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An overview of the FT832 CPU Core. Includes documentation on core register set, core instructions, parameters and configuration.

FT832 CPU Core

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# Overview

The design of this core has been guided by discussions on the 6502.org forum. Features of the core include truly flat 32 bit addressing and 32 bit indirect addresses. The core is 65832 backwards compatible. Also supported by this core is simple high-performance task switching. New instructions have been added to support core functionality.

# Programming Model

The programming model is compatible with the W65C816S programming model, with the addition of two new segment registers and a task register. A number of new instructions and addressing modes have been added using the opcode reserved for that purpose (the WDM opcode). There is also an array of 512 task context registers if the core is configured for hardware support of tasks.

|  |  |  |  |
| --- | --- | --- | --- |
| Register | Size |  |  |
| CS | 32 | code segment |  |
| PB | 8 | program bank |  |
| PC | 16 | program counter |  |
| Acc | 32 | accumulator |  |
| x | 32 | x index register |  |
| y | 32 | y index register |  |
| SP | 32 | stack pointer |  |
| DS | 32 | data segment |  |
| DB | 8 | data bank |  |
| DPR | 16 | direct page register |  |
| SR | 8 | status register |  |
| SRX | 8 | status register extension |  |
| TR | 16 | Task Register |  |

Task Context Register Array (present only if hardware task support is configured):

|  |  |
| --- | --- |
| Register |  |
| 0 | Register context |
| … |  |
| 511 |  |

Register Settings on Reset

|  |  |  |
| --- | --- | --- |
|  |  | Note: |
| CS | Zero | * reset to zero – required since the CS is not part of the reset vector |
| PB | $00 | * reset to zero – required since the PB is not part of the reset vector |
| PC | $FFF0 | * this register value will be overwritten and automatically loaded from the reset vector in memory on a reset |
| DS | --- | * not set by reset |
| DB | --- | “ |
| DPR | --- | “ |
| A |  | “ |
| X |  | “ |
| Y |  | “ |
| SP | $000001FF | * since the stack page is being set to page 1, the remainder of the stack pointer is set as well |
| SR | %xx0x01xx | * interrupts are masked, and decimal mode is cleared (note the m and x bits are set but not visible as part of the status register because the core starts in eight bit emulation mode). |
| SRX | %xxxxxx00 | * the emulation mode is set to eight bit, both the 32 and 16 bit emulation flags are cleared |
| TR | $00 | * the task register identifies which task is running. It is an internal register, set indirectly by the TSK instruction. |
|  |  |  |

On reset the contents of the task context register array is undefined.

## New Registers

There are two new segment registers CS and DS standing for Code Segment and Data Segment respectively. The addition of these registers is a result of discussions on 6502.org. Forum members expressed a desire to have a full 32 bit program bank and data bank registers allowing the base address of the program or data to be placed anywhere in memory. This is the function of a segment register. Rather than modify the existing program bank and data bank registers, two new segment registers were added. This allows the core to be backwards compatible with the 65816/65832 design. If desired the program bank and data bank registers may be set to zero, and the 32 bit CS and DS registers used to place code / data in memory. Alternately the CS and DS registers could be set to zero and the core used as a 65816/65832 compatible core. There are new instructions ([PHCS](#_PHCS), [PHDS](#_PHDS), [PLDS](#_PLDS)) to support use of the CS and DS registers in a manner similar to the program bank and data bank registers.

There is an extension to the status register called the SRX register, which contains the emulation mode setting bits. The emulation mode setting is stored as part of the task context. This allows the core to run different emulation modes in different tasks. The 65816/65832 doubles up on the usage of the C and V flags in the status register in order to set the processor mode. This approach was likely used in order to avoid creating another program visible register in the processor. This is acceptable because there isn’t really a need to store the emulation mode bits. A new register has been added in this design in order to support additional core options.

The task register TR is used to hold the index of the current context register. This could be thought of as the current process ID. The contents of the task register are made available with the [TTA](#_TTA) instruction. The task register is set by the task switching instructions.

## Status Register Extension

|  |  |  |
| --- | --- | --- |
| Bit |  | Usage |
| 0 | m816 | 16 bit emulation mode flag |
| 1 | m832 | 32 bit native mode operation flag |
| 2 | in | interpreter mode |
| 3 | ~ |  |
| 4 | ssm | single step mode |
| 5 | ~ |  |
| 6 | ~ |  |
| 7 | ~ |  |

## Context Registers

When configured with hardware task functionality (the default configuration) the core includes an array of 512 context registers. Each register holds an entire program visible register set. The contents of the context registers may be set using the [LDT](#_LDT) instruction (the back link field is not settable). The contents of the context register may also be inherited from the current task when the [FORK](#_FORK) instruction is executed.

Context Register Layout

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 263+ 256 | 255 224 | 223 192 | 191 168 | 167 136 | 135 104 | 103 72 | 71 40 | 39 32 | 31 24 | 23 16 | 15 0 |
| Back Link | CS | DS | PC | ACC | .X | .Y | SP | SR | SRX | DB | DPR |
| 10 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | 8 | 9 |

To switch between tasks switch the active context of the processor using the [TSK](#_TSK) instruction. The currently active context is pointed to by the task register (TR).

Memory Layout for LDT instruction:

|  |  |
| --- | --- |
| TaskStartTbl:  .WORD 0 ; CS  .WORD 0  .WORD 0 ; DS  .WORD 0  .WORD Task0 ; PC  .BYTE Task0>>16  .WORD 0 ; acc  .WORD 0  .WORD 0 ; x  .WORD 0  .WORD 0 ; y  .WORD 0  .WORD $3FFF ; sp  .WORD 0  .BYTE 0 ; SR  .BYTE 1 ; SR extension  .BYTE 0 ; DB  .WORD 0 ; DPR |  |
|  |  |

# Instruction Cache

For better performance, memory is often organized in a hierarchy that consists of caches isolating the access to main memory. Caches are faster than main memory, and higher level caches (closest to the cpu) are faster than lower leveled ones. In the FT832 cpu all instruction accesses are cached. While this doesn’t necessarily result in better instruction execution performance for the intended target of the FT832 (a PLD), it does reduce the amount of traffic on the bus. This means that systems sharing the bus can have better performance as bus availability is increased. For instance the [TSK](#_TSK) instruction takes four cycles to execute, but doesn’t use the bus. Hence the bus is available for at least four consecutive clock cycles while the TSK instruction executes.

