
Telos

Ultra low power IEEE 802.15.4 compliant wireless sensor module

Revision B : Humidity, Light, and Temperature sensors with USB

Product Description

Telos is an ultra low power wireless module for use in sensor networks, monitoring applications, and rapid application prototyping. Telos leverages industry standards like USB and IEEE 802.15.4 to interoperate seamlessly with other devices. By using industry standards, integrating humidity, temperature, and light sensors, and providing flexible interconnection with peripherals, Telos enables a wide range of



mesh network applications. Telos Revision B is a drop-in replacement for Moteiv's successful Revision A design. Revision B includes increased performance, functionality, and expansion. With TinyOS support out-of-the-box, Telos leverages emerging wireless protocols and the open source software movement. Telos is part of a line of modules featuring on-board sensors to increase robustness while decreasing cost and package size.

Key Features

- 250kbps 2.4GHz IEEE 802.15.4 Chipcon Wireless Transceiver
- Interoperability with other IEEE 802.15.4 devices
- 8MHz Texas Instruments MSP430 microcontroller (10k RAM, 48k Flash)
- Integrated ADC, DAC, Supply Voltage Supervisor, and DMA Controller
- Integrated onboard antenna with 50m range indoors / 125m range outdoors
- Integrated Humidity, Temperature, and Light sensors
- Ultra low current consumption
- Fast wakeup from sleep (<math><6\mu\text{s}</math>)
- Hardware link-layer encryption and authentication
- Programming and data collection via USB
- 16-pin expansion support and optional SMA antenna connector
- TinyOS support : mesh networking and communication implementation



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Module Description

The Telos module is a low power “mote” with integrated sensors, radio, antenna, microcontroller, and programming capabilities.

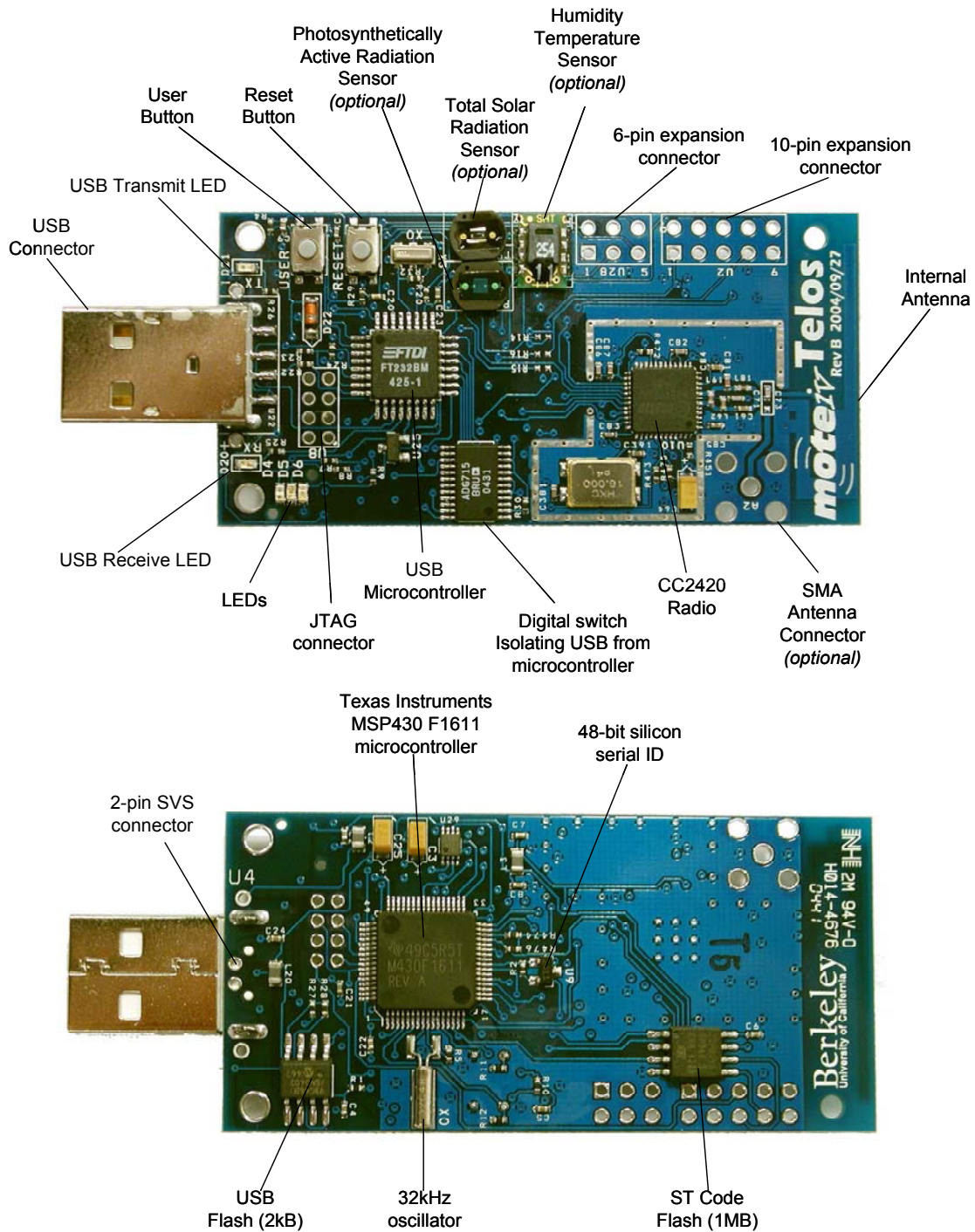


Figure 1 : Front and Back of the Telos module



Power

Telos may be powered by two AA batteries. The module was designed to fit the two AA battery form factor. AA cells may be used in the operating range of 2.1 to 3.6V DC, however the voltage must be at least 2.7V when programming the microcontroller flash or external flash.

If the Telos module is plugged into the USB port for programming or communication, it will receive power from the host computer. The mote operating voltage when attached to USB is 3V. If Telos will always be attached to a USB port, no battery pack is necessary.

The 16-pin expansion connector (described in the Section on page 19) can provide power to the module. Any of the battery terminal connections may also provide power to the module. At no point should the input voltage exceed 3.6V—doing so may damage the microcontroller, radio, or other components.

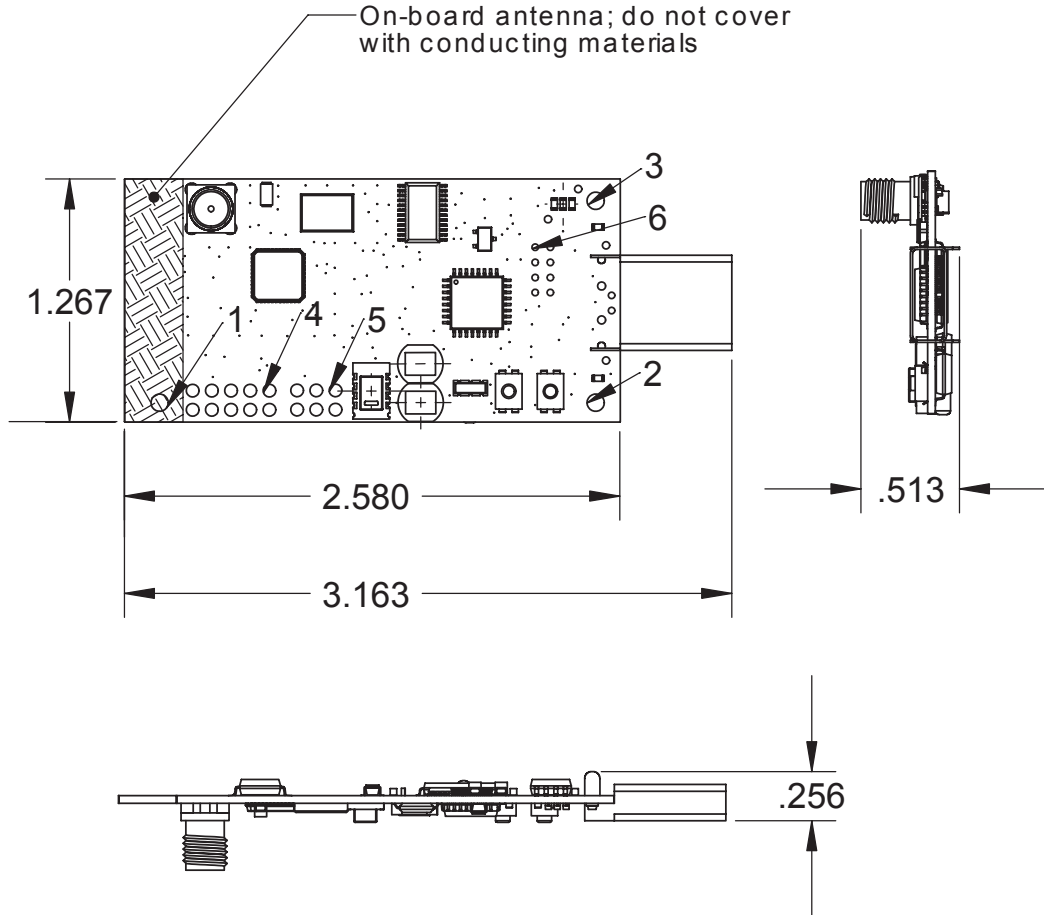
Typical Operating Conditions

	MIN	NOM	MAX	UNIT
Supply voltage	2.1		3.6	V
Supply voltage during flash memory programming	2.7		3.6	V
Operating free air temperature	-40		85	°C
Current Consumption: MCU on, Radio RX		21.8	23	mA
Current Consumption: MCU on, Radio TX		19.5	21	mA
Current Consumption: MCU on, Radio off		1800	2400	µA
Current Consumption: MCU idle, Radio off		54.5	1200	µA
Current Consumption: MCU standby		5.1	21.0	µA



Caution! ESD sensitive device.
Precaution should be used when handling the device in order to prevent permanent damage.

