
Getting Started with AT91SAM7S Microcontrollers

1. Introduction

This application note is aimed at helping the reader become familiar with the Atmel ARM® Thumb®-based AT91SAM7S microcontroller.

It describes in detail a simple project that uses several important features present on AT91SAM7S chips. This includes how to setup the microcontroller prior to executing the application, as well as how to add the functionalities themselves. After going through this guide, the reader should be able to successfully start a new project from scratch.

This document also explains how to setup and use a GNU ARM toolchain in order to compile and run a software project.

Note that the Getting Started example has been ported and is included in IAR® EWARM 4.41A; the reader should disregard the section “Building the Project” on page 16 when using this version.

To be able to use this document efficiently, the reader should be experienced in using the ARM core. For more information about the ARM core architecture, please refer to the appropriate documents available from <http://www.arm.com>.

2. Requirements

The software provided with this application notes requires several components:

- The AT91SAM7S Evaluation Kit
- A computer running Microsoft® Windows® 2000/XP
- An ARM cross-compiler toolchain (such as YAGARTO)
- AT91-ISP V1.8 or later



AT91 ARM Thumb Microcontrollers

Application Note



3. Getting Started with a Software Example

This section describes how to program a basic application that helps you to become familiar with AT91SAM7S microcontrollers. It is divided into two main sections: the first one covers the specification of the example (what it does, what peripherals are used); the other details the programming aspect.

3.1 Specification

3.1.1 Features

The demonstration program makes two LEDs on the board blink at a fixed rate. This rate is generated by using a timer for the first LED; the second one uses a Wait function based on a 1 ms tick. The blinking can be stopped using two buttons (one for each LED).

While this software may look simple, it uses several peripherals which make up the basis of an operating system. As such, it makes a good starting point for someone wanting to become familiar with the AT91SAM microcontroller series.

3.1.2 Peripherals

In order to perform the operations described in the previous section, the software example uses the following set of peripherals:

- Parallel Input/Output (PIO) controller
- Timer Counter (TC)
- Periodic Interval Timer (PIT)
- Advanced Interrupt Controller (AIC)
- Debug Unit (DBGU)

LEDs and buttons on the board are connected to standard input/output pins of the chip; those are managed by a PIO controller. In addition, it is possible to have the controller generate an interrupt when the status of one of its pins changes; buttons are configured to have this behavior.

The TC and PIT are used to generate two time bases, in order to obtain the LED blinking rates. They are both used in interrupt mode: the TC triggers an interrupt at a fixed rate, each time toggling the LED state (on/off). The PIT triggers an interrupt every millisecond, incrementing a variable by one tick; the Wait function monitors this variable to provide a precise delay for toggling the second LED state.

Using the AIC is required to manage interrupts. It allows the configuration of a separate vector for each source; three different functions are used to handle PIO, TC and PIT interrupts.

Finally, an additional peripheral is used to output debug traces on a serial line: the DBGU. Having the firmware send debug traces at key points of the code can greatly help the debugging process.

3.1.3 Evaluation Kit

3.1.3.1 Booting

The AT91SAM7S256 found on AT91SAM7S-EK evaluation boards features two internal memories: a 256 KB Flash and a 64 KB SRAM. The Getting Started example software can be compiled and loaded on both.

3.1.3.2 Buttons

The AT91SAM7S Evaluation Kit features four pushbuttons, connected to pins PA19, PA20, PA14 and PA15. When pressed, they force a logical low level on the corresponding PIO line.

The Getting Started example uses the first two buttons (PA19 and PA20).

3.1.3.3 LEDs

There are four general-purpose green LEDs on the AT91SAM7S-EK; they are wired to pins PA0, PA1, PA2 and PA3. Setting a logical low level on one of these PIO lines turns the corresponding LED on.

The example application uses the first two LEDs (PA0 and PA1).

3.1.3.4 Debug Unit

On the AT91SAM7S, the Debug Unit uses pins PA9 and PA10 for the DRXD and DTXD signals, respectively.

3.2 Implementation

As stated previously, the example defined above requires the use of several peripherals. It must also provide the necessary code for starting up the microcontroller. Both aspects are described in detail in this section, with commented source code when appropriate.

3.2.1 C-Startup

Most of the code of an embedded application is written in C. This makes the program easier to understand, more portable and modular. However, using the C language requires the initialization of several components. These initialization procedures must be performed using assembly language, and are grouped into a file referred to as **C-startup**. The C-startup code must:

- Provide exception vectors
- Initialize critical peripherals
- Initialize stacks
- Initialize memory segments

These steps are described in the following paragraphs. More information about startup code can be found in the *AT91 Assembler Code Startup Sequence for C Code Applications Software* application note (literature no. 2644), available on <http://www.atmel.com>.

3.2.1.1 Exception Vectors

When an exception occurs (e.g., data abort, undefined instruction, IRQ, etc.), the core instantly jumps to one of the 8 instructions located between addresses 0x00 and 0x1C.

If the program does not need to handle an exception, then the corresponding instruction can simply be set to an infinite loop, i.e. a branch to the same address. For vectors which are to be handled, a branch instruction to a function must be provided. Since address 0x00 is used after a Reset, the associated branch must always jump to the beginning of the code.

In this example, the only relevant vector is the one for IRQs (excluding the Reset vector). It must simply branch to the IRQ handler, which is described in [Section 3.2.1.2 on page 4](#).

