APPLICATION NOTE

AT11489: Low Power Techniques for Atmel SMART ARM MCUs

SMART ARM-based Microcontrollers

Introduction

This application note explains about low power modes available in Atmel® | SMART SAM3/SAM4 Microcontroller family. This application note also gives a walkthrough on information, techniques, and strategies, which can help in achieving low power with Atmel SMART ARM®-based MCUs.

In low power targeted applications, many factors have to be considered to bring down the power consumption of an MCU. These includes specific low power configurations in the MCU, external components used and the hardware design.

This application note helps the readers in understanding the internal settings and configurations of SAM3/SAM4 MCUs, which can give better low power performance.

The SAM4L MCUs series has picoPower® technology for ultra-low power consumption, which supports multiple power configurations to allow the user to optimize its power consumption in different use cases.

This application note also demonstrates low power measurement with Atmel Xplained Pro kits.

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1 Power Modes in SAM3/SAM4 MCUs

This chapter gives on overview on power mode available in SAM3/SAM4 family. Corresponding device datasheet has to be referred for complete information on a specific device.

1.1 SAM3/SAM4 Power Modes

In SAM3/SAM4 MCUs, low power modes are mostly common except SAM4L MCU. SAM4L MCU low power modes are explained in Section 1.2 in this application note.

1.1.1 Active Mode

Active mode is the normal running mode with the core clock running from the fast RC oscillator, the main crystal oscillator, or the PLLA. The Power Management Controller (PMC) module can be used to change the CPU frequency and to enable/disable the peripheral clocks.

1.1.2 Low Power Modes

Sleep Mode

The purpose of sleep mode is to optimize power consumption of the device versus response time. In this mode, only the core clock is stopped. The peripheral clocks can be enabled. The current consumption in this mode is application dependent.

Wait Mode

The purpose of wait mode is to achieve very low power consumption while maintaining the whole device in a powered state for a startup time of less than 10µs (except SAM4N device in which startup time of less than few hundred µs).

In this mode, the clocks of the core, peripherals, and memories are stopped. However, the core, peripherals, and memories are still powered. From this mode, a fast start up is possible. Fast wake up uses internal Fast RC oscillator. Note that Fast RC oscillator should be enabled and selected as Main Clock before entering wait mode.

In SAM4S, SAM4E, and SAM4N devices, wait mode still has sub category depending on Flash low power mode. In both cases, depending on the value of the field Flash Low Power Mode (FLPM), the Flash enters three different modes:

- FLPM = 0 in Standby mode (Low consumption)
- FLPM = 1 in Deep power down mode (Extra low consumption)
- FLPM = 2 in Idle mode. Memory ready for Read access

The power consumption reduction is optimal when configuring 1 (Deep power down mode) in field FLPM. If 0 is programmed (Standby mode), the power consumption is slightly higher than in Deep-power-down mode. When programming 2 in field FLPM, the Wait mode Flash power consumption is equivalent to that of the Active mode when there is no read access on the Flash.

Backup Mode

The purpose of backup mode is to achieve the least power consumption possible in a system, which is performing periodic wake-ups to perform tasks but not requiring fast startup time.

In this mode Supply Controller, zero-power power-on reset, RTT, RTC, backup registers, and the 32kHz oscillator (RC or crystal oscillator selected by software in the Supply Controller) are running. The regulator and the core supply are off.

The SAM3/SAM4 devices can be awakened from this mode using the WKUP0-15 pins, the supply monitor (SM), the RTT or RTC wake-up event.

Table 1-1 gives an idea about various low power modes in SAM3/SAM4 devices. Entry and exit conditions are stated in the same table. Refer the specific device datasheet for details about sleep modes.

Table 1-1. Low Power Mode Configuration Summary

Mode	SUPC, 32kHz oscillator, RTT, RTC, backup registers (backup region)	Core, memory and peripherals	Mode entry	Wakeup sources	Regulator	Core at wakeup
Backup Mode	ON	OFF (not powered)	WFE + SLEEPDEEP bit = 1	WUP0-15 pins RTT alarm RTC alarm SM alarm	OFF	Reset
Wait Mode	ON	Powered (not clocked)	WFE + SLEEPDEEP bit =0 + LPM bit =1	Any event from WUPO pins, RTT, RTC, and USB Wakeup	ON	Clocked back
Sleep Mode	ON	Powered (not clocked)	WFE or WFI+ SLEEPDEEP bit =0 + LPM bit =0	Any enabled interrupt and/or WFE + SLEEPDEEP bit = 0 + LPM bit =1	ON	Clocked back

VDDBU pin (only on SAM3X)

This section is about specific feature of SAM3X device for backup battery connection.