Mechanical Characteristics



Tag	X	Y	Size	Notes
1	0.183	0.099	Ø 0.090	Mounting hole, do not use metal fixture
2	2.454	0.099	Ø 0.090	Mounting hole
3	2.454	1.151	Ø 0.090	Mounting hole
4	0.755	0.162	Ø 0.066	Pin 1 of 10-pin 0.1in rect IDC connector
5	1.099	0.163	Ø 0.066	Pin 1 of 6-pin 0.1in rect IDC connector
6	2.139	0.909	Ø 0.034	Pin 1 of 8-pin 2mm rect JTAG connector

Figure 2 : Physical dimensions of Telos Revision B.
All units are in inches unless otherwise noted.

	MIN	NOM	MAX	UNIT
Width	1.24	1.26	1.29	in
Length	2.55	2.58	2.60	in
Height (without battery pack and SMA antenna)	0.24	0.26	0.27	in

Block Diagram

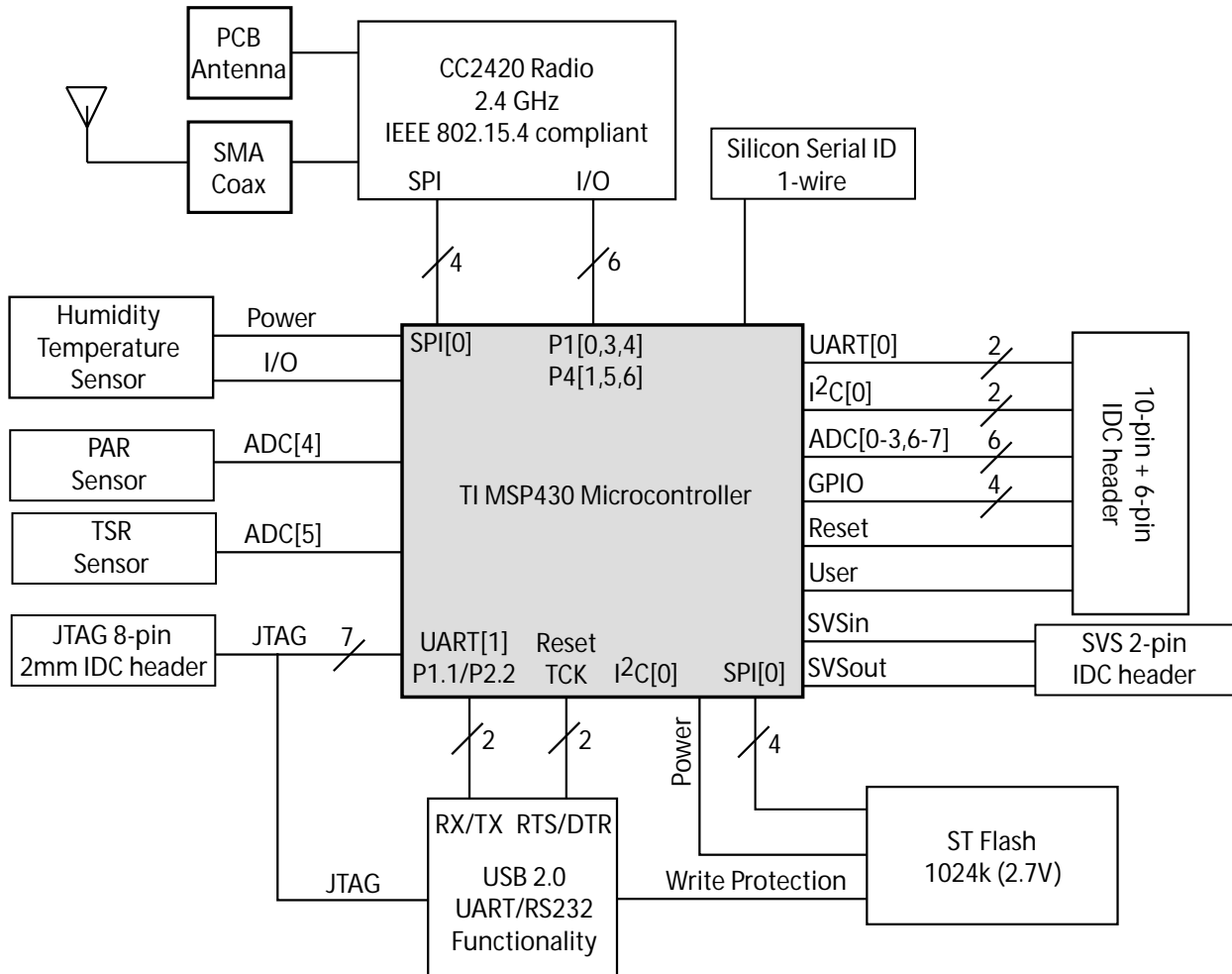
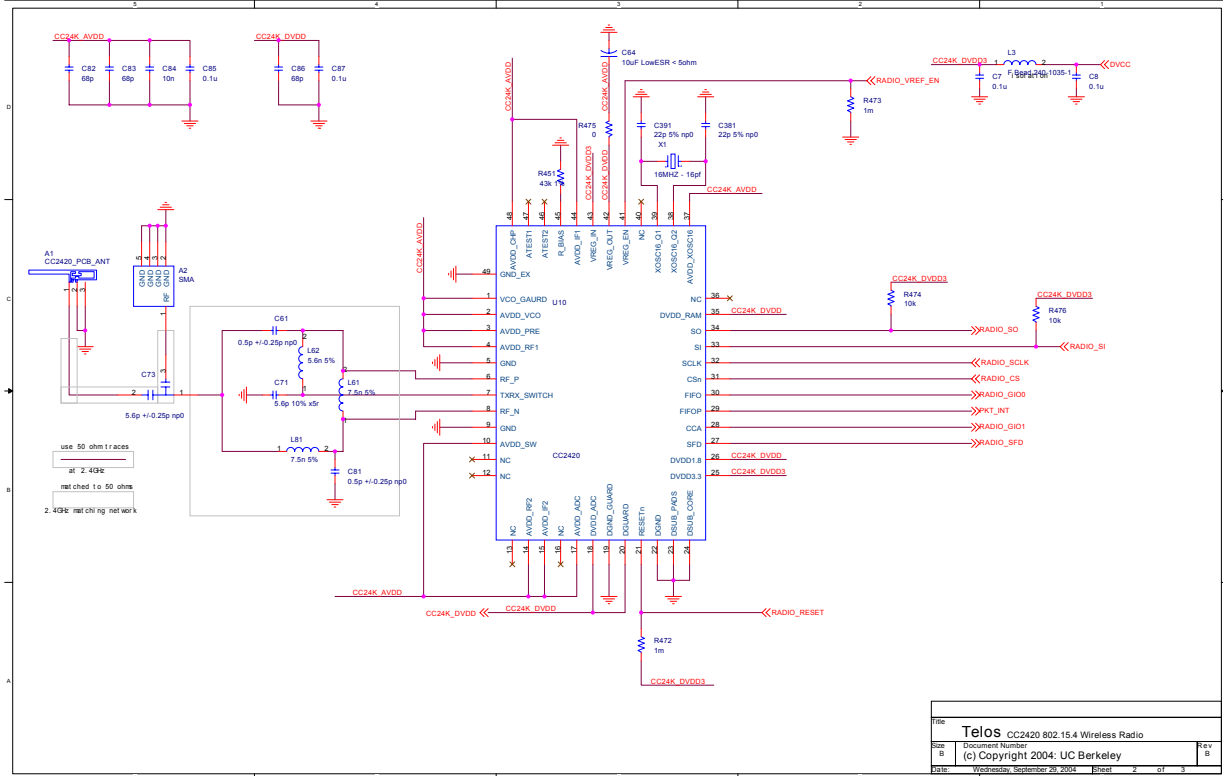
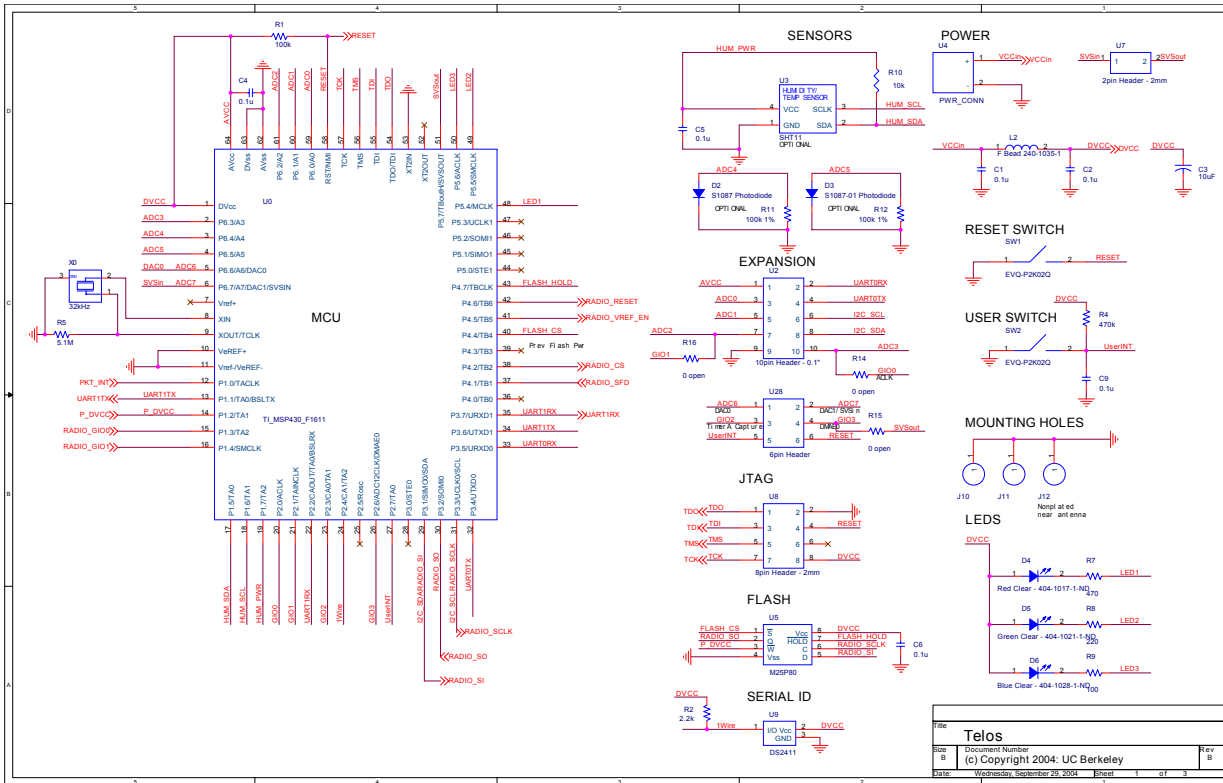


