A Low-Power Battery-Less Wireless Temperature and Humidity Sensor for the TI PaLFI Device

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ABSTRACT

This application report describes a battery-less operation of a temperature and humidity sensor application. The implementation is done using the SHT21 relative humidity and temperature (RH&T) sensor from Sensirion (http://www.sensirion.com), an MSP430F2274 microcontroller, and the TMS37157 (PaLFI) low-frequency device from TI. The complete power for operating the wireless sensor and the MSP430F2274 is derived from the RF field of a low-frequency reader (134.2 kHz) module. The hardware is based on the eZ430-TMS37157 PaLFI Demo Tool. Some changes were made to the original eZ430-TMS37157 to implement the RH&T sensor. The connection between the MSP430F2274 and the RH&T sensor has been implemented via software I2C. The SPI communication between the TMS37157 and the MSP430F2274 is based on the SPI library for the TMS37157.

Related code examples and other files can be downloaded from http://www.ti.com/lit/zip/swra395.

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1 Introduction

Several applications require hermetically sealed environments, where physical parameter measurements such as temperature, humidity, or pressure are measured and, for several reasons, a battery-less operation is required. In such applications, a wireless data and power transfer is necessary. This application report shows how to implement an easy-to-use low-power wireless humidity and temperature sensor comprising a SHT21 from Sensrion, a MSP430F2274 microcontroller, and a TMS37157 PaLFI (passive low-frequency interface). The complete power for the wireless sensor and the MSP430F2274 is provided by the RFID base station (ADR2) reader included in the eZ430-TMS37157 demo kit.

The application is divided in four steps:

- Charge phase: Generate an RF field of 134.2 kHz from the ADR2 reader to the wireless sensor module to charge the power capacitor.
- Downlink phase: Send command or instruction to wireless sensor to start measurement.
- Measurement and recharge phase: Trigger measurement of temperature, recharge the power capacitor on the sensor device, and trigger humidity measurement.
- Uplink phase: Send measurement results via RF interface (134.2 kHz) back to ADR2 reader.

2 Hardware Description

2.1 Device Specifications

2.1.1 MSP430F2274

The MSP430F2274 is a 16-bit microcontroller from the 2xx family of the ultra-low-power MSP430™ family of devices from Texas Instruments.[2] The supply voltage for this microcontroller ranges from 1.8 V to 3.6 V. The MCU is capable of operating at frequencies up to 16 MHz. It also has an internal very-low-power low-frequency oscillator (VLO) that operates at 12 kHz at room temperature. It has two 16-bit timers (Timer_A and Timer_B), each with three capture/compare registers. An integrated 10-bit analog-to-digital converter (ADC10) supports conversion rates of up to 200 ksps. The current consumption of 0.7 mA during standby mode (LPM3) and 250 mA during active mode makes it an excellent choice for battery-powered applications.

2.1.2 TMS37157 PaLFI

The TMS37157 PaLFI is a dual interface passive RFID product from Texas Instruments. The device can communicate via the RF and the SPI (wired) interfaces. It offers 121 bytes of programmable EEPROM memory. The complete memory can be altered through the wireless interface, if the communication/read distances between the reader antenna and the PaLFI antenna are less than 10 cm to 30 cm (depending on the antenna geometry and reader power). For wireless memory access, a battery supply is not required. A microcontroller with a SPI interface has access to the entire memory through the 3-wire SPI interface of the TMS37157. In addition, the TMS37157 can pass through received data from the wireless interface to the microcontroller and send data from the microcontroller back over the wireless interface. If the TMS37157 is connected to a battery, it offers a battery charge function and a battery check function without waking the microcontroller. If connected to a battery, the TMS37157 has an ultralow power consumption of about 60 nA in standby mode and about 70 µA in active mode. The PaLFI can completely switch off the microcontroller, resulting in an ultralow power consumption of the complete system. This application report does not cover this. Further information can be found in the application report *TMS37157 Passive Low-Frequency Interface IC Performance With Neosid Antennas* (SWRA382).

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2.1.3 SHT21 Humidity and Temperature Sensor

The extremely small SHT21 digital humidity and temperature sensor integrates sensors, calibration memory, and digital interface on 3x3 mm footprint. This results in cost savings, because no additional components are need and no investments in calibration equipment or process are necessary. One-chip integration allows for lowest power consumption, thus enabling energy harvesting and passive RFID solutions. The complete over-molding of the sensor chip, with the exception of the humidity sensor area, protects the reflow solderable sensor against external impact and leads to an excellent long term stability.