In a product where backup battery needs to be connected, SAM3X offers an advantage of dedicated VDDBU pin where battery can be connected apart from main supply on VDDIO/VDDIN pins. SHDN (Shutdown) pin is also available on the SAM3X to control the main supply for the device. This SHDN pin should be connected to switch which controls the device's main supply.

1.2 SAM4L Power Modes

The SAM4L MCU embeds picoPower technology for ultra-low power consumption. The SAM4L device series has many features which can be useful in a low power design.

1.2.1 Active Mode

At power-up or after a reset, the SAM4L is in the RUN0 mode. Only the necessary clocks are enabled allowing software execution. The Power Manager (PM) can be used to adjust the clock frequencies and to enable and disable the peripheral clocks.

RUN0/RUN1 are modes depending on the Power scaling modes available in SAM4L device. This Power scaling feature is explained in Section 2.11.

1.2.2 Low Power Modes/Power Save Mode

When the CPU is entering a Power Save Mode, it stops executing code. The user can choose between four Power Save modes to optimize power consumption.

Refer "Precautions When Entering Power Save Mode" section in SAM4L datasheet to know about precautions while entering any low power mode.

SLEEP mode

The Cortex-M4 core is stopped, optionally some clocks are stopped, and peripherals are kept running if enabled by the user. Sleep mode has four sub-modes where peripheral bus clocks ON/OFF status varies. SLEEP mode section in SAM4L datasheet can be referred for more details.

WAIT mode

All clock sources are stopped, the core and all the peripherals are stopped except the modules running with the 32kHz clock if enabled. This is the lowest power configuration where SleepWalking is supported. SleepWalking is explained in Section 2.10.

RETENTION mode

Similar to the WAIT mode in terms of clock activity. This is the lowest power configuration where the internal SRAM and registers contents of the Core domain are preserved. The difference between RETENTION and WAIT mode is that SleepWalking is not supported in this mode.

BACKUP mode

The Core domain is powered off, the Backup domain is kept powered.

Power Domain Overview section in SAM4L datasheet shows modules present in Core domain and Backup domain. Backup System Control Interface, Backup Power Manager, Backup registers, Asynchronous Timers, External Interrupt Controller, and Watchdog Timer are the modules present in Backup Domain.

Table 1-2 gives an idea about various low power modes in the SAM4L series of devices.

Table 1-2. Power Save Mode Configuration Summary

Mode	Mode entry	Wakeup sources	Core domain	Backup domain
SLEEP	WFI + SCR.SLEEPDEEP bit = 0 + BPM.PMCON.BKUP bit = 0	Any interrupt	CPU clock OFF Other clocks OFF depending on the BPM.PMCON.SLEEP field	Clocks OFF depending on the BPM.PMCON.SLEEP Field
WAIT	WFI + SCR.SLEEPDEEP bit = 1 + BPM.PMCON.RET bit = 0 + BPM.PMCON.BKUP bit = 0	PM WAKE interrupt	All clocks are OFF Core domain is retained	All clocks are OFF except RC32K or OSC32K if running
RETENTION	WFI + SCR.SLEEPDEEP bit = 1 + BPM.PMCON.RET bit = 1 + BPM.PMCON.BKUP bit = 0	PM WAKE interrupt	All clocks are OFF Core domain is retained	All clocks are OFF except RC32K or OSC32K if running
BACKUP	WFI + SCR.SLEEPDEEP bit = 1 + BPM.PMCON.BKUP bit = 1	EIC interrupt BOD33, BOD18 interrupt and reset AST alarm, periodic, overflow WDT interrupt and reset external reset on RESET_N pin	OFF (not powered)	All clocks are OFF except RC32K or OSC32K if running

2 Techniques/Strategies to Achieve Low Power Consumption

2.1 Power Consumption vs Operating Voltage

Operating voltage is a parameter which affects the power consumption to a great extent. The device datasheet has power consumption data measured at typical voltage in the device's operating voltage range specified.

The power consumption increases proportionally to the square of the device's supply voltage. So in a low power application, we have to see the possibility to keep operating voltage at a lower voltage than typical value. Constraint or limitation in this case is that certain peripherals (e.g.: USB, ADC, and DAC) cannot be used below specified voltage levels. So if the application doesn't require these modules, then we can operate the MCU at a lower voltage to reduce the power consumption of the MCU. One more point to be cross checked is that, the supply voltage level chosen needs to be compatible with the external components connected the I/O pins of the MCU.