Figure 3 : Functional Block Diagram of the Telos Module, its components, and buses

Schematic



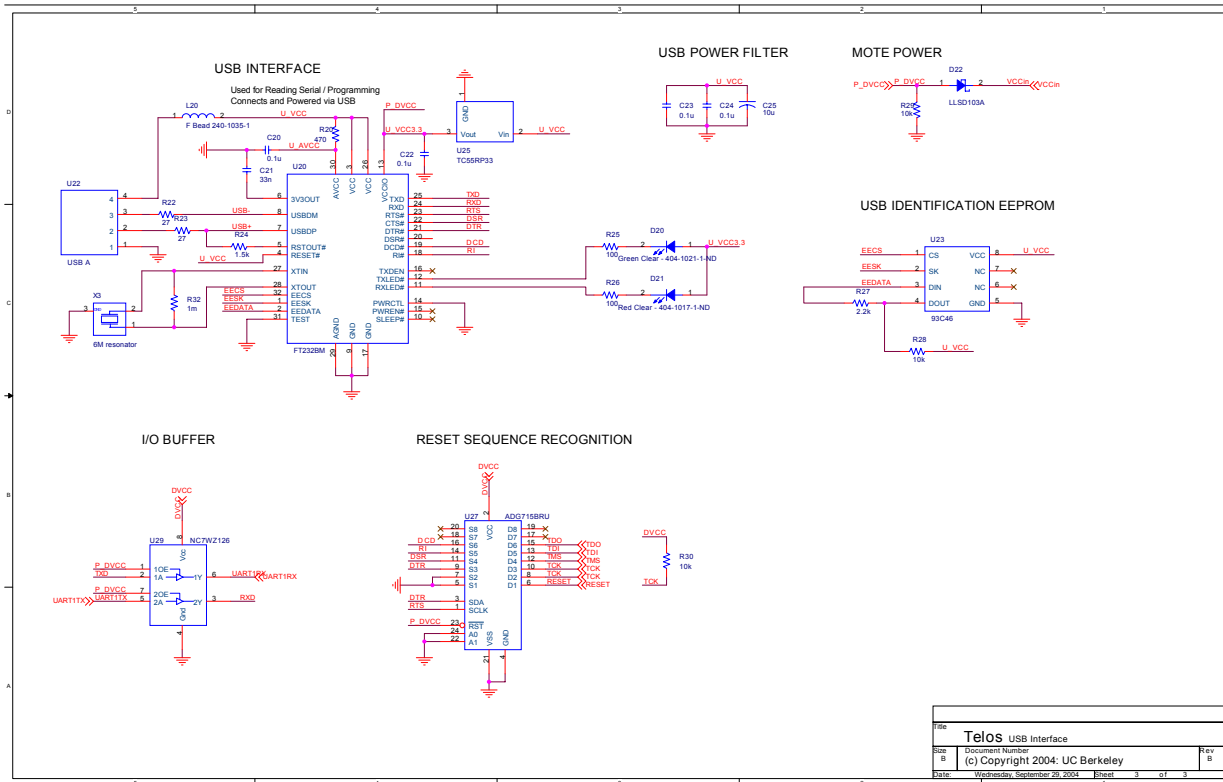


Figure 4 : Schematics for the Telos module (Rev B)

Telos USB Interface			
Doc	Document Number	Rev	
IS	(c) Copyright 2004: UC Berkeley	B	
3/14/04	Hydroswave September 29, 2004	3	21 3



Microprocessor

Description

The low power operation of the Telos module is due to the ultra low power Texas Instruments MSP430 F1611 microcontroller featuring 10kB of RAM, 48kB of flash, and 128B of information storage. This 16-bit RISC processor features extremely low active and sleep current consumption that permits Telos to run for years on a single pair of AA batteries. The MSP430 has an internal digitally controlled oscillator (DCO) that may operate up to 8MHz. The DCO may be turned on from sleep mode in 6 μ s, however 292ns is typical at room temperature. When the DCO is off, the MSP430 operates off an eternal 32768Hz watch crystal. Although the DCO frequency changes with voltage and temperature, it may be calibrated by using the 32kHz oscillator.

In addition to the DCO, the MSP430 has 8 external ADC ports and 8 internal ADC ports. The ADC internal ports may be used to read the internal thermistor or monitor the battery voltage. A variety of peripherals are available including SPI, UART, digital I/O ports, Watchdog timer, and Timers with capture and compare functionality. The F1611 also includes a 2-port 12-bit DAC module, Supply Voltage Supervisor, and 3-port DMA controller.

The features of the MSP430 F1611 are presented in detail in the Texas Instruments MSP430x1xx Family User's Guide available at <http://ti.com/msp430>.

Typical Operating Conditions

	MIN	NOM	MAX	UNIT
Supply voltage during program execution	1.8		3.6	V
Supply voltage during flash memory programming	2.7		3.6	V
Operating free air temperature	-40		85	°C
Low frequency crystal frequency		32.768		kHz
Active current at Vcc = 3V, 1MHz		500	600	μ A
Sleep current in LPM3 Vcc = 3V, 32.768kHz active		2.6	3.0	μ A
Wake up from LPM3 (low power mode)			6	μ s

PC Communication

Telos uses a USB controller from FTDI to communicate with the host computer. In order to communicate with the mote, the FTDI drivers must be installed on the host. FTDI provides drivers for Windows, Linux, BSD, Macintosh, and Windows CE. These drivers are included on the Moteiv CD shipped with your order. Windows users will need the Virtual Com Port (VCP) drivers. They may also be downloaded from FTDI's website at: <http://www.ftdichip.com/>

After installing the driver, Telos appears as a COM port in Windows' device manager (or as a device in /dev in Linux, OSX, and BSD). Multiple Telos motes may be connected to a single computer's USB ports at the same time. Each mote will receive a different COM port identifier. In the example below, one Telos is connected and assigned COM6 "USB Serial Port".

An application may read from Telos by opening the COM port assigned to the Telos mote. Telos communicates with the host PC through USART1 on the TI MSP430.