The default instruction cache is organized as 256, 16 byte lines. An entire cache line is loaded with back-to-back memory read operations as fast as the memory system will allow. The leading byte of an instruction cache line fetch is signified with both VPA and VDA signals being active. This is similar to the first byte of an opcode fetch being signified in the same manner on the 65816.

Cache lines may be pre-loaded so that the performance of specific code is not impacted by line loads. The cache may also be invalidated on a line-by-line basis, or the entire cache can be invalidated. Cache control is via the ‘[CACHE](#_CACHE)’ command instruction. Note that invalidating or pre-loading a cache line that conflicts with the current instruction’s cache line causes the instruction’s cache line to be reloaded from memory (otherwise the core wouldn’t be able to execute instructions). Care must be taken to place code such that cache line conflicts do not occur if it is desired to preload the cache lines.

The core uses a 16 byte window into the instruction cache from which instruction data is read. All 16 bytes are available in parallel within a single clock cycle. This means that the instruction fetch time is always fixed at a single clock cycle regardless of the length of an instruction. IT also means that an instruction including any prefixes cannot be longer than 16 bytes. The window slides as the program counter value changes. This window will usually span two cache lines. On occasion it may be necessary to fetch two lines from memory in order for an instruction spanning cache lines to execute.

The instruction cache is physically indexed and tagged. The cache is driven by the address resulting from the sum of the code segment and program counter. This results in only a single image of instructions in the cache when different combinations of the program counter and code segment result in the same address.

# Segmentation Model

The segmentation model used by FT832 is extremely simple. There are only two segment registers (code and data) and addresses are formed by a simple addition to the program counter and effective data address. All data access is associated with the data segment. All instruction access is associated with the code segment. There is no way to override the association of the code segment with instruction access (program counter). For data access the segment may be overridden using one of the segment override prefixes ([CS:](#_CS:), [SEG:](#_SEG:), [SEG0](#_SEG0:), [IOS:](#_IOS:) )

On reset both the code segment and data segment registers are set to zero.

The code segment may be set using the [JMF](#_JMF), or [JSF](#_JSF) far instructions. The code segment may also be set in the task start-up record and loaded with the context via the [LDT](#_LDT) instruction.

The data segment may be set by pushing a value on the stack then pulling the data segment from the stack using the [PLDS](#_PLDS) instruction.

Notable is the lack of a stack segment. Since data in the stack is usually accessed with stack pointer relative addressing and not absolute addressing, having a stack segment is of limited usefulness. The stack pointer itself provides a level of relatively required by programs. The reason segmentation is in use here is to allow shortened address modes to be used. That’s not applicable to the stack. The programming model can be viewed as having a stack segment which is permanently set to zero. If it is desired to reference the stack with a normal data access instruction, the zero segment ([ZS:](#_ZS:)) prefix can be specified.

# Multi-Tasking

## Overview

The FT832 core has hardware support for a multi-tasking operating system. One of the requirements for the tasking system is that it be fast. A goal was that context switching be at least as fast as could be done on the 65xxx series. One of the attractive features of the 65xxx series is the limited amount of context which is required to be stored during a context switch. This results in extremely fast context switching. As a result the latency in processing interrupt routines is low. One of the problems with adding additional registers to the programming model is that the context switch time is impacted. In keeping with low latency context switches, switching contexts with the FT832 can be done in as little as four clock cycles. Unlike some other cpu’s supporting multi-tasking, the register context isn’t saved to memory during a context switch. Instead the register context is saved in a dedicated register array. Access to this register array is single cycle for storing all registers or restoring all registers. This allows the FT832 to be even faster (lower latency) for processing interrupt routines while at the same time supporting an expanded programming model.

A second requirement of the tasking system is that it be simple. Target applications of the FT832 are more for embedded systems rather than being a full-fledged workstation type processor.

## Operation

At reset the core begins running software in task #0. Since the core does not automatically load from the task start-up table at reset, it is necessary to initialize the register set manually. This is no different than the existing 65xxx series initialization requirements. See the table “Reset Settings on Reset” to determine which registers are pre-set to which values. For other tasks the entire register set may be pre-set from entries in the task start-up table.

The task start-up table is table of 32 byte entries which contain starting values for each of the processor’s program visible registers. This table may be located anywhere in memory. The processor’s internal registers are not loaded from the start-up table; just the ones that can be programmed. Entries in the start-up table may be loaded into processor’s task context registers using the [LDT](#_LDT) instruction. Loading a task context from a start-up table entry does not automatically start the task. The task will be started when it is invoked with the TSK instruction.

In native 32 bit mode task numbers are used for interrupt vectors rather than addresses. It’s lower latency to switch tasks automatically on interrupt rather than first going to an interrupt service routine. Using a task number allows the interrupt processing routine to be located anywhere in memory while the vector contents are only 16 bits.

# Assembler Notations

Since the core supports 32 bit indirect addressing a new notation is required for assembler code. Thirty-two bit indirect addresses are denoted with { } characters. For instance to access data pointed to with a 32 bit indirect address: LDA {$23},Y

The FT832 core also has operand size control prefixes. These prefixes are specified by appending a dot code onto the instruction they apply to. For instance to apply the BYT prefix to the LDA instruction use the notation “LDA.B”.

|  |  |  |
| --- | --- | --- |
| Instruction Suffix |  |  |
| .B | signed byte operand |  |
| .UB | unsigned byte operand |  |
| .H | signed half-word (16 bit) operand |  |
| .UH | unsigned half-word (16 bit) operand |  |

# New Addressing Modes

There are several new addressing modes for existing instructions. Extra-long addressing for both absolute and absolute indexed addresses is available. The extra-long addressing mode is formed by prefixing the regular absolute address modes opcode with the extended opcode indicator byte ($42). This gives access to a 32 bit offset for a number of instructions which were not supported by the absolute long address modes. Extra-long indirect addressing modes are additional addressing mode available in the same manner as extra-long addressing. The indirect address mode instructions are prefixed with the opcode extension byte ($42).