2.2 Power Consumption vs Operating Temperature

Operating temperature is another parameter which affects the power consumption to a great extent. Normally the device datasheet has the power consumption data measured at two or three specific temperatures in the range specified. Consumption increases with increase in operating temperature. So while comparing datasheet power numbers with measured value, this factor should also be considered.

2.3 Power Consumption vs Operating Frequency

In Active Mode or Normal Mode, power consumption is directly proportional to the operating frequency of CPU. If application doesn't demand high frequency operation, then operating MCU in lower frequency range is always good for a low power application.

Electrical Characteristics section in corresponding device datasheet has to be referred for operating conditions, power consumption, and I/O pin characteristics details for specific device.

2.4 Unused GPIO Pins Configuration

Unused GPIOs of MCU should be configured correctly which will help MCU to consume less power. In most cases, due to leakage current on floating pins, MCU can consume additional power which can be eliminated in a low power application.

All MCUs will have a GPIO configuration (for example input with Pull up resistor enabled) in which the MCU will consume least power. This configuration varies from one device family to other according to the chip design. In some cases, default configuration itself could result in best power result. In such cases, GPIO configuration can be left in default state.

All the above information are on a general note. When considering Atmel SAM3/SAM4 devices, the following configuration is recommended for unused GPIO pins in the design.

SAM3S and SAM4S

To reduce power consumption, if a GPIO is not used, it can be configured as an output and driven at logic low ('0') with internal pull-up disabled.

SAM4L

To reduce power consumption, unused I/O pins should be made stable by either:

a. Setting I/O as input with internal pull-up enabled.
b. Setting I/O as output and driven at '0' with internal pull-up disabled.

2.5 Individual Peripheral Power Consumption

Device datasheet shows power consumption numbers for all peripherals.

These power numbers will be in µA/MHz. If the peripheral clocking speed increases, then power consumption will also increase. It is good to consider following points in a low power design:

- When a peripheral is not needed, keeping it disabled is always recommended. Like peripherals used for debugging in development stage can be finally disabled in release mode.
- Running peripheral at minimum required speed will help to reduce the power consumption

2.6 Internal vs External Oscillators

Atmel SAM3/SAM4 MCUs embeds internal clock sources. So, devices can run with internal oscillators and even communication interfaces (like UART) also can use the internal clock. This eliminates the usage of external crystals in applications where crystal oscillator accuracy is not required.

Either we use internal or external oscillator in SAM3/SAM4 devices, there is little difference in power consumption. But still as far as low power applications are concerned, using external crystals are always recommended. This leads low power consumption with additional advantage of accurate clocks.

If there is requirement where BOM and reducing PCB space is main concern than accuracy and power consumption, then using internal oscillators is a good option.

2.7 Status of Unused Peripheral Clocks

Though the Peripheral Modules are disabled, the Module clocks still consume power. Unused Peripheral clock should be disabled to save power.

2.8 Restricted Peripheral Usage

While checking the possibility for operating MCU at lower voltage, certain peripherals has restrictions in supply voltage for being operational.

Refer the respective device datasheet for more details. Below is an example for such case.

Restrictions:

- For USB, VDDIO needs to be greater than 3.0V
- For ADC and DAC, VDDIN needs to be greater than 2.4V

2.9 Internal Regulator Modes

The SAM3/SAM4 embeds a voltage regulator that is managed by the Supply Controller. User has no control of Regulator modes in these devices.

This internal regulator is designed to supply the internal core of SAM3/SAM4. It features two operating modes:

- Normal mode
- Backup mode or Shutdown mode

The maximum load current and other details regarding the internal regulator are device specific. Refer device datasheet for more information.

SAM4L

An embedded voltage regulator supplies all the digital logic in the Core and the Backup power domains.

The regulator has two functional modes depending of BUCK/LDOn (PA02) pin value. When this pin is low, the regulator is in linear mode and VDDOUT must be connected to VDDCORE externally.

When this pin is high, it behaves as a switching regulator and an inductor must be placed between VDDOUT and VDDCORE.

The voltage regulator features three different modes:

- **Normal mode**
  The regulator is configured as linear or switching regulator. It can support all different Run and Sleep modes.
- **Low Power (LP) mode**
  The regulator consumes little static current. It can be used in Wait modes.
- **Ultra-Low Power (ULP) mode**
  The regulator consumes very little static current. It is dedicated to Retention and Backup modes. In Backup mode, the regulator only supplies the backup domain.

The Power consumption varies depending on the functional mode (Linear or switching). The power consumption data is available in SAM4L device datasheet.