The code for all eight vectors looks like this:

```
reset_vector:
    ldr pc, =reset_handler
```

```

undef_vector:
    b undef_vector /* Undefined Instruction */
swi_vector:
    b swi_vector /* Software Interrupt */
pabt_vector:
    ldr pc, =pabt_handler /* Prefetch Abort */
dabt_vector:
    ldr pc, =dabt_handler /* Data Abort */
rsvd_vector:
    b rsvd_vector /* reserved */
irq_vector:
    b irq_handler /* IRQ : read the AIC */
fiq_vector:
    b fiq_vector /* FIQ */

```

3.2.1.2 Exception Vectors: IRQ Handler

The main purpose of the IRQ handler is to fetch the correct jump address for the pending interrupt. This information is held in the Interrupt Vector Register (IVR) of the AIC (see [Section 3.2.3 on page 8](#) for more information about the AIC). Once the address is loaded, the handler just branches to it. This is done as follows:

```

ldr r14, =AT91C_BASE_AIC
ldr r0, [r14, #AIC_IVR]
bx r0

```

Registers r0 to 12 are not banked, which means they are shared between (almost) all modes. Since r0-r3 and r12 are defined as scratch registers by the ARM C calling convention, they must be saved prior to the jump. In addition, r14 contains the interrupt handler return address plus 4, so it must also be decremented and then saved. The following code saves registers on the stack and jumps to the interrupt vector:

```

sub r14, r14, #4
stmfd sp!, {r0-r3, r12, r14}
ldr r14, =AT91C_BASE_AIC
ldr r0, [r14, #AIC_IVR]
bx r0

```

The final step is to acknowledge the pending interrupt in the AIC (by writing anything in the End Of Interrupt Command Register), restore registers and then jump back to the main program:

```

ldr r14, =AT91C_BASE_AIC
str r14, [r14, #AIC_EOICR]
ldmfd sp!, {r0-r3, r12, pc}^

```

Note that such a handler does not allow for nested interrupts (since IRQs are masked when the core enters the IRQ mode).

3.2.1.3 Low-Level Initialization

The first step of the initialization process is to configure critical peripherals:

- Embedded Flash Controller (EFC)
- Main oscillator and its PLL
- Advanced Interrupt Controller

- Watchdog

These operations are often grouped into one C function. Since it is likely the function tries to access the stack, the stack pointer (r13) must be set to the top memory address before the call:

```
ldr sp, =STACK_ADDR
ldr r0, =AT91C_LowLevelInit
mov lr, pc
bx r0
```

After carrying out all of these actions, the program can jump to the main application.

The following sections explain why these peripherals are considered critical, and detail the required operations to configure them properly.

3.2.1.4 Low-Level Initialization: Embedded Flash Controller

Whenever the microcontroller core runs too fast for the internal Flash, it uses one or more **wait states**, i.e. cycles during which it does nothing but wait for the memory. The number of wait states can be configured in the EFC.

After reset, the chip uses its internal slow clock (cadenced at 32 kHz), so there is no need for any wait state. However, before switching to the main oscillator (in order to run at full-speed), the correct number of wait states must be set. If not, the core may no longer be able to read the code from the Flash.

Configuring the number of wait states is done in the Flash Mode Register (FMR) of the EFC. For example, a 48 MHz operation requires the use of one wait state:

```
AT91C_BASE_MC->MC_FMR = AT91C_FMR_FWS_1FWS;
```

For more information about the required number of wait states depending on the operating frequency of a microcontroller, please refer to the AC Electrical Characteristics section of the corresponding datasheet.

3.2.1.5 Low-Level Initialization: Main Oscillator and PLL

After reset, the chip is running using a slow clock, which is cadenced at 32 kHz. The main oscillator and its Phase Lock Loop (PLL) must be configured in order to run at full speed. Both can be configured in the Power Management Controller (PMC).

The first step is to enable the main oscillator and wait for it to stabilize. Writing the oscillator startup time and the MOSCEN bit in the Main Oscillator Register (MOR) of the PMC starts the oscillator; stabilization occurs when bit MOSCS of the PMC Status Register becomes set. The following piece of code performs these two operations:

```
AT91C_BASE_PMC->PMC_MOR = (AT91C_CKGR_OSCOUNT & (0x8 << 8))
                          | AT91C_CKGR_MOSCEN;
while (!(AT91C_BASE_PMC->PMC_SR & AT91C_PMC_MOSCS));
```

Calculation of the correct oscillator startup time value is done by looking at the DC characteristics given in the datasheet of the product. Note that the internal slow clock of the AT91SAM7S is generated using a RC oscillator; this must be taken into account as this impacts the slow clock accuracy. Here is an example:

RC oscillator frequency range in kHz: $22 \leq f_{RC} \leq 42$

Oscillator frequency range in MHz: $3 \leq f_{Osc} \leq 20$

Oscillator frequency on EK: $f_{Osc} = 18.432 MHz$

Oscillator startup time: $1ms \leq t_{Startup} \leq 1.4ms$

Value for a 2ms startup: $OSCOUNT = \frac{42000 \times 0.0014}{8} = 8$

Once the oscillator is started and stabilized, the PLL can be configured. The PLL is made up of two chained blocks: the first one divides the input clock, while the second one multiplies it. The *MUL* and *DIV* factors are set in the PLL Register (PLLR) of the PMC. These two values must be chosen according to the main oscillator (input) frequency and the desired main clock (output) frequency. In addition, the multiplication block has a minimum input frequency, and the master clock has a maximum allowed frequency; these two constraints have to be taken into account. The PLL calculator (available on <http://www.atmel.com>) can be used to compute the best *MUL* and *DIV* values. Example given for the AT91SAM7S-EK:

$$f_{Input} = 18.432$$

$$DIV = 14$$

$$MUL = (73 - 1) = 72$$

$$f_{Output} = \frac{18.432}{14} \times 73 = 96.109MHz$$

Like the main oscillator, a PLL startup time must also be provided. Again, it can be calculated by looking at the DC characteristics given in the datasheet of the corresponding microcontroller. After PLLR is modified with the PLL configuration values, the software must wait for the PLL to become locked; this is done by monitoring the Status Register of the PMC.

```
AT91C_BASE_PMC->PMC_PLLR = AT91C_CKGR_OUT_0
                               | (AT91C_CKGR_PLLCOUNT & (40 << 8))
                               | (AT91C_CKGR_MUL & (72 << 16))
                               | (AT91C_CKGR_DIV & 14);

while(!(AT91C_BASE_PMC->PMC_SR & AT91C_PMC_LOCK));
```

Finally, the prescaling value of the main clock must be set, and the PLL output selected. Note that the prescaling value must be set first, to avoid having the chip run at a frequency higher than the maximum operating frequency defined in the AC characteristics. As such, this step is done using two register writes, with two loops to wait for the main clock to be ready:

```
AT91C_BASE_PMC->PMC_MCKR = AT91C_PMC_PRES_CLK_2;
while (!(AT91C_BASE_PMC->PMC_SR & AT91C_PMC_MCKRDY));

AT91C_BASE_PMC->PMC_MCKR |= AT91C_PMC_CSS_PLL_CLK;
while (!(AT91C_BASE_PMC->PMC_SR & AT91C_PMC_MCKRDY));
```

At this point, the chip is configured to run on the main clock with the PLL, at the desired frequency.