About Sensirion

The Swiss sensor manufacturer Sensirion AG is a leading international supplier of CMOS-based sensor components and systems. Its range of high-quality products includes humidity and temperature sensors, mass flow meters and controllers, gas and liquid flow sensors, and differential pressure sensors. Sensirion supports its international OEM customers with tailor-made sensor system solutions for a wide variety of applications. Among others, they include analytical instruments, consumer goods, and applications in the medical technology, automotive and HVAC sectors. Sensirion products are distinguished by their use of patented CMOSens® technology. This enables customers to benefit from intelligent system integration, including calibration and digital interfaces.

Contact: www.sensirion.com, support@sensirion.com, Tel. +41 44 306 40 00, Fax +41 44 306 40 30

2.2 *Interfaces from MSP430F2274 to TMS37157 and SHT21*

2.2.1 Interface Between MSP430F2274 and TMS37157 PaLFI

Figure 1 shows the interface between MSP430F2274 and TMS37157. The TMS37157 is connected to the MSP430F2274 through a 3-wire SPI interface. To simplify communication between the MSP430F2274 and TMS37157, the BUSY pin of the TMS37157 is connected to the MSP430. The BUSY pin indicates the readiness of the TMS37157 to receive the next data byte from the MSP430F2274. The PUSH pin is used to wake up the PaLFI from standby mode so that the MSP430F2274 can access the EEPROM of the PaLFI. CLKAM is used for the antenna automatic tune feature of the PaLFI target board.

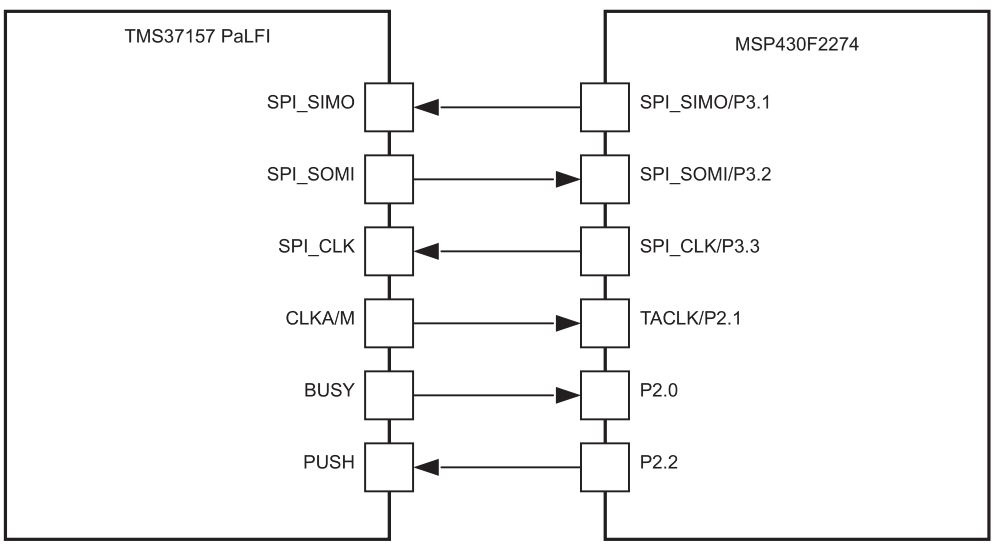

Figure 1. Block Diagram of Interface Between MSP430F2274 and TMS37157

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2.2.2 Interface Between MSP430F2274 and SHT21

Figure 2 shows the interface between MSP430F2274 and SHT21. I2C is used to connect both devices. The MSP430F2274 contains two communication modules. One is used as UART connection to a host PC, the other one is used to communicate to the TMS37157. Therefore, the I2C interface has been implemented completely in software.

