

eZ430-RF2500-SEH Solar Energy Harvesting Development Tool

User's Guide



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Read This First

If You Need Assistance

If you have any feedback or questions, support for the MSP430 device and the eZ430-RF2500 is provided by the Texas Instruments Product Information Center (PIC) and the TI E2E Forum (<http://e2e.ti.com>). Contact information for the PIC can be found on the TI web site at <http://support.ti.com>. Additional device-specific information can be found on the MSP430 web site <http://www.ti.com/msp430>.

NOTE: Support for the Solar Energy Harvesting Module

The Solar Energy Harvester module (SEH-01) is a product of Cymbet Corporation. For any questions specifically on the SEH-01 module, contact Cymbet at www.cymbet.com or +1-763-633-1780.

Related Documentation from Texas Instruments

The primary sources of MSP430 information are the device-specific data sheets and user's guides. The most up-to-date versions of the user's guide documents available at the time of production have been provided on the CD-ROM included with this tool. However, the most current information is found at <http://www.ti.com/msp430>.

Information specific to the eZ430-RF2500-SEH development tool can be found at <http://www.ti.com/tool/ez430-rf2500-seh>.

MSP430 device user's guides and the FET user's guide ([SLAU157](#)) may be accessed on the included CD-ROM under the User's Guides section. The FET user's guide includes detailed information on setting up a project for the MSP430 using Code Composer Studio.

eZ430-RF2500-SEH Overview

1.1 Solar Energy Harvesting

The eZ430-RF2500-SEH is a complete Solar Energy Harvesting development kit to help create a perpetually powered wireless sensor network based on the ultra-low-power MSP430 microcontroller.

The Solar Energy Harvesting module includes a high-efficiency solar (2.25 in x 2.25 in) panel optimized for operating indoors under low-intensity florescent lights, which provides enough power to run a wireless sensor application with no additional batteries. Inputs are also available for external energy harvesters such as thermal, piezoelectric, or another solar panel.

The system also manages and stores additional energy in a pair of thin-film rechargeable EnerChips which are capable of delivering enough power for 400+ transmissions. The EnerChips act as an energy buffer that stores the energy while the application is sleeping and has light available to harvest. The batteries are environmentally friendly and can be recharged thousands of times. They also have a very low self discharge, which is vital for a no-power, energy harvesting system.

The eZ430-RF2500 is used to run the energy harvesting application. It is a complete USB-based MSP430 wireless development tool and provides all the hardware and software necessary to use the MSP430F2274 microcontroller and CC2500 2.4-GHz wireless transceiver. It includes a USB debugging interface that allows for real-time, in-system debugging and programming for the MSP430, and it is also the interface to transfer data to a PC from the wireless system.

The integrated temperature and RF signal strength indicators can be used to monitor the environment, and many external sensors can be used to collect additional data.

eZ430-RF2500-SEH Features

- Efficient solar energy harvesting module for the eZ430-RF2500
- Battery-less operation
- Works in low ambient light
- 400+ transmissions in dark
- Adaptable to any RF network or sensor input
- Inputs available for external harvesters (such as thermal or piezoelectric)
- USB debugging and programming interface with an application backchannel to the PC
- 18 available analog and communications input/output pins
- Highly integrated, ultra-low-power MSP430 MCU with 16-MHz performance
- Two green and red LEDs for visual feedback
- Interruptible push button for user feedback