3.2.1.6 Low-Level Initialization: Advanced Interrupt Controller

How to set up the AIC properly is described in [Section 3.2.3 on page 8](#).

3.2.1.7 Low-Level Initialization: Watchdog

The Watchdog peripheral is enabled by default after a processor reset. If the application does not use it, which is the case in this example, then it shall be disabled in the Watchdog Mode Register (WDMR):

```
AT91C_BASE_WDTC->WDTC_WDMR = AT91C_WDTC_WDDIS;
```

3.2.1.8 Initializing Stacks

Each ARM mode has its own stack pointer (register `sp`); thus, each mode which is used in the application must have its stack initialized.

Since stacks are descending, i.e. the stack pointer decreases in value when data is stored, the first stack pointer is located at the top of the internal SRAM. A particular length is reserved for each mode, depending on its uses. Supervisor and user modes usually have big stacks, IRQ and FIQ modes have a medium-sized stack, and other modes most often have only a few bytes. In this example, only the Supervisor (SVC) and IRQ modes are used.

Stack initialization is done by entering each mode one after another, setting `r13` to the correct value. The top memory address is stored in a register, and decremented each time the stack pointer is set. Note that interrupts are masked (i.e., I and F bits set) during this whole process, except for the last mode (only F bit set). This results in the following code:

```
/*- Load top memory address in r0
ldr r0, =IRAMEND

/*- Enter Interrupt mode, setup stack */
msr CPSR_c, #ARM_MODE_IRQ | I_BIT | F_BIT
mov r13, r0
sub r0, r0, #IRQ_STACK_SIZE

/*- Enter Supervisor mode, setup stack, IRQs unmasked */
msr CPSR_c, #ARM_MODE_SVC | F_BIT
mov r13, r0
```

3.2.1.9 Initializing BSS and Data Segments

A binary file is usually divided into two segments: the first one holds the executable code of the application, as well as read-only data (declared as *const* in C). The second segment contains read/write data, i.e., data that can be modified. These two sections are called **text** and **data**, respectively.

Variables in the *data* segment are said to be either uninitialized or initialized. In the first case, the programmer has not set a particular value when declaring the variable; conversely, variables fall in the second case when they have been declared with a value. Uninitialized variables are held in a special subsection called BSS (for Block Started by Symbol).

Whenever the application is loaded in the internal Flash memory of the chip, the Data segment must be initialized at startup. This is necessary because read/write variables are located in SRAM, not in Flash. Depending on the toolchain used, there might be library function for doing this; for example, IAR Embedded Workbench® provides `__segment_init()`.

Initialized data is contained in the binary file and loaded with the rest of the application in the memory. Usually, it is located right after the *text* segment. This makes it easy to retrieve the starting and ending address of the data to copy. To load these addresses faster, they are explicitly stored in the code using a compiler-specific instruction. Here is an example for the GNU toolchain:

```
_lp_data:
.word _etext
.word _sdata
.word _edata
```

The actual copy operation consists of loading these values and several registers, and looping through the data:

```

_init_data:
    ldr    r2,=_lp_data
    ldmia  r2, {r1, r3, r4}
    cmp    r1, r3
    beq    _branch_main

1:
    cmp    r3, r4
    ldrc  r2, [r1], #4
    strcc  r2, [r3], #4
    bcc    1b

```

In addition, it is both safer and more useful for debug purposes to initialize the BSS segment by filling it with zeroes. Theoretically, this operation is unneeded; however, it can have several benefits. For example, it makes it easier when debugging to see which memory regions have been modified. This can be a valuable tool for spotting stack overflow and similar problems.

Initialization of the BSS and Data segments are similar, except register r2 is initialized at zero after the *ldmia* instruction and never modified (c.f. the above code).

3.2.2 Generic Peripheral Usage

3.2.2.1 Initialization

Most peripherals are initialized by performing three actions

- Enabling the peripheral clock in the PMC
- Enabling the control of the peripheral on PIO pins
- Configuring the interrupt source of the peripheral in the AIC
- Enabling the interrupt source at the peripheral level

Most peripherals are not clocked by default. This makes it possible to reduce the power consumption of the system at startup. However, it requires that the programmer explicitly enable the peripheral clock. This is done in the Power Management Controller (PMC). Exception is made for the System Controller (which comprises several different controllers), as it is continuously clocked.

For peripherals which need to use one or more pins of the chip as external inputs/outputs, it is necessary to configure the Parallel Input/Output controller first. This operation is described in more detail in [Section 3.2.6 on page 12](#).

Finally, if an interrupt is to be generated by the peripheral, then the source must be configured properly in the Advanced Interrupt Controller. Please refer to [Section 3.2.3 on page 8](#) for more information.

3.2.3 Using the Advanced Interrupt Controller

3.2.3.1 Purpose

The AIC manages all internal and external interrupts of the system. It enables the definition of one handler for each interrupt source, i.e., a function which is called whenever the corresponding event occurs. Interrupts can also be individually enabled or masked, and have several different priority levels.

In the example software, using the AIC is required because several interrupt sources are present (see [Section 3.1.2 on page 2](#)).

3.2.3.2 Initialization

Unlike most other peripherals, the AIC is always clocked and cannot be shut down. Therefore, there is no need to enable its peripheral clock in the PMC.