# Instruction Set Summary

## AAX

Add .X register to accumulator.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | 8A |

3 clock cycles

The C, N, V, and Z flags are updated by this instruction.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode / execute the instruction |

## ASR

This instruction shifts the accumulator to the right while preserving the sign bit.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | 0A |

3 clock cycles

The C, N, and Z flags are updated by this instruction.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode / execute the instruction |

## BGT

BGT stands for branch greater than. This is a branch based on a signed comparison of two values. It takes only the negative and zero flags into consideration. The branch is taken if both the negative and zero flags are false. Overflow can be checked with the BVS instruction prior to executing BGT.

3 clock cycles (regardless of taken or not taken).

No flags are affected by this instruction.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode / execute the instruction |

## BLE

BLE stands for branch less or equal. This is a branch based on a signed comparison of two values. Only the negative and zero flags are tested. This instruction is the same as a combination of BEQ and BMI. If an overflow check is required the BVS instruction can be used prior to executing this instruction.

3 clock cycles (regardless of taken or not taken).

No flags are affected by this instruction.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode / execute the instruction |

## CACHE

CACHE issues a command to the cache. Currently only three commands are supported:

00 – invalidate entire instruction cache, (3 clock cycles)

01 – invalidate instruction cache line identified by accumulator (3 clock cycles)

02 – preload instruction cache line identified by accumulator ( 19 clock cycles)

When the instruction cache line needs to be identified the accumulator holds the address desired to be invalidated, not the line number. The line number is determined by the address. Currently with a 16 byte cache line size the address is shifted right four times and masked with $FF to determine the line number. The cache line is loaded using back-to-back memory read operations.

Opcode Format (3 bytes)

|  |  |  |
| --- | --- | --- |
| 42 | E0 | Immediate8 |

No flags are affected by this instruction.

## CMC

This instruction complements the carry flag. While not used very often, it can be tricky to complement the carry flag. Availability of this instruction eases some programming tasks.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | 18 |

3 clock cycles

The carry flag is inverted.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode / execute the instruction |

## CS:

This is a segment override prefix indicating to use the CS register in calculating a data address rather than the DS register. This prefix is treated as part of the current instruction. No interrupt will be allowed between the prefix and following instruction.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | 1B |

2 clock cycle

No flags are affected by this instruction.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode the following instruction |
| …. | states for following instruction |

## DEX4

Decrement the .X index register by four. Similar to the DEX instruction except decrements by four rather than by one. With a 32 bit word size for most registers arrays are often 32 bits (four bytes). Indexing into word arrays requires adjusting the index by four.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | CA |

3 clock cycles

N and Z flags are affected.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode / execute the instruction |

## DEY4

Decrement the .Y index register by four. Similar to the DEY instruction except decrements by four rather than by one. With a 32 bit word size for most registers arrays are often 32 bits (four bytes). Indexing into word arrays requires adjusting the index by four.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | 88 |

3 clock cycles

N and Z flags are affected.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode / execute the instruction |

## FILL

Fill memory. Fills a block of memory with the value contained in the .X register. The .Y register along with the data bank specified in the instruction points to the beginning of the block of memory. The .Y register is incremented and the accumulator decremented until the accumulator reaches minus one. The accumulator holds one less than the count of how many bytes to fill. In 8/16 modes, at the end of the fill operation the data bank is loaded with the value specified in the instruction. The data bank setting is ignored in 32 bit mode. The MVN / MVP instructions may also be used to fill a block of memory however the FILL instruction is faster as it only performs memory stores.

In native 32 bit mode the data bank specified in the instruction is not used to determine the fill address. The block filled may span a bank boundary. The instruction remains three bytes long.

The fill operation is interruptible.

Opcode Format (3 bytes)

|  |  |  |
| --- | --- | --- |
| 42 | 44 | DBR8 |

6 clock cycles per byte stored

No flags are affected by this instruction.

Machine States:

The following machine states repeat until the store is complete.

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode / execute the instruction |
| STORE1 |  |
| STORE2 | Increment / decrement registers |
| MVN816 | Test accumulator for -1 |

## FORK

Fork starts a new task by making a copy of the current task’s registers. Note that all registers are copied including the data segment and stack pointer. It will often be desirable to subsequently set the stack pointer and possibly the data segment to new values so that the new task has its own local data. Note that a task started with FORK does not require an entry in the task start-up table or use of the LDT instruction. Since FORK inherits all the register values from the current task, the core remains in the same mode. An attempt to fork the same task as the one that is already running is ignored.

The operand to this instruction specifies which task context register to use to store the new task’s registers in.

Opcode Format:

|  |  |  |  |
| --- | --- | --- | --- |
| 42 | A0 | Immediate16 | Immediate Mode |
| 42 | AA |  | Accumulator Mode |

3 clock cycles

The task register (TR) is updated by this instruction.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode / execute the instruction |

Sample:

|  |
| --- |
| ; Since fork causes a task switch, the original task may return to the  ; instruction following the fork. Which task is actually running can be  ; determined from the task register with the [TTA](#_TTA) instruction.  FORK #1  TTA  CMP #1  BNE .0001  ; initialize the registers for task #1 as desired  ; and perform task #1 code  ...  BRA .0002  .0001:  ; continue with the original task's code  ...  .0002:  ; It is more likely that FORK be called using the accumulator as a parameter. |

## INF

The INF instruction can be used to return general information about the processor including the contents of task registers.

Bits 4 to 15 of the .X index register indicate which context to return information for. Bits 0 to 3 of the .X index register indicate which field of information to return.

|  |  |  |
| --- | --- | --- |
| X[3:0] | Information returned |  |
| 0 | CS register |  |
| 1 | DS register |  |
| 2 | Program counter and program bank |  |
| 3 | accumulator |  |
| 4 | .X index register |  |
| 5 | .Y index register |  |
| 6 | SP – stack pointer |  |
| 7 | SR,SRX – status register and extended status register |  |
| 8 | DBR – data bank register |  |
| 9 | DPR – direct page register |  |
| 10 | back link |  |
| 11 |  |  |
| 12 |  |  |
| 13 |  |  |
| 14 |  |  |
| 15 |  |  |

If bits 4 to 15 of the .X register are all ones, then INF returns global information about the core.

