to leverage the PowerISA large vector register set to avoid exposing these results (and partial products) to memory/cache side channel attacks.

#### 7.7.3.1 Some useful arithmetic facts (you may of forgotten)

First multiplying a M-digits by N-digits number requires up to (M+N)-digits to store the result. This is true independent of the size of your digit, including decimal, hexadecimal, and computer words/doublewords/quadwords. This explains why a 32-bit (word) by 32-bit integer multiply product is either:

- Truncated (modulo) to 32-bits, potentially losing the high order precision.
- Expanded to the next larger (double) size (in this case 64-bit doubleword).

The hardware has to one or the other.

Let's look at some examples of multiplying two maximal 4-digit numbers:

```
Decimal: 9999 x 9999 = 99980001
Hexadecimal: FFFF x FFFF = FFFE0001
```

And to drive home the point, let's look at the case of multiplying two maximal (32-bit word) 4-digit numbers:

```
quadword: FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
x FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
= FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFE
00000000 00000000 00000000 00000001
```

This is also a (128-bit quadword) digit multiply with a (256-bit) 2 quadword digit result.

Adding asymmetric example; 4-digit by 1 digit multiply:

```
Decimal: 9999 x 9 = 89991
Hexadecimal: FFFF x F = EFFF1
quadword: FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
x FFFFFFFF
= FFFFFFFE FFFFFFFF FFFFFFFF FFFFFFFF 00000001
```

This pattern repeats across the all digit bases/size and values of M, N.

Note that the product is not the maximum value for the product width. It seem the product leave *room* to add another digit or two without overflowing the double wide product. Lets try some 4 digit examples by adding a maximal 4 digit value to the product.

```
Decimal: 9999 x 9999 = 99980001
 + 9999
 = 99990000

Hexadecimal: FFFF x FFFF = FFFE0001
 + FFFF
 = FFFF0000
```

Looks like there is still room in the double wide product to add another maximal 4 digit value.

```
Decimal: 9999 x 9999 = 99980001
 + 9999
 + 9999
 = 99999999

Hexadecimal: FFFF x FFFF = FFFE0001
 + FFFF
 + FFFF
 = FFFFFFFF
```

But any more then that would cause a overflow.

Now we should look addends to asymmetric multiply. For example 4-digit by 1 digit multiply:

```
Decimal: 9999 x 9 = 89991
 + 9999
 + 9
 = 99999
Hexadecimal: FFFF x F = EFFF1
 + FFFF
 + F
 = FFFFF
quadword: FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
x FFFFFFFF
= FFFFFFFE FFFFFFFF FFFFFFFF FFFFFFFF 00000001
+ FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
+ FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
= FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
```

Note that when M not equal N then the addends are restrict to size M and/or size N. Two addends of the larger multiplier size can overflow. This pattern repeats across the all digit bases/sizes and values of M, N. For the binary fixed pointer multiply-add or bit sizes M/N we can write the equation:

$$(2^{(M+N)} - 1) = ((2^M - 1) * (2^N - 1)) + (2^M - 1) + (2^N - 1)$$

Or in terms of fixed sized "words" of W-bits and M by N words.

$$(2^{(W*(M+N))} - 1) = ((2^{(W*M)} - 1) * (2^{(W*N)} - 1)) + (2^{(W*M)} - 1) + (2^{(W*N)} - 1)$$

### 7.7.3.2 Why does this matter?

Because with modern hardware the actual multiply operations are faster and have less impact while the summation across the partial products becomes the major bottleneck. For recent POWER processors fixed-point are 5-7 cycles latency and dual issue (2/cycle). These multiplies are only dependent on the inputs (multiplicands). This allows the compiler and (super-scalar processor) to schedule the multiply operations early to prepare for summation. In many cases the 3rd and 4th multiplies are complete before the summation of the first two multiplies completes.

The add operations involved in partial product summation are dependent on the current column multiply and the high order word of summation of the previous stage. While add operations are nominally faster (2-3 cycles) than multiplies, they can generate carries that have to be propagated.

The Fixed-Point Unit has a dedicated *carry-bit (CA)* which becomes the critical resource. This dependency on the carry (in addition to the column multiply and previous summation) limits the compiler's (and hardware's) ability to parallelize stages of the summation. The Vector unit (PowerISA 2.07+) has quadword (vs Fixed point doubleword) binary add/subtract with carry/extend. The Vector Unit requires separate *write Carry* instructions to detect and return the carry to VRs. The *write Carry* instructions are paired with *Unsigned Quadword Modulo* instructions that generates the (modulo) 128-bit result.

#### Note

In PowerISA 3.0B has a new add extended (addex) instruction that can use the *overflow-bit (OF)* as a second carry (independent of CA). However the OF must be explicitly cleared (using subfo) before use as a carry flag.

The Vector Unit has the effective use of up to 32 carry bits. The down-side is it requires an extra instruction and whole 128-bit VR to generate and hold each carry bit.

So knowing how to avoid overflows and carries in the summation of partial products can be useful. To illustrate we can examine the POWER8 implementation of `vec_muluwq()`. POWER8 (PowerISA 2.07) does support add quadword but the largest vector fixed-point multiply is 32-bit Vector Multiply Even/Odd Unsigned Words (`vec_muleuw()` and `vec_mulouw()`). The implementation generates four quadword by word (160-bit) partial products that are summed in four stages to generate the final 256-bit product.

Code for the first stage looks like this:

```
// Splat the lowest order word of b to tsw for word multiply
tsw = vec_splat ((vui32_t) b, VEC_WE_3);
// Multiply quadword a by lowest order word of b
t_even = (vui32_t)vec_vmuleuw((vui32_t)a, tsw);
t_odd = (vui32_t)vec_vmulouw((vui32_t)a, tsw);
// Rotate the low 32-bits (right) into tmq. This is actually
// implemented as 96-bit (12-byte) shift left.
tmq = vec_sld (t_odd, z, 12);
// shift the low 128 bits of partial product right 32-bits
t_odd = vec_sld (z, t_odd, 12);
// add the high 128 bits of even / odd partial products
t = (vui32_t) vec_adduqm ((vui128_t) t_even, (vui128_t) t_odd);
```

Note in this case we can assume that the sum of aligned even/odd quadwords will not generate a carry. For example with maximum values for multiplicands a,b:

```
quadword a: FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
quadword b x FFFFFFFF[3]
t_even = FFFFFFFE 00000001 FFFFFFFE 00000001
t_odd >> 32 + 00000000 FFFFFFFE 00000001 FFFFFFFF
t = FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
tmq = 00000001
```

The high order 128-bits of the sum did not overflow.

The next tree stages are more complex.

```
// Splat the next word of b to tsw for word multiply
tsw = vec_splat ((vui32_t) b, VEC_WE_2);
// Multiply quadword a by next word of b
t_even = (vui32_t)vec_vmulouw((vui32_t)a, tsw);
t_odd = (vui32_t)vec_vmulouw((vui32_t)a, tsw);
// Add with carry the odd multiply with previous partial product
tc = (vui32_t) vec_addcuq ((vuil28_t) t_odd, (vuil28_t) t);
t_odd = (vui32_t) vec_adduqm ((vuil28_t) t_odd, (
 vuil28_t) t);
// Rotate the low 32-bits (right) into tmq.
tmq = vec_sld (t_odd, tmq, 12);
// shift the low 128 bits (with carry) right 32-bits
t_odd = vec_sld (tc, t_odd, 12);
// add the high 128 bits of even / odd partial products
t = (vui32_t) vec_adduqm ((vuil28_t) t_even, (vuil28_t) t_odd);
```

Here we need a 3-way sum of the previous partial product, and the odd, even products from this stage. In this case the high 128-bits of previous partial product needs to align with the lower 128-bits of this stages 160-bit product for the first quadword add. This can produce a overflow, so we need to capture the carry and concatenate it the odd sum before shifting right 32-bits. Again we can assume that the sum of aligned even/odd quadwords will not generate a carry. For example stage 2 with maximum values for multiplicands a,b:

```
quadword a: FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
quadword b x FFFFFFFF[2]

t_odd FFFFFFFE 00000001 FFFFFFFE 00000001
t + FFFFFFFE FFFFFFFF FFFFFFFF FFFFFFFF
t_odd = FFFFFFFD 00000001 FFFFFFFE 00000000
tc = 00000000 00000000 00000000 00000001

tc|t_odd>>32 = 00000001 FFFFFFFD 00000001 FFFFFFFE
t_odd|tmq = 00000000 00000001

t_even = FFFFFFFE 00000001 FFFFFFFE 00000001
tc|t_odd>>32 + 00000001 FFFFFFFD 00000001 FFFFFFFE
t = FFFFFFFF FFFFFFFE FFFFFFFF FFFFFFFF
```

For POWER8 this 3-way sum and the required write-carry adds significant latency to stages 2, 3, and 4 of this multiply.

In POWER8 the vector quadword add/subtract instructions are cracked into 2 dependent simple fixed-point (XS) IOPs. So the effective instruction latency is (2+2=4) cycles. Also cracked instructions must be *first in group*, so back-to-back vaddcuq/vadduqm sequences will be dispatched separately. There no possibility of executing the pair concurrently, so the latency for the pair is 5-6 cycles.

So there is value in finding an alternative summation that avoids/reduces the number write-carry operations. From above ([Some useful arithmetic facts \(you may of forgotten\)](#)) we know it is possible to add one or two unsigned words to each of the doubleword products generated by vmuleuw/vmulouw.

We need to align the words of the quadword addend (zero extended on the left to doublewords) with the corresponding doublewords of the products. We can use Vector Merge Even/Odd Word operations to split and pad the addend into to align with the products. Then we use Vector Add Doubleword for the even/odd product-sums. Finally we use shift and add quadword to produce the 160-bit stage 2 sum.

```

quadword a: FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
quadword b x FFFFFFFF[2]
quadword t: FFFFFFFE FFFFFFFF FFFFFFFF FFFFFFFF

t_even = FFFFFFFE 00000001 FFFFFFFE 00000001
mrgew(z,t) + 00000000 FFFFFFFE 00000000 FFFFFFFF
 = FFFFFFFE FFFFFFFF FFFFFFFF 00000000

t_odd = FFFFFFFE 00000001 FFFFFFFE 00000001
mrgow(z,t) + 00000000 FFFFFFFF 00000000 FFFFFFFF
 = FFFFFFFF 00000000 FFFFFFFF 00000000

t_odd>>32 = 00000000 FFFFFFFF 00000000 FFFFFFFF
t_odd|tmq>>32= 00000000 00000001

t_even = FFFFFFFE FFFFFFFF FFFFFFFF 00000000
t_odd>>32 + 00000000 FFFFFFFF 00000000 FFFFFFFF
t = FFFFFFFF FFFFFFFE FFFFFFFF FFFFFFFF
t_odd|tmq = 00000000 00000001

```

This sequence replaces two instructions (vaddcuq/vadduqm) with four instructions (vmrgew/vmrgow/vaddudm/vaddudm), all of which;

- have 2 cycle latency
- are dual issue
- without dispatch restrictions

We expect a latency of 4 cycles over the whole sequence. And splitting the first add into even/odd add blocks allows the compiler (and out-of-order hardware) more flexibility for instruction scheduling.

#### 7.7.3.2.1 Vector Multiply-Add

Multiply-add seems to be a useful operation that does not exist in the current PowerISA. But it is simple enough to create an in-line PVECLIB operation that we can use here. For example:

```

static inline vui64_t
vec_vmaddeuw (vui32_t a, vui32_t b, vui32_t c)
{
 const vui32_t zero = { 0, 0, 0, 0 };
 vui64_t res;
 vui32_t c_euw = vec_mrgahw ((vui64_t) zero, (vui64_t) c);
 res = vec_vmuleuw (a, b);
 return vec_addudm (res, (vui64_t) c_euw);
}

```

Which generates the following instruction sequence:

```

<__vec_vmaddeuw_PWR8>:
 d70: vmuleuw v2,v2,v3
 d74: vspltisw v0,0
 d78: vmrgew v4,v0,v4
 d7c: vaddudm v2,v2,v4

```

The vspltisw loads (immediate) the zero vector and the compiler should *common* this across operations and schedule this instruction once, early in the function. The vmrgew has a latency of 2 cycles and should execute concurrently with vmuleuw. Similarly for [vec\\_vmaddouw\(\)](#).

These operations ([vec\\_vmaddeuw\(\)](#) and [vec\\_vmaddouw\(\)](#)) are included in [vec\\_int64\\_ppc.h](#) as they require [vec\\_←addudm\(\)](#) and produce doubleword results. With this addition we can improve and simplify the code for stages 2-4 of the \_ARCH\_PWR8 implementation of [vec\\_muludq\(\)](#). For example:

```

// Splat the next word of b to tsw for word multiply
tsw = vec_splat ((vui32_t) b, VEC_WE_2);
// Multiply quadword a by next word of b and add previous partial
// product using multiply-add even/odd
t_even = (vui32_t)vec_vmaddeuw((vui32_t)a, tsw, t);
t_odd = (vui32_t)vec_vmaddouw((vui32_t)a, tsw, t);
// Rotate the low 32-bits (right) into tmq.
tmq = vec_sld (t_odd, tmq, 12);
// shift the low 128 bits (with carry) right 32-bits
t_odd = vec_sld (z, t_odd, 12);
// add the high 128 bits of even / odd partial products
t = (vui32_t) vec_adduqm ((vui128_t) t_even, (vui128_t) t_odd);

```

### 7.7.3.2.2 And Vector Multiply-Add2

From the description above ([Some useful arithmetic facts \(you may of forgotten\)](#)) we know we can add two unsigned words to the doubleword product without overflow. This is another useful operation that does not exist in the current PowerISA. But it is simple enough to create an in-line PVECLIB operation. For example:

```

static inline vui64_t
vec_vmadd2euw (vui32_t a, vui32_t b, vui32_t c,
 vui32_t d)
{
 const vui32_t zero = { 0, 0, 0, 0 };
 vui64_t res, sum;
 vui32_t c_euw = vec_mrgahw ((vui64_t) zero, (vui64_t) c);
 vui32_t d_euw = vec_mrgahw ((vui64_t) zero, (vui64_t) d);
 res = vec_vmuleuw (a, b);
 sum = vec_addudm ((vui64_t) c_euw, (vui64_t) d_euw);
 return vec_addudm (res, sum);
}

```

Which generates to following instruction sequence:

```

<__vec_vmadd2euw_PWR8>:
db0: vmuleuw v2,v2,v3
db4: vspltisw v0,0
db8: vmrgew v4,v0,v4
dbc: vmrgew v5,v0,v5
dc0: vaddudm v5,v4,v5
dc4: vaddudm v2,v2,v5

```

The vspltisw loads (immediate) the zero vector and the compiler should *common* this across operations and schedule this instruction once, early in the function. The vmrgew/vmrgew/vaddudm sequence has a latency of 4-6 cycles and should execute concurrently with vmuleuw. Similarly for [vec\\_vmadd2ouw\(\)](#).

### 7.7.3.2.3 Why not Vector Multiply-Sum

The PowerISA has a number of Multiply-Sum instructions that look a lot like the Multiply-Add described above? Well not exactly:

- The behavior of Multiply-Sum allows overflow without any architected way to detect/capture and propagate the carry.
  - Each of the two (even/odd) halves of each "word" element of VRA and VRB: Multiply the even halves of each "word" element. Then multiply the odd halves of each "word" element. This generates two unsigned integer "word" products for each "word" element.
  - The sum of these two integer "word" products is added to the corresponding integer "word" element in VRC.
  - This 3-way sum of can overflow without notification.

- Multiply-Sum instructions can be used to emulate Multiply Even/Odd and Multiply-Add Even/Odd by constraining the inputs.
  - Using Multiply-Sum to add prior partial-sums creates a serial dependency that limits instruction scheduling and slows execution.
- The PowerISA does not have Multiply-Sum Word instructions.
- The PowerISA 3.0 has a Multiply-Sum Unsigned Doubleword instruction but it does not exist in POWER8.
- The base AltiVec has Multiply-Sum Halfword/Byte instructions. But using POWER8's Multiply Even/Odd Unsigned Word is better for implementing quadword multiply on POWER8.

First we should look at the arithmetic of Multiply-Sum using maximal unsigned integer values.

```
VRA: FFFF x FFFF
VRB: FFFF x FFFF
VRC: FFFF FFFF

Even half: FFFF x FFFF -> FFFE0001
odd half: FFFF x FFFF -> + FFFE0001
Word addend -> + FFFFFFFF
 = 2 FFFC0001
```

Note the sum overflows the word twice and high order bits of the sum will be lost.

For POWER9 we can simulate Vector Multiply Even/Odd Unsigned Doubleword by setting the Odd/Even doubleword of VRB to zero and the whole quadword addend VRC to zero. For example the even doubleword multiply.

```
static inline vui128_t
vec_vmuleud (vui64_t a, vui64_t b)
{
 const vui64_t zero = { 0, 0 };
 vui64_t b_eud = vec_mrgahd ((vui128_t) b, (vui128_t) zero);
 return vec_msumudm(a, b_eud, zero);
}
```

And similarly for the odd doubleword multiply.

```
static inline vui128_t
vec_vmuloud (vui64_t a, vui64_t b)
{
 const vui64_t zero = { 0, 0 };
 vui64_t b_oud = vec_mrgald ((vui128_t) zero, (
 vui128_t) b);
 return vec_msumudm(a, b_oud, (vui128_t) zero);
}
```

And review the arithmetic for `vec_vmuleud()` using maximal quadword values for a and b.

```
quadword a: FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
quadword b: FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
quadword z: 00000000 00000000 00000000 00000000

mrged(b,z) = FFFFFFFF FFFFFFFF 00000000 00000000

Even prod: FFFFFFFF FFFFFFFE 00000000 00000001
odd prod + 00000000 00000000 00000000 00000000
Word addend + 00000000 00000000 00000000 00000000
msumudm = FFFFFFFF FFFFFFFE 00000000 00000001
```



And for `vec_vmulddud()`.

```
quadword a: FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
quadword b: FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
quadword z: 00000000 00000000 00000000 00000000

mrgod(z,b) = 00000000 00000000 FFFFFFFF FFFFFFFF

Even prod: 00000000 00000000 00000000 00000000
odd prod + FFFFFFFF FFFFFFFF 00000000 00000001
Word addend + 00000000 00000000 00000000 00000000
msumudm = FFFFFFFF FFFFFFFF 00000000 00000001
```

We can also simulate Vector Multiply-Add Even/Odd Unsigned Doubleword by setting the odd/even doubleword of  $V_{\leftarrow}$  RB to zero and the whole quadword addend to the even/odd double word of VRC. For example the even doubleword multiply-add.

```
static inline vui128_t
vec_vmaddeud (vui64_t a, vui64_t b, vui64_t c)
{
 const vui64_t zero = { 0, 0 };
 vui64_t b_eud = vec_mrgahd ((vui128_t) b, (vui128_t) zero);
 vui64_t c_eud = vec_mrgahd ((vui128_t) zero, (
 vui128_t) c);
 return vec_msumudm(a, b_eud, (vui128_t) c_eud);
}
```

And similarly for the odd doubleword multiply-add.

```
static inline vui128_t
vec_vmaddoud (vui64_t a, vui64_t b, vui64_t c)
{
 const vui64_t zero = { 0, 0 };
 vui64_t b_oud = vec_mrgald ((vui128_t) zero, (
 vui128_t) b);
 vui64_t c_oud = vec_mrgald ((vui128_t) zero, (
 vui128_t) c);
 return vec_msumudm(a, b_oud, (vui128_t) c_oud);
}
```

And review the arithmetic for `vec_vmaddeud()` using maximal quadword values for a and b. The even/odd doublewords of c have slightly different values for illustrative purposes.

```
quadword a: FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
quadword b: FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
quadword c: FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFE

mrged(b,z) = FFFFFFFF FFFFFFFF 00000000 00000000
mrged(z,c) = 00000000 00000000 FFFFFFFF FFFFFFFF

Even prod: FFFFFFFF FFFFFFFE 00000000 00000001
odd prod + 00000000 00000000 00000000 00000000
Word addend + 00000000 00000000 FFFFFFFF FFFFFFFF
msumudm = FFFFFFFF FFFFFFFF 00000000 00000000
```

And for `vec_vmaddoud()`.

```
quadword a: FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
quadword b: FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF
quadword c: FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFE

mrgod(z,b) = 00000000 00000000 FFFFFFFF FFFFFFFF
mrgod(z,c) = 00000000 00000000 FFFFFFFF FFFFFFFF

Even prod: 00000000 00000000 00000000 00000000
odd prod + FFFFFFFF FFFFFFFE 00000000 00000001
Word addend + 00000000 00000000 FFFFFFFF FFFFFFFE
msumudm = FFFFFFFF FFFFFFFE FFFFFFFF FFFFFFFF
```

This multiply-add even/odd doubleword form only adds one additional (xxmrghd AKA xxpermdi) instruction over that required for the base multiply even/odd doubleword operation.

```
<__vmuleud_PWR9>:
120: xxspltib v0,0
124: xxmrghd v3,v3,v0
128: vmsumudm v2,v2,v3,v0

<__vmaddeud_PWR9>:
1a0: xxspltib v0,0
1a4: xxmrghd v3,v3,v0
1a8: xxmrghd v4,v0,v4
1ac: vmsumudm v2,v2,v3,v4
```

The xxspltib loads (immediate) the zero vector and the compiler should *common* this across operations and schedule this instruction once, early in the function.

For POWER9 instruction timing is different and there are some unique trade-offs. The implementations above are small and appropriate for single instances of multiply doubleword or implementations of multiply quadword. However using the vmsumudm (operand VRC) addend creates a serial dependency within the multiply quadword implementation. When multiply quadword and multiply-add quadword are used in the implementation of wider multiplies (see [vec\\_int512\\_ppc.h](#)) these serial dependencies actually slow down the implementation.

- A full 128 x 128-bit multiply only requires two stages of even/odd doubleword multiplies. This allows some simplification.
  - Alignment shifts can be replaced with permute doubleword immediate (xxmrghd/xxmrghd/xxpermdi) operations.
  - Careful rearrangement of the operations and operands allow the compiler to optimize (as common subexpressions) some of the doubleword masking operations.
- The multiply even/odd doubleword operations require explicit masking of the even/odd multiplicands.
  - Doubleword masking can be done with xxmrghd/xxmrghd/xxpermdi instructions which are dual issue with a 3 cycle latency.
  - The multiplies (vmsumudm) are serially dependent on these masking instructions.
  - In the POWER8 implementation (using vmuleuw/vmulouw) the multiplicand masking is implicit to the instruction.
- The vmsumudm with the VRC addend can be used to combine the multiply-add of the partial production from the previous stage.
  - This also requires explicit doubleword masking to avoid overflowing the quadword sum.
  - This can make the masking operation and the multiply itself, serially dependent on the partial product sum from the previous stage.
- The add (modulo/write-carry/extend) quadword instructions are dual issue with a 3 cycle latency. So the cost of quadword sums and generating/propagating carries is of less concern (than on POWER8).
  - It can be better to use explicit add quadword and avoid the serial dependency on the vmsumudm (VRC) addend.
  - This allows the compiler (and out-of-order hardware) more flexibility for instruction scheduling.

So lets look at some examples using the vmsumudm (VRC) addend and the alternative using VRC (setting VRA to zero) and explicit add quadword. First a 128x128-bit unsigned multiply using vmsumudm and exploiting the VRC addend where appropriate.

```

vui128_t
__test_muludq_y_PWR9 (vui128_t *mulu, vui128_t a, vui128_t b)
{
 vui32_t t, tmq;
 // compute the 256 bit product of two 128 bit values a, b.
 // The high 128 bits are accumulated in t and the low 128-bits
 // in tmq. The high 128-bits of the product are returned to the
 // address of the 1st parm. The low 128-bits are the return
 // value.
 const vui64_t zero = { 0, 0 };
 vui64_t a_swap = vec_swapd ((vui64_t) a);
 vui128_t tmh, tab, tba, tb0, tc1, tc2;
 // multiply the low 64-bits of a and b. For PWR9 this is just
 // vmsumudm with conditioned inputs.
 tmq = (vui32_t) vec_vmuloud ((vui64_t) a, (vui64_t) b);
 // compute the 2 middle partial products. Use vmaddeud to add the
 // high 64-bits of the low product to one of the middle products.
 // This can not overflow.
 tab = vec_vmuloud (a_swap, (vui64_t) b);
 tba = vec_vmaddeud (a_swap, (vui64_t) b, (vui64_t) tmq);
 // sum the two middle products (plus the high 64-bits of the low
 // product. This will generate a carry that we need to capture.
 t = (vui32_t) vec_adduqm (tab, tba);
 tc1 = vec_addcuq (tab, tba);
 // result = t[1] || tmq[1].
 tmq = (vui32_t) vec_mrgald ((vui128_t) t, (vui128_t) tmq);
 // we can use multiply sum here because the high product plus the
 // high sum of middle partial products can't overflow.
 t = (vui32_t) vec_permdi ((vui64_t) tc1, (vui64_t) t, 2);
 // This is equivalent to vec_vmadd2eud(a, b, tab, tba)
 // were (tab_even + tba_even) was pre-computed including the carry,
 // so no masking is required.
 t = (vui32_t) vec_vmsumeud ((vui64_t) a, (vui64_t) b, (
 vui128_t) t);

 *mulu = (vui128_t) t;
 return ((vui128_t) tmq);
}

<__test_muludq_y_PWR9>:
370: xxspltib v1,0
374: xxswapd v12,v2
378: xxlor v13,v2,v2
37c: xxmrgld v0,v1,v3
380: xxmrghd v3,v3,v1
384: vmsumudm v2,v2,v0,v1
388: vmsumudm v0,v12,v0,v1
38c: xxmrghd v1,v1,v2
390: vmsumudm v1,v12,v3,v1
394: vadduqm v12,v1,v0
398: vaddcuq v0,v0,v1
39c: xxmrgld v2,v12,v2
3a0: xxpermdi v0,v0,v12,2
3a4: vmsumudm v13,v13,v3,v0
3a8: stxv v13,0(r3)
3ac: blr

```

### Note

that first vmsumudm instruction is only dependent on the parameters a, masked b<sub>odd</sub>, and const zero. The second vmsumudm instruction is only dependent on the parameters a<sub>swap</sub>, masked b<sub>odd</sub>, and const zero. The swap/mask operations requires 3-4 cycles and 7 cycles to complete first two vmsumudm's. The third vmsumudm instruction is dependent on the parameters a<sub>swap</sub>, masked b<sub>even</sub>, and masked tmq<sub>even</sub>. The masked tmq<sub>even</sub> is dependent on the xxmrghd of the results of the first vmsumudm. This adds another 10 cycles. The forth and final vmsumudm instruction is dependent on the parameters a, masked b<sub>even</sub>, and the shifted sum (with carry) of (tab + tba). This is in turn dependent on the results from the second and third vmsumudm instructions. This adds another (6+7= 13) cycles for a total of 34 cycles. When this operation is expanded in-line the stxv and xxspltib will be optimized and can be ignored for this analysis.

Next a 128x128-bit unsigned multiply using vmsumudm but only passing const zero to the VRC addend.

```

vui128_t
__test_muludq_x_PWR9 (vui128_t *mulu, vui128_t a, vui128_t b)
{
 // compute the 256 bit product of two 128 bit values a, b.
 // The high 128 bits are accumulated in t and the low 128-bits
 // in tmq. The high 128-bits of the product are returned to the
 // address of the 1st parm. The low 128-bits are the return
 // value.
 const vui64_t zero = { 0, 0 };
 vui64_t a_swap = vec_swapd ((vui64_t) a);
 vui128_t thq, tlq, tx;
 vui128_t t0l, tcl;
 vui128_t thh, thl, tlh, tll;
 // multiply the low 64-bits of a and b. For PWR9 this is just
 // vmsumudm with conditioned inputs.
 tll = vec_vmuloud ((vui64_t)a, (vui64_t)b);
 thh = vec_vmuleud ((vui64_t)a, (vui64_t)b);
 thl = vec_vmuloud (a_swap, (vui64_t)b);
 tlh = vec_vmuleud (a_swap, (vui64_t)b);
 // sum the two middle products (plus the high 64-bits of the low
 // product. This will generate a carry that we need to capture.
 t0l = (vui128_t) vec_mrgahd ((vui128_t) zero, tll);
 tcl = vec_addcuq (thl, tlh);
 tx = vec_adduqm (thl, tlh);
 tx = vec_adduqm (tx, t0l);
 // result = t[1] || tll[1].
 tlq = (vui128_t) vec_mrgald ((vui128_t) tx, (
 vui128_t) tll);
 // Sum the high product plus the high sum (with carry) of middle
 // partial products. This can't overflow.
 thq = (vui128_t) vec_permdi ((vui64_t) tcl, (vui64_t) tx, 2);
 thq = vec_adduqm (thh, thq);

 *mulu = (vui128_t) thq;
 return ((vui128_t) tlq);
}

```

```

<__test_muludq_x_PWR9>:
320: xxspltib v0,0
324: xxswapd v12,v2
328: xxmrgld v13,v0,v3
32c: xxmrghd v3,v3,v0
330: vmsumudm v1,v12,v13,v0
334: vmsumudm v13,v2,v13,v0
338: vmsumudm v12,v12,v3,v0
33c: xxmrghd v10,v0,v13
340: vadduqm v11,v12,v1
344: vmsumudm v3,v2,v3,v0
348: vaddcuq v1,v1,v12
34c: vadduqm v2,v11,v10
350: xxpermdi v1,v1,v2,2
354: xxmrgld v2,v2,v13
358: vadduqm v3,v3,v1
35c: stxv v3,0(r3)
360: blr

```

## Note

that the vmsumudm instructions only depend on the parameters a/a\_swap, masked b\_odd/b\_even, and const zero. After the parameters are conditioned (swapped/masked) the independent vmsumudm's can be scheduled early. The swap/mask operations requires 3-4 cycles and 8 cycles to complete four independent vmsumudm's. The partial product alignment and sums require another 12 cycles, for a total of 24 cycles. When this operation is expanded in-line the stxv and xxspltib will be optimized and can be ignored for this analysis.

The second example (using explicit add quadword);

- only adds 1 instruction over the first example,
- and executes 10 cycles faster.

### 7.7.3.2.4 Vector Multiply-Add Quadword

We can use multiply-add operation for wider word sizes (quadword and multiple precision quadword). The simplest quadword implementation would create a `vec_madduq()` operation based on `vec_muludq()` and add a quadword parameter "c" for the addend. Then modify the first stage of the platform specific multiplies to replace vector multiply even/odd with vector multiply-add even/odd, passing the addend as the the third parameter.

This works well for the POWER8 implementation because the additional vector add doublewords can be scheduled independently of the vector multiply even/odd words. But for POWER9 we need to avoid the serial dependences explained above in [Why not Vector Multiply-Sum](#).

For the POWER9 implementation we use an explicit add quadword (and write-Carry) to sum the addend parameter to the first stage Multiply odd doubleword. For example:

```

vui128_t
__test_madduq_y_PWR9 (vui128_t *mulu, vui128_t a, vui128_t b,
 vui128_t c)
{
 // compute the 256 bit sum of product of two 128 bit values a, b
 // plus the quadword addend c.
 vui64_t a_swap = vec_swapd ((vui64_t) a);
 vui128_t thq, tlq, tx;
 vui128_t t0l, tcl, tcl;
 vui128_t thh, thl, tlh, tll;
 // multiply the four combinations of a_odd/a_even by b_odd/b_even.
 tll = vec_vmuloud ((vui64_t) a, (vui64_t) b);
 thh = vec_vmuleud ((vui64_t) a, (vui64_t) b);
 thl = vec_vmuloud (a_swap, (vui64_t) b);
 tlh = vec_vmuleud (a_swap, (vui64_t) b);
 // Add c to lower 128-bits of the partial product.
 tcl = vec_addcuq (tll, c);
 tll = vec_adduqm (tll, c);
 t0l = (vui128_t) vec_permdi ((vui64_t) tcl, (vui64_t) tll, 2);
 // sum the two middle products (plus the high 65-bits of the low
 // product-sum).
 tcl = vec_addcuq (thl, tlh);
 tx = vec_adduqm (thl, tlh);
 tx = vec_adduqm (tx, t0l);
 // result = tx[1]_odd || tll[1]_odd.
 tlq = (vui128_t) vec_mrgald ((vui128_t) tx, (
 vui128_t) tll);
 // Sum the high product plus the high sum (with carry) of middle
 // partial products. This can't overflow.
 thq = (vui128_t) vec_permdi ((vui64_t) tcl, (vui64_t) tx, 2);
 thq = vec_adduqm (thh, thq);

 *mulu = (vui128_t) thq;
 return ((vui128_t) tlq);
}

```

The generated code is the same size as the serially depended version

This is just another example where the shortest instruction sequence or using the most powerful instructions, may not be the fastest implementation. The key point is that avoiding serial dependencies in the code and allowing the compiler to schedule high latency instructions early, allows better performance. This effect is amplified when quadword multiplies (`vec_muludq()`, `vec_madduq()`, and `vec_madd2uq()`) are used to compose wider multiply operations (see [vec\\_int512\\_ppc.h](#)).

## 7.7.4 Vector Quadword Examples

The PowerISA Vector facilities provide logical and integer arithmetic quadword (128-bit) operations. Some operations as direct PowerISA instructions and other operations composed of short instruction sequences. The Power Vector Library provides a higher level and comprehensive API of quadword integer arithmetic and support for extended arithmetic to multiple quadwords.

#### 7.7.4.1 Printing Vector `__int128` values

The GCC compiler supports the (vector) `__int128` type but the runtime does not support **printf()** formatting for `__int128` types. However if we can use divide/modulo operations to split vector `__int128` values into modulo  $10^{16}$  long int (doubleword) chunks, we can use `printf()` to convert and concatenate the decimal values into a complete number.

For example, from the `__int128` value (39 decimal digits):

- Detect the sign and set a char to '+' or '-'
- Then from the absolute value, divide/modulo by 10000000000000000. Producing:
  - The highest 7 digits (`t_high`)
  - The middle 16 digits (`t_mid`)
  - The lowest 16 digits (`t_low`)

We can use signed compare to detect the sign and set a char value to print a '-' or '+' prefix. If the value is negative we want the absolute value before we do the divide/modulo steps. For example:

```
if (vec_cmpsq_all_ge (value, zero128))
{
 sign = '+';
 val128 = (vu128_t) value;
}
else
{
 sign = '-';
 val128 = vec_subuqm ((vu128_t) zero128, (vu128_t) value);
}
```

Here we use the **pveclib** operation `vec_cmpsq_all_ge()` because the ABI and compilers do not define compare built-ins operations for the vector `__int128` type. For the negative case we use the **pveclib** operation `vec_subuqm()` instead of `vec_abs`. Again the ABI and compilers do not define `vec_abs` built-ins for the vector `__int128` type. Using **pveclib** operations have the additional benefit of supporting older compilers and platform specific implementations for POWER7 and POWER8.

Now we have the absolute value in `val128` we can factor it into (3) chunks of 16 digits each. Normally scalar codes would use integer divide/modulo by 10000000000000000. And we are reminded that the PowerISA vector unit does not support integer divide operations and definitely not for quadword integers.

Instead we can use the multiplicative inverse which is a scaled fixed point fraction calculated from the original divisor. This works nicely if the fixed radix point is just before the 128-bit fraction and we have a multiply high (`vec_mulhuq()`) operation. Multiplying a 128-bit unsigned integer by a 128-bit unsigned fraction generates a 256-bit product with 128-bits above (integer) and below (fraction) the radix point. The high 128-bits of the product is the integer quotient and we can discard the low order 128-bits.

It turns out that generating the multiplicative inverse can be tricky. To produce correct results over the full range requires, possible pre-scaling and post-shifting, and sometimes a corrective addition is necessary. Fortunately the mathematics are well understood and are commonly used in optimizing compilers. Even better, Henry Warren's book has a whole chapter on this topic.

## See also

"Hacker's Delight, 2nd Edition," Henry S. Warren, Jr, Addison Wesley, 2013. Chapter 10, Integer Division by Constants.

In the chapter above;

Figure 10-2 Computing the magic number for unsigned division.

provides a sample C function for generating the magic number (actually a struct containing; the magic multiplicative inverse, "add" indicator, and the shift amount.). For quadword and the divisor 1000000000000000, this is { 76624777043294442917917351357515459181, 0, 51 }:

- the multiplier is 76624777043294442917917351357515459181.
- no corrective add is required.
- the final shift is 51-bits right.

```
const vui128_t mul_ten16 = (vui128_t) CONST_VINT128_DW(
 0UL, 100000000000000000UL);
// Magic numbers for multiplicative inverse to divide by 10**16
// are 76624777043294442917917351357515459181, no corrective add,
// and shift right 51 bits.
const vui128_t mul_invs_ten16 = (vui128_t) CONST_VINT128_DW(
 0x39a5652fb1137856UL, 0xd30baf9a1e626a6dUL);
const int shift_ten16 = 51;
...

// first divide/modulo the 39 digits __int128 by 10**16.
// This separates the high/middle 23 digits (tmpq) and low 16 digits.
tmpq = vec_mulhuq (vall128, mul_invs_ten16);
tmpq = vec_srqi (tmpq, shift_ten16);
// Compute remainder of vall128 / 10**16
// t_low = vall128 - (tmpq * 10**16)
// Here we know tmpq and mul_ten16 are less than 64-bits
// so can use vec_vmuloud instead of vec_mulluq
tmp = vec_vmuloud ((vui64_t) tmpq, (vui64_t) mul_ten16);
t_low = (vui64_t) vec_subuqm (vall128, tmp);

// Next divide/modulo the high/middle digits by 10**16.
// This separates the high 7 and middle 16 digits.
vall128 = tmpq;
tmpq = vec_mulhuq (tmpq, mul_invs_ten16);
t_high = (vui64_t) vec_srqi (tmpq, shift_ten16);
tmp = vec_vmuloud (t_high, (vui64_t) mul_ten16);
t_mid = (vui64_t) vec_subuqm (vall128, tmp);
```

All the operations used above are defined and implemented by **pveclib**. Most of these operations is not defined as single instructions in the PowerISA or as built-ins the ABI or require alternative implementations for older processors.

Now we have three vector unsigned \_\_int128 values (t\_low, t\_mid, t\_high) in the range 0-9999999999999999. Fixed point values in that range fit into the low order doubleword of each quadword. We can access these doublewords with array notation ([VEC\_DW\_L]) and the compiler will transfer them to fixed point (long int) GPRs. Then use normal char and long int printf() formatting. For example:

```
printf ("%c%07lld%016lld%016lld", sign,
 t_high[VEC_DW_L], t_mid[VEC_DW_L], t_low[VEC_DW_L]);
```

Here is the complete vector \_\_int128 printf example:

```

void
example_print_vint128 (vint128_t value)
{
 const vint128_t max_neg = (vint128_t) CONST_VINT128_DW(
 0x8000000000000000UL, 0UL);
 const vint128_t zero128 = (vint128_t) CONST_VINT128_DW(
 0x0UL, 0UL);
 const vuint128_t mul_ten16 = (vuint128_t) CONST_VINT128_DW(
 0UL, 10000000000000000UL);
 // Magic numbers for multiplicative inverse to divide by 10**16
 // are 76624777043294442917917351357515459181, no corrective add,
 // and shift right 51 bits.
 const vuint128_t mul_invs_ten16 = (vuint128_t) CONST_VINT128_DW(
 0x39a5652fb1137856UL, 0xd30baf9a1e626a6dUL);
 const int shift_ten16 = 51;

 vint128_t tmpq, tmp;
 vui64_t t_low, t_mid, t_high;
 vint128_t val128;
 char sign;

 if (vec_cmpsq_all_ge (value, zero128))
 {
 sign = '+';
 val128 = (vint128_t) value;
 }
 else
 {
 sign = '-';
 val128 = vec_subuqm ((vint128_t) zero128, (vint128_t) value);
 }
 // Convert the absolute (unsigned) value to Decimal and
 // prefix the sign.

 // first divide/modulo the 39 digits __int128 by 10**16.
 // This separates the high/middle 23 digits (tmpq) and low 16 digits.
 tmpq = vec_muluq (val128, mul_invs_ten16);
 tmpq = vec_srqi (tmpq, shift_ten16);
 // Compute remainder of val128 / 10**16
 // t_low = val128 - (tmpq * 10**16)
 // Here we know tmpq and mul_ten16 are less than 64-bits
 // so can use vec_vmuloud instead of vec_muluq
 tmp = vec_vmuloud ((vui64_t) tmpq, (vui64_t) mul_ten16);
 t_low = (vui64_t) vec_subuqm (val128, tmp);

 // Next divide/modulo the high/middle digits by 10**16.
 // This separates the high 7 and middle 16 digits.
 val128 = tmpq;
 tmpq = vec_muluq (tmpq, mul_invs_ten16);
 t_high = (vui64_t) vec_srqi (tmpq, shift_ten16);
 tmp = vec_vmuloud (t_high, (vui64_t) mul_ten16);
 t_mid = (vui64_t) vec_subuqm (val128, tmp);

 printf ("%c%07lld%016lld%016lld", sign, t_high[VEC_DW_L],
 t_mid[VEC_DW_L], t_low[VEC_DW_L]);
}

```

#### 7.7.4.2 Converting Vector \_\_int128 values to BCD

POWER8 and POWER9 added a number of Binary Code Decimal (BCD) and Zoned Decimal operations that should be helpful for radix conversion and even faster large integer formatting for print.

See also

[vec\\_bcd\\_ppc.h](#)

The issue remains that \_\_int128 values can represent up to 39 decimal digits while Signed BCD supports only 31 digits. POWER9 provides a **Decimal Convert From Signed Quadword** instruction with the following restriction:



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Again as the `vec_mulluq()` operation is relatively expensive and we expect most `__int128` values to 31-digits or less, using a compare to bypass the multiplication and return the input value as the remainder, seems a prudent optimization.

We expect these operations to be used together as in this example.

```
q = vec_divuq_10e31 (a);
r = vec_moduq_10e31 (a, q);
```

We also expect the compiler to common the various constant loads across the two operations as the code is in-lined. This header also provides variants for factoring by 10e32 (to use with the Zone conversion) and signed variants of the 10e31 operation for direct conversion to extend precision signed BCD.

See also

[vec\\_divuq\\_10e32\(\)](#), [vec\\_moduq\\_10e32\(\)](#), [vec\\_divsq\\_10e31](#), [vec\\_modsq\\_10e31](#).

### 7.7.4.3 Extending integer operations beyond Quadword

Some algorithms require even high integer precision than `__int128` provides. this includes:

- POSIX compliant conversion between `__float128` and `_Decimal128` types
- POSIX compliant conversion from double and `__float128` to decimal for print.
- Cryptographic operations for Public-key cryptography and Elliptic Curves

The POWER8 provides instructions for extending add and subtract to 128-bit integer and beyond with carry/extend operations (see [vec\\_addcuq\(\)](#), [vec\\_addecuq\(\)](#), [vec\\_addeuqm\(\)](#), [vec\\_adduqm\(\)](#), (see [vec\\_subcuq\(\)](#), [vec\\_subecuq\(\)](#), [vec\\_subeuqm\(\)](#), [vec\\_subuqm\(\)](#)). POWER9 adds instructions to improve decimal / binary conversion to/from 128-bit integer and beyond with carry/extend operations. And while the PowerISA does not yet provide full 128 x 128 bit integer multiply instructions, it has provided wider integer multiply instructions, beginning in POWER8 (see [vec\\_mulesw\(\)](#), [vec\\_mulosw\(\)](#), [vec\\_muleuw\(\)](#), [vec\\_mulouw\(\)](#)) and again in POWER9 (see [vec\\_msumudm\(\)](#)).

This all allows the **pveclib** to improve (reduce the latency of) the implementation of multiply quadword operations. This includes operations that generate the full 256-bit multiply product (see [vec\\_muludq\(\)](#), [vec\\_muluq\(\)](#), [vec\\_mulluq\(\)](#)). And this in combination with add/subtract with carry extend quadword allows the coding of even wider (multiple quadword) multiply operations.

#### 7.7.4.3.1 Extended Quadword multiply

The following example performs a 256x256 bit unsigned integer multiply generating a 512-bit product:

```
void
test_mul4uq (vui128_t *__restrict__ mulu, vui128_t m1h, vui128_t m1l,
 vui128_t m2h, vui128_t m2l)
{
 vui128_t mc, mp, mq, mqhl;
 vui128_t mphh, mphi, mplh, mp1l;
 mp1l = vec_muludq (&mplh, m1l, m2l);
 mp = vec_muludq (&mphi, m1h, m2l);
 mplh = vec_addcq (&mc, mplh, mp);
 mphi = vec_addeuqm (mphi, mc);
 mp = vec_muludq (&mqhl, m2h, m1l);
 mplh = vec_addcq (&mq, mplh, mp);
 mphi = vec_addeq (&mc, mphi, mqhl, mq);
 mp = vec_muludq (&mphh, m2h, m1h);
 mphi = vec_addcq (&mq, mphi, mp);
 mphh = vec_addeuqm (mphh, mq, mc);

 mulu[0] = mp1l;
 mulu[1] = mplh;
 mulu[2] = mphi;
 mulu[3] = mphh;
}
```

This example generates some additional questions:

- Why use `vec_muludq()` instead of pairing `vec_mulhuq()` and `vec_mulluq()`?
- Why use `vec_addcq()` instead of pairing `vec_addcuq()` and `vec_adduqm()`?
- Why return the 512-bit product via a pointer instead of returning a struct or array of 4 x `vui128_t` (*homogeneous aggregates*)?

The detailed rationale for this is documented in section [Returning extended quadword results](#). In this specific case (quadword integer operations that generate two vector values) **pveclib** provides both alternatives:

- separate operations each returning a single (high or low order) vector.
- combined operations providing:
  - the lower order vector as the function return value.
  - the high order (carry or high product) vector via a pointer reference parameter.