The only mandatory action to perform at this point is to disable and clear all interrupts. This is done with these two instructions:

```
// Disable all interrupts
AT91C_BASE_AIC->AIC_IDCR = 0xFFFFFFFF;
// Clear all interrupts
AT91C_BASE_AIC->AIC_ICCR = 0xFFFFFFFF;
```

For debug purposes, it is good practice to use dummy handlers (i.e., which loop indefinitely) for all interrupt sources. This way, if an interrupt is triggered before being configured, the debugger is stuck in the handler instead of jumping to a random address.

In addition, an application which may perform a processor reset (i.e., reset of the ARM core without resetting peripherals) must write the End Of Interrupt Command Register (EOICR) of the AIC eight times. This is necessary to clear any interrupt which may have been pushed on the internal hardware stack of the AIC during a previous execution of the program.

3.2.3.3 Configuring an Interrupt

Configuring an interrupt source requires five steps:

- Disable the interrupt in case it was enabled
- Configure the interrupt Source Mode Register
- Configure the interrupt Source Vector Register
- Enable the interrupt at the peripheral level
- Enable the interrupt at AIC level

The first step is to disable the interrupt source. An interrupt triggering at the same time that its mode or vector registers are read may result in unpredictable behavior of the system. The Interrupt Disable Command Register (IDCR) of the AIC must be written with the interrupt source ID to mask it. Please refer to the corresponding datasheet for a list of peripheral IDs.

There are two parameters to set in the **Source Mode Register**: the interrupt priority and trigger mode. The former is completely up to the programmer; the interrupt can have a priority between 0 (lowest) and 7 (highest). Internal interrupts (i.e., coming from peripherals) must always be configured as level-sensitive; external interrupt (i.e., IRQ[0..3], FIQ) shall be setup depending on how they have been wired to the chip.

The **Source Vector Register** contains the address of the handler function for the interrupt. A function pointer must be cast as an *unsigned long* value in C to avoid generating a warning when setting SVR.

Finally, the interrupt source can be enabled, both on the peripheral (in a mode register usually) and in the Interrupt Enable Command Register (IECR) of the AIC. At this point, the interrupt is fully configured and operational.

3.2.4 Using the Timer Counter

3.2.4.1 Purpose

Timer Counters on AT91SAM chips can perform several functions, e.g., frequency measurement, pulse generation, delay timing, Pulse Width Modulation (PWM), etc.

In this example, a single Timer Counter channel is going to provide a fixed-period delay. An interrupt is generated each time the timer expires, toggling the associated LED on or off. This makes the LED blink at a fixed rate.

3.2.4.2 Initialization

In order to reduce power consumption, most peripherals are not clocked by default. Writing the ID of a peripheral in the Peripheral Clock Enable Register (PCER) of the Power Management Controller (PMC) activates its clock. This is the first step when initializing the Timer Counter.

The TC is then disabled, in case it has been turned on by a previous execution of the program. This is done by setting the CLKDIS bit in the corresponding Channel Control Register (CCR). In the example, timer channel 0 is used.

The next step is to configure the Channel Mode Register (CMR). TC channels can operate in two different modes. The first one, which is referred to as the Capture mode, is normally used for performing measurements on input signals. The second one, the Waveform mode, enables the generation of pulses. In the example, the purpose of the TC is to generate an interrupt at a fixed rate. Actually, such an operation is possible in both the Capture and Waveform mode. Since no signal is being sampled or generated, there is no reason to choose one mode over the other. However, setting the TC in Waveform mode and outputting the tick on TIOA or TIOB can be helpful for debugging purpose.

Setting the CPCTR bit of the CMR resets the timer and restarts its clock every time the counter reaches the value programmed in the TC Register C. Generating a specific delay is thus done by choosing the correct value for RC. It is also possible to choose between several different input clocks for the channel, which in practice makes it possible to prescale MCK. Since the timer resolution is 16 bits, using a high prescale factor may be necessary for bigger delays.

Consider the following example: the timer must generate a 500 ms delay with a 48 MHz main clock frequency. RC must be equal to the number of clock cycles generated during the delay period; here are the results with different prescaling factors:

$$Clock = \frac{MCK}{2}, RC = 24000000 \times 0.5 = 12000000$$

$$Clock = \frac{MCK}{8}, RC = 6000000 \times 0.5 = 3000000$$

$$Clock = \frac{MCK}{128}, RC = 375000 \times 0.5 = 187500$$

$$Clock = \frac{MCK}{1024}, RC = 46875 \times 0.5 = 23437.5$$

$$Clock = 32kHz, RC = 32768 \times 0.5 = 16384$$

Since the maximum value for RC is 65535, it is clear from these results that using MCK divided by 1024 or the internal slow clock is necessary for generating long (about 1s) delays. In the example, a 250 ms delay is used; this means that the slowest possible input clock is selected in the CMR, and the corresponding value written in RC. The following two operations configure a 250 ms period by selecting the slow clock and dividing its frequency by 4:

```
AT91C_BASE_TC0->TC_CMR = AT91C_TC_CLKS_TIMER_DIV5_CLOCK
                          | AT91C_TC_CPCTR;
AT91C_BASE_TC0->TC_RC = AT91B_SLOW_CLOCK >> 2;
```

The last initialization step is to configure the interrupt whenever the counter reaches the value programmed in RC. At the TC level, this is easily done by setting the CPCS bit of the Interrupt Enable Register. Refer to [Section 3.2.3.3 on page 9](#) for more information on configuring interrupts in the AIC.

3.2.4.3 *Interrupt Handler*

The first action to do in the handler is to acknowledge the pending interrupt from the peripheral. Otherwise, the latter continues to assert the IRQ line. In the case of a Timer Counter channel, acknowledging is done by reading the corresponding Status Register (SR).

Special care must be taken to avoid having the compiler optimize away a dummy read to this register. In C, this is done by declaring a *volatile* local variable and setting it to the register content. The *volatile* keyword tells the compiler to never optimize accesses (read/write) to a variable.