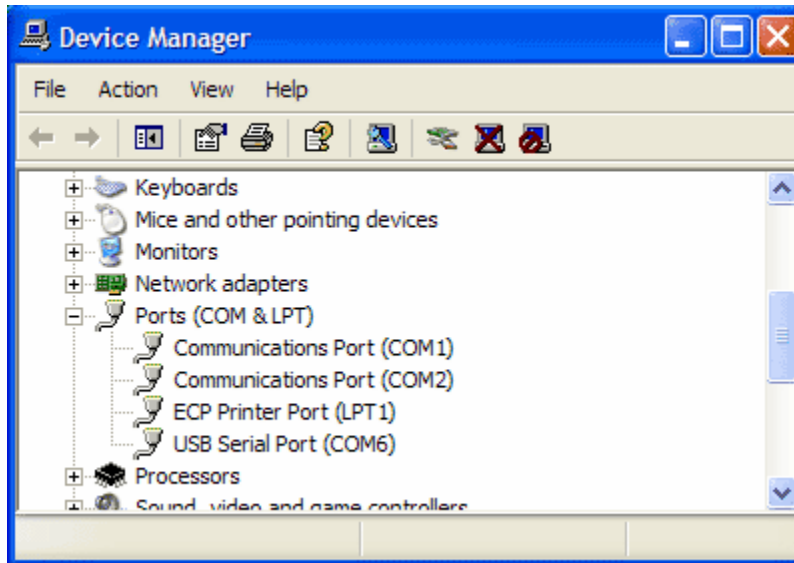


Figure 5 : Device Manager showing Telos installed as COM6

The `motelist` command line utility lists all of the Telos motes currently connected to a computer. This utility optionally lists previously connected motes that the system has cached. Invoke `motelist` with the `-h` option for more information.

```
> motelist
Reference  CommPort  Description
-----
M4MXVA4Y  COM6      Telos (Rev B 2004-09-27)
```

! **NOTE:** Telos (Revision B) uses an I²C digital switch to prevent unwanted conventional serial port signals from reaching the TI microcontroller. The I²C protocol must be implemented and sent over the RTS and DTR lines in order to obtain direct access between the Telos and USB controller. The UART lines do not use the I²C switch allowing direct communication (but not programming or JTAG) without additional software.

Programming

The Telos module is programmed through the onboard USB connector. A modified version of the MSP430 Bootstrap Loader, `mSP430-bs1`, programs the microcontroller's flash. Telos has a unique hardware circuit that prevents the mote from spuriously resetting. This hardware circuit makes it necessary to have a special sequence sent to the module in order to program it.

By invoking `mSP430-bs1`, verify you have the patched BSL by looking for the "telos" keyword. Version 1.39-telos-6 or later is required for Telos (Rev B).

```
> mSP430-bs1
MSP430 Bootstrap Loader Version: 1.39-telos-6
Use -h for help
```



To communicate with Telos, the MSP430 Bootstrap Loader requires a set of options to provide the proper signals to the microcontroller to initiate programming. For convenience, the options have been folded into a single Telos (Revision B) flag:

```
--telosb
```

To program a Telos module on COM3 (or /dev/ttyUSB2 in Linux) with an application image named `app.ihex`, invoke the MSP430 Bootstrap loader with the following options.

```
> msp430-bsl --telosb -c 2 -r -e -I -p app.ihex
MSP430 Bootstrap Loader Version: 1.39-telos-6
Mass Erase...
Transmit default password ...
Invoking BSL...
Transmit default password ...
Current bootstrap loader version: 1.61 (Device ID: f16c)
Changing baudrate to 38400 ...
Program ...
2742 bytes programmed.
Reset device ...
```

If you are using TinyOS, it has support for programming Telos. After compiling your application, you may install it with the following command

```
> make telosb install.x bsl,n
```

Where `x` is the 16-bit address assigned to the mote and `n` is the COM port that Telos is currently using. Note that not including “`bsl`” or “`bsl,n`” will program automatically using the `bsl` to the first Telos mote found on the USB bus using the `motelist` command.

For more information about the options in the MSP430 Bootstrap loader, invoke `msp430-bsl` with the `-h` option to display the help information.

`Motelist` and `msp430-bsl` are available from Moteiv Corporation at <http://www.moteiv.com> in the “Support” section.



NOTE: `msp430-bsl` starts counting from 0, but COM ports in Windows start counting at 1. If Telos is connected to COM3 in Windows, you must program it using “`-c 2`” or “`bsl,2`” when invoking `msp430-bsl`. In Linux, Telos will appear as /dev/ttyUSB2 and may be programmed using “`-c 2`” or “`bsl,2`”.

Block Diagram

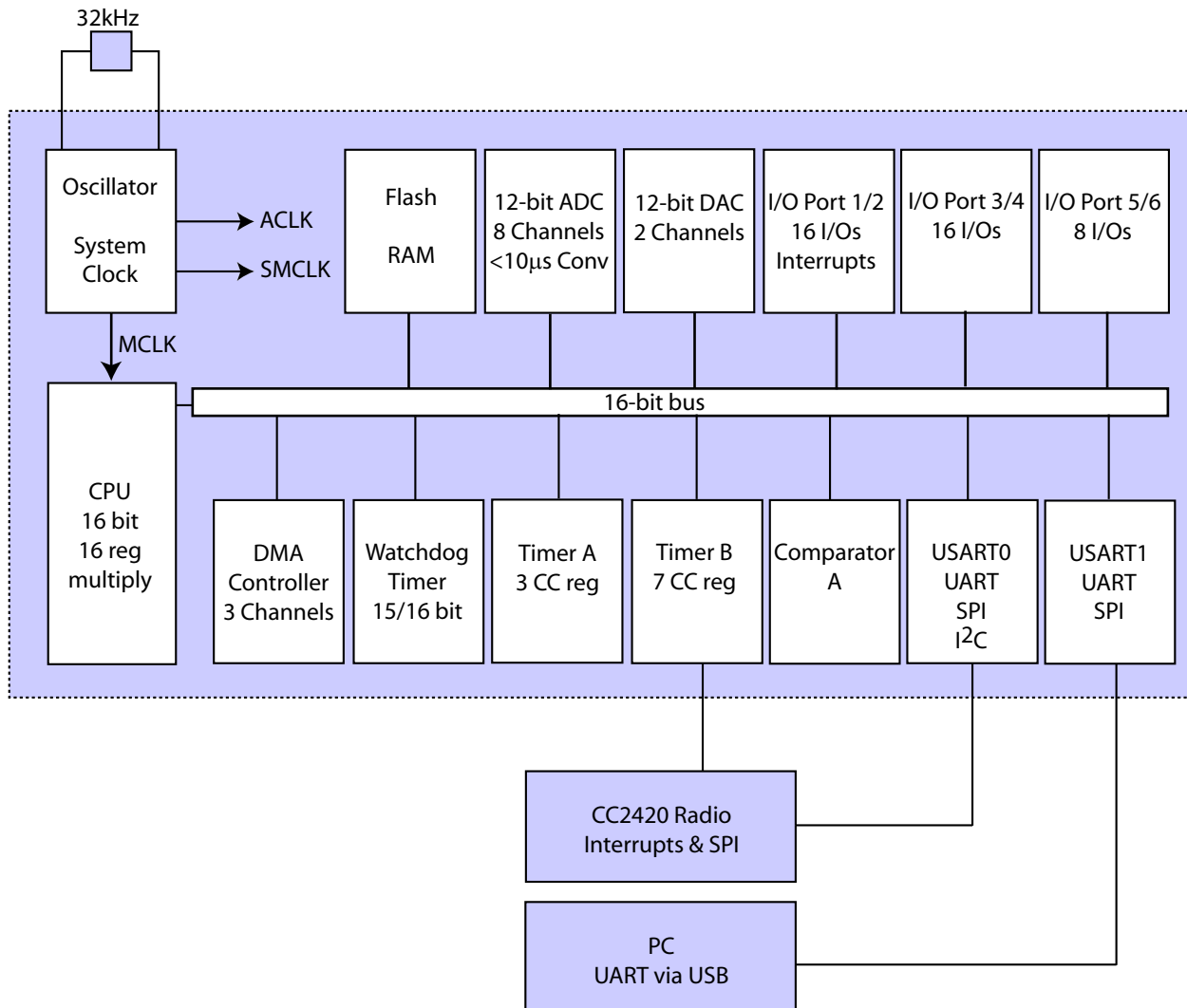


Figure 6 : Block diagram of the TI MSP430 microcontroller and its connection to other peripherals in the Telos module

Radio

Description

Telos features the Chipcon CC2420 radio for wireless communications. The CC2420 is an IEEE 802.15.4 compliant radio providing the PHY and some MAC functions. With sensitivity exceeding the IEEE 802.15.4 specification and low power operation, the CC2420 provides reliable wireless communication. The CC2420 is highly configurable for many applications with the default radio settings providing IEEE 802.15.4 compliance. Features and usage of the CC2420 is available in Chipcon's datasheet at <http://www.chipcon.com>

The CC2420 is controlled by the TI MSP430 microcontroller through the SPI port and a series of digital I/O lines and interrupts (see the Schematics on page 7 for more information). The radio may be shut off by the microcontroller for low power duty cycled operation.

The CC2420 has programmable output power. Common CC2420 register values and their corresponding current consumption and output power are shown in Figure 7.

PA_LEVEL	TXCTRL register	Output Power [dBm]	Current Consumption [mA]
31	0xA0FF	0	17.4
27	0xA0FB	-1	16.5
23	0xA0F7	-3	15.2
19	0xA0F3	-5	13.9
15	0xA0EF	-7	12.5
11	0xA0EB	-10	11.2
7	0xA0E7	-15	9.9
3	0xA0E3	-25	8.5

Figure 7 : Output power configuration for the CC2420

The CC2420 provides a digital received signal strength indicator (RSSI) that may be read any time. Additionally, on each packet reception, the CC2420 samples the first eight chips, calculates the error rate, and produces a link quality indication (LQI) value with each received packet. A mapping from RSSI to the RF level in dBm is shown in Figure 8.