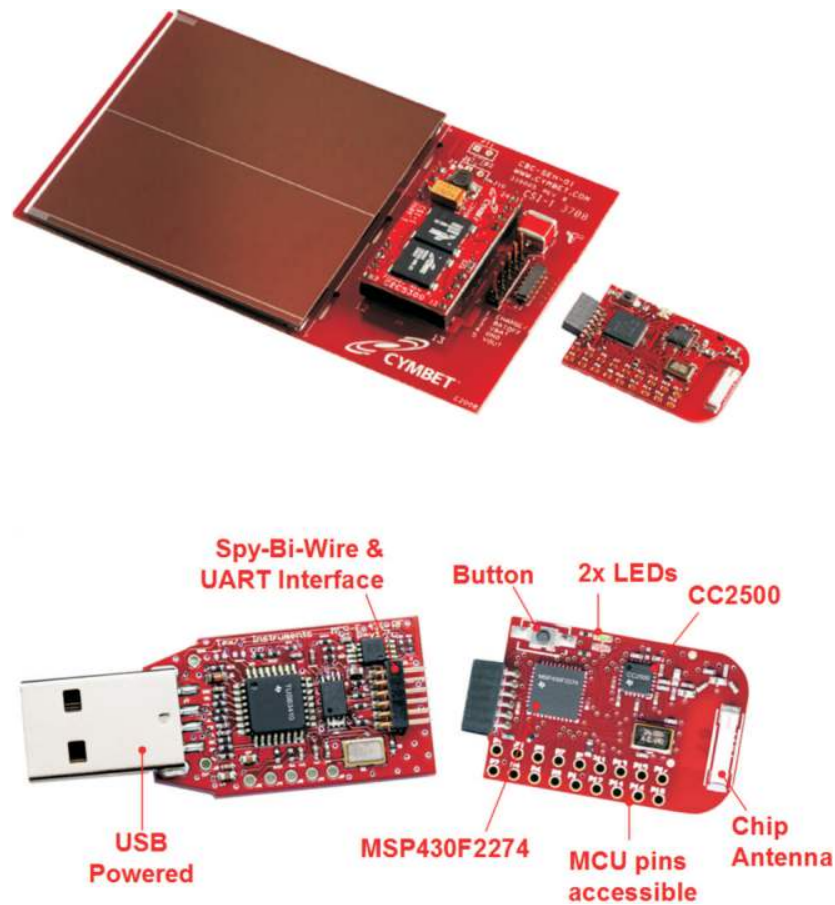


Figure 1-1. eZ430-RF2500-SEH

1.2 Kit Contents, eZ430-RF2500-SEH

- Two eZ430-RF2500T wireless target boards
- One eZ430-RF USB debugging interface
- One AAA battery pack with expansion board (batteries included)
- One SEH-01-DK Solar Energy Harvesting Board
- One MSP430 Development Tool CD containing documentation and development software
 - eZ430-RF2500-SEH Demo and Source Code ([SLAC219](#))
 - eZ430-RF2500-SEH Development Tool User's Guide ([SLAU273](#))
 - eZ430-RF2500 Development Tool User's Guide ([SLAU227](#))
 - MSP430x2xx Family User's Guide ([SLAU144](#))
 - Code Composer Studio v5.4 for MSP430 User's Guide ([SLAU157](#))
 - Code Composer Studio v5.4 ([CCSTUDIO](#))

NOTE: For the latest software and documentation, go to <http://www.ti.com/tool/ez430-rf2500-seh>.

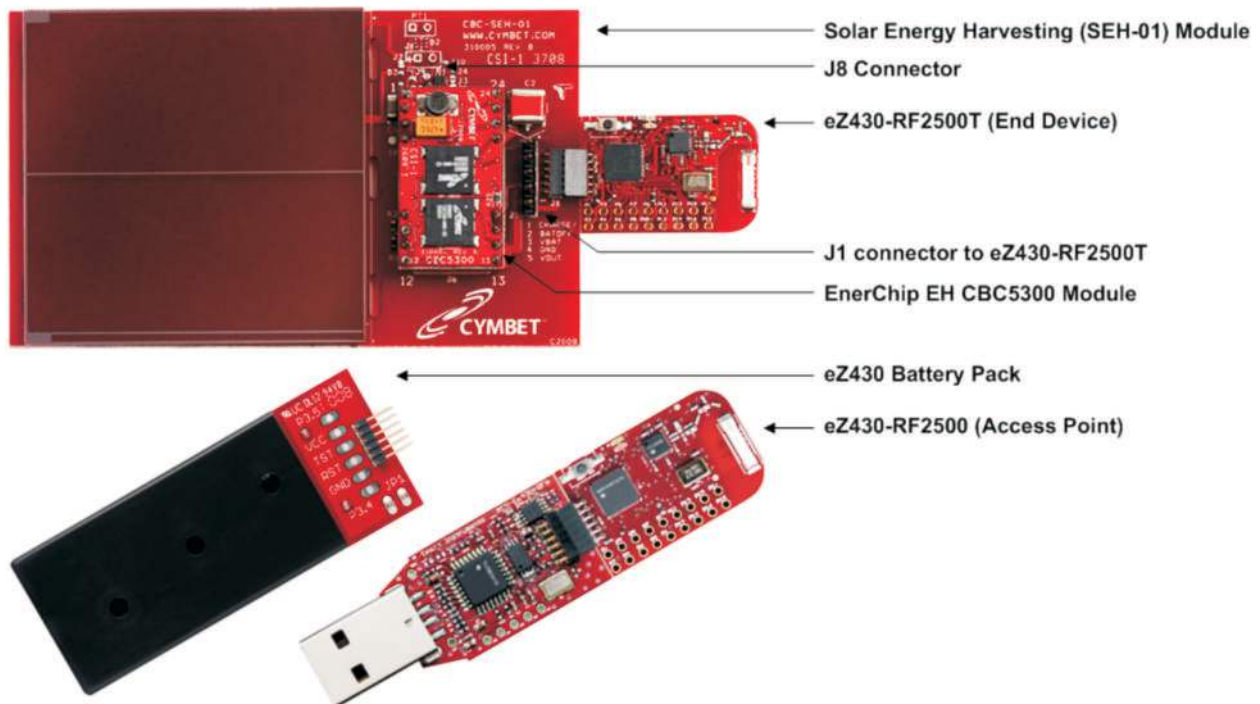


Figure 1-2. eZ430-RF2500-SEH Development Tool Features

1.3 Working With the eZ430-RF2500

For detailed information on the eZ430-RF2500 Wireless Development Tool, see its user's guide—the *eZ430-RF2500 Development Tool User's Guide* ([SLAU227](#)) includes the following information that is not covered in this document:

- eZ430-RF2500T target board pinout
- MSP430F2274 and CC2500 specifications
- List of eZ430 emulator supported devices
- MSP430 application UART description
- Detailed eZ430-RF2500 hardware installation
- eZ430-RF2500 FAQ
- eZ430-RF2500 schematics and layout

Getting Started

2.1 Prepare Solar Energy Harvester Module

1. Remove the Battery Enable jumper, J8 (see [Figure 1-2](#)).
2. Place the solar module in a well lit location for at least a few minutes prior to use. In average indoor lighting, it may take up to one hour to fully charge the system. However, approximately five minutes should be sufficient for initial startup.

2.2 Install Sensor Monitor Application and Drivers

1. Download the eZ430-RF2500-SEH Demo and Source Code ([SLAC219](#)) from the [eZ430-RF2500-SEH Development Tool web page](#) or from the included CD.
2. Unzip the archive and run SEH-demo-setup-vx.x.exe.
3. Respond to the prompts to install the application.
4. Open the eZ430-RF2500-SEH Sensor Monitor program. A shortcut is available on the Desktop and in the Start Menu under Programs > Texas Instruments > eZ430-RF2500-SEH Sensor Monitor.

