Proyecto de ejemplo de AVR de baja potencia

Objetivo

Esta página ilustra varios métodos para configurar un MCU AVR ® de 8 bits para que funcione con bajo consumo de energía. Con este ejercicio lograrás:

- Cree un proyecto y agregue un código simple para hacer parpadear un LED
- Ejecutar el proyecto y medir el consumo de energía
- Hacer modificaciones al código para reducir la potencia
- Ejecute el proyecto modificado y observe un consumo de energía reducido

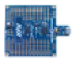
Materiales

Requisitos de Software

		Instaladores			
Herramienta	Sobre	ventanas	linux	Mac OS X	Instrucciones de instalación
Entorno de desarrollo integrado **Atmel®** **Studio**	(/atstudio:start)	(http://studio.download.atmel.com/7.0.1931/as-installer-7.0.1931-full.exe)			(/install:atstudio)

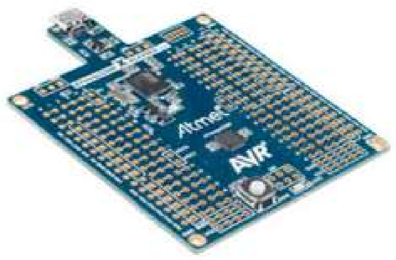
Requisitos de hardware

- ATmega328PB Mini tablero explicado
- Kit depurador de energía
- Dos cables micro USB
- Tres cables hembra a macho y un cable macho a macho

Herramienta	Sobre		
 (http://www.atmel.com/tools/MEGA328PB-XMINI.aspx)	Mini kit de evaluación **ATmega328PB Xplained**	(http://www.atmel.com/tools/MEGA328PB-XMINI.aspx)	(https://www.microchipdirect.com/pro

ATmega328PB Tarjeta explicada

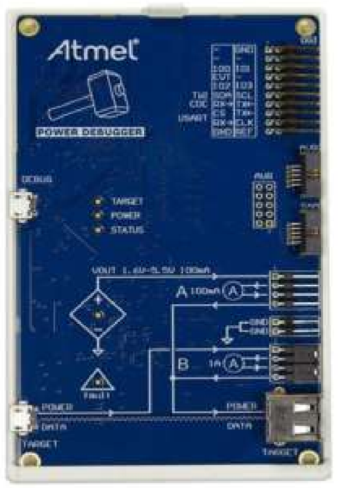
The **ATmega328PB Xplained Mini Evaluation Kit** is a hardware platform for evaluating the Atmel ATmega328PB microcontroller. An external debugger is NOT needed to run these exercises. The ATmega328PB has a fully integrated embedded debugger on-board.



(/local--files/8avr:low-power-example/xplained-board.png)

Power Debugger Kit

The Power Debugger is a CMSIS-DAP compatible debugger which works with Atmel Studio v7.0 or later. The power Debugger sends runtime power measurement and application debug data to the Data Visualizer.



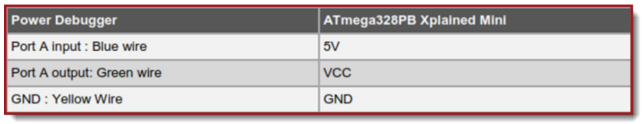
(/local--files/8avr:low-power-example/power-debug.png)

The Power Debugger has two independent current sensing channels for measuring and optimizing the power consumption of a design.
The 'A' channel is the recommend channel for accurately measuring low currents.
The 'B' channel is the recommended channel for measuring higher currents with lower resolution.

Hardware Setup

Connecting the Power Debugger to the ATmega328PB Xplained Board.

The 'A' and 'B' channel current measurement ports on the Power Debugger board are depicted with ammeter symbols on the silkscreen. The voltage supply is connected to the input of the ammeter, and the load (target) is connected to the output. With the following steps, the power debugger measures the consumption on the AVR core.
Table 1-1 Power Debugger and **ATmega328PB Xplained Mini** connection.



Power Debugger	ATmega328PB Xplained Mini
Port A input : Blue wire	5V
Port A output: Green wire	VCC
GND : Yellow Wire	GND

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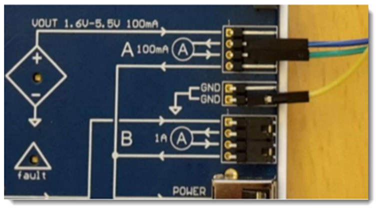
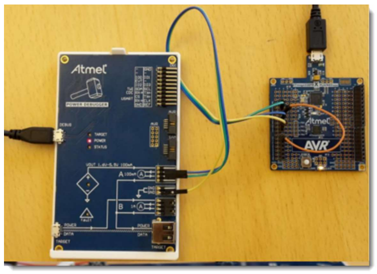
Figure 1-1 Power Debugger and **ATmega328PB Xplained Mini** connection.