2.10 SleepWalking (specific to SAM4L)

SleepWalking is a feature which adds intelligence to the SAM4L peripherals. This allows a peripheral to determine if incoming data requires use of the CPU or not.

This is called as SleepWalking because this feature allows the CPU to sleep peacefully until a relevant event occurs. In the traditional way of addressing this, the internal timer wakes up the microcontroller periodically to check whether certain conditions that require its attention are present or not. The CPU and RAM traditionally consume the majority of the power in active mode, and so waking up the CPU to check for these conditions will consume a lot of power in the long run. In some cases where the reaction time is too short, it might not even be possible for the CPU to go back into sleep mode at all.

The Atmel SAM4L microcontroller solves this problem with its SleepWalking peripherals. SleepWalking allows the microcontroller to be put into sleep and wake up only upon a pre-qualified event. The CPU no longer needs to check whether or not a specific condition is present, such as an address match condition on the TWI (I^2C) interface, or a sensor connected to an ADC that has exceeded a specific threshold.

The application note AT04113: How to implement SleepWalking on an ARM Cortex-M4 MCU Application explains this feature in detail.

2.11 Power Scaling (specific to SAM4L)

The Power Scaling is achieved by adjusting the internal regulator output voltage (voltage scaling) to reduce the power consumption. According to the requirements in terms of performance, operating modes, and current consumption, the user can select the Power Scaling configuration that fits the best with the given application.

If application can run at lower voltage and frequency, we can adopt to the specific power scaling where power consumption is reduced. The Power Scaling configuration field (PMCON.PS) is provided in the Backup Power Manager (BPM) module.