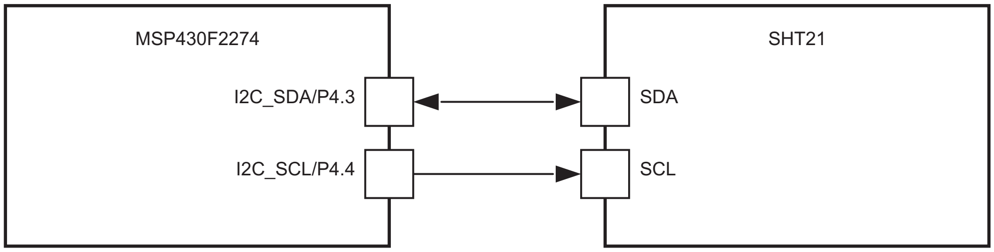

Figure 2. Block Diagram of Interface Between MSP430F2274 and SHT21

2.3 Hardware Changes to Original PaLFI Board

Several changes were made to the standard PaLFI board to implement the wireless sensor application.

The most important change is to use an external DC/DC converter attached to VCL to generate a VBAT/VCC voltage out of the 134.2-kHz RF field. Figure 3 shows the basic principle of this circuit.

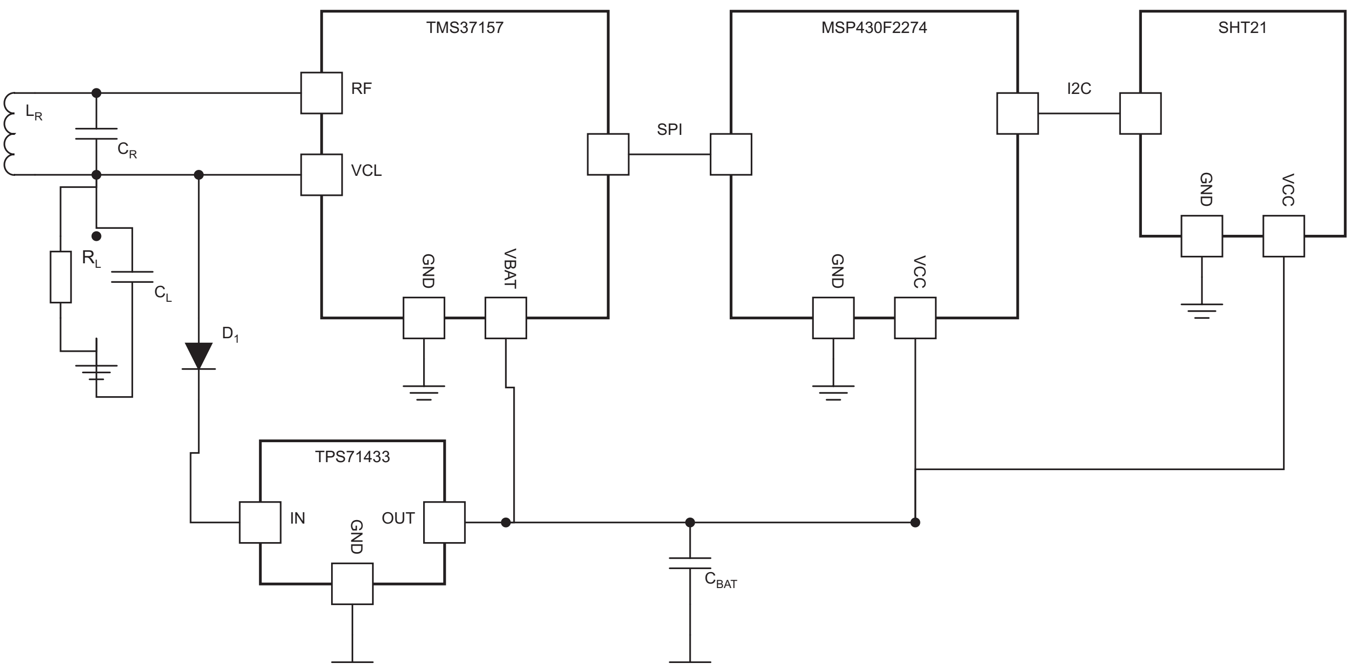

Figure 3. Principle Schematic of the Wireless Sensor

The input of the dc/dc converter TPS71433 is connected to VCL via diode D_1. D_1 prevents the resonance circuit (consisting of L_R and C_R) from any disturbances coming from the dc/dc converter. Capacitor C_{BAT} stores the energy derived from the RF field.

Using an external dc/dc converter instead of the internal of the TMS37157 overcomes two issues. The first advantage of an external dc/dc converter is that it can provide higher output currents in comparison to the internal regulator (80 mA compared to 5 mA). The second advantage using an external regulator is the simpler flow for the application and the firmware (see Table 1).