(/local--files/8avr:low-power-example/connection.png)

Hardware Configuration



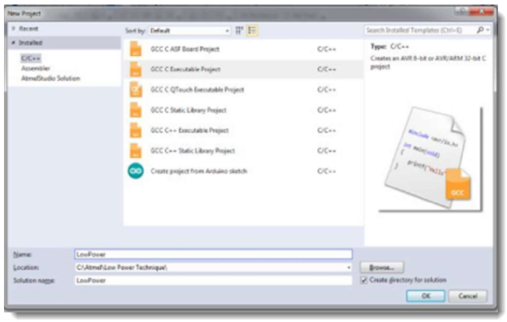
(/local--files/8avr:low-power-example/hw.png)

Measuring the Current in Active Mode

Procedure

A Project Creation

- Open Atmel Studio 7
- Select **File > New > Project**
- Select **GCC C Executable Project** and give it the name **LowPower**.
- Choose a location to save the project on your computer.



New Project

Sort by: Default

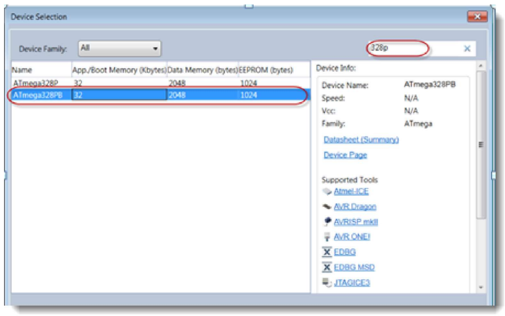
GCC C ASF Board Project	C/C++
GCC C Executable Project	C/C++
GCC C QTouch Executable Project	C/C++
GCC C Static Library Project	C/C++
GCC C++ Executable Project	C/C++
GCC C++ Static Library Project	C/C++
Create project from Arduino sketch	C/C++

Type: C/C++
Creates an AVR 8-bit or AVR/ARM 32-bit C project

Name: LowPower
Location: C:\Atmel\Low Power Technique\
Solution name: LowPower
☑ Create directory for solution

(/local--files/8avr:low-power-example/location.png)

- When the Device Selection window appears, enter 328P into the search window and then select the Atmega328PB. Click OK.



Device Selection

Device Family: All

328p

Name	App./Boot Memory (Kbytes)	Data Memory (bytes)	EEPROM (bytes)
ATmega328P	32	2048	1024
ATmega328PB	32	2048	1024

Device Info:

Device Name:	ATmega328PB
Speed:	N/A
Vcc:	N/A
Family:	ATmega

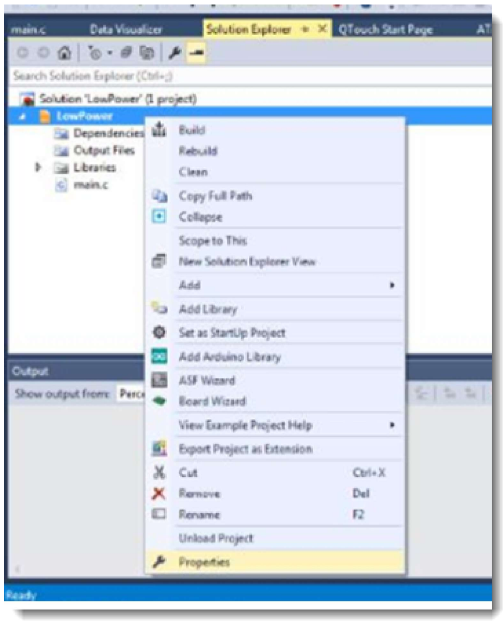
(/local--files/8avr:low-power-example/device-selection.png)

- A project will be created containing an empty `while(1) loop` in `main()`.

```
<font></font>
#include <avr/io.h><font></f
<font></font>
int main(void)<font></font>
{<font></font>
    /* Replace with your app
    while (1) <font></font>
    {<font></font>
    }<font></font>
} <font></font>
<font></font>
```

Select **View > Solution Explorer** from the menu bar.