Global Information Returned:

|  |  |  |
| --- | --- | --- |
| X[3:0] | Information returned |  |
| 0 | core number |  |
| 1 |  |  |
| 2 |  |  |
| 3 |  |  |
| 4 |  |  |
| 5 |  |  |
| 6 |  |  |
| 7 |  |  |
| 8 |  |  |
| 9 |  |  |
| 10 |  |  |
| 11 |  |  |
| 12 |  |  |
| 13 |  |  |
| 14 |  |  |
| 15 |  |  |

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | 4A |

4 clock cycles

N and Z flags are affected.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode / select context reg |
| INF1 | obtain info, select original context reg |

## INX4

Increment the .X index register by four. Similar to the INX instruction except increments by four rather than by one. With a 32 bit word size for most registers arrays are often 32 bits (four bytes). Indexing into word arrays requires adjusting the index by four.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | E8 |

3 clock cycles

N and Z flags are affected.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode / execute the instruction |

## INY4

Increment the .Y index register by four. Similar to the INY instruction except increments by four rather than by one. With a 32 bit word size for most registers arrays are often 32 bits (four bytes). Indexing into word arrays requires adjusting the index by four.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | C8 |

3 clock cycles

N and Z flags are affected.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode / execute the instruction |

## IOS:

IOS: - forces the segment value to $FFD00000 during an address calculation, an address range reserved for I/O. The segment value is a core parameter, which has $FFD00000 as the default. This allows shorter addressing modes to be used to access the I/O. It also avoids the problem of how to find the I/O address when the data segment is in use. I/O addresses are at fixed physical locations. Modifying the data segment to be non-zero means that the I/O addresses are no longer available at the same memory locations. Without using a pre-determined segment for I/O, the I/O addresses would have to be calculated for each data segment in use.

Interrupts are not allowed between this prefix and the following instruction.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | 7B |

2 clock cycles

No flags are affected by this instruction.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode the following instruction |
| …. | states for following instruction |

## JCI

JCI – Jump to context routine indirect allows specification of a new context when jumping to a target address. The lower 24 bits of the accumulator are loaded into the program counter and program bank. The upper eight bits of the accumulator identify the context register. The specified context register is then used to set the code segment, data segment and other registers. Registers .A, .X, .Y, and flags are copied from the current context to the new one. This allows parameter passing to the routine in the new context. Note that context routines cannot be re-entrant. Calling a context routine that has already been called will form a processing loop. This is because there is only a single back-link to the caller not a stack. Care must be taken not to call context routines in a re-entrant fashion. Return from a context routine using the [RTC](#_RTC) instruction.

This instruction allows access to only the first 256 context registers. If a context register greater than 255 is required then the JCL instruction must be used.

The intended use for this instruction is in synchronous context switching where the called context will execute then return to the invoking context in a manner analogous to a subroutine call. The called context should not be asynchronous running.

The appeal of a context based routine is that the data segment and stack pointer may be private to the context routine and these registers are switched automatically by the context routine call. Calling a context based routine is also faster than a subroutine call as it is register based rather than memory based.

This instruction cannot be used to call a routine in the current context. Attempting to do so will cause the instruction to act like a NOP operation.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | 80 |

4 clock cycles

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode / save register context |
| TSK1 | load registers from context |

## JCL

JCL – Jump to context routine long allows specification of a new context when jumping to a target address. The 24 bit offset field is loaded into the program counter and program bank. The specified context register is then used to set the code segment, data segment and other registers. Registers .A, .X, .Y, and flags may copied from the current context to the new one if the preserve (P) bit is set in the instruction. This allows parameter passing to the routine in the new context. Up to 16 bytes may be popped off the stack of the caller and placed onto the context’s stack, allowing parameters to be passed on the stack.

Note that context routines cannot be re-entrant. Calling a context routine that has already been called will form a processing loop. This is because there is only a single back-link to the caller not a stack. Care must be taken not to call context routines in a re-entrant fashion. A context routine may always call a re-entrant subroutine if re-entrancy is required. Return from a context routine using the [RTC](#_RTC) instruction.

The intended use for this instruction is in synchronous context switching where the called context will execute then return to the invoking context in a manner analogous to a subroutine call. The called context should not be asynchronous running.

The appeal of a context based routine is that the data segment and stack pointer may be private to the context routine and these registers are switched automatically by the context routine call. Calling a context based routine is also faster than a subroutine call as it is register based rather than memory based.

This instruction cannot be used to call a routine in the current context. Attempting to do so will cause the instruction to act like a NOP operation.

See also the [JCR](#_JCR_1) instruction.

Opcode Format (8 bytes)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 42 | 82 | Offset24 | Context#16 | P | ~2 | Immed5 |

4 clock cycles + 2 per bytes copied on stack

Machine States:

The JCL instruction first copies the specified number of bytes from the stack into an internal buffer. The stack pointer is incremented by the number of bytes copied. Next the task registers are switched including the stack pointer. Then the internal buffer is copied back to the stack. The stack pointer is decremented by the number of bytes copied to the stack.

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode / save register context |
| LOAD2 | only if copying stack parameters |
| … | repeats for each byte copied |
| TSK1 | load registers from context |
| STORE2 | only if copying stack parameters |
| … | repeats for each byte copied |

## JCR

JCR – Jump to context routine allows specification of a new context when jumping to a target address. The 16 bit offset field is loaded into the program counter. The program bank is set to zero. The specified context register is then used to set the code segment, data segment and other registers. Registers .A, .X, .Y, and flags are copied from the current context to the new one. This allows parameter passing to the routine in the new context. Note that context routines cannot be re-entrant. Calling a context routine that has already been called will form a processing loop. This is because there is only a single back-link to the caller not a stack. Care must be taken not to call context routines in a re-entrant fashion. Return from a context routine using the [RTC](#_RTC) instruction.

Much of the time it will be desirable to implement a jump table in the called context. If this jump table is placed near the start of the code segment, then this short form addressing instruction can be used. Otherwise if a 24 bit address specification is required the [JCL](#_JCL) instruction can be used.

To conserve memory this instruction allows access to only the first 256 context registers. If a context register greater than 255 is required then the JCL instruction must be used.