Figure 2-1. Power Scaling and Power Save Mode Overview

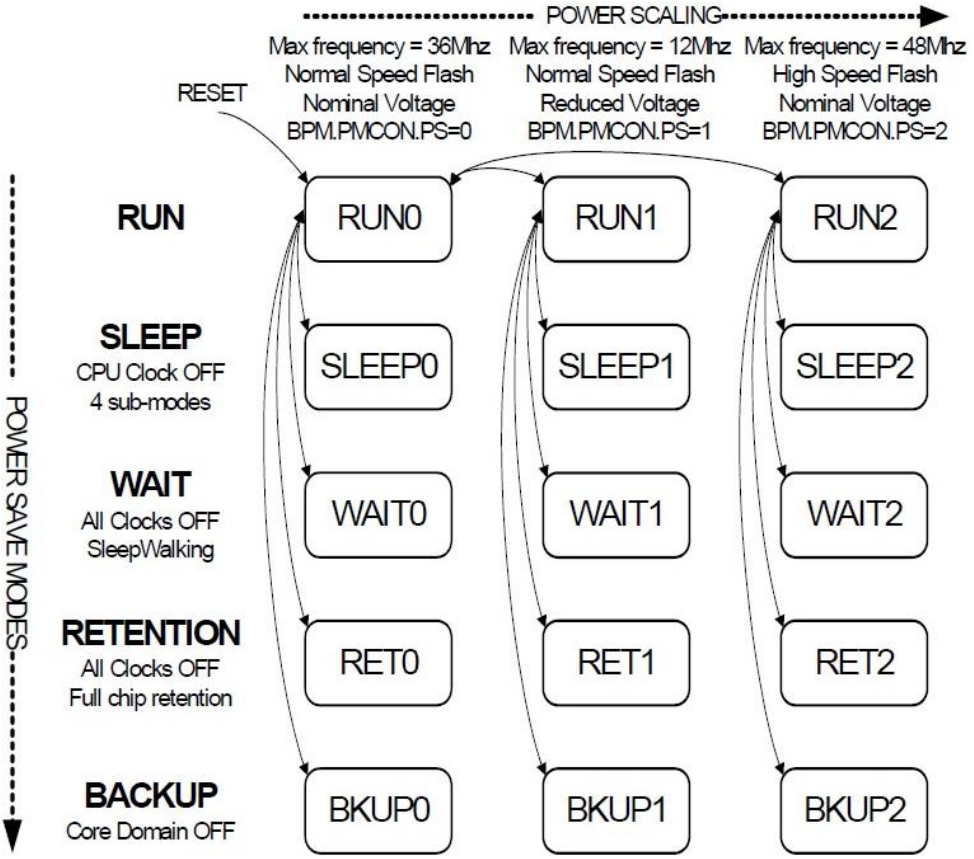
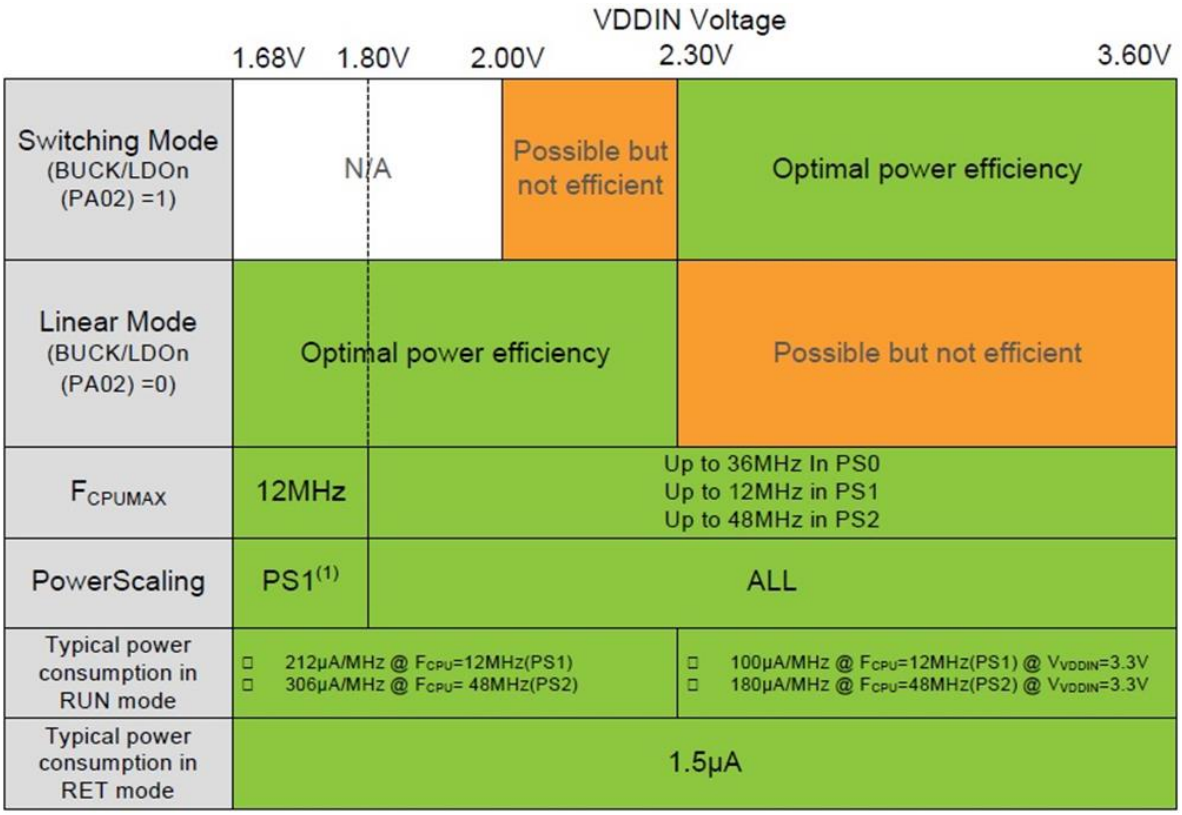


Figure 2-1 shows an overview of power scaling and Power Modes available in SAM4L device. From the diagram it is evident that the maximum CPU frequency, flash speed mode, and supply voltage are the parameters that decide which is the most suitable power scale mode for the given scenario.

Figure 2-2. Efficient Power Strategy



Note: 1. The SAM4L boots in PS0 on RCSYS (115kHz), then the application must switch to PS1 before running on higher frequency (<12MHz).

Flash has two read modes with respect to speed, they are high speed mode and normal speed mode. High speed mode offer higher flash read speed at the cost of higher power consumption. By default, all features are available in all Power Scaling modes. However, some specific features are not available in PS1 (BPM.PMCON.PS=1) mode:

- USB
- DFLL
- PLL
- Programming/Erasing in Flash

Flash Characteristics section in Electrical characteristics chapter in the SAM4L datasheet has to be referred for relation between Flash read mode, Power scale mode, Flash Wait state, and Maximum operating frequency.

Power Scaling Modes section in SAM4L datasheet has to be referred for complete details on Power scaling modes.

2.12 Disabling Debug Module

After the development phase, the Debug module can be disabled if no debug feature is required after release.

In SAM4L device, peripheral clock mask for the OCD module can to be stopped to disable the Debug module. This can help in further reducing the current consumption.

2.13 SAM4L Low Power Design Checklist (specific to SAM4L)

Low Power Design Checklist table is provided in SAM4L schematic checklist for low power design with SAM4L device. The points in the checklist are helpful in designing a SAM4L based low power application.