2.3 Connect Hardware

1. Insert the eZ430-RF2500 into a USB port on the PC. This acts as the Access Point.
If prompted for the driver for the MSP430 Application UART, allow Windows to 'Install the software automatically'. This is only possible if the Sensor Monitor has already been installed.
For more information, see Section 14, *Detailed Hardware Installation Guide* in the eZ430-RF2500 user's guide ([SLAU227](#)).
The Sensor Monitor PC application should now detect the MSP430 Application UART on the appropriate COM port, and the center bubble in the program blinks once per second.
2. Attach the second eZ430-RF2500T target board to the Solar Energy Harvesting Module (SEH-01) on connector J1. All components on the boards should be face up. A second bubble should appear in the Sensor Monitor window representing the End Device. If the second bubble does not appear, place the SEH-01 directly under a bright light for a few seconds and try again. Also try using the battery pack to make sure the hardware is programmed properly.
3. By default, the End Device transmits every 10 seconds. Push the button on the End Device to change the transmission duty cycle in the following intervals: 10 seconds, 20 seconds, 40 seconds, 2 minutes, 4 minutes, and 5 seconds.
4. Cover the solar panel to force the system run from the stored energy. The number of remaining transmissions is displayed.
5. When finished, remove the eZ430-RF2500T End Device from the SEH-01 module, replace jumper on J8, and close any open programs.

For troubleshooting tips, see [Frequently Asked Questions](#).

2.4 Install Code Composer Studio

To edit and download code to the MSP430, Code Composer Studio v5.4 or higher must be installed.

1. Download Code Composer Studio from <http://www.ti.com/tool/ccstudio> or from the included CD.
2. Extract the zip file and run the installation program.
3. Respond to the prompts to install the IDE.

NOTE: IDE Selection

The eZ430-RF2500-SEH firmware is provided for both Code Composer Studio and IAR Embedded Workbench, and the user has the option to select the IDE of their choice. However, the firmware is larger than IAR KickStart's 4KB limit, so a full license of IAR Workbench is required to compile the application using IAR. An evaluation version of IAR is available from <http://supp.iar.com/Download/SW/?item=EW430-EVAL>.

This document describes working with only Code Composer Studio.

2.5 Install the eZ430-RF2500-SEH Sensor Monitor Firmware Source

To edit the original energy harvesting project, the source code must be installed.

1. Download the eZ430-RF2500-SEH Demo and Source Code ([SLAC219](#)) from the [eZ430-RF2500-SEH Development Tool web page](#) or from the included CD.
2. Unzip the archive and run SEH-firmware-install-vx.x.exe.
3. Respond to the prompts to install the application.
4. Follow the steps described in [Section 4.1.1](#) to download the firmware to the MSP430.

Solar Energy Harvester Module (SEH-01)

3.1 Functional Description

The core technology behind the Solar Energy Harvesting module is the photovoltaic or solar cell that converts ambient light into electrical energy. The energy from the solar cell must be converted, managed and stored. This process is handled by the EnerChip EH CBC5300, the small DIP mounted board on the Solar Energy Harvesting Module (SEH-01). A boost converter is used to increase the voltage from the solar cell to a sufficient level to charge the thin-film battery and run the rest of the system.

The Charge Control block continuously monitors the output of the boost converter. If the output of the boost converter falls below the voltage needed to charge the EnerChip, the charge controller disconnects the boost converter from the system to prevent back powering the boost converter in low light conditions.

The Power Management block prevents the EnerChip from discharging too deeply in low-light conditions or under abnormally high current loads. It also ensures that the load is powered up with a smooth power-on transition. The Power Management block has a control line, CHARGE, which indicates to the MSP430 that the solar energy harvester is actively charging the EnerChip. The control line input, BATOFF, is available for the MSP430 to isolate itself from the EnerChip to conserve battery life in prolonged low-light conditions.

The Solar Energy Harvesting Module features two EnerChip batteries mounted on the board with a 100- μ Ahr capacity and a 1000- μ F capacitor for high-current pulses during wireless transmissions.

Using the power management status and control signals on the SEH-01, the firmware on the MSP430 has been written to make the application 'Energy Aware' to maximize the overall lifetime of the system.

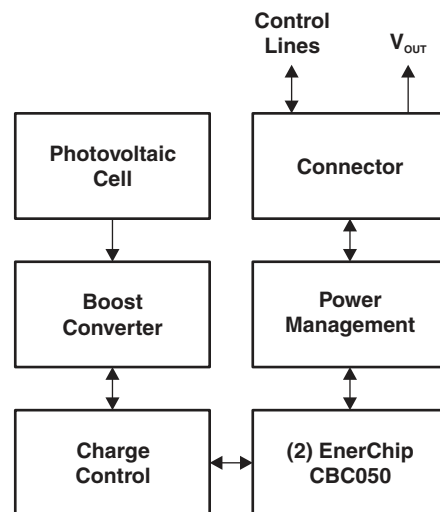
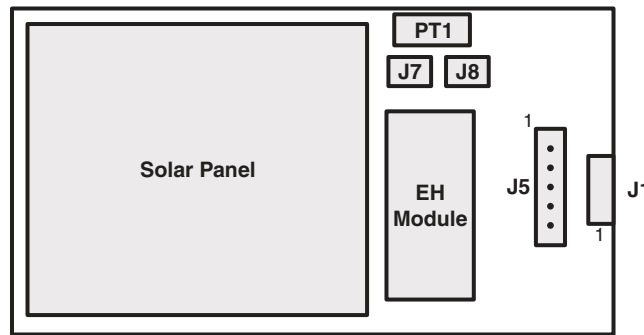


Figure 3-1. Solar Energy Harvester Module (SEH-01) Block Diagram

3.2 Solar Energy Harvester Module (SEH-01) Figure and Description

Figure 3-2 shows the connections to the Solar Energy Harvester module.