The intended use for this instruction is in synchronous context switching where the called context will execute then return to the invoking context in a manner analogous to a subroutine call. The called context should not be asynchronous running.

The appeal of a context based routine is that the data segment and stack pointer may be private to the context routine and these registers are switched automatically by the context routine call. Calling a context based routine is also faster than a subroutine call as it is register based rather than memory based.

This instruction cannot be used to call a routine in the current context. Attempting to do so will cause the instruction to act like a NOP operation.

Opcode Format (5 bytes)

|  |  |  |  |
| --- | --- | --- | --- |
| 42 | 20 | Offset16 | Context#8 |

4 clock cycles

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode / save register context |
| TSK1 | load registers from context |

## JMF

JMF – Jump Far allows specification of a new segment when jumping to a target address. The 24 bit offset field is loaded into the program counter and program bank. The 32 bit segment field is loaded into the code segment register. The special segment value $FFFFFFFF causes a switch to 8 bit emulation mode. The special segment value $FFFFFFFE causes a switch to 16 bit emulation mode.

Switching to an emulation mode zeros out the code and data segments and the upper portion of the index registers.

Opcode Format (9 bytes)

|  |  |  |  |
| --- | --- | --- | --- |
| 42 | 5C | Offset24 | Segment32 |

3 clock cycles

IF switching modes, the m816, m832 flags are affected in the extended status register. The m and x bits are set to one

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode / Execute the instruction |

## JSF

JSF – Jump to Subroutine Far, allows specification of a new segment when calling a subroutine. Both the code segment and program counter value are pushed onto the stack. A total of seven bytes are pushed onto the stack.

Note that it is much faster to switch tasks with the TSK instruction than it is to jump and return from a far subroutine. In many cases when a accessing a new code segment is desired, what is really desired is to invoke a different task. For instance the operating system may be a ‘far’ distance away from code that is running. Rather than doing a far jump to operating system code, a task switch can be done instead. Synchronous calls to the operating system could be implemented with the [JCR](#_JMF) instruction.

There is a dead cycle inserted between each memory access.

Opcode Format (9 bytes)

|  |  |  |  |
| --- | --- | --- | --- |
| 42 | 22 | Offset24 | Segment32 |

17 clock cycles

No flags are affected by this instruction.

## LDT

The LDT instruction has two forms of addressing. The first, indexed addressing form allows an entry from a table to be loaded. The indexed form shifts the .X register left five times before using it to index into a table as table entries are 32 bytes in size. The .X register also indicates which task context register to load. The second form of the instruction allows loading a context register from memory without indexing; however the .X register still indicates which context register to load.

Opcode Format (6 bytes)

|  |  |  |  |
| --- | --- | --- | --- |
| 42 | 4C | Address32 | Indexed by .X |
| 42 | 6C | Address32 | non-indexed |

Memory Layout for LDT instruction:

|  |  |
| --- | --- |
| TaskStartTbl:  .WORD 0 ; CS  .WORD 0  .WORD 0 ; DS  .WORD 0  .WORD Task0 ; PC  .BYTE Task0>>16  .WORD 0 ; acc  .WORD 0  .WORD 0 ; x  .WORD 0  .WORD 0 ; y  .WORD 0  .WORD $3FFF ; sp  .WORD 0  .BYTE 0 ; SR  .BYTE 1 ; SR extension  .BYTE 0 ; DB  .WORD 0 ; DPR |  |

The LDT instruction can take a large number (44) clock cycles to execute. It has to load 32 bytes from memory into the context register. Note that in many cases the entire tasking system can be setup before interrupts are enabled. So the LDT instruction does not necessarily impact interrupt latencies. IF interrupt latency is a concern then the [FORK](#_FORK) instruction which has a much lower latency could be used to start a task. However the FORK instruction does not set new register values.

There is a dead cycle between each word (4 bytes) loaded from memory so that the instruction doesn’t hog the bus too much.

44 clock cycles

Machine States:

|  |  |  |
| --- | --- | --- |
| IFETCH | Fetch the instruction |  |
| DECODE | Decode the page 2 prefix |  |
| DECODE | Decode the instruction |  |
| LDT1 |  |  |
| LOAD2 | load LSB from memory (CS[7:0]) |  |
| LOAD2 |  |  |
| LOAD2 |  |  |
| LOAD2 | load MSB from memory (CS[31:24]) |  |
| LDT1 |  | Repeats six more times to load the remaining registers. |
| LOAD2 | load LSB from memory (DS[7:0]) |
| LOAD2 |  |
| LOAD2 |  |
| LOAD2 | load LSB from memory (DS[31:24]) |
| … |  |  |
| LDT1 | update task context registers |  |

## MUL

MUL – Performs an unsigned multiply of the .A and .X registers and leaves the product in the accumulator and .X register. When multiplying byte registers the 16 bit product is available in the .A (low order) and .B (higher order) registers. Multiply respects the register size settings.

Bits 0 to 31 of the product are placed in the accumulator.

Bits 32 to 63 of the product are placed into the .X register.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | 2A |

3 clock cycles

The N flag is set to bit 31 of the result. The Z flag is set if the result is zero. The V flag is set if the high order 32 bits of the product are non-zero.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode / execute the instruction |

## PHCS

PHCS – pushes the code segment on the stack. Four bytes are pushed onto the stack.

Bytes are written ‘back-to-back’ without dead cycles in between.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | 4B |

7 clock cycles (3 + 4 memory accesses)

No flags are affected by this instruction.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode the instruction |
| STORE2 | store MSB to memory |
| STORE2 |  |
| STORE2 |  |
| STORE2 | store LSB to memory |

## PHDS

PHDS – pushes the data segment on the stack. Four bytes are pushed onto the stack.

Bytes are written ‘back-to-back’ without dead cycles in between.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | 0B |

7 clock cycles (3 + 4 memory accesses)

No flags are affected by this instruction.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode the instruction |
| STORE2 | store LSB to memory |
| STORE2 |  |
| STORE2 |  |
| STORE2 | store MSB to memory |

## PLDS

PLDS – pulls the data segment from the stack. Four bytes are pulled from the stack.