Either method should provide the same results. For example:

```
mplh = vec_addcq (&mc, mplh, mp);
```

is equivalent to

```
mc = vec_addcuq (mplh, mp);
mplh = vec_adduqm (mplh, mp);
```

and

```
mpll = vec_muludq (&mplh, m1l, m2l);
```

is equivalent to

```
mpll = vec_mulluq (m1l, m2l);
mplh = vec_mulhud (m1l, m2l);
```

So is there any advantage to separate versus combined operations?

Functionally it is useful to have separate operations for the cases where only one quadword part is needed. For example if you know that a add/subtract operation can not overflow, why generate the carry? Alternatively the quadword greater/less-than compares are based solely on the carry from the subtract quadword, why generate lower 128-bit (modulo) difference? For multiplication the modulo (multiply low) operation is the expected semantic or is known to be sufficient. Alternatively the multiplicative inverse only uses the high order (multiply high) quadword of the product.

From the performance (instruction latency and throughput) perspective, if the algorithm requires the extended result or full product, the combined operation is usually the better choice. Otherwise use the specific single return operation needed. At best, the separate operations may generate the same instruction sequence as the combined operation, But this depends on the target platform and specific optimizations implemented by the compiler.

#### Note

For inlined operations the pointer reference in the combined form, is usually optimized to a simple register assignment, by the compiler.

For platform targets where the separate operations each generate a single instruction, we expect the compiler to generate the same instructions as the combined operation. But this is only likely for add/sub quadword on the POWER8 and multiply by 10 quadword on POWER9.

### 7.7.4.3.2 Quadword Long Division

In the section [Converting Vector \\_\\_int128 values to BCD](#) above we used multiplicative inverse to factor a binary quadword value in two (high quotient and low remainder) parts. Here we divide by a large power of 10 ( $10^{31}$  or  $10^{32}$ ) of a size where the quotient and remainder allow direct conversion to BCD (see [vec\\_bcdcfq\(\)](#), [vec\\_bcdcfuq\(\)](#)). After conversion, the BCD parts can be concatenated to form the larger (39 digit) decimal radix value equivalent of the 128-bit binary value.

We can extend this technique to larger (multiple quadword) binary values but this requires long division. This is the version of the long division you learned in grade school, where a multi-digit value is divided in stages by a single digit. But the digits we are using are really big ( $10^{31}-1$  or  $10^{32}-1$ ).

The first step is relatively easy. Start by dividing the left-most *digit* of the dividend by the divisor, generating the integer quotient and remainder. We already have operations to implement that.

```
// initial step for the top digits
dn = d[0];
qh = vec_divuq_10e31 (dn);
rh = vec_moduq_10e31 (dn, qh);
q[0] = qh;
```

The array *d* contains the quadwords of the extended precision integer dividend. The array *q* will contain the quadwords of the extended precision integer quotient. Here we have generated the first *quadword* *q[0]* digit of the quotient. The remainder *rh* will be used in the next step of the long division.

The process repeats except after the first step we have an intermediate dividend formed from:

- The remainder from the previous step
- Concatenated with the next *digit* of the extended precision quadword dividend.

So for each additional step we need to divide two quadwords (256-bits) by the quadword divisor. Actually this dividend should be less than a full 256-bits because we know the remainder is less than the divisor. So the intermediate dividend is less than  $((\text{divisor} - 1) * 2^{128})$ . So we know the quotient can not exceed  $(2^{128}-1)$  or one quadword.

Now we need an operation that will divide this double quadword value and provide quotient and remainder that are correct (or close enough). Remember your grade school long division where you would:

- estimate the quotient
- multiply the quotient by the divisor
- subtract this product from the current 2 digit dividend
- check that the remainder is less than the divisor.
  - if the remainder is greater than the divisor; the estimated quotient is too small
  - if the remainder is negative (the product was greater than the dividend); the estimated quotient is too large.
- correct the quotient and remainder if needed before doing the next step.

So we don't need to be perfect, but close enough. As long as we can detect any problems and (if needed) correct the results, we can implement long division to any size.

We already have an operation for dividing a quadword by  $10^{31}$  using the magic numbers for multiplicative inverse. This can easily be extended to multiply double quadword high. For example:

```

// Multiply high [vra||vrb] * mul_invs_ten31
q = vec_mulhuq (vrb, mul_invs_ten31);
q1 = vec_muludq (&t, vra, mul_invs_ten31);
c = vec_addcuq (q1, q);
q = vec_adduqm (q1, q);
q1 = vec_adduqm (t, c);
// corrective add [q2||q1||q] = [q1||q] + [vra||vrb]
c = vec_addcuq (vrb, q);
q = vec_adduqm (vrb, q);
// q2 is the carry-out from the corrective add
q2 = vec_addecuq (q1, vra, c);
q1 = vec_addeuqm (q1, vra, c);
// shift 384-bits (including the carry) right 107 bits
// Using shift left double quadword shift by (128-107)-bits
r2 = vec_sldqi (q2, q1, (128 - shift_ten31));
result = vec_sldqi (q1, q, (128 - shift_ten31));

```

Here we generate a 256-bit multiply high using the `vec_mulhuq()` for the low dividend (vrb) and `vec_muludq()` for high dividend (vra). Then sum the partial products ( $[t||q1] + [0||q]$ ) to get initial 256-bit product  $[q1||q]$ . Then apply the corrective add ( $[q1||q] + [vra||vrb]$ ). This may generate a carry which needs to be included in the final shift.

Technically we only expect a 128-bit quotient after the shift, but we have 3 quadwords (2 quadwords and a carry) going into the shift right. Also our (estimated) quotient may be *off by 1* and generate a 129-bit result. This is due to using a the magic numbers for 128-bit multiplicative inverse and not regenerating magic numbers for 256-bits. We can't do anything about that now and so return a 256-bit double quadword quotient.

#### Note

This is where only needing to be "close enough", works in our favor. We will check and correct the quotient in the modulo operation.

The 256-bits we want are spanning multiple quadwords so we replace a simple quadword shift right with two **Shift Left Double Quadword Immediate** operations and complement the shift count (128 - shift\_ten31). This gives a 256-bit quotient which we expect to have zero in the high quadword.

As this operation will be used in a loop for long division operations and the extended multiplies are fairly expensive, we should check for an short-circuit special conditions. The most important special condition is when the dividend is less than the divisor and the quotient is zero. This also helps when the long division dividend may have leading quadword zeros that need to be skipped over. For the full implementation looks like:

```

static inline vui128_t
vec_divudq_10e31 (vui128_t *qh, vui128_t vra,
 vui128_t vrb)
{
 const vui128_t ten31 = (vui128_t)
 { (__int128) 10000000000000000UL * (__int128) 10000000000000000UL };
 const vui128_t zero = (vui128_t) { (__int128) 0UL };
 // Magic numbers for multiplicative inverse to divide by 10**31
 // are 4804950418589725908363185682083061167, corrective add,
 // and shift right 103 bits.
 const vui128_t mul_invs_ten31 = (vui128_t) CONST_VINT128_DW(
 0x039d66589687f9e9UL, 0x01d59f290ee19dafUL);
 const int shift_ten31 = 103;
 vui128_t result, r2, t, q, q1, q2, c;

 if (vec_cmpuq_all_ne (vra, zero) || vec_cmpuq_all_ge (vrb, ten31))
 {
 // Multiply high [vra||vrb] * mul_invs_ten31
 q = vec_mulhuq (vrb, mul_invs_ten31);
 q1 = vec_muludq (&t, vra, mul_invs_ten31);
 c = vec_addcuq (q1, q);
 q = vec_adduqm (q1, q);
 q1 = vec_adduqm (t, c);
 // corrective add [q2||q1||q] = [q1||q] + [vra||vrb]
 c = vec_addcuq (vrb, q);
 q = vec_adduqm (vrb, q);
 }
}

```

```

 // q2 is the carry-out from the corrective add
 q2 = vec_addecuq (q1, vra, c);
 q1 = vec_addeuqm (q1, vra, c);
 // shift 384-bits (including the carry) right 103 bits
 // Using shift left double quadword shift by (128-103)-bits
 r2 = vec_sldqi (q2, q1, (128 - shift_ten31));
 result = vec_sldqi (q1, q, (128 - shift_ten31));
}
else
{
 // Dividend is less than divisor then return zero quotient
 r2 = zero;
 result = zero;
}

// return 256-bit quotient
*qh = r2;
return result;
}

```

To complete the long division operation we need to perform double quadword modulo operations. Here the dividend is two quadwords and the low quadword of the quotient from the divide double quadword operation above. We use multiply double quadword to compute the remainder  $([vra||vrb] - (q * 10^{31}))$ . Generating the 256-bit product and difference ensure we can detect the case where the quotient is off-by-1 on the high side.

```

t = vec_muludq (&th, *q1, ten31);
c = vec_subcuq (vrb, t);
t = vec_subuqm (vrb, t);
th = vec_subeuqm (vra, th, c);
// The remainder should be less than the divisor
if (vec_cmpuq_all_ne (th, zero) && vec_cmpuq_all_ge (t, ten31))
{
 // Otherwise the estimated quotient is off by 1
 *q1 = vec_adduqm (*q1, minus_one);
 // And the remainder is negative, so add the divisor
 t = vec_adduqm (t, ten31);
}
result = t;

```

In this case we need to correct both remainder and the (estimated) quotient. This is a bit tricky as the quotient is normally passed by value, but for this operation we need to pass by reference, which allows the corrected quotient to be passed on to the next step.

Again as this operation will be used in a loop for long division operations and the extended multiplies are fairly expensive, we should check for and short-circuit special conditions. The most important special condition is when the dividend is less than the divisor and the remainder is simply the dividend.

```

static inline vui128_t
vec_modudq_10e31 (vui128_t vra, vui128_t vrb,
 vui128_t *q1)
{
 // ten31 = +10000000000000000000000000000000UQ
 const vui128_t ten31 = (vui128_t)
 { (__int128) 1000000000000000000UL * (__int128) 10000000000000000UL };
 const vui128_t zero = (vui128_t) { (__int128) 0UL };
 const vui128_t minus_one = (vui128_t) { (__int128) -1L };
 vui128_t result, t, th, c;

 if (vec_cmpuq_all_ne (vra, zero) || vec_cmpuq_all_ge (vrb, ten31))
 {
 t = vec_muludq (&th, *q1, ten31);
 c = vec_subcuq (vrb, t);
 t = vec_subuqm (vrb, t);
 th = vec_subeuqm (vra, th, c);
 // The remainder should be less than the divisor
 if (vec_cmpuq_all_ne (th, zero) && vec_cmpuq_all_ge (t, ten31))
 {
 // If not the estimated quotient is off by 1
 *q1 = vec_adduqm (*q1, minus_one);
 }
 }
}

```



## 7.7.6 Macro Definition Documentation

### 7.7.6.1 CONST\_VUINT128\_Qx16d

```
#define CONST_VUINT128_Qx16d(
 __q0,
 __q1)
```

**Value:**

```
((vui128_t) \
 (((unsigned __int128) __q0) * 10000000000000000UL) \
 + ((unsigned __int128) __q1))
```

Generate a vector unsigned \_\_int128 constant from doublewords.

Combine 2 x 16 decimal digit long long constants into a single 32 decimal digit \_\_int128 constant. The 2 parameters are long integer constant values in high to low order. This order is consistent for big and little endian and the result loaded into vector registers is correct for quadword integer operations.

For example

```
const vui128_t ten32 = CONST_VUINT128_Qx16d (10000000000000000UL, 0UL);
```

### 7.7.6.2 CONST\_VUINT128\_Qx18d

```
#define CONST_VUINT128_Qx18d(
 __q0,
 __q1)
```

**Value:**

```
((vui128_t) \
 (((unsigned __int128) __q0) * 100000000000000000UL) \
 + ((unsigned __int128) __q1))
```

Generate a vector unsigned \_\_int128 constant from doublewords.

Combine 2 x 18 decimal digit long long constants into a single 36 decimal digit \_\_int128 constant. The 2 parameters are long integer constant values in high to low order. This order is consistent for big and little endian and the result loaded into vector registers is correct for quadword integer operations.

For example

```
vui128_t ten36-1 = CONST_VUINT128_Qx18d (9999999999999999UL, 999999999999999999UL);
```



## 7.7.6.3 CONST\_VUINT128\_Qx19d

```
#define CONST_VUINT128_Qx19d(
 __q0,
 __q1)
```

**Value:**

```
((vui128_t) \
 (((unsigned __int128) __q0) * 1000000000000000000UL) \
 + ((unsigned __int128) __q1))
```

Generate a vector unsigned \_\_int128 constant from doublewords.

Combine 2 x 19 decimal digit long long constants into a single 38 decimal digit \_\_int128 constant. The 2 parameters are long integer constant values in high to low order. This order is consistent for big and little endian and the result loaded into vector registers is correct for quadword integer operations.

For example

```
const vui128_t mul_invs_ten16 = CONST_VUINT128_Qx19d(
 7662477704329444291UL, 7917351357515459181UL);
```

## 7.7.6.4 CONST\_VUINT128\_QxD

```
#define CONST_VUINT128_QxD(
 __q0,
 __q1)
```

**Value:**

```
((vui128_t) \
 (((unsigned __int128) __q0) << 64) \
 + ((unsigned __int128) __q1))
```

Generate a vector unsigned \_\_int128 constant from doublewords.

Combine 2 x 64-bit long long constants into a single \_\_int128 constant. The 2 parameters are long integer constant values in high to low order. This order is consistent for big and little endian and the result loaded into vector registers is correct for quadword integer operations.

For example

```
vui128_t ten32 = CONST_VUINT128_QxD (0x000004ee2d6d415bUL, 0x85acef8100000000UL);
```



| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 14      | 1/cycle    |
| power9    | 11      | 1/cycle    |

## Parameters

|            |                             |
|------------|-----------------------------|
| <i>vra</i> | vector of unsigned __int128 |
| <i>vrb</i> | vector of unsigned __int128 |

## Returns

vector of the absolute difference.

## 7.7.7.2 vec\_addcq()

```
static vui128_t vec_addcq (
 vui128_t * cout,
 vui128_t a,
 vui128_t b) [inline], [static]
```

Vector Add with carry Unsigned Quadword.

Add two vector \_\_int128 values and return sum and the carry out.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8       | 1/2 cycles |
| power9    | 6       | 2/cycle    |

## Parameters

|              |                                    |
|--------------|------------------------------------|
| <i>*cout</i> | carry out from the sum of a and b. |
| <i>a</i>     | 128-bit vector treated a __int128. |
| <i>b</i>     | 128-bit vector treated a __int128. |

## Returns

\_\_int128 (lower 128-bits) sum of a and b.

### 7.7.7.3 vec\_addcuq()

```
static vuil28_t vec_addcuq (
 vuil28_t a,
 vuil28_t b) [inline], [static]
```

Vector Add & write Carry Unsigned Quadword.

Add two vector \_\_int128 values and return the carry out.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 2/2 cycles |
| power9    | 3       | 2/cycle    |

#### Parameters

|          |                                    |
|----------|------------------------------------|
| <i>a</i> | 128-bit vector treated a __int128. |
| <i>b</i> | 128-bit vector treated a __int128. |

#### Returns

\_\_int128 carry of the sum of a and b.

### 7.7.7.4 vec\_addecuq()

```
static vuil28_t vec_addecuq (
 vuil28_t a,
 vuil28_t b,
 vuil28_t ci) [inline], [static]
```

Vector Add Extended & write Carry Unsigned Quadword.

Add two vector \_\_int128 values plus a carry-in (0|1) and return the carry out bit.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 2/2 cycles |
| power9    | 3       | 2/cycle    |

#### Parameters

|           |                                    |
|-----------|------------------------------------|
| <i>a</i>  | 128-bit vector treated a __int128. |
| <i>b</i>  | 128-bit vector treated a __int128. |
| <i>ci</i> | Carry-in from vector bit[127].     |

**Returns**

carry-out in bit[127] of the sum of  $a + b + c$ .

**7.7.7.5 vec\_addeq()**

```
static vui128_t vec_addeq (
 vui128_t * cout,
 vui128_t a,
 vui128_t b,
 vui128_t ci) [inline], [static]
```

Vector Add Extend with carry Unsigned Quadword.

Add two vector `__int128` values plus a carry-in (0|1) and return sum and the carry out.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8       | 1/2 cycles |
| power9    | 6       | 2/cycle    |

**Parameters**

|              |                                                  |
|--------------|--------------------------------------------------|
| <i>*cout</i> | carry out from the sum of a and b.               |
| <i>a</i>     | 128-bit vector treated a <code>__int128</code> . |
| <i>b</i>     | 128-bit vector treated a <code>__int128</code> . |
| <i>ci</i>    | Carry-in from vector bit[127].                   |

**Returns**

`__int128` (lower 128-bits) sum of  $a + b + c$ .

**7.7.7.6 vec\_addeuqm()**

```
static vui128_t vec_addeuqm (
 vui128_t a,
 vui128_t b,
 vui128_t ci) [inline], [static]
```

Vector Add Extended Unsigned Quadword Modulo.

Add two vector `__int128` values plus a carry (0|1) and return the modulo 128-bit result.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 2/2 cycles |
| power9    | 3       | 2/cycle    |

**Parameters**

|           |                                    |
|-----------|------------------------------------|
| <i>a</i>  | 128-bit vector treated a __int128. |
| <i>b</i>  | 128-bit vector treated a __int128. |
| <i>ci</i> | Carry-in from vector bit[127].     |

**Returns**

\_\_int128 sum of a + b + c, modulo 128-bits.

**7.7.7.7 vec\_adduqm()**

```
static vuil28_t vec_adduqm (
 vuil28_t a,
 vuil28_t b) [inline], [static]
```

Vector Add Unsigned Quadword Modulo.

Add two vector \_\_int128 values and return result modulo 128-bits.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 2/2 cycles |
| power9    | 3       | 2/cycle    |

**Parameters**

|          |                                       |
|----------|---------------------------------------|
| <i>a</i> | 128-bit vector treated as a __int128. |
| <i>b</i> | 128-bit vector treated as a __int128. |

**Returns**

\_\_int128 sum of a and b.

**7.7.7.8 vec\_avguq()**

```
static vuil28_t vec_avguq (
 vuil28_t vra,
 vuil28_t vrb) [inline], [static]
```

Vector Average Unsigned Quadword.

Compute the average of two unsigned quadwords as  $(VRA + VRB + 1) / 2$ .

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 14      | 1/cycle    |
| power9    | 11      | 1/cycle    |

#### Parameters

|            |                           |
|------------|---------------------------|
| <i>vra</i> | vector unsigned quadwords |
| <i>vrb</i> | vector unsigned quadwords |

#### Returns

vector of the absolute differences.

#### 7.7.7.9 vec\_clzq()

```
static vui128_t vec_clzq (
 vui128_t vra) [inline], [static]
```

Vector Count Leading Zeros Quadword.

Count leading zeros for a vector `__int128` and return the count in a vector suitable for use with vector shift (left|right) and vector shift (left|right) by octet instructions.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 19-28   | 1/cycle    |
| power9    | 25-36   | 1/cycle    |

#### Parameters

|            |                                                    |
|------------|----------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated a <code>__int128</code> . |
|------------|----------------------------------------------------|

#### Returns

a 128-bit vector with bits 121:127 containing the count of leading zeros.

### 7.7.7.10 `vec_cmpeqsq()`

```
static vb128_t vec_cmpeqsq (
 vi128_t vra,
 vi128_t vrb) [inline], [static]
```

Vector Compare Equal Signed Quadword.

Compare signed `__int128` (128-bit) integers and return all '1's, if `vra == vrb`, otherwise all '0's. We use `vec_cmpequq` as it works for both signed and unsigned compares.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6       | 2/cycle    |
| power9    | 7       | 2/cycle    |

#### Parameters

|                  |                                                             |
|------------------|-------------------------------------------------------------|
| <code>vra</code> | 128-bit vector treated as an signed <code>__int128</code> . |
| <code>vrb</code> | 128-bit vector treated as an signed <code>__int128</code> . |

#### Returns

128-bit vector boolean reflecting vector signed `__int128` compare equal.

### 7.7.7.11 `vec_cmpequq()`

```
static vb128_t vec_cmpequq (
 vui128_t vra,
 vui128_t vrb) [inline], [static]
```

Vector Compare Equal Unsigned Quadword.

Compare unsigned `__int128` (128-bit) integers and return all '1's, if `vra == vrb`, otherwise all '0's.

For POWER8 (PowerISA 2.07B) or later, use the Vector Compare Equal Unsigned DoubleWord (**`vcmpequd`**) instruction. To get the correct quadword result, the doubleword element equal truth values are swapped, then *anded* with the original compare results. Otherwise use vector word compare and additional boolean logic to insure all word elements are equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6       | 2/cycle    |
| power9    | 7       | 2/cycle    |



**Parameters**

|            |                                                                |
|------------|----------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an unsigned <code>__int128s</code> . |
| <i>vrb</i> | 128-bit vector treated as an unsigned <code>__int128</code> .  |

**Returns**

128-bit vector boolean reflecting vector unsigned `__int128` compare equal.

**7.7.7.12 `vec_cmpgesq()`**

```
static vb128_t vec_cmpgesq (
 vi128_t vra,
 vi128_t vrb) [inline], [static]
```

Vector Compare Greater Than or Equal Signed Quadword.

Compare signed `__int128` (128-bit) integers and return all '1's, if `vra >= vrb`, otherwise all '0's.

Flip the operand sign bits and use `vec_cmpgeuq` for signed compare.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10-16   | 1/ 2cycles |
| power9    | 8-14    | 1/cycle    |

**Parameters**

|            |                                                             |
|------------|-------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an signed <code>__int128</code> . |
| <i>vrb</i> | 128-bit vector treated as an signed <code>__int128</code> . |

**Returns**

128-bit vector boolean reflecting vector signed `__int128` compare greater than.

**7.7.7.13 `vec_cmpgeuq()`**

```
static vb128_t vec_cmpgeuq (
 vui128_t vra,
 vui128_t vrb) [inline], [static]
```

Vector Compare Greater Than or Equal Unsigned Quadword.

Compare unsigned `__int128` (128-bit) integers and return all '1's, if `vra >= vrb`, otherwise all '0's.

For POWER8 (PowerISA 2.07B) or later, use the Vector Subtract & write Carry QuadWord (**vsubcuq**) instruction. This generates a carry for greater than or equal and NOT carry for less than. Then use `vec_setb_cyq` to convert the carry into a vector bool. Here we use the pveclib implementations (`vec_subcuq()` and `vec_setb_cyq()`), instead of `<altivec.h>` intrinsics, to address older compilers and POWER7.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8       | 2/ 2cycles |
| power9    | 6       | 2/cycle    |

#### Parameters

|            |                                                               |
|------------|---------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an unsigned <code>__int128</code> . |
| <i>vrb</i> | 128-bit vector treated as an unsigned <code>__int128</code> . |

#### Returns

128-bit vector boolean reflecting vector unsigned `__int128` compare greater than.

#### 7.7.7.14 `vec_cmpgtsq()`

```
static vb128_t vec_cmpgtsq (
 vi128_t vra,
 vi128_t vrb) [inline], [static]
```

Vector Compare Greater Than Signed Quadword.

Compare signed `__int128` (128-bit) integers and return all '1's, if `vra > vrb`, otherwise all '0's.

Flip the operand sign bits and use `vec_cmpgtuq` for signed compare.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10-16   | 1/ 2cycles |
| power9    | 8-14    | 1/cycle    |

#### Parameters

|            |                                                             |
|------------|-------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an signed <code>__int128</code> . |
| <i>vrb</i> | 128-bit vector treated as an signed <code>__int128</code> . |

**Returns**

128-bit vector boolean reflecting vector signed `__int128` compare greater than.

**7.7.7.15 `vec_cmpgtuq()`**

```
static vb128_t vec_cmpgtuq (
 vui128_t vra,
 vui128_t vrb) [inline], [static]
```

Vector Compare Greater Than Unsigned Quadword.

Compare unsigned `__int128` (128-bit) integers and return all '1's, if `vra > vrb`, otherwise all '0's.

For POWER8 (PowerISA 2.07B) or later, use the Vector Subtract & write Carry QuadWord (**vsubcuq**) instruction with the parameters reversed. This generates a carry for less than or equal and NOT carry for greater than. Then use `vec_setb_ncq` to convert the carry into a vector bool. Here we use the pveclib implementations ([vec\\_subcuq\(\)](#) and [vec\\_setb\\_ncq\(\)](#)), instead of `<altivec.h>` intrinsics, to address older compilers and POWER7.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8       | 2/ 2cycles |
| power9    | 6       | 2/cycle    |

**Parameters**

|            |                                                               |
|------------|---------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an unsigned <code>__int128</code> . |
| <i>vrb</i> | 128-bit vector treated as an unsigned <code>__int128</code> . |

**Returns**

128-bit vector boolean reflecting vector unsigned `__int128` compare greater than.

**7.7.7.16 `vec_cmplesq()`**

```
static vb128_t vec_cmplesq (
 vil128_t vra,
 vil128_t vrb) [inline], [static]
```

Vector Compare Less Than or Equal Signed Quadword.

Compare signed `__int128` (128-bit) integers and return all '1's, if `vra <= vrb`, otherwise all '0's.

Flip the operand sign bits and use `vec_cmpleuq` for signed compare.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10-16   | 1/ 2cycles |
| power9    | 8-14    | 1/cycle    |

#### Parameters

|            |                                                             |
|------------|-------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an signed <code>__int128</code> . |
| <i>vrb</i> | 128-bit vector treated as an signed <code>__int128</code> . |

#### Returns

128-bit vector boolean reflecting vector signed `__int128` compare less than or equal.

#### 7.7.7.17 `vec_cmpleuq()`

```
static vb128_t vec_cmpleuq (
 vui128_t vra,
 vui128_t vrb) [inline], [static]
```

Vector Compare Less Than or Equal Unsigned Quadword.

Compare unsigned `__int128` (128-bit) integers and return all '1's, if `vra <= vrb`, otherwise all '0's.

For POWER8 (PowerISA 2.07B) or later, use the Vector Subtract & write Carry QuadWord (**`vsubcuq`**) instruction. This generates a carry for greater than or equal and NOT carry for less than. Then use `vec_setb_ncq` to convert the carry into a vector bool. Here we use the pveclib implementations (**`vec_subcuq()`**) and **`vec_setb_cyq()`**, instead of `<altivec.h>` intrinsics, to address older compilers and POWER7.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8       | 2/ 2cycles |
| power9    | 6       | 2/cycle    |

#### Parameters

|            |                                                               |
|------------|---------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an unsigned <code>__int128</code> . |
| <i>vrb</i> | 128-bit vector treated as an unsigned <code>__int128</code> . |

#### Returns

128-bit vector boolean reflecting vector unsigned `__int128` compare less than or equal.

**7.7.7.18 vec\_cmpltuq()**

```
static vb128_t vec_cmpltuq (
 vi128_t vra,
 vi128_t vrb) [inline], [static]
```

Vector Compare Less Than Signed Quadword.

Compare signed \_\_int128 (128-bit) integers and return all '1's, if  $vra < vrb$ , otherwise all '0's.

Flip the operand sign bits and use `vec_cmpltuq` for signed compare.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10-16   | 1/ 2cycles |
| power9    | 8-14    | 1/cycle    |

**Parameters**

|            |                                               |
|------------|-----------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an signed __int128. |
| <i>vrb</i> | 128-bit vector treated as an signed __int128. |

**Returns**

128-bit vector boolean reflecting vector unsigned \_\_int128 compare less than.

**7.7.7.19 vec\_cmpltuq()**

```
static vb128_t vec_cmpltuq (
 vui128_t vra,
 vui128_t vrb) [inline], [static]
```

Vector Compare Less Than Unsigned Quadword.

Compare unsigned \_\_int128 (128-bit) integers and return all '1's, if  $vra < vrb$ , otherwise all '0's.

For POWER8 (PowerISA 2.07B) or later, use the Vector Subtract & write Carry QuadWord (**vsubcuq**) instruction. This generates a carry for greater than or equal and NOT carry for less than. Then use `vec_setb_ncq` to convert the carry into a vector bool. Here we use the pveclib implementations (`vec_subcuq()` and `vec_setb_ncq()`), instead of `<altivec.h>` intrinsics, to address older compilers and POWER7.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8       | 2/ 2cycles |
| power9    | 6       | 2/cycle    |

**Parameters**

|            |                                                               |
|------------|---------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an unsigned <code>__int128</code> . |
| <i>vrb</i> | 128-bit vector treated as an unsigned <code>__int128</code> . |

**Returns**

128-bit vector boolean reflecting vector unsigned `__int128` compare less than.

**7.7.7.20 `vec_cmpnesq()`**

```
static vb128_t vec_cmpnesq (
 vi128_t vra,
 vi128_t vrb) [inline], [static]
```

Vector Compare Equal Signed Quadword.

Compare signed `__int128` (128-bit) integers and return all '1's, if `vra != vrb`, otherwise all '0's. We use `vec_cmpequq` as it works for both signed and unsigned compares.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6       | 2/cycle    |
| power9    | 7       | 2/cycle    |

**Parameters**

|            |                                                             |
|------------|-------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an signed <code>__int128</code> . |
| <i>vrb</i> | 128-bit vector treated as an signed <code>__int128</code> . |

**Returns**

128-bit vector boolean reflecting vector signed `__int128` compare not equal.

**7.7.7.21 `vec_cmpneuq()`**

```
static vb128_t vec_cmpneuq (
 vui128_t vra,
 vui128_t vrb) [inline], [static]
```

Vector Compare Not Equal Unsigned Quadword.

Compare unsigned `__int128` (128-bit) integers and return all '1's, if `vra != vrb`, otherwise all '0's.

For POWER8 (PowerISA 2.07B) or later, use the Vector Compare Equal Unsigned DoubleWord (**vcmpequd**) instruction. To get the correct quadword result, the doubleword element equal truth values are swapped, then *not anded* with the original compare results. Otherwise use vector word compare and additional boolean logic to insure all word elements are equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6       | 2/cycle    |
| power9    | 7       | 2/cycle    |

#### Parameters

|            |                                                               |
|------------|---------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an unsigned <code>__int128</code> . |
| <i>vrb</i> | 128-bit vector treated as an unsigned <code>__int128</code> . |

#### Returns

128-bit vector boolean reflecting vector unsigned `__int128` compare equal.

#### 7.7.7.22 `vec_cmpsq_all_eq()`

```
static int vec_cmpsq_all_eq (
 vi128_t vra,
 vi128_t vrb) [inline], [static]
```

Vector Compare all Equal Signed Quadword.

Compare vector signed `__int128` values and return true if `vra` and `vrb` are equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|            |                                                                                   |
|------------|-----------------------------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector signed <code>__int128</code> (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector signed <code>__int128</code> (qword) element. |

#### Returns

boolean int for all 128-bits, true if equal, false otherwise.

### 7.7.7.23 vec\_cmpsq\_all\_ge()

```
static int vec_cmpsq_all_ge (
 vi128_t vra,
 vi128_t vrb) [inline], [static]
```

Vector Compare any Greater Than or Equal Signed Quadword.

Compare vector unsigned \_\_int128 values and return true if vra >= vrb.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10-15   | 1/ 2cycles |
| power9    | 8       | 1/cycle    |

#### Parameters

|            |                                                                      |
|------------|----------------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector signed __int128 (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector signed __int128 (qword) element. |

#### Returns

boolean int for all 128-bits, true if Greater Than or Equal, false otherwise.

### 7.7.7.24 vec\_cmpsq\_all\_gt()

```
static int vec_cmpsq_all_gt (
 vi128_t vra,
 vi128_t vrb) [inline], [static]
```

Vector Compare any Greater Than Signed Quadword.

Compare vector signed \_\_int128 values and return true if vra > vrb.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10-15   | 1/ 2cycles |
| power9    | 8       | 1/cycle    |

#### Parameters

|            |                                                                      |
|------------|----------------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector signed __int128 (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector signed __int128 (qword) element. |



**Returns**

boolean int for all 128-bits, true if Greater Than, false otherwise.

**7.7.7.25 vec\_cmpsq\_all\_le()**

```
static int vec_cmpsq_all_le (
 vi128_t vra,
 vi128_t vrb) [inline], [static]
```

Vector Compare any Less Than or Equal Signed Quadword.

Compare vector signed \_\_int128 values and return true if  $vra \leq vrb$ .

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10-15   | 1/ 2cycles |
| power9    | 8       | 1/cycle    |

**Parameters**

|            |                                                                      |
|------------|----------------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector signed __int128 (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector signed __int128 (qword) element. |

**Returns**

boolean int for all 128-bits, true if Less Than or Equal, false otherwise.

**7.7.7.26 vec\_cmpsq\_all\_lt()**

```
static int vec_cmpsq_all_lt (
 vi128_t vra,
 vi128_t vrb) [inline], [static]
```

Vector Compare any Less Than Signed Quadword.

Compare vector signed \_\_int128 values and return true if  $vra < vrb$ .

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10-15   | 1/ 2cycles |
| power9    | 8       | 1/cycle    |

**Parameters**

|            |                                                                      |
|------------|----------------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector signed __int128 (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector signed __int128 (qword) element. |

**Returns**

boolean int for all 128-bits, true if Less Than, false otherwise.

**7.7.7.27 vec\_cmpsq\_all\_ne()**

```
static int vec_cmpsq_all_ne (
 vi128_t vra,
 vi128_t vrb) [inline], [static]
```

Vector Compare all Not Equal Signed Quadword.

Compare vector signed \_\_int128 values and return true if vra and vrb are not equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|            |                                                                      |
|------------|----------------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector signed __int128 (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector signed __int128 (qword) element. |

**Returns**

boolean \_\_int128 for all 128-bits, true if equal, false otherwise.

**7.7.7.28 vec\_cmpuq\_all\_eq()**

```
static int vec_cmpuq_all_eq (
 vui128_t vra,
 vui128_t vrb) [inline], [static]
```

Vector Compare all Equal Unsigned Quadword.

Compare vector unsigned \_\_int128 values and return true if vra and vrb are equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|                    |                                                                        |
|--------------------|------------------------------------------------------------------------|
| <i>vra</i>         | 128-bit vector treated as an vector unsigned __int128 (qword) element. |
| <i>vr</i> <i>b</i> | 128-bit vector treated as an vector unsigned __int128 (qword) element. |

## Returns

boolean int for all 128-bits, true if equal, false otherwise.

## 7.7.7.29 vec\_cmpuq\_all\_ge()

```
static int vec_cmpuq_all_ge (
 vui128_t vra,
 vui128_t vrb) [inline], [static]
```

Vector Compare any Greater Than or Equal Unsigned Quadword.

Compare vector unsigned \_\_int128 values and return true if *vra* >= *vr**b*.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8-13    | 2/ 2cycles |
| power9    | 6       | 2/cycle    |

## Parameters

|                    |                                                                        |
|--------------------|------------------------------------------------------------------------|
| <i>vra</i>         | 128-bit vector treated as an vector unsigned __int128 (qword) element. |
| <i>vr</i> <i>b</i> | 128-bit vector treated as an vector unsigned __int128 (qword) element. |

## Returns

boolean int for all 128-bits, true if Greater Than or Equal, false otherwise.

## 7.7.7.30 vec\_cmpuq\_all\_gt()

```
static int vec_cmpuq_all_gt (
 vui128_t vra,
 vui128_t vrb) [inline], [static]
```

Vector Compare any Greater Than Unsigned Quadword.

Compare vector unsigned `__int128` values and return true if `vra > vrb`.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8-13    | 2/ 2cycles |
| power9    | 6       | 2/cycle    |

#### Parameters

|            |                                                                                     |
|------------|-------------------------------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector unsigned <code>__int128</code> (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector unsigned <code>__int128</code> (qword) element. |

#### Returns

boolean int for all 128-bits, true if Greater Than, false otherwise.

#### 7.7.7.31 `vec_cmpuq_all_le()`

```
static int vec_cmpuq_all_le (
 vui128_t vra,
 vui128_t vrb) [inline], [static]
```

Vector Compare any Less Than or Equal Unsigned Quadword.

Compare vector unsigned `__int128` values and return true if `vra <= vrb`.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8-13    | 2/ 2cycles |
| power9    | 6       | 2/cycle    |

#### Parameters

|            |                                                                                     |
|------------|-------------------------------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector unsigned <code>__int128</code> (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector unsigned <code>__int128</code> (qword) element. |

#### Returns

boolean int for all 128-bits, true if Less Than or Equal, false otherwise.

## 7.7.7.32 vec\_cmpuq\_all\_lt()

```
static int vec_cmpuq_all_lt (
 vui128_t vra,
 vui128_t vrb) [inline], [static]
```

Vector Compare any Less Than Unsigned Quadword.

Compare vector unsigned \_\_int128 values and return true if  $vra < vrb$ .

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8-13    | 2/ 2cycles |
| power9    | 6       | 2/cycle    |

## Parameters

|            |                                                                        |
|------------|------------------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector unsigned __int128 (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector unsigned __int128 (qword) element. |

## Returns

boolean int for all 128-bits, true if Less Than, false otherwise.

## 7.7.7.33 vec\_cmpuq\_all\_ne()

```
static int vec_cmpuq_all_ne (
 vui128_t vra,
 vui128_t vrb) [inline], [static]
```

Vector Compare all Not Equal Unsigned Quadword.

Compare vector unsigned \_\_int128 values and return true if  $vra$  and  $vrb$  are not equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|            |                                                                        |
|------------|------------------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as an vector unsigned __int128 (qword) element. |
| <i>vrb</i> | 128-bit vector treated as an vector unsigned __int128 (qword) element. |

**Returns**

boolean `__int128` for all 128-bits, true if equal, false otherwise.

**7.7.7.34 `vec_cmul100cuq()`**

```
static vuil28_t vec_cmul100cuq (
 vuil28_t * cout,
 vuil28_t a) [inline], [static]
```

Vector combined Multiply by 100 & write Carry Unsigned Quadword.

compute the product of a 128 bit values  $a * 100$ . Only the low order 128 bits of the product are returned.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 13-15   | 1/cycle    |
| power9    | 6       | 1/cycle    |

**Parameters**

|              |                                                            |
|--------------|------------------------------------------------------------|
| <i>*cout</i> | pointer to upper 128-bits of the product.                  |
| <i>a</i>     | 128-bit vector treated as unsigned <code>__int128</code> . |

**Returns**

vector `__int128` (lower 128-bits of the 256-bit product)  $a * 100$ .

**7.7.7.35 `vec_cmul100ecuq()`**

```
static vuil28_t vec_cmul100ecuq (
 vuil28_t * cout,
 vuil28_t a,
 vuil28_t cin) [inline], [static]
```

Vector combined Multiply by 100 Extended & write Carry Unsigned Quadword.

Compute the product of a 128 bit value  $a * 100 + \text{digit}(\text{cin})$ . The function return its low order 128 bits of the extended product. The first parameter (*\*cout*) it the address of the vector to receive the generated carry out in the range 0-99.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 15-17   | 1/cycle    |
| power9    | 9       | 1/cycle    |

## Parameters

|              |                                                            |
|--------------|------------------------------------------------------------|
| <i>*cout</i> | pointer to upper 128-bits of the product.                  |
| <i>a</i>     | 128-bit vector treated as unsigned <code>__int128</code> . |
| <i>cin</i>   | values 0-99 in bits 120:127 of a vector.                   |

## Returns

vector `__int128` (lower 128-bits of the 256-bit product)  $a * 100$ .

7.7.7.36 `vec_cmul10cuq()`

```
static vui128_t vec_cmul10cuq (
 vui128_t * cout,
 vui128_t a) [inline], [static]
```

Vector combined Multiply by 10 & write Carry Unsigned Quadword.

compute the product of a 128 bit values  $a * 10$ . Only the low order 128 bits of the product are returned.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 13-15   | 1/cycle    |
| power9    | 3       | 1/ 2cycles |

## Parameters

|              |                                                              |
|--------------|--------------------------------------------------------------|
| <i>*cout</i> | pointer to upper 128-bits of the product.                    |
| <i>a</i>     | 128-bit vector treated as a unsigned <code>__int128</code> . |

## Returns

vector `__int128` (lower 128-bits of the 256-bit product)  $a * 10$ .

7.7.7.37 `vec_cmul10ecuq()`

```
static vui128_t vec_cmul10ecuq (
 vui128_t * cout,
 vui128_t a,
 vui128_t cin) [inline], [static]
```

Vector combined Multiply by 10 Extended & write Carry Unsigned Quadword.

Compute the product of a 128 bit value  $a * 10 + \text{digit}(\text{cin})$ . Only the low order 128 bits of the extended product are returned.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 13-15   | 1/cycle    |
| power9    | 3       | 1/ 2cycles |

#### Parameters

|              |                                                |
|--------------|------------------------------------------------|
| <i>*cout</i> | pointer to upper 128-bits of the product.      |
| <i>a</i>     | 128-bit vector treated as a unsigned __int128. |
| <i>cin</i>   | values 0-9 in bits 124:127 of a vector.        |

#### Returns

vector \_\_int128 (upper 128-bits of the 256-bit product)  $a * 10$ .

#### 7.7.7.38 `vec_divsq_10e31()`

```
static vi128_t vec_divsq_10e31 (
 vi128_t vra) [inline], [static]
```

Vector Divide by const 10e31 Signed Quadword.

Compute the quotient of a 128 bit values `vra / 10e31`.

#### Note

`vec_divsq_10e31()` and `vec_modsq_10e31()` can be used to prepare for **Decimal Convert From Signed Quadword** (See `vec_bcdcfsq()`), This guarantees that the conversion to Vector BCD does not overflow and the 39-digit extended result is obtained.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 18-60   | 1/cycle    |
| power9    | 20-45   | 1/cycle    |

#### Parameters

|            |                                                          |
|------------|----------------------------------------------------------|
| <i>vra</i> | the dividend as a vector treated as a unsigned __int128. |
|------------|----------------------------------------------------------|

#### Returns

the quotient as vector unsigned \_\_int128.



## 7.7.7.39 vec\_divudq\_10e31()

```
static vuil28_t vec_divudq_10e31 (
 vuil28_t * qh,
 vuil28_t vra,
 vuil28_t vrb) [inline], [static]
```

Vector Divide Unsigned Double Quadword by const 10e31.

Compute the quotient of 256 bit value  $vra||vrb / 10e31$ .

## Note

[vec\\_divudq\\_10e31\(\)](#) and [vec\\_modudq\\_10e31\(\)](#) can be used to perform long division of a multi-quadword binary value by the constant 10e31. The final remainder can be passed to **Decimal Convert From Signed Quadword** (See [vec\\_bcdcfsq\(\)](#)). Long division is repeated on the resulting multi-quadword quotient to extract 31-digits for each step. This continues until the multi-quadword quotient is less than 10e31 which provides the highest order 31-digits of the of the multiple precision binary to BCD conversion.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 12-192  | 1/cycle    |
| power9    | 9-127   | 1/cycle    |

## Parameters

|            |                                                  |
|------------|--------------------------------------------------|
| <i>*qh</i> | the high quotient as a vector unsigned __int128. |
| <i>vra</i> | the high dividend as a vector unsigned __int128. |
| <i>vrb</i> | the low dividend as a vector unsigned __int128.  |

## Returns

the low quotient as vector unsigned \_\_int128.

## 7.7.7.40 vec\_divudq\_10e32()

```
static vuil28_t vec_divudq_10e32 (
 vuil28_t * qh,
 vuil28_t vra,
 vuil28_t vrb) [inline], [static]
```

Vector Divide Unsigned Double Quadword by const 10e32.

Compute the quotient of 256 bit value  $vra||vrb / 10e32$ .

**Note**

[vec\\_divudq\\_10e32\(\)](#) and [vec\\_modudq\\_10e32\(\)](#) can be used to perform long division of a multi-quadword binary value by the constant 10e32. The final remainder can be passed to **Decimal Convert From Unsigned Quadword** (See [vec\\_bcdcfuq\(\)](#)). Long division is repeated on the resulting multi-quadword quotient to extract 32-digits for each step. This continues until the multi-quadword quotient result is less than 10e32 which provides the highest order 32-digits of the multiple precision binary to BCD conversion.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 12-192  | 1/cycle    |
| power9    | 9-127   | 1/cycle    |

**Parameters**

|            |                                                  |
|------------|--------------------------------------------------|
| <i>*qh</i> | the high quotient as a vector unsigned __int128. |
| <i>vra</i> | the high dividend as a vector unsigned __int128. |
| <i>vrh</i> | the low dividend as a vector unsigned __int128.  |

**Returns**

the low quotient as vector unsigned \_\_int128.

**7.7.7.41 vec\_divuq\_10e31()**

```
static vuil28_t vec_divuq_10e31 (
 vuil28_t vra) [inline], [static]
```

Vector Divide by const 10e31 Unsigned Quadword.

Compute the quotient of a 128 bit values  $vra / 10e31$ .

**Note**

[vec\\_divuq\\_10e31\(\)](#) and [vec\\_moduq\\_10e31\(\)](#) can be used to prepare for **Decimal Convert From Signed Quadword** (See [vec\\_bcdcfuq\(\)](#)). This guarantees that the conversion to Vector BCD does not overflow and the 39-digit extended result is obtained.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8-48    | 1/cycle    |
| power9    | 9-31    | 1/cycle    |

**Parameters**

|            |                                                          |
|------------|----------------------------------------------------------|
| <i>vra</i> | the dividend as a vector treated as a unsigned __int128. |
|------------|----------------------------------------------------------|

**Returns**

the quotient as vector unsigned \_\_int128.

**7.7.7.42 vec\_divuq\_10e32()**

```
static vuil128_t vec_divuq_10e32 (
 vuil128_t vra) [inline], [static]
```

Vector Divide by const 10e32 Unsigned Quadword.

Compute the quotient of a 128 bit values vra / 10e32.