2.14 Power Measurement General Considerations

When measuring power consumption on a custom board or evaluation kit, certain points need to be remembered.

- Operating condition can be different from the test conditions mentioned in the datasheet. So while verifying power consumption numbers, the differences in operating conditions should also be taken into consideration.
  Operating conditions includes operating voltage, frequency, temperature, peripherals used, clock sources used, etc.
- When the MCU is connected with many other components on the board or kit, these components could also influence the power consumption of the MCU. The numbers mentioned in the datasheet are measured only with the device, so before comparing the numbers, effect of influence due to the external components should be considered.
- Generally, evaluation kits have additional components like LCDs, Memory ICs, LEDs, etc. These components may or may not influence the MCU power consumption.
  So when checking the power consumption with a starter kit or evaluation kit, power numbers given in the datasheet may not be achieved.
- Programmer/Debugger connected with the device has to be removed while checking the power number. Sometimes the debugger can also influence the power number being measured.

3 Power Consumption Demonstration

Low Power Demo examples in Atmel Studio for SAM Xplained Pro kits are used to demonstrate low power mode power consumption in SAM3/SAM4 devices.

Note: Since this measurement condition is different from the datasheet test condition, there may be difference in power consumption numbers mentioned in the datasheet and those are given in this application note. So the numbers given in this application note are meant for reference and to show that power consumption reduces on entering different sleep modes.

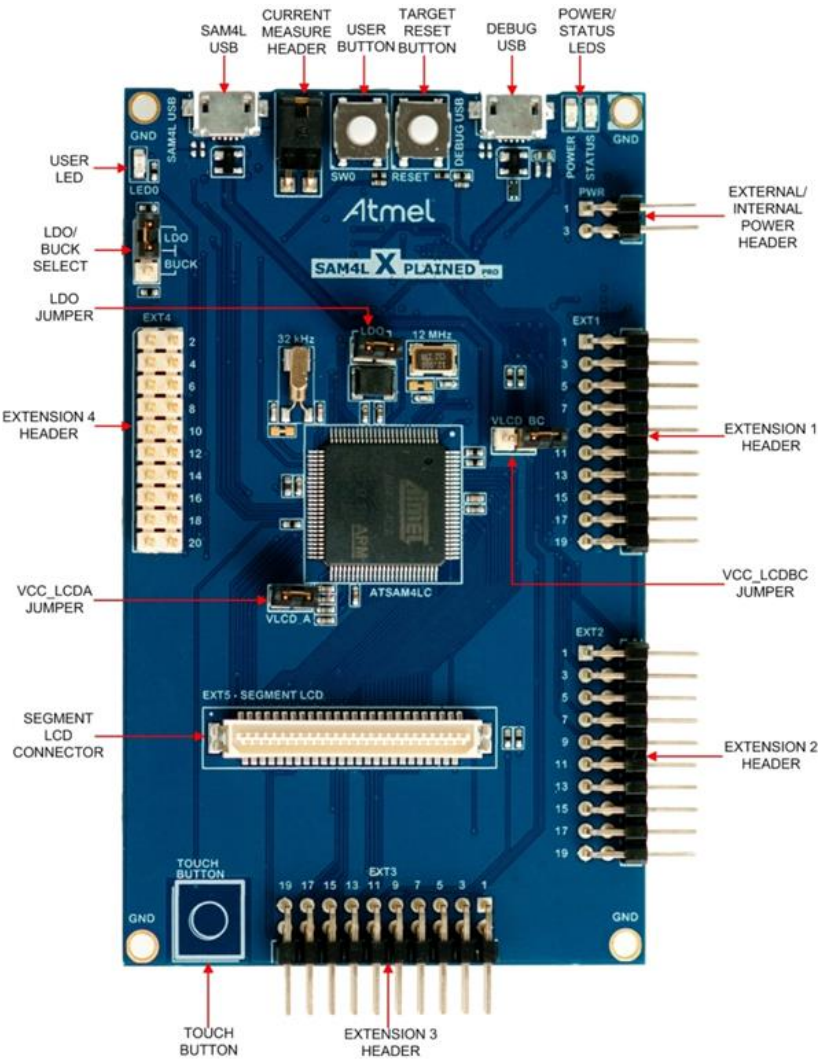
3.1 Hardware Platform

Kits considered for Demo:

- SAM4S Xplained Pro
- SAM4L Xplained Pro

The current measurement header in Xplained Pro kits is used for measuring current consumed by the device. All Xplained Pro series kits have this current measurement header for power consumption measurement purpose.