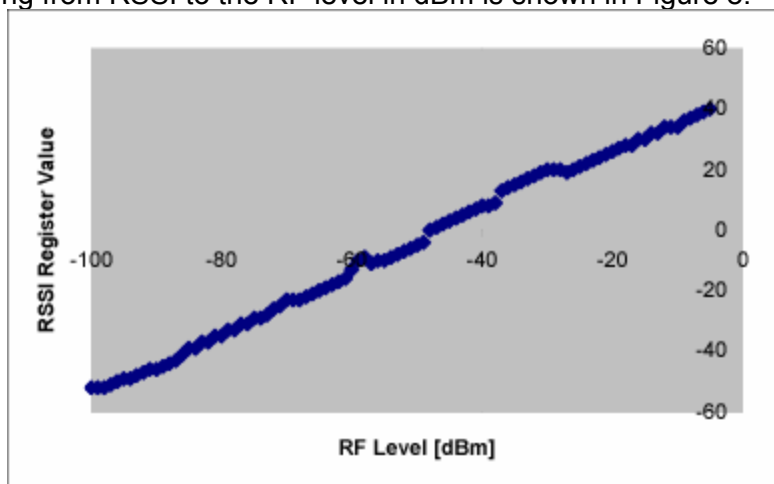


Figure 8 : Received Signal Strength Indicator mapping to RF Power [dBm]

Typical Operating Conditions

	MIN	NOM	MAX	UNIT
Supply voltage during radio operation (Vreg on)	2.1		3.6	V
Operating free air temperature	-40		85	°C
RF frequency range	2400		2483.5	MHz
Transmit bit rate	250		250	kbps
Nominal output power	-3	0		dBm
Programmable output power range		40		dBm
Receiver sensitivity	-90	-94		dBm
Current consumption: Radio transmitting at 0 dBm		17.4		mA
Current consumption: Radio receiving		19.7		mA
Current consumption: Radio on, Oscillator on		365		μA
Current consumption: Idle mode, Oscillator off		20		μA
Current consumption: Power Down mode, Vreg off			1	μA
Voltage regulator current draw	13	20	29	μA
Radio oscillator startup time		580	860	μS

Measured Output Power

The RF output power of the Telos module from the CC2420 radio is shown in Figure 9. For this test, the Telos module is transmitting at 2.405GHz (IEEE 802.15.4 channel 11) using the O-QPSK modulation with DSSS. The CC2420 programmed output power is set to 0 dBm. The measured output power of the entire modulated spectrum is 2.4 dBm.

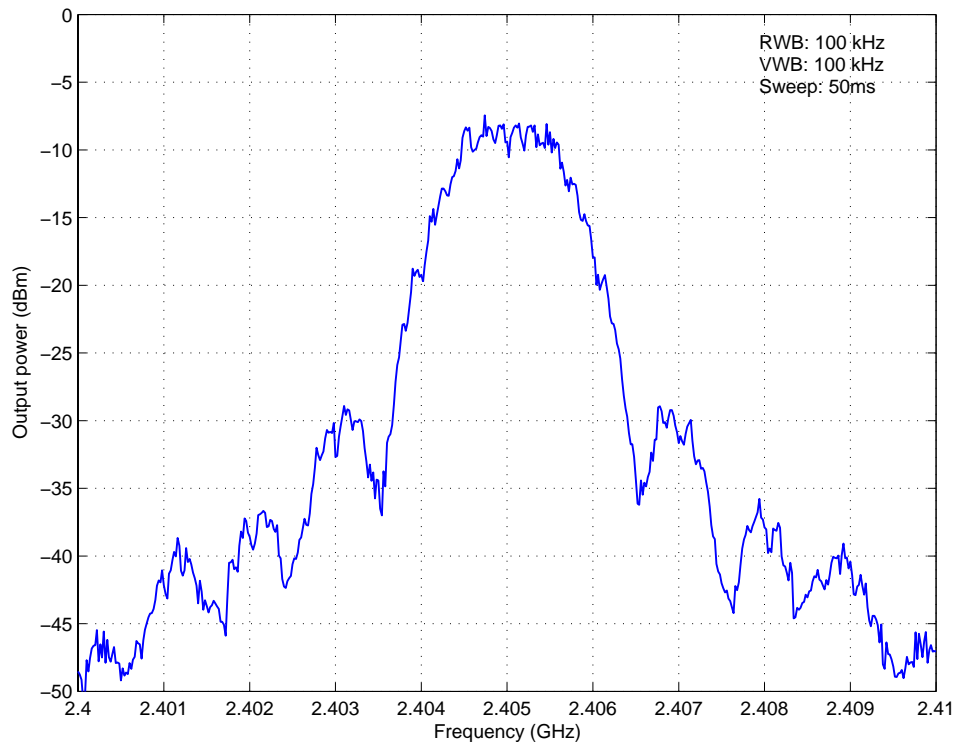


Figure 9 : Measured RF output power over the modulated spectrum from the Telos module

Antenna

Telos has two antenna options—and internal antenna built into the module and an external SMA connector for connecting to external antennas. By default, Telos is shipped with the internal antenna enabled. If an application requires an external antenna or a different directional pattern than the internal antenna, an SMA connector may be installed and an antenna may be connected directly to Telos' SMA female connector.

In order to switch between the internal antenna and the SMA connector, the capacitor at C73 must be moved from the two left pads to the two right pads connecting the radio to the SMA connector. This process may be completed quickly with a heat gun and tweezers by sliding the capacitor over to the adjacent pad once the solder begins to melt.

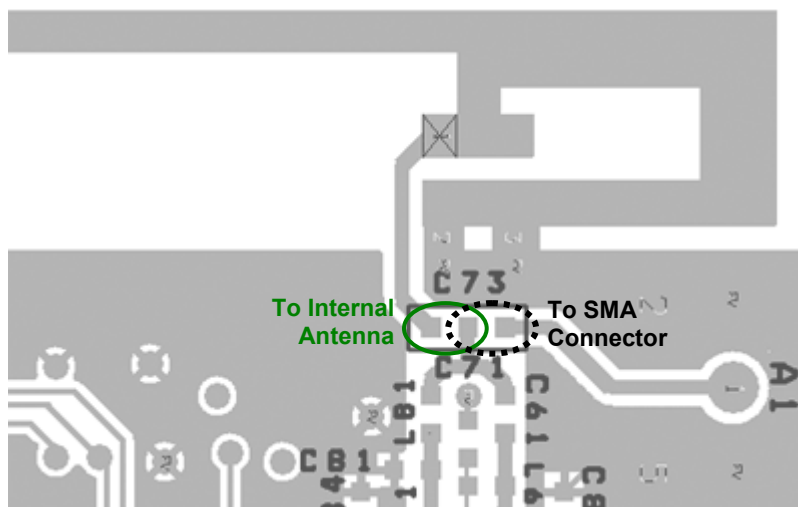


Figure 10 : Moving C73 to select between the internal antenna and the SMA connector

Internal Antenna

Telos' internal antenna is an Inverted-F microstrip design protruding from the end of the board away from the battery pack. The Inverted-F antenna is a wire monopole where the top section is folded down to be parallel with the ground plane. Although not a perfect omnidirectional pattern, the antenna may attain 50-meter range indoors and upwards of 125-meter range outdoors. Measurements of the internal antenna's performance with and without a battery pack are shown in Figure 11 and Figure 12. Approximate radiation patterns for the Inverted-F antenna as provided by Chipcon AS are shown in Figure 13 and Figure 14.

Internal Antenna without Battery Pack

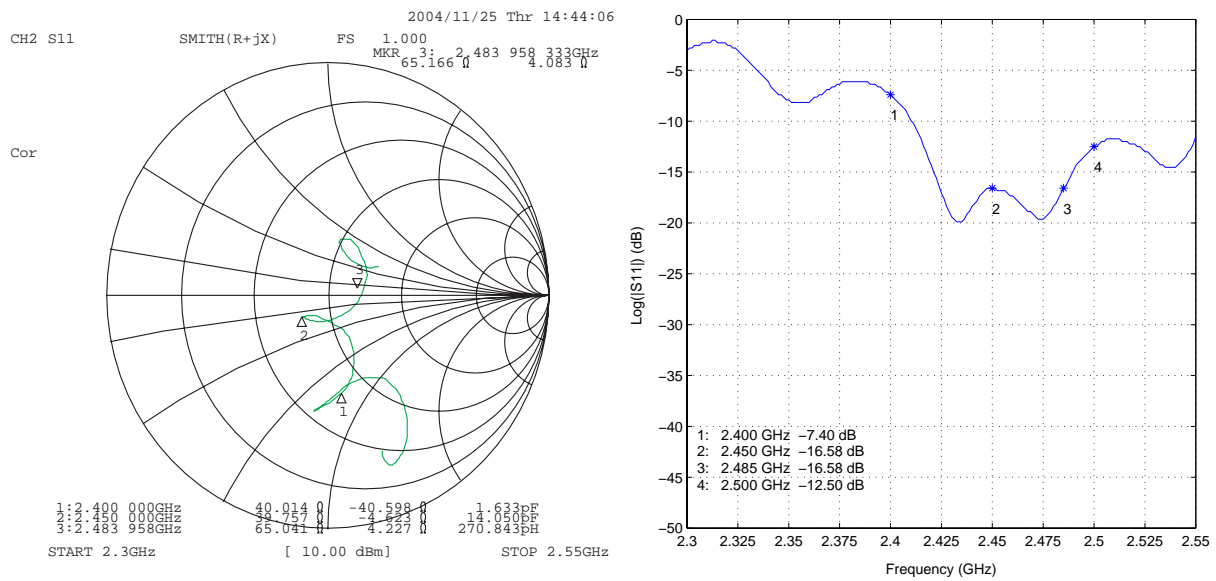


Figure 11 : S11 measurements for the internal inverted-F antenna when no battery pack is present