In the Solution Explorer, right click the project and select **Properties**.



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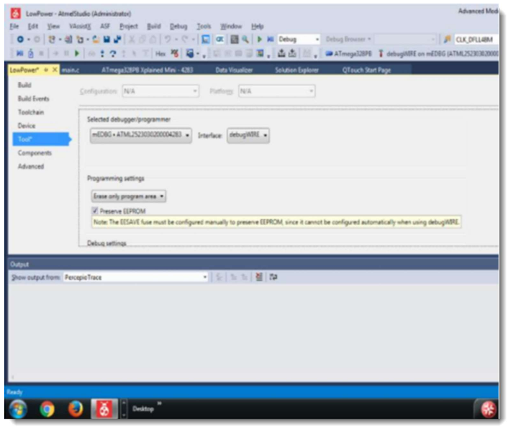
Under **Tool**, Select **mEDBG** and **debugWIRE**



Selected debugger/programmer: mEDBG • ATML2523030200004283

Interface: debugWIRE

Erase only program area

☑ Preserve EEPROM

Note: The EESAVE fuse must be configured manually to preserve EEPROM, since it cannot be configured automatically when using debugWIRE.

(/local--files/8avr:low-power-example/debugwire.png)

B Add Code to the Project

- Add the following two statements in `main()` to call `TMR0_init` and set an I/O pin as an output:

```
<font></font>
TMR0_init();<font></font>
<font></font>
DDRB |= 1<<DDRB5;   // Direction o
<font></font>
```

Add the Timer 0 initialization routine

```
<font></font>
/**********************************
                                TM
**********************************
void TMR0_init( void ){<font></fon
<font></font>
    // enable timer overflow inter
    TIMSK0=(1<<TOIE0) <font></font
    // set timer0 counter initial 
    TCNT0=0x00;<font></font>
    // start timer0 with /1024 pre
    TCCR0B = (1<<CS02) | (1<<CS00)
<font></font>
    // enable interrupts<font></fo
    sei(); <font></font>
<font></font>
}<font></font>
<font></font>
```

- Provide the TMR0 interrupt service routine to the project, and make the LED blink at about 1 Hz.

```
<font></font>
uint8_t    count;<font></font>
ISR(TIMER0_OVF_vect){<font></font>
<font></font>
    count++;<font></font>
    if(count==20){<font></font>
        count=0;<font></font>
        // Toogle LED<font></font>
        PORTB=PORTB ^ 0x20;<font></f
    }<font></font>
}<font></font>
<font></font>
```

The complete program is as follow,

```
<font></font>
#include <avr/io.h><font></font>
#include "avr/interrupt.h"<font></
<font></font>
    uint8_t    count;<font></font>
/* Timer 0 Interrupt */<font></fon
ISR(TIMER0_OVF_vect){<font></font>
<font></font>
    count++;<font></font>
    if(count==20){<font></font>
        count=0;<font></font>
        // Toogle LED<font></font>
        PORTB=PORTB ^ 0x20;<font><
    }<font></font>
}<font></font>
<font></font>
int main(void)<font></font>
{<font></font>
    TMR0_init();<font></font>
<font></font>
    DDRB |= 1<<DDRB5;   // Directi
    /* Replace with your applicati
    while (1) <font></font>
    {<font></font>
    }<font></font>
}<font></font>
<font></font>
/**********************************
                                TM
**********************************
void TMR0_init( void ){<font></fon
<font></font>
    // enable timer overflow inter
    TIMSK0=(1 <<TOIE0) ;<font></fo
<font></font>
    // set timer0 counter initial 
    TCNT0=0x00;<font></font>
<font></font>
    // start timer0 with /1024 pre
    TCCR0B = (1 <<CS02) | (1<<CS00
<font></font>
    // enable interrupts<font></fo
    sei(); <font></font>
<font></font>
}<font></font>
<font></font>
```

C Verify the Project Runs

- Build the project and program the device by selecting **Debug > Continue**.

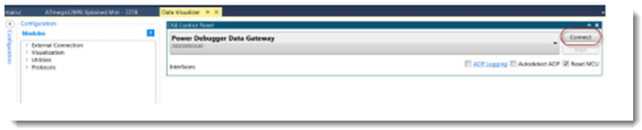
The LED will blink if the project is working correctly

- Ensure debugging for the project is terminated by selecting **Debug > Disable debugWire** then **Close**.