The rest of the interrupt handler is straightforward. It simply toggles the state (on or off) of one of the blinking LED. Refer to [Section 3.2.6 on page 12](#) for more details on how to control LEDs with the PIO controller.

3.2.5 Using the Periodic Interval Timer

3.2.5.1 *Purpose*

The primary goal of the Peripheral Interval Timer (PIT) is to generate periodic interrupts. This is most often used to provide the base tick of an operating system. The PIT uses MCK divided by 16 as its input clock, as well as a 20-bit counter. Each time the counter reaches a programmable value, an interrupt is generated, and a second counter increments. The latter makes it possible to never miss a tick, even when the system is overloaded.

The getting started example uses the PIT to provide a 1 ms time base. Each time the PIT interrupt is triggered, a 32-bit counter is incremented. A Wait function uses this counter to provide a precise way for an application to suspend itself for a specific amount of time.

3.2.5.2 *Initialization*

Since the PIT is part of the System Controller, it is continuously clocked. As such, there is no need to enable its peripheral clock in the PMC.

The Mode Register contains the Periodic Interval Value (PIV) which indicates to the PIT when to reset the internal counter. It must be programmed to the number of ticks generated by MCK/16 in one millisecond:

$$PIV = \frac{MCK}{16} \times 0,001$$

This is done with the following line of code:

```
AT91C_BASE_PITC->PITC_PIMR = AT91B_MCK / (16 * 1000) - 1;
```

Before starting the timer, the interrupt must be configured in the AIC. Please refer to [Section 3.2.3.3 on page 9](#) for more information about that step. Once the AIC configuration is done, the interrupt can be enabled in the PIT Mode Register by setting bit PITIEN; the PIT can also be started in the same operation by setting bit PITEN.

3.2.5.3 *Interrupt Handler*

Acknowledging the interrupt is implicitly done when reading the PIT Value Register. This register contains two values: the current value of the internal counter (CPIV), and the number of ticks

that have been generated since the last read of PIVR (Periodic Interval Counter, PICNT). A second register, the PIT Image Register, contains the same values but does not acknowledge the pending interrupt.

The interrupt handler for the PIT is thus very simple. First, the PIVR value is read to retrieve PICNT. A global variable is incremented with the number of ticks read.

Note that it is necessary to check whether there really is a pending interrupt on the PIT; since the system controller interrupt is shared by several peripheral, any of them can have triggered it. This is verified by reading the Status Register of the PIT; bit PITS is set when an interrupt is pending.

Finally, using a 32-bit counter may not be always appropriate, depending on how long the system should stay up and on the tick period. In the example, a 1 ms tick overflows the counter after about 50 days; this may not be enough for a real application. In that case, a larger counter can be implemented.

3.2.5.4 *Wait Function*

Using the global counter, a wait function taking a number of milliseconds as its parameter is very easy to implement.

When called, the function first saves the current value of the global counter in a local variable. It adds the requested number of milliseconds which has been given as an argument. Then, it simply loops until the global counter becomes equal to or greater than the computed value.

For proper implementation, the global counter must be declared with the *volatile* keyword in C. Otherwise, the compiler might decide that being in a empty loop prevents the modification of the counter; obviously, this is not the case since it can be altered by the interrupt handler.

3.2.6 Using the Parallel Input/Output controller

3.2.6.1 *Purpose*

Most pins on AT91SAM microcontrollers can either be used by a peripheral function (e.g. USART, SPI, etc.) or used as generic input/outputs. All those pins are managed by one or more **Parallel Input/Output (PIO)** controllers.

A PIO controller enables the programmer to configure each pin as used by the associated peripheral or as a generic IO. In the second case, the level of the pin can be read/written using several registers of the PIO controller. Each pin can also have an internal pull-up activated individually.

In addition, the PIO controller can detect a status change on one or more pins, optionally triggering an interrupt whenever this event occurs. Note that the generated interrupt is considered **internal** by the AIC, so it must be configured as level-sensitive (see [Section 3.2.3.3](#)).

In this example, the PIO controller manages two LEDs and two buttons. The buttons are configured to trigger an interrupt when pressed (as defined in [Section 3.1.1 on page 2](#)).

3.2.6.2 *Initialization*

There are two step for initializing the PIO controller. First, its peripheral clock must be enabled in the PMC. After that, its interrupt source can be configured in the AIC.

3.2.6.3 *Configuring LEDs*

The two PIOs connected to the LEDs must be configured as outputs, in order to turn them on or off. First, the PIOC control must be enabled in PIO Enable Register (PER) by writing the value corresponding to a logical OR between the two LED IDs.

PIO direction is controlled using two registers: Output Enable Register (OER) and Output Disable Register (ODR). Since in this case the two PIOs must be output, the same value as before shall be written in OER.

Note that there are individual internal pull-ups on each PIO pin. These pull-ups are enabled by default. Since they are useless for driving LEDs, they should be disabled, as this reduces power consumption. This is done through the Pull Up Disable Register (PPUDR) of the PIOC.

Here is the code for LED configuration:

```
/* Configure the pins as outputs */
AT91C_BASE_PIOA->PIO_OER = (LED_A | LED_B);

/* Enable PIOC control on the pins*/
AT91C_BASE_PIOA->PIO_PER = (LED_A | LED_B);

/* Disable pull-ups */
AT91C_BASE_PIOA->PIO_PPUDR = (LED_A | LED_B);
```

3.2.6.4 *Controlling LEDs*

LEDs are turned on or off by changing the level on the PIOs to which they are connected. After those PIOs have been configured, their output values can be changed by writing the pin IDs in the Set Output Data Register (SODR) and the Clear Output Data Register (CODR) of the PIO controller.

In addition, a register indicates the current level on each pin (Pin Data Status Register, PDSR). It can be used to create a toggle function, i.e. when the LED is ON according to PDSR, then it is turned off, and vice-versa.

```
/* Turn LED off */
AT91C_BASE_PIOA->PIO_SODR = LED_A;

/* Turn LED on */
AT91C_BASE_PIOA->PIO_CODR = LED_A;
```

3.2.6.5 *Configuring Buttons*

As stated previously, the two PIOs connected to the switches on the board shall be inputs. Also, a “state change” interrupt is configured for both buttons. This triggers an interrupt when a button is pressed or released.