**Note**

[vec\\_divuq\\_10e32\(\)](#) and [vec\\_moduq\\_10e32\(\)](#) can be used to prepare for **Decimal Convert From Unsigned Quadword** (See [vec\\_bcdcfuq\(\)](#)), This guarantees that the conversion to Vector BCD does not overflow and the 39-digit extended result is obtained.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8-48    | 1/cycle    |
| power9    | 9-31    | 1/cycle    |

**Parameters**

|            |                                                          |
|------------|----------------------------------------------------------|
| <i>vra</i> | the dividend as a vector treated as a unsigned __int128. |
|------------|----------------------------------------------------------|

**Returns**

the quotient as vector unsigned \_\_int128.

**7.7.7.43 vec\_madd2uq()**

```
static vuil128_t vec_madd2uq (
 vuil128_t * mulu,
 vuil128_t a,
 vuil128_t b,
 vuil128_t c1,
 vuil128_t c2) [inline], [static]
```

Vector Multiply-Add2 Unsigned Quadword.

Compute the sum of the 256 bit product of two 128 bit values a, b plus the sum of 128 bit values c1 and c2. The low order 128 bits of the sum are returned, while the high order 128-bits are "stored" via the mulu pointer.

**Note**

The advantage of this form (versus Multiply-Sum) is that the final 256 bit sum can not overflow.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 60-66   | 1/cycle    |
| power9    | 30-36   | 1/cycle    |

**Parameters**

|              |                                                                                                              |
|--------------|--------------------------------------------------------------------------------------------------------------|
| <i>*mulu</i> | pointer to vector unsigned __int128 to receive the upper 128-bits of the 256 bit sum $((a * b) + c1 + c2)$ . |
| <i>a</i>     | 128-bit vector treated as unsigned __int128.                                                                 |
| <i>b</i>     | 128-bit vector treated as unsigned __int128.                                                                 |
| <i>c1</i>    | 128-bit vector treated as unsigned __int128.                                                                 |
| <i>c2</i>    | 128-bit vector treated as unsigned __int128.                                                                 |

**Returns**

vector unsigned \_\_int128 (lower 128-bits) of  $((a * b) + c1 + c2)$ .

**7.7.7.44 vec\_madduq()**

```
static vu128_t vec_madduq (
 vu128_t * mulu,
 vu128_t a,
 vu128_t b,
 vu128_t c) [inline], [static]
```

Vector Multiply-Add Unsigned Quadword.

Compute the sum of the 256 bit product of two 128 bit values a, b plus the 128 bit value c. The low order 128 bits of the sum are returned, while the high order 128-bits are "stored" via the mulu pointer.

**Note**

The advantage of this form (versus Multiply-Sum) is that the final 256 bit sum can not overflow.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 56-62   | 1/cycle    |
| power9    | 27-33   | 1/cycle    |

## Parameters

|              |                                                                                                     |
|--------------|-----------------------------------------------------------------------------------------------------|
| <i>*mulu</i> | pointer to vector unsigned __int128 to receive the upper 128-bits of the 256 bit sum ((a * b) + c). |
| <i>a</i>     | 128-bit vector treated as unsigned __int128.                                                        |
| <i>b</i>     | 128-bit vector treated as unsigned __int128.                                                        |
| <i>c</i>     | 128-bit vector treated as unsigned __int128.                                                        |

## Returns

vector unsigned \_\_int128 (lower 128-bits) of ((a \* b) + c).

## 7.7.7.45 vec\_maxsq()

```
static vi128_t vec_maxsq (
 vi128_t vra,
 vi128_t vrb) [inline], [static]
```

Vector Maximum Signed Quadword.

Compare Quadwords vra and vrb as signed integers and return the larger value in the result.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 12-18   | 2/cycle    |
| power9    | 10-18   | 2/cycle    |

## Parameters

|            |                          |
|------------|--------------------------|
| <i>vra</i> | 128-bit vector __int128. |
| <i>vrb</i> | 128-bit vector __int128. |

## Returns

vector \_\_int128 maximum of a and b.

## 7.7.7.46 vec\_maxuq()

```
static vui128_t vec_maxuq (
 vui128_t vra,
 vui128_t vrb) [inline], [static]
```

Vector Maximum Unsigned Quadword.

Compare Quadwords vra and vrb as unsigned integers and return the larger value in the result.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10      | 2/cycle    |
| power9    | 8       | 2/cycle    |

#### Parameters

|            |                                   |
|------------|-----------------------------------|
| <i>vra</i> | 128-bit vector unsigned __int128. |
| <i>vrb</i> | 128-bit vector unsigned __int128. |

#### Returns

vector unsigned \_\_int128 maximum of a and b.

#### 7.7.7.47 vec\_minsq()

```
static vi128_t vec_minsq (
 vi128_t vra,
 vi128_t vrb) [inline], [static]
```

Vector Minimum Signed Quadword.

Compare Quadwords vra and vrb as signed integers and return the smaller value in the result.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 12-18   | 2/cycle    |
| power9    | 10-18   | 2/cycle    |

#### Parameters

|            |                          |
|------------|--------------------------|
| <i>vra</i> | 128-bit vector __int128. |
| <i>vrb</i> | 128-bit vector __int128. |

#### Returns

vector \_\_int128 minimum of a and b.

#### 7.7.7.48 vec\_minuq()

```
static vui128_t vec_minuq (
 vui128_t vra,
 vui128_t vrb) [inline], [static]
```

Vector Minimum Unsigned Quadword.

Compare Quadwords *vra* and *vrb* as unsigned integers and return the smaller value in the result.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10      | 2/cycle    |
| power9    | 8       | 2/cycle    |

#### Parameters

|            |                                       |
|------------|---------------------------------------|
| <i>vra</i> | 128-bit vector unsigned __int128 int. |
| <i>vrb</i> | 128-bit vector unsigned __int128 int. |

#### Returns

vector unsigned \_\_int128 minimum of *a* and *b*.

#### 7.7.7.49 vec\_modsq\_10e31()

```
static vi128_t vec_modsq_10e31 (
 vi128_t vra,
 vi128_t q) [inline], [static]
```

Vector Modulo by const 10e31 Signed Quadword.

Compute the remainder of a 128 bit values *vra* % 10e31.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8-52    | 1/cycle    |
| power9    | 9-23    | 2/cycle    |

#### Parameters

|            |                                                                                          |
|------------|------------------------------------------------------------------------------------------|
| <i>vra</i> | the dividend as a vector treated as a signed __int128.                                   |
| <i>q</i>   | 128-bit signed __int128 containing the quotient from <a href="#">vec_divuq_10e31()</a> . |

#### Returns

the remainder as vector signed \_\_int128.

#### 7.7.7.50 `vec_modudq_10e31()`

```
static vuil28_t vec_modudq_10e31 (
 vuil28_t vra,
 vuil28_t vrb,
 vuil28_t * ql) [inline], [static]
```

Vector Modulo Unsigned Double Quadword by const 10e31.

Compute the remainder  $(vra || vrb) - (ql * 10e31)$ .

##### Note

As we are using 128-bit multiplicative inverse for 128-bit integer in a 256-bit divide, so the quotient may not be exact (one bit off). So we check here if the remainder is too high (greater than 10e31) and correct both the remainder and quotient if needed.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 12-124  | 1/cycle    |
| power9    | 12-75   | 1/cycle    |

##### Parameters

|            |                                                                                          |
|------------|------------------------------------------------------------------------------------------|
| <i>vra</i> | the high dividend as a vector unsigned __int128.                                         |
| <i>vrb</i> | the low dividend as a vector unsigned __int128.                                          |
| <i>*ql</i> | 128-bit unsigned __int128 containing the quotient from <code>vec_divudq_10e31()</code> . |

##### Returns

the remainder as vector unsigned \_\_int128.

#### 7.7.7.51 `vec_modudq_10e32()`

```
static vuil28_t vec_modudq_10e32 (
 vuil28_t vra,
 vuil28_t vrb,
 vuil28_t * ql) [inline], [static]
```

Vector Modulo Unsigned Double Quadword by const 10e32.

Compute the remainder  $(vra || vrb) - (ql * 10e32)$ .

##### Note

As we are using 128-bit multiplicative inverse for 128-bit integer in a 256-bit divide, so the quotient may not be exact (one bit off). So we check here if the remainder is too high (greater than 10e32) and correct both the remainder and quotient if needed.



| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 12-124  | 1/cycle    |
| power9    | 12-75   | 1/cycle    |

**Parameters**

|            |                                                                                             |
|------------|---------------------------------------------------------------------------------------------|
| <i>vra</i> | the high dividend as a vector unsigned __int128.                                            |
| <i>vrb</i> | the low dividend as a vector unsigned __int128.                                             |
| <i>*q/</i> | 128-bit unsigned __int128 containing the quotient from <a href="#">vec_divudq_10e31()</a> . |

**Returns**

the remainder as vector unsigned \_\_int128.

**7.7.7.52 vec\_moduq\_10e31()**

```
static vuil28_t vec_moduq_10e31 (
 vuil28_t vra,
 vuil28_t q) [inline], [static]
```

Vector Modulo by const 10e31 Unsigned Quadword.

Compute the remainder of a 128 bit values *vra* % 10e31.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8-52    | 1/cycle    |
| power9    | 9-23    | 2/cycle    |

**Parameters**

|            |                                                                                            |
|------------|--------------------------------------------------------------------------------------------|
| <i>vra</i> | the dividend as a vector treated as a unsigned __int128.                                   |
| <i>q</i>   | 128-bit unsigned __int128 containing the quotient from <a href="#">vec_divuq_10e31()</a> . |

**Returns**

the remainder as vector unsigned \_\_int128.

#### 7.7.7.53 vec\_moduq\_10e32()

```
static vuil28_t vec_moduq_10e32 (
 vuil28_t vra,
 vuil28_t q) [inline], [static]
```

Vector Modulo by const 10e32 Unsigned Quadword.

Compute the remainder of a 128 bit values vra % 10e32.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 8-52    | 1/cycle    |
| power9    | 9-23    | 2/cycle    |

##### Parameters

|            |                                                                                            |
|------------|--------------------------------------------------------------------------------------------|
| <i>vra</i> | the dividend as a vector treated as a unsigned __int128.                                   |
| <i>q</i>   | 128-bit unsigned __int128 containing the quotient from <a href="#">vec_divuq_10e32()</a> . |

##### Returns

the remainder as vector unsigned \_\_int128.

#### 7.7.7.54 vec\_msumudm()

```
static vuil28_t vec_msumudm (
 vui64_t a,
 vui64_t b,
 vuil28_t c) [inline], [static]
```

Vector Multiply-Sum Unsigned Doubleword Modulo.

compute the even and odd 128-bit products of doubleword 64-bit element values from a, b. Then compute the 128-bit sum  $(a_{\text{even}} * b_{\text{even}}) + (a_{\text{odd}} * b_{\text{odd}}) + c$ . Only the low order 128 bits of the Multiply-Sum are returned and any overflow/carry-out is ignored/lost.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 30-32   | 1/cycle    |
| power9    | 5-7     | 2/cycle    |

##### Parameters

|          |                                     |
|----------|-------------------------------------|
| <i>a</i> | 128-bit __vector unsigned long int. |
| <i>b</i> | 128-bit __vector unsigned long int. |

## Parameters

|   |                                     |
|---|-------------------------------------|
| c | 128-bit __vector unsigned __int128. |
|---|-------------------------------------|

## Returns

\_\_vector unsigned Modulo Sum of the 128-bit even / odd products of operands a and b plus the unsigned \_\_int128 operand c.

## 7.7.7.55 vec\_mul10cuq()

```
static vuil28_t vec_mul10cuq (
 vuil28_t a) [inline], [static]
```

Vector Multiply by 10 & write Carry Unsigned Quadword.

compute the product of a 128 bit value  $a * 10$ . Only the high order 128 bits of the product are returned. This will be binary coded decimal value 0-9 in bits 124-127, Bits 0-123 will be '0'.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 13-15   | 1/cycle    |
| power9    | 3       | 1/cycle    |

## Parameters

|   |                                                |
|---|------------------------------------------------|
| a | 128-bit vector treated as a unsigned __int128. |
|---|------------------------------------------------|

## Returns

\_\_int128 (upper 128-bits of the 256-bit product)  $a * 10 \gg 128$ .

## 7.7.7.56 vec\_mul10ecuq()

```
static vuil28_t vec_mul10ecuq (
 vuil28_t a,
 vuil28_t cin) [inline], [static]
```

Vector Multiply by 10 Extended & write Carry Unsigned Quadword.

Compute the product of a 128 bit value  $a * 10 + \text{digit}(\text{cin})$ . Only the low order 128 bits of the extended product are returned.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 15-17   | 1/cycle    |
| power9    | 3       | 1/cycle    |

**Parameters**

|            |                                                            |
|------------|------------------------------------------------------------|
| <i>a</i>   | 128-bit vector treated as unsigned <code>__int128</code> . |
| <i>cin</i> | values 0-9 in bits 124:127 of a vector.                    |

**Returns**

`__int128` (upper 128-bits of the 256-bit product)  $a * 10 \gg 128$ .

**7.7.7.57 `vec_mul10euq()`**

```
static vuil28_t vec_mul10euq (
 vuil28_t a,
 vuil28_t cin) [inline], [static]
```

Vector Multiply by 10 Extended Unsigned Quadword.

compute the product of a 128 bit value  $a * 10 + \text{digit}(\text{cin})$ . Only the low order 128 bits of the extended product are returned.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 13-15   | 1/cycle    |
| power9    | 3       | 1/cycle    |

**Parameters**

|            |                                                            |
|------------|------------------------------------------------------------|
| <i>a</i>   | 128-bit vector treated as unsigned <code>__int128</code> . |
| <i>cin</i> | values 0-9 in bits 124:127 of a vector.                    |

**Returns**

`__int128` (lower 128-bits)  $a * 10$ .

**7.7.7.58 `vec_mul10uq()`**

```
static vuil28_t vec_mul10uq (
 vuil28_t a) [inline], [static]
```

Vector Multiply by 10 Unsigned Quadword.

compute the product of a 128 bit value  $a * 10$ . Only the low order 128 bits of the product are returned.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 13-15   | 1/cycle    |
| power9    | 3       | 1/cycle    |

#### Parameters

|          |                                              |
|----------|----------------------------------------------|
| <i>a</i> | 128-bit vector treated as unsigned __int128. |
|----------|----------------------------------------------|

#### Returns

\_\_int128 (lower 128-bits)  $a * 10$ .

#### 7.7.7.59 vec\_muleud()

```
static vui128_t vec_muleud (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Multiply Even Unsigned Doublewords.

Multiple the even 64-bit doublewords of two vector unsigned long values and return the unsigned \_\_int128 product of the even doublewords.

#### Note

The element numbering changes between big and little-endian. So the compiler and this implementation adjusts the generated code to reflect this.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 21-23   | 1/cycle    |
| power9    | 8-13    | 2/cycle    |

#### Parameters

|          |                                   |
|----------|-----------------------------------|
| <i>a</i> | 128-bit vector unsigned long int. |
| <i>b</i> | 128-bit vector unsigned long int. |

**Returns**

vector unsigned \_\_int128 product of the even double words of a and b.

**7.7.7.60 vec\_mulhud()**

```
static vui64_t vec_mulhud (
 vui64_t vra,
 vui64_t vrb) [inline], [static]
```

Vector Multiply High Unsigned Doubleword.

Multiple the corresponding doubleword elements of two vector unsigned long values and return the high order 64-bits, from each 128-bit product.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 28-32   | 1/cycle    |
| power9    | 11-16   | 1/cycle    |

**Note**

This operation can be used to effectively perform a divide by multiplying by the scaled multiplicative inverse (reciprocal).

Warren, Henry S. Jr and *Hacker's Delight*, 2nd Edition, Addison Wesley, 2013. Chapter 10, Integer Division by Constants.

**Parameters**

|            |                                   |
|------------|-----------------------------------|
| <i>vra</i> | 128-bit vector unsigned long int. |
| <i>vrb</i> | 128-bit vector unsigned long int. |

**Returns**

vector unsigned long int of the high order 64-bits of the unsigned 128-bit product of the doubleword elements from vra and vrb.

**7.7.7.61 vec\_mulhuq()**

```
static vui128_t vec_mulhuq (
 vui128_t a,
 vui128_t b) [inline], [static]
```

Vector Multiply High Unsigned Quadword.

compute the 256 bit product of two 128 bit values a, b. The high order 128 bits of the product are returned.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 56-64   | 1/cycle    |
| power9    | 33-39   | 1/cycle    |

**Parameters**

|          |                                              |
|----------|----------------------------------------------|
| <i>a</i> | 128-bit vector treated as unsigned __int128. |
| <i>b</i> | 128-bit vector treated as unsigned __int128. |

**Returns**

vector unsigned \_\_int128 (upper 128-bits) of  $a * b$ .

**7.7.7.62 vec\_mulluq()**

```
static vui128_t vec_mulluq (
 vui128_t a,
 vui128_t b) [inline], [static]
```

Vector Multiply Low Unsigned Quadword.

compute the 256 bit product of two 128 bit values a, b. Only the low order 128 bits of the product are returned.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 42-48   | 1/cycle    |
| power9    | 16-20   | 2/cycle    |

**Parameters**

|          |                                              |
|----------|----------------------------------------------|
| <i>a</i> | 128-bit vector treated as unsigned __int128. |
| <i>b</i> | 128-bit vector treated as unsigned __int128. |

**Returns**

vector unsigned \_\_int128 (lower 128-bits)  $a * b$ .

**7.7.7.63 vec\_muloud()**

```
static vui128_t vec_muloud (
 vui64_t a,
 vui64_t b) [inline], [static]
```



Vector Multiply Odd Unsigned Doublewords.

Multiple the odd 64-bit doublewords of two vector unsigned long values and return the unsigned \_\_int128 product of the odd doublewords.

#### Note

The element numbering changes between big and little-endian. So the compiler and this implementation adjusts the generated code to reflect this.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 21-23   | 1/cycle    |
| power9    | 8-13    | 2/cycle    |

#### Parameters

|          |                                   |
|----------|-----------------------------------|
| <i>a</i> | 128-bit vector unsigned long int. |
| <i>b</i> | 128-bit vector unsigned long int. |

#### Returns

vector unsigned \_\_int128 product of the odd double words of a and b.

#### 7.7.7.64 vec\_muludm()

```
static vui64_t vec_muludm (
 vui64_t vra,
 vui64_t vrb) [inline], [static]
```

Vector Multiply Unsigned Doubleword Modulo.

Multiple the corresponding doubleword elements of two vector unsigned long values and return the low order 64-bits of the 128-bit product for each element.

#### Note

vec\_muludm can be used for unsigned or signed integers. It is the vector equivalent of Multiply Low Doubleword.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 19-28   | 1/cycle    |
| power9    | 11-16   | 1/cycle    |

## Parameters

|            |                                   |
|------------|-----------------------------------|
| <i>vra</i> | 128-bit vector unsigned long int. |
| <i>vrb</i> | 128-bit vector unsigned long int. |

## Returns

vector unsigned long int of the low order 64-bits of the unsigned 128-bit product of the doubleword elements from *vra* and *vrb*.

7.7.7.65 `vec_muludq()`

```
static vuil128_t vec_muludq (
 vuil128_t * mulu,
 vuil128_t a,
 vuil128_t b) [inline], [static]
```

Vector Multiply Unsigned Double Quadword.

compute the 256 bit product of two 128 bit values *a*, *b*. The low order 128 bits of the product are returned, while the high order 128-bits are "stored" via the *mulu* pointer.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 52-56   | 1/cycle    |
| power9    | 24-30   | 1/cycle    |

## Parameters

|              |                                                                                                |
|--------------|------------------------------------------------------------------------------------------------|
| <i>*mulu</i> | pointer to vector unsigned <code>__int128</code> to receive the upper 128-bits of the product. |
| <i>a</i>     | 128-bit vector treated as unsigned <code>__int128</code> .                                     |
| <i>b</i>     | 128-bit vector treated as unsigned <code>__int128</code> .                                     |

## Returns

vector unsigned `__int128` (lower 128-bits) of *a* \* *b*.

7.7.7.66 `vec_popcntq()`

```
static vuil128_t vec_popcntq (
 vuil128_t vra) [inline], [static]
```

Vector Population Count Quadword.

Count the number of '1' bits within a vector `__int128` and return the count (0-128) in a vector `__int128`.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 15      | 2/2 cycles |
| power9    | 16      | 2/cycle    |

#### Parameters

|            |                                                |
|------------|------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as unsigned __int128. |
|------------|------------------------------------------------|

#### Returns

a 128-bit vector with bits 121:127 containing the population count.

#### 7.7.7.67 vec\_revbq()

```
static vuil28_t vec_revbq (
 vuil28_t vra) [inline], [static]
```

Vector Byte Reverse Quadword.

Return the bytes / octets of a 128-bit vector in reverse order.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-13    | 2 cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|            |                                                |
|------------|------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as unsigned __int128. |
|------------|------------------------------------------------|

#### Returns

a 128-bit vector with the bytes in reserve order.

#### 7.7.7.68 vec\_rlq()

```
static vuil28_t vec_rlq (
 vuil28_t vra,
 vuil28_t vrb) [inline], [static]
```

Vector Rotate Left Quadword.

Vector Rotate Left Quadword 0-127 bits. The shift amount is from bits 121-127 of vrb.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10      | 1 cycle    |
| power9    | 14      | 1/cycle    |

**Parameters**

|            |                                                              |
|------------|--------------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as unsigned <code>__int128</code> . |
| <i>vrb</i> | Shift amount in bits 121:127.                                |

**Returns**

Left shifted vector.

**7.7.7.69 `vec_rlqi()`**

```
static vuil28_t vec_rlqi (
 vuil28_t vra,
 const unsigned int shb) [inline], [static]
```

Vector Rotate Left Quadword Immediate.

Vector Rotate Left Quadword 0-127 bits. The shift amount is from bits 121-127 of *vrb*.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10      | 1 cycle    |
| power9    | 14      | 1/cycle    |

**Parameters**

|            |                                                              |
|------------|--------------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as unsigned <code>__int128</code> . |
| <i>shb</i> | Shift amount in the range 0-127.                             |

**Returns**

Left shifted vector.

**7.7.7.70 `vec_setb_cyq()`**

```
static vb128_t vec_setb_cyq (
 vuil28_t vcy) [inline], [static]
```

Vector Set Bool from Quadword Carry.

If the vector quadword carry bit (vcy.bit[127]) is '1' then return a vector bool \_\_int128 that is all '1's. Otherwise return all '0's.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4 - 6   | 2/2 cycles |
| power9    | 3 - 5   | 2/cycle    |

Vector quadword carries are normally the result of a *write-Carry* operation. For example; [vec\\_addcuq\(\)](#), [vec\\_addecuq\(\)](#), [vec\\_subcuq\(\)](#), [vec\\_subecuq\(\)](#), [vec\\_addcq\(\)](#), [vec\\_addeq\(\)](#).

#### Parameters

|     |                                                                 |
|-----|-----------------------------------------------------------------|
| vcy | a 128-bit vector generated from a <i>write-Carry</i> operation. |
|-----|-----------------------------------------------------------------|

#### Returns

a 128-bit vector bool of all '1's if the carry bit is '1'. Otherwise all '0's.

##### 7.7.7.71 vec\_setb\_ncq()

```
static vb128_t vec_setb_ncq (
 vui128_t vcy) [inline], [static]
```

Vector Set Bool from Quadword not Carry.

If the vector quadword carry bit (vcy.bit[127]) is '1' then return a vector bool \_\_int128 that is all '0's. Otherwise return all '1's.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4 - 6   | 2/2 cycles |
| power9    | 3 - 5   | 2/cycle    |

Vector quadword carries are normally the result of a *write-Carry* operation. For example; [vec\\_addcuq\(\)](#), [vec\\_addecuq\(\)](#), [vec\\_subcuq\(\)](#), [vec\\_subecuq\(\)](#), [vec\\_addcq\(\)](#), [vec\\_addeq\(\)](#).

#### Parameters

|     |                                                                 |
|-----|-----------------------------------------------------------------|
| vcy | a 128-bit vector generated from a <i>write-Carry</i> operation. |
|-----|-----------------------------------------------------------------|

**Returns**

a 128-bit vector bool of all '1's if the carry bit is '0'. Otherwise all '0's.

**7.7.7.72 vec\_setb\_sq()**

```
static vb128_t vec_setb_sq (
 vi128_t vra) [inline], [static]
```

Vector Set Bool from Signed Quadword.

If the quadword's sign bit is '1' then return a vector bool \_\_int128 that is all '1's. Otherwise return all '0's.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4 - 6   | 2/cycle    |
| power9    | 5 - 8   | 2/cycle    |

**Parameters**

|            |                                              |
|------------|----------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as signed __int128. |
|------------|----------------------------------------------|

**Returns**

a 128-bit vector bool of all '1's if the sign bit is '1'. Otherwise all '0's.

**7.7.7.73 vec\_sldq()**

```
static vui128_t vec_sldq (
 vui128_t vrw,
 vui128_t vrX,
 vui128_t vrb) [inline], [static]
```

Vector Shift Left Double Quadword.

Vector Shift Left double Quadword 0-127 bits. Return a vector \_\_int128 that is the left most 128-bits after shifting left 0-127-bits of the 256-bit double vector (vrw||vrX). The shift amount is from bits 121:127 of vrb.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10      | 1 cycle    |
| power9    | 14      | 1/cycle    |

**Parameters**

|            |                                              |
|------------|----------------------------------------------|
| <i>vrw</i> | upper 128-bits of the 256-bit double vector. |
| <i>vrx</i> | lower 128-bits of the 256-bit double vector. |
| <i>vrb</i> | Shift amount in bits 121:127.                |

**Returns**

high 128-bits of left shifted double vector.

**7.7.7.74 vec\_sldqi()**

```
static vuil28_t vec_sldqi (
 vuil28_t vrw,
 vuil28_t vrx,
 const unsigned int shb) [inline], [static]
```

Vector Shift Left Double Quadword Immediate.

Vector Shift Left double Quadword 0-127 bits. Return a vector \_\_int128 that is the left most 128-bits after shifting left 0-127-bits of the 256-bit double vector (vrw||vrx). The shift amount is from bits 121:127 of vrb.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10      | 1 cycle    |
| power9    | 14      | 1/cycle    |

**Parameters**

|            |                                              |
|------------|----------------------------------------------|
| <i>vrw</i> | upper 128-bits of the 256-bit double vector. |
| <i>vrx</i> | lower 128-bits of the 256-bit double vector. |
| <i>shb</i> | Shift amount in the range 0-127.             |

**Returns**

high 128-bits of left shifted double vector.

**7.7.7.75 vec\_slq()**

```
static vuil28_t vec_slq (
 vuil28_t vra,
 vuil28_t vrb) [inline], [static]
```

Vector Shift Left Quadword.

Vector Shift Left Quadword 0-127 bits. The shift amount is from bits 121-127 of *vr*b.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 1/cycle    |
| power9    | 6       | 1/cycle    |

#### Parameters

|             |                                                              |
|-------------|--------------------------------------------------------------|
| <i>vra</i>  | a 128-bit vector treated as unsigned <code>__int128</code> . |
| <i>vr</i> b | Shift amount in bits 121:127.                                |

#### Returns

Left shifted vector.

#### 7.7.7.76 `vec_slq4()`

```
static vuil28_t vec_slq4 (
 vuil28_t vra) [inline], [static]
```

**Deprecated** Vector Shift Left 4-bits Quadword. Replaced by `vec_slqi` with `shb` param = 4.

Vector Shift Left Quadword 0-127 bits. The shift amount is from bits 121-127 of *vr*b.

#### Parameters

|            |                                                    |
|------------|----------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated a <code>__int128</code> . |
|------------|----------------------------------------------------|

#### Returns

Left shifted vector.

#### 7.7.7.77 `vec_slq5()`

```
static vuil28_t vec_slq5 (
 vuil28_t vra) [inline], [static]
```



**Deprecated** Vector Shift Left 5-bits Quadword. Replaced by `vec_slqi` with `shb` param = 5.

Vector Shift Left Quadword 0-127 bits. The shift amount is from bits 121-127 of `vrb`.

```
@param vra a 128-bit vector treated a __int128.
@return Left shifted vector.
```

#### 7.7.7.78 `vec_slqi()`

```
static vuil128_t vec_slqi (
 vuil128_t vra,
 const unsigned int shb) [inline], [static]
```

Vector Shift Left Quadword Immediate.

Shift left Quadword 0-127 bits. The shift amount is a `const unsigned int` in the range 0-127. A shift count of 0 returns the original value of `vra`. Shift counts greater than 127 bits return zero.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-13    | 2 cycle    |
| power9    | 3-15    | 2/cycle    |

#### Parameters

|            |                                                              |
|------------|--------------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as unsigned <code>__int128</code> . |
| <i>shb</i> | Shift amount in the range 0-127.                             |

#### Returns

128-bit vector shifted left `shb` bits.

#### 7.7.7.79 `vec_sraq()`

```
static vil128_t vec_sraq (
 vil128_t vra,
 vuil128_t vrb) [inline], [static]
```

Vector Shift Right Algebraic Quadword.

Vector Shift Right Algebraic Quadword 0-127 bits. The shift amount is from bits 121-127 of `vrb`.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 10      | 1 cycle    |
| power9    | 14      | 1/cycle    |

#### Parameters

|            |                                                            |
|------------|------------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as signed <code>__int128</code> . |
| <i>vrb</i> | Shift amount in bits 121:127.                              |

#### Returns

Right algebraic shifted vector.

#### 7.7.7.80 `vec_sraqi()`

```
static vi128_t vec_sraqi (
 vi128_t vra,
 const unsigned int shb) [inline], [static]
```

Vector Shift Right Algebraic Quadword Immediate.

Vector Shift Right Algebraic Quadword 0-127 bits. The shift amount is from bits 121-127 of *vr*.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 6-15    | 1 cycle    |
| power9    | 9-18    | 1/cycle    |

#### Note

`vec_sraqi` optimizes for some special cases. For shift by octet (multiple of 8 bits) use `vec_setb_sq()` to extend sign then vector shift left double by octet immediate by  $(16 - (shb / 8))$  to effect the right octet shift. For `_ARCH_PWR8` and shifts less than 64 bits, use both `vec_srqi()` and vector shift right algebraic doubleword. Then use `vec_pasted()` to combine the high 64-bits from `vec_sradi()` and the low 64-bits from `vec_srqi()`.

#### Parameters

|            |                                                            |
|------------|------------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as signed <code>__int128</code> . |
| <i>shb</i> | Shift amount in the range 0-127.                           |

#### Returns

Right algebraic shifted vector.

## 7.7.7.81 vec\_srq()

```
static vui128_t vec_srq (
 vui128_t vra,
 vui128_t vrb) [inline], [static]
```

Vector Shift Right Quadword.

Vector Shift Right Quadword 0-127 bits. The shift amount is from bits 121-127 of vrb.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 1/cycle    |
| power9    | 6       | 1/cycle    |

## Parameters

|            |                                                |
|------------|------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as unsigned __int128. |
| <i>vrb</i> | Shift amount in bits 121:127.                  |

## Returns

Right shifted vector.

## 7.7.7.82 vec\_srq4()

```
static vui128_t vec_srq4 (
 vui128_t vra) [inline], [static]
```

**Deprecated** Vector Shift right 4-bits Quadword. Replaced by vec\_srq4 with shb param = 4.

Vector Shift Right Quadword 0-127 bits. The shift amount is from bits 121-127 of vrb.

## Parameters

|            |                                         |
|------------|-----------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a __int128. |
|------------|-----------------------------------------|

## Returns

Right shifted vector.

### 7.7.7.83 vec\_sr5()

```
static vui128_t vec_sr5 (
 vui128_t vra) [inline], [static]
```

**Deprecated** Vector Shift right 5-bits Quadword. Replaced by vec\_srqi with shb param = 5.

Vector Shift Right Quadword 0-127 bits. The shift amount is from bits 121-127 of vrb.

#### Parameters

|            |                                      |
|------------|--------------------------------------|
| <i>vra</i> | a 128-bit vector treated a __int128. |
|------------|--------------------------------------|

#### Returns

Right shifted vector.

### 7.7.7.84 vec\_srqi()

```
static vui128_t vec_srqi (
 vui128_t vra,
 const unsigned int shb) [inline], [static]
```

Vector Shift Right Quadword Immediate.

Shift right Quadword 0-127 bits. The shift amount is a const unsigned int in the range 0-127. A shift count of 0 returns the original value of vra. Shift counts greater then 127 bits return zero.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-13    | 2 cycle    |
| power9    | 3-15    | 2/cycle    |

#### Parameters

|            |                                                |
|------------|------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as unsigned __int128. |
| <i>shb</i> | Shift amount in the range 0-127.               |

**Returns**

128-bit vector shifted right shb bits.

**7.7.7.85 vec\_subcuq()**

```
static vuil128_t vec_subcuq (
 vuil128_t vra,
 vuil128_t vrb) [inline], [static]
```

Vector Subtract and Write Carry Unsigned Quadword.

Generate the carry-out of the sum ( $vra + \text{NOT}(vrb) + 1$ ).

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 2/2 cycles |
| power9    | 3       | 2/cycle    |

**Parameters**

|            |                                              |
|------------|----------------------------------------------|
| <i>vra</i> | 128-bit vector treated as unsigned __int128. |
| <i>vrb</i> | 128-bit vector treated as unsigned __int128. |

**Returns**

\_\_int128 carry from the unsigned difference  $vra - vrb$ .

**7.7.7.86 vec\_subecuq()**

```
static vuil128_t vec_subecuq (
 vuil128_t vra,
 vuil128_t vrb,
 vuil128_t vrc) [inline], [static]
```

Vector Subtract Extended and Write Carry Unsigned Quadword.

Generate the carry-out of the sum ( $vra + \text{NOT}(vrb) + vrc.\text{bit}[127]$ ).

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 2/2 cycles |
| power9    | 3       | 2/cycle    |

## Parameters

|            |                                                            |
|------------|------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as unsigned <code>__int128</code> . |
| <i>vrb</i> | 128-bit vector treated as unsigned <code>__int128</code> . |
| <i>vrc</i> | 128-bit vector carry-in from bit 127.                      |

## Returns

`__int128` carry from the extended `__int128` difference.

7.7.7.87 `vec_subeuqm()`

```
static vuil28_t vec_subeuqm (
 vuil28_t vra,
 vuil28_t vrb,
 vuil28_t vrc) [inline], [static]
```

Vector Subtract Extended Unsigned Quadword Modulo.

Subtract two vector `__int128` values and return result modulo 128-bits.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 2/2 cycles |
| power9    | 3       | 2/cycle    |

## Parameters

|            |                                                            |
|------------|------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as unsigned <code>__int128</code> . |
| <i>vrb</i> | 128-bit vector treated as unsigned <code>__int128</code> . |
| <i>vrc</i> | 128-bit vector carry-in from bit 127.                      |

## Returns

`__int128` unsigned difference of *vra* minus *vrb*.

7.7.7.88 `vec_subuqm()`

```
static vuil28_t vec_subuqm (
 vuil28_t vra,
 vuil28_t vrb) [inline], [static]
```

Vector Subtract Unsigned Quadword Modulo.

Subtract two vector `__int128` values and return result modulo 128-bits.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 2/2 cycles |
| power9    | 3       | 2/cycle    |

## Parameters

|                    |                                              |
|--------------------|----------------------------------------------|
| <i>vra</i>         | 128-bit vector treated as unsigned __int128. |
| <i>vr</i> <i>b</i> | 128-bit vector treated as unsigned __int128. |

## Returns

\_\_int128 unsigned difference of *vra* minus *vr**b*.

## 7.7.7.89 vec\_vmadd2eud()

```
static vui128_t vec_vmadd2eud (
 vui64_t a,
 vui64_t b,
 vui64_t c,
 vui64_t d) [inline], [static]
```

Vector Multiply-Add2 Even Unsigned Doublewords.

Multiply the even 64-bit doublewords of vector unsigned long values ( $a * b$ ) and return sum of the unsigned \_\_int128 product and the even doublewords of *c* and *d* ( $(a_{\text{even}} * b_{\text{even}}) + c_{\text{even}} + d_{\text{even}}$ ).

## Note

The advantage of this form (versus Multiply-Sum) is that the final 128 bit sum can not overflow.  
This implementation is NOT endian sensitive and the function is stable across BE/LE implementations.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 25-28   | 1/cycle    |
| power9    | 13-18   | 2/cycle    |

## Parameters

|          |                                   |
|----------|-----------------------------------|
| <i>a</i> | 128-bit vector unsigned long int. |
| <i>b</i> | 128-bit vector unsigned long int. |
| <i>c</i> | 128-bit vector unsigned long int. |
| <i>d</i> | 128-bit vector unsigned long int. |

**Returns**

vector unsigned \_\_int128 sum ( $a_{\text{even}} * b_{\text{even}} + c_{\text{even}} + d_{\text{even}}$ ).

**7.7.7.90 vec\_vmadd2oud()**

```
static vui128_t vec_vmadd2oud (
 vui64_t a,
 vui64_t b,
 vui64_t c,
 vui64_t d) [inline], [static]
```

Vector Multiply-Add2 Odd Unsigned Doublewords.

Multiply the odd 64-bit doublewords of two vector unsigned long values ( $a * b$ ) and return the sum of the unsigned \_\_int128 product and the odd doublewords of c and d ( $(a_{\text{odd}} * b_{\text{odd}}) + c_{\text{odd}} + d_{\text{odd}}$ ).

**Note**

The advantage of this form (versus Multiply-Sum) is that the final 128 bit sum can not overflow.  
This implementation is NOT endian sensitive and the function is stable across BE/LE implementations.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 25-28   | 1/cycle    |
| power9    | 13-18   | 2/cycle    |

**Parameters**

|          |                                   |
|----------|-----------------------------------|
| <i>a</i> | 128-bit vector unsigned long int. |
| <i>b</i> | 128-bit vector unsigned long int. |
| <i>c</i> | 128-bit vector unsigned long int. |
| <i>d</i> | 128-bit vector unsigned long int. |

**Returns**

vector unsigned \_\_int128 sum ( $a_{\text{odd}} * b_{\text{odd}} + c_{\text{odd}} + d_{\text{odd}}$ ).

**7.7.7.91 vec\_vmaddeud()**

```
static vui128_t vec_vmaddeud (
 vui64_t a,
```



```

vui64_t b,
vui64_t c) [inline], [static]

```

Vector Multiply-Add Even Unsigned Doublewords.

Multiply the even 64-bit doublewords of vector unsigned long values ( $a * b$ ) and return sum of the unsigned `__int128` product and the even doubleword of  $c$  ( $a_{\text{even}} * b_{\text{even}} + c_{\text{even}}$ ).

#### Note

The advantage of this form (versus Multiply-Sum) is that the final 128 bit sum can not overflow.  
This implementation is NOT endian sensitive and the function is stable across BE/LE implementations.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 25-28   | 1/cycle    |
| power9    | 10-13   | 2/cycle    |

#### Parameters

|          |                                   |
|----------|-----------------------------------|
| <i>a</i> | 128-bit vector unsigned long int. |
| <i>b</i> | 128-bit vector unsigned long int. |
| <i>c</i> | 128-bit vector unsigned long int. |

#### Returns

vector unsigned `__int128` sum ( $a_{\text{even}} * b_{\text{even}} + c_{\text{even}}$ ).

#### 7.7.7.92 vec\_vmaddoud()

```

static vui128_t vec_vmaddoud (
 vui64_t a,
 vui64_t b,
 vui64_t c) [inline], [static]

```

Vector Multiply-Add Odd Unsigned Doublewords.

Multiply the odd 64-bit doublewords of two vector unsigned long values ( $a * b$ ) and return the sum of the unsigned `__int128` product and the odd doubleword of  $c$  ( $a_{\text{odd}} * b_{\text{odd}} + c_{\text{odd}}$ ).

#### Note

The advantage of this form (versus Multiply-Sum) is that the final 128 bit sum can not overflow.  
This implementation is NOT endian sensitive and the function is stable across BE/LE implementations.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 25-28   | 1/cycle    |
| power9    | 10-13   | 2/cycle    |

#### Parameters

|          |                                   |
|----------|-----------------------------------|
| <i>a</i> | 128-bit vector unsigned long int. |
| <i>b</i> | 128-bit vector unsigned long int. |
| <i>c</i> | 128-bit vector unsigned long int. |

#### Returns

vector unsigned \_\_int128 sum ( $a_{\text{odd}} * b_{\text{odd}}$ ) +  $c_{\text{odd}}$ .

#### 7.7.7.93 vec\_vmsumemd()

```
static vuil28_t vec_vmsumemd (
 vui64_t a,
 vui64_t b,
 vuil28_t c) [inline], [static]
```

Vector Multiply-Sum Even Unsigned Doublewords.

Multiply the even 64-bit doublewords of vector unsigned long values ( $a * b$ ) and return sum of the unsigned \_\_int128 product and  $c$  ( $a_{\text{even}} * b_{\text{even}}$ ) +  $c$ .

#### Note

This form (Multiply-Sum) can overflow the final 128 bit sum, unless the addend ( $c$ ) is restricted to (**INT64\_MAX** \* 2) or less.

This implementation is NOT endian sensitive and the function is stable across BE/LE implementations.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 25-28   | 1/cycle    |
| power9    | 10-13   | 2/cycle    |

#### Parameters

|          |                                   |
|----------|-----------------------------------|
| <i>a</i> | 128-bit vector unsigned long int. |
| <i>b</i> | 128-bit vector unsigned long int. |
| <i>c</i> | 128-bit vector unsigned __int128. |

**Returns**

vector unsigned \_\_int128 sum ( $a_{\text{even}} * b_{\text{even}}$ ) + c.

**7.7.7.94 vec\_vmsumoud()**

```
static vui128_t vec_vmsumoud (
 vui64_t a,
 vui64_t b,
 vui128_t c) [inline], [static]
```

Vector Multiply-Sum Odd Unsigned Doublewords.

Multiply the odd 64-bit doublewords of two vector unsigned long values ( $a * b$ ) and return the sum of the unsigned \_\_int128 product and variable c ( $a_{\text{odd}} * b_{\text{odd}}$ ) + c>.

**Note**

This form (Multiply-Sum) can overflow the final 128 bit sum, unless the addend (c) is restricted to (**INT64\_MAX** \* 2) or less.

This implementation is NOT endian sensitive and the function is stable across BE/LE implementations.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 25-28   | 1/cycle    |
| power9    | 10-13   | 2/cycle    |

**Parameters**

|          |                                   |
|----------|-----------------------------------|
| <i>a</i> | 128-bit vector unsigned long int. |
| <i>b</i> | 128-bit vector unsigned long int. |
| <i>c</i> | 128-bit vector unsigned __int128. |

**Returns**

vector unsigned \_\_int128 sum ( $a_{\text{odd}} * b_{\text{odd}}$ ) + c.

**7.7.7.95 vec\_vmuleud()**

```
static vui128_t vec_vmuleud (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Multiply Even Unsigned Doublewords.

Multiply the even 64-bit doublewords of two vector unsigned long values and return the unsigned \_\_int128 product of the even doublewords.

**Note**

This function implements the operation of a Vector Multiply Even Doubleword instruction, as if the PowerISA included such an instruction. This implementation is NOT endian sensitive and the function is stable across BE/LE implementations.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 21-23   | 1/cycle    |
| power9    | 8-11    | 2/cycle    |

**Parameters**

|          |                                   |
|----------|-----------------------------------|
| <i>a</i> | 128-bit vector unsigned long int. |
| <i>b</i> | 128-bit vector unsigned long int. |

**Returns**

vector unsigned \_\_int128 product of the even double words of a and b.

**7.7.7.96 vec\_vmuloud()**

```
static vui128_t vec_vmuloud (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Multiply Odd Unsigned Doublewords.

Multiply the odd 64-bit doublewords of two vector unsigned long values and return the unsigned \_\_int128 product of the odd doublewords.

**Note**

This function implements the operation of a Vector Multiply Odd Doubleword instruction, as if the PowerISA included such an instruction. This implementation is NOT endian sensitive and the function is stable across BE/LE implementations.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 21-23   | 1/cycle    |
| power9    | 8-13    | 2/cycle    |

**Parameters**

|          |                                   |
|----------|-----------------------------------|
| <i>a</i> | 128-bit vector unsigned long int. |
| <i>b</i> | 128-bit vector unsigned long int. |

## Returns

vector unsigned \_\_int128 product of the odd double words of a and b.

## 7.8 src/pveclib/vec\_int16\_ppc.h File Reference

Header package containing a collection of 128-bit SIMD operations over 16-bit integer elements.