D Measure the Power Consumption in Active Mode

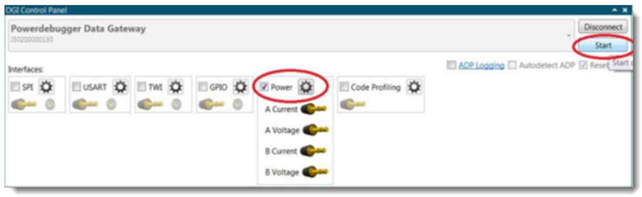
- In Atmel Studio 7, open the menu **Tools > Data Visualizer**

Power Debugger Data Gateway should be selected by default in DGI Control Panel, select it if not. Click on **Connect**.

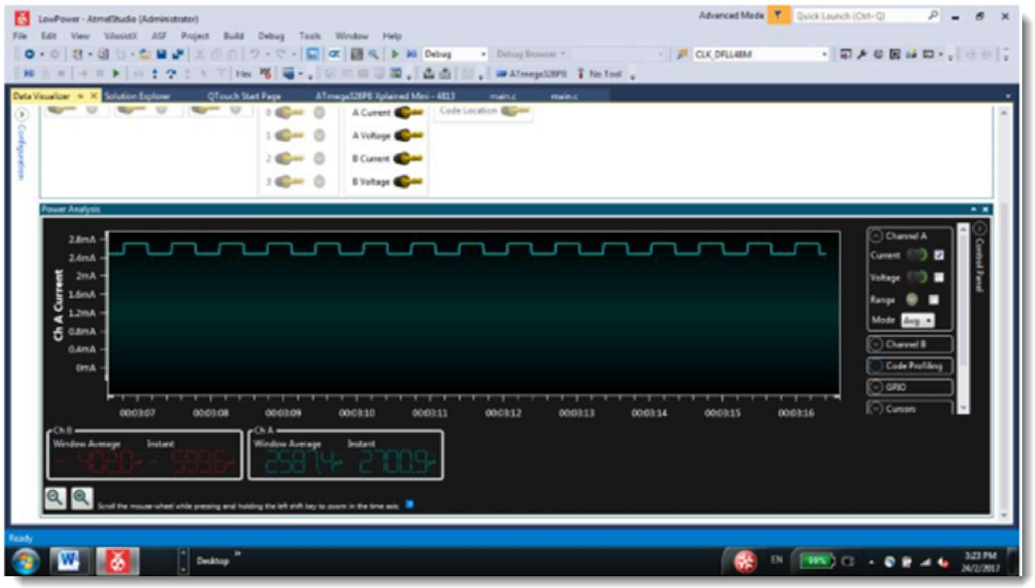


(/local--files/8avr:low-power-example/connect.png)

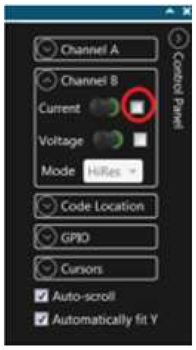
- Select **Power** and **Start**



(/local--files/8avr:low-power-example/power-and-start.png)



(/local--files/8avr:low-power-example/power-monitor.png)
Turn off the target Power Supply to Xplained board and enable power measurement



(/local--files/8avr:low-power-example/enable-power.png)

- Close the Device Programming
- Verify that the average current consumption is about 2.6 mA

Reducing the power consumption

There are several methods you can use to reduce the power consumption of an AVR® microcontroller. This example reduces power by:

- turning off unused peripherals
- Stopping leakage current on the digital I/O pins
- Using sleep mode. Power consumption optimization techniques are implementing in the function `Optimize_power_consumption()` which is called from `main()`.

Disable digital input buffers and Analog comparator

For analog input pins, the digital input buffer should be disabled.

The digital input buffer measures the voltage on the pin and represents the value as a logical one or zero. An analog signal level close to VCC/2 on an input pin can cause significant additional current consumption. If the pin is used as analog pin there is no need to know if the analog signal's digital value would be a one or zero; these digital pins should be disabled.

Turn off unused peripherals

Disable the peripherals not used in the application. The **Power Reduction Register** (**PRR0**) and (**PRR1**) can stop the clock to individual peripherals to reduce power consumption. Resources used by the peripheral remain occupied when the clock is stopped. In most instances, peripherals should be disabled before the clock is halted.