J1 Connector for TI ED	
Pin Number(s)	Description
1	BATOFF
2	GND
3	Not Connected
4	Not Connected
5	V_{OUT2}
6	$\overline{\text{Charge}}$
Connector Type: Rt Angle SIP	

J5 Connector for User	
Pin Number(s)	Description
1	$\overline{\text{Charge}}$
2	BATOFF
3	V_{BAT}
4	GND
5	V_{OUT2}
Connector Type: Upright SIP	

J7 Connector	
Pin Number(s)	Description
1	Cut trace to use external source
Connector Type: Trace	

J8 Connector	
Pin Number(s)	Description
1	Positive input
2	GND
Connector Type: Trace Vias	

PT1 Connector	
Pin Number(s)	Description
1	Piezo input 1
2	Piezo input 2
Connector Type: Trace Vias	

Figure 3-2. Solar Energy Harvester Module Connections

J1 Connector: Connection to the eZ430-RF2500T target board.

J5 Connector: Alternate connection point to power an external device or for measuring SEH-01 output levels.

J7 Connector: Trace to cut if an alternate solar panel is connected to J8.

J8 Jumper: Battery enable jumper—the shunt must be removed before the module is charged. This connector can also be used to connect an alternate solar panel to the SEH-01.

PT1 Connector: An alternate piezoelectric energy harvesting transducer can be connected. It can be connected in parallel with the SEH-01 solar panel by leaving J7 intact or the piezoelectric transducer can be used standalone by cutting the J7 trace.

CAUTION

The EnerChip EH CBC5300 module is mounted on a DIP socket that is removable from the Solar Energy Harvesting (SEH-01) board. The pins on the CBC5300 are fragile and care must be taken when removing the module.

3.3 Solar Energy Harvester Module (SEH-01) Operating Characteristics

Table 3-1 shows the operating characteristics of the Solar Energy Harvester Module.

Table 3-1. SEH-01 Operating Characteristics

PARAMETER	CONDITION	MIN	TYP	MAX	UNIT
Input luminous intensity ⁽¹⁾	Minimum operating lux	200			lux
	Full charge rate	700			lux
Parasitic load current	Boost converter off		800		nA
	Boost converter on		20		μA
Average output power (measured at V _{OUT2} pin)	1000 lux (FL), battery not charging		350		μW
	200 lux (FL), Battery not charging		80		μW
Output voltage, V _{OUT2}	2-μA load, Battery charged	3.5	3.55	3.6	V
V _{BAT} charging voltage			4.06		V
Battery cutoff voltage		3	3.3	3.6	V
Pulse discharge current	20 ms		30		mA
Self discharge rate (non-recoverable average)	25°C, Per year		2.5		%
Operating temperature		0	25	70	°C
Recharge cycles (to 80% of rated capacity, 4.1-V charge voltage)	25°C	10% depth-of-discharge		5000	
		50% depth-of-discharge		1000	
	40°C	10% depth-of-discharge		2500	
		50% depth-of-discharge		500	
Recharge time (to 80% of rated capacity)	4.1-V constant voltage	500			min
Capacity	8-μA discharge; 25°C		100		μAh

⁽¹⁾ Fluorescent (FL) light conditions specifications subject to change without notice.

3.4 Solar Energy Harvester Module (SEH-01) Circuit Schematic

Figure 3-3 shows a schematic of the Solar Energy Harvester module.

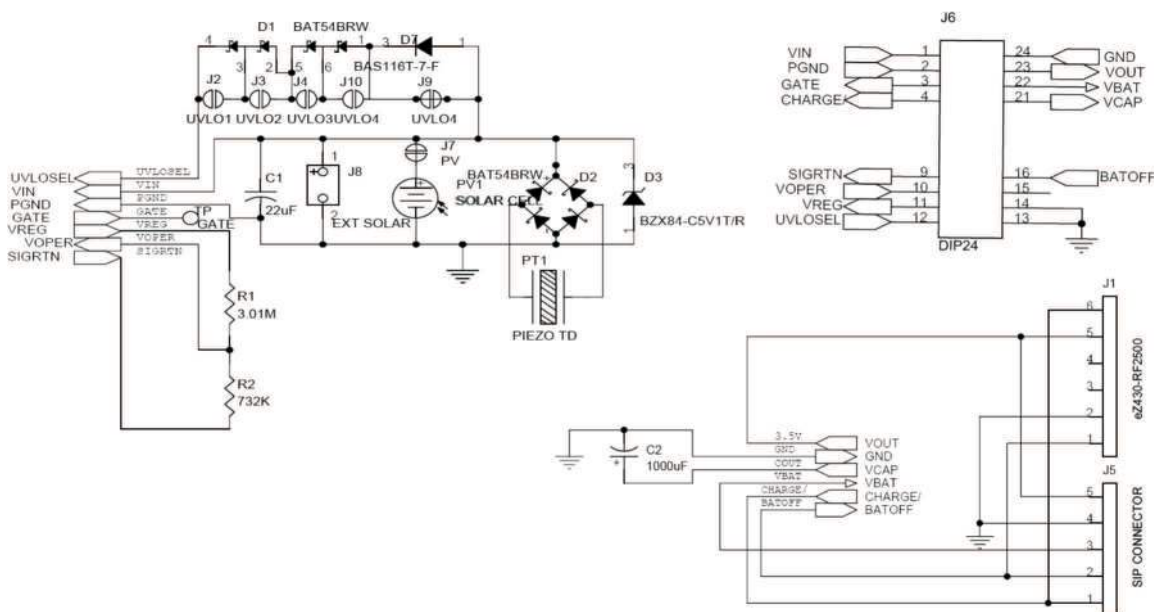


Figure 3-3. Solar Energy Harvester Module Schematic

3.5 Pulse Discharge Current for a Wireless End Device

High current pulses place special demands on batteries. Repeated delivery of pulse currents exceeding the recommended load current of a given chemistry diminishes the useful life of the cell. The effects can be severe, depending on the amplitude of the current and the particular cell chemistry and construction. Pulse currents of tens of milliamperes are common in wireless sensor systems during transmit and receive modes. Moreover, the internal impedance of the cell often results in an internal voltage drop that precludes the cell from delivering the pulse current at the voltage necessary to operate the external circuit.