After the PIOC control has been enabled on the PIOs (by writing PER), they are configured as inputs by writing their IDs in ODR. Conversely to the LEDs, it is necessary to keep the pull-ups enabled.

Enabling interrupts on the two pins is simply done in the Interrupt Enable Register (IER). However, the PIO controller interrupt must be configured as described in [Section 3.2.3.3 on page 9](#).

3.2.6.6 *Interrupt Handler*

The interrupt handler for the PIO controller must first check which button has been pressed. PDSR indicates the level on each pin, so it can show if each button is currently pressed or not. Alternatively, the Interrupt Status Register (ISR) reports which PIOs have had their status changed since the last read of the register.

In the example software, the two are combined to detect a state change interrupt as well as a particular level on the pin. This corresponds to either the press or the release action on the button.

As said in the application description ([Section 3.1.1 on page 2](#)), each button enables or disables the blinking of one LED. Two variables are used as boolean values, to indicate if either LED is blinking. When the status of the LED which is toggled by the Timer Counter is modified, the TC clock is either stopped or restarted by the interrupt handler as well.

Note that the interrupt must be acknowledged in the PIOC. This is done implicitly when ISR is read by the software. However, conversely to the Timer Counter (see [Section 3.2.4.3 on page 11](#)), since the ISR value is actually used in several operations, there is no need to worry about the compiler inadvertently

3.2.7 **Using the Debug Unit**

3.2.7.1 *Purpose*

The Debug Unit provides a two-pins Universal Asynchronous Receiver and Transmitter (UART) as well as several other debug functionalities. The UART is ideal for outputting debug traces on a terminal, or as an In-System Programming (ISP) communication port. Other features include chip identification registers, management of debug signals from the ARM core, and so on.

The DBGU is used in the example to output a single string of text whenever the application starts. It is configured with a baudrate of 115200, 8 bits of data, no parity, one stop bit and no flow control.

3.2.7.2 *Initialization*

As the Debug Unit is part of the System Controller peripheral, there is no need to enable its clock in the PMC. The DBGU is continuously clocked and cannot be disabled. However, it is necessary to configure its two pins (DTXD and DRXD) in the PIO controller.

Writing both pin IDs in the PIO Disable Register (PDR) of the corresponding PIO controller enables peripheral control on those pins. However, some PIOs are shared between two different peripherals; Peripheral A Select Register (ASR) and Peripheral B Selected Register (BSR) are used to switch control between the two.

The very next action to perform is to disable the receiver and transmitter logic, as well as disable interrupts. This enables smooth reconfiguration of the peripheral in case it had already been initialized during a previous execution of the application. Setting bits RSTRX and RSTTX in the Control Register (CR) of the DBGU resets and disables the receiver and transmitter, respectively. Setting all bits of the Interrupt Disable Register (IDR) disable all interrupts coming from the Debug Unit.

The baud rate clock must now be set up. The input clock is equal to MCK divided by a programmable factor. The Clock Divisor value is held in the Baud Rate Generate Register (BRGR). The following values are possible:

Table 3-1. Possible Values for the Clock Divisor field of BRGR

Value	Comment
0	Baud rate clock is disabled
1	Baud rate clock is MCK divided by 16
2 to 65535	Baud rate clock is MCK divided by (CD x 16)

The following formula can be used to compute the value of CD given the microcontroller operating frequency and the desired baud rate:

$$CD = \frac{MCK}{16 \times \text{Baudrate}}$$

For example, a 115200 baud rate can be obtained with a 48MHz master clock frequency by writing a value of 26 in CD. Obviously, there is a slight deviation from the desired baudrate; these values yield a true rate of 115384 bauds. However, it is a mere 1.6% error, so it does not have any impact in practice.

The Mode Register (MR) has two configurable values. The first one is the Channel Mode in which the DBGU is operating. Several modes are available for testing purpose; in this example, only the normal mode is of interest. Setting the CHMODE field to a null-value selects the normal mode.

It is also possible to configure a parity bit in the Mode Register. Even, odd, mark and space parity calculations are supported. In the example, no parity bit is being used (PAR value of 1xx).

The DBGU features its own Peripheral DMA Controller. It enables faster transfer of data and reduces the processor overhead by taking care of most of the transmission and reception operations. The PDC is not used in this example, so it should be disabled by setting bits RXTDIS and TXTDIS in the PDC Transfer Control Register (PTCR) of the DBGU.

At this point the DBGU is fully configured. The last step is to enable the transmitter; the received is not being used in this demo application, so it is useless (but not harmful) to enable it as well. Transmitter enabling is done by setting bit TXEN in the Control Register.

3.2.7.3 Sending a Character

Transmitting a character on the DBGU line is simple: writing the character value in the Transmit Holding Register (THR) starts the transfer. However, the transmitter must be ready at this time.

Two bits in the DBGU Status Register (SR) indicate the transmitter state. Bit TXEMPTY indicates if the transmitter is enabled and sending characters. If it is set, no character is being currently sent on the DBGU line.

The second meaningful bit is TXRDY. When this bit is set, the transmitter has finished copying the value of THR in its internal shift register that it uses for sending the data. In practice, this means that THR can be written when TXRDY is set, regardless of the value of TXEMPTY. When TXEMPTY rises, the whole transfer is finished.

3.2.7.4 String Print Function

A `dbg_u_print_ascii()` function is defined in the example application. It takes a string pointer as an argument, and sends it across the DBGU.

Its operation is quite simple. C-style strings are simple byte arrays terminated by a null (0) value. Thus, the function just loops and outputs all the characters of the array until a zero is encountered.

3.2.7.5 Hexadecimal Print Function

Another print function, `dbg_u_print_hex8()`, outputs a word (32 bits) value in hexadecimal format.