```
#include <pveclib/vec_char_ppc.h>
```

### Functions

- static [vui16\\_t](#) [vec\\_absduh](#) ([vui16\\_t](#) vra, [vui16\\_t](#) vrb)  
*Vector Absolute Difference Unsigned halfword.*
- static [vui16\\_t](#) [vec\\_clzh](#) ([vui16\\_t](#) vra)  
*Count Leading Zeros for a vector unsigned short (halfword) elements.*
- static [vui16\\_t](#) [vec\\_mrgahh](#) ([vui32\\_t](#) vra, [vui32\\_t](#) vrb)  
*Vector Merge Algebraic High Halfword operation.*
- static [vui16\\_t](#) [vec\\_mrgalh](#) ([vui32\\_t](#) vra, [vui32\\_t](#) vrb)  
*Vector Merge Algebraic Low Halfword operation.*
- static [vui16\\_t](#) [vec\\_mrgeh](#) ([vui16\\_t](#) vra, [vui16\\_t](#) vrb)  
*Vector Merge Even Halfwords operation.*
- static [vui16\\_t](#) [vec\\_mrgoh](#) ([vui16\\_t](#) vra, [vui16\\_t](#) vrb)  
*Vector Merge Odd Halfwords operation.*
- static [vi16\\_t](#) [vec\\_mulhsh](#) ([vi16\\_t](#) vra, [vi16\\_t](#) vrb)  
*Vector Multiply High Signed halfword.*
- static [vui16\\_t](#) [vec\\_mulhuh](#) ([vui16\\_t](#) vra, [vui16\\_t](#) vrb)  
*Vector Multiply High Unsigned halfword.*
- static [vui16\\_t](#) [vec\\_muluhm](#) ([vui16\\_t](#) vra, [vui16\\_t](#) vrb)  
*Vector Multiply Unsigned halfword Modulo.*
- static [vui16\\_t](#) [vec\\_popcnth](#) ([vui16\\_t](#) vra)  
*Vector Population Count halfword.*
- static [vui16\\_t](#) [vec\\_revbh](#) ([vui16\\_t](#) vra)  
*byte reverse each halfword of a vector unsigned short.*
- static [vui16\\_t](#) [vec\\_slhi](#) ([vui16\\_t](#) vra, const unsigned int shb)  
*Vector Shift left Halfword Immediate.*
- static [vui16\\_t](#) [vec\\_srhi](#) ([vui16\\_t](#) vra, const unsigned int shb)  
*Vector Shift Right Halfword Immediate.*
- static [vi16\\_t](#) [vec\\_srahi](#) ([vi16\\_t](#) vra, const unsigned int shb)  
*Vector Shift Right Algebraic Halfword Immediate.*
- static [vui32\\_t](#) [vec\\_vmaddeuh](#) ([vui16\\_t](#) a, [vui16\\_t](#) b, [vui16\\_t](#) c)  
*Vector Multiply-Add Even Unsigned Halfwords.*
- static [vui32\\_t](#) [vec\\_vmaddouh](#) ([vui16\\_t](#) a, [vui16\\_t](#) b, [vui16\\_t](#) c)  
*Vector Multiply-Add Odd Unsigned Halfwords.*
- static [vui16\\_t](#) [vec\\_vmrgeh](#) ([vui16\\_t](#) vra, [vui16\\_t](#) vrb)  
*Vector Merge Even Halfwords.*
- static [vui16\\_t](#) [vec\\_vmrgoh](#) ([vui16\\_t](#) vra, [vui16\\_t](#) vrb)  
*Vector Merge Odd Halfwords.*

### 7.8.1 Detailed Description

Header package containing a collection of 128-bit SIMD operations over 16-bit integer elements.

Most of these operations are implemented in a single instruction on newer (POWER6/POWER7/POWER8/POWER9) processors. This header serves to fill in functional gaps for older (POWER7, POWER8) processors and provides a in-line assembler implementation for older compilers that do not provide the build-ins.

Most vector short (16-bit integer halfword) operations are implemented with PowerISA VMX instructions either defined by the original VMX (AKA AltiVec) or added to later versions of the PowerISA. PowerISA 2.07B (POWER8) added several useful halfword operations (count leading zeros, population count) not included in the original VMX. PowerISA 3.0B (POWER9) adds several more (absolute difference, compare not equal, count trailing zeros, extend sign, extract/insert, and reverse bytes). Most of these intrinsic (compiler built-ins) operations are defined in `<altivec.h>` and described in the compiler documentation.

#### Note

The compiler disables associated `<altivec.h>` built-ins if the `mcpu` target does not enable the specific instruction. For example if you compile with `-mcpu=power7`, `vec_vclz` and `vec_vclzh` will not be defined. Another example if you compile with `-mcpu=power8`, `vec_revb` will not be defined. But `vec_vclzh` and `vec_revbh` is always defined in this header. This header provides the appropriate substitutions, will generate the minimum code, appropriate for the target, and produce correct results.

Most ppc64le compilers will default to `-mcpu=power8` if not specified.

This header covers operations that are either:

- Implemented in hardware instructions for later processors and useful to programmers, on slightly older processors, even if the equivalent function requires more instructions. Examples include Count Leading Zeros, Population Count and Byte Reverse.
- Defined in the OpenPOWER ABI but *not* yet defined in `<altivec.h>` provided by available compilers in common use. Examples include Count Leading Zeros, Population Count and Byte Reverse.
- Commonly used operations, not covered by the ABI or `<altivec.h>`, and require multiple instructions or are not obvious. Examples include the multiply-add, multiply-high and shift immediate operations.

### 7.8.2 Recent Additions

Added `vec_vmaddeuh()` and `vec_vmaddouh()` as an optimization for the vector multiply quadword implementations on POWER7.

### 7.8.3 Endian problems with halfword operations

It would be useful to provide a vector multiply high halfword (return the high order 16-bits of the 32-bit product) operation. This can be used for multiplicative inverse (effectively integer divide) operations. Neither integer multiply high nor divide are available as vector instructions. However the multiply high halfword operation can be composed from the existing multiply even/odd halfword operations followed by the vector merge even halfword operation. Similarly a multiply low (modulo) halfword operation can be composed from the existing multiply even/odd halfword operations followed by the vector merge odd halfword operation.

As a prerequisite we need to provide the merge even/odd halfword operations. While PowerISA has added these operations for word and doubleword, instructions are not defined for byte and halfword. Fortunately vector merge operations are just a special case of vector permute. So the [vec\\_vmrgoh\(\)](#) and [vec\\_vmrgeh\(\)](#) implementation can use [vec\\_perm](#) and appropriate selection vectors to provide these merge operations.

But this is complicated by *little-endian* (LE) support as specified in the OpenPOWER ABI and as implemented in the compilers. Little-endian changes the effective vector element numbering and the location of even and odd elements. This means that the vector built-ins provided by [altivec.h](#) may not generate the instructions you would expect.

#### See also

[General Endian Issues](#)  
[Endian problems with word operations](#)

The OpenPOWER ABI provides a helpful table of [Endian Sensitive Operations](#). For for [vec\\_mule](#) ([vmuleuh](#), [vmulesh](#)):

Replace with [vmulouh](#) and so on, for LE.

For for [vec\\_mulo](#) ([vmulouh](#), [vmulosh](#)):

Replace with [vmuleuh](#) and so on, for LE.

Also for [vec\\_perm](#) ([vperm](#)) it specifies:

For LE, Swap input arguments and complement the selection vector.

The above is just a sampling of a larger list of Endian Sensitive Operations.

The obvious coding for Vector Multiply High Halfword would be:

```
vui16_t
test_mulhw (vui16_t vra, vui16_t vrb)
{
 return vec_mergee ((vui16_t)vec_mule (vra, vrb),
 (vui16_t)vec_mulo (vra, vrb));
}
```

A couple problems with this:

- [vec\\_mergee](#) is only defined for vector int/long and float/double (word/doubleword) types.

- `vec_mergee` is endian sensitive and would produce the wrong results in LE mode.
- `vec_mule/vec_mulo` are endian sensitive and produce the wrong results in LE mode.

The first step is to implement Vector Merge Even Halfword operation:

```
static inline vuil6_t
vec_vmrggeh (vuil6_t vra, vuil6_t vrb)
{
 #if __BYTE_ORDER__ == __ORDER_LITTLE_ENDIAN__
 vuil6_t permute =
 { 0x0302, 0x1312, 0x0706, 0x1716, 0x0B0A, 0x1B1A, 0x0F0E, 0x1F1E };

 return vec_perm (vrb, vra, (vuil8_t)permute);
 #else
 vuil6_t permute =
 { 0x0001, 0x1011, 0x0405, 0x1415, 0x0809, 0x1819, 0x0C0D, 0x1C1D };

 return vec_perm (vra, vrb, (vuil8_t)permute);
 #endif
}
```

For big-endian we have a straight forward `vec_perm` with a permute select vector interleaving even halfwords from vectors `vra` and `vrb`.

For little-endian we need to nullify the LE transform applied by the compiler. So the select vector looks like it interleaves odd halfwords from vectors `vrb` and `vra`. It also reverses byte numbering within halfwords. The compiler transforms this back into the operation we wanted in the first place. The result is *not* endian sensitive and is stable across BE/LE implementations. Similarly for the Vector Merge Odd Halfword operation.

As good OpenPOWER ABI citizens we should also provide endian sensitive operations `vec_mrgeh()` `vec_mrgoh()`. For example:

```
static inline vuil6_t
vec_mrgeh (vuil6_t vra, vuil6_t vrb)
{
 #if __BYTE_ORDER__ == __ORDER_LITTLE_ENDIAN__
 return vec_vmrgoh ((vuil6_t) vrb, (vuil6_t) vra);
 #else
 return vec_vmrggeh ((vuil6_t) vra, (vuil6_t) vrb);
 #endif
}
```

#### Note

This is essentially what the compiler would do for `vec_mergee`.

Also to follow that pattern established for `vec_int32_ppc.h` we should provide implementations for Vector Merge Algebraic High/Low Halfword. For example:

```
static inline vuil6_t
vec_mrgahh (vui32_t vra, vui32_t vrb)
{
 return vec_vmrggeh ((vuil6_t) vra, (vuil6_t) vrb);
}
```

This is simpler as we can use the endian invariant `vec_vmrggeh()` operation. Similarly for Vector Merge Algebraic Low Halfword using `vec_vmrgoh()`.



**Note**

The inputs are defined as 32-bit to match the results from multiply even/odd halfword.

Now we have all the parts we need to implement multiply high/low halfword. For example Multiply High Unsigned Halfword:

```
static inline vui16_t
vec_mulhuh (vui16_t vra, vui16_t vrb)
{
 #if __BYTE_ORDER__ == __ORDER_LITTLE_ENDIAN__
 return vec_mrgahh (vec_mulo (vra, vrb), vec_mule (vra, vrb));
 #else
 return vec_mrgahh (vec_mule (vra, vrb), vec_mulo (vra, vrb));
 #endif
}
```

Similarly for Multiply High Signed Halfword.

**Note**

For LE we need to nullify the compiler transform by reversing of the order of vec\_mulo/vec\_mule. This is required to get the algebraically correct (multiply high) result.

Finally we can implement the Multiply Low Halfword which by PowerISA conventions is called Multiply Unsigned Halfword Modulo:

```
static inline vui16_t
vec_muluhm (vui16_t vra, vui16_t vrb)
{
 #if __BYTE_ORDER__ == __ORDER_LITTLE_ENDIAN__
 return vec_mrgalh (vec_mulo (vra, vrb), vec_mule (vra, vrb));
 #else
 return vec_mrgalh (vec_mule (vra, vrb), vec_mulo (vra, vrb));
 #endif
}
```

**Note**

We use the endian stable [vec\\_mrgalh\(\)](#) for multiply low. Again for LE we have to nullify the compiler transform by reversing of the order of vec\_mulo/vec\_mule. This is required to get the algebraically correct (multiply high) result. [vec\\_muluhm\(\)](#) works for signed and unsigned multiply low (modulo).

**7.8.3.1 Multiply High Unsigned Halfword Example**

So what does the compiler generate after unwinding three levels of inline functions. For this test case:

```
vui16_t
__test_mulhuh (vui16_t a, vui16_t b)
{
 return vec_mulhuh (a, b);
}
```

The GCC 8 compiler targeting powerpc64le and -mcpu=power8 generates:

```

addis r9,r2,.rodata.cst16@ha
vmulouh v1,v2,v3
vmuleuh v2,v2,v3
addi r9,r9,.rodata.cst16@l
lvx v0,0,r9
xxlnor vs32,vs32,vs32
vperm v2,v2,v1,v0

```

The `addis`, `addi`, `lvx` instruction sequence loads the permute selection constant vector. The `xxlnor` instruction complements the selection vector for LE. These instructions are only needed once per function and can be hoisted out of loops and shared across instances of `vec_mulhuh()`. Which might look like this:

```

addis r9,r2,.rodata.cst16@ha
addi r9,r9,.rodata.cst16@l
lvx v0,0,r9
xxlnor vs32,vs32,vs32
...
Loop:
vmulouh v1,v2,v3
vmuleuh v2,v2,v3
vperm v2,v2,v1,v0
...

```

The `vmulouh`, `vmuleuh`, `vperm` instruction sequence is the core of the function. They multiply the elements and selects/merges the high order 16-bits of each product into the result vector.

#### 7.8.4 Examples, Divide by integer constant

Suppose we have a requirement to convert an array of 16-bit unsigned short values to decimal. The classic *itoa* implementation performs a sequence of divide / modulo by 10 operations that produce one (decimal) value per iteration, until the divide returns 0.

For this example we want to vectorize the operation and the PowerISA (and most other platforms) does not provide a vector integer divide instruction. But we do have vector integer multiply. As we will see the multiply high defined above is very handy for applying the multiplicative inverse. Also, the conversion divide is a constant value applied across the vector which simplifies the coding.

Here we can use the multiplicative inverse which is a scaled fixed point fraction calculated from the original divisor. This works nicely if the fixed radix point is just before the 16-bit fraction and we have a multiply high (`vec_mulhuh()`) operation. Multiplying a 16-bit unsigned integer by a 16-bit unsigned fraction generates a 32-bit product with 16-bits above (integer) and below (fraction) the radix point. The high 16-bits of the product is a good approximation of the integer quotient.

It turns out that generating the multiplicative inverse can be tricky. To produce correct results over the full range, requires possible pre-scaling and post-shifting, and sometimes a corrective addition. Fortunately, the mathematics are well understood and are commonly used in optimizing compilers. Even better, Henry Warren's book has a whole chapter on this topic.

#### See also

"Hacker's Delight, 2nd Edition," Henry S. Warren, Jr, Addison Wesley, 2013. Chapter 10, Integer Division by Constants.

#### 7.8.4.1 Divide by constant 10 examples

In the chapter above;

Figure 10-2 Computing the magic number for unsigned division.

provides a sample C function for generating the magic number (actually a struct containing; the magic multiplicative inverse, "add" indicator, and the shift amount). For the 16-bit unsigned divisor 10, this is { 52429, 0, 3 }:

- the multiplier is 52429.
- no corrective add of the dividend is required.
- the final shift is 3-bits right.

Which could look like this:

```
vuil6_t
__test_div10 (vuil6_t n)
{
 vuil6_t q;
 // M= 52429, a=0, s=3
 vuil6_t magic = vec_splats ((unsigned short) 52429);
 const int s = 3;

 q = vec_mulhuh (magic, n);
 return vec_srhi (q, s);
}
```

But we also need the modulo to extract each digit. The simplest and oldest technique is to multiply the quotient by the divisor (constant 10) and subtract that from the original dividend. Here we can use the `vec_muluhm()` operation we defined above. Which could look like this:

```
vuil6_t
__test_mod10 (vuil6_t n)
{
 vuil6_t q;
 // M= 52429, a=0, s=3
 vuil6_t magic = vec_splats ((unsigned short) 52429);
 vuil6_t c_10 = vec_splats ((unsigned short) 10);
 const int s = 3;
 vuil6_t tmp, rem, q_10;

 q = vec_mulhuh (magic, n);
 q_10 = vec_srhi (q, s);
 tmp = vec_muluhm (q_10, c_10);
 rem = vec_sub (n, tmp);
 return rem;
}
```

#### Note

`vec_sub()` and `vec_splats()` are an existing altivec.h generic built-ins.

#### 7.8.4.2 Divide by constant 10000 example

As we mentioned above, some divisors require an add before the shift as a correction. For the 16-bit unsigned divisor 10000 this is { 41839, 1, 14 }:

- the multiplier is 41839.
- corrective add of the dividend is required.
- the final shift is 14-bits right.

In this case the perfect multiplier is too large ( $\geq 2^{16}$ ). So the magic multiplier is reduced by  $2^{16}$  and to correct for this we need to add the dividend to the product. This add may generate a carry that must be included in the shift. Here `vec_avg` handles the 17-bit sum internally before shifting right 1. But `vec_avg` adds an extra +1 (for rounding) that we don't want. So we use (n-1) for the product correction then complete the operation with shift right (s-1). Which could look like this:

```
vui16_t
__test_div10000 (vui16_t n)
{
 vui16_t result, q;
 // M= 41839, a=1, s=14
 vui16_t magic = vec_splats ((unsigned short) 41839);
 const int s = 14;
 vui16_t tmp, rem;

 q = vec_mulhuh (magic, n);
 {
 const vui16_t vec_ones = vec_splat_u16 (1);
 vui16_t n_1 = vec_sub (n, vec_ones);
 // avg = (q + (n-1) + 1) >> 1
 q = vec_avg (q, n_1);
 result = vec_srhi (q, (s - 1));
 }
 return result;
}
```

#### Note

`vec_avg()`, `vec_sub()`, `vec_splats()` and `vec_splat_u16()` are existing `altivec.h` generic built-ins.

The modulo computation remains the same as [Divide by constant 10 examples](#).

#### 7.8.5 Performance data.

We can use the example above (see [Multiply High Unsigned Halfword Example](#)) to illustrate the performance metrics `pveclib` provides. For `vec_mulhuh()` the core operation is the sequence `vmulouh/vmuleuh/vperm`. This represents the best case latency, when it is used multiple times in a single larger function.

The compiler notes that `vmulouh/vmuleuh` are independent instructions that can execute concurrently (in separate vector pipelines). The compiler schedules them to issue in same cycle. The latency for `vmulouh/vmuleuh` is listed as 7 cycle and the throughput of 2 per cycle (there are 2 vector pipes for multiply). As we assume this function will use both vector pipelines, the throughput for this function is reduced to 1 per cycle.

We still need to select/merge the results. The `vperm` instruction is dependent on the execution of both `vmulouh/vmuleuh` and load of the select vector complete. For this case we assume that the load of the permute select vector has already

executed. The processor can not issue the vperm until both vmulouh/vmuleuh instructions execute. The latency for vperm is 2 cycles (3 on POWER9). So the best case latency for this operation is is (7 + 2 = 9) cycles (10 on POWER9).

Looking at the first or only execution of `vec_mulhuh()` in a function defines the worse case latency. Here we have to include the permute select vector load and (for LE) the select vector complement. However this case provides additional multiple pipe parallelism that needs to be accounted for in the latencies.

The compiler notes that addis/vmulouh/vmuleuh are independent instructions that can execute concurrently in separate pipelines. So the compiler schedules them to issue in same cycle. The latency for vmulouh/vmuleuh is 7 cycles while the addis latency is only 2 cycles. The dependent addi instruction can issue in the 3rd cycle, while vmulouh/vmuleuh are still executing. The addi also has a 2 cycle latency, so the dependent lvx can issue in the 5th cycle, while vmulouh/vmuleuh are still executing. The lvx has a latency of 5 cycles and will not complete execution until 2 cycles after vmulouh/vmuleuh. The dependent xxlnor is waiting of the load (lvx) and has a latency of 2 cycles.

So there are two independent instruction sequences; vmulouh/vmuleuh and addis/addi/lvx/xxlnor. Both must complete execution before the vperm can issue and complete the operation. The later sequence has the longer (2+2+5+2=11) latency and dominates the timing. So the worst latency for the full sequence is (2+2+5+2+2 = 13) cycles (14 on POWER9).

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 9-13    | 1/cycle    |
| power9    | 10-14   | 1/cycle    |

#### 7.8.5.1 More information.

High level performance estimates are provided as an aid to function selection when evaluating algorithms. For background on how *Latency* and *Throughput* are derived see: [Performance data](#).

### 7.8.6 Function Documentation

#### 7.8.6.1 vec\_absduh()

```
static vui16_t vec_absduh (
 vui16_t vra,
 vui16_t vrb) [inline], [static]
```

Vector Absolute Difference Unsigned halfword.

Compute the absolute difference for each halfword. For each unsigned halfword, subtract VRB[i] from VRA[i] and return the absolute value of the difference.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 1/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|            |                                 |
|------------|---------------------------------|
| <i>vra</i> | vector of 8 x unsigned halfword |
| <i>vrb</i> | vector of 8 x unsigned halfword |

## Returns

vector of the absolute differences.

7.8.6.2 `vec_clzh()`

```
static vuil6_t vec_clzh (
 vuil6_t vra) [inline], [static]
```

Count Leading Zeros for a vector unsigned short (halfword) elements.

Count the number of leading '0' bits (0-16) within each halfword element of a 128-bit vector.

For POWER8 (PowerISA 2.07B) or later use the Vector Count Leading Zeros Halfword instruction **vclzh**. Otherwise use sequence of pre 2.07 VMX instructions.

## Note

SIMDized count leading zeros inspired by: Warren, Henry S. Jr and *Hacker's Delight*, 2nd Edition, Addison Wesley, 2013. Chapter 5 Counting Bits, Figure 5-12.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|            |                                                                   |
|------------|-------------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as 8 x 16-bit integer (halfword) elements. |
|------------|-------------------------------------------------------------------|

## Returns

128-bit vector with the Leading Zeros count for each halfword element.

## 7.8.6.3 vec\_mrgahh()

```
static vui16_t vec_mrgahh (
 vui32_t vra,
 vui32_t vrb) [inline], [static]
```

Vector Merge Algebraic High Halfword operation.

Merge only the high halfwords from 8 x Algebraic words across vectors vra and vrb. This is effectively the Vector Merge Even Halfword operation that is not modified for endian.

For example merge the high 16-bits from each of 8 x 32-bit products as generated by vec\_muleuh/vec\_mulouh. This result is effectively a vector multiply high unsigned halfword.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-13    | 2/cycle    |
| power9    | 3-14    | 2/cycle    |

## Parameters

|            |                              |
|------------|------------------------------|
| <i>vra</i> | 128-bit vector unsigned int. |
| <i>vrb</i> | 128-bit vector unsigned int. |

## Returns

A vector merge from only the high halfwords of the 8 x Algebraic words across vra and vrb.

## 7.8.6.4 vec\_mrgalh()

```
static vui16_t vec_mrgalh (
 vui32_t vra,
 vui32_t vrb) [inline], [static]
```

Vector Merge Algebraic Low Halfword operation.

Merge only the low halfwords from 8 x Algebraic words across vectors vra and vrb. This is effectively the Vector Merge Odd Halfword operation that is not modified for endian.

For example merge the low 16-bits from each of 8 x 32-bit products as generated by vec\_muleuh/vec\_mulouh. This result is effectively a vector multiply low unsigned halfword.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-13    | 2/cycle    |
| power9    | 3-14    | 2/cycle    |

## Parameters

|            |                              |
|------------|------------------------------|
| <i>vra</i> | 128-bit vector unsigned int. |
| <i>vrb</i> | 128-bit vector unsigned int. |

## Returns

A vector merge from only the high halfwords of the 8 x Algebraic words across *vra* and *vrb*.

7.8.6.5 `vec_mrgeh()`

```
static vuil6_t vec_mrgeh (
 vuil6_t vra,
 vuil6_t vrb) [inline], [static]
```

Vector Merge Even Halfwords operation.

Merge the even halfword elements from the concatenation of 2 x vectors (*vra* and *vrb*).

## Note

The element numbering changes between big and little-endian. So the compiler and this implementation adjusts the generated code to reflect this.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-13    | 2/cycle    |
| power9    | 3-14    | 2/cycle    |

## Parameters

|            |                                |
|------------|--------------------------------|
| <i>vra</i> | 128-bit vector unsigned short. |
| <i>vrb</i> | 128-bit vector unsigned short. |

## Returns

A vector merge from only the even halfwords of *vra* and *vrb*.

7.8.6.6 `vec_mrgoh()`

```
static vuil6_t vec_mrgoh (
 vuil6_t vra,
 vuil6_t vrb) [inline], [static]
```



Vector Merge Odd Halfwords operation.

Merge the odd halfword elements from the concatenation of 2 x vectors (vra and vrb).

#### Note

The element numbering changes between big and little-endian. So the compiler and this implementation adjusts the generated code to reflect this.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-13    | 2/cycle    |
| power9    | 3-14    | 2/cycle    |

#### Parameters

|                    |                                |
|--------------------|--------------------------------|
| <i>vra</i>         | 128-bit vector unsigned short. |
| <i>vr</i> <i>b</i> | 128-bit vector unsigned short. |

#### Returns

A vector merge from only the odd halfwords of vra and vrb.

#### 7.8.6.7 vec\_mulhsh()

```
static vi16_t vec_mulhsh (
 vi16_t vra,
 vi16_t vrb) [inline], [static]
```

Vector Multiply High Signed halfword.

Multiple the corresponding halfword elements of two vector signed short values and return the high order 16-bits, for each 32-bit product element.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 9-13    | 1/cycle    |
| power9    | 10-14   | 1/cycle    |

#### Parameters

|                    |                              |
|--------------------|------------------------------|
| <i>vra</i>         | 128-bit vector signed short. |
| <i>vr</i> <i>b</i> | 128-bit vector signed short. |

**Returns**

vector of the high order 16-bits of the product of the halfword elements from vra and vrb.

**7.8.6.8 vec\_mulhuh()**

```
static vui16_t vec_mulhuh (
 vui16_t vra,
 vui16_t vrb) [inline], [static]
```

Vector Multiply High Unsigned halfword.

Multiply the corresponding halfword elements of two vector unsigned short values and return the high order 16-bits, for each 32-bit product element.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 9-13    | 1/cycle    |
| power9    | 10-14   | 1/cycle    |

**Parameters**

|            |                                |
|------------|--------------------------------|
| <i>vra</i> | 128-bit vector unsigned short. |
| <i>vrb</i> | 128-bit vector unsigned short. |

**Returns**

vector of the high order 16-bits of the product of the halfword elements from vra and vrb.

**7.8.6.9 vec\_muluhm()**

```
static vui16_t vec_muluhm (
 vui16_t vra,
 vui16_t vrb) [inline], [static]
```

Vector Multiply Unsigned halfword Modulo.

Multiply the corresponding halfword elements of two vector unsigned short values and return the low order 16-bits of the 32-bit product for each element.

**Note**

vec\_muluhm can be used for unsigned or signed short integers. It is the vector equivalent of Multiply Low Halfword.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 9-13    | 1/cycle    |
| power9    | 10-14   | 1/cycle    |

## Parameters

|            |                                |
|------------|--------------------------------|
| <i>vra</i> | 128-bit vector unsigned short. |
| <i>vrh</i> | 128-bit vector unsigned short. |

## Returns

vector of the low order 16-bits of the unsigned product of the halfword elements from *vra* and *vrh*.

## 7.8.6.10 vec\_popcnth()

```
static vuil6_t vec_popcnth (
 vuil6_t vra) [inline], [static]
```

Vector Population Count halfword.

Count the number of '1' bits (0-16) within each byte element of a 128-bit vector.

For POWER8 (PowerISA 2.07B) or later use the Vector Population Count Halfword instruction. Otherwise use simple Vector (VMX) instructions to count bits in bytes in parallel.

## Note

SIMDized population count inspired by: Warren, Henry S. Jr and *Hacker's Delight*, 2nd Edition, Addison Wesley, 2013. Chapter 5 Counting Bits, Figure 5-2.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|            |                                                                    |
|------------|--------------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as 8 x 16-bit integers (halfword) elements. |
|------------|--------------------------------------------------------------------|

## Returns

128-bit vector with the population count for each halfword element.

### 7.8.6.11 `vec_revbh()`

```
static vui16_t vec_revbh (
 vui16_t vra) [inline], [static]
```

byte reverse each halfword of a vector unsigned short.

For each halfword of the input vector, reverse the order of bytes / octets within the halfword.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-11    | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|            |                                  |
|------------|----------------------------------|
| <i>vra</i> | a 128-bit vector unsigned short. |
|------------|----------------------------------|

#### Returns

a 128-bit vector with the bytes of each halfword reversed.

### 7.8.6.12 `vec_slhi()`

```
static vui16_t vec_slhi (
 vui16_t vra,
 const unsigned int shb) [inline], [static]
```

Vector Shift left Halfword Immediate.

Shift left each halfword element [0-7], 0-15 bits, as specified by an immediate value. The shift amount is a const unsigned int in the range 0-15. A shift count of 0 returns the original value of *vra*. Shift counts greater than 15 bits return zero.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-11    | 2/cycle    |
| power9    | 5-11    | 2/cycle    |

#### Parameters

|            |                                                      |
|------------|------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector unsigned short. |
| <i>shb</i> | Shift amount in the range 0-15.                      |

**Returns**

128-bit vector unsigned short, shifted left shb bits.

**7.8.6.13 vec\_srahi()**

```
static vil6_t vec_srahi (
 vil6_t vra,
 const unsigned int shb) [inline], [static]
```

Vector Shift Right Algebraic Halfword Immediate.

Shift right algebraic each halfword element [0-7], 0-15 bits, as specified by an immediate value. The shift amount is a const unsigned int in the range 0-15. A shift count of 0 returns the original value of vra. Shift counts greater than 7 bits return the sign bit propagated to each bit of each element.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-11    | 2/cycle    |
| power9    | 5-11    | 2/cycle    |

**Parameters**

|            |                                                   |
|------------|---------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector signed char. |
| <i>shb</i> | Shift amount in the range 0-7.                    |

**Returns**

128-bit vector signed short, shifted right shb bits.

**7.8.6.14 vec\_srhi()**

```
static vuil6_t vec_srhi (
 vuil6_t vra,
 const unsigned int shb) [inline], [static]
```

Vector Shift Right Halfword Immediate.

Shift right each halfword element [0-7], 0-15 bits, as specified by an immediate value. The shift amount is a const unsigned int in the range 0-15. A shift count of 0 returns the original value of vra. Shift counts greater than 15 bits return zero.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-11    | 2/cycle    |
| power9    | 5-11    | 2/cycle    |

#### Parameters

|            |                                                      |
|------------|------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector unsigned short. |
| <i>shb</i> | Shift amount in the range 0-15.                      |

#### Returns

128-bit vector unsigned short, shifted right shb bits.

#### 7.8.6.15 vec\_vmaddeuh()

```
static vui32_t vec_vmaddeuh (
 vui16_t a,
 vui16_t b,
 vui16_t c) [inline], [static]
```

Vector Multiply-Add Even Unsigned Halfwords.

Multiply the even 16-bit Words of vector unsigned short values ( $a * b$ ) and return sums of the unsigned 32-bit product and the even 16-bit halfwords of  $c$  ( $a_{\text{even}} * b_{\text{even}} + \text{EXTZ}(c_{\text{even}})$ ).

#### Note

The advantage of this form (versus Multiply-Sum) is that the final 32 bit sums can not overflow.  
This implementation is NOT endian sensitive and the function is stable across BE/LE implementations.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 9-18    | 2/cycle    |
| power9    | 9-16    | 2/cycle    |

#### Parameters

|          |                                |
|----------|--------------------------------|
| <i>a</i> | 128-bit vector unsigned short. |
| <i>b</i> | 128-bit vector unsigned short. |
| <i>c</i> | 128-bit vector unsigned short. |

**Returns**

vector unsigned int sum ( $a_{\text{even}} * b_{\text{even}} + \text{EXTZ}(c_{\text{even}})$ ).

**7.8.6.16 vec\_vmaddouh()**

```
static vui32_t vec_vmaddouh (
 vui16_t a,
 vui16_t b,
 vui16_t c) [inline], [static]
```

Vector Multiply-Add Odd Unsigned Halfwords.

Multiply the odd 16-bit Halfwords of vector unsigned short values ( $a * b$ ) and return sums of the unsigned 32-bit product and the odd 16-bit halfwords of  $c$  ( $a_{\text{odd}} * b_{\text{odd}} + \text{EXTZ}(c_{\text{odd}})$ ).

**Note**

The advantage of this form (versus Multiply-Sum) is that the final 32 bit sums can not overflow.  
This implementation is NOT endian sensitive and the function is stable across BE/LE implementations.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 9-18    | 2/cycle    |
| power9    | 9-16    | 2/cycle    |

**Parameters**

|          |                                |
|----------|--------------------------------|
| <i>a</i> | 128-bit vector unsigned short. |
| <i>b</i> | 128-bit vector unsigned short. |
| <i>c</i> | 128-bit vector unsigned short. |

**Returns**

vector unsigned int sum ( $a_{\text{odd}} * b_{\text{odd}} + \text{EXTZ}(c_{\text{odd}})$ ).

**7.8.6.17 vec\_vmrgeh()**

```
static vui16_t vec_vmrgeh (
 vui16_t vra,
 vui16_t vrb) [inline], [static]
```

Vector Merge Even Halfwords.

Merge the even halfword elements from the concatenation of 2 x vectors (*vra* and *vrb*).

**Note**

This function implements the operation of a Vector Merge Even Halfword instruction, if the PowerISA included such an instruction. This implementation is NOT endian sensitive and the function is stable across BE/LE implementations. Using big-endian element numbering:

- `res[0] = vra[0];`
- `res[1] = vrb[0];`
- `res[2] = vra[2];`
- `res[3] = vrb[2];`
- `res[4] = vra[4];`
- `res[5] = vrb[4];`
- `res[6] = vra[6];`
- `res[7] = vrb[6];`

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-13    | 2/cycle    |
| power9    | 3-14    | 2/cycle    |

**Parameters**

|            |                                |
|------------|--------------------------------|
| <i>vra</i> | 128-bit vector unsigned short. |
| <i>vrb</i> | 128-bit vector unsigned short. |

**Returns**

A vector merge from only the even halfwords of *vra* and *vrb*.

**7.8.6.18 `vec_vmrgh()`**

```
static vuil6_t vec_vmrgh (
 vuil6_t vra,
 vuil6_t vrb) [inline], [static]
```

Vector Merge Odd Halfwords.

Merge the odd halfword elements from the concatenation of 2 x vectors (*vra* and *vrb*).



**Note**

This function implements the operation of a Vector Merge Odd Halfword instruction, if the PowerISA included such an instruction. This implementation is NOT endian sensitive and the function is stable across BE/LE implementations. Using big-endian element numbering:

- `res[0] = vra[1];`
- `res[1] = vrb[1];`
- `res[2] = vra[3];`
- `res[3] = vrb[3];`
- `res[4] = vra[5];`
- `res[5] = vrb[5];`
- `res[6] = vra[7];`
- `res[7] = vrb[7];`

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-13    | 2/cycle    |
| power9    | 3-14    | 2/cycle    |

**Parameters**

|            |                                |
|------------|--------------------------------|
| <i>vra</i> | 128-bit vector unsigned short. |
| <i>vrb</i> | 128-bit vector unsigned short. |

**Returns**

A vector merge from only the odd halfwords of *vra* and *vrb*.

## 7.9 src/pveclib/vec\_int32\_ppc.h File Reference

Header package containing a collection of 128-bit SIMD operations over 32-bit integer elements.

```
#include <pveclib/vec_int16_ppc.h>
```

**Functions**

- static [vui32\\_t vec\\_absduw](#) ([vui32\\_t](#) vra, [vui32\\_t](#) vrb)  
*Vector Absolute Difference Unsigned Word.*
- static [vui32\\_t vec\\_clzw](#) ([vui32\\_t](#) vra)  
*Vector Count Leading Zeros word.*
- static [vui32\\_t vec\\_mrgahw](#) ([vui64\\_t](#) vra, [vui64\\_t](#) vrb)  
*Vector Merge Algebraic High Words.*
- static [vui32\\_t vec\\_mrgalw](#) ([vui64\\_t](#) vra, [vui64\\_t](#) vrb)

- Vector merge Algebraic low words.*

  - static `vui32_t vec_mrgew` (`vui32_t` vra, `vui32_t` vrb)

*Vector Merge Even Words.*

  - static `vui32_t vec_mrgow` (`vui32_t` vra, `vui32_t` vrb)

*Vector Merge Odd Words.*

  - static `vi64_t vec_mulesw` (`vi32_t` a, `vi32_t` b)

*Vector multiply even signed words.*

  - static `vi64_t vec_mulosw` (`vi32_t` a, `vi32_t` b)

*Vector multiply odd signed words.*

  - static `vui64_t vec_muleuw` (`vui32_t` a, `vui32_t` b)

*Vector multiply even unsigned words.*

  - static `vui64_t vec_mulouw` (`vui32_t` a, `vui32_t` b)

*Vector multiply odd unsigned words.*

  - static `vi32_t vec_mulhsw` (`vi32_t` vra, `vi32_t` vrb)

*Vector Multiply High Signed Word.*

  - static `vui32_t vec_mulhuw` (`vui32_t` vra, `vui32_t` vrb)

*Vector Multiply High Unsigned Word.*

  - static `vui32_t vec_muluwm` (`vui32_t` a, `vui32_t` b)

*Vector Multiply Unsigned Word Modulo.*

  - static `vui32_t vec_popcntw` (`vui32_t` vra)

*Vector Population Count word.*

  - static `vui32_t vec_revbw` (`vui32_t` vra)

*byte reverse each word of a vector unsigned int.*

  - static `vui32_t vec_slwi` (`vui32_t` vra, const unsigned int shb)

*Vector Shift left Word Immediate.*

  - static `vi32_t vec_srawi` (`vi32_t` vra, const unsigned int shb)

*Vector Shift Right Algebraic Word Immediate.*

  - static `vui32_t vec_srwi` (`vui32_t` vra, const unsigned int shb)

*Vector Shift Right Word Immediate.*

  - static `vui64_t vec_vmadd2euw` (`vui32_t` a, `vui32_t` b, `vui32_t` c, `vui32_t` d)

*Vector Multiply-Add2 Even Unsigned Words.*

  - static `vui64_t vec_vmadd2ouw` (`vui32_t` a, `vui32_t` b, `vui32_t` c, `vui32_t` d)

*Vector Multiply-Add2 Odd Unsigned Words.*

  - static `vui64_t vec_vmaddeuw` (`vui32_t` a, `vui32_t` b, `vui32_t` c)

*Vector Multiply-Add Even Unsigned Words.*

  - static `vui64_t vec_vmaddouw` (`vui32_t` a, `vui32_t` b, `vui32_t` c)

*Vector Multiply-Add Odd Unsigned Words.*

  - static `vui64_t vec_vmsumuw` (`vui32_t` a, `vui32_t` b, `vui64_t` c)

*Vector Multiply-Sum Unsigned Word Modulo.*

  - static `vui64_t vec_vmuleuw` (`vui32_t` vra, `vui32_t` vrb)

*Vector Multiply Even Unsigned words.*

  - static `vui64_t vec_vmulouw` (`vui32_t` vra, `vui32_t` vrb)

*Vector Multiply Odd Unsigned Words.*

### 7.9.1 Detailed Description

Header package containing a collection of 128-bit SIMD operations over 32-bit integer elements.

Most of these operations are implemented in a single instruction on newer (POWER8/POWER9) processors. This header serves to fill in functional gaps for older (POWER7, POWER8) processors and provides a in-line assembler implementation for older compilers that do not provide the build-ins.

Most vector int (32-bit integer word) operations are implemented with PowerISA VMX instructions either defined by the original VMX (AKA AltiVec) or added to later versions of the PowerISA. Vector word-wise merge, shift, and splat operations were added with VSX in PowerISA 2.06B (POWER7). PowerISA 2.07B (POWER8) added several useful word wise operations (multiply, merge even/odd, count leading zeros, population count) not included in the original VMX. PowerISA 3.0B (POWER9) adds several more (compare not equal, count trailing zeros, extend sign, extract/insert, and parity). Most of these intrinsic (compiler built-ins) operations are defined in `<altivec.h>` and described in the compiler documentation.

#### Note

The compiler disables associated `<altivec.h>` built-ins if the `mcpu` target does not enable the specific instruction. For example if you compile with `-mcpu=power7`, `vec_vclz` and `vec_vclzw` will not be defined. Another example if you compile with `-mcpu=power8`, `vec_revb` will not be defined. This header provides the appropriate substitutions, will generate the minimum code, appropriate for the target, and produce correct results.

Most ppc64le compilers will default to `-mcpu=power8` if not specified.

The newly introduced vector operations imply some useful composite operations. For example, we can make the vector multiply even/odd/modulo word operations available for older compilers. And provide implementations for older (POWER7 and earlier) processors using the original VMX operations.

This header covers operations that are either:

- Implemented in hardware instructions for later processors and useful to programmers, on slightly older processors, even if the equivalent function requires more instructions. Examples include the multiply even/odd/modulo word operations.
- Defined in the OpenPOWER ABI but *not* yet defined in `<altivec.h>` provided by available compilers in common use. Examples include Count Leading Zeros, Population Count and Byte Reverse.
- Commonly used operations, not covered by the ABI or `<altivec.h>`, and require multiple instructions or are not obvious. Examples include the shift immediate, merge algebraic high/low, and multiply high operations.

### 7.9.2 Recent Additions

Added `vec_vmaddeuw()`, `vec_vmaddouw()`, `vec_vmadd2euw()`, and `vec_vmadd2ouw()` as an optimization for the vector multiply quadword implementations on POWER8.

### 7.9.3 Endian problems with word operations

It would be useful to provide a vector multiply high word (return the high order 32-bits of the 64-bit product) operation. This can be used for multiplicative inverse (effectively integer divide) operations. Neither integer multiply high nor divide are available as vector instructions. However the multiply high word operation can be composed from the existing multiply even/odd word operations followed by the vector merge even word instruction.

As a prerequisite we need to provide the merge even/odd word operations for older compilers and an implementation for older (POWER7) processors. Fortunately vector merge operations are just a special case of vector permute. So the POWER7 (and earlier) implementation can use `vec_perm` and appropriate selection vectors to provide these merge operations.

But this is complicated by *little-endian* (LE) support as specified in the OpenPOWER ABI and as implemented in the compilers. Little-endian changes the effective vector element numbering and the location of even and odd elements. This means that the vector built-ins provided by `altivec.h` may not generate the instructions you would expect.

See also

[General Endian Issues](#)

The OpenPOWER ABI provides a helpful table of [Endian Sensitive Operations](#). For `vec_mergee` (`vmrgew`) it specifies:

Swap inputs and use `vmrgow`, for LE.

Also for `vec_mule` (`vmuleuw`, `vmulesw`):

Replace with `vmulouw` and so on, for LE.

Also for `vec_perm` (`vperm`) it specifies:

For LE, Swap input arguments and complement the selection vector.

The above is just a sampling of a larger list of Endian Sensitive Operations.

So the obvious coding for Vector Multiply High Word:

```
vui32_t
test_mulhw (vui32_t vra, vui32_t vrb)
{
 return vec_mergee ((vui32_t)vec_mule (vra, vrb),
 (vui32_t)vec_mulo (vra, vrb));
}
```

Would produce the expected code and correct results when compiled for BE:

```
<test_mulhw>:
 vmuleuw v0,v2,v3
 vmuluuw v2,v2,v3
 vmrgew v2,v0,v2
 blr
```

But the following and wrong code for LE:

```
<test_mulhw>:
 vmulouw v0,v2,v3
 vmuleuw v2,v2,v3
 vmrgow v2,v2,v0
 blr
```

The compiler swapped the multiplies even for odd and odd of even. That is somewhat mitigated by swapping the input arguments in the merge. But changing the merge from even to odd actually returns the low order 32-bits of the product. This is not the correct result for multiply high.

This header provides implementations of vector merge even/odd word ([vec\\_mrgew\(\)](#) and [vec\\_mrgow\(\)](#)) that support older compilers and older (POWER7) processor. Similarly for the multiply Even/odd unsigned/signed word instructions ([vec\\_mulesw\(\)](#), [vec\\_mulosw\(\)](#), [vec\\_muleuw\(\)](#) and [vec\\_mulouw\(\)](#)). These implementations include the mandated LE transforms.

### 7.9.3.1 Vector Merge Algebraic High Word example

This header also provides the higher level operations Vector Merge Algebraic High/low Word ([vec\\_mrgahw\(\)](#) and [vec\\_mrgalw\(\)](#)). These implementations generate the correct merge even/odd word instruction for the operation independent of endian.

#### Note

The parameters are vector unsigned long ([vui64\\_t](#)) to match results from [vec\\_muleuw\(\)](#) and [vec\\_mulouw\(\)](#).

```
static inline vui32_t
vec_mrgahw (vui64_t vra, vui64_t vrb)
{
 vui32_t res;
#ifdef _ARCH_PWR8
#ifdef vec_vmrgew // Use altivec.h builtins
#if __BYTE_ORDER__ == __ORDER_LITTLE_ENDIAN__
 // really want vmrgew here! So do the opposite.
 res = vec_vmrgow ((vui32_t)vrb, (vui32_t)vra);
#else
 res = vec_vmrgew ((vui32_t)vra, (vui32_t)vrb);
#endif
#else
 // Generate vmrgew directly in assembler
 __asm__(
 "vmrgew %0,%1,%2;\n"
 : "=v" (res)
 : "v" (vra),
 "v" (vrb)
 :);
#endif
#else // POWER7 and earlier, Assume BE only
 const vui32_t vconstp =
 CONST_VINT32_W(0x00010203, 0x10111213, 0x08090a0b, 0x18191a1b);
 res = (vui32_t) vec_perm ((vui8_t) vra, (vui8_t) vrb, (
 vui8_t) vconstp);
#endif
 return (res);
}
```

The implementation is a bit complicated so that it can nullify the unwanted LE transformation of [vec\\_vmrgew\(\)](#), in addition to handling older compilers and processors.

### 7.9.3.2 Vector Multiply High Unsigned Word example

Now we can implement Vector Multiply High Unsigned Word (`vec_mulhuw()`):

```
static inline vui32_t
vec_mulhuw (vui32_t vra, vui32_t vrb)
{
 if __BYTE_ORDER__ == __ORDER_LITTLE_ENDIAN__
 return vec_mrgahw (vec_muluw (vra, vrb), vec_muleuw (vra, vrb));
 else
 return vec_mrgahw (vec_muleuw (vra, vrb), vec_muluw (vra, vrb));
 #endif
}
```

Again the implementation is more complicated than expected as we still have to nullify the LE transformation associated with multiply even/odd.

The good news is all this complexity is contained within pveclib and the generated code is still just 3 instructions.