One method of mitigating such effects is to place a low equivalent series resistance (ESR) capacitor across the battery. The battery charges the capacitor between discharge pulses, and the capacitor delivers the pulse current to the load. Specifying the capacitance for a given battery in an application is a straightforward procedure once a few key parameters are known. The key parameters are:

- Battery impedance (at temperature and state-of-charge)
- Battery voltage (as a function of state-of-charge)
- Operating temperatures
- Pulse current amplitude
- Pulse current duration
- Allowable voltage drop during pulse discharge

Two equations are used to calculate two unknown parameters:

- The output capacitance needed to deliver the specified pulse current of a known duration
- The latency time that must be imposed between pulses to allow the capacitor to be recharged by the battery

Both formulas assume that the capacitor ESR is sufficiently low to result in negligible internal voltage drop while delivering the specified pulse current; consequently, only the battery resistance is considered in the formula used to compute capacitor charging time, and only the load resistance is considered when computing the capacitance needed to deliver the discharge current.

The first step in creating a battery-capacitor couple for pulse-current applications is to size the capacitance using the following formula:

$$\text{Discharge formula: } C = t / R \times [-I_n (V_{\min} / V_{\max})]$$

Where:

C = output capacitance in parallel with battery

t = pulse duration

R = load resistance = $V_{\text{OUT(average)}} / I_{\text{pulse}}$

V_{\min} and V_{\max} are determined by the combination of the battery voltage at a given state-of-charge and the operating voltage requirement of the external circuit.

Once the capacitance has been determined, the capacitor charging time can be calculated using the following formula:

$$\text{Charge formula: } t = R \times C \times [-I_n (1 - V_{\min} / V_{\max})]$$

Where:

t = capacitor charging time from V_{\min} to V_{\max}

R = battery resistance

C = output capacitance in parallel with battery

Again, V_{\min} and V_{\max} are functions of the battery voltage and the circuit operating specifications. Battery resistance varies according to temperature and state-of-charge as described above. Worst-case conditions are often applied to the calculations to ensure proper system operation over temperature extremes, battery condition, capacitance tolerance, etc.

eZ430-RF2500-SEH Sensor Monitor

The eZ430-RF2500-SEH Sensor Monitor is a full demonstration application that includes both the firmware for the MSP430 that takes into consideration the constraints of running in an energy harvesting environment as well as a PC application that can display all connected wireless nodes and the data that they are reporting. Both the MSP430 firmware and the PC application (both binary and full source) are included in [SLAC219](#).

4.1 MSP430 Firmware

The eZ430-RF2500-SEH Sensor Monitor firmware is preloaded on the MSP430 devices and consists of a wireless temperature sensor network and may be reprogrammed at any time. The network consists of an Access Point that measures its own temperature and also receives data from End Devices. End Devices measure their own temperature periodically and then enter low-power mode to reduce energy consumption. The Access Point receives the information and transmits it to the PC through USB. SimpliciTI™ is the RF network protocol used to establish the network. For more information on SimpliciTI, visit www.ti.com/simpliciti.

4.1.1 Downloading Firmware to the MSP430

The firmware comes preloaded onto the MSP430 devices; however, it can be restored with the following steps. The source code will be installed on the PC with the setup program included in [SLAC219](#).

1. Open Code Composer Studio.
2. Open any available Workspace.
3. Import the project to the Workspace.
 - (a) Click Project > Open Existing Project > Browse.
 - (b) Navigate to the source code location. The default location is `C:\Texas Instruments\ez430-rf2500-seh_sensor_monitor-v2.0\CCS_Source`.
 - (c) Ensure "SEH Sensor Monitor" is selected under Projects.
 - (d) Click Finish.
4. Connect one of the eZ430-RF2500T target boards to the eZ430 Emulator and plug it into a USB port on the computer.
5. Right-click the project name "SEH Sensor Monitor" in the Project Explorer panel and click Build Configurations > Set Active > End Device - Debug.
6. Click Project > Clean...
7. Click Run > Debug Active Project.
8. Click the Terminate button (red square in the top left 'Debug' view) to terminate the debugging session.
9. Remove the eZ430-RF2500T target board from the emulator. It has now been programmed as the End Device.
10. Connect the second eZ430-RF2500T target board to the eZ430 Emulator and plug it into a USB port on the computer.
11. If not already in the CCS Edit perspective, return to it by clicking the CCS Edit button at the top right corner of the screen. Click the >> arrows if the button has moved off-screen.
12. Right-click the "SEH Sensor Monitor" project name in the Project Explorer panel and click Build Configurations > Set Active > Access Point - Debug.
13. Click Project > Clean...

14. Click Run > Debug Active Project and click the green Run arrow button.
15. Connect the first eZ430-RF2500T (End Device) target board to the battery pack or the Solar Energy Harvesting board.
16. Open the eZ430-RF2500 Sensor Monitor PC program installed on the PC to watch the network form or receive data from the wireless node.