Figure 3-1. SAM4L Xplained Pro Kit



The Atmel SAM4L Xplained Pro evaluation kit is a hardware platform to evaluate the ATSAM4LC4C microcontroller. The Xplained Pro MCU series evaluation kits include an on-board Embedded Debugger (EDBG) thus no external tools are necessary to program and debug the target microcontroller.

Xplained Pro series kits have less onboard components and hence influence of external components in power consumption is minimal.

To measure the current consumption on the SAM4L Xplained Pro kit, remove the jumper (Current Measurement Header) near to SAM4L USB and connect a multi-meter configured to measure current. A micro-USB cable can be connected to PC to power the board.

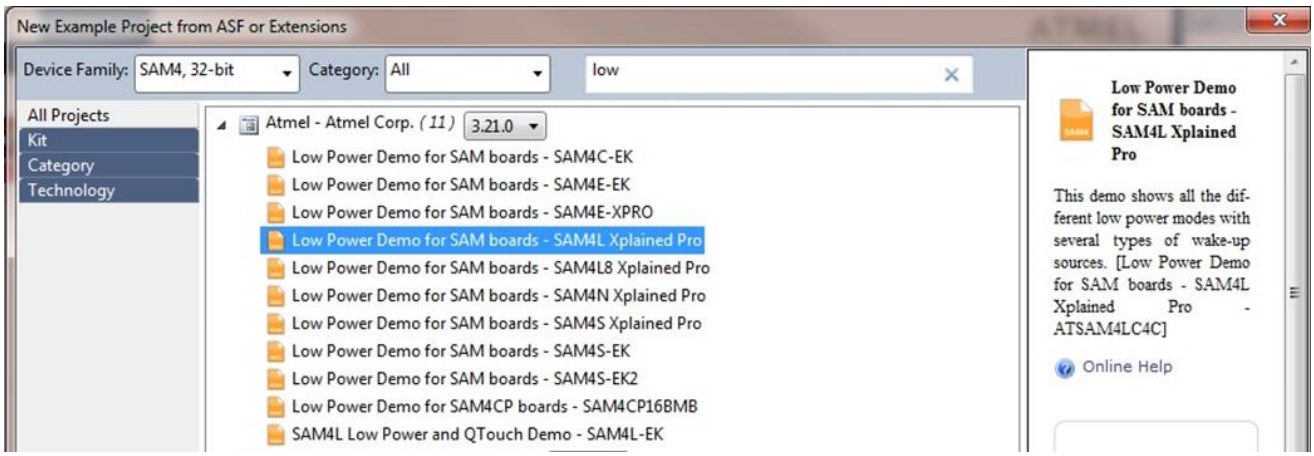
3.2 Software Platform

The Power numbers given in this document are measured using example project for the specific board, taken from ASF. These examples have the same name “Low Power Demo” as shown in the Figure 3-2 ASF Example.

Following are the steps to open example project in Atmel Studio and running the application.

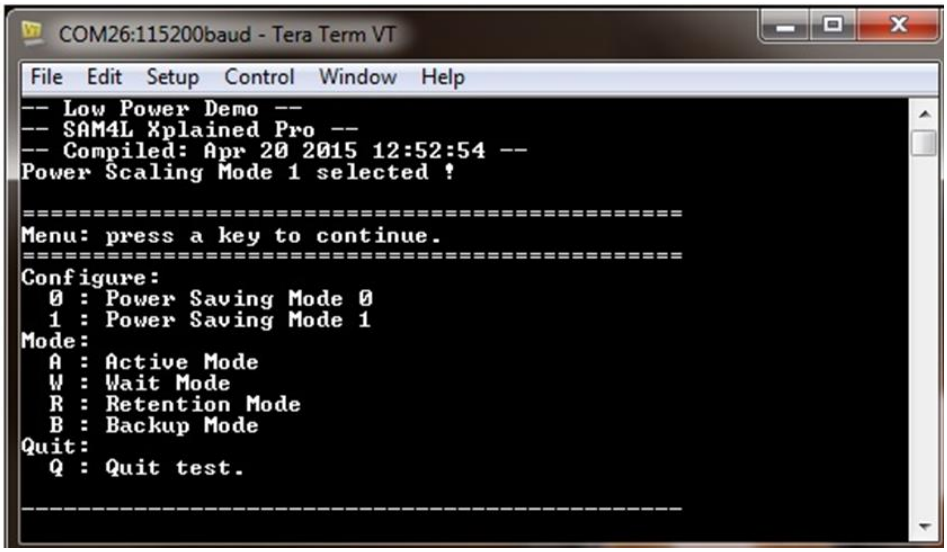
1. Go to File → New Example Project then select Device Family as “SAM, 32-bit” and search for “low” → Select the Low Power Demo project based on the board being used.
2. Build the project and program the application.
3. Once the application is programmed to SAM4L Xplained Pro, open any terminal software on the PC with EDBG COM port and 115200 baud rate.
   The Atmel Embedded Debugger (EDBG) is an onboard debugger for kits with Atmel devices. EDBG enables the user to debug the target device without an external debugger. EDBG also brings additional features with a Data Gateway Interface (DGI) and a Virtual COM Port for streaming of data to a host PC. The Atmel EDBG will enumerate as a composite USB device with separate interfaces for each function.