Internal Antenna with Battery Pack

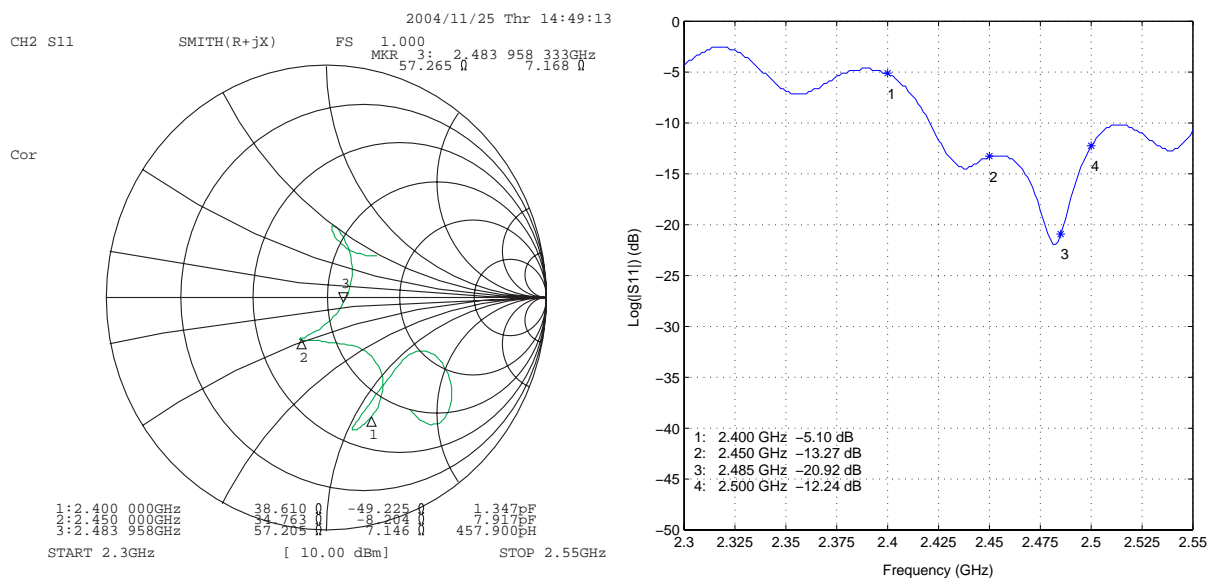


Figure 12 : S11 measurements for the internal inverted-F antenna with battery pack underneath

Radiation Pattern

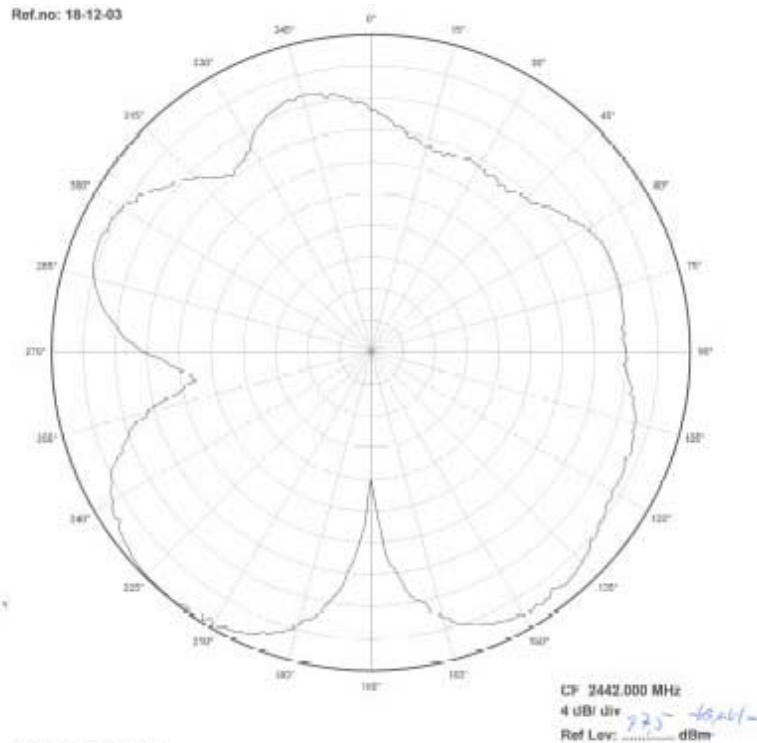


Figure 13 : Radiated pattern of the Inverted-F antenna with horizontal mounting (from Chipcon AS)

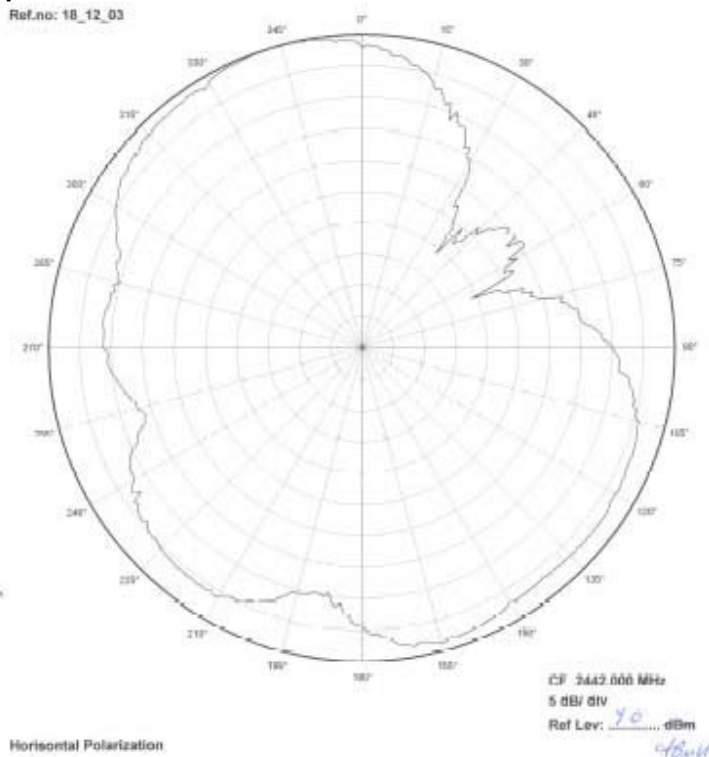


Figure 14 : Radiated pattern of the Inverted-F antenna with vertical mounting (from Chipcon AS)

SMA Connector

The SMA connector is a surface mount female coax connector for attaching an external antenna. The default Telos configuration does not include the SMA connector. The connector may be purchased separately from Digikey (<http://www.digikey.com>). The manufacturer's part number is 901-144 from Amphenol RF (Digikey part number ARF1205-ND).

The performance of the SMA connector is independent of the presence of the battery pack. The S11 network analyzer measurements for the SMA connector performance are shown in Figure 15.

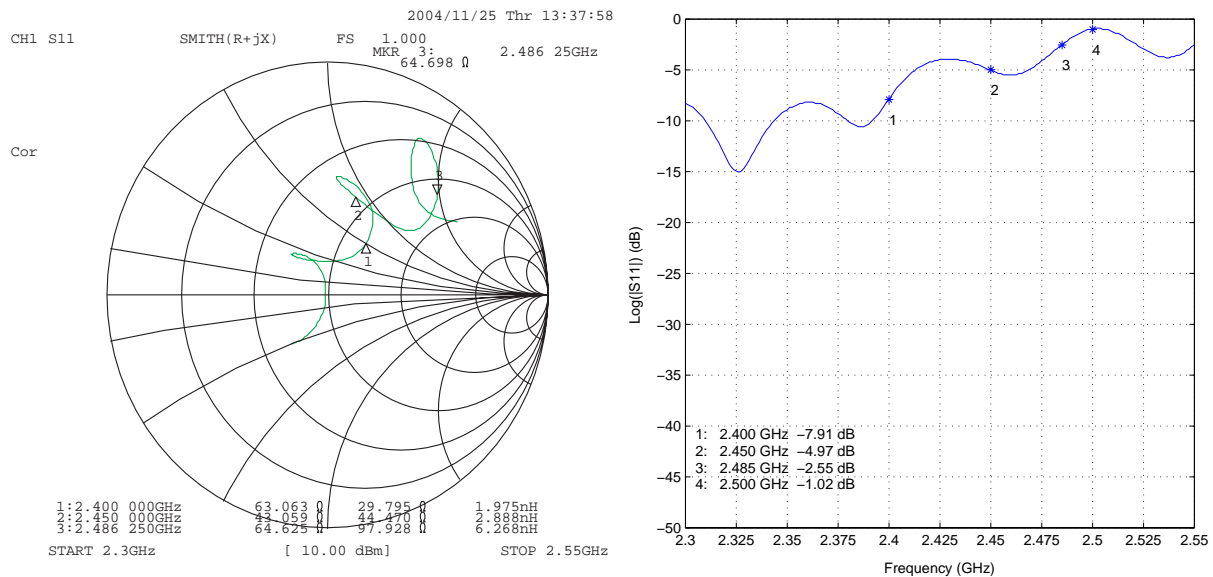


Figure 15 : S11 measurements of the SMA connector (minimal variance with/without battery pack)

External Flash

Telos Revision B uses the ST M25P80 40MHz serial code flash for external data and code storage. The flash holds 1024kB of data and is decomposed into 16 segments, each 64kB in size. The flash shares SPI communication lines with the CC2420 transceiver. Care must be taken when reading or writing to flash such that it is interleaved with radio communication, typically implemented as a software arbitration protocol for the SPI bus on the microcontroller.