4.2 PC Sensor Monitor Application

The Sensor Monitor PC application is a graphical representation of the star network and displays the sampled data from each wireless device. The center node is the Access Point and the attached nodes are the End Devices, which display their temperature, voltage, and their transmission frequency. The physical distance of the End Device from the Access Point is simulated on-screen by measuring the signal strength (RSSI) of the received signal. The number of End Devices can be expanded by adding more wireless nodes to the network as shown in [Figure 4-1](#).



Figure 4-1. eZ430-RF2500-SEH Sensor Monitor

4.2.1 Energy Awareness

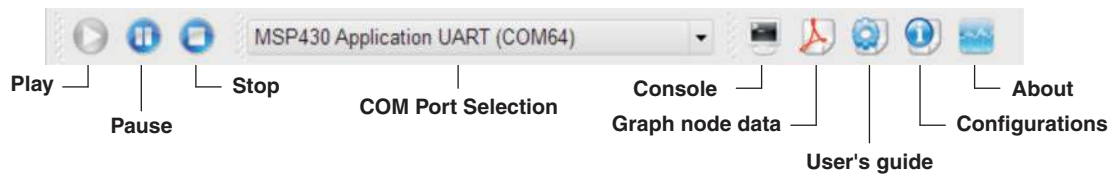
Because the End Devices are 'Energy Aware', they dynamically switch power sources from the solar cell to the EnerChip if sufficient ambient light is not available to run the system. The node's color on the PC Sensor Monitor window also displays its current power source. The node is yellow when powered from the solar panel or the traditional battery back and is blue when running from the EnerChip.

4.2.2 Remaining Transmissions

When running from the EnerChip, the application also display the number of transmissions left before the stored energy is depleted. On average, ~400 transmissions are possible before the system needs to be recharged.

4.2.3 Menu Bar

[Figure 4-2](#) describes the eZ430-RF2500-SEH Sensor Monitor menu bar.


Figure 4-2. Menu Bar

4.2.3.1 Action Toolbar: Play, Pause, Stop

By default, the Sensor Monitor scans all available COM ports until it finds an MSP430 Application UART and begins receiving data. The Play, Pause, and Stop controls are available to control the connection with the COM port.

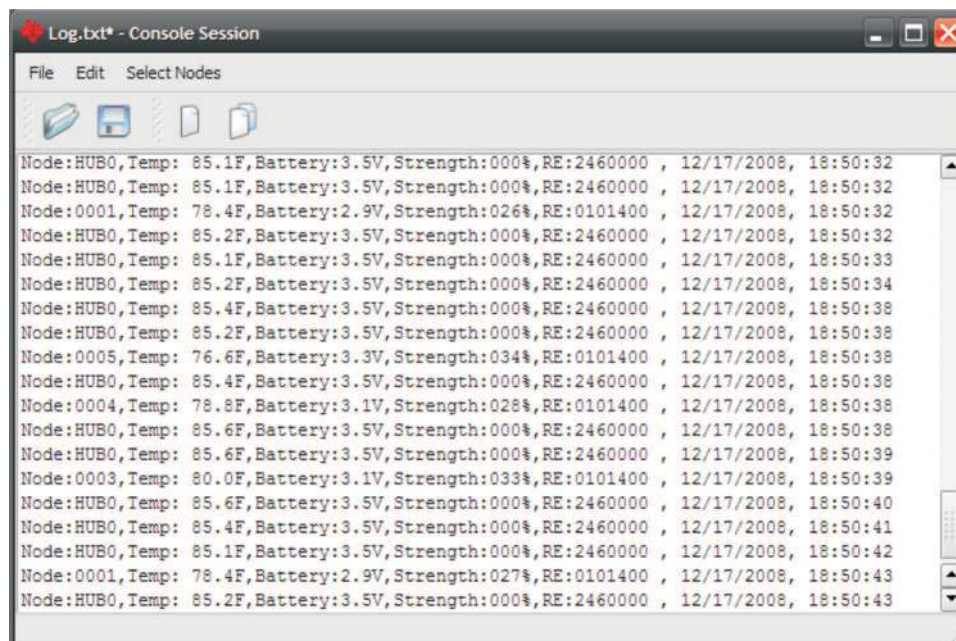
Play — Opens the MSP430 application UART COM port and resumes receiving data.

Pause — Closes the COM port, which stops the application from receiving data.

Stop — Closes the COM port, which stops the application from receiving data and clears the nodes from the window.

4.2.3.2 Console Window

The console window (see [Figure 4-3](#)) is used to view a real-time output of all node data in text format. Individual nodes, including the access point, can be removed from the console if necessary. This can be useful when looking for a specific node's information. It is also possible to save the data in the console to a text file for further analysis and processing.


Figure 4-3. Console Window

4.2.3.3 Graph Window

Temperature data and RF signal strength (RSSI) for all nodes can be plotted in a graph (see [Figure 4-4](#)). The signal strength is displayed as a percentage. The last 60 transmissions are stored and displayed. Only 24 hours worth of data can be displayed.