Bytes are read ‘back-to-back’ without dead cycles in between.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | 2B |

8 clock cycles

No flags are affected by this instruction.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 prefix |
| DECODE | Decode the instruction |
| LOAD1 |  |
| LOAD2 | load LSB from memory |
| LOAD2 |  |
| LOAD2 |  |
| LOAD2 | load MSB from memory |

## RTC

The RTC instruction (return from context routine) switches contexts from the current back to the invoking context. This is accomplished by reading the back-link field in the current context register. This instruction also copies the .A, .X, .Y and flags registers to the returned context. The operation of this instruction is almost identical to the [RTT](#_RTT_1) instruction with the exception that register values are returned. Additionally, up to 255 bytes may be popped off the stack.

This instruction paired with the [JCR](#_JCR) instruction allows a context to be treated like a subroutine. The instruction is used with synchronous context calls.

Opcode Format (3 bytes)

|  |  |  |
| --- | --- | --- |
| 42 | 40 | Immed8 |

4 clock cycles

No flags are affected by this instruction.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode page 2 prefix |
| DECODE | Decode / execute –save register set |
| TASK1 | load the register set |

## RTF

The RTF instruction performs a far return from subroutine operation. This is similar to a long subroutine return operation (RTL) except that the code segment is loaded from the stack in addition to the program counter and program bank. There is a dead cycle between each byte loaded by the instruction.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | 6B |

17 clock cycles

No flags are affected by this instruction.

## 

## RTI

In native mode the RTI instruction (return from interrupt) switches tasks from the current task back to the interrupted task. This is accomplished by reading the back-link field in the current task’s context register. It has the same effect as the RTT instruction and either instruction may be used to return from an interrupt task. In emulation modes this instruction works in manner compatible with the 65c02/65c816 cores.

The RTI instruction is one byte shorter and one clock cycle faster than the RTT instruction. However this is only valid in native mode. The RTT instruction may be used in emulation modes as well as native mode.

Opcode Format (1 bytes)

|  |
| --- |
| 40 |

3 clock cycles (native mode operation)

No flags are affected by this instruction.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode / execute –save register set |
| TASK1 | load the register set |

## RTT

The RTT instruction (return from task) switches tasks from the current task back to the invoking task. This is accomplished by reading the back-link field in the current task’s context register. A full context switch takes place; all registers are restored from the context returned to. A similar operation is the [RTC](#_RTC) instruction which allows values in registers to be passed back to the invoking task.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | 60 |

4 clock cycles

All registers are restored by this instruction.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode page 2 prefix |
| DECODE | Decode / execute –save register set |
| TASK1 | load the register set |

## SEG:

SEG: - forces use of the specified segment value for address calculations. The prefix with segment value is six bytes. No interrupt is allowed to occur between the prefix and the following instruction.

Opcode Format (6 bytes)

|  |  |  |
| --- | --- | --- |
| 42 | 3B | Immediate32 |

2 clock cycle

No flags are affected by this instruction.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode / execute the prefix |
| DECODE | Decode the following instruction |
| … | continue with states for the following instruction |

## SEG0:

SEG0: - forces the segment value zero to be used during address calculations. This is only a two byte prefix. Using this prefix effectively allows access to physical addresses. It can be useful when accessing system components which are at fixed locations in memory (video frame buffer). No interrupt is allowed to occur between the prefix and the following instruction.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | 5B |

2 clock cycle

No flags are affected by this instruction.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode / execute the prefix |
| DECODE | Decode the following instruction |
| … | continue with states for the following instruction |

## TSK

The TSK instruction is similar to a subroutine call except that it invokes another task rather than a subroutine. When the TSK instruction is executed, it stores the current task number in a back-link field in the new task’s context register. This allows a task switch back to the original invoking task when the task is finished running via the [RTT](#_RTT) (return from task) instruction. An attempt to switch to the same task as the one that is already running is ignored. In that case the instruction executes in 3 clock cycles.

The context register must have been previously set by the [LDT](#_LDT) instruction, or by the [FORK](#_FORK) instruction.

The TSK instruction first stores all the program visible registers in the current context register, then loads all the program visible registers from the context register being switched to.

TSK sets the task register (TR) so that the currently running task may be identified by the processor.

The task system allows the core operating mode to be switched at task switch time.

Opcode Format:

|  |  |  |  |
| --- | --- | --- | --- |
| 42 | A2 | Immediate16 | Immediate Mode |
| 42 | 3A |  | Accumulator Mode |

4 clock cycles

All registers are affected by this instruction.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 opcode |
| DECODE | Decode and execute the instruction (save current task state) |
| TASK1 | load new task state |

## TTA

Transfer task register (TR) to accumulator. This instruction allows a program to determine which task is active. Note that there is no instruction to transfer to the task register. Transfers to the task register are accomplished by switching the task with the [TSK](#_TSK) instruction.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | 1A |

3 clock cycles

N and Z flags are affected by this instruction.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 opcode |
| DECODE | Decode and execute the instruction |

## XBAW

Exchange high order and low order word of accumulator. Bits 0 to 15 are exchanged with bits 16 to 31. Operation of this instruction is similar to the XBA instruction. This instruction can be used to obtain access to bits 16 to 31 of the multiplier product.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | EB |

3 clock cycles

N is set to bit 15 of the result. Z is set if bits 0 to 15 of the result are zero.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the page 2 opcode |
| DECODE | Decode and execute the instruction |

## ZS:

ZS: - forces the segment value zero to be used during address calculations. This is only a two byte prefix. Using this prefix effectively allows access to physical addresses. It can be useful when accessing system components which are at fixed locations in memory (video frame buffer). No interrupt is allowed to occur between the prefix and the following instruction.

Opcode Format (2 bytes)

|  |  |
| --- | --- |
| 42 | 5B |

Since this instruction eliminates the instruction fetch for the following instruction, it reduces the cycle count of the following instruction by one. This means that prefix is executed in two clock cycles.

2 clock cycle

No flags are affected by this instruction.