```
vmuluw v0,v2,v3
vmuleuw v2,v2,v3
vmrgew v2,v2,v0
```

## 7.9.4 Vector Word Examples

Suppose we have a requirement to convert an array of 32-bit time-interval values that need to convert to timespec format. For simplicity we will also assume that the array is nicely (Quadword) aligned and an integer multiple of 4 words.

The PowerISA provides a 64-bit TimeBase register that clocks at a constant 512MHz. The TimeBase can be read directly as either the full 64-bit value or as 32-bit upper and lower halves. For this example we assume that the lower 32-bits of the TimeBase is sufficient to compute intervals (~8.38 seconds). TimeBase values of adjacent events are subtracted to generate the intervals stored in the array.

The timespec format is a struct of unsigned int fields for seconds and microseconds. So the task is to convert the 512MHz TimeBase intervals to microseconds and then split the integer seconds and microseconds for the timespec.

First the TimeBase to microseconds conversion is simply  $(1000000 / 512000000)$  which reduces to  $(1 / 512)$  or divide by 512. The vector unit does not provide integer divide but luckily, 512 is a power of 2 and we can shift right. If we don't care for the niceties of rounding we can simply shift right 9 bits:

```
tb_usec = vec_srwi (*tb++, 9);
```

But if we decide that rounding is important we can leverage the Vector Average Unsigned Word (`vavguw`) instruction. Here we need to add 256 ( $512 / 2 = 256$ ) to the timeBase interval before we shift right.

But we need to reverse engineer the `vavguw` operation to get the results we want. For each word, `vavguw` computes the sum of A and B plus 1, then shifts the 33-bit sum right 1 bit. We can effectively round by passing the rounding factor as the B operand to the `vec_avg()` built-in. But we get a +1 and 1 bit right shift for free. So in this case the rounding constant is  $256-1 = 255$ . And we only need to shift an additional 8 bits to complete the conversion:

```
const vui32_t rnd_512 =
 { (256-1), (256-1), (256-1), (256-1) };
// Convert 512MHz timebase to microseconds with rounding.
tmp = vec_avg (*tb++, rnd_512);
tb_usec = vec_srwi (tmp, 8);
```

**Note**

`vec_avg()` is an existing `altivec.h` generic built-in.

Next we need to separate TimeBase microseconds into the integer seconds and microseconds. Normally scalar codes would use integer divide/modulo by 1000000. Did I mention that the PowerISA vector unit does not have a integer divide operation?

Instead we can use the multiplicative inverse which is a scaled fixed point fraction calculated from the original divisor. This works nicely if the fixed radix point is just before the 32-bit fraction and we have a multiply high (`vec_mulhuw()`) operation. Multiplying a 32-bit unsigned integer by a 32-bit unsigned fraction generates a 64-bit product with 32-bits above (integer) and below (fraction) the radix point. The high 32-bits of the product is the integer quotient.

It turns out that generating the multiplicative inverse can be tricky. To produce correct results over the full analysis, possible pre-scaling and post-shifting, and sometimes a corrective addition is necessary. Fortunately the mathematics are well understood and are commonly used in optimizing compilers. Even better, Henry Warren's book has a whole chapter on this topic.

**See also**

"Hacker's Delight, 2nd Edition," Henry S. Warren, Jr, Addison Wesley, 2013. Chapter 10, Integer Division by Constants.

In the chapter above;

Figure 10-2 Computing the magic number for unsigned division.

provides a sample C function for generating the magic number (actually a struct containing; the magic multiplicative inverse, "add" indicator, and the shift amount.). For the divisor 1000000 this is { 1125899907, 0 , 18 }:

- the multiplier is 1125899907.
- no corrective add of the dividend is required.
- the final shift is 18-bits right.

```
const vui32_t mul_invs_lm =
{ 1125899907, 1125899907, 1125899907, 1125899907 };
const int shift_lm = 18;

tmp = vec_mulhuw (tb_usec, mul_invs_lm);
seconds = vec_srwi (tmp, shift_lm);
```

Now we need to compute the remainder to get microseconds.

```
const vui32_t usec_sec =
{ 1000000, 1000000, 1000000, 1000000 };

tmp = vec_muluwm (seconds, usec_sec);
useconds = vec_sub (tb_usec, tmp);
```

Finally we need to merge the vectors of seconds and useconds into vectors of timespec.

```
timespec1 = vec_mergeh (seconds, useconds);
timespec2 = vec_mergel (seconds, useconds);
```

**Note**

`vec_sub()`, `vec_mergeh()`, and `vec_mergel()` are an existing `altivec.h` generic built-ins.

#### 7.9.4.1 Vectorized TimeBase conversion example

Here is the complete vectorized TimeBase to timespec conversion example:

```
void
example_convert_timebase (vui32_t *tb, vui32_t *timespec, int n)
{
 const vui32_t rnd_512 =
 { (256-1), (256-1), (256-1), (256-1) };
 // Magic numbers for multiplicative inverse to divide by 1,000,000
 // are 1125899907 and shift right 18 bits.
 const vui32_t mul_invs_lm =
 { 1125899907, 1125899907, 1125899907, 1125899907 };
 const int shift_lm = 18;
 // Need const for microseconds/second to extract remainder.
 const vui32_t usec_sec =
 { 1000000, 1000000, 1000000, 1000000 };
 vui32_t tmp, tb_usec, seconds, useconds;
 vui32_t timespec1, timespec2;
 int i;

 for (i = 0; i < n; i++)
 {
 // Convert 512MHz timebase to microseconds with rounding.
 tmp = vec_avg (*tb++, rnd_512);
 tb_usec = vec_srwi (tmp, 8);
 // extract integer seconds from tb_usec.
 tmp = vec_mulhuw (tb_usec, mul_invs_lm);
 seconds = vec_srwi (tmp, shift_lm);
 // Extract remainder microseconds.
 tmp = vec_muluwm (seconds, usec_sec);
 useconds = vec_sub (tb_usec, tmp);
 // Use merge high/low to interleave seconds and useconds in timespec.
 timespec1 = vec_mergeh (seconds, useconds);
 timespec2 = vec_mergel (seconds, useconds);
 // Store timespec.
 *timespec++ = timespec1;
 *timespec++ = timespec2;
 }
}
```

#### 7.9.5 Performance data.

High level performance estimates are provided as an aid to function selection when evaluating algorithms. For background on how *Latency* and *Throughput* are derived see: [Performance data](#).

#### 7.9.6 Function Documentation

##### 7.9.6.1 vec\_absduw()

```
static vui32_t vec_absduw (
 vui32_t vra,
 vui32_t vrb) [inline], [static]
```

Vector Absolute Difference Unsigned Word.

Compute the absolute difference for each word. For each unsigned word, subtract VRB[i] from VRA[i] and return the absolute value of the difference.



| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 1/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|            |                              |
|------------|------------------------------|
| <i>vra</i> | vector of 4 x unsigned words |
| <i>vrb</i> | vector of 4 x unsigned words |

## Returns

vector of the absolute differences.

## 7.9.6.2 vec\_clzw()

```
static vui32_t vec_clzw (
 vui32_t vra) [inline], [static]
```

Vector Count Leading Zeros word.

Count the number of leading '0' bits (0-32) within each word element of a 128-bit vector.

For POWER8 (PowerISA 2.07B) or later use the Vector Count Leading Zeros Word instruction **vclzw**. Otherwise use sequence of pre 2.07 VMX instructions. SIMDized count leading zeros inspired by:

Warren, Henry S. Jr and *Hacker's Delight*, 2nd Edition, Addison Wesley, 2013. Chapter 5 Counting Bits, Figure 5-12.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|            |                                                                |
|------------|----------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as 4 x 32-bit integer (words) elements. |
|------------|----------------------------------------------------------------|

## Returns

128-bit vector with the Leading Zeros count for each word element.

### 7.9.6.3 vec\_mrgahw()

```
static vui32_t vec_mrgahw (
 vui64_t vra,
 vui64_t vrb) [inline], [static]
```

Vector Merge Algebraic High Words.

Merge only the high words from 4 x Algebraic doublewords across vectors vra and vrb. This effectively the Vector Merge Even Word operation that is not modified for endian.

For example merge the high 32-bits from 4 x 64-bit products as generated by vec\_muleuw/vec\_mulouw. This result is effectively a vector multiply high unsigned word.

#### Note

This implementation is NOT endian sensitive and the function is stable across BE/LE implementations.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 2       | 2/cycle    |

#### Parameters

|            |                               |
|------------|-------------------------------|
| <i>vra</i> | 128-bit vector unsigned long. |
| <i>vrb</i> | 128-bit vector unsigned long. |

#### Returns

A vector merge from only the high words of the 4 x Algebraic doublewords across vra and vrb.

### 7.9.6.4 vec\_mrgalw()

```
static vui32_t vec_mrgalw (
 vui64_t vra,
 vui64_t vrb) [inline], [static]
```

Vector merge Algebraic low words.

Merge the arithmetic low words 4 x Algebraic doublewords across vectors vra and vrb. This is effectively the Vector Merge Odd Word operation that is not modified for endian.

For example merge the low 32-bits from 4 x 64-bit products as generated by vec\_muleuw/vec\_mulouw. This result is effectively a vector multiply low unsigned word (multiply unsigned word modulo).

#### Note

This implementation is NOT endian sensitive and the function is stable across BE/LE implementations.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 2       | 2/cycle    |

## Parameters

|            |                               |
|------------|-------------------------------|
| <i>vra</i> | 128-bit vector unsigned long. |
| <i>vrh</i> | 128-bit vector unsigned long. |

## Returns

A vector merge from only the low words of the 4 x Algebraic doublewords across *vra* and *vrh*.

## 7.9.6.5 vec\_mrgew()

```
static vui32_t vec_mrgew (
 vui32_t vra,
 vui32_t vrh) [inline], [static]
```

Vector Merge Even Words.

Merge the even word elements from the concatenation of 2 x vectors (*vra* and *vrh*).

- `res[0] = vra[0];`
- `res[1] = vrh[0];`
- `res[2] = vra[2];`
- `res[3] = vrh[2];`

The element numbering changes between big and little-endian environments. So the compiler and this implementation adjusts the generated code to reflect this.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 2       | 2/cycle    |

## Parameters

|            |                              |
|------------|------------------------------|
| <i>vra</i> | 128-bit vector unsigned int. |
| <i>vrh</i> | 128-bit vector unsigned int. |

**Returns**

A vector merge from only the even words of vra and vrb.

**7.9.6.6 vec\_mrgow()**

```
static vui32_t vec_mrgow (
 vui32_t vra,
 vui32_t vrb) [inline], [static]
```

Vector Merge Odd Words.

Merge the odd word elements from the concatenation of 2 x vectors (vra and vrb).

- res[0] = vra[1];
- res[1] = vrb[1];
- res[2] = vra[3];
- res[3] = vrb[3];

The element numbering changes between big and little-endian environments. So the compiler and this implementation adjusts the generated code to reflect this.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 2       | 2/cycle    |

**Parameters**

|            |                              |
|------------|------------------------------|
| <i>vra</i> | 128-bit vector unsigned int. |
| <i>vrb</i> | 128-bit vector unsigned int. |

**Returns**

A vector merge from only the even words of vra and vrb.

**7.9.6.7 vec\_mulesw()**

```
static vi64_t vec_mulesw (
 vi32_t a,
 vi32_t b) [inline], [static]
```

Vector multiply even signed words.

Multiple the even words of two vector signed int values and return the signed long product of the even words.

For POWER8 and later we can use the vmulesw instruction. But for POWER7 and earlier we have to construct word multiplies from halfword multiplies. See [vec\\_muleuw\(\)](#).

Here we start with a unsigned vec\_muleuw product, then correct the high 32-bits of the product to signed. Based on: Warren, Henry S. Jr and *Hacker's Delight*, 2nd Edition, Addison Wesley, 2013. Chapter 8 Multiplication, Section 8-3 High-Order Product Signed from/to Unsigned.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 7       | 2/cycle    |
| power9    | 7       | 2/cycle    |

#### Parameters

|          |                            |
|----------|----------------------------|
| <i>a</i> | 128-bit vector signed int. |
| <i>b</i> | 128-bit vector signed int. |

#### Returns

vector signed long product of the even words of a and b.

#### 7.9.6.8 vec\_muleuw()

```
static vui64_t vec_muleuw (
 vui32_t a,
 vui32_t b) [inline], [static]
```

Vector multiply even unsigned words.

Multiple the even words of two vector unsigned int values and return the unsigned long product of the even words.

For POWER8 and later we can use the vmuleuw instruction. But for POWER7 and earlier we have to construct word multiplies from two halfword multiplies (vmuleuh and vmulouh). Then sum the partial products for the final doubleword results. This is complicated by the fact that vector add doubleword is not available for POWER7. So we need to construct the doubleword add from Vector Add Unsigned Word Modulo (vadduwm) and Vector Add and Write Carry-Out Unsigned Word (vaddcuw) with shift double quadword to reposition the low word carry and a final vadduwm to complete the carry propagation for the doubleword add.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 7       | 2/cycle    |
| power9    | 7       | 2/cycle    |

**Parameters**

|          |                              |
|----------|------------------------------|
| <i>a</i> | 128-bit vector unsigned int. |
| <i>b</i> | 128-bit vector unsigned int. |

**Returns**

vector unsigned long product of the even words of *a* and *b*.

**7.9.6.9 vec\_mulhsw()**

```
static vi32_t vec_mulhsw (
 vi32_t vra,
 vi32_t vrb) [inline], [static]
```

Vector Multiply High Signed Word.

Multiple the corresponding word elements of two vector signed int values and return the high order 32-bits, for each 64-bit product element.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 9       | 1/cycle    |
| power9    | 9       | 1/cycle    |

**Parameters**

|            |                            |
|------------|----------------------------|
| <i>vra</i> | 128-bit vector signed int. |
| <i>vrb</i> | 128-bit vector signed int. |

**Returns**

vector of the high order 32-bits of the product of the word elements from *vra* and *vrb*.

**7.9.6.10 vec\_mulhuw()**

```
static vui32_t vec_mulhuw (
 vui32_t vra,
 vui32_t vrb) [inline], [static]
```

Vector Multiply High Unsigned Word.

Multiple the corresponding word elements of two vector unsigned int values and return the high order 32-bits, from each 64-bit product.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 9       | 1/cycle    |
| power9    | 9       | 1/cycle    |

**Note**

This operation can be used to effectively perform a divide by multiplying by the scaled multiplicative inverse (reciprocal).

Warren, Henry S. Jr and *Hacker's Delight*, 2nd Edition, Addison Wesley, 2013. Chapter 10, Integer Division by Constants.

**Parameters**

|            |                              |
|------------|------------------------------|
| <i>vra</i> | 128-bit vector unsigned int. |
| <i>vrh</i> | 128-bit vector unsigned int. |

**Returns**

vector of the high order 32-bits of the signed product of the word elements from *vra* and *vrh*.

**7.9.6.11 vec\_mulosw()**

```
static vi64_t vec_mulosw (
 vi32_t a,
 vi32_t b) [inline], [static]
```

Vector multiply odd signed words.

Multiple the odd words of two vector signed int values and return the signed long product of the odd words.

For POWER8 and later we can use the vmulow instruction. But for POWER7 and earlier we have to construct word multiplies from halfword multiplies. See [vec\\_muloww\(\)](#).

Here we start with a unsigned vec\_muloww product, then correct the high-order 32-bits of the product to signed. Based on: Warren, Henry S. Jr and *Hacker's Delight*, 2nd Edition, Addison Wesley, 2013. Chapter 8 Multiplication, Section 8-3 High-Order Product Signed from/to Unsigned.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 7       | 2/cycle    |
| power9    | 7       | 2/cycle    |

**Parameters**

|          |                            |
|----------|----------------------------|
| <i>a</i> | 128-bit vector signed int. |
| <i>b</i> | 128-bit vector signed int. |

**Returns**

vector signed long product of the odd words of a and b.

**7.9.6.12 vec\_mulouw()**

```
static vui64_t vec_mulouw (
 vui32_t a,
 vui32_t b) [inline], [static]
```

Vector multiply odd unsigned words.

Multiple the odd words of two vector unsigned int values and return the unsigned long product of the odd words.

For POWER8 and later we can use the vmulouw instruction. But for POWER7 and earlier we have to construct word multiplies from two halfword multiplies (vmuleuh and vmulouh). Then sum the partial products for the final doubleword results. This is complicated by the fact that vector add doubleword is not available for POWER7. So we need to construct the doubleword add from Vector Add Unsigned Word Modulo (vadduwm) and Vector Add and Write Carry-Out Unsigned Word (vaddcuw) with shift double quadword to reposition the low word carry and a final vadduwm to complete the carry propagation for the doubleword add.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 7       | 2/cycle    |
| power9    | 7       | 2/cycle    |

**Parameters**

|          |                              |
|----------|------------------------------|
| <i>a</i> | 128-bit vector unsigned int. |
| <i>b</i> | 128-bit vector unsigned int. |

**Returns**

vector unsigned long product of the odd words of a and b.



## 7.9.6.13 vec\_muluwm()

```
static vui32_t vec_muluwm (
 vui32_t a,
 vui32_t b) [inline], [static]
```

Vector Multiply Unsigned Word Modulo.

Multiple the corresponding word elements of two vector unsigned int values and return the low order 32-bits of the 64-bit product for each element.

**Note**

vec\_muluwm can be used for unsigned or signed integers. It is the vector equivalent of Multiply Low Word.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 7       | 2/cycle    |
| power9    | 7       | 2/cycle    |

**Parameters**

|          |                            |
|----------|----------------------------|
| <i>a</i> | 128-bit vector signed int. |
| <i>b</i> | 128-bit vector signed int. |

**Returns**

vector of the low order 32-bits of the unsigned product of the word elements from vra and vrb.

## 7.9.6.14 vec\_popcntw()

```
static vui32_t vec_popcntw (
 vui32_t vra) [inline], [static]
```

Vector Population Count word.

Count the number of '1' bits (0-32) within each word element of a 128-bit vector.

For POWER8 (PowerISA 2.07B) or later use the Vector Population Count Word instruction. Otherwise use the pveclib vec\_popcntb to count each byte then sum across with Vector Sum across Quarter Unsigned Byte Saturate.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|            |                                                                |
|------------|----------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as 4 x 32-bit integer (words) elements. |
|------------|----------------------------------------------------------------|

**Returns**

128-bit vector with the population count for each word element.

**7.9.6.15 vec\_revbw()**

```
static vui32_t vec_revbw (
 vui32_t vra) [inline], [static]
```

byte reverse each word of a vector unsigned int.

For each word of the input vector, reverse the order of bytes / octets within the word.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-11    | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|            |                                |
|------------|--------------------------------|
| <i>vra</i> | a 128-bit vector unsigned int. |
|------------|--------------------------------|

**Returns**

a 128-bit vector with the bytes of each word reversed.

**7.9.6.16 vec\_slwi()**

```
static vui32_t vec_slwi (
 vui32_t vra,
 const unsigned int shb) [inline], [static]
```

Vector Shift left Word Immediate.

Shift left each word element [0-3], 0-31 bits, as specified by an immediate value. The shift amount is a const unsigned int in the range 0-31. A shift count of 0 returns the original value of vra. Shift counts greater than 31 bits return zero.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-11    | 2/cycle    |
| power9    | 5-11    | 2/cycle    |

**Parameters**

|            |                                                    |
|------------|----------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector unsigned int. |
| <i>shb</i> | shift amount in the range 0-31.                    |

**Returns**

128-bit vector unsigned int, shifted left shb bits.

**7.9.6.17 vec\_srawi()**

```
static vi32_t vec_srawi (
 vi32_t vra,
 const unsigned int shb) [inline], [static]
```

Vector Shift Right Algebraic Word Immediate.

Shift Right Algebraic each word element [0-3], 0-31 bits, as specified by an immediate value. The shift amount is a const unsigned int in the range 0-31. A shift count of 0 returns the original value of vra. Shift counts greater than 31 bits return the sign bit propagated to each bit of each element.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-11    | 2/cycle    |
| power9    | 5-11    | 2/cycle    |

**Parameters**

|            |                                                  |
|------------|--------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector signed int. |
| <i>shb</i> | shift amount in the range 0-31.                  |

**Returns**

128-bit vector signed int, shifted right shb bits.

### 7.9.6.18 vec\_srwi()

```
static vui32_t vec_srwi (
 vui32_t vra,
 const unsigned int shb) [inline], [static]
```

Vector Shift Right Word Immediate.

Shift right each word element [0-3], 0-31 bits, as specified by an immediate value. The shift amount is a const unsigned int in the range 0-31. A shift count of 0 returns the original value of vra. Shift counts greater than 31 bits return zero.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-11    | 2/cycle    |
| power9    | 5-11    | 2/cycle    |

#### Parameters

|            |                                                     |
|------------|-----------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector unsigned char. |
| <i>shb</i> | shift amount in the range 0-31.                     |

#### Returns

128-bit vector unsigned int, shifted right shb bits.

### 7.9.6.19 vec\_vmadd2euw()

```
static vui64_t vec_vmadd2euw (
 vui32_t a,
 vui32_t b,
 vui32_t c,
 vui32_t d) [inline], [static]
```

Vector Multiply-Add2 Even Unsigned Words.

#### Note

this implementation exists in `vec_int64_ppc::h::vec_vmadd2euw()` as it requires `vec_addudm()`.

#### 7.9.6.20 vec\_vmadd2ouw()

```
static vui64_t vec_vmadd2ouw (
 vui32_t a,
 vui32_t b,
 vui32_t c,
 vui32_t d) [inline], [static]
```

Vector Multiply-Add2 Odd Unsigned Words.

##### Note

this implementation exists in [vec\\_int64\\_ppc::h::vec\\_vmadd2ouw\(\)](#) as it requires [vec\\_addudm\(\)](#).

#### 7.9.6.21 vec\_vmaddeuw()

```
static vui64_t vec_vmaddeuw (
 vui32_t a,
 vui32_t b,
 vui32_t c) [inline], [static]
```

Vector Multiply-Add Even Unsigned Words.

##### Note

this implementation exists in [vec\\_int64\\_ppc::h::vec\\_vmaddeuw\(\)](#) as it requires [vec\\_addudm\(\)](#).

#### 7.9.6.22 vec\_vmaddouw()

```
static vui64_t vec_vmaddouw (
 vui32_t a,
 vui32_t b,
 vui32_t c) [inline], [static]
```

Vector Multiply-Add Odd Unsigned Words.

##### Note

this implementation exists in [vec\\_int64\\_ppc::h::vec\\_vmaddouw\(\)](#) as it requires [vec\\_addudm\(\)](#).

### 7.9.6.23 `vec_vmsumuw()`

```
static vui64_t vec_vmsumuw (
 vui32_t a,
 vui32_t b,
 vui64_t c) [inline], [static]
```

Vector Multiply-Sum Unsigned Word Modulo.

#### Note

this implementation exists in `vec_int64_ppc::h::vec_vmsumuw()` as it requires `vec_addudm()`.

### 7.9.6.24 `vec_vmuleuw()`

```
static vui64_t vec_vmuleuw (
 vui32_t vra,
 vui32_t vrb) [inline], [static]
```

Vector Multiply Even Unsigned words.

Multiply the even words of two vector unsigned int values and return the unsigned long product of the even words.

For POWER8 and later we can use the vmuleuw instruction. But for POWER7 and earlier we have to construct word multiplies from two halfword multiplies (vmuleuh and vmulouh). Then sum the partial products for the final doubleword results. This is complicated by the fact that vector add doubleword is not available for POWER7. So we need to construct the doubleword add from Vector Add Unsigned Word Modulo (vadduwm) and Vector Add and Write Carry-Out Unsigned Word (vaddcuw) with shift double quadword to reposition the low word carry and a final vadduwm to complete the carry propagation for the doubleword add.

#### Note

This implementation is NOT endian sensitive and the function is stable across BE/LE implementations.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 7       | 2/cycle    |
| power9    | 7       | 2/cycle    |

#### Parameters

|                    |                              |
|--------------------|------------------------------|
| <i>vra</i>         | 128-bit vector unsigned int. |
| <i>vr</i> <i>b</i> | 128-bit vector unsigned int. |

**Returns**

vector unsigned long product of the even words of a and b.

**7.9.6.25 vec\_vmulouw()**

```
static vui64_t vec_vmulouw (
 vui32_t vra,
 vui32_t vrb) [inline], [static]
```

Vector Multiply Odd Unsigned Words.

Multiply the odd words of two vector unsigned int values and return the unsigned long product of the odd words.

For POWER8 and later we can use the vmulouw instruction. But for POWER7 and earlier we have to construct word multiplies from two halfword multiplies (vmuleuh and vmulouh). Then sum the partial products for the final doubleword results. This is complicated by the fact that vector add doubleword is not available for POWER7. So we need to construct the doubleword add from Vector Add Unsigned Word Modulo (vadduwm) and Vector Add and Write Carry-Out Unsigned Word (vaddcuw) with shift double quadword to reposition the low word carry and a final vadduwm to complete the carry propagation for the doubleword add.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 7       | 2/cycle    |
| power9    | 7       | 2/cycle    |

**Parameters**

|            |                              |
|------------|------------------------------|
| <i>vra</i> | 128-bit vector unsigned int. |
| <i>vrb</i> | 128-bit vector unsigned int. |

**Returns**

vector unsigned long product of the odd words of a and b.

**7.10 src/pveclib/vec\_int512\_ppc.h File Reference**

Header package containing a collection of multiple precision quadword integer computation functions implemented with 128-bit PowerISA VMX and VSX instructions.

```
#include <pveclib/vec_int128_ppc.h>
```

## Classes

- struct [\\_\\_VEC\\_U\\_256](#)  
A vector representation of a 256-bit unsigned integer.
- struct [\\_\\_VEC\\_U\\_512](#)  
A vector representation of a 512-bit unsigned integer.
- struct [\\_\\_VEC\\_U\\_640](#)  
A vector representation of a 640-bit unsigned integer.
- union [\\_\\_VEC\\_U\\_512x1](#)  
A vector representation of a 512-bit unsigned integer and a 128-bit carry-out.
- struct [\\_\\_VEC\\_U\\_1024](#)  
A vector representation of a 1024-bit unsigned integer.
- struct [\\_\\_VEC\\_U\\_1152](#)  
A vector representation of a 1152-bit unsigned integer.
- struct [\\_\\_VEC\\_U\\_2048](#)  
A vector representation of a 2048-bit unsigned integer.
- union [\\_\\_VEC\\_U\\_1024x512](#)  
A vector representation of a 1024-bit unsigned integer as two 512-bit fields.
- union [\\_\\_VEC\\_U\\_2048x512](#)  
A vector representation of a 2048-bit unsigned integer as 4 x 512-bit integer fields.
- struct [\\_\\_VEC\\_U\\_2176](#)  
A vector representation of a 2176-bit unsigned integer.
- struct [\\_\\_VEC\\_U\\_4096](#)  
A vector representation of a 4096-bit unsigned integer.
- union [\\_\\_VEC\\_U\\_4096x512](#)  
A vector representation of a 4096-bit unsigned integer as 8 x 512-bit integer fields.

## Macros

- #define [CONST\\_VINT512\\_Q](#)(\_\_q0, \_\_q1, \_\_q2, \_\_q3) {\_\_q3, \_\_q2, \_\_q1, \_\_q0}  
Generate a 512-bit vector unsigned integer constant from 4 x quadword constants.
- #define [COMPILE\\_FENCE](#) \_\_asm (";";:::)  
A compiler fence to prevent excessive code motion.
- #define [\\_\\_VEC\\_PWR\\_IMP](#)(FNAME) FNAME ## \_PWR7  
Macro to add platform suffix for static calls.

## Functions

- static [\\_\\_VEC\\_U\\_640 vec\\_add512cu](#) ([\\_\\_VEC\\_U\\_512](#) a, [\\_\\_VEC\\_U\\_512](#) b)  
Vector Add 512-bit Unsigned Integer & Write Carry.
- static [\\_\\_VEC\\_U\\_640 vec\\_add512ecu](#) ([\\_\\_VEC\\_U\\_512](#) a, [\\_\\_VEC\\_U\\_512](#) b, [vui128\\_t](#) c)  
Vector Add Extended 512-bit Unsigned Integer & Write Carry.
- static [\\_\\_VEC\\_U\\_512 vec\\_add512eum](#) ([\\_\\_VEC\\_U\\_512](#) a, [\\_\\_VEC\\_U\\_512](#) b, [vui128\\_t](#) c)  
Vector Add Extended 512-bit Unsigned Integer Modulo.
- static [\\_\\_VEC\\_U\\_512 vec\\_add512um](#) ([\\_\\_VEC\\_U\\_512](#) a, [\\_\\_VEC\\_U\\_512](#) b)  
Vector Add 512-bit Unsigned Integer Modulo.



- static `__VEC_U_512 vec_add512ze (__VEC_U_512 a, vui128_t c)`  
*Vector Add 512-bit to Zero Extended Unsigned Integer Modulo.*
- static `__VEC_U_512 vec_add512ze2 (__VEC_U_512 a, vui128_t c1, vui128_t c2)`  
*Vector Add 512-bit to Zero Extended2 Unsigned Integer Modulo.*
- static `__VEC_U_256 vec_mul128x128_inline (vui128_t a, vui128_t b)`  
*Vector 128x128bit Unsigned Integer Multiply.*
- static `__VEC_U_512 vec_mul256x256_inline (__VEC_U_256 m1, __VEC_U_256 m2)`  
*Vector 256x256-bit Unsigned Integer Multiply.*
- static `__VEC_U_640 vec_mul512x128_inline (__VEC_U_512 m1, vui128_t m2)`  
*Vector 512x128-bit Unsigned Integer Multiply.*
- static `__VEC_U_640 vec_madd512x128a128_inline (__VEC_U_512 m1, vui128_t m2, vui128_t a1)`  
*Vector 512x128-bit Multiply-Add Unsigned Integer.*
- static `__VEC_U_640 vec_madd512x128a512_inline (__VEC_U_512 m1, vui128_t m2, __VEC_U_512 a2)`  
*Vector 512x128-bit Multiply-Add Unsigned Integer.*
- static `__VEC_U_640 vec_madd512x128a128a512_inline (__VEC_U_512 m1, vui128_t m2, vui128_t a1, __VEC_U_512 a2)`  
*Vector 512x128-bit Multiply-Add Unsigned Integer.*
- static `__VEC_U_1024 vec_mul512x512_inline (__VEC_U_512 m1, __VEC_U_512 m2)`  
*Vector 512x512-bit Unsigned Integer Multiply.*
- static `__VEC_U_1024 vec_madd512x512a512_inline (__VEC_U_512 m1, __VEC_U_512 m2, __VEC_U_512 a1)`  
*Vector 512-bit Unsigned Integer Multiply-Add.*
- `__VEC_U_256 vec_mul128x128 (vui128_t m1, vui128_t m2)`  
*Vector 128x128bit Unsigned Integer Multiply.*
- `__VEC_U_512 vec_mul256x256 (__VEC_U_256 m1, __VEC_U_256 m2)`  
*Vector 256x256-bit Unsigned Integer Multiply.*
- `__VEC_U_640 vec_mul512x128 (__VEC_U_512 m1, vui128_t m2)`  
*Vector 512x128-bit Unsigned Integer Multiply.*
- `__VEC_U_640 vec_madd512x128a512 (__VEC_U_512 m1, vui128_t m2, __VEC_U_512 a2)`  
*Vector 512x128-bit Multiply-Add Unsigned Integer.*
- `__VEC_U_1024 vec_mul512x512 (__VEC_U_512 m1, __VEC_U_512 m2)`  
*Vector 512x512-bit Unsigned Integer Multiply.*
- void `vec_mul1024x1024 (__VEC_U_2048 *p2048, __VEC_U_1024 *m1, __VEC_U_1024 *m2)`  
*Vector 1024x1024-bit Unsigned Integer Multiply.*
- void `vec_mul2048x2048 (__VEC_U_4096 *p4096, __VEC_U_2048 *m1, __VEC_U_2048 *m2)`  
*Vector 2048x2048-bit Unsigned Integer Multiply.*
- void `vec_mul128_byMN (vui128_t *p, vui128_t *m1, vui128_t *m2, unsigned long M, unsigned long N)`  
*Vector Unsigned Integer Quadword MxN Multiply.*
- void `vec_mul512_byMN (__VEC_U_512 *p, __VEC_U_512 *m1, __VEC_U_512 *m2, unsigned long M, unsigned long N)`  
*Vector Unsigned Integer Quadword 4xMxN Multiply.*

### 7.10.1 Detailed Description

Header package containing a collection of multiple precision quadword integer computation functions implemented with 128-bit PowerISA VMX and VSX instructions.

PVECLIB [vec\\_int128\\_ppc.h](#) provides the 128x128-bit multiply and 128-bit add with carry/extend operations. This is most of what we need to implement multiple precision integer computation. This header builds on those operations to build 256x256, 512x128, 512x512, 1024x1024 and 2048x2048 multiplies. We also provide 512-bit add with carry/extend operations as a general aid to construct multiple quadword precision arithmetic.

We provide static inline implementations for up to 512x512 multiplies and 512x512 add with carry/extend. These in-line operations are provided as building blocks for coding implementations of larger multiply and sum operations. Otherwise the in-line code expansion is getting too large for normal coding. So we also provide callable (static and dynamic) library implementations as well ([Building libraries for vec\\_int512\\_ppc](#)).

### 7.10.2 Security related implications

The challenge is delivering a 2048x2048 bit multiply, producing a 4096-bit product, while minimizing cache and timing side-channel exploits. The goal is to minimize the memory visibility of intermediate products and sums and internal conditional logic (like early exit optimizations). The working theory is to use vector registers and operations and avoid storing intermediate results. This implies:

- While the final 4096-bit product is so large (32 quadwords), it requires a memory buffer for the result, we should not use any part of this buffer to hold intermediate partial sums.
- The 2048-bit multiplicands are also large (2 x 16 quadwords) and will be passed in memory buffers that are effectively constant.
- All intermediate partial products and sums should be held in vector registers (VSRs) until quadwords of the final product are computed and ready to store into the result buffer.
- Avoid conditional logic that effects function timing based on values of the inputs or results.
- Internally the code can be organized as straight line code or loops, in-line functions or calls to carefully crafted leaf functions, as long as the above goals are met.

Achieving these goals requires some knowledge of the Application Binary Interface (ABI) and foibles of the Instruction Set Architecture (PowerISA) and how they impact what the compiler can generate. The compiler itself has internal strategies (and foibles) that need to be managed as well.

#### 7.10.2.1 Implications of the ABI

The computation requires a number of internal temporary vectors in addition to the inputs and outputs. The Power Architecture, 64-Bit ELF V2 ABI Specification (AKA the ABI) places some generous but important restrictions on how the compiler generates code (and how compliant assembler code is written).

- Up to 20 volatile vector registers v0-v19 (VSRs vs32-vs51) of which 12 can be used for function arguments/return values.
  - Up to 12 vector arguments are passed in vector registers v2-v13 (VSRs vs34-vs45).

- Longer vector argument lists are forced into the callers parameter save area (Stack pointer +32).
- Functions can return a 128-bit vector value or a homogeneous aggregate of up to 8 vector values in vector registers v2-v9 (VSRs 34-41).
- Wider (8 x vectors) function return values are returned in memory via a reference pointer passed as a hidden parameter in GPR 3.
- Up to 12 additional non-volatile vector registers v20-v31 (vs51-vs63). Any non-volatile registers must be saved before use and restored before function return.
- The lower half for the VSRs (vs0-vs31) are prioritized for scalar floating-point operations. If a function is using vectors and but not scalar floating-point then the lower VSRs are available for vector logical and integer operations and temporary spill from vector registers.
  - Up to 14 volatile float double (f0-f13) or vector registers (vs0-vs13).
  - Up to 18 non-volatile float double (f14-f31) or vector registers (vs14-vs31).
- All volatile registers are a considered “clobbered” after a function call.
  - So the calling function must hold any local vector variables in memory or non-volatile registers if the live range extends across the function call.
  - In-lining the called function allows the compiler to manage register allocation across the whole sequence. This can reduce register pressure when the called function does not actually use/modify all the volatile registers.

#### 7.10.2.1.1 Implications for parameter passing and Product size

Care is required in selecting the width (256, 512-bit etc) of parameter and return values. Parameters totaling more than 12 vector quadwords or return values totaling more than 8 vector quadwords will be spilled to the callers parameter save area. This may expose intermediate partial products to cache side-channel attacks. A 512x128-bit multiply returning a 640-bit product and a 512x512-bit multiply returning a 1024-bit product meets this criteria (both the parameters and return values fit within the ABI limits). But a 1024x128-bit multiply returning 1152-bits is not OK because the 1152-bit return value requires 9 vector registers, which will be returned in memory.

Also if any of these sub-functions are used without in-lining, the generated code must be inspected to insure it is not spilling any local variables. In my experiments with GCC 8.1 the 128x128, 256x256, and 512x128 multiplies all avoid spilling. However the stand-alone 512x512 implementation does require saving 3 non-volatile registers. This can be eliminated by in-lining the 512x512 multiply into the 2048x2048 multiply function.

#### Note

GCC compilers before version 8 have an incomplete design for homogeneous aggregates of vectors and may generate sub-optimal code for these parameters.

#### 7.10.2.2 Implications of the PowerISA

The Power Instruction Set Architecture (PowerISA) also imposes some restriction on the registers vector instructions can access.

- The original VMX (AKA AltiVec) facility has 32 vector registers and instruction encoding to access those 32 registers.
  - This original instruction set was incorporated unchanged into the later versions of the PowerISA.

- When Vector Scalar Extended facility was added, the original VMX instructions were restricted to the upper 32 VSRs (original vector registers).
- VSX was originally focused on vector and scalar floating-point operations. With a handful of vector logical/permute/splat operations added for completeness. These instructions were encoded to access all 64 VSRs.
  - All vector integer arithmetic operations remained restricted to the upper 32 VSRs (the original VRs).
  - Later versions of the PowerISA (POWER8/9) added new vector integer arithmetic operations. This includes word/doubleword multiply and doubleword/quadword add/subtract. But these are also encoded to access only 32 vector registers.
  - The lower VSRs can still be used to hold temporaries and local variables for vector integer operations.

### 7.10.2.3 Implications for the compiler

The compiler has to find a path through the ABI and ISA restriction above while it performs:

- function in-lining
- instruction selection
- instruction scheduling
- register allocation

For operations defined in PVECLIB, most operations are defined in terms of Altivec/VSX Built-in Functions. So the compiler does not get much choice for instruction selection. The PVECLIB coding style does leverage C language vector extensions to load constants and manage temporary variables. Using compiler Altivec/VSX built-ins and vector extensions allows the compiler visibility to and control of these optimizations.

Internal function calls effectively *clobber* all (32 VSRs) volatile registers. As the compiler marshals parameters into ABI prescribed VRs it needs to preserve previous live content for later computation. Similarly for volatile registers not used for parameter passing as they are assumed to be clobbered by the called function. The compiler preserves local live variables before the call by copying their contents to non-volatile registers or spilling to memory. This may put more *register pressure* on the available non-volatile registers. Small to medium sized functions often require only a fraction of the available volatile registers. In this case, in-lining the function avoids the disruptive volatile register clobber and allows better overall register allocation. So there is a strong incentive to in-line local/static functions.

These compiler optimizations are not independent processes. For example specific VSX instruction can access all 64 VSRs, others are restricted to the 32 VRs (like vector integer instructions). So the compiler prioritizes VRs (the higher 32 VSRs) for allocation to vector integer computation. While the lower 32 VSRs can be used for logical/permute operations and as a *level 1* spill area for VRs. These restrictions combined with code size/complexity can increase *register pressure* to the point the compiler is forced to spill active (or live) vector registers to secondary storage. This secondary storage can be:

- other architected registers that are available for direct transfer but not usable in the computation.
- Local variables allocated on the stack
- Compiler temporaries allocated on the stack.

Instruction scheduling can increase register pressure by moving (reordering) instructions. This is more prevalent when there are large differences in instruction latency in the code stream. For example moving independent / long latency instructions earlier and dependent / short latency instructions later. This tends to increase the distance between the instruction that sets a register result and the next instruction the uses that result in its computation. The distance between a registers set and use is called the *live range*. This also tends to increase the number of concurrently active and overlapping live ranges.

For this specific (multi-precision integer multiply) example, integer multiple and add/carry/extend instructions predominate. For POWER9, vector integer multiply instructions run 7 cycles, while integer add/carry/extend quadword instruction run 3 cycles. The compiler will want to move the independent multiply instructions earlier while the dependent add/carry instructions are moved later until the latency of the (multiply) instruction (on which it depends) is satisfied. Moving dependent instructions apart and moving independent instructions into the scheduling gap increases register pressure.

In extreme cases, this can get out of hand. At high optimization levels, the compiler can push instruction scheduling to the point that it runs out of registers. This forces the compiler to spill live register values, splitting the live range into two smaller live ranges. Any spilled values have to be reloaded later so they can be used in computation. This causes the compiler to generate more instructions that need additional register allocation and scheduling.

#### Note

A 2048x2048-bit multiply is definitely an extreme case. The implementation requires 256 128x128-bit multiplies, where each 128x128-bit multiply requires 18-30 instructions. The POWER9 implementation requires 1024 vector doubleword multiplies plus 2400+ vector add/carry/extend quadword instructions. When implemented as straight line code and expanded in-line (*attribute (flatten)*) the total runs over 6000 instructions.

Compiler spill code usually needs registers in addition (perhaps of a different class) to the registers being spilled. This can be as simple as moving to a register of the same size but different class. For example, register moves to/from VRs and the lower 32 VSRs. But it gets more complex when spilling vector registers to memory. For example, vector register spill code needs GPRs to compute stack addresses for vector load/store instructions. Normally this is OK, unless the spill code consumes so many GPRs that it needs to spill GPRs. In that case we can see serious performance bottlenecks.

But remember that a primary goal ([Security related implications](#)) was to avoid spilling intermediate results to memory. Spilling between high and low VSRs is acceptable (no cache side-channel), but spilling to memory must be avoided. The compiler should have heuristics to back off in-lining and scheduling-driven code motions just enough to avoid negative performance impacts. But this is difficult to model and may not handle all cases with equal grace. Also this may not prevent spilling VRs to memory if the compiler scheduler's cost computation indicates that is an acceptable trade-off.

So we will have to directly override compiler settings and heuristics to guarantee the result we want/need. The PVECLIB implementation already marks most operations as **static inline**. But as we use these inline operations as building blocks to implement larger operations we can push the resulting code size over the compiler's default inline limits (**-finline-limit**). Then compiler will stop in-lining for the duration of compiling the current function.

This may require stronger options/attributes to the compiler like (*attribute (always\_inline)*), (*attribute (gnu\_inline)*), or (*attribute (flatten)*). The first two are not any help unless you are compiling at lower optimization level (**-O0** or **-O1**). **-O2** defaults to **-finline-small-functions** and **-O3** defaults to the stronger **-finline-functions**. However *attribute (flatten)* seems to do exactly what we want. Every call inside this function is in-lined unless explicitly told not to (*attribute (noinline)*). It seems that *attribute (flatten)* ignores the **-finline-limit**.

## Note

You should be compiling PVECLIB applications at **-O3** anyway.

Now we have a large block of code for the compiler's instruction scheduler to work on. In this case the code is very repetitive (multiply, add the column, generate carries, repeat). The instruction will have lots of opportunity for scheduling long vs short latency instructions and create new and longer live ranges.

/note In fact after applying *attribute (flatten)* to `vec_mul2048x2048_PWR9` we see a lot of spill code. This expands the code to over 9300 instructions with ~3300 instructions associated with spill code.

We need a mechanism to limit (set boundaries) on code motion while preserving optimization over smaller blocks of code. This is normally called a *compiler fence* but there are multiple definitions so we need to be careful what we use.

We want something that will prevent the compiler from moving instructions (in either direction) across specified *lines in the code*.

We don't need an atomic memory fence (like `__atomic_thread_fence` or `__sync_synchronize`) that forces the processor to order loads and stores relative to a specific synchronization point.

We don't need a compiler memory fence (like `asm ("" ::: "memory")`). The "memory" clobber forces GCC to assume that any memory may be arbitrarily read or written by the asm block. So any registers holding live local variables will be forced to memory before and need to be reloaded after. This prevents the compiler from reordering loads, stores, and arithmetic operations across it, but does not prevent the processor from reordering them.

## Note

POWER process have an aggressively *Speculative Superscalar* design with out-of-order issue and execution.

Neither of the above are what we want for this case. We specifically want to avoid memory side effects in this computation. We only need the minimal compiler fence (like `asm (";" :::)`) that prevents the compiler from reordering any code across it but does not prevent the processor from reordering them.

By placing this compiler fence between multiply/sum stages of `vec_mul512x128_inline()`, `vec_mul512x512_inline()` and `vec_mul2048x2048()` we limit instruction scheduling and code motion to smaller code blocks. This in turn reduces register pressure to the point where all 64 VSRs are in use, but no spilling to stack memory is required.

## 7.10.2.4 So what does this all mean?

The 2048x2048 multiplicands and the resulting product are so large (8192-bits, 64 quadwords total) that at the outer most function the inputs and the result must be in memory and passed by reference. The implementation of a 2048x2048-bit multiply requires 256 128x128-bit multiplies. Otherwise the code can be organized into sub-functions generating intermediate partial products and sums.

Coding 256 128x128 products and generating column sums would be tedious. One approach builds up products into larger and larger blocks in stages. For example code a `vec_mul512x128_inline()` operation then use that in the implementation of `vec_mul512x512_inline()`. We also provide 512-bit add/carry/extend operations to simplify generating sums of 512-bit partial products. Then load blocks of 512-bits (4 quadwords, 64-bytes) using `vec_mul512x512_inline()` to produce a 1024-bit partial product ([Implications for parameter passing and Product size](#)).

Then multiply the 512-bit blocks across one 2048-bit (4 x 512-bit) multiplicand. The completion of a 2048x512-bit partial product (of 2560-bits) includes the low order 512-bits ready to store to the output operand. Repeat for each 512-bit block of the other 2048-bit multiplicand summing across the 512-bit columns. The final sum, after the final 2048x512 partial product, produces the high order 2048-bits of the 2048x2048 product ready to store to the output operand.

#### Note

Security aware implementations could use masking countermeasures associated with these load/store operations. The base PVECLIB implementation does not do this. The source is available in `./src/vec_int512_runtime.c`.

It is best if the sub-functions code can be fully in-lined into the 2048x2048-bit multiply or the sub-functions are carefully written. In this case these sub-functions should be leaf-functions (does not call other functions) and can execute without spilling register state or requiring stored (by reference) parameters.

All levels of implementation should avoid conditional logic based on values of inputs or partial products (For example early exits for leading or trailing zero quadwords). Doing so may expose the multiply function to timing side-channel attacks. So the best case would be one large function implemented as straight-line code.

We will need all 64 VSX registers for operations and local variables. So the outer function will need to allocate a stack-frame and save all of the non-volatile floating point registers (allowing the use of vs14-vs31 for local vector variables) and vector registers (v20-v31 AKA vs51-vs63) on entry. This frees up (18+12=) 30 additional quadword registers for local vector variables within the outer multiply function.

These saved registers reflect the state of the calling (or higher) function and may not have any crypto sensitive content. These register save areas will not be updated with internal state from the 2048x2048-bit multiply operation itself.

The 128x128-bit vector multiply is implemented with Vector Multiply-Sum Unsigned Doubleword Modulo for Power9 and Vector Multiply Even/Odd Unsigned Word for Power8. The timing for vector integer multiply operations are fixed at 7 cycles latency for Power8/9. The sums of partial products are implemented with Vector Add Unsigned Quadword Modulo/write-Carry/Extended. The timing of integer add quadword operations are fixed at 4 cycles for Power8 and 3 cycles for Power9. The rest of the 128x128-bit multiply operation is a combination of Vector Doubleword Permute Immediate, Vector Shift Left Double by Octet Immediate, Vector Splats, and Vector Logical Or (used as a vector register move spanning the 64 VSRs). All of these have fixed timings of 2 or 3 cycles.

So the overall timing of the 2048x2048-bit multiply should be consistent independent of input values. The only measurable variations would be as the processor changes Simultaneous Multithreading (SMT) modes (controlled by the virtual machine and kernel). The SMT mode (1,2,4,8) controls each hardware thread's priority to issue instructions to the core and if the instruction stream is dual or single issue (from that thread's perspective).

But the better news is that with some extra function attributes (`always_inline` and `flatten`) the entire 2048x2048 multiply function can be flattened into a single function of straight line code (no internal function calls or conditional branches) running ~6.3K instructions. And no spill code was generated for local variables (no register spill within the function body).

### 7.10.3 Endian for Multi-quadword precision operations

As described in [General Endian Issues](#) and [Endian problems with quadword implementations](#) supporting both big and little endian in a single implementation has its challenges. But I think we can leave the details of quadword operations to the `vec_int128_ppc.h` implementation. The decision needed for these implementations is how the quadwords of a multi-quadword integer are ordered in storage. For example given an array or structure of 16 quadwords representing a single 2048-bit binary number which quadword contains the low order bits and which the high order bits.

This is largely arbitrary and independent from the system endian. But we should be consistent within the API defined by this header and PVECLIB as a whole. Placing the low order bits in the first (lowest address in memory) quadword and the high order bits in last (highest address in memory) quadword would be consistent with little endian. While placing the high order bits in the first (lowest address in memory) quadword and the low order bits in last (highest address in memory) quadword would be consistent with big endian. Either is valid internal to the implementation where the key

issue is accessing the quadwords of the multiplicands in a convenient order to generate the partial products in an order that support efficient generation of column sums and carries.

It is best for the API if the order of quadwords in multi-quadword integers match the endian of the platform. This should be helpful where we want to use the PVECLIB implementations under existing APIs using arrays of smaller integer types.

So on powerpc64le systems the low order quadword is the first quadword. While on older powerpc64 systems the high order quadword is the first quadword. For example we can represent a 512-bit integer with the following structure.