This C function takes an *unsigned int* value as an argument. A loop displays each byte, starting with the upper one. This is done by shifting the byte to the rightmost (lowest) position and masking it.

4. Building the Project

The development environment for this getting started is a PC running Microsoft® Windows® OS.

The required software tools for building the project and loading the binary file are:

- an ARM cross-compiler toolchain
- AT91-ISP v1.8 or later (available at www.atmel.com).

The connection between the PC and the board is achieved with a USB cable.

4.1 ARM Compiler Toolchain

To generate the binary file to be downloaded into the target, we use the YAGARTO GNU ARM compiler toolchain (www.yagarto.de).

This toolchain provides ARM assembler, compiler, and linker tools. Useful programs for debug are also included.

We also require another software that is not included into the Yagarto package: the *make* utility. We get it by installing the unxutils package available at unxutils.sourceforge.net.

4.1.1 Makefile

The Makefile contains rules indicating how to assemble, compile and link the project source files to create a binary file ready to be downloaded on the target.

The makefile is divided into two parts, one for variables settings, and the other for rules implementation.

4.1.1.1 Variables

The first part of the Makefile contains variables (uppercase), used to set up some environment parameters, such as the compiler toolchain prefix and program names, and options to be used with the compiler.

```
CROSS_COMPILE=arm-elf-
```

- Defines the cross-compiler toolchain prefix.

```
OUTFILE_SRAM=at91sam7s_getting_started_sram
```

```
OUTFILE_FLASH=at91sam7s_getting_started_flash
```

- Outfile name (without extension).

INCL=../include

- Paths for header files.

OPTIM = -Os

- Level of optimization used during compilation (-Os optimizes for size).

AS=\$(CROSS_COMPILE)gcc

CC=\$(CROSS_COMPILE)gcc

LD=\$(CROSS_COMPILE)gcc

NM= \$(CROSS_COMPILE)nm

SIZE=\$(CROSS_COMPILE)size

OBJCOPY=\$(CROSS_COMPILE)objcopy

OBJDUMP=\$(CROSS_COMPILE)objdump

- Names of cross-compiler toolchain binutils (assembler, compiler, linker, symbol list extractor, etc.).

\$(OPTIM)CCFLAGS=-g -mcpu=arm7tdmi \$(OPTIM) -Wall -I\$(INCL)

- Compiler options:

- -g: generate debugging information for GDB usage.
- -mcpu = arm7tdmi type of ARM CPU core.
- -c: indicates to gcc to only compile the file, and to not link it (link is done later, when all code files are compiled).
- -Wall: displays all warnings.
- -I\$(INCL): set paths for include files.

ASFLAGS=-D__ASSEMBLY__ -g -mcpu=arm7tdmi -c -Os -Wall -I\$(INCL)

- Assembler options:

- -D__ASSEMBLY__ : defines the __ASSEMBLY__ symbol, which is used in header files to distinguish inclusion of the file in assembly code or in C code.

LDFLAGS+=-nostartfiles -Wl,--cref

LDFLAGS+=-lc -lgcc

LDFLAGS+=-T elf32-littlearm.lds

- Linker options:

- -nostartfile: Do not use the standard system startup files when linking.
- -Wl,--cref: Pass the --cref option to the linker (generates cross-reference in map file if this one is requested).
- -lc: use standard C library.
- -lgcc: use gcc library.
- -T elf32-littlearm.lds: use the file elf32-littlearm.lds as linker file.

```
OBJS=cstartup.o
OBJS+= lowlevel.o \
    main.o
```

- List of all object file names.

For more detailed information about gcc options, please refer to gcc documentation (gcc.gnu.org).

4.1.1.2 Rules

The second part contains rules. Each rule is composed on the same line by a target name, and the files needed to create this target.

The first rule, 'all', is the default rule used by the make command if none is specified in command line.

```
all: sram flash
```

The following rules create the 3 object files from the 3 corresponding source files. The option -c tells gcc to run the compiler and assembler, but not the linker.

```
main.o: main.c
    $(CC) -c $(CCFLAGS) main.c -o main.o

lowlevel.o: lowlevel.c
    $(CC) -c $(CCFLAGS) lowlevel.c -o lowlevel.o

cstartup.o: cstartup.S
    $(AS) $(ASFLAGS) cstartup.S -o cstartup.o
```

The last rules describe how to compile source files and link object files together to generate one binary file per configuration: program running in Flash and program running in RAM. It describes how to compile source files and link object files together. The first line calls the linker with the previously defined flags, and the addresses of the text and the data segments via the *-Ttext address* and *-Tdata address* options. This generates an elf format file, which is converted to a binary file without any debug information by using the objcopy program.

```
sram: $(OBJS)
    $(LD) $(LDFLAGS) -Ttext 0x201000 -Tdata 0x200000 -n -o $(OUTFILE_SRAM).elf $(OBJS)
    $(OBJCOPY) --strip-debug --strip-unneeded $(OUTFILE_SRAM).elf -O binary
    $(OUTFILE_SRAM).bin

flash: $(OBJS)
    $(LD) $(LDFLAGS) -Ttext 0x100000 -Tdata 0x200000 -n -o $(OUTFILE_FLASH).elf $(OBJS)
    $(OBJCOPY) --strip-debug --strip-unneeded $(OUTFILE_FLASH).elf -O binary
    $(OUTFILE_FLASH).bin
```

4.1.2 Linker File

At link stage, the elf32-littlearm.lids file is sent in option to the linker.

This file describes the order in which the linker must put the different memory sections into the binary file. The addresses are indicated via the *-Ttext* and *-Tdata* options of the linker command line (see the Makefile chapter).

4.1.2.1 Header

```
OUTPUT_FORMAT("elf32-littlearm", "elf32-littlearm", "elf32-littlearm")
```

Set the object file format to elf32-littlearm.

```
OUTPUT_ARCH(arm)
```

Specify the machine architecture.

```
ENTRY(reset)
```

Set the symbol 'reset' as the entry point of the program.