Machine States:

|  |  |
| --- | --- |
| IFETCH | Fetch the instruction |
| DECODE | Decode the prefix |
| DECODE | Decode the following instruction |
| … | continue with states for the following instruction |

# Core Parameters

|  |  |  |
| --- | --- | --- |
| Parameter | Default value | What it does |
| EXTRA\_LONG\_BRANCHES | 1 | Causes the core to generate hardware to support extra-long branching for the general purpose branch instructions. |
| IO\_SEGMENT | $FFD00000 | The segment value used when the IOS: prefix is present in the instruction stream |
| PC24 | 1 | Causes the program counter to be a true 24 bit program counter (increments automatically across banks). Set to zero to force a 16 bit program counter which wraps around at a bank boundary. Setting this value to zero may generate slightly less hardware and is consistent with the 65c816. |
| POPBF | 0 | If set to one, allows popping the break flag from the stack. The default setting is consistent with 65xxx operation. |
| TASK\_VECTORING | 1 | Controls whether or not the core uses task id’s for interrupt vectors instead of addresses.  This parameter must be set to zero to be consistent with 65xxx behaviour. |

# Configuration Defines

|  |  |  |
| --- | --- | --- |
|  | Default Value | What it does |
| SUPPORT\_TASK | 1 | Causes the core to include hardware for task switching. Un-defining this symbol may result in a slightly smaller core (10%). |
| TASK\_MEM | 512 | Specifies the number of entries in the task context array. This should be a power of two. Increasing this value will increase the amount of RAM used. Note that reducing this value may not result in lower RAM usage as RAM resources typically have a minimum size. |
| TASK\_MEM\_ABIT | 8 | The bit number of the most significant bit needed to access the task memory. This parameter will need to be changed to be consistent with the TASM\_MEM parameter. |
| SUPPORT\_SEG | 1 | Causes the core to implement the segmentation model. Un-defining this symbol removes the segment registers and associated instructions from the core resulting in a slightly smaller core. |
| ICACHE\_4K | 1 | Causes the core to use a 4kB instruction cache. |
| ICACHE\_16K | 0 | Causes the core to use a 16kB instruction cache. Cannot be defined at the same time as ICACHE\_4K. |
| SUPPORT\_BCD | 1 | Causes the core to include logic to support BCD addition and subtraction. BCD support is necessary to remain compatible with the 65xxx series. |
| SUPPORT\_NEW\_INSN | 1 | Causes the core to include new instructions. Commenting out this definition will significantly reduce the size of the core; however instructions supporting new core features will not be available. |

# I/O Ports

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | In/Out | Width |  |  |
| corenum | I | 32 | core number, if left unassigned zero is assumed. This input is reflected by the INF instruction. |  |
| rst | I | 1 | reset, active low – resets the core |  |
| clk | I | 1 | input clock, this clock is not directly used to clock the core. Instead it is gated internally to allow the core clock to be stopped with the STP instruction. |  |
| clko | O | 1 | output clock. – this is the input clock gated and drives the core. this clock may stop if the STP instruction is executed. |  |
| phi11 | O | 1 | Phase one of the input clock divided by 32. This is a low speed clock output designed to drive peripherals. |  |
| phi12 | O | 1 | Phase two of the input clock divided by 32. This is a low speed clock output designed to drive peripherals. |  |
| phi81 | O | 1 | Phase one of the input clock divided by 8. This is a low speed clock output designed to drive peripherals / low speed memory. |  |
| phi82 | O | 1 | Phase two of the input clock divided by 8. This is a low speed clock output designed to drive peripherals / low speed memory. |  |
| nmi | I | 1 | active low input for non-maskable interrupt |  |
| irq | I | 1 | active low input for interrupt |  |
| abort | I | 1 | active low input for abort interrupt |  |
| e | O | 1 | ‘e’ flag indicator reflects the status of the emulation flag |  |
| mx | O | 1 | m and x status output ‘m’ when clock is high, otherwise ‘x’ |  |
| rdy | I | 1 | active high ready input, pull low to insert wait states |  |
| be | I | 1 | bus enable, tri-states the address, data, and r/w lines when active |  |
| vpa | O | 1 | valid program address, set high during an instruction cache line fetch |  |
| vda | O | 1 | valid data address, set high during a data access, also set high during the first cycle of an instruction cache line fetch |  |
| mlb | O | 1 | memory lock, active high |  |
| vpb | O | 1 | vector pull, set high during a vector fetch |  |
| rw | O | 1 | read/write, active high for read, low for write cycle |  |
| ad | O | 32 | address bus |  |
| db | I/O | 8 | data bus , input for read cycles, output for write cycles |  |
|  |  |  |  |  |