```
typedef struct
{
 #if __BYTE_ORDER__ == __ORDER_LITTLE_ENDIAN__
 vui128_t vx0;
 vui128_t vx1;
 vui128_t vx2;
 vui128_t vx3;
 #else
 vui128_t vx3;
 vui128_t vx2;
 vui128_t vx1;
 vui128_t vx0;
 #endif
} __VEC_U_512;
```

In this example the field vx0 is always the low order quadword and vx3 is always the high order quadword, independent of endian. We repeat this pattern for the range of multi-quadword integer sizes (from [\\_\\_VEC\\_U\\_256](#) to [\\_\\_VEC\\_U\\_4096](#)) supported by this header. In each case the field name vx0 is consistently the low order quadword. The field name suffix numbering continues from low to high with the highest numbered field name being the high order quadword.

### 7.10.3.1 Multi-quadword Integer Constants

As we have seen, initializing larger multiple precision constants can be challenging ([Quadword Integer Constants](#)). The good news we can continue to use aggregate initializers for structures and arrays of vector quadwords. For example:

```
const __VEC_U_512 vec512_one =
{
 (vui128_t) ((unsigned __int128) 0x00000000),
 (vui128_t) ((unsigned __int128) 0x00000000),
 (vui128_t) ((unsigned __int128) 0x00000000),
 (vui128_t) ((unsigned __int128) 0x00000001)
};
```

This example is in the expected high to low order for the 512-bit constant 1. Unfortunately endian raises its ugly head again and this would have a different value on a little endian platform.

So PVECLIB provides another helper macro ([CONST\\_VINT512\\_Q\(\)](#)) to provide a consistent numerical order for multiple quadword constants. For example:

```
const __VEC_U_512 vec512_one = CONST_VINT512_Q
(
 (vui128_t) ((unsigned __int128) 0x00000000),
 (vui128_t) ((unsigned __int128) 0x00000000),
 (vui128_t) ((unsigned __int128) 0x00000000),
 (vui128_t) ((unsigned __int128) 0x00000001)
);
```



and

```
// const for 10**128
const __VEC_U_512 vec512_ten128th = CONST_VINT512_Q
(
 CONST_VUINT128_QxW (0x00000000, 0x00000000, 0x0000024e, 0xe91f2603),
 CONST_VUINT128_QxW (0xa6337f19, 0xbccdb0da, 0xc404dc08, 0xd3cff5ec),
 CONST_VUINT128_QxW (0x2374e42f, 0x0f1538fd, 0x03df9909, 0x2e953e01),
 CONST_VUINT128_QxW (0x00000000, 0x00000000, 0x00000000, 0x00000000)
);
```

Unfortunately the compiler can not help with multi-quadword decimal constants. So we must resort to external tools like **bc** to compute large constant values and convert them to hexadecimal which are easier to break into words and doubleword. These can then be used as constants in program source to represent arbitrarily large binary values.

#### 7.10.4 Building libraries for vec\_int512\_ppc

See also

[Putting the Library into PVECLIB](#)

Many of the implementations associated with 512-bit integer operations are uncomfortably large to expand as in-line code (Examples include [vec\\_mul512x512\(\)](#), [vec\\_mul1024x1024\(\)](#), and [vec\\_mul2048x2048\(\)](#)). It is better to collect these large implementations in separately compiled run-time libraries. Another consideration is that most of these operations are multiple quadword multiplies and the optimum quadword multiply is processor (and PowerISA version) dependent. This is especially true for Vector integer multiplies across POWER7-POWER9.

This places requirements on the structure of runtime implementation codes and the library build process.

- Building a set of source implementations for multiple compile (-mcpu=) targets.
- Providing unique function names based on the operation and the compile target.
- Providing static (archive) and dynamic (DSO) libraries, while adjusting the the compile options appropriately for each.
  - Objects compiled for inclusion in dynamic libraries should be position independent code (i.e. compiled with -fpic or -fPIC).
  - DSOs supporting operations optimized for multiple compile (-mcpu=) targets need to export matching [IF↔UNC](#) symbols and resolver stubs.

For the first requirement we can collect the runtime implementations for vec\_int512\_ppc in to a single source file (vec↔\_int512\_runtime.c). The build system can then collect this and other runtime source files to compile for different targets. This can be as simple as:

```
// \file vec_runtime_PWR9.c
#include "vec_int512_runtime.c"
...
```

and similarly for `vec_runtime_PWR7.c` and `vec_runtime_PWR8.c`.

As the implementation of `vec_int512_ppc.c` is already leveraging `_ARCH_PWR7/8/9` tuned static inline operations from `vec_int512_ppc.h`, `vec_int128_ppc.h`, etc, all we need to do is apply the appropriate `-mcpu=power7/8/9` compile option to each (target qualified) runtime source file.

The second requirement is addressed by applying a target qualifying suffix to each runtime function implementation. Here we use the `__VEC_PWR_IMP()` as function name wrapper macro.

```
#ifdef _ARCH_PWR9
#define __VEC_PWR_IMP(FNAME) FNAME ## _PWR9
#else
#ifdef _ARCH_PWR8
#define __VEC_PWR_IMP(FNAME) FNAME ## _PWR8
#else
#define __VEC_PWR_IMP(FNAME) FNAME ## _PWR7
#endif
#endif
#endif
```

We need to apply the name wrapper to both the functions extern (in `vec_int512_ppc.h`) and the function implementation (in `vec_int512_runtime.c`). For example:

```
// \file vec_int512_ppc.h
...
extern __VEC_U_256
__VEC_PWR_IMP(vec_mul128x128) (vui128_t m11,
 vui128_t m21);
...
```

#### Note

Doxygen does not tolerate attributes or macros in function prototypes. So these externs are guarded by a `@cond INTERNAL ... @endcond` block. The `\brief` and `@param` descriptions are provided for the unqualified dynamic function symbol and apply to the corresponding qualified function symbols.

```
// \file vec_int512_runtime.c
#include <altivec.h>
#include <pveclib/vec_int128_ppc.h>
#include <pveclib/vec_int512_ppc.h>
...
// vec_mul128x128_inline is defined in vec_int512_ppc.h
__VEC_U_256
__VEC_PWR_IMP(vec_mul128x128) (vui128_t m11,
 vui128_t m21)
{
 return vec_mul128x128_inline(m11, m21);
}
```

This ensures that target specific runtime implementations have unique function symbols. This is important to avoid linker errors (due to duplicate symbol names).

#### Note

Each runtime operation will have 2 or 3 target qualified implementations. This is times 2 with separate builds for static archives and dynamic (DSO) libraries. The big endian powerpc64 platform supports 3 VSX enabled targets `-mcpu=[power7|power8|power9]`. The little endian powerpc64le platform currently supports 2 VSX enabled targets `-mcpu=[power8|power9]`. POWER7 is not supported for powerpc64le and the `vec_runtime_PWR7.c` source files are conditionally nulled out for powerpc64le targets. As new POWER processors are released, additional targets will be added.

#### 7.10.4.1 Static linkage to platform specific functions

For static linkage the application is compiled for a specific platform target (via `-mcpu=`). So function calls should be bound to the matching platform specific implementations. The application may select the platform specific function directly by defining a *extern* and invoking the platform qualified function.

For applications binding to PVECLIB via static archives it is convenient to apply the `__VEC_PWR_IMP()` wrapper to the function call:

```
k = __VEC_PWR_IMP (vec_mul128x128) (i, j);
```

The function call symbol picks up the target suffix based on the compile target (`-mcpu=`) for the application (see [Static linkage to platform specific functions](#)). The linker will extract the matching implementations from the PVECLIB archive and (statically) bind them with the application. This simplifies binding the application to the matching target specific implementations.

#### 7.10.4.2 Dynamic linkage to platform specific functions

For applications binding to dynamic libraries, the target qualified naming strategy also simplifies the implementation of IFUNC resolvers for the DSO library (see [Building dynamic runtime libraries](#)). Here the target qualified names of the PIC implementations are known to the corresponding resolver function but are not exported from the DSO. Allowing the application to bind to the target qualified names would defeat the automatic selection of target optimized implementations.

Applications using dynamic linkage will call the unqualified function symbol. For example:

```
// \file vec_int512_ppc.h
...
extern __VEC_U_256
vec_mul128x128 (vu128_t, vu128_t);
```

This symbol's implementation has a special **STT\_GNU\_IFUNC** attribute recognized by the dynamic linker. This attribute associates this symbol with the corresponding runtime resolver function. So in addition to any platform specific implementations we need to provide the resolver function referenced by the *IFUNC* symbol. For example:

```
// \file vec_runtime_DYN.c
...
extern __VEC_U_256
vec_mul128x128_PWR7 (vu128_t, vu128_t);

extern __VEC_U_256
vec_mul128x128_PWR8 (vu128_t, vu128_t);

extern __VEC_U_256
vec_mul128x128_PWR9 (vu128_t, vu128_t);

static __VEC_U_256
(*resolve_vec_mul128x128 (void)) (vu128_t, vu128_t)
{
#ifdef __BUILTIN_CPU_SUPPORTS__
 if (__builtin_cpu_is ("power9"))
 return vec_mul128x128_PWR9;
 else
 {
 if (__builtin_cpu_is ("power8"))
 return vec_mul128x128_PWR8;
 else
 return vec_mul128x128_PWR7;
 }
#else // ! __BUILTIN_CPU_SUPPORTS__
 return vec_mul128x128_PWR7;
#endif
}

__VEC_U_256
vec_mul128x128 (vu128_t, vu128_t)
__attribute__ ((ifunc ("resolve_vec_mul128x128")));
```

On the program's first call to a *IFUNC* symbol, the dynamic linker calls the resolver function associated with that symbol. The resolver function performs a runtime check to determine the platform, selects the (closest) matching platform specific function, then returns that functions address to the dynamic linker.

The dynamic linker stores this function address in the callers Procedure Linkage Tables (PLT) before forwarding the call to the resolved implementation. Any subsequent calls to this function symbol branch (via the PLT) directly to appropriate platform specific implementation.

#### Note

The operation `vec_mul128x128()` has multiple implementations and names. It has a static inline implementation `vec_mul128x128_inline()`. This uses the static inline `vec_muludq()` from `_vec_int128_ppc.h` but returns the 256-bit result as a single struct `__VEC_U_256`. It has a number (currently 2 or 3) of target qualified extern declarations and static implementations for static linkage. And it has a unqualified extern declaration and IFUNC attributed symbol associated with its resolver for dynamic linkage.

**Todo** Currently the dynamic resolvers and *IFUNC* symbols for `vec_int512_runtime.c` are contained within `vec_runtime_↵_DYN.c`. As the list of runtime operations expands to other element sizes/types, `vec_runtime_DYN.c` should be refactored into multiple files.

## 7.10.5 Macro Definition Documentation

### 7.10.5.1 COMPILE\_FENCE

```
#define COMPILE_FENCE __asm (";":::)
```

A compiler fence to prevent excessive code motion.

We use the `COMPILER_FENCE` to limit instruction scheduling and code motion to smaller code blocks. This in turn reduces register pressure and avoids generating spill code.

### 7.10.5.2 CONST\_VINT512\_Q

```
#define CONST_VINT512_Q(
 __q0,
 __q1,
 __q2,
 __q3) {__q3, __q2, __q1, __q0}
```

Generate a 512-bit vector unsigned integer constant from 4 x quadword constants.

Combine 4 x quadwords constants into a 512-bit `__VEC_U_512` constant. The 4 parameters are quadword integer constant values in high to low order. For example:

```
// 512-bit integer constant for 10**128
const __VEC_U_512 vec512_ten128th = CONST_VINT512_Q(
 (
 CONST_VUINT128_QxW (0x00000000, 0x00000000, 0x0000024e, 0xe91f2603),
 CONST_VUINT128_QxW (0xa6337f19, 0xbccdb0da, 0xc404dc08, 0xd3cff5ec),
 CONST_VUINT128_QxW (0x2374e42f, 0x0f1538fd, 0x03df9909, 0x2e953e01),
 CONST_VUINT128_QxW (0x00000000, 0x00000000, 0x00000000, 0x00000000)
)
);
```

### 7.10.6 Function Documentation

#### 7.10.6.1 vec\_add512cu()

```
static __VEC_U_640 vec_add512cu (
 __VEC_U_512 a,
 __VEC_U_512 b) [inline], [static]
```

Vector Add 512-bit Unsigned Integer & Write Carry.

Compute the 512 bit sum of two 512 bit values a, b and produce the carry. The sum (with-carry) is returned as single 640-bit integer in a homogeneous aggregate structure.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 16      | 1/cycle    |
| power9    | 12      | 1/cycle    |

#### Parameters

|          |                                                      |
|----------|------------------------------------------------------|
| <i>a</i> | vector representation of a unsigned 512-bit integer. |
| <i>b</i> | vector representation of a unsigned 512-bit integer. |

#### Returns

homogeneous aggregate representation of the unsigned 640-bit sum of a + b.

#### 7.10.6.2 vec\_add512ecu()

```
static __VEC_U_640 vec_add512ecu (
 __VEC_U_512 a,
 __VEC_U_512 b,
 vui128_t c) [inline], [static]
```

Vector Add Extended 512-bit Unsigned Integer & Write Carry.

Compute the 512 bit sum of two 512 bit values a, b and 1 bit value carry-in value c. Produce the carry out of the high order bit of the sum. The sum (with-carry) is returned as single 640-bit integer in a homogeneous aggregate structure.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 16      | 1/cycle    |
| power9    | 12      | 1/cycle    |

**Parameters**

|          |                                                      |
|----------|------------------------------------------------------|
| <i>a</i> | vector representation of a unsigned 512-bit integer. |
| <i>b</i> | vector representation of a unsigned 512-bit integer. |
| <i>c</i> | vector representation of a unsigned 1-bit carry.     |

**Returns**

homogeneous aggregate representation of the unsigned 640-bit sum of  $a + b + c$ .

**7.10.6.3 vec\_add512eum()**

```
static __VEC_U_512 vec_add512eum (
 __VEC_U_512 a,
 __VEC_U_512 b,
 vui128_t c) [inline], [static]
```

Vector Add Extended 512-bit Unsigned Integer Modulo.

Compute the 512 bit sum of two 512 bit values *a*, *b* and 1 bit value carry-in value *c*. The sum is returned as single 512-bit integer in a homogeneous aggregate structure. Any carry-out of the high order bit of the sum is lost.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 16      | 1/cycle    |
| power9    | 12      | 1/cycle    |

**Parameters**

|          |                                                      |
|----------|------------------------------------------------------|
| <i>a</i> | vector representation of a unsigned 512-bit integer. |
| <i>b</i> | vector representation of a unsigned 512-bit integer. |
| <i>c</i> | vector representation of a unsigned 1-bit carry.     |

**Returns**

homogeneous aggregate representation of the unsigned 512-bit sum of  $a + b + c$ .

**7.10.6.4 vec\_add512um()**

```
static __VEC_U_512 vec_add512um (
 __VEC_U_512 a,
 __VEC_U_512 b) [inline], [static]
```

Vector Add 512-bit Unsigned Integer Modulo.

Compute the 512 bit sum of two 512 bit values a, b. The sum is returned as single 512-bit integer in a homogeneous aggregate structure. Any carry-out of the high order bit of the sum is lost.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 16      | 1/cycle    |
| power9    | 12      | 1/cycle    |

#### Parameters

|          |                                                      |
|----------|------------------------------------------------------|
| <i>a</i> | vector representation of a unsigned 512-bit integer. |
| <i>b</i> | vector representation of a unsigned 512-bit integer. |

#### Returns

homogeneous aggregate representation of the unsigned 512-bit sum of a + b.

#### 7.10.6.5 vec\_add512ze()

```
static __VEC_U_512 vec_add512ze (
 __VEC_U_512 a,
 vui128_t c) [inline], [static]
```

Vector Add 512-bit to Zero Extended Unsigned Integer Modulo.

The carry-in is zero extended to the left before computing the 512-bit sum a + c. The sum is returned as single 512-bit integer in a homogeneous aggregate structure. Any carry-out of the high order bit of the sum is lost.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 16      | 1/cycle    |
| power9    | 12      | 1/cycle    |

#### Parameters

|          |                                                      |
|----------|------------------------------------------------------|
| <i>a</i> | vector representation of a unsigned 512-bit integer. |
| <i>c</i> | vector representation of a unsigned 1-bit carry.     |

#### Returns

homogeneous aggregate representation of the unsigned 512-bit sum of a + c.

### 7.10.6.6 `vec_add512ze2()`

```
static __VEC_U_512 vec_add512ze2 (
 __VEC_U_512 a,
 vui128_t c1,
 vui128_t c2) [inline], [static]
```

Vector Add 512-bit to Zero Extended2 Unsigned Integer Modulo.

The two carry-ins are zero extended to the left before Computing the 512 bit sum  $a + c1 + c2$ . The sum is returned as single 512-bit integer in a homogeneous aggregate structure. Any carry-out of the high order bit of the sum is lost.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 16      | 1/cycle    |
| power9    | 12      | 1/cycle    |

#### Parameters

|           |                                                      |
|-----------|------------------------------------------------------|
| <i>a</i>  | vector representation of a unsigned 512-bit integer. |
| <i>c1</i> | vector representation of a unsigned 1-bit carry.     |
| <i>c2</i> | vector representation of a unsigned 1-bit carry.     |

#### Returns

homogeneous aggregate representation of the unsigned 512-bit sum of  $a + c1 + c2$ .

### 7.10.6.7 `vec_madd512x128a128_inline()`

```
static __VEC_U_640 vec_madd512x128a128_inline (
 __VEC_U_512 m1,
 vui128_t m2,
 vui128_t a1) [inline], [static]
```

Vector 512x128-bit Multiply-Add Unsigned Integer.

Compute the 640 bit sum of 512 bit value *m1* and 128-bit value *m2* plus 128-bit value *a1*. The product is returned as single 640-bit integer in a homogeneous aggregate structure.

#### Note

The advantage of this form is that the final 640 bit sum can not overflow and carries between stages are eliminated. Also applying the addend early (1st multiply stage) reduces the live ranges for registers passing partial products for larger multiple precision multiplies.

We use the `COMPILER_FENCE` to limit instruction scheduling and code motion to smaller code blocks. This in turn reduces register pressure and avoids generating spill code.



| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 224-232 | 1/cycle    |
| power9    | 132-135 | 1/cycle    |

**Parameters**

|           |                                                      |
|-----------|------------------------------------------------------|
| <i>m1</i> | vector representation of a unsigned 512-bit integer. |
| <i>m2</i> | vector representation of a unsigned 128-bit integer. |
| <i>a1</i> | vector representation of a unsigned 128-bit integer. |

**Returns**

homogeneous aggregate representation of the unsigned 640-bit sum of  $(m1 * m2) + c$ .

**7.10.6.8 vec\_madd512x128a128a512\_inline()**

```
static __VEC_U_640 vec_madd512x128a128a512_inline (
 __VEC_U_512 m1,
 vuil28_t m2,
 vuil28_t a1,
 __VEC_U_512 a2) [inline], [static]
```

Vector 512x128-bit Multiply-Add Unsigned Integer.

Compute the 640 bit sum of 512 bit value m1 and 128-bit value m2, plus 128-bit value a1, plus 512-bit value a2. The sum is returned as single 640-bit integer in a homogeneous aggregate structure.

**Note**

The advantage of this form is that the final 640 bit sum can not overflow and carries between stages are eliminated. Also applying the addend early (1st multiply stage) reduces the live ranges for registers passing partial products for larger multiple precision multiplies.

We use the COMPILER\_FENCE to limit instruction scheduling and code motion to smaller code blocks. This in turn reduces register pressure and avoids generating spill code.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 224-232 | 1/cycle    |
| power9    | 132-135 | 1/cycle    |

**Parameters**

|           |                                                      |
|-----------|------------------------------------------------------|
| <i>m1</i> | vector representation of a unsigned 512-bit integer. |
| <i>m2</i> | vector representation of a unsigned 128-bit integer. |

**Parameters**

|           |                                                      |
|-----------|------------------------------------------------------|
| <i>a1</i> | vector representation of a unsigned 128-bit integer. |
| <i>a2</i> | vector representation of a unsigned 512-bit integer. |

**Returns**

homogeneous aggregate representation of the unsigned 640-bit sum of  $(m1 * m2) + a1 + a2$ .

**7.10.6.9 vec\_madd512x128a512()**

```
__VEC_U_640 vec_madd512x128a512 (
 __VEC_U_512 m1,
 vui128_t m2,
 __VEC_U_512 a2)
```

Vector 512x128-bit Multiply-Add Unsigned Integer.

Compute the 640 bit sum of the product of the 512 bit value m1 and 128-bit value m2 plus the 512-bit value a2. The sum is returned as single 640-bit integer in a homogeneous aggregate structure.

**Note**

The advantage of this form is that the final 640 bit sum can not overflow and carries between stages are eliminated. Also applying the addend early (1st multiply stage) reduces the live ranges for registers passing partial products for larger multiple precision multiplies.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 224-232 | 1/cycle    |
| power9    | 132-135 | 1/cycle    |

**Parameters**

|           |                                                      |
|-----------|------------------------------------------------------|
| <i>m1</i> | vector representation of a unsigned 512-bit integer. |
| <i>m2</i> | vector representation of a unsigned 128-bit integer. |
| <i>a2</i> | vector representation of a unsigned 512-bit integer. |

**Returns**

homogeneous aggregate representation of the unsigned 640-bit sum of  $(m1 * m2) + a2$ .

## 7.10.6.10 vec\_madd512x128a512\_inline()

```
static __VEC_U_640 vec_madd512x128a512_inline (
 __VEC_U_512 m1,
 vui128_t m2,
 __VEC_U_512 a2) [inline], [static]
```

Vector 512x128-bit Multiply-Add Unsigned Integer.

Compute the 640 bit sum of 512 bit value m1 and 128-bit value m2 plus 512-bit value a2. The sum is returned as single 640-bit integer in a homogeneous aggregate structure.

**Note**

The advantage of this form is that the final 640 bit sum can not overflow and carries between stages are eliminated. Also applying the addend early (1st multiply stage) reduces the live ranges for registers passing partial products for larger multiple precision multiplies.

We use the COMPILER\_FENCE to limit instruction scheduling and code motion to smaller code blocks. This in turn reduces register pressure and avoids generating spill code.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 224-232 | 1/cycle    |
| power9    | 132-135 | 1/cycle    |

**Parameters**

|           |                                                      |
|-----------|------------------------------------------------------|
| <i>m1</i> | vector representation of a unsigned 512-bit integer. |
| <i>m2</i> | vector representation of a unsigned 128-bit integer. |
| <i>a2</i> | vector representation of a unsigned 512-bit integer. |

**Returns**

homogeneous aggregate representation of the unsigned 640-bit sum of  $(m1 * m2) + a2$ .

## 7.10.6.11 vec\_madd512x512a512\_inline()

```
static __VEC_U_1024 vec_madd512x512a512_inline (
 __VEC_U_512 m1,
 __VEC_U_512 m2,
 __VEC_U_512 a1) [inline], [static]
```

Vector 512-bit Unsigned Integer Multiply-Add.

Compute the 1024 bit sum of the product of 512 bit values m1 and m2 and 512 bit addend a1. The sum is returned as single 1024-bit integer in a homogeneous aggregate structure.

**Note**

The advantage of this form is that the final 1024 bit sum can not overflow and carries between stages are eliminated. Also applying the addend early (1st multiply stage) reduces the live ranges for registers passing partial products for larger multiple precision multiplies.

We use the COMPILER\_FENCE to limit instruction scheduling and code motion to smaller code blocks. This in turn reduces register pressure and avoids generating spill code.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | ~600    | 1/cycle    |
| power9    | ~210    | 1/cycle    |

**Parameters**

|           |                                                      |
|-----------|------------------------------------------------------|
| <i>m1</i> | vector representation of a unsigned 512-bit integer. |
| <i>m2</i> | vector representation of a unsigned 512-bit integer. |
| <i>a1</i> | vector representation of a unsigned 512-bit integer. |

**Returns**

homogeneous aggregate representation of the unsigned 1028-bit product of  $a * b$ .

**7.10.6.12 vec\_mul1024x1024()**

```
void vec_mul1024x1024 (
 __VEC_U_2048 * p2048,
 __VEC_U_1024 * m1,
 __VEC_U_1024 * m2)
```

Vector 1024x1024-bit Unsigned Integer Multiply.

Compute the 2048 bit product of 1024 bit values m1 and m2. The product is returned as single 2048-bit integer in a homogeneous aggregate structure.

**Note**

This is the dynamic call ABI for IFUNC selection. The static implementations are vec\_mul1024x1024\_PWR8 and vec\_mul1024x1024\_PWR9. For static calls the `__VEC_PWR_IMP()` macro will add appropriate suffix based on the compile -mcpu= option.

The storage order for quadwords matches the system endian. On Little Endian systems the least significant quadword is quadword element 0. The most significant is quadword elements [M-1], [N-1], and [M+N-1]. On Big Endian systems the least significant quadword is quadword elements [M-1], [N-1], and [M+N-1]. The most significant is quadword element 0.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | ~2500   | 1/cycle    |
| power9    | ~810    | 1/cycle    |

## Parameters

|              |                                                          |
|--------------|----------------------------------------------------------|
| <i>p2048</i> | vector result as a unsigned 2048-bit integer in storage. |
| <i>m1</i>    | vector representation of a unsigned 1024-bit integer.    |
| <i>m2</i>    | vector representation of a unsigned 1024-bit integer.    |

## 7.10.6.13 vec\_mul128\_byMN()

```
void vec_mul128_byMN (
 vui128_t * p,
 vui128_t * m1,
 vui128_t * m2,
 unsigned long M,
 unsigned long N)
```

Vector Unsigned Integer Quadword MxN Multiply.

Compute the M+N quadword product of two quadword arrays m1, m2. The product is returned as M+N quadword array p.

## Note

This is the dynamic call ABI for IFUNC selection. The static implementations are `vec_mul128_byMN_PWR8` and `vec_mul128_byMN_PWR9`. For static calls the `__VEC_PWR_IMP()` macro will add appropriate suffix based on the compile `-mcpu=` option.

The storage order for quadwords matches the system endian. On Little Endian systems the least significant quadword is quadword element 0. The most significant is quadword elements [M-1], [N-1], and [M+N-1]. On Big Endian systems the least significant quadword is quadword elements [M-1], [N-1], and [M+N-1]. The most significant is quadword element 0.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | ???     | 1/cycle    |
| power9    | ???     | 1/cycle    |

## Parameters

|           |                                                                          |
|-----------|--------------------------------------------------------------------------|
| <i>p</i>  | pointer to vector result as a unsigned (M+N)x128-bit integer in storage. |
| <i>m1</i> | pointer to vector representation of a unsigned Mx128-bit integer.        |
| <i>m2</i> | pointer to vector representation of a unsigned Nx128-bit integer.        |
| <i>M</i>  | long int specifying the number of quadword in m1.                        |

## Parameters

|          |                                                   |
|----------|---------------------------------------------------|
| <i>N</i> | long int specifying the number of quadword in m2. |
|----------|---------------------------------------------------|

7.10.6.14 `vec_mul128x128()`

```
__VEC_U_256 vec_mul128x128 (
 vui128_t m1,
 vui128_t m2)
```

Vector 128x128bit Unsigned Integer Multiply.

Compute the 256 bit product of two 128 bit values a, b. The product is returned as single 256-bit integer in a homogeneous aggregate structure.

## Note

This is the dynamic call ABI for IFUNC selection. The static implementations are `vec_mul128x128_PWR8` and `vec_mul128x128_PWR9`. For static calls the `__VEC_PWR_IMP()` macro will add appropriate suffix based on the compile `-mcpu=` option.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 48-56   | 1/cycle    |
| power9    | 16-24   | 1/cycle    |

## Parameters

|           |                                                      |
|-----------|------------------------------------------------------|
| <i>m1</i> | vector representation of a unsigned 128-bit integer. |
| <i>m2</i> | vector representation of a unsigned 128-bit integer. |

## Returns

homogeneous aggregate representation of the unsigned 256-bit product of  $a * b$ .

7.10.6.15 `vec_mul128x128_inline()`

```
static __VEC_U_256 vec_mul128x128_inline (
 vui128_t a,
 vui128_t b) [inline], [static]
```

Vector 128x128bit Unsigned Integer Multiply.

Compute the 256 bit product of two 128 bit values a, b. The product is returned as single 256-bit integer in a homogeneous aggregate structure.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 56-64   | 1/cycle    |
| power9    | 33-39   | 1/cycle    |

**Parameters**

|          |                                                      |
|----------|------------------------------------------------------|
| <i>a</i> | vector representation of a unsigned 128-bit integer. |
| <i>b</i> | vector representation of a unsigned 128-bit integer. |

**Returns**

homogeneous aggregate representation of the unsigned 256-bit product of  $a * b$ .

**7.10.6.16 vec\_mul2048x2048()**

```
void vec_mul2048x2048 (
 __VEC_U_4096 * p4096,
 __VEC_U_2048 * m1,
 __VEC_U_2048 * m2)
```

Vector 2048x2048-bit Unsigned Integer Multiply.

Compute the 4096 bit product of 2048 bit values m1 and m2. The product is returned as single 4096-bit integer in a homogeneous aggregate structure.

**Note**

This is the dynamic call ABI for IFUNC selection. The static implementations are vec\_mul2048x2048\_PWR8 and vec\_mul2048x2048\_PWR9. For static calls the `__VEC_PWR_IMP()` macro will add appropriate suffix based on the compile -mcpu= option.

The storage order for quadwords matches the system endian. On Little Endian systems the least significant quadword is quadword element 0. The most significant is quadword elements [M-1], [N-1], and [M+N-1]. On Big Endian systems the least significant quadword is quadword elements [M-1], [N-1], and [M+N-1]. The most significant is quadword element 0.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | ~12000  | 1/cycle    |
| power9    | 4770    | 1/cycle    |

**Parameters**

|              |                                                          |
|--------------|----------------------------------------------------------|
| <i>p4096</i> | vector result as a unsigned 4096-bit integer in storage. |
| <i>m1</i>    | vector representation of a unsigned 2048-bit integer.    |

## Parameters

|           |                                                       |
|-----------|-------------------------------------------------------|
| <i>m2</i> | vector representation of a unsigned 2048-bit integer. |
|-----------|-------------------------------------------------------|

7.10.6.17 `vec_mul256x256()`

```
__VEC_U_512 vec_mul256x256 (
 __VEC_U_256 m1,
 __VEC_U_256 m2)
```

Vector 256x256-bit Unsigned Integer Multiply.

Compute the 512 bit product of two 256 bit values a, b. The product is returned as single 512-bit integer in a homogeneous aggregate structure.

## Note

This is the dynamic call ABI for IFUNC selection. The static implementations are `vec_mul256x256_PWR8` and `vec_mul256x256_PWR9`. For static calls the `__VEC_PWR_IMP()` macro will add appropriate suffix based on the compile `-mcpu=` option.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 140-150 | 1/cycle    |
| power9    | 46-58   | 1/cycle    |

## Parameters

|           |                                                      |
|-----------|------------------------------------------------------|
| <i>m1</i> | vector representation of a unsigned 256-bit integer. |
| <i>m2</i> | vector representation of a unsigned 256-bit integer. |

## Returns

homogeneous aggregate representation of the unsigned 512-bit product of  $m1 * m2$ .

7.10.6.18 `vec_mul256x256_inline()`

```
static __VEC_U_512 vec_mul256x256_inline (
 __VEC_U_256 m1,
 __VEC_U_256 m2) [inline], [static]
```

Vector 256x256-bit Unsigned Integer Multiply.

Compute the 512 bit product of two 256 bit values a, b. The product is returned as single 512-bit integer in a homogeneous aggregate structure.



**Note**

Using the Multiply-Add form which applies the addend early reduces the live ranges for registers passing partial products for larger multiple precision multiplies.

We use the COMPILER\_FENCE to limit instruction scheduling and code motion to smaller code blocks. This in turn reduces register pressure and avoids generating spill code.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 224-232 | 1/cycle    |
| power9    | 132-135 | 1/cycle    |

**Parameters**

|           |                                                      |
|-----------|------------------------------------------------------|
| <i>m1</i> | vector representation of a unsigned 256-bit integer. |
| <i>m2</i> | vector representation of a unsigned 256-bit integer. |

**Returns**

homogeneous aggregate representation of the unsigned 512-bit product of  $m1 * m2$ .

**7.10.6.19 vec\_mul512\_byMN()**

```
void vec_mul512_byMN (
 __VEC_U_512 * p,
 __VEC_U_512 * m1,
 __VEC_U_512 * m2,
 unsigned long M,
 unsigned long N)
```

Vector Unsigned Integer Quadword 4xMxN Multiply.

Compute the 4xM+N quadword product of two quadword arrays m1, m2. The product is returned as 4xM+N quadword array p.

**Note**

This is the dynamic call ABI for IFUNC selection. The static implementations are vec\_mul512\_byMN\_PWR8 and vec\_mul512\_byMN\_PWR9. For static calls the `__VEC_PWR_IMP()` macro will add appropriate suffix based on the compile -mcpu= option.

The storage order for quadwords matches the system endian. On Little Endian systems the least significant quadword is quadword element 0. The most significant is quadword elements [M-1], [N-1], and [M+N-1]. On Big Endian systems the least significant quadword is quadword elements [M-1], [N-1], and [M+N-1]. The most significant is quadword element 0.

| processor | Latency              | Throughput |
|-----------|----------------------|------------|
| power8    | $\sim 570 * (M * N)$ | 1/cycle    |
| power9    | $\sim 260 * (M * N)$ | 1/cycle    |

#### Parameters

|           |                                                                          |
|-----------|--------------------------------------------------------------------------|
| <i>p</i>  | pointer to vector result as a unsigned (M+N)x512-bit integer in storage. |
| <i>m1</i> | pointer to vector representation of a unsigned Mx512-bit integer.        |
| <i>m2</i> | pointer to vector representation of a unsigned Nx512-bit integer.        |
| <i>M</i>  | long int specifying the number of 4x quadwords in m1.                    |
| <i>N</i>  | long int specifying the number of 4x quadwords in m2.                    |

#### 7.10.6.20 vec\_mul512x128()

```
__VEC_U_640 vec_mul512x128 (
 __VEC_U_512 m1,
 vui128_t m2)
```

Vector 512x128-bit Unsigned Integer Multiply.

Compute the 640 bit product of 512 bit value m1 and 128-bit value m2. The product is returned as single 640-bit integer in a homogeneous aggregate structure.

#### Note

This is the dynamic call ABI for IFUNC selection. The static implementations are `vec_mul256x256_PWR8` and `vec_mul256x256_PWR9`. For static calls the `__VEC_PWR_IMP()` macro will add appropriate suffix based on the compile `-mcpu=` option.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 224-232 | 1/cycle    |
| power9    | 132-135 | 1/cycle    |

#### Parameters

|           |                                                      |
|-----------|------------------------------------------------------|
| <i>m1</i> | vector representation of a unsigned 512-bit integer. |
| <i>m2</i> | vector representation of a unsigned 128-bit integer. |

#### Returns

homogeneous aggregate representation of the unsigned 640-bit product of  $m1 * m2$ .

## 7.10.6.21 vec\_mul512x128\_inline()

```
static __VEC_U_640 vec_mul512x128_inline (
 __VEC_U_512 m1,
 vui128_t m2) [inline], [static]
```

Vector 512x128-bit Unsigned Integer Multiply.

Compute the 640 bit product of 512 bit value m1 and 128-bit value m2. The product is returned as single 640-bit integer in a homogeneous aggregate structure.

**Note**

Using the Multiply-Add form which applies the addend early reduces the live ranges for registers passing partial products for larger multiple precision multiplies.

We use the COMPILER\_FENCE to limit instruction scheduling and code motion to smaller code blocks. This in turn reduces register pressure and avoids generating spill code.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 224-232 | 1/cycle    |
| power9    | 132-135 | 1/cycle    |

**Parameters**

|           |                                                      |
|-----------|------------------------------------------------------|
| <i>m1</i> | vector representation of a unsigned 512-bit integer. |
| <i>m2</i> | vector representation of a unsigned 128-bit integer. |

**Returns**

homogeneous aggregate representation of the unsigned 640-bit product of  $m1 * m2$ .

## 7.10.6.22 vec\_mul512x512()

```
__VEC_U_1024 vec_mul512x512 (
 __VEC_U_512 m1,
 __VEC_U_512 m2)
```

Vector 512x512-bit Unsigned Integer Multiply.

Compute the 1024 bit product of 512 bit values m1 and m2. The product is returned as single 1024-bit integer in a homogeneous aggregate structure.

**Note**

This is the dynamic call ABI for IFUNC selection. The static implementations are vec\_mul512x512\_PWR8 and vec\_mul512x512\_PWR9. For static calls the `__VEC_PWR_IMP()` macro will add appropriate suffix based on the compile -mcpu= option.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | ~600    | 1/cycle    |
| power9    | ~210    | 1/cycle    |

#### Parameters

|           |                                                      |
|-----------|------------------------------------------------------|
| <i>m1</i> | vector representation of a unsigned 512-bit integer. |
| <i>m2</i> | vector representation of a unsigned 512-bit integer. |

#### Returns

homogeneous aggregate representation of the unsigned 1028-bit product of  $a * b$ .

#### 7.10.6.23 `vec_mul512x512_inline()`

```
static __VEC_U_1024 vec_mul512x512_inline (
 __VEC_U_512 m1,
 __VEC_U_512 m2) [inline], [static]
```

Vector 512x512-bit Unsigned Integer Multiply.

Compute the 1024 bit product of 512 bit values *m1* and *m2*. The product is returned as single 1024-bit integer in a homogeneous aggregate structure.

#### Note

We use the `COMPILER_FENCE` to limit instruction scheduling and code motion to smaller code blocks. This in turn reduces register pressure and avoids generating spill code.

Using the Multiply-Add form which applies the addend early reduces the live ranges for registers passing partial products for larger multiple precision multiplies.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | ~600    | 1/cycle    |
| power9    | ~210    | 1/cycle    |

#### Parameters

|           |                                                      |
|-----------|------------------------------------------------------|
| <i>m1</i> | vector representation of a unsigned 512-bit integer. |
| <i>m2</i> | vector representation of a unsigned 512-bit integer. |

## Returns

homogeneous aggregate representation of the unsigned 1028-bit product of  $m1 * m2$ .

## 7.11 src/pveclib/vec\_int64\_ppc.h File Reference

Header package containing a collection of 128-bit SIMD operations over 64-bit integer elements.