1. Include the <power.h> file in the main program
#include <avr/power.h>
2. Add below code to `optimize_power_consumption()`.

```
<font></font>
/* Power shutdown to unused periph
PPR0 = 0xDF;<font></font>
PPR1 = 0x3F;<font></font>
<font></font>
```

3. Add and #include for <wdt.h> to main.c.
#include <avr/wdt.h>
4. Add the following code in `optimize_power_consumption()` to turn off watch dog timer.

```
<font></font>
/* Disable interrupts*/<font></fon
Cli();<font></font>
Wdt_reset();<font></font>
MCUSR&= ~(1<<WDRF);<font></font>
<font></font>
```

Apply pull-up resistors

Unused and unconnected pins consume power. The un-needed power load of floating pins can be avoided by using the AVR's internal pull-up resistors on the unused pins. Port pins can be set to input pull-ups by setting the **DDxn** bit to 0 and **PORTxn** bit to 1. (where **x** is PORT B,C,D,E and **n** is 0 to 7)

```
<font></font>
    /* Unused pins set as inpu
        DDRB  &= 0xE0;<font><,
        DDRC &= 0xC9;<font></
        DDRD &= 0x03;<font></
        DDRE &= 0xF3;<font></
<font></font>
        PORTB |= ~(0xE0);<font
        PORTC |= ~(0xC9);<font
        PORTD |= ~(0x03);<font
        PORTE |= ~(0xF3);<font
<font></font>
```

Use Sleep function

Sleep mode allows the application to save power by shutting down unused modules. The AVR provides various sleep modes allowing the user to tailor the power consumption to the application's requirements.

1. **Include <avr/sleep.h>** header file from AVR library at the top of file.
2. Set the desired sleep mode in the `optimize_power_consumption ()` function by configuring the microcontroller to use the sleep mode **SLEEP_MODE_PWR_DOWN** for minimum power consumption.

```
<font></font>
               /* Set sleep mode */<
            set_sleep_mode(SLEEP_MOD
<font></font>
```

3. Call the `function sleep_mode()` from `main()` to enter sleep mode.

```
<font></font>
                       while

                          sle
         }<font></font>
<font></font>
```

Using Pin Change Interrupt

To wake up the microcontroller from **SLEEP_MODE_PWR_DOWN** the **Pin Change Interrupt** is used. The **ATmega328PB Xplained Mini** board's switch (SW0) is connected to **PB7**. Pin **PB7** is the source for the pin change interrupt. Make the following additions to `main()`:

#include avr/interrupt.h

Configuring bit PCINT7 and PCICR register:

```
<font></font>
 PCMSK0 |= (1<<PCINT7); //Enable P
    PCICR |= (1<<PCIE0); //Enable
    sei();<font></font>
<font></font>
```

Add the interrupt service routine:

In order to enable the ISR routines, the vector name for the PCINT7 is ISR (PCINT0_vect), defined in device header file.

```
<font></font>
   ISR (PCINT0_vect)<font></font>
{<font></font>
     if (!(PINB & (1<<PINB7))) //
    {<font></font>
        PORTB |= (1 <<PORTB5); //
    }<font></font>
    else<font></font>
    {<font></font>
        PORTB &= ~(1<<PORTB5); //
    } <font></font>
}         }<font></font>
<font></font>
```