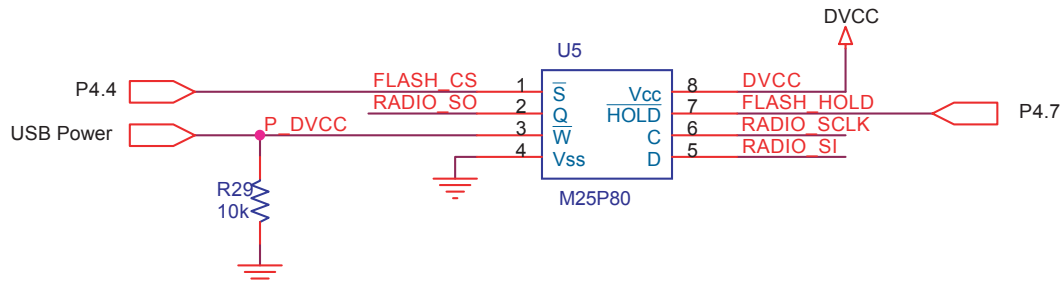


Figure 16 : External serial flash schematic

Typical Operating Conditions

	MIN	NOM	MAX	UNIT
Supply voltage during flash memory programming	2.7		3.6	V
Operating free air temperature	-40		85	°C
Erase/Programming cycles			100,000	cycles
Data Retention			20	years
Active current (READ)			4	mA
Active current (WRITE/ERASE)			20	mA
Standby current		8	50	µA
Deep Power Down current		1	10	µA



NOTE: The ST M25P-series of code flash always starts in the standby state. For low power applications, the flash must be sent a command at boot time to place it in the deep power down mode. If using TinyOS, the flash is automatically put into deep power down mode and must be instructed to exit deep power down mode the first time the flash is accessed. See the ST M25P80 datasheet for more information.
<http://www.st.com/stonline/books/pdf/docs/8495.pdf>

Flash Hardware Write Protection

The flash includes hardware write protection functionality. The write protection exists on a sector basis as shown in Figure 18. The hardware write protection pin (Pin 3 of the M25P80 shown in Figure 16) only disables write protection when the module is powered by the USB port. When connected to USB, the status register must be updated by removing the write protect and block protect bits in Figure 17. The write protected segments may only be changed after the module connected to USB and the write protect bit is cleared.

Telos ships with sector 15 (the upper sixteenth sector) write protected and the SRWD bit set. In sector 15 is the “Golden Image” and factor metadata. The “Golden Image” is a factory program image that includes network reprogramming so that Telos may always return to a known good state, even if loaded with a malfunctioning program image. When Telos is connected to the USB, the “Golden Image” may be changed. See the TinyOS Deluge documentation in `tinyos-1.x/docs` of the TinyOS distribution included with Telos.

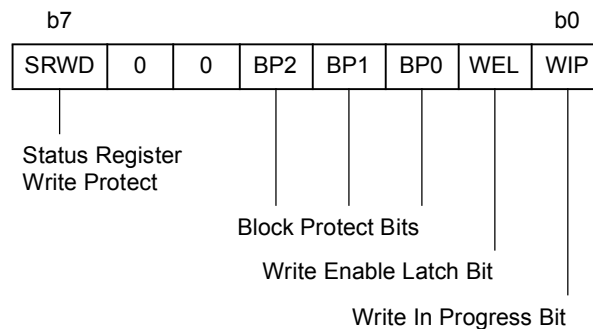


Figure 17 : ST M25P80 Status Register contents (from ST).

Status Register Content			Memory Content (Sectors)	
BP2 Bit	BP1 Bit	BP0 Bit	Protected Area	Unprotected Area
0	0	0	None	All sectors (0-15)
0	0	1	Upper sixteenth (15)	Lower fifteen-sixteenths (0-14)
0	1	0	Upper eighth (14-15)	Lower seven-eighths (0-13)
0	1	1	Upper quarter (12-15)	Lower three-quarters (0-11)
1	0	0	Upper half (8-15)	Lower half (0-7)
1	0	1	All sectors (0-15)	None
1	1	0	All sectors (0-15)	None
1	1	1	All sectors (0-15)	None

Figure 18 : Write protection settings for the ST M25P80 flash. Telos Rev B modules are shipped with the gray setting (001).



NOTE: When programming data to write protected segments of external flash, do not disconnect the module before the programming is completely. If the module is disconnected from the USB, the write may be interrupted or the status register may not be updated to reflect the new write protection settings.

Sensors

Humidity/Temperature Sensor

The optional humidity/temperature sensor is manufactured by Sensirion AG. The SHT11 and SHT15 models may be directly mounted on the Telos module in the U3 component position.

The SHT11/SHT15 sensors are calibrated and produce a digital output. The calibration coefficients are stored in the sensor's onboard EEPROM. The difference between the SHT11 and SHT15 model is that the SHT15 produces higher accuracy readings as shown in Figure 20. The sensor is produced using a CMOS process and is coupled with a 14-bit A/D converter. The low power relative humidity sensor is small in size and may be used for a variety of environmental monitoring applications.

More information can be found in the SHT1x datasheet available at <http://www.sensirion.com>

Parameter	MIN	TYP	MAX	Units
Humidity				
Resolution	0.5	0.03	0.03	%RH
	8	12	12	Bit
Repeatability		±0.1		%RH
Range	0		100	%RH
Temperature				
Resolution	0.04	0.01	0.01	°C
	0.07	0.02	0.02	°F
	12	14	14	bit
Repeatability		±0.1		°C
		±0.2		°F
Range	-40		123.8	°C
	-40		254.9	°F

Figure 19 : Sensirion relative humidity and temperature performance specifications

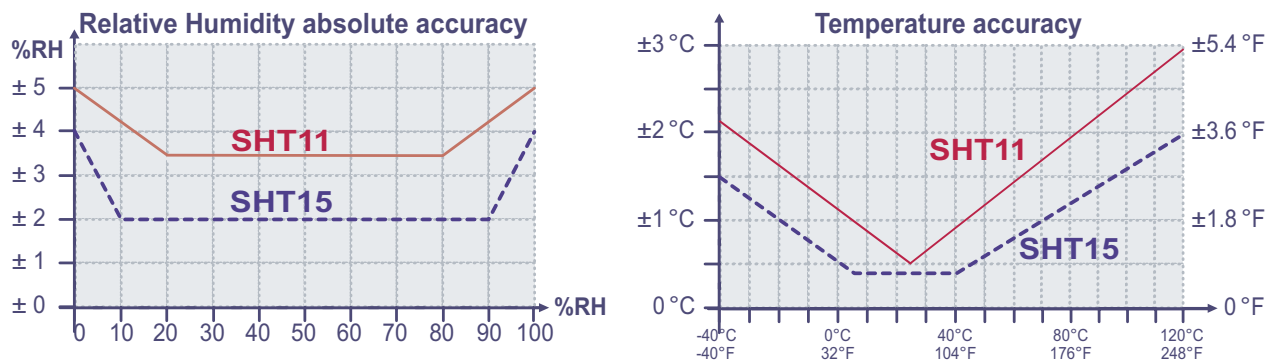


Figure 20 : Accuracy of Sensirion relative humidity and temperature sensors (courtesy Sensirion)

Light Sensors

A variety of light sensors may be used with Telos. Telos (rev A) has connections for two photodiodes. Moteiv currently uses photodiodes from Hamamatsu Corporation (<http://www.hamamatsu.com>)

If your mote is populated with light photodiodes, the default diodes are the S1087 for sensing photosynthetically active radiation and the S1087-01 for sensing the entire visible spectrum including infrared

Although these photodiodes from Hamamatsu have been tested with Telos, any photodiode with similar physical dimensions may be used with Telos.