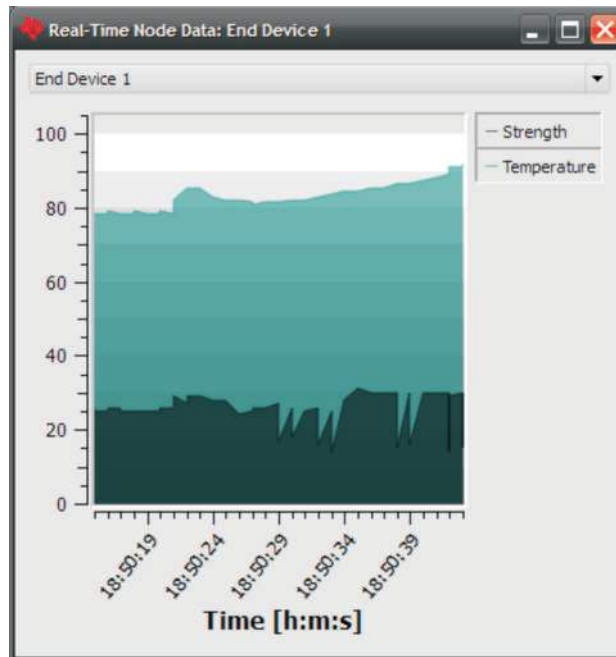


Figure 4-4. Real-Time Node Data from the Graph Window

4.2.3.4 COM Port Selection

By default, the application selects and opens the first available MSP430 Application UART and refreshes the drop down whenever a new COM port is available. This means it is rarely necessary to use the COM port selection list unless multiple MSP430 Applications UARTs are available on the PC.

4.2.3.5 Configurations

Settings for the Sensor Monitor application can be changed in the configurations window. The default temperature unit can be modified as well as the time required before a node is removed if a packet has not been received in a while.

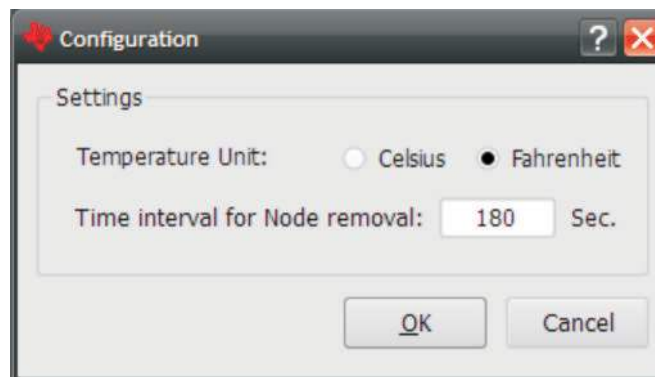


Figure 4-5. Configurations Window

4.2.4 PC Sensor Monitor Application Source Code

The eZ430-RF2500-SEH Sensor Monitor application is open source and is licensed under GNU General Public License v2. The source code is included in [SLAC219](#). It was developed using the open source Qt cross-platform applications framework ([QWT](#)) and compiled using [Microsoft Visual C++ 2008 Express Edition](#), which are freely available. For detailed instructions on how to setup the environment to edit the project, see the README.txt in the source code directory.

Frequently Asked Questions

A.1 FAQs

1. **My End Device doesn't join the network or it takes several tries to successfully join the network?**

The startup and network linking process is a very demanding from a power-consumption perspective, because both the MSP430 and the CC2500 turn on in a full active mode at startup, which is a drain on power when working with such a limited power budget. Also, linking to an RF network requires scanning the area and exchanging packets between the ED and AP with the potential for re-transmissions. High-current pulses, such as RF communication, are sourced from the 1000- μ F capacitor, and if all the energy is drained in a short period of time, it must be recharged prior by holding the solar cell under a bright light prior to another attempt to join the network.

2. **I've left the Solar Energy Harvesting Module under a bright light for three days, but it still doesn't work in the dark?**

The shunt on J8 must be removed to charge the EnerChip from the solar cell. With J8 in place, the battery is isolated to prevent potential damage caused by it draining while in transport or storage.

3. **Why does the Solar Energy Harvester Module use thin film rechargeable batteries instead of a rechargeable AA, super cap, or other exotic storage solution?**

Energy harvesting applications can also run from any other storage element. Thin film batteries have the advantage of being easily recharged, have a small profile and, most importantly, have a negligible self-discharge. Self discharge is the property of batteries or capacitors to lose charge over time; however, thin film batteries lose only a small percentage of their charge over a long period of time.

4. **Why is the battery pack included if the eZ430-RF2500T is intended to run from the Solar Energy Harvester?**

The battery pack is may be useful when trying to debug an application that has not been optimally tuned to run in an efficient energy harvesting environment.

5. **The reported temperature is incorrect, how can I calibrate the sensor?**

A temperature offset is stored in Flash, which is calibrated at production. If the offset is erased or is incorrect, it can be changed to an appropriate level for your application.

6. **Where can I get the part number for the solar panel or the rest of build of material (BOM) for the Solar Energy Harvesting module?**

Please send all questions on the Solar Energy Harvesting Module to Cymbet (www.cymbet.com)

7. **Where do I find more information on the eZ430-RF2500 wireless development tool?**

The *eZ430-RF2500 Development Tool User's Guide* ([SLAU227](#))

8. **When I try to compile the source code with IAR Kickstart, I get the following error: Fatal Error[e89]: Too much object code produced (more than 0x1000 bytes) for this package**

IAR KickStart currently has a 4KB code size limitation, and the project being compiled is larger than 4KB. (0x1000 = 4096). To compile, a full license of IAR is required. A 30-day evaluation version of IAR is available from <http://supp.iar.com/Download/SW/?item=EW430-EVAL>.

9. **Why is the solar panel on the energy harvesting board so large when my TI-36X works fine with a tiny solar panel?**

The current required to run a calculator and LCD is relatively small. Running a wireless sensor network, however, consumes approximately 10 mA to 25 mA when trying to simultaneously sample sensors and transmit data wirelessly. This current might be 100 to 1000 times more than a calculator application. A larger solar panel allows collection of more solar energy to keep up with the real-time demands of a wireless system with a high duty cycle. The design could be optimized with a smaller solar cell, but the frequency of RF transmissions would have to be reduced.