4.1.2.2 Section Organization

The *SECTION* part deals with the different sections of code used in the project. It tells the linker where to put the sections it finds while parsing all the project object files.

- .vectors: exception vector table and IRQ handler
- .text: code
- .data: initialized data
- .bss: uninitialized data

```
SECTIONS
```

```
{
    .text : {
        _stext = .;
        *(.text)
        *(.rodata)
        *(.rodata*)
        . = ALIGN(4);
        _etext = .;
    }
```

```
/* collect all initialized .data sections that go into FLASH */
```

```
.data : AT ( ADDR (.text) + SIZEOF (.text) ) {
    _sdata = .;
    *(.vectors)
    *(.data)
    _edata = .;
}
```

```
/* collect all uninitialized .bss sections that go into FLASH */
```

```
.bss (NOLOAD) : {
    . = ALIGN(4);
    _sbss = .;
}
```

```
        *(.bss)
        _ebss = .;
    }
}
end = .;
```

In the `.text` section, the `__stext` symbol is set in order to retrieve this address at runtime, then all `.text`, and `.rodata` sections found in all object file are placed here, and finally the `__etext` symbol is set and aligned on a 4 byte address.

The same operation is done with the `.data` and `.bss` sections.

In the `.data` section, the `AT (ADDR (.text) + SIZEOF(.text))` command specifies that the load address (the address in the binary file after link step) of this section is just after the `.text` section. Thus there is no hole between these two sections.

The `.vectors` section (defined in the `cstartup.S` file) is placed just before the `.data` section. Providing a link address set at the beginning of the internal RAM allows this section to be automatically copied at the right place when the reset handler copies the `.data` section in RAM.

4.2 Loading the Code

Once the build step is completed, one `.bin` file is available and ready to be loaded into the board.

The AT91-ISP solution offers an easy way to download files into AT91 products on Atmel Evaluation Kits through a USB, COM or J-TAG link. Target programming is done here via SAM-BA™ tools.

Two DOS batch files (`prog_sram.bat` and `prog_flash.bat`) and two TCL script files (`prog_sram.tcl` and `prog_flash.tcl`) are provided to process the loading of the binary file.

The `.bat` file launches SAM-BA in command line mode. Parameters provided to SAM-BA are: the connection link used, the target board, and the `.tcl` script file to use.

The `.tcl` script file contains indications about the name of the file to load, which memory module is used, the address of code loading, and operates a go command at the code start address. A log file is displayed at the end of the loading process.

Follow the steps below to load the code:

- Shut down the board.
- Set the JP28 jumper on the board to erase the internal Flash.
- Plug the USB cable between the PC and the board and wait for a few seconds.
- Shut down the board and remove the jumper.
- Set the JP5 jumper to set the board in test mode
- Plug the USB cable between the PC and the board and wait for about 10 seconds
- Shut down the board and remove the jumper.
- Plug the USB cable between the PC and the board.
- Execute the `prog_sram.bat` file to test the code running in internal SRAM.
- Execute the `prog_flash.bat` file to test the code running in internal Flash.

The code then starts running, and the LEDs are now controlled by two push buttons.

4.3 Debug Support

When debugging the Getting Started example with GDB, it is best to disable compiler optimizations. Otherwise, the source code will not correctly match the actual execution of the program. To do that, simply comment out (with a '#') the "OPTIM = -Os" line of the makefile and rebuild the project.

For more information on debugging with GDB, refer to the Atmel application note [GNU-Based Software Development](#) and to the GDB manual available on gcc.gnu.org.

5. Revision History

Table 5-1.

Document Ref.	Comments	Change Request Ref.
6293A	First issue.	



Atmel Corporation

2325 Orchard Parkway
San Jose, CA 95131, USA
Tel: 1(408) 441-0311
Fax: 1(408) 487-2600

Regional Headquarters

Atmel Europe

Le Krebs
8, rue Jean-Pierre Timbaud
BP 309
78054 Saint-Quentin-en-Yvelines
Cedex
France
Tel: (33) 1-30-60-70-00
Fax: (33) 1-30-60-71-11

Asia

Room 1219
Chinachem Golden Plaza
77 Mody Road Tsimshatsui
East Kowloon
Hong Kong
Tel: (852) 2721-9778
Fax: (852) 2722-1369

Japan

9F, Tonetsu Shinkawa Bldg.
1-24-8 Shinkawa
Chuo-ku, Tokyo 104-0033
Japan
Tel: (81) 3-3523-3551
Fax: (81) 3-3523-7581

Atmel Operations

Memory

2325 Orchard Parkway
San Jose, CA 95131, USA
Tel: 1(408) 441-0311
Fax: 1(408) 436-4314

Microcontrollers

2325 Orchard Parkway
San Jose, CA 95131, USA
Tel: 1(408) 441-0311
Fax: 1(408) 436-4314

La Chantrerie
BP 70602
44306 Nantes Cedex 3, France
Tel: (33) 2-40-18-18-18
Fax: (33) 2-40-18-19-60

ASIC/ASSP/Smart Cards

Zone Industrielle
13106 Rousset Cedex, France
Tel: (33) 4-42-53-60-00
Fax: (33) 4-42-53-60-01

1150 East Cheyenne Mtn. Blvd.
Colorado Springs, CO 80906, USA
Tel: 1(719) 576-3300
Fax: 1(719) 540-1759

Scottish Enterprise Technology Park
Maxwell Building
East Kilbride G75 0QR, Scotland
Tel: (44) 1355-803-000
Fax: (44) 1355-242-743

RF/Automotive

Theresienstrasse 2
Postfach 3535
74025 Heilbronn, Germany
Tel: (49) 71-31-67-0
Fax: (49) 71-31-67-2340

1150 East Cheyenne Mtn. Blvd.
Colorado Springs, CO 80906, USA
Tel: 1(719) 576-3300
Fax: 1(719) 540-1759

Biometrics

Avenue de Rochepleine
BP 123
38521 Saint-Egreve Cedex, France
Tel: (33) 4-76-58-47-50
Fax: (33) 4-76-58-47-60



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