Completed Code

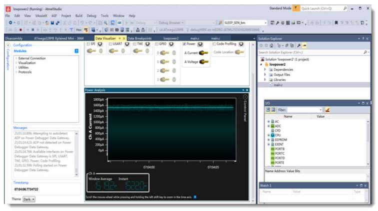
After making the previous changes the complete code should like the following:

```
<font></font>
/*<font></font>
 * lowpower2.c<font></font>
 */ <font></font>
<font></font>
//#include <avr/io.h><font></font>
<font></font>
#include <avr/io.h><font></font>
#include "avr/interrupt.h"<font></
#include "avr/wdt.h"<font></font>
#include "avr/sleep.h"<font></font
<font></font>
#include <avr/power.h><font></font
#include <avr/interrupt.h><font></
//#include <util/delay.h><font></f
<font></font>
void    optimize_power_consumption
<font></font>
    /* Disable digital input buffe
    DIDR0 = (1 << ADC5D) | (1 << A
    DIDR0 |= 0xC0 ;   /*ADC7D and
<font></font>
    /* Disable digital input buffe
    DIDR1 |= (1 << AIN1D) | (1 <<
    /* Disable Analog Comparator *
    ACSR |= (1 << ACD);<font></fon
<font></font>
    /*Power shutdown to unused per
    PRR0 = 0xDF;<font></font>
    PRR1 = 0x3F;<font></font>
    /*Unused pins set as input pul
    DDRB &= 0xE0;<font></font>
    DDRC &= 0xC9;<font></font>
    DDRD &= 0x03;<font></font>
    DDRE &=0xF3;<font></font>
<font></font>
    PORTB |=~(0xE0);<font></font>
    PORTC |=~(0xC9);<font></font>
    PORTD |=~(0x03);<font></font>
    PORTE |=~(0xf3);<font></font>
<font></font>
    /*Watchdog Timer OFF*/<font></
<font></font>
    /* Disable interrupts */<font>
    cli();<font></font>
    /* Reset watchdog timer */<fon
    wdt_reset();<font></font>
    /* Clear WDRF in MCUSR */<font
    MCUSR &= ~(1<<WDRF);<font></fo
    /* Turn off WDT */<font></font
    WDTCSR = 0x00;<font></font>
<font></font>
    /* Set sleep mode */<font></fo
    set_sleep_mode(SLEEP_MODE_PWR_
<font></font>
}<font></font>
<font></font>
/**********************************
                                 TM
**********************************
 void TMR0_init( void ){<font></fo
<font></font>
    // enable timer overflow inter
    TIMSK0=(1<<TOIE0) ;<font></fon
<font></font>
    // set timer0 counter initial
    TCNT0=0x00;<font></font>
```

```
<font></font>
    // start timer0 with /1024 pre
    TCCR0B = (1<<CS02) | (1<<CS00)
<font></font>
    // enable interrupts<font></fo
    sei(); <font></font>
<font></font>
}  <font></font>
     uint8_t    count;<font></font
/* Timer 0 Interrupt */<font></fon
 ISR(TIMER0_OVF_vect){<font></font
<font></font>
    count++;<font></font>
    if(count==20){<font></font>
        count=0;<font></font>
        // Toogle LED<font></font>
        PORTB=PORTB ^ 0x20;<font><
    }<font></font>
}<font></font>
<font></font>
ISR (PCINT0_vect)<font></font>
{<font></font>
     if (!(PINB & (1<<PINB7))) //
    {<font></font>
        PORTB |= (1<<PORTB5); // T
    }<font></font>
    else<font></font>
    {<font></font>
        PORTB &= ~(1<<PORTB5); //
    } <font></font>
}<font></font>
<font></font>
int main(void)<font></font>
{<font></font>
    TMR0_init();<font></font>
<font></font>
    DDRB |= 1<<DDRB5;   // Directi
    DDRB &= ~(1<<DDB7); //Set PORT
<font></font>
    optimize_power_consumption();<
<font></font>
    PCMSK0 |= (1<<PCINT7); //Enabl
    PCICR |= (1<<PCIE0); //Enable
    sei();<font></font>
<font></font>
    //set_sleep_mode(SLEEP_MODE_PW
    //sleep_enable();<font></font>
    //sleep_cpu();<font></font>
<font></font>
    /* Replace with your applicati
    while (1) <font></font>
    {<font></font>
        sleep_mode();<font></font>
    }<font></font>
}<font></font>
<font></font>
```

Program the application and measure power consumption.

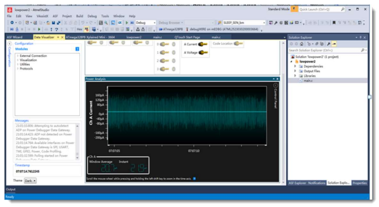
1. Program the code by selecting **Debug > Continue**.
2. Wait until the application is programmed and the message at the bottom of the window appears as **Running**.
3. Exit the debugger by selecting **Debug > Disable debugWire** then **Close**.
4. Open the **DataVisualizer window** and check the power consumption as shown below.



(/local--files/8avr:low-power-example/one-five.png)

Current consumption observed should be down to around 1.52 mA.

- Set target power switch off: **Tools > Device Programming > Tools** setting


(/local--files/8avr:low-power-example/threema.png)

Current consumption should have been lowered to approximately 20.7 µA.

Note that the Timer does not wake the device from SLEEP mode. The application is set to exit sleep mode when the **Pin Change Interrupt** occurs.

Conclusions

This example demonstrated several different techniques to lower the power consumption of an AVR application. The power consumption can be significantly reduced by:

- Intelligent design
- Using sleep modes
- Switching off unused peripherals

This example used the **Atmel Studio 7 Data Visualizer** and the **Power Debugger Board** to measure the power.