```
#include <pveclib/vec_int32_ppc.h>
```

### Functions

- static [vui64\\_t](#) [vec\\_absdud](#) ([vui64\\_t](#) vra, [vui64\\_t](#) vrb)  
*Vector Absolute Difference Unsigned Doubleword.*
- static [vui64\\_t](#) [vec\\_addudm](#) ([vui64\\_t](#) a, [vui64\\_t](#) b)  
*Vector Add Unsigned Doubleword Modulo.*
- static [vui64\\_t](#) [vec\\_clzd](#) ([vui64\\_t](#) vra)  
*Count leading zeros for a vector unsigned long int.*
- static [vb64\\_t](#) [vec\\_cmpeqsd](#) ([vi64\\_t](#) a, [vi64\\_t](#) b)  
*Vector Compare Equal Signed Doubleword.*
- static [vb64\\_t](#) [vec\\_cmpequd](#) ([vui64\\_t](#) a, [vui64\\_t](#) b)  
*Vector Compare Equal Unsigned Doubleword.*
- static [vb64\\_t](#) [vec\\_cmpgesd](#) ([vi64\\_t](#) a, [vi64\\_t](#) b)  
*Vector Compare Greater Than or Equal Signed Doubleword.*
- static [vb64\\_t](#) [vec\\_cmpgeud](#) ([vui64\\_t](#) a, [vui64\\_t](#) b)  
*Vector Compare Greater Than or Equal Unsigned Doubleword.*
- static [vb64\\_t](#) [vec\\_cmpgtsd](#) ([vi64\\_t](#) a, [vi64\\_t](#) b)  
*Vector Compare Greater Than Signed Doubleword.*
- static [vb64\\_t](#) [vec\\_cmpgtud](#) ([vui64\\_t](#) a, [vui64\\_t](#) b)  
*Vector Compare Greater Than Unsigned Doubleword.*
- static [vb64\\_t](#) [vec\\_cmpleud](#) ([vi64\\_t](#) a, [vi64\\_t](#) b)  
*Vector Compare Less Than Equal Signed Doubleword.*
- static [vb64\\_t](#) [vec\\_cmpleud](#) ([vui64\\_t](#) a, [vui64\\_t](#) b)  
*Vector Compare Less Than Equal Unsigned Doubleword.*
- static [vb64\\_t](#) [vec\\_cmpltud](#) ([vi64\\_t](#) a, [vi64\\_t](#) b)  
*Vector Compare less Than Signed Doubleword.*
- static [vb64\\_t](#) [vec\\_cmpltud](#) ([vui64\\_t](#) a, [vui64\\_t](#) b)  
*Vector Compare less Than Unsigned Doubleword.*
- static [vb64\\_t](#) [vec\\_cmpnesd](#) ([vi64\\_t](#) a, [vi64\\_t](#) b)  
*Vector Compare Not Equal Signed Doubleword.*
- static [vb64\\_t](#) [vec\\_cmpneud](#) ([vui64\\_t](#) a, [vui64\\_t](#) b)  
*Vector Compare Not Equal Unsigned Doubleword.*
- static int [vec\\_cmpsd\\_all\\_eq](#) ([vi64\\_t](#) a, [vi64\\_t](#) b)  
*Vector Compare all Equal Signed Doubleword.*
- static int [vec\\_cmpsd\\_all\\_ge](#) ([vi64\\_t](#) a, [vi64\\_t](#) b)

*Vector Compare all Greater Than or Equal Signed Doubleword.*

- static int `vec_cmpsd_all_gt` (`vi64_t` a, `vi64_t` b)

*Vector Compare all Greater Than Signed Doubleword.*

- static int `vec_cmpsd_all_le` (`vi64_t` a, `vi64_t` b)

*Vector Compare all Less than equal Signed Doubleword.*

- static int `vec_cmpsd_all_lt` (`vi64_t` a, `vi64_t` b)

*Vector Compare all Less than Signed Doubleword.*

- static int `vec_cmpsd_all_ne` (`vi64_t` a, `vi64_t` b)

*Vector Compare all Not Equal Signed Doubleword.*

- static int `vec_cmpsd_any_eq` (`vi64_t` a, `vi64_t` b)

*Vector Compare any Equal Signed Doubleword.*

- static int `vec_cmpsd_any_ge` (`vi64_t` a, `vi64_t` b)

*Vector Compare any Greater Than or Equal Signed Doubleword.*

- static int `vec_cmpsd_any_gt` (`vi64_t` a, `vi64_t` b)

*Vector Compare any Greater Than Signed Doubleword.*

- static int `vec_cmpsd_any_le` (`vi64_t` a, `vi64_t` b)

*Vector Compare any Less than equal Signed Doubleword.*

- static int `vec_cmpsd_any_lt` (`vi64_t` a, `vi64_t` b)

*Vector Compare any Less than Signed Doubleword.*

- static int `vec_cmpsd_any_ne` (`vi64_t` a, `vi64_t` b)

*Vector Compare any Not Equal Signed Doubleword.*

- static int `vec_cmpud_all_eq` (`vui64_t` a, `vui64_t` b)

*Vector Compare all Equal Unsigned Doubleword.*

- static int `vec_cmpud_all_ge` (`vui64_t` a, `vui64_t` b)

*Vector Compare all Greater Than or Equal Unsigned Doubleword.*

- static int `vec_cmpud_all_gt` (`vui64_t` a, `vui64_t` b)

*Vector Compare all Greater Than Unsigned Doubleword.*

- static int `vec_cmpud_all_le` (`vui64_t` a, `vui64_t` b)

*Vector Compare all Less than equal Unsigned Doubleword.*

- static int `vec_cmpud_all_lt` (`vui64_t` a, `vui64_t` b)

*Vector Compare all Less than Unsigned Doubleword.*

- static int `vec_cmpud_all_ne` (`vui64_t` a, `vui64_t` b)

*Vector Compare all Not Equal Unsigned Doubleword.*

- static int `vec_cmpud_any_eq` (`vui64_t` a, `vui64_t` b)

*Vector Compare any Equal Unsigned Doubleword.*

- static int `vec_cmpud_any_ge` (`vui64_t` a, `vui64_t` b)

*Vector Compare any Greater Than or Equal Unsigned Doubleword.*

- static int `vec_cmpud_any_gt` (`vui64_t` a, `vui64_t` b)

*Vector Compare any Greater Than Unsigned Doubleword.*

- static int `vec_cmpud_any_le` (`vui64_t` a, `vui64_t` b)

*Vector Compare any Less than equal Unsigned Doubleword.*

- static int `vec_cmpud_any_lt` (`vui64_t` a, `vui64_t` b)

*Vector Compare any Less than Unsigned Doubleword.*

- static int `vec_cmpud_any_ne` (`vui64_t` a, `vui64_t` b)

*Vector Compare any Not Equal Unsigned Doubleword.*

- static `vi64_t` `vec_maxsd` (`vi64_t` vra, `vi64_t` vrb)

*Vector Maximum Signed Doubleword.*

- static `vui64_t vec_maxud` (`vui64_t vra`, `vui64_t vrb`)  
*Vector Maximum Unsigned Doubleword.*
- static `vi64_t vec_minsd` (`vi64_t vra`, `vi64_t vrb`)  
*Vector Minimum Signed Doubleword.*
- static `vui64_t vec_minud` (`vui64_t vra`, `vui64_t vrb`)  
*Vector Minimum Unsigned Doubleword.*
- static `vui64_t vec_mrgahd` (`vui128_t vra`, `vui128_t vrb`)  
*Vector Merge Algebraic High Doublewords.*
- static `vui64_t vec_mrgald` (`vui128_t vra`, `vui128_t vrb`)  
*Vector Merge Algebraic Low Doublewords.*
- static `vui64_t vec_mrged` (`vui64_t __VA`, `vui64_t __VB`)  
*Vector Merge Even Doubleword. Merge the even doubleword elements from two vectors into the high and low doubleword elements of the result. This is effectively the VSX Permute Doubleword Immediate operation modified for endian.*
- static `vui64_t vec_mrghd` (`vui64_t __VA`, `vui64_t __VB`)  
*Vector Merge High Doubleword. Merge the high doubleword elements from two vectors into the high and low doubleword elements of the result. This is effectively the VSX Permute Doubleword Immediate operation modified for endian.*
- static `vui64_t vec_mrgld` (`vui64_t __VA`, `vui64_t __VB`)  
*Vector Merge Low Doubleword. Merge the low doubleword elements from two vectors into the high and low doubleword elements of the result. This is effectively the VSX Permute Doubleword Immediate operation modified for endian.*
- static `vui64_t vec_mrgod` (`vui64_t __VA`, `vui64_t __VB`)  
*Vector Merge Odd Doubleword. Merge the odd doubleword elements from two vectors into the high and low doubleword elements of the result. This is effectively the VSX Permute Doubleword Immediate operation modified for endian.*
- static `vui128_t vec_msumudm` (`vui64_t a`, `vui64_t b`, `vui128_t c`)  
*Vector Multiply-Sum Unsigned Doubleword Modulo.*
- static `vui128_t vec_muleud` (`vui64_t a`, `vui64_t b`)  
*Vector Multiply Even Unsigned Doublewords.*
- static `vui64_t vec_mulhud` (`vui64_t vra`, `vui64_t vrb`)  
*Vector Multiply High Unsigned Doubleword.*
- static `vui128_t vec_muloud` (`vui64_t a`, `vui64_t b`)  
*Vector Multiply Odd Unsigned Doublewords.*
- static `vui64_t vec_muludm` (`vui64_t vra`, `vui64_t vrb`)  
*Vector Multiply Unsigned Doubleword Modulo.*
- static `vui64_t vec_pasted` (`vui64_t __VH`, `vui64_t __VL`)  
*Vector doubleword paste. Concatenate the high doubleword of the 1st vector with the low double word of the 2nd vector.*
- static `vui64_t vec_permdi` (`vui64_t vra`, `vui64_t vrb`, `const int ctl`)  
*Vector Permute Doubleword Immediate. Combine a doubleword selected from the 1st (vra) vector with a doubleword selected from the 2nd (vrb) vector.*
- static `vui64_t vec_popcntd` (`vui64_t vra`)  
*Vector Population Count doubleword.*
- static `vui64_t vec_revbd` (`vui64_t vra`)  
*byte reverse each doubleword for a vector unsigned long int.*
- static `vui64_t vec_vrld` (`vui64_t vra`, `vui64_t vrb`)  
*Vector Rotate Left Doubleword.*
- static `vui64_t vec_vslld` (`vui64_t vra`, `vui64_t vrb`)  
*Vector Shift Left Doubleword.*
- static `vui64_t vec_vsrld` (`vui64_t vra`, `vui64_t vrb`)  
*Vector Shift Right Doubleword.*
- static `vi64_t vec_vsrdd` (`vi64_t vra`, `vui64_t vrb`)

*Vector Shift Right Algebraic Doubleword.*

- static `vui64_t vec_rldi (vui64_t vra, const unsigned int shb)`

*Vector Rotate left Doubleword Immediate.*

- static `vui64_t vec_sldi (vui64_t vra, const unsigned int shb)`

*Vector Shift left Doubleword Immediate.*

- static `vui64_t vec_splatd (vui64_t vra, const int ctl)`

*Vector splat doubleword. Duplicate the selected doubleword element across the doubleword elements of the result. This is effectively the VSX Merge doubleword operation modified for endian.*

- static `vui64_t vec_spltd (vui64_t vra, const int ctl)`
- static `vui64_t vec_srldi (vui64_t vra, const unsigned int shb)`

*Vector Shift Right Doubleword Immediate.*

- static `vi64_t vec_sradi (vi64_t vra, const unsigned int shb)`

*Vector Shift Right Algebraic Doubleword Immediate.*

- static `vui64_t vec_subudm (vui64_t a, vui64_t b)`

*Vector Subtract Unsigned Doubleword Modulo.*

- static `vui64_t vec_swapd (vui64_t vra)`

*Vector doubleword swap. Exchange the high and low doubleword elements of a vector.*

- static `vui128_t vec_vmadd2eud (vui64_t a, vui64_t b, vui64_t c, vui64_t d)`

*Vector Multiply-Add2 Even Unsigned Doublewords.*

- static `vui128_t vec_vmaddeud (vui64_t a, vui64_t b, vui64_t c)`

*Vector Multiply-Add Even Unsigned Doublewords.*

- static `vui128_t vec_vmadd2oud (vui64_t a, vui64_t b, vui64_t c, vui64_t d)`

*Vector Multiply-Add2 Odd Unsigned Doublewords.*

- static `vui128_t vec_vmaddoud (vui64_t a, vui64_t b, vui64_t c)`

*Vector Multiply-Add Odd Unsigned Doublewords.*

- static `vui128_t vec_vmuleud (vui64_t a, vui64_t b)`

*Vector Multiply Even Unsigned Doublewords.*

- static `vui128_t vec_vmuloud (vui64_t a, vui64_t b)`

*Vector Multiply Odd Unsigned Doublewords.*

- static `vui128_t vec_vmsumeud (vui64_t a, vui64_t b, vui128_t c)`

*Vector Multiply-Sum Even Unsigned Doublewords.*

- static `vui128_t vec_vmsumoud (vui64_t a, vui64_t b, vui128_t c)`

*Vector Multiply-Sum Odd Unsigned Doublewords.*

- static `vui32_t vec_vpkudum (vui64_t vra, vui64_t vrb)`

*Vector Pack Unsigned Doubleword Unsigned Modulo.*

- static `vui64_t vec_xxspltd (vui64_t vra, const int ctl)`

*Vector splat doubleword. Duplicate the selected doubleword element across the doubleword elements of the result.*

- static `vui64_t vec_vmaddeuw (vui32_t a, vui32_t b, vui32_t c)`

*Vector Multiply-Add Even Unsigned Words.*

- static `vui64_t vec_vmadd2euw (vui32_t a, vui32_t b, vui32_t c, vui32_t d)`

*Vector Multiply-Add2 Even Unsigned Words.*

- static `vui64_t vec_vmaddouuw (vui32_t a, vui32_t b, vui32_t c)`

*Vector Multiply-Add Odd Unsigned Words.*

- static `vui64_t vec_vmadd2ouuw (vui32_t a, vui32_t b, vui32_t c, vui32_t d)`

*Vector Multiply-Add2 Odd Unsigned Words.*

- static `vui64_t vec_vmsumuwm (vui32_t vra, vui32_t vrb, vui64_t vrc)`

*Vector Multiply-Sum Unsigned Word Modulo.*



### 7.11.1 Detailed Description

Header package containing a collection of 128-bit SIMD operations over 64-bit integer elements.

Most of these operations are implemented in a single instruction on newer (POWER8/POWER9) processors. This header serves to fill in functional gaps for older (POWER7, POWER8) processors and provides a in-line assembler implementation for older compilers that do not provide the built-ins.

The original VMX (AKA AltiVec) did not define any doubleword element (long long integer or double float) operations. The VSX facility (introduced with POWER7) added vector double float but did not add any integer doubleword (64-bit) operations. However it did add a useful doubleword permute immediate and word wise; merge, shift, and splat immediate operations. Otherwise vector long int (64-bit elements) operations have to be implemented using VMX word and halfword element integer operations for POWER7.

POWER8 (PowerISA 2.07B) adds important doubleword integer (add, subtract, compare, shift, rotate, ...) VMX operations. POWER8 also added multiply word operations that produce the full doubleword product and full quadword add / subtract (with carry extend).

POWER9 (PowerISA 3.0B) adds the **Vector Multiply-Sum Unsigned Doubleword Modulo** instruction. This is not the expected multiply even/odd/modulo doubleword nor a full multiply modulo quadword. But with a few extra (permutes and splat zero) instructions you can get equivalent function.

#### Note

The doubleword integer multiply implementations are included in [vec\\_int128\\_ppc.h](#). This resolves a circular dependency as 64-bit by 64-bit integer multiplies require 128-bit integer addition ([vec\\_adduqm\(\)](#)) to produce the full product.

#### See also

[vec\\_msumudm](#), [vec\\_muleud](#), [vec\\_mulhud](#), [vec\\_muloud](#), [vec\\_muludm](#), [vec\\_vmuleud](#), and [vec\\_vmuloud](#)

Most of these intrinsic (compiler built-in) operations are defined in `<altivec.h>` and described in the compiler documentation. However it took several compiler releases for all the new POWER8 64-bit integer vector intrinsics to be added to **altivec.h**. This support started with the GCC 4.9 but was not complete across function/type and bug free until GCC 6.0.

#### Note

The compiler disables associated `<altivec.h>` built-ins if the **mcpu** target does not enable the specific instruction. For example, if you compile with **-mcpu=power7**, `vec_vclz` and `vec_vclzd` will not be defined. But `vec_clzd` is always defined in this header, will generate the minimum code, appropriate for the target, and produce correct results.

64-bit integer operations are commonly used in the implementation of optimized double float math library functions and this applies to the vector equivalents of math functions. So missing, incomplete or buggy support for vector long integer intrinsics can be a impediment to the implementation of optimized and portable vector double math libraries. This header is a prerequisite for [vec\\_f64\\_ppc.h](#) which together are intended to support the implementation of vector math libraries.

Most of these operations are implemented in a single instruction on newer (POWER8/POWER9) processors. So this header serves to fill in functional gaps for older (POWER7, POWER8) processors and provides a in-line assembler implementation for older compilers that do not provide the built-ins.

This header covers operations that are any of the following:

- Implemented in hardware instructions for later processors and useful to programmers, on slightly older processors, even if the equivalent function requires more instructions. Examples include the doubleword operations: Add, Compare, Maximum, Minimum and Subtract.
- Defined in the OpenPOWER ABI but *not* yet defined in `<altivec.h>` provided by available compilers in common use. Examples include doubleword forms of: Multiply Even/Odd/Modulo, Count Leading Zeros, Population Count, and Byte Reverse operations.
- Commonly used operations, not covered by the ABI or `<altivec.h>`, and require multiple instructions or are not obvious. Examples include doubleword forms of: Merge Algebraic High/Low, Paste, and Rotate/Shift Immediate operations.
- Commonly used operations that are useful for doubleword, but are missing from the PowerISA and OpenPOWER ABI. Examples include: Absolute Difference Doubleword and Multiply-Sum Unsigned Word Modulo.

### 7.11.2 Some missing doubleword operations

The original VMX instruction set extension was limited to byte, halfword, and word size element operations. This limited vector arithmetic operations to char, short, int and float elements. This limitation persisted until PowerISA 2.06 (POWER7) added the Vector Scalar Extensions (VSX) facility. VSX combined/extended the FPRs and VRs into 64 by 128-bit Vector/Scalar Registers (VSRs).

VSX added a large number of scalar double-precision and vector single / double-precision floating-point operations. The double-precision scalar (**xs** prefix) instructions were largely duplicates of the existing Floating-Point Facility operations, extended to access the whole (64) VSX register set. Similarly the VSX vector single precision floating-point (**xv** prefix, **sp** suffix) instructions were added to give vectorized float code access to 64 VSX registers.

The addition of VSX vector double-precision (**xv** prefix) instructions was the most significant addition. This added vector doubleword floating-point operations and provided access to all 64 VSX registers. Alas, there are no doubleword (64-bit long) integer operations in the initial VSX. A few logical and permute class (**xx** prefix) operations on word/doubleword elements were tacked on. These apply equally to float and integer elements. But nothing for 64-bit integer arithmetic.

#### Note

The full title in PowerISA 2.06 is **Vector-Scalar Floating-Point Operations [Category: VSX]**.

PowerISA 2.07 (POWER8) did add a significant number of doubleword (64-bit) integer operations. Including;

- Add and subtract modulo
- Signed and unsigned compare, maximum, minimum,
- Shift and rotate
- Count leading zeros and population count

Also a number of new word (32-bit) integer operations;

- Multiply even/odd/modulo.
- Pack signed/unsigned/saturate and Unpack signed.
- Merge even/odd words

And some new quadword (128-bit) integer operations;

- Add and Subtract modulo/extend/write-carry
- Decimal Add and Subtract modulo

And some specialized operations;

- Crypto, Raid, Polynomial multiply-sum

#### Note

The operations above are all Vector Category and can only access the 32 original vector registers (VSRs 32-63).

The new VSX operations (with access to all 64 VSRs) were not directly applicable to 64-bit integer arithmetic:

- Scalar single precision floating-point
- Direct move between GPRs and VSRs
- Logical operations; equivalence, not and, or compliment

PowerISA 3.0 (POWER9) adds a few more doubleword (64-bit) integer operations. Including;

- Compare not equal
- Count trailing zeros and parity
- Extract and Insert
- Multiply-sum modulo
- Negate
- Rotate Left under mask

Also a number of new word (32-bit) integer operations;

- Absolute Difference word
- Extend Sign word to doubleword

And some new quadword (128-bit) integer operations;

- Multiply-by-10 extend/write-carry
- Decimal convert from/to signed (binary) quadword
- Decimal convert from/to zoned (ASCII char)
- Decimal shift/round/truncate

The new VSX operations (with access to all 64 VSRs) were not directly applicable to 64-bit integer arithmetic:

- Scalar quad-precision floating-point
- Scalar and Vector convert with rounding
- Scalar and Vector extract/insert exponent/significand
- Scalar and Vector test data class
- Permute and Permute right index

An impressive list of operations that can be used for;

- Vectorizing long integer loops
- Implementing useful quadword integer operations which do not have corresponding PowerISA instructions
- implementing extended precision multiply and multiplicative inverse operations

The challenge is that useful operations available for POWER9 will need equivalent implementations for POWER8 and POWER7. Similarly for operations introduced for POWER8 will need POWER7 implementations. Also there are some obvious missing operations;

- Absolute Difference Doubleword (we have byte, halfword, and word)
- Average Doubleword (we have byte, halfword, and word)
- Extend Sign Doubleword to quadword (we have byte, halfword, and word)
- Multiply-sum Word (we have byte, halfword, and doubleword)
- Multiply Even/Odd Doublewords (we have byte, halfword, and word)

#### 7.11.2.1 Challenges and opportunities

The stated goals for pveclib are:

- Provide equivalent functions across versions of the compiler.
- Provide equivalent functions across versions of the PowerISA.
- Provide complete arithmetic operations across supported C types.

So the first step is to provide implementations for the key POWER8 doubleword integer operations for older compilers. For example, some of the generic doubleword integer operations were not defined until GCC 6.0. Here we define the specific Compare Equal Unsigned Doubleword implementation:

```

static inline
vb64_t
vec_cmpequd (vui64_t a, vui64_t b)
{
 vb64_t result;
#ifdef _ARCH_PWR8
 #if __GNUC__ >= 6
 result = vec_cmpeq(a, b);
 #else
 __asm__(
 "vcmpqud %0,%1,%2;\n"
 : "=v" (result)
 : "v" (a),
 "v" (b)
 :);
 #endif
#else
 // _ARCH_PWR7 implementation ...
#endif
 return (result);
}

```

The implementation checks if the compile target is POWER8 then checks if the compiler is new enough to use the generic vector compare built-in. If the generic built-in is not defined in `<altivec.h>` then we provide the equivalent inline assembler.

For POWER7 targets we don't have any vector compare doubleword operations and we need to define the equivalent operation using PowerISA 2.06B (and earlier) instructions. For example:

```

#else
 // _ARCH_PWR7 implementation ...
 vui8_t permute =
 { 0x04, 0x05, 0x06, 0x07, 0x00, 0x01, 0x02, 0x03,
 0x0C, 0x0D, 0x0E, 0x0F, 0x08, 0x09, 0x0A, 0x0B };
 vui32_t r, rr;
 r = (vui32_t) vec_cmpeq ((vui32_t) a, (vui32_t) b);
 if (vec_any_ne ((vui32_t) a, (vui32_t) b))
 {
 rr = vec_perm(r, r, permute);
 r = vec_and(r, rr);
 }
 result = (vb64_t)r;
#endif

```

Here we use Compare Equal Unsigned Word. If all words are equal, use the result as is. Otherwise, if any word elements are not equal, we do some extra work. For each doubleword, rotate the word compare result by 32-bits (here we use permute as we don't have rotate doubleword either). Then logical and the original word compare and rotated results to get the final doubleword compare results.

Similarly for all the doubleword compare variants. Similarly for doubleword; add, subtract, maximum, minimum, shift, rotate, count leading zeros, population count, and Byte reverse.

### 7.11.2.2 More Challenges

Now we can look at the case where vector doubleword operations of interest don't have an equivalent instruction. Here interesting operations include those that are supported for other element sizes and types.

The simplest example is absolute difference which was introduced in PowerISA 3.0 for byte, halfword and word elements. From the implementation of `vec_absduw()` we see how to implement the operation for POWER8 using subtract, maximum, and minimum. For example:

```
static inline vui64_t
vec_absdud (vui64_t vra, vui64_t vrb)
{
 return vec_subudm (vec_maxud (vra, vrb), vec_minud (vra, vrb));
}
```

This works because pveclib provides implementations for min, max, and sub operations that work across GCC versions and provide processor specific implementations for POWER8/9 and POWER7.

Now we need to look at the multiply doubleword situation. We need implementations for `vec_msumudm()`, `vec_muleud()`, `vec_mulhud()`, `vec_muloud()`, and `vec_muludm()`. We saw in the implementations of `vec_int32_ppc.h` that multiply high and low/modulo can implemented using multiply and merge even/odd of that element size. Multiply low can also be implemented using the multiply sum and multiply odd of the next smaller element size. Also multiply-sum can be implemented using multiply even/odd and a couple of adds. And multiply even/odd can be implemented using multiply sum by supplying zeros to appropriate inputs/elements.

The above discussion has many circular dependencies. Eventually we need to get down to an implementation on each processor using actual hardware instructions. So what multiply doubleword operations does the PowerISA actually have from the list above:

- POWER9 added multiply-sum unsigned doubleword modulo but no multiply doubleword even/odd/modulo instructions.
- POWER8 added multiply even/odd/modulo word but no multiply-sum word instructions
- POWER7 and earlier we have the original VMX multiply even/odd halfword, and multiply-sum unsigned halfword modulo, but no multiply modulo halfword.

It seems the best implementation strategy uses;

- Multiply-sum doubleword for POWER9
- Multiply even/odd word for POWER8
- Multiply even/odd halfword for POWER7

We really care about performance and latency for POWER9/8. We need POWER7 to work correctly so we can test on and support *legacy* hardware. The rest is grade school math.

First we need to make sure we have implementations across the GCC versions 6, 7, and 8 for the instructions we need. For example:

```
static inline vui128_t
vec_msumudm (vui64_t a, vui64_t b, vui128_t c)
{
 vui128_t res;
 #if defined (__ARCH_PWR9) && ((__GNUC__ >= 6) || (__clang_major__ >= 11))
 __asm__(
 "vmsumudm %0,%1,%2,%3;\n"
 : "=v" (res)
 : "v" (a), "v" (b), "v" (c)
 :);
 #else
 vui128_t p_even, p_odd, p_sum;

 p_even = vec_muleud (a, b);
 p_odd = vec_muloud (a, b);
 p_sum = vec_adduqm (p_even, p_odd);
 res = vec_adduqm (p_sum, c);
 #endif
 return (res);
}
```

**Note**

The `_ARCH_PWR8` implementation above depends on `vec_muleud()` and `vec_muloud()` for which there are no hardware instructions. Hold that thought.

While we are it we can implement multiply-sum unsigned word modulo.

```
static inline vui64_t
vec_vmsumuwmm (vui32_t vra, vui32_t vrb, vui64_t vrc)
{
 vui64_t peven, podd, psum;

 peven = vec_muleuw (vra, vrb);
 podd = vec_mulouw (vra, vrb);
 psum = vec_addudm (peven, podd);

 return vec_addudm (psum, vrc);
}
```

We will need this later.

Now we need to provide implementations of `vec_muleud()` and `vec_muloud()`. For example:

```
static inline vui128_t
vec_muleud (vui64_t a, vui64_t b)
{
 #if __BYTE_ORDER__ == __ORDER_LITTLE_ENDIAN__
 return vec_vmuloud (a, b);
 #else
 return vec_vmuleud (a, b);
 #endif
}
```

The implementation above is just handling the pesky little endian transforms. The real implementations are in `vec_v←vmuleud()` and `vec_vmuloud()` which implement the operation as if the PowerISA included such an instruction. These implementation is NOT endian sensitive and the function is stable across BE/LE implementations. For example:

```
static inline vui128_t
vec_vmuleud (vui64_t a, vui64_t b)
{
 vui64_t res;
 #if defined (_ARCH_PWR9) && ((__GNUC__ >= 6) || (__clang_major__ >= 11))
 const vui64_t zero = { 0, 0 };
 vui64_t b_eud = vec_mrgahd ((vui128_t) b, (vui128_t) zero);
 __asm__(
 "vmsumudm %0,%1,%2,%3;\n"
 : "=v" (res)
 : "v" (a), "v" (b_eud), "v" (zero)
 :);
 #else
 #ifdef _ARCH_PWR8
 const vui64_t zero = { 0, 0 };
 vui64_t p0, p1, pp10, pp01;
 vui32_t m0, m1;

 // Need the endian invariant merge word high here
 #if __BYTE_ORDER__ == __ORDER_LITTLE_ENDIAN__
 // Nullify the little endian transform
 m0 = vec_mergel ((vui32_t) b, (vui32_t) b);
 #else
 m0 = vec_mergeh ((vui32_t) b, (vui32_t) b);
 #endif
 m1 = (vui32_t) vec_xxspltd ((vui64_t) a, 0);

 // Need the endian invariant multiply even/odd word here
 #if __BYTE_ORDER__ == __ORDER_LITTLE_ENDIAN__
 // Nullify the little endian transform
 p1 = vec_muleuw (m1, m0);
```

```

 p0 = vec_mulouw (m1, m0);
#else
 p1 = vec_mulouw (m1, m0);
 p0 = vec_muleuw (m1, m0);
#endif
 // res[1] = p1[1]; res[0] = p0[0];
 res = vec_pasted (p0, p1);

 // pp10[1] = p1[0]; pp10[0] = 0;
 // pp01[1] = p0[1]; pp01[0] = 0;
 // Need the endian invariant merge algebraic high/low here
 pp10 = (vui64_t) vec_mrgahd ((vui128_t) zero, (
 vui128_t) p1);
 pp01 = (vui64_t) vec_mrgald ((vui128_t) zero, (
 vui128_t) p0);
 // pp01 = pp01 + pp10.
 pp01 = (vui64_t) vec_adduqm ((vui128_t) pp01, (
 vui128_t) pp10);

 // res = res + (pp01 << 32)
 pp01 = (vui64_t) vec_sld ((vi32_t) pp01, (vi32_t) pp01, 4);
 res = (vui64_t) vec_adduqm ((vui128_t) pp01, (
 vui128_t) res);
#else
 // _ARCH_PWR7 implementation ...
#endif
#endif
 return ((vui128_t) res);
}

```

The `_ARCH_PWR9` implementation uses the multiply-sum doubleword operation but implements the multiply even behavior by forcing the contents of doubleword element 1 of [VRB] and the contents of [VRC] to 0.

The `_ARCH_PWR8` implementation looks ugly but it works. It starts with some merges and splats to get inputs columns lined up for the multiply. Then we use (POWER8 instructions) Multiply Even/Odd Unsigned Word to generate doubleword partial products. Then more merges and a rotate to line up the partial products for summation as the final quadword product.

Individually `vec_vmuleud()` and `vec_vmuloud()` execute with a latency of 21-23 cycles on POWER8. Normally these operations are used and scheduled together as in the POWER8 implementation of `vec_msumudm()` or `vec_mulhud()`. Good scheduling by the compiler and pipelining keeps the POWER8 latency in the 28-32 cycle range. For example, the `vec_mulhud()` implementation:

```

static inline vui64_t
vec_mulhud (vui64_t vra, vui64_t vrb)
{
 return vec_mrgahd (vec_vmuleud (vra, vrb), vec_vmuloud (vra, vrb));
}

```

Generates the following code for POWER8:

```

vspltisw v0,0
xxmrghw vs33,vs35,vs35
xxspltd vs45,vs34,0
xxmrglw vs35,vs35,vs35
vmulouw v11,v13,v1
xxspltd vs34,vs34,1
xxmrghd vs41,vs32,vs43
vmulouw v12,v2,v3
vmuleuw v13,v13,v1
vmuleuw v2,v2,v3
xxmrghd vs42,vs32,vs44
xxmrghd vs33,vs32,vs45
xxmrghd vs32,vs32,vs34
xxpermdi vs44,vs34,vs44,1
vadduqm v1,v1,v9
xxpermdi vs45,vs45,vs43,1
vadduqm v0,v0,v10
vsldoi v1,v1,v1,4
vsldoi v0,v0,v0,4
vadduqm v2,v1,v13
vadduqm v0,v0,v12
xxmrghd vs34,vs34,vs32

```



The POWER9 latencies for this operation range from 5-7 (for `vmsumudm` itself) to 11-16 (for `vec_mulhud()`). The additional latency reflects zero constant vector generation and merges required to condition the inputs and output. For these operations the `vec_msumudm()`, `vrc` operand is always zero. Selecting the even/odd doubleword for input requires a merge low/high. And selecting the high doubleword for multiply high require a final merge high.

`vec_mulhud()` generates the following code for POWER9:

```
xxspltib vs32,0
xxmrghd vs33,vs35,vs32
xxmrghd vs35,vs32,vs35
vmsumudm v1,v2,v1,v0
vmsumudm v2,v2,v3,v0
xxmrghd vs34,vs33,vs34
```

Wrapping up the doubleword multiplies we should look at the multiply low (AKA Multiply Unsigned Doubleword Modulo). The POWER9 implementation is similar to `vec_mulhud()` and the generated code is similar to the example above.

Multiply low doubleword is a special case, as we are discarding the highest partial doubleword product. For POWER8 we can optimize for that case using multiply odd and multiply-sum word operations. Also as we are only generating doubleword partial products we only need add doubleword modulo operations to sum the results. This avoids the more expensive add quadword operation required for the general case. The fact that `vec_vmsumuwm()` is only a software construct is not an issue. It expands into hardware multiple even/odd word and add doubleword instructions that the compiler can schedule and optimize.

Here `vec_mulouw()` generates low order partial product. Then `vec_vrld()` and `vec_vmsumuwm()` generate doubleword sums of the two middle order partial products. Then `vec_vslld()` shifts the middle order partial sum left 32-bits (discarding the unneeded high order 32-bits). Finally sum the low and middle order partial doubleword products to produce the multiply-low doubleword result. For example, this POWER8 only implementation:

```
static inline vui64_t
vec_muludm (vui64_t vra, vui64_t vrb)
{
 vui64_t s32 = { 32, 32 }; // shift / rotate amount.
 vui64_t z = { 0, 0 };
 vui64_t t2, t3, t4;
 vui32_t t1;

 t1 = (vui32_t) vec_vrld (vrb, s32);
 #if __BYTE_ORDER__ == __ORDER_LITTLE_ENDIAN__
 // Nullify the little endian transform, really want mulouw here.
 t2 = vec_muleuw ((vui32_t) vra, (vui32_t) vrb);
 #else
 t2 = vec_mulouw ((vui32_t) vra, (vui32_t) vrb);
 #endif
 t3 = vec_vmsumuwm ((vui32_t) vra, t1, z);
 t4 = vec_vslld (t3, s32);
 return (vui64_t) vec_vaddudm (t4, t2);
}
```

Which generates the following for POWER8:

```
addis r9,r2,.rodata.cst16+0x60@ha
addi r9,r9,.rodata.cst16+0x60@l
lxv vs33,0,r9
vmulouw v13,v2,v3
vrld v0,v3,v1
vmulouw v3,v2,v0
vmuleuw v2,v2,v0
vaddudm v2,v3,v2
vslld v2,v2,v1
vaddudm v2,v13,v2
```

#### Note

The addition of zeros to the final sum of `vec_vmsumuwm()` (`vec_addudm (psum, vrc)`) has been optimized away by the compiler. This eliminates the `xxspltib` and one `vaddudm` instruction from the final code sequence.

And we can assume that the constant load of `{ 32, 32 }` will be common-ed with other operations or hoisted out of loops. So the shift constant can be loaded early and `vrld` is not delayed. This keeps the POWER8 latency in the 19-28 cycle range.

### 7.11.3 Endian problems with doubleword operations

From the examples above we see that the construction of higher precision multiplies requires significant massaging of input and output elements. Here merge even/odd, merge high/low, swap, and splat doubleword element operations are commonly used.

PowerISA 2.06 VSX (POWER7) added the general purpose Vector Permute Doubleword Immediate (xxpermdi). The compiler generates some form of xxpermdi for the doubleword (double float, long int, bool long) merge/splat/swap operations. As xxpermdi's element selection is an immediate field, most operations require only a single instruction. All the merge/splat/swap doubleword variants are just a specific select mask value and the inputs to xxpermdi.

Which is very useful indeed for assembling, disassembling, merging, splatting, swapping, and pasting doubleword elements.

Of course it took several compiler releases to implement all the generic merge/splat/swap operations for the supported types. GCC 4.8 as the first to support vec\_xxpermdi as a built-in. GCC 4.8 also supported the generic built-ins vec\_mergeh, vec\_mergel, and vec\_splat for the vector signed/unsigned/bool long type. But endian sensitive vec\_mergeh, vec\_mergel, and vec\_splat were not supported until GCC 7. And the generic vec\_mergee, vec\_mergeo built-ins were not supported until GCC 8.

But as we have explained in [General Endian Issues](#) and [Endian problems with word operations](#) the little endian transforms applied by the compiler can cause problems for developers of multi-precision libraries. The doubleword forms of the generic merge/splat operations etc. are no exception. This is especially annoying when the endian sensitive transforms are applied between releases of the compiler.

So we need a strategy to provide endian invariant merge/splat/swap operations to be used in multi-precision arithmetic. And another set of endian sensitive operations that are mandated by the OpenPOWER ABI.

First we need a safely endian invariant version of xxpermdi to use in building other variants:

- [vec\\_permdi\(\)](#) provides the basic xxpermdi operation but nullifies the little endian transforms.

Then build the core set of endian invariant permute doubleword operations using [vec\\_permdi\(\)](#):

- Merge algebraic high/low doubleword operations [vec\\_mrgahd\(\)](#) and [vec\\_mrgald\(\)](#).
- Merge the left and right most doublewords from a double quadword operation [vec\\_pasted\(\)](#).
- Splat from the high/even or low/odd doubleword operation [vec\\_xxspltd\(\)](#).
- Swap high and low doublewords operation [vec\\_swapd\(\)](#).

We use the merge algebraic high/low doubleword operations in the implementation of [vec\\_mulhud\(\)](#), [vec\\_muleud\(\)](#), and [vec\\_vmuloud\(\)](#). We use the vec\_xxspltd operation in the implementation of [vec\\_vrld\(\)](#), [vec\\_vmuleud\(\)](#), and [vec\\_vmuloud\(\)](#). We use the paste doubleword ([vec\\_pasted\(\)](#)) operation in the implementation of [vec\\_vsrld\(\)](#), [vec\\_vmuleud\(\)](#), and [vec\\_vmuloud\(\)](#). We use the swap doubleword operation in the implementation of [vec\\_cmpequq\(\)](#), [vec\\_cmpneuq\(\)](#), [vec\\_muludq\(\)](#), and [vec\\_mulluq\(\)](#).

Then use the compilers `__BYTE_ORDER__ == ORDER_LITTLE_ENDIAN` conditional to invert the [vec\\_permdi\(\)](#) select control for endian sensitive merge/splat doubleword operations:

- Merge even/odd doubleword operations [vec\\_mrged\(\)](#) and [vec\\_mrgod\(\)](#).
- Merge high/low doubleword operations [vec\\_mrghd\(\)](#) and [vec\\_mrgld\(\)](#).
- Splat even/odd doubleword operation [vec\\_spltd\(\)](#).

### 7.11.4 Vector Doubleword Examples

Suppose we have a requirement to convert an array of 64-bit time-interval values that need to convert to timespec format. For simplicity we will also assume that the array is nicely (Quadword) aligned and an integer multiple of 2 doublewords or 4 words.

The PowerISA provides a 64-bit TimeBase register that clocks at a constant 512MHz. The TimeBase can be read directly as either the full 64-bit value or as 32-bit upper and lower halves. For this example we assume are dealing with longer intervals (greater than ~8.38 seconds) so the full 64-bit TimeBase is required. TimeBase values of adjacent events are subtracted to generate the intervals stored in the array.

The timespec format is a struct of unsigned int fields for seconds and nanoseconds. So the task is to convert the 512MHz 64-bit TimeBase intervals to seconds and remaining clock ticks. Then convert the remaining (subsecond) clock ticks from 512MHz to nanoseconds. The separate seconds and nanoseconds are combined in the timespec structure.

First we need to separate the raw TimeBase into the integer seconds and (subsecond) clock-ticks. Normally scalar codes would use integer divide/modulo by 512000000. Did I mention that the PowerISA vector unit does not have a integer divide operation?

Instead we can use the multiplicative inverse which is a scaled fixed point fraction calculated from the original divisor. This works nicely if the fixed radix point is just before the 64-bit fraction and we have a multiply high ([vec\\_mulhud\(\)](#)) operation. Multiplying a 64-bit unsigned integer by a 64-bit unsigned fraction generates a 128-bit product with 64-bits above (integer) and below (fraction) the radix point. The high 64-bits of the product is the integer quotient.

It turns out that generating the multiplicative inverse can be tricky. To produce correct results over the full range requires, possible pre-scaling and post-shifting, and sometimes a corrective addition is necessary. Fortunately the mathematics are well understood and are commonly used in optimizing compilers. Even better, Henry Warren's book has a whole chapter on this topic.

See also

"Hacker's Delight, 2nd Edition," Henry S. Warren, Jr, Addison Wesley, 2013. Chapter 10, Integer Division by Constants.

In the chapter above;

Figure 10-2 Computing the magic number for unsigned division.

provides a sample C function for generating the magic number (actually a struct containing; the magic multiplicative inverse, "add" indicator, and the shift amount.).

For the divisor 512000000 this is { 4835703278458516699, 0 , 27 }:

- the multiplier is 4835703278458516699.
- no corrective add of the dividend is required.
- the final shift is 27-bits right.

```
// Magic numbers for multiplicative inverse to divide by 512,000,000
// are 4835703278458516699 and shift right 27 bits.
const vui64_t mul_invs_clock =
 { 4835703278458516699UL, 4835703278458516699UL };
const int shift_clock = 27;
// Need const for TB clocks/second to extract remainder.
const vui64_t tb_clock_sec =
 { 512000000, 512000000 };
vui64_t tb_v, tmp, tb_clocks, seconds, nseconds;
vui64_t timespec1, timespec2;

// extract integer seconds from timebase vector.
tmp = vec_mulhud (tb_v, mul_invs_clock);
seconds = vec_srdi (tmp, shift_clock);
// Extract the remainder in tb clock ticks.
tmp = vec_muludm (seconds, tb_clock_sec);
tb_clocks = vec_sub (tb_v, tmp);
```

Next we need to convert the subseconds from TimeBase clock-ticks to nanoseconds. The subsecond remainder is now small enough (compared to a doubleword) that we can perform the conversion *in place*. The nanosecond conversion is  $((tb\_clocks * 1000000000) / 512000000)$ . And we can reduce this to  $((tb\_clocks * 1000) / 512)$ . We still have a small multiply but the divide can be converted to shift right of 9-bits.

```
const int shift_512 = 9;
const vui64_t nano_512 =
 { 1000, 1000 };

// Convert 512MHz timebase to nanoseconds.
// nseconds = tb_clocks * 1000000000 / 512000000
// reduces to (tb_clocks * 1000) >> 9
tmp = vec_muludm (tb_clocks, nano_512);
nseconds = vec_srdi (tmp, shift_512);
```

Finally we need to merge the vectors of seconds and nanoseconds into vectors of timespec. So far we have been working with 64-bit integers but the timespec is a struct of 32-bit (word) integers. Here 32-bit seconds and nanosecond provided sufficient range and precision. So the final step *packs* a pair of 64-bit timespec values into a vector of two 32-bit timespec values, each containing 2 32-bit (second, nanosecond) values.

```
timespec1 = vec_mergeh (seconds, nseconds);
timespec2 = vec_mergel (seconds, nseconds);
// seconds and nanoseconds fit int 32-bits after conversion.
// So pack the results and store the timespec.
*timespec++ = vec_vpkudum (timespec1, timespec2);
```

#### Note

`vec_sub()`, `vec_mergeh()`, and `vec_mergel()` are existing `altivec.h` generic built-ins.

`vec_vpkudum()` is an existing `altivec.h` built-in that is only defined for `_ARCH_PWR8` and later. This header insures that `vec_vpkudum` is defined for older compilers and provides an functional equivalent implementation for POWER7.

#### 7.11.4.1 Vectorized 64-bit TimeBase conversion example

Here is the complete vectorized 64-bit TimeBase to timespec conversion example:

```

void
example_dw_convert_timebase (vui64_t *tb, vui32_t *timespec, int n)
{
 // Magic numbers for multiplicative inverse to divide by 512,000,000
 // are 4835703278458516699 and shift right 27 bits.
 const vui64_t mul_invs_clock =
 { 4835703278458516699UL, 4835703278458516699UL };
 const int shift_clock = 27;
 // Need const for TB clocks/second to extract remainder.
 const vui64_t tb_clock_sec =
 { 512000000, 512000000 };
 const int shift_512 = 9;
 const vui64_t nano_512 =
 { 1000, 1000 };
 vui64_t tb_v, tmp, tb_clocks, seconds, nseconds;
 vui64_t timespec1, timespec2;
 int i;

 for (i = 0; i < n; i++)
 {
 tb_v = *tb++;
 // extract integer seconds from timebase vector.
 tmp = vec_mulhud (tb_v, mul_invs_clock);
 seconds = vec_srdi (tmp, shift_clock);
 // Extract remainder in tb clock ticks.
 tmp = vec_muludm (seconds, tb_clock_sec);
 tb_clocks = vec_sub (tb_v, tmp);
 // Convert 512MHz timebase to nanoseconds.
 // nseconds = tb_clocks * 1000000000 / 512000000
 // reduces to (tb_clocks * 1000) >> 9
 tmp = vec_muludm (tb_clocks, nano_512);
 nseconds = vec_srdi (tmp, shift_512);
 // Use merge high/low to interleave seconds and nseconds
 // into timespec.
 timespec1 = vec_mergeh (seconds, nseconds);
 timespec2 = vec_mergel (seconds, nseconds);
 // seconds and nanoseconds fit int 32-bits after conversion.
 // So pack the results and store the timespec.
 *timespec++ = vec_vp kudum (timespec1, timespec2);
 }
}

```

### 7.11.5 Performance data.

High level performance estimates are provided as an aid to function selection when evaluating algorithms. For background on how *Latency* and *Throughput* are derived see: [Performance data](#).

### 7.11.6 Function Documentation

#### 7.11.6.1 vec\_absdud()

```

static vui64_t vec_absdud (
 vui64_t vra,
 vui64_t vrb) [inline], [static]

```

Vector Absolute Difference Unsigned Doubleword.

Compute the absolute difference for each doubleword. For each unsigned doubleword, subtract VRB[i] from VRA[i] and return the absolute value of the difference.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 1/cycle    |
| power9    | 5       | 1/cycle    |

#### Parameters

|            |                                    |
|------------|------------------------------------|
| <i>vra</i> | vector of 2 x unsigned doublewords |
| <i>vrb</i> | vector of 2 x unsigned doublewords |

#### Returns

vector of the absolute differences.

#### 7.11.6.2 vec\_addudm()

```
static vui64_t vec_addudm (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Add Unsigned Doubleword Modulo.

Add two vector long int values and return modulo 64-bits result.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 2       | 2/cycle    |

#### Parameters

|          |                          |
|----------|--------------------------|
| <i>a</i> | 128-bit vector long int. |
| <i>b</i> | 128-bit vector long int. |

#### Returns

vector long int sums of a and b.

#### 7.11.6.3 vec\_clzd()

```
static vui64_t vec_clzd (
 vui64_t vra) [inline], [static]
```

Count leading zeros for a vector unsigned long int.

Count leading zeros for a vector `__int128` and return the count in a vector suitable for use with vector shift (left|right) and vector shift (left|right) by octet instructions.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 2       | 2/cycle    |

#### Parameters

|            |                                                    |
|------------|----------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated a <code>__int128</code> . |
|------------|----------------------------------------------------|

#### Returns

a 128-bit vector with bits 121:127 containing the count of leading zeros.

#### 7.11.6.4 `vec_cmpeqsd()`

```
static vb64_t vec_cmpeqsd (
 vi64_t a,
 vi64_t b) [inline], [static]
```

Vector Compare Equal Signed Doubleword.

Compare each signed long (64-bit) integer and return all '1's, if `a[i] == b[i]`, otherwise all '0's.

For POWER8 (PowerISA 2.07B) or later, use the Vector Compare Equal Unsigned DoubleWord (**vcmpequd**) instruction. Otherwise use boolean logic using word compares.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |

#### Returns

128-bit vector with each dword boolean reflecting compare equal result for each element.

### 7.11.6.5 `vec_cmpequd()`

```
static vb64_t vec_cmpequd (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Compare Equal Unsigned Doubleword.

Compare each unsigned long (64-bit) integer and return all '1's, if  $a[i] == b[i]$ , otherwise all '0's.

For POWER8 (PowerISA 2.07B) or later, use the Vector Compare Equal Unsigned DoubleWord (**vcmpequd**) instruction. Otherwise use boolean logic using word compares.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

#### Returns

128-bit vector with each dword boolean reflecting compare equal result for each element.

### 7.11.6.6 `vec_cmpgesd()`

```
static vb64_t vec_cmpgesd (
 vi64_t a,
 vi64_t b) [inline], [static]
```

Vector Compare Greater Than or Equal Signed Doubleword.

Compare each signed long (64-bit) integer and return all '1's, if  $a[i] \geq b[i]$ , otherwise all '0's. Use `vec_cmpgtsd` with parameters reversed to implement `vec_cmpltud`, then return the logical inverse.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 2/cycle    |
| power9    | 5       | 2/cycle    |

#### Parameters

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |
|----------|----------------------------------------------------------------------------|



## Parameters

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| <i>b</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |
|----------|----------------------------------------------------------------------------|

## Returns

128-bit vector with each dword boolean reflecting compare greater then or equal result for each element.

## 7.11.6.7 vec\_cmpgeud()

```
static vb64_t vec_cmpgeud (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Compare Greater Than or Equal Unsigned Doubleword.