# Opcode Map

Opcode Map – 8 bit mode W65C816 compatible

|  |  |
| --- | --- |
|  | = W65C816S instructions |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | -0 | -1 | -2 | -3 | -4 | -5 | -6 | -7 | -8 | -9 | -A | -B | -C | -D | -E | -F |
| 0- | BRK | ORA (d,x) | COP | ORA d,s | TSB d | ORA d | ASL d | ORA [d] | PHP | OR #i8 | ASL acc | PHD | TSB abs | ORA abs | ASL abs | ORA AL |
| 1- | BPL disp | ORA (d),y | ORA (d) | ORA (d,s),y | TRB d | OR d,x | ASL d,x | ORA [d],y | CLC | OR abs,y | INA | TAS | TRB abs | ORA abs,x | ASL abs,x | ORA AL,x |
| 2- | JSR abs | AND (d,x) | JSL abs24 | AND d,s | BIT d | AND d | ROL d | AND [d] | PLP | AND #i8 | ROL acc | PLD | BIT abs | AND abs | ROL abs | AND AL |
| 3- | BMI disp | AND (d),y | AND (d) | AND (d,s),y | BIT d,x | AND d,x | ROL d,x | AND [d],y | SEC | AND abs,y | DEA | TSA | BIT abs,x | AND abs,x | ROL abs,x | AND AL,x |
| 4- | RTI | EOR (d,x) | WDM | EOR d,s | MVP | EOR d | LSR d | EOR [d] | PHA | EOR #i8 | LSR acc | PHK | JMP abs | EOR abs | LSR abs | EOR AL |
| 5- | BVC disp | EOR (d),y | EOR (d) | EOR (d,s),y | MVN | EOR d,x | LSR d,x | EOR [d],y | CLI | EOR abs,y | PHY | TCD | JML abs24 | EOR abs,x | LSR abs,x | EOR AL,x |
| 6- | RTS | ADC (d,x) | PER | ADC d,s | STZ d | ADC d | ROR d | ADC [d] | PLA | ADC #i8 | ROR acc | RTL | JMP (abs) | ADC abs | ROR abs | ADC AL |
| 7- | BVS disp | ADC (d),y | ADC (d) | ADC (d,s),y | STZ d,x | ADC d,x | ROR d,x | ADC [d],y | SEI | ADC abs,y | PLY | TDC | JMP (abs,x) | ADC abs,x | ROR abs,x | ADC AL,x |
| 8- | BRA disp | STA (d,x) | BRL disp | STA d,s | STY d | STA d | STX d | STA [d] | DEY | BIT # | TXA | PHB | STY abs | STA abs | STX abs | STA AL |
| 9- | BCC disp | STA (d),y | STA (d) | STA (d,s),y | STY d,x | STA d,x | STX d,y | STA [d],y | TYA | STA abs,y | TXS | TXY | STZ abs | STA abs,x | STZ abs,x | STA AL,x |
| A- | LDY #i8 | LDA (d,x) | LDX #i8 | LDA d,s | LDY d | LDA d | LDX d | LDA [d] | TAY | LDA #i8 | TAX | PLB | LDY abs | LDA abs | LDX abs | LDA AL |
| B- | BCS disp | LDA (d),y | LDA (d) | LDA (d,s),y | LDY d,x | LDA d,x | LDX d,y | LDA [d],y | CLV | LDA abs,y | TSX | TYX | LDY abs,x | LDA abs,x | LDX abs,x | LDA AL,x |
| C- | CPY #i8 | CMP (d,x) | REP # | CMP d,s | CPY d | CMP d | DEC d | CMP [d] | INY | CMP #i8 | DEX | WAI | CPY abs | CMP abs | DEC abs | CMP AL |
| D- | BNE disp | CMP (d),y | CMP (d) | CMP (d,s),y | PEI | CMP d,x | DEC d,r | CMP [d],y | CLD | CMP abs,y | PHX | STP | JML (a) | CMP abs,x | DEC abs,x | CMP AL,x |
| E- | CPX #i8 | SBC(d,x) | SEP # | SBC d,s | CPX d | SUB d | INC d | SBC [d] | INX | SBC #i8 | NOP | XBA | CPX abs | SBC abs | INC abs | SBC AL, |
| F- | BEQ disp | SBC (d),y | SBC(r) | SBC (d,s),y | PEA | SUB d,x | INC d,r | SBC [d],y | SED | SBC abs,y | PLX | XCE | JSR (abs,x) | SBC abs,x | INC abs,x | SBC AL,x |

Opcode Map – Page 2 Opcodes

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | -0 | -1 | -2 | -3 | -4 | -5 | -6 | -7 | -8 | -9 | -A | -B | -C | -D | -E | -F |
| 0- | BRK2 | ORA {d,x} |  |  |  |  |  |  |  |  | ASR acc | PHDS | TSB xlabs | ORA xlabs | ASL xlabs |  |
| 1- | BGT disp | ORA {d},y | ORA {d} | ORA {d,s},y |  |  |  |  | CMC | OR xlabs,y | TTA | CS: | TRB xlabs | ORA xlabs,x | ASL xlabs,x |  |
| 2- | JCR | AND {d,x} | JSF seg:offs |  |  |  |  |  |  |  | MUL | PLDS | BIT xlabs | AND xlabs | ROL xlabs |  |
| 3- |  | AND {d},y | AND {d} | AND {d,s},y |  |  |  |  |  | AND xlabs,y | TSK acc | SEG: | BIT xlabs,x | AND xlabs,x | ROL xlabs,x |  |
| 4- | RTC | EOR {d,x} | WDM2 |  | FILL |  |  |  |  |  | INF | PHCS | LDT xlabs,x | EOR xlabs | LSR xlabs |  |
| 5- |  | EOR {d},y | EOR {d} | EOR {d,s},y |  |  |  |  |  | EOR xlabs,y |  | ZS: | JMF seg:offs | EOR xlabs,x | LSR xlabs,x |  |
| 6- | RTT | ADC {d,x} |  |  |  |  |  |  |  |  |  | RTF | LDT xlabs | ADC xlabs | ROR xlabs |  |
| 7- |  | ADC {d},y | ADC {d} | ADC {d,s},y |  |  |  |  |  | ADC xlabs,y |  | IOS: | JML [xlabs,x] | ADC xlabs,x | ROR xlabs,x |  |
| 8- | JCI | STA {d,x} | JCL |  |  |  |  |  | DEY4 |  | AAX | BYT: | STY xlabs | STA xlabs | STX xlabs |  |
| 9- |  | STA {d},y | STA {d} | STA {d,s},y |  |  |  |  |  | STA xlabs,y |  | UBT: | STZ xlabs | STA xlabs,x | STZ xlabs,x |  |
| A- | FORK # | LDA {d,x} | TSK # |  |  |  |  |  |  |  | FORK | HAF: | LDY xlabs | LDA xlabs | LDX xlabs |  |
| B- | BLE disp | LDA {d},y | LDA {d} | LDA {d,s},y |  |  |  |  |  | LDA xlabs,y |  | UHF: | LDY xlabs,x | LDA xlabs,x | LDX xlabs,x |  |
| C- |  | CMP {d,x} | REP # |  |  |  |  |  | INY4 |  | DEX4 |  | CPY xlabs | CMP xlabs | DEC xlabs |  |
| D- |  | CMP {d},y | CMP {d} | CMP {d,s},y | PEA { } |  |  |  |  | CMP xlabs,y |  | CLK | JML [xlabs] | CMP xlabs,x | DEC xlabs,x |  |
| E- | CACHE # | SBC{d,x} | SEP # |  |  |  |  |  | INX4 |  | NOP2 | XBAW | CPX xlabs | SBC xlabs | INC xlabs |  |
| F- | PCHIST | SBC {d},y | SBC{d} | SBC {d,s},y | PEA xlabs |  |  |  | NXT | SBC xlabs,y |  |  | JSL [xlabs,x] | SBC xlabs,x | INC xlabs,x |  |