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Texas Instruments (TI) provides the enclosed Evaluation Board/Kit/Module (EVM) under the following conditions:

The user assumes all responsibility and liability for proper and safe handling of the goods. Further, the user indemnifies TI from all claims arising from the handling or use of the goods.

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As noted in the EVM User's Guide and/or EVM itself, this EVM and/or accompanying hardware may or may not be subject to the Federal Communications Commission (FCC) and Industry Canada (IC) rules.

For EVMs **not** subject to the above rules, this evaluation board/kit/module is intended for use for ENGINEERING DEVELOPMENT, DEMONSTRATION OR EVALUATION PURPOSES ONLY and is not considered by TI to be a finished end product fit for general consumer use. It generates, uses, and can radiate radio frequency energy and has not been tested for compliance with the limits of computing devices pursuant to part 15 of FCC or ICES-003 rules, which are designed to provide reasonable protection against radio frequency interference. Operation of the equipment may cause interference with radio communications, in which case the user at his own expense will be required to take whatever measures may be required to correct this interference.

General Statement for EVMs including a radio

User Power/Frequency Use Obligations: This radio is intended for development/professional use only in legally allocated frequency and power limits. Any use of radio frequencies and/or power availability of this EVM and its development application(s) must comply with local laws governing radio spectrum allocation and power limits for this evaluation module. It is the user's sole responsibility to only operate this radio in legally acceptable frequency space and within legally mandated power limitations. Any exceptions to this are strictly prohibited and unauthorized by Texas Instruments unless user has obtained appropriate experimental/development licenses from local regulatory authorities, which is responsibility of user including its acceptable authorization.

For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant

Caution

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

For EVMs annotated as IC – INDUSTRY CANADA Compliant

This Class A or B digital apparatus complies with Canadian ICES-003.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

Concerning EVMs including radio transmitters

This device complies with Industry Canada licence-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concerning EVMs including detachable antennas

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication.

This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Cet appareil numérique de la classe A ou B est conforme à la norme NMB-003 du Canada.

Les changements ou les modifications pas expressément approuvés par la partie responsable de la conformité ont pu vider l'autorité de l'utilisateur pour actionner l'équipement.

Concernant les EVMs avec appareils radio

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes : (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante.

Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur.

【Important Notice for Users of EVMs for RF Products in Japan】

This development kit is NOT certified as Confirming to Technical Regulations of Radio Law of Japan

If you use this product in Japan, you are required by Radio Law of Japan to follow the instructions below with respect to this product:

1. Use this product in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,
2. Use this product only after you obtained the license of Test Radio Station as provided in Radio Law of Japan with respect to this product, or
3. Use of this product only after you obtained the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to this product. Also, please do not transfer this product, unless you give the same notice above to the transferee. Please note that if you could not follow the instructions above, you will be subject to penalties of Radio Law of Japan.

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EVALUATION BOARD/KIT/MODULE (EVM) WARNINGS, RESTRICTIONS AND DISCLAIMERS

For Feasibility Evaluation Only, in Laboratory/Development Environments. Unless otherwise indicated, this EVM is not a finished electrical equipment and not intended for consumer use. It is intended solely for use for preliminary feasibility evaluation in laboratory/development environments by technically qualified electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems and subsystems. It should not be used as all or part of a finished end product.

Your Sole Responsibility and Risk. You acknowledge, represent and agree that:

1. You have unique knowledge concerning Federal, State and local regulatory requirements (including but not limited to Food and Drug Administration regulations, if applicable) which relate to your products and which relate to your use (and/or that of your employees, affiliates, contractors or designees) of the EVM for evaluation, testing and other purposes.
2. You have full and exclusive responsibility to assure the safety and compliance of your products with all such laws and other applicable regulatory requirements, and also to assure the safety of any activities to be conducted by you and/or your employees, affiliates, contractors or designees, using the EVM. Further, you are responsible to assure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard.
3. Since the EVM is not a completed product, it may not meet all applicable regulatory and safety compliance standards (such as UL, CSA, VDE, CE, RoHS and WEEE) which may normally be associated with similar items. You assume full responsibility to determine and/or assure compliance with any such standards and related certifications as may be applicable. You will employ reasonable safeguards to ensure that your use of the EVM will not result in any property damage, injury or death, even if the EVM should fail to perform as described or expected.
4. You will take care of proper disposal and recycling of the EVM's electronic components and packing materials.

Certain Instructions. It is important to operate this EVM within TI's recommended specifications and environmental considerations per the user guidelines. Exceeding the specified EVM ratings (including but not limited to input and output voltage, current, power, and environmental ranges) may cause property damage, personal injury or death. If there are questions concerning these ratings please contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM User's Guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, some circuit components may have case temperatures greater than 60°C as long as the input and output are maintained at a normal ambient operating temperature. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors which can be identified using the EVM schematic located in the EVM User's Guide. When placing measurement probes near these devices during normal operation, please be aware that these devices may be very warm to the touch. As with all electronic evaluation tools, only qualified personnel knowledgeable in electronic measurement and diagnostics normally found in development environments should use these EVMs.

Agreement to Defend, Indemnify and Hold Harmless. You agree to defend, indemnify and hold TI, its licensors and their representatives harmless from and against any and all claims, damages, losses, expenses, costs and liabilities (collectively, "Claims") arising out of or in connection with any use of the EVM that is not in accordance with the terms of the agreement. This obligation shall apply whether Claims arise under law of tort or contract or any other legal theory, and even if the EVM fails to perform as described or expected.

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