Figure 3-2. ASF Example



This example application shows different low power mode configurations available on the SAM4L device. \

Figure 3-3. Terminal Window



Type any of the characters listed in the menu to switch the device to corresponding low power mode.

By default, Power scaling mode 1 is selected. Send character 'W' over the UART to enter into WAIT Mode with Power Scaling Mode 1. Press switch SW0 (available on the SAM4L Xplained Pro) to exit from WAIT Mode.

3.3 Power Consumption Numbers when Running the ASF Demo Application

3.3.1 SAM4S Xplained Pro

Table 3-1. Power Consumption of SAM4S Xplained Pro for Active Power Consumption

Clock source	Core clock	Consumption	
		128-bit flash access	64-bit flash access
PLL	24MHz	5.493mA	7.195mA
	32MHz	6.727mA	8.758mA
	48MHz	9.617mA	11.597mA
	64MHz	12.063mA	15.094mA
	84MHz	15.758mA	19.430mA
	100MHz	20.659mA	24.671mA
	120MHz	22.535mA	27.095mA
Fast RC	125kHz	143.23µA	168.22µA
	250kHz	162.93µA	212.70µA
	500kHz	203.01µA	301.90µA
	1MHz	281.65µA	479.7µA
	2MHz	441.75µA	834.4µA
	4MHz	754.8µA	1.533mA
	8MHz	1.379mA	2.608mA
	12MHz	2.027mA	3.848mA

Table 3-2. Power Consumption of SAM4S Xplained Pro in Sleep Mode

Clock source	Core clock	Consumption	
		128-bit flash access	64-bit flash access
PLL	24MHz	3.455mA	3.456mA
	32MHz	4.017mA	4.019mA
	48MHz	5.107mA	5.107mA
	64MHz	6.722mA	6.722mA
	84MHz	8.763mA	8.764mA
	100MHz	12.266mA	12.267mA
	120MHz	12.481mA	12.484mA
Fast RC	125kHz	133.14µA	134.20µA
	250kHz	142.02µA	142.80µA
	500kHz	159.71µA	160.44µA
	1MHz	194.99µA	195.80µA
	2MHz	265.73µA	266.54µA
	4MHz	406.48µA	407.35µA
	8MHz	686.5µA	687.6µA
	12MHz	989.3µA	990.5µA

Table 3-3. Power Consumption of SAM4S Xplained Pro in Wait Mode

Conditions	Total consumption
4 MHZ Fast RC oscillator. PLL stopped.	40.42µA

Table 3-4. Power Consumption of SAM4S Xplained Pro in Backup Mode

Conditions	Total consumption
VDDIO = 3.3V	2.32µA

3.3.2 SAM4L Xplained Pro

Table 3-5. Power Consumption of SAM4L Xplained Pro in Various Modes

Mode	Power scaling mode	Measured current
Active Mode	0	4.4mA
	1	2.935mA
Wait Mode	0	7.1µA
	1	5.45µA
Retention Mode	0	4.35µA
	1	4.07µA
Backup Mode	0	1.34µA
	1	1.25µA

4 References

4.1 Device Datasheets

SAM3/SAM4 device datasheets have to be referred for detailed information on low power modes.

Devices referred in this application note are:

- SAM3 series: SAM3S, SAM3X/A, SAM3N, and SAM3U series of devices
- SAM4 series: SAM4S, SAM4E, SAM4N, and SAM4L series of devices

Device datasheets can be found in:
http://www.atmel.com/products/microcontrollers/arm/default.aspx?tab=documents

Document Type should be selected as “Datasheets”.

4.2 Schematic Checklists

Schematic checklists are available for above mentioned device families as application notes in following link:

http://www.atmel.com/products/microcontrollers/arm/default.aspx?tab=documents

Document Type should be selected as “Application Notes”.

5 Revision History

Doc Rev.	Date	Comments
42501A	08/2015	Initial document release.

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