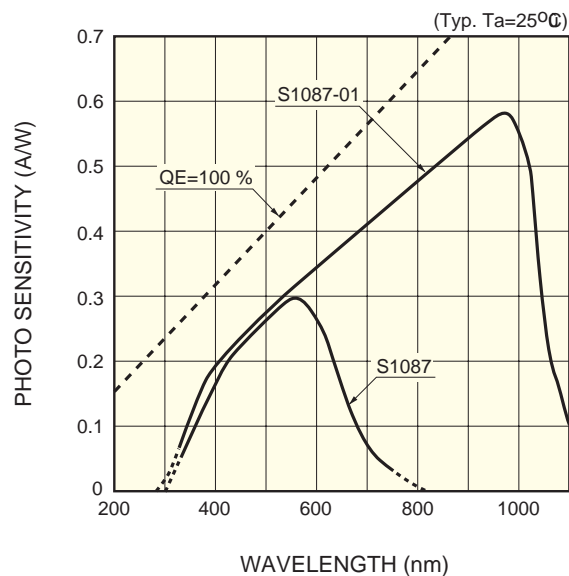


Figure 21 : Photo Sensitivity of the Light sensors on Telos (from Hamamatsu)

Expansion Connector

Telos has two expansion connectors and a pair of onboard jumpers that may be configured so that additional devices (analog sensors, LCD displays, and digital peripherals) may be controlled by the Telos module. On the far side of the board from the USB connector is a 10-pin IDC header at position U2 and a 6-pin IDC header at U28. The 10-pin connector has the same connections as Telos Revision A and is the primary connector. It provides digital input and output signals as well as analog inputs. Peripherals may be connected to the 10-pin connector using an IDC header, an IDC ribbon cable, or by designing a printed circuit board that solders directly on to the IDC header providing a robust connection to the module. An additional 6-pin (U28) header provides access to the exclusive features of Revision B. Two additional ADC inputs are provided that may be reconfigured by software to be two 12-bit DAC outputs. ADC7 may also act as the input to the supply voltage supervisor. The user interface elements—the reset and user buttons—are exported by the 6-pin header for use in external interfaces and packaging.

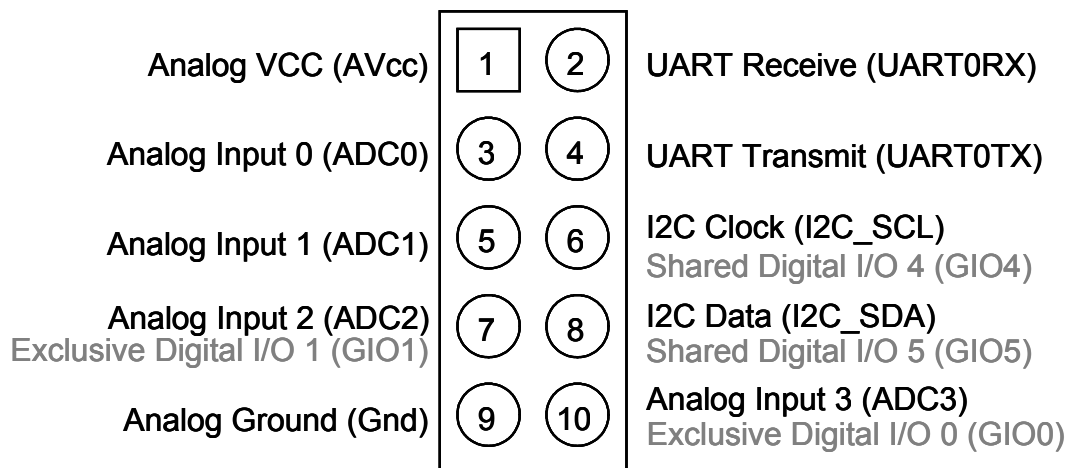


Figure 22 : Functionality of the 10-pin expansion connector (U2).
Alternative pin uses are shown in gray.

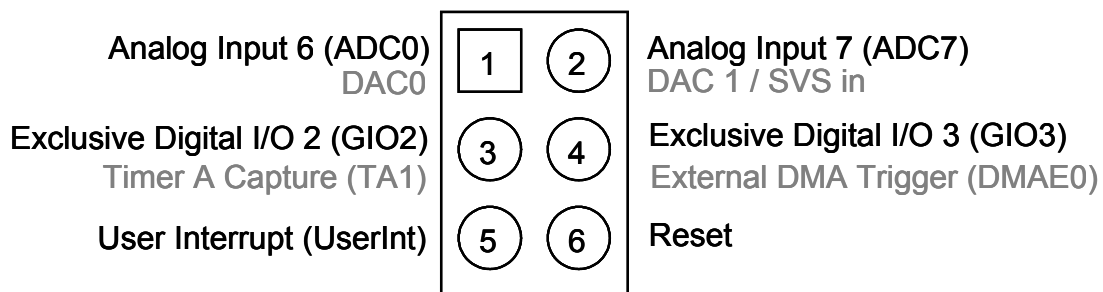


Figure 23 : Functionality of the 6-pin expansion connector (U28).



NOTE: The I²C pins are shared with the radio's data input pin and the radio clock. Care must be taken by application developers to multiplex operations on the I²C bus and the radio.

If expansion pin 10 (ADC3) is used for digital I/O instead of analog inputs, R14 must be populated with a 0 ohm resistor to enable the pin for digital I/O (GIO0) on the microcontroller. R16 must be populated with a 0 ohm resistor to enable GIO1. R14 and R16 are located on the top side of Telos between the USB controller and the radio.

! **NOTE:** When R14/R16 is populated (GIO0/GIO1 enabled), ADC3/ADC2 will not provide reliable readings if an application reverts to using the ADC input instead of the digital I/O port input on the microcontroller. R14/R16 should be removed when using ADC3/ADC2 for analog input.

The 6-pin IDC header also has an optional jumper, R15. By installing a 0 ohm resistor at R15, GIO3 is directly connected to SVSout. By making GIO3 an input and using the SVS features of the microcontroller, the SVSout function can be exported via pin 4 of U28.

A separate Supply Voltage Supervisor (SVS) 2-pin IDC header is provided underneath the USB connector at position U7. The SVS header allows add-on boards to be built that connect to the positive and negative battery terminals and the SVS pins in order to provide power the module and use the microcontroller’s advanced SVS functionality for boost converters, solar systems, and rechargeable systems. The SVS header is shown in Figure 24 and includes the SVSin and SVSout pins from the microcontroller.

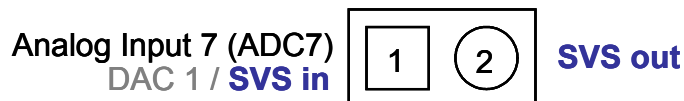
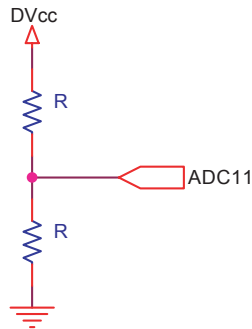


Figure 24 : Functionality of the 2-pin Supply Voltage Supervisor connector (U7).

Internal Temperature and Voltage Monitoring

The MSP430 microcontroller has internal temperature and voltage sensors that may be used through the microcontroller's ADC interface.

The voltage port (input 11) on the 12-bit ADC monitors the output from a voltage divider.



Voltage monitoring for Telos motes.

Converting the ADC units to a voltage reading can be done with the following formula:

$$DV_{cc} = \frac{ADCCounts}{4096} \times V_{ref} \times \frac{2R}{R}$$

The temperature input is internal ADC port 10. It consists of an uncalibrated diode. When using the temperature sensor, the sample period must be greater than 30 μ s. The temperature sensor offset error can be large, and may need to be calibrated for most applications. The typical response of the temperature sensor is shown in Figure 25.

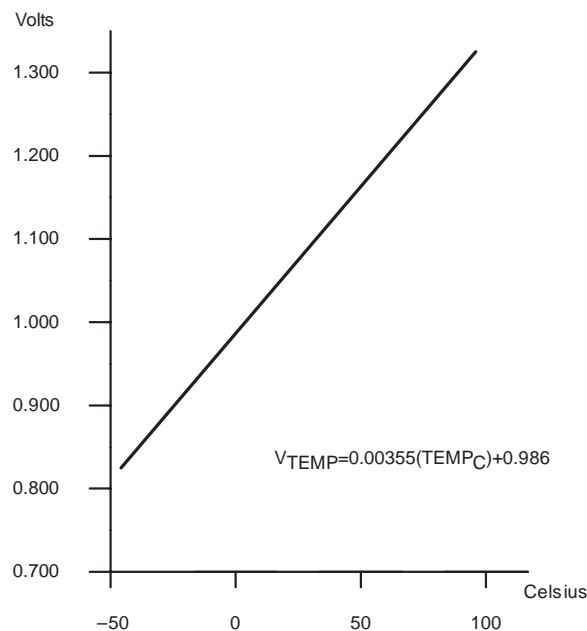


Figure 25 : Typical response of the internal temperature sensor. Results vary and the sensor should be calibrated for most applications. Response curve from Texas Instruments.



General Information

Document History

Revision	Date	Notes
1.0	2004/12/05	Initial Release

Product Status Definitions

Data Sheet Identification	Product Status	Definition
Advance Information	Planned or under development	This data sheet contains the design specifications for product development. Specifications may change in any manner without notice.
Preliminary	Engineering samples or first production	This data sheet contains preliminary data, and supplementary data will be published at a later date. Moteiv reserves the right to make changes at any time without notice in order to improve design and supply the best possible product.
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Telos

Rev B (Low Power Wireless Sensor Module)

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