Compare each unsigned long (64-bit) integer and return all '1's, if  $a[i] \geq b[i]$ , otherwise all '0's. Use `vec_cmpgtud` with parameters reversed to implement `vec_cmpltud`, then return the logical inverse.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 2/cycle    |
| power9    | 5       | 2/cycle    |

## Parameters

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

## Returns

128-bit vector with each dword boolean reflecting compare greater then or equal result for each element.

## 7.11.6.8 vec\_cmpgtsd()

```
static vb64_t vec_cmpgtsd (
 vi64_t a,
 vi64_t b) [inline], [static]
```

Vector Compare Greater Than Signed Doubleword.

Compare each signed long (64-bit) integer and return all '1's, if  $a[i] > b[i]$ , otherwise all '0's.

For POWER8 (PowerISA 2.07B) or later use the Vector Compare Greater Than Unsigned DoubleWord (**vcmpgtud**) instruction. Otherwise use boolean logic using word compares.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

#### Returns

128-bit vector with each dword boolean reflecting compare greater result for each element.

#### 7.11.6.9 `vec_cmpgtud()`

```
static vb64_t vec_cmpgtud (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Compare Greater Than Unsigned Doubleword.

Compare each unsigned long (64-bit) integer and return all '1's, if  $a[i] > b[i]$ , otherwise all '0's.

For POWER8 (PowerISA 2.07B) or later use the Vector Compare Greater Than Unsigned DoubleWord (**vcmpgtud**) instruction. Otherwise use boolean logic using word compares.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

#### Returns

128-bit vector with each dword boolean reflecting compare greater result for each element.

## 7.11.6.10 vec\_cmplesd()

```
static vb64_t vec_cmplesd (
 vi64_t a,
 vi64_t b) [inline], [static]
```

Vector Compare Less Than Equal Signed Doubleword.

Compare each signed long (64-bit) integer and return all '1's, if  $a[i] > b[i]$ , otherwise all '0's. Use `vec_cmpgtsd` with parameters reversed to implement `vec_cmpltzd` then return the logical inverse.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 2/cycle    |
| power9    | 5       | 2/cycle    |

## Parameters

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |

## Returns

128-bit vector with each dword boolean reflecting compare greater result for each element.

## 7.11.6.11 vec\_cmpleud()

```
static vb64_t vec_cmpleud (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Compare Less Than Equal Unsigned Doubleword.

Compare each unsigned long (64-bit) integer and return all '1's, if  $a[i] > b[i]$ , otherwise all '0's. Use `vec_cmpgtud` with parameters reversed to implement `vec_cmpltud`. Use `vec_cmpgtud` then return the logical inverse.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 2/cycle    |
| power9    | 5       | 2/cycle    |

## Parameters

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

**Returns**

128-bit vector with each dword boolean reflecting compare greater result for each element.

**7.11.6.12 vec\_cmpltsd()**

```
static vb64_t vec_cmpltsd (
 vi64_t a,
 vi64_t b) [inline], [static]
```

Vector Compare less Than Signed Doubleword.

Compare each signed long (64-bit) integer and return all '1's, if  $a[i] < b[i]$ , otherwise all '0's. Use `vec_cmpgtsd` with parameters reversed to implement `vec_cmpltsd`.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |

**Returns**

128-bit vector with each dword boolean reflecting compare less result for each element.

**7.11.6.13 vec\_cmpltud()**

```
static vb64_t vec_cmpltud (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Compare less Than Unsigned Doubleword.

Compare each unsigned long (64-bit) integer and return all '1's, if  $a[i] < b[i]$ , otherwise all '0's. Use `vec_cmpgtud` with parameters reversed to implement `vec_cmpltud`.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

## Returns

128-bit vector with each dword boolean reflecting compare less result for each element.

7.11.6.14 `vec_cmpnesd()`

```
static vb64_t vec_cmpnesd (
 vi64_t a,
 vi64_t b) [inline], [static]
```

Vector Compare Not Equal Signed Doubleword.

Compare each signed long (64-bit) integer and return all '1's, if  $a[i] \neq b[i]$ , otherwise all '0's. Use `vec_cmpequd` then return the logical inverse.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 2/cycle    |
| power9    | 5       | 2/cycle    |

## Parameters

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |

## Returns

128-bit vector with each dword boolean reflecting compare not equal result for each element.

7.11.6.15 `vec_cmpneud()`

```
static vb64_t vec_cmpneud (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Compare Not Equal Unsigned Doubleword.

Compare each unsigned long (64-bit) integer and return all '1's, if  $a[i] \neq b[i]$ , otherwise all '0's. Use `vec_cmpequd` then return the logical inverse.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 2/cycle    |
| power9    | 5       | 2/cycle    |

**Parameters**

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

**Returns**

128-bit vector with each dword boolean reflecting compare not equal result for each element.

**7.11.6.16 vec\_cmpsd\_all\_eq()**

```
static int vec_cmpsd_all_eq (
 vi64_t a,
 vi64_t b) [inline], [static]
```

Vector Compare all Equal Signed Doubleword.

Compare each signed long (64-bit) integer and return true if all elements of a and b are equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |

**Returns**

boolean int for all 128-bits, true if equal, false otherwise.

**7.11.6.17 vec\_cmpsd\_all\_ge()**

```
static int vec_cmpsd_all_ge (
 vi64_t a,
 vi64_t b) [inline], [static]
```

Vector Compare all Greater Than or Equal Signed Doubleword.

Compare each signed long (64-bit) integer and return true if all elements of  $a \geq b$ .

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |

#### Returns

boolean int for all 128-bits, true if all Greater Than, false otherwise.

#### 7.11.6.18 vec\_cmpsd\_all\_gt()

```
static int vec_cmpsd_all_gt (
 vi64_t a,
 vi64_t b) [inline], [static]
```

Vector Compare all Greater Than Signed Doubleword.

Compare each signed long (64-bit) integer and return true if all elements of  $a > b$ .

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |

#### Returns

boolean int for all 128-bits, true if all Greater Than, false otherwise.

7.11.6.19 `vec_cmpsd_all_le()`

```
static int vec_cmpsd_all_le (
 vi64_t a,
 vi64_t b) [inline], [static]
```

Vector Compare all Less than equal Signed Doubleword.

Compare each signed long (64-bit) integer and return true if all elements of  $a \leq b$ .

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |

## Returns

boolean int for all 128-bits, true if all Greater Than, false otherwise.

7.11.6.20 `vec_cmpsd_all_lt()`

```
static int vec_cmpsd_all_lt (
 vi64_t a,
 vi64_t b) [inline], [static]
```

Vector Compare all Less than Signed Doubleword.

Compare each signed long (64-bit) integer and return true if all elements of  $a < b$ .

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |



**Returns**

boolean int for all 128-bits, true if all Greater Than, false otherwise.

**7.11.6.21 vec\_cmpsd\_all\_ne()**

```
static int vec_cmpsd_all_ne (
 vi64_t a,
 vi64_t b) [inline], [static]
```

Vector Compare all Not Equal Signed Doubleword.

Compare each signed long (64-bit) integer and return true if all elements of a and b are not equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |

**Returns**

boolean int for all 128-bits, true if equal, false otherwise.

**7.11.6.22 vec\_cmpsd\_any\_eq()**

```
static int vec_cmpsd_any_eq (
 vi64_t a,
 vi64_t b) [inline], [static]
```

Vector Compare any Equal Signed Doubleword.

Compare each signed long (64-bit) integer and return true if any elements of a and b are equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |

**Returns**

boolean int for all 128-bits, true if equal, false otherwise.

**7.11.6.23 vec\_cmpsd\_any\_ge()**

```
static int vec_cmpsd_any_ge (
 vi64_t a,
 vi64_t b) [inline], [static]
```

Vector Compare any Greater Than or Equal Signed Doubleword.

Compare each signed long (64-bit) integer and return true if any elements of a >= b.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |

**Returns**

boolean int for all 128-bits, true if all Greater Than, false otherwise.

**7.11.6.24 vec\_cmpsd\_any\_gt()**

```
static int vec_cmpsd_any_gt (
 vi64_t a,
 vi64_t b) [inline], [static]
```

Vector Compare any Greater Than Signed Doubleword.

Compare each signed long (64-bit) integer and return true if all elements of a > b.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |

**Returns**

boolean int for all 128-bits, true if all Greater Than, false otherwise.

**7.11.6.25 vec\_cmpsd\_any\_le()**

```
static int vec_cmpsd_any_le (
 vi64_t a,
 vi64_t b) [inline], [static]
```

Vector Compare any Less than equal Signed Doubleword.

Compare each signed long (64-bit) integer and return true if any elements of a <= b.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |

**Returns**

boolean int for any 128-bits, true if any Greater Than, false otherwise.

**7.11.6.26 vec\_cmpsd\_any\_lt()**

```
static int vec_cmpsd_any_lt (
 vi64_t a,
 vi64_t b) [inline], [static]
```

Vector Compare any Less than Signed Doubleword.

Compare each signed long (64-bit) integer and return true if any elements of  $a < b$ .

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |

#### Returns

boolean int for any 128-bits, true if any Greater Than, false otherwise.

#### 7.11.6.27 `vec_cmpsd_any_ne()`

```
static int vec_cmpsd_any_ne (
 vi64_t a,
 vi64_t b) [inline], [static]
```

Vector Compare any Not Equal Signed Doubleword.

Compare each signed long (64-bit) integer and return true if any elements of  $a$  and  $b$  are not equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit signed long integer (dword) elements. |

#### Returns

boolean int for any 128-bits, true if equal, false otherwise.

## 7.11.6.28 vec\_cmpud\_all\_eq()

```
static int vec_cmpud_all_eq (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Compare all Equal Unsigned Doubleword.

Compare each unsigned long (64-bit) integer and return true if all elements of a and b are equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

## Returns

boolean int for all 128-bits, true if equal, false otherwise.

## 7.11.6.29 vec\_cmpud\_all\_ge()

```
static int vec_cmpud_all_ge (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Compare all Greater Than or Equal Unsigned Doubleword.

Compare each unsigned long (64-bit) integer and return true if all elements of a  $\geq$  b.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

**Returns**

boolean int for all 128-bits, true if all Greater Than, false otherwise.

**7.11.6.30 vec\_cmpud\_all\_gt()**

```
static int vec_cmpud_all_gt (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Compare all Greater Than Unsigned Doubleword.

Compare each unsigned long (64-bit) integer and return true if all elements of a > b.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

**Returns**

boolean int for all 128-bits, true if all Greater Than, false otherwise.

**7.11.6.31 vec\_cmpud\_all\_le()**

```
static int vec_cmpud_all_le (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Compare all Less than equal Unsigned Doubleword.

Compare each unsigned long (64-bit) integer and return true if all elements of a <= b.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

## Returns

boolean int for all 128-bits, true if all Greater Than, false otherwise.

## 7.11.6.32 vec\_cmpud\_all\_lt()

```
static int vec_cmpud_all_lt (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Compare all Less than Unsigned Doubleword.

Compare each unsigned long (64-bit) integer and return true if all elements of  $a < b$ .

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

## Returns

boolean int for all 128-bits, true if all Greater Than, false otherwise.

## 7.11.6.33 vec\_cmpud\_all\_ne()

```
static int vec_cmpud_all_ne (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Compare all Not Equal Unsigned Doubleword.

Compare each unsigned long (64-bit) integer and return true if all elements of  $a$  and  $b$  are not equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

**Returns**

boolean int for all 128-bits, true if equal, false otherwise.

**7.11.6.34 vec\_cmpud\_any\_eq()**

```
static int vec_cmpud_any_eq (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Compare any Equal Unsigned Doubleword.

Compare each unsigned long (64-bit) integer and return true if any elements of a and b are equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

**Returns**

boolean int for all 128-bits, true if equal, false otherwise.

**7.11.6.35 vec\_cmpud\_any\_ge()**

```
static int vec_cmpud_any_ge (
 vui64_t a,
 vui64_t b) [inline], [static]
```



Vector Compare any Greater Than or Equal Unsigned Doubleword.

Compare each unsigned long (64-bit) integer and return true if any elements of  $a \geq b$ .

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

#### Returns

boolean int for all 128-bits, true if all Greater Than, false otherwise.

#### 7.11.6.36 vec\_cmpud\_any\_gt()

```
static int vec_cmpud_any_gt (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Compare any Greater Than Unsigned Doubleword.

Compare each unsigned long (64-bit) integer and return true if all elements of  $a > b$ .

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

#### Returns

boolean int for all 128-bits, true if all Greater Than, false otherwise.

7.11.6.37 `vec_cmpud_any_le()`

```
static int vec_cmpud_any_le (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Compare any Less than equal Unsigned Doubleword.

Compare each unsigned long (64-bit) integer and return true if any elements of  $a \leq b$ .

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

## Returns

boolean int for any 128-bits, true if any Greater Than, false otherwise.

7.11.6.38 `vec_cmpud_any_lt()`

```
static int vec_cmpud_any_lt (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Compare any Less than Unsigned Doubleword.

Compare each unsigned long (64-bit) integer and return true if any elements of  $a < b$ .

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

**Returns**

boolean int for any 128-bits, true if any Greater Than, false otherwise.

**7.11.6.39 vec\_cmpud\_any\_ne()**

```
static int vec_cmpud_any_ne (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Compare any Not Equal Unsigned Doubleword.

Compare each unsigned long (64-bit) integer and return true if any elements of a and b are not equal.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4-9     | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|          |                                                                              |
|----------|------------------------------------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |
| <i>b</i> | 128-bit vector treated as 2 x 64-bit unsigned long integer (dword) elements. |

**Returns**

boolean int for any 128-bits, true if equal, false otherwise.

**7.11.6.40 vec\_maxsd()**

```
static vi64_t vec_maxsd (
 vi64_t vra,
 vi64_t vrb) [inline], [static]
```

Vector Maximum Signed Doubleword.

For each doubleword element [0|1] of vra and vrb compare as signed integers and return the larger value in the result.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|                    |                          |
|--------------------|--------------------------|
| <i>vra</i>         | 128-bit vector long int. |
| <i>vr</i> <i>b</i> | 128-bit vector long int. |

## Returns

vector long maximum of a and b.

7.11.6.41 `vec_maxud()`

```
static vui64_t vec_maxud (
 vui64_t vra,
 vui64_t vrb) [inline], [static]
```

Vector Maximum Unsigned Doubleword.

For each doubleword element [0|1] of *vra* and *vr**b* compare as unsigned integers and return the larger value in the result.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|                    |                          |
|--------------------|--------------------------|
| <i>vra</i>         | 128-bit vector long int. |
| <i>vr</i> <i>b</i> | 128-bit vector long int. |

## Returns

vector unsigned long maximum of a and b.

7.11.6.42 `vec_minsd()`

```
static vi64_t vec_minsd (
 vi64_t vra,
 vi64_t vrb) [inline], [static]
```

Vector Minimum Signed Doubleword.

For each doubleword element [0|1] of *vra* and *vr**b* compare as signed integers and return the smaller value in the result.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|            |                          |
|------------|--------------------------|
| <i>vra</i> | 128-bit vector long int. |
| <i>vrh</i> | 128-bit vector long int. |

#### Returns

vector long minimum of a and b.

#### 7.11.6.43 vec\_minud()

```
static vui64_t vec_minud (
 vui64_t vra,
 vui64_t vrh) [inline], [static]
```

Vector Minimum Unsigned Doubleword.

For each doubleword element [0|1] of vra and vrh compare as unsigned integers and return the smaller value in the result.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|            |                                   |
|------------|-----------------------------------|
| <i>vra</i> | 128-bit vector unsigned long int. |
| <i>vrh</i> | 128-bit vector unsignedlong int.  |

#### Returns

vector unsigned long minimum of a and b.

#### 7.11.6.44 vec\_mrgahd()

```
static vui64_t vec_mrgahd (
 vui128_t vra,
 vui128_t vrh) [inline], [static]
```

Vector Merge Algebraic High Doublewords.

Merge only the high doublewords from 2 x Algebraic quadwords across vectors *vra* and *vrh*. This is effectively the Vector Merge Even Doubleword operation that is not modified for endian.

For example, merge the high 64-bits from 2 x 128-bit products as generated by `vec_muleud/vec_muloud`. This result is effectively a vector multiply high unsigned doubleword.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 2       | 2/cycle    |

#### Parameters

|            |                                                 |
|------------|-------------------------------------------------|
| <i>vra</i> | 128-bit vector unsigned <code>__int128</code> . |
| <i>vrh</i> | 128-bit vector unsigned <code>__int128</code> . |

#### Returns

A vector merge from only the high doublewords of the 2 x algebraic quadwords across *vra* and *vrh*.

#### 7.11.6.45 `vec_mrgald()`

```
static vui64_t vec_mrgald (
 vui128_t vra,
 vui128_t vrh) [inline], [static]
```

Vector Merge Algebraic Low Doublewords.

Merge only the low doublewords from 2 x Algebraic quadwords across vectors *vra* and *vrh*. This effectively the Vector Merge Odd doubleword operation that is not modified for endian.

For example, merge the low 64-bits from 2 x 128-bit products as generated by `vec_muleud/vec_muloud`. This result is effectively a vector multiply low unsigned doubleword.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 2       | 2/cycle    |

#### Parameters

|            |                                                 |
|------------|-------------------------------------------------|
| <i>vra</i> | 128-bit vector unsigned <code>__int128</code> . |
| <i>vrh</i> | 128-bit vector unsigned <code>__int128</code> . |

**Returns**

A vector merge from only the low doublewords of the 2 x algebraic quadwords across vra and vrb.

**7.11.6.46 vec\_mrged()**

```
static vui64_t vec_mrged (
 vui64_t __VA,
 vui64_t __VB) [inline], [static]
```

Vector Merge Even Doubleword. Merge the even doubleword elements from two vectors into the high and low doubleword elements of the result. This is effectively the VSX Permute Doubleword Immediate operation modified for endian.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|                   |                                                                |
|-------------------|----------------------------------------------------------------|
| <code>__VA</code> | a 128-bit vector as the source of the results even doubleword. |
| <code>__VB</code> | a 128-bit vector as the source of the results odd doubleword.  |

**Returns**

A vector merge from only the even doublewords of the 2 x quadwords across `__VA` and `__VB`.

**7.11.6.47 vec\_mrghd()**

```
static vui64_t vec_mrghd (
 vui64_t __VA,
 vui64_t __VB) [inline], [static]
```

Vector Merge High Doubleword. Merge the high doubleword elements from two vectors into the high and low doubleword elements of the result. This is effectively the VSX Permute Doubleword Immediate operation modified for endian.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|                   |                                                                |
|-------------------|----------------------------------------------------------------|
| <code>__VA</code> | a 128-bit vector as the source of the results even doubleword. |
| <code>__VB</code> | a 128-bit vector as the source of the results odd doubleword.  |

**Returns**

A vector merge from only the high doublewords of the 2 x quadwords across `__VA` and `__VB`.

**7.11.6.48 `vec_mrgld()`**

```
static vui64_t vec_mrgld (
 vui64_t __VA,
 vui64_t __VB) [inline], [static]
```

Vector Merge Low Doubleword. Merge the low doubleword elements from two vectors into the high and low doubleword elements of the result. This is effectively the VSX Permute Doubleword Immediate operation modified for endian.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|                   |                                                                |
|-------------------|----------------------------------------------------------------|
| <code>__VA</code> | a 128-bit vector as the source of the results even doubleword. |
| <code>__VB</code> | a 128-bit vector as the source of the results odd doubleword.  |

**Returns**

A vector merge from only the low doublewords of the 2 x quadwords across `__VA` and `__VB`.

**7.11.6.49 `vec_mrgod()`**

```
static vui64_t vec_mrgod (
 vui64_t __VA,
 vui64_t __VB) [inline], [static]
```

Vector Merge Odd Doubleword. Merge the odd doubleword elements from two vectors into the high and low doubleword elements of the result. This is effectively the VSX Permute Doubleword Immediate operation modified for endian.



| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|                   |                                                                |
|-------------------|----------------------------------------------------------------|
| <code>__VA</code> | a 128-bit vector as the source of the results even doubleword. |
| <code>__VB</code> | a 128-bit vector as the source of the results odd doubleword.  |

#### Returns

A vector merge from only the odd doublewords of the 2 x quadwords across `__VA` and `__VB`.

##### 7.11.6.50 `vec_msumudm()`

```
static vuil28_t vec_msumudm (
 vui64_t a,
 vui64_t b,
 vuil28_t c) [inline], [static]
```

Vector Multiply-Sum Unsigned Doubleword Modulo.

#### Note

this implementation exists in [vec\\_int128\\_ppc::h::vec\\_msumudm\(\)](#) as it requires [vec\\_adduqm\(\)](#).

##### 7.11.6.51 `vec_muleud()`

```
static vuil28_t vec_muleud (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Multiply Even Unsigned Doublewords.

#### Note

this implementation exists in [vec\\_int128\\_ppc::h::vec\\_muleud\(\)](#) as it requires `vec_vmuleud` and [vec\\_adduqm\(\)](#).

7.11.6.52 `vec_mulhud()`

```
static vui64_t vec_mulhud (
 vui64_t vra,
 vui64_t vrb) [inline], [static]
```

Vector Multiply High Unsigned Doubleword.

**Note**

this implementation exists in `vec_int128_ppc::h::vec_mulhud()` as it requires `vec_vmuleud()` and `vec_vmuloud()`.

7.11.6.53 `vec_muloud()`

```
static vui128_t vec_muloud (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Multiply Odd Unsigned Doublewords.

**Note**

this implementation exists in `vec_int128_ppc::h::vec_muloud()` as it requires `vec_vmuloud()` and `vec_adduqm()`.

7.11.6.54 `vec_muludm()`

```
static vui64_t vec_muludm (
 vui64_t vra,
 vui64_t vrb) [inline], [static]
```

Vector Multiply Unsigned Doubleword Modulo.

**Note**

this implementation exists in `vec_int128_ppc::h::vec_muludm()` as it requires `vec_vmuleud()` and `vec_vmuloud()`.

7.11.6.55 `vec_pasted()`

```
static vui64_t vec_pasted (
 vui64_t __VH,
 vui64_t __VL) [inline], [static]
```

Vector doubleword paste. Concatenate the high doubleword of the 1st vector with the low double word of the 2nd vector.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|                   |                                                              |
|-------------------|--------------------------------------------------------------|
| <code>__VH</code> | a 128-bit vector as the source of the high order doubleword. |
| <code>__VL</code> | a 128-bit vector as the source of the low order doubleword.  |

#### Returns

The combined 128-bit vector composed of the high order doubleword of `__VH` and the low order doubleword of `__VL`.

#### 7.11.6.56 vec\_permdi()

```
static vui64_t vec_permdi (
 vui64_t vra,
 vui64_t vrb,
 const int ctl) [inline], [static]
```

Vector Permute Doubleword Immediate. Combine a doubleword selected from the 1st (*vra*) vector with a doubleword selected from the 2nd (*vr**b*) vector.

#### Note

This function implements the operation of a VSX Permute Doubleword Immediate instruction. This implementation is NOT Endian sensitive and the function is stable across BE/LE implementations.

The 2-bit control operand (*ctl*) selects which doubleword from the 1st and 2nd vector operands are transferred to the result vector. Control table:

| ctl | vrt[0:63]   | vrt[64:127]          |
|-----|-------------|----------------------|
| 0   | vra[0:63]   | vr <b>b</b> [0:63]   |
| 1   | vra[0:63]   | vr <b>b</b> [64:127] |
| 2   | vra[64:127] | vr <b>b</b> [0:63]   |
| 3   | vra[64:127] | vr <b>b</b> [64:127] |

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|            |                                                                                                                             |
|------------|-----------------------------------------------------------------------------------------------------------------------------|
| <i>vra</i> | a 128-bit vector as the source of the high order doubleword of the result.                                                  |
| <i>vrb</i> | a 128-bit vector as the source of the low order doubleword of the result.                                                   |
| <i>ctl</i> | const integer where the low order 2 bits control the selection of doublewords from input vector <i>vra</i> and <i>vrb</i> . |

**Returns**

The combined 128-bit vector composed of the high order doubleword of *vra* and the low order doubleword of *vrb*.

**7.11.6.57 vec\_popcntd()**

```
static vui64_t vec_popcntd (
 vui64_t vra) [inline], [static]
```

Vector Population Count doubleword.

Count the number of '1' bits (0-64) within each doubleword element of a 128-bit vector.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 4       | 2/2 cycles |
| power9    | 3       | 2/cycle    |

For POWER8 (PowerISA 2.07B) or later use the Vector Population Count DoubleWord (**vpopcntd**) instruction. Otherwise use the pveclib `vec_popcntw` to count each word then sum across with Vector Sum across Half Signed Word Saturate (**vsum2sws**).

**Parameters**

|            |                                                                 |
|------------|-----------------------------------------------------------------|
| <i>vra</i> | 128-bit vector treated as 2 x 64-bit integer (dwords) elements. |
|------------|-----------------------------------------------------------------|

**Returns**

128-bit vector with the population count for each dword element.

**7.11.6.58 vec\_revbd()**

```
static vui64_t vec_revbd (
 vui64_t vra) [inline], [static]
```

byte reverse each doubleword for a vector unsigned long int.

For each doubleword of the input vector, reverse the order of bytes / octets within the doubleword.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-11    | 2/cycle    |
| power9    | 3       | 2/cycle    |

**Parameters**

|            |                                     |
|------------|-------------------------------------|
| <i>vra</i> | a 128-bit vector unsigned long int. |
|------------|-------------------------------------|

**Returns**

a 128-bit vector with the bytes of each doubleword reversed.

**7.11.6.59 vec\_rldi()**

```
static vui64_t vec_rldi (
 vui64_t vra,
 const unsigned int shb) [inline], [static]
```

Vector Rotate left Doubleword Immediate.

Rotate left each doubleword element [0-1], 0-63 bits, as specified by an immediate value. The rotate amount is a const unsigned int in the range 0-63. A rotate count of 0 returns the original value of vra. Shift counts greater than 63 bits handled modulo 64.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-4     | 2/cycle    |
| power9    | 2-5     | 2/cycle    |

**Parameters**

|            |                                                         |
|------------|---------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector unsigned long int. |
| <i>shb</i> | rotate amount in the range 0-63.                        |

**Returns**

128-bit vector unsigned long int, shifted left shb bits.

**7.11.6.60 vec\_sldi()**

```
static vui64_t vec_sldi (
 vui64_t vra,
 const unsigned int shb) [inline], [static]
```

Vector Shift left Doubleword Immediate.

Shift left each doubleword element [0-1], 0-63 bits, as specified by an immediate value. The shift amount is a const unsigned long int in the range 0-63. A shift count of 0 returns the original value of *vra*. Shift counts greater than 63 bits return zero.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-4     | 2/cycle    |
| power9    | 2-5     | 2/cycle    |

#### Parameters

|            |                                                         |
|------------|---------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector unsigned long int. |
| <i>shb</i> | shift amount in the range 0-63.                         |

#### Returns

128-bit vector unsigned long int, shifted left *shb* bits.

#### 7.11.6.61 vec\_splatd()

```
static vui64_t vec_splatd (
 vui64_t vra,
 const int ctl) [inline], [static]
```

Vector splat doubleword. Duplicate the selected doubleword element across the doubleword elements of the result. This is effectively the VSX Merge doubleword operation modified for endian.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

The 1-bit control operand (*ctl*) selects which (0:1) doubleword element, from the vector operand, is replicated to both doublewords of the result vector. Control table:

| ctl | vrt[0]         | vrt[1]         |
|-----|----------------|----------------|
| 0   | <i>vra</i> [0] | <i>vra</i> [0] |
| 1   | <i>vra</i> [1] | <i>vra</i> [1] |

#### Parameters

|            |                                                 |
|------------|-------------------------------------------------|
| <i>vra</i> | a 128-bit vector.                               |
| <i>ctl</i> | a const integer encoding the source doubleword. |

**Returns**

The original vector with the doubleword elements swapped.

**7.11.6.62 vec\_spltd()**

```
static vui64_t vec_spltd (
 vui64_t vra,
 const int ctl) [inline], [static]
```

**Deprecated** Vector splat doubleword. Duplicate the selected doubleword element across the doubleword elements of the result.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

The 1-bit control operand (ctl) selects which (0:1) doubleword element, from the vector operand, is replicated to both doublewords of the result vector. Control table:

| ctl | vrt[0:63]   | vrt[64:127] |
|-----|-------------|-------------|
| 0   | vra[0:63]   | vra[0:63]   |
| 1   | vra[64:127] | vra[64:127] |

**Parameters**

|            |                                                 |
|------------|-------------------------------------------------|
| <i>vra</i> | a 128-bit vector.                               |
| <i>ctl</i> | a const integer encoding the source doubleword. |

**Returns**

The original vector with the doubleword elements swapped.

**7.11.6.63 vec\_sradi()**

```
static vi64_t vec_sradi (
 vi64_t vra,
 const unsigned int shb) [inline], [static]
```

Vector Shift Right Algebraic Doubleword Immediate.

Shift Right Algebraic each doubleword element [0-1], 0-63 bits, as specified by an immediate value. The shift amount is a const unsigned int in the range 0-63. A shift count of 0 returns the original value of vra. Shift counts greater then 63 bits return the sign bit propagated to each bit of each element.



| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-4     | 2/cycle    |
| power9    | 2-5     | 2/cycle    |

#### Parameters

|            |                                                       |
|------------|-------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector signed long int. |
| <i>shb</i> | shift amount in the range 0-63.                       |

#### Returns

128-bit vector signed long int, shifted right shb bits.

#### 7.11.6.64 vec\_srdi()

```
static vui64_t vec_srdi (
 vui64_t vra,
 const unsigned int shb) [inline], [static]
```

Vector Shift Right Doubleword Immediate.

Shift Right each doubleword element [0-1], 0-63 bits, as specified by an immediate value. The shift amount is a const unsigned int in the range 0-63. A shift count of 0 returns the original value of vra. Shift counts greater than 63 bits return zero.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2-4     | 2/cycle    |
| power9    | 2-5     | 2/cycle    |

#### Parameters

|            |                                                         |
|------------|---------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as a vector unsigned long int. |
| <i>shb</i> | shift amount in the range 0-63.                         |

#### Returns

128-bit vector unsigned long int, shifted right shb bits.

7.11.6.65 `vec_subudm()`

```
static vui64_t vec_subudm (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Subtract Unsigned Doubleword Modulo.

For each unsigned long (64-bit) integer element  $c[i] = a[i] + \text{NOT}(b[i]) + 1$ .

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 2       | 2/cycle    |

For POWER8 (PowerISA 2.07B) or later use the Vector Subtract Unsigned Doubleword Modulo (**vsubudm**) instruction. Otherwise use vector add word modulo forms and propagate the carry bits.

## Parameters

|          |                                                  |
|----------|--------------------------------------------------|
| <i>a</i> | 128-bit vector treated as 2 X unsigned long int. |
| <i>b</i> | 128-bit vector treated as 2 X unsigned long int. |

## Returns

vector unsigned long int sum of  $a[0] + \text{NOT}(b[0]) + 1$  and  $a[1] + \text{NOT}(b[1]) + 1$ .

7.11.6.66 `vec_swapd()`

```
static vui64_t vec_swapd (
 vui64_t vra) [inline], [static]
```

Vector doubleword swap. Exchange the high and low doubleword elements of a vector.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

## Parameters

|            |                   |
|------------|-------------------|
| <i>vra</i> | a 128-bit vector. |
|------------|-------------------|

**Returns**

The original vector with the doubleword elements swapped.

**7.11.6.67 vec\_vmadd2eud()**

```
static vui128_t vec_vmadd2eud (
 vui64_t a,
 vui64_t b,
 vui64_t c,
 vui64_t d) [inline], [static]
```

Vector Multiply-Add2 Even Unsigned Doublewords.

**Note**

this implementation exists in [vec\\_int128\\_ppc::h::vec\\_vmadd2eud\(\)](#) as it requires [vec\\_msumudm\(\)](#) and [vec\\_↵ adduqm\(\)](#).

**7.11.6.68 vec\_vmadd2euw()**

```
static vui64_t vec_vmadd2euw (
 vui32_t a,
 vui32_t b,
 vui32_t c,
 vui32_t d) [inline], [static]
```

Vector Multiply-Add2 Even Unsigned Words.

Multiply the even 32-bit Words of vector unsigned int values ( $a * b$ ) and return sums of the unsigned 64-bit product and the even 32-bit words of c and d ( $a_{\text{even}} * b_{\text{even}} + \text{EXTZ}(c_{\text{even}} + \text{EXTZ}(d_{\text{even}}))$ ).

**Note**

The advantage of this form (versus Multiply-Sum) is that the final 64 bit sums can not overflow.  
This implementation is NOT endian sensitive and the function is stable across BE/LE implementations.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 9       | 1/cycle    |
| power9    | 9       | 1/cycle    |

## Parameters

|          |                              |
|----------|------------------------------|
| <i>a</i> | 128-bit vector unsigned int. |
| <i>b</i> | 128-bit vector unsigned int. |
| <i>c</i> | 128-bit vector unsigned int. |
| <i>d</i> | 128-bit vector unsigned int. |

## Returns

vector unsigned long int sum ( $a_{\text{even}} * b_{\text{even}}$ ) + EXTZ( $c_{\text{even}}$ ) + EXTZ( $d_{\text{even}}$ ).

7.11.6.69 `vec_vmadd2oud()`

```
static vui128_t vec_vmadd2oud (
 vui64_t a,
 vui64_t b,
 vui64_t c,
 vui64_t d) [inline], [static]
```

Vector Multiply-Add2 Odd Unsigned Doublewords.

## Note

this implementation exists in `vec_int128_ppc::h::vec_vmadd2oud()` as it requires `vec_msumudm()` and `vec_↵ adduqm()`.

7.11.6.70 `vec_vmadd2ouw()`

```
static vui64_t vec_vmadd2ouw (
 vui32_t a,
 vui32_t b,
 vui32_t c,
 vui32_t d) [inline], [static]
```

Vector Multiply-Add2 Odd Unsigned Words.

Multiply the odd 32-bit Words of vector unsigned int values ( $a * b$ ) and return sums of the unsigned 64-bit product and the odd 32-bit words of  $c$  and  $d$  ( $a_{\text{odd}} * b_{\text{odd}}$ ) + EXTZ( $c_{\text{odd}}$ ) + EXTZ( $d_{\text{odd}}$ ).

## Note

The advantage of this form (versus Multiply-Sum) is that the final 64 bit sums can not overflow.  
This implementation is NOT endian sensitive and the function is stable across BE/LE implementations.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 9       | 1/cycle    |
| power9    | 9       | 1/cycle    |

#### Parameters

|          |                              |
|----------|------------------------------|
| <i>a</i> | 128-bit vector unsigned int. |
| <i>b</i> | 128-bit vector unsigned int. |
| <i>c</i> | 128-bit vector unsigned int. |
| <i>d</i> | 128-bit vector unsigned int. |

#### Returns

vector unsigned long int sum ( $a_{\text{odd}} * b_{\text{odd}} + \text{EXTZ}(c_{\text{odd}} + \text{EXTZ}(d_{\text{odd}}))$ ).

##### 7.11.6.71 vec\_vmaddeud()

```
static vui128_t vec_vmaddeud (
 vui64_t a,
 vui64_t b,
 vui64_t c) [inline], [static]
```

Vector Multiply-Add Even Unsigned Doublewords.

#### Note

this implementation exists in `vec_int128_ppc::h::vec_vmaddeud()` as it requires `vec_msumudm()` and `vec_↔adduqm()`.

##### 7.11.6.72 vec\_vmaddeuw()

```
static vui64_t vec_vmaddeuw (
 vui32_t a,
 vui32_t b,
 vui32_t c) [inline], [static]
```

Vector Multiply-Add Even Unsigned Words.

Multiply the even 32-bit Words of vector unsigned int values ( $a * b$ ) and return sums of the unsigned 64-bit product and the even 32-bit words of  $c$  ( $a_{\text{even}} * b_{\text{even}} + \text{EXTZ}(c_{\text{even}})$ ).

#### Note

The advantage of this form (versus Multiply-Sum) is that the final 64 bit sums can not overflow.  
This implementation is NOT endian sensitive and the function is stable across BE/LE implementations.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 9       | 2/cycle    |
| power9    | 9       | 2/cycle    |

#### Parameters

|          |                              |
|----------|------------------------------|
| <i>a</i> | 128-bit vector unsigned int. |
| <i>b</i> | 128-bit vector unsigned int. |
| <i>c</i> | 128-bit vector unsigned int. |

#### Returns

vector unsigned long int sum ( $a_{\text{even}} * b_{\text{even}}$ ) + EXTZ( $c_{\text{even}}$ ).

#### 7.11.6.73 `vec_vmaddoud()`

```
static vui128_t vec_vmaddoud (
 vui64_t a,
 vui64_t b,
 vui64_t c) [inline], [static]
```

Vector Multiply-Add Odd Unsigned Doublewords.

#### Note

this implementation exists in `vec_int128_ppc::h::vec_vmaddoud()` as it requires `vec_msumudm()` and `vec_↵ adduqm()`.

#### 7.11.6.74 `vec_vmaddouw()`

```
static vui64_t vec_vmaddouw (
 vui32_t a,
 vui32_t b,
 vui32_t c) [inline], [static]
```

Vector Multiply-Add Odd Unsigned Words.

Multiply the odd 32-bit Words of vector unsigned int values ( $a * b$ ) and return sums of the unsigned 64-bit product and the odd 32-bit words of  $c$  ( $a_{\text{odd}} * b_{\text{odd}}$ ) + EXTZ( $c_{\text{odd}}$ ).

#### Note

The advantage of this form (versus Multiply-Sum) is that the final 64 bit sums can not overflow.  
This implementation is NOT endian sensitive and the function is stable across BE/LE implementations.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 9       | 2/cycle    |
| power9    | 9       | 2/cycle    |

**Parameters**

|          |                              |
|----------|------------------------------|
| <i>a</i> | 128-bit vector unsigned int. |
| <i>b</i> | 128-bit vector unsigned int. |
| <i>c</i> | 128-bit vector unsigned int. |

**Returns**

vector unsigned long int sum ( $a_{\text{odd}} * b_{\text{odd}} + \text{EXTZ}(c_{\text{odd}})$ ).

**7.11.6.75 vec\_vmsumeud()**

```
static vui128_t vec_vmsumeud (
 vui64_t a,
 vui64_t b,
 vui128_t c) [inline], [static]
```

Vector Multiply-Sum Even Unsigned Doublewords.

**Note**

this implementation exists in [vec\\_int128\\_ppc::h::vec\\_vmsumeud\(\)](#) as it requires [vec\\_msumudm\(\)](#) and [vec\\_↵ adduqm\(\)](#).

**7.11.6.76 vec\_vmsumoud()**

```
static vui128_t vec_vmsumoud (
 vui64_t a,
 vui64_t b,
 vui128_t c) [inline], [static]
```

Vector Multiply-Sum Odd Unsigned Doublewords.

**Note**

this implementation exists in [vec\\_int128\\_ppc::h::vec\\_vmsumoud\(\)](#) as it requires [vec\\_msumudm\(\)](#) and [vec\\_↵ adduqm\(\)](#).

### 7.11.6.77 `vec_vmsumuwmm()`

```
static vui64_t vec_vmsumuwmm (
 vui32_t vra,
 vui32_t vrb,
 vui64_t vrc) [inline], [static]
```

Vector Multiply-Sum Unsigned Word Modulo.

Multiply the unsigned word elements of *vra* and *vr**b*, internally generating doubleword products. Then generate three-way sum of adjacent doubleword product pairs, plus the doubleword elements from *vrc*. The final summation is modulo 64-bits.

#### Note

This function implements the operation of a Vector Multiply-Sum Unsigned Word Modulo instruction, if the PowerPC ISA included such an instruction. This implementation is NOT endian sensitive and the function is stable across BE/LE implementations.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 11      | 1/cycle    |
| power9    | 11      | 1/cycle    |

#### Parameters

|                    |                               |
|--------------------|-------------------------------|
| <i>vra</i>         | 128-bit vector unsigned int.  |
| <i>vr</i> <i>b</i> | 128-bit vector unsigned int.  |
| <i>vrc</i>         | 128-bit vector unsigned long. |

#### Returns

vector of doubleword elements where each is the sum of the even and odd adjacent products of the *vra* and *vr**b*, plus the corresponding doubleword element of *vrc*.

### 7.11.6.78 `vec_vmuleud()`

```
static vui128_t vec_vmuleud (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Multiply Even Unsigned Doublewords.

#### Note

this implementation exists in `vec_int128_ppc::vec_vmuleud()` as it requires `vec_msumudm()` and `vec_adduqm()`.



## 7.11.6.79 vec\_vmuloud()

```
static vui128_t vec_vmuloud (
 vui64_t a,
 vui64_t b) [inline], [static]
```

Vector Multiply Odd Unsigned Doublewords.

## Note

this implementation exists in [vec\\_int128\\_ppc::h::vec\\_vmuloud\(\)](#) as it requires [vec\\_msumudm\(\)](#) and [vec\\_adduqm\(\)](#).

## 7.11.6.80 vec\_vpkudum()

```
static vui32_t vec_vpkudum (
 vui64_t vra,
 vui64_t vrb) [inline], [static]
```

Vector Pack Unsigned Doubleword Unsigned Modulo.

The doubleword source is the concatenation of vra and vrb. For each integer word from 0 to 3, of the result vector, do the following: place the contents of bits 32:63 of the corresponding doubleword source element [i] into word element [i] of the result.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 2       | 2/cycle    |

## Note

Use vec\_vpkudum naming but only if the compiler does not define it in <altivec.h>.

## Parameters

|                    |                                                         |
|--------------------|---------------------------------------------------------|
| <i>vra</i>         | a 128-bit vector treated as 2 x unsigned long integers. |
| <i>vr</i> <i>b</i> | a 128-bit vector treated as 2 x unsigned long integers. |

## Returns

128-bit vector treated as 4 x unsigned integers.

7.11.6.81 `vec_vrld()`

```
static vui64_t vec_vrld (
 vui64_t vra,
 vui64_t vrb) [inline], [static]
```

Vector Rotate Left Doubleword.

Vector Rotate Left Doubleword 0-63 bits. The shift amount is from bits 58-63 and 122-127 of vrb.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 2       | 2/cycle    |

## Note

Use `vec_vrld` naming but only if the compiler does not define it in `<altivec.h>`.

## Parameters

|            |                                                         |
|------------|---------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as 2 x unsigned long integers. |
| <i>vrb</i> | shift amount in bits 58:63 and 122:127.                 |

## Returns

Left shifted vector unsigned long.

7.11.6.82 `vec_vslld()`

```
static vui64_t vec_vslld (
 vui64_t vra,
 vui64_t vrb) [inline], [static]
```

Vector Shift Left Doubleword.

Vector Shift Left Doubleword 0-63 bits. The shift amount is from bits 58-63 and 122-127 of vrb.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 2       | 2/cycle    |

**Note**

Can not use `vec_sld` naming here as that would conflict with the generic Shift Left Double Vector. Use `vec_vsl` but only if the compiler does not define it in `<altivec.h>`.

**Parameters**

|            |                                                         |
|------------|---------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as 2 x unsigned long integers. |
| <i>vr</i>  | shift amount in bits 58:63 and 122:127.                 |

**Returns**

Left shifted vector unsigned long.

**7.11.6.83 vec\_vsr**

```
static vi64_t vec_vsr (
 vi64_t vra,
 vui64_t vr) [inline], [static]
```

Vector Shift Right Algebraic Doubleword.

Vector Shift Right Algebraic Doubleword 0-63 bits. The shift amount is from bits 58-63 and 122-127 of *vr*.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 2       | 2/cycle    |

**Note**

Use the `vec_vsr` for consistency with `vec_vsl` above. Define `vec_vsr` only if the compiler does not define it in `<altivec.h>`.

**Parameters**

|            |                                                         |
|------------|---------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as 2 x unsigned long integers. |
| <i>vr</i>  | shift amount in bits 58:63 and 122:127.                 |

**Returns**

Right shifted vector unsigned long.

7.11.6.84 `vec_vsrld()`

```
static vui64_t vec_vsrld (
 vui64_t vra,
 vui64_t vrb) [inline], [static]
```

Vector Shift Right Doubleword.

Vector Shift Right Doubleword 0-63 bits. The shift amount is from bits 58-63 and 122-127 of vrb.

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 2       | 2/cycle    |

**Note**

Use the `vec_vsrld` for consistency with `vec_vsld` above. Define `vec_vsrld` only if the compiler does not define it in `<altivec.h>`.

**Parameters**

|            |                                                         |
|------------|---------------------------------------------------------|
| <i>vra</i> | a 128-bit vector treated as 2 x unsigned long integers. |
| <i>vrb</i> | shift amount in bits 58:63 and 122:127.                 |

**Returns**

Right shifted vector unsigned long.

7.11.6.85 `vec_xxspltd()`

```
static vui64_t vec_xxspltd (
 vui64_t vra,
 const int ctl) [inline], [static]
```

Vector splat doubleword. Duplicate the selected doubleword element across the doubleword elements of the result.

**Note**

This function implements the operation of a VSX Splat Doubleword Immediate instruction. This implementation is NOT Endian sensitive and the function is stable across BE/LE implementations.

The 1-bit control operand (ctl) selects which (0:1) doubleword element, from the vector operand, is replicated to both doublewords of the result vector. Control table:

| ctl | vrt[0:63]   | vrt[64:127] |
|-----|-------------|-------------|
| 0   | vra[0:63]   | vra[0:63]   |
| 1   | vra[64:127] | vra[64:127] |

| processor | Latency | Throughput |
|-----------|---------|------------|
| power8    | 2       | 2/cycle    |
| power9    | 3       | 2/cycle    |

#### Parameters

|            |                                                 |
|------------|-------------------------------------------------|
| <i>vra</i> | a 128-bit vector.                               |
| <i>ctl</i> | a const integer encoding the source doubleword. |

#### Returns

The original vector with the doubleword elements swapped.



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