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Table 1. Comparison of Implementing a Wireless Sensor Between eZ430 PaLFI Board and Wireless Sensor Board

	Using Internal Regulator	Using External Regulator (see Figure 4)
1	Charge Phase	Charge phase
2	Send first MSP access command to trigger measurement	Send MSP access command to trigger measurement
3	send battery charge command to enable internal regulator to supply MSP and sensor	Keep RF field to supply MSP and sensor
4	Send second MSP access command to retrieve data from TMS37157	Disable RF field and wait for response from TMS37157

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2.4 Schematic and Layout of the Wireless Sensor

2.4.1 Schematic

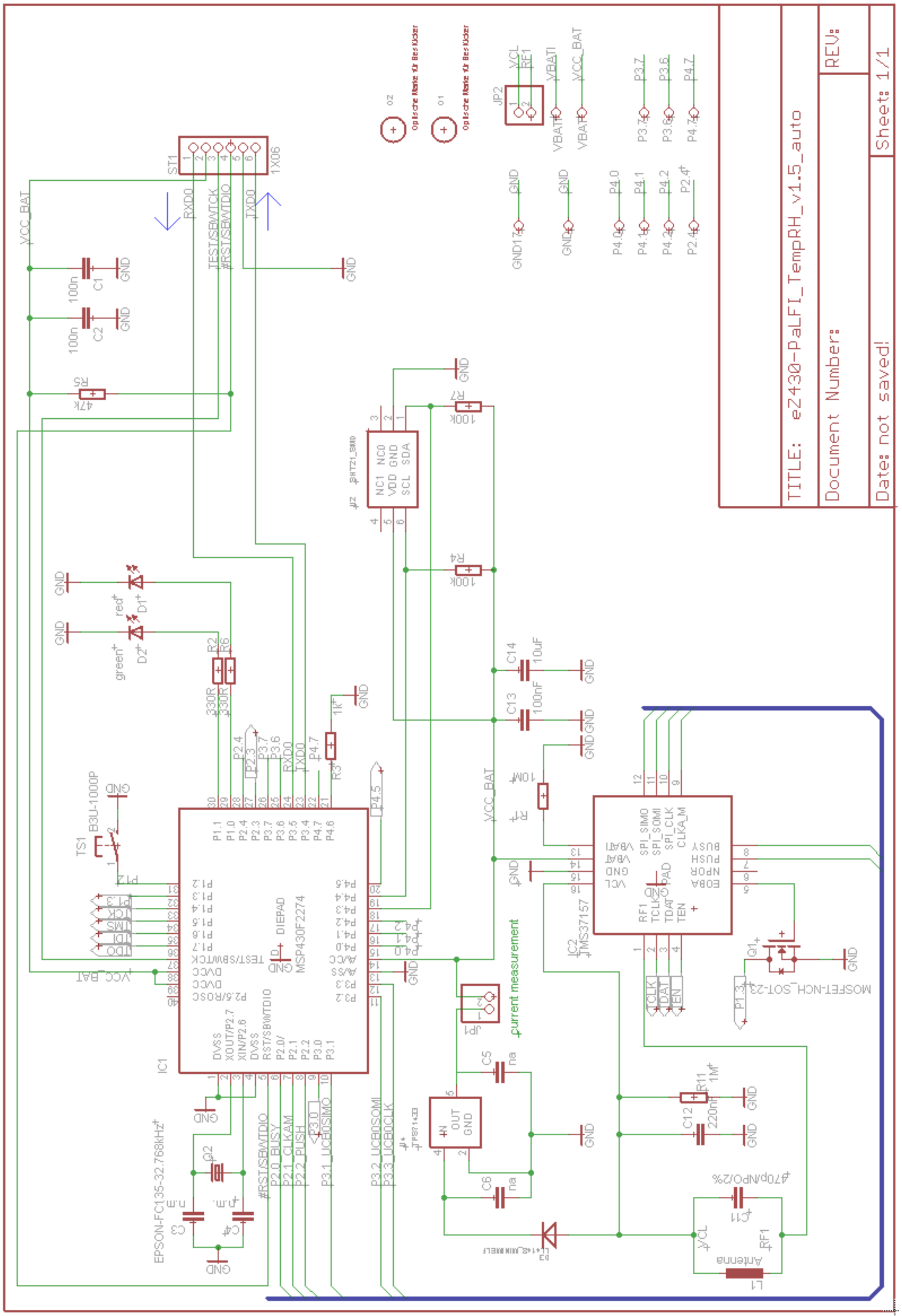

Figure 4. Eagle Schematic of the Wireless Sensor

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2.4.2 Layout

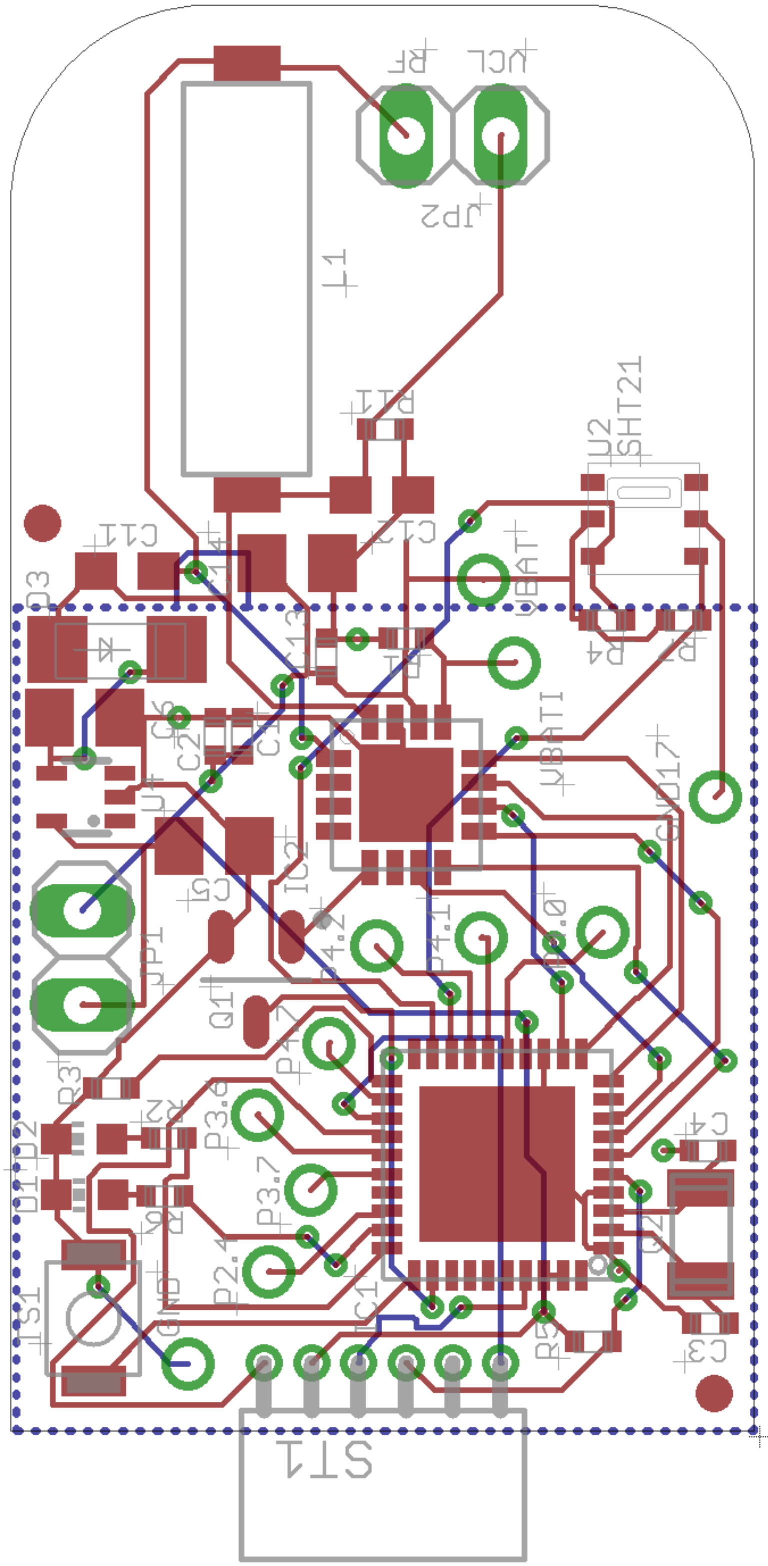

Figure 5. Eagle Layout of the Wireless Sensor

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3 Software and Firmware Description

This section describes the Windows GUI and the MSP430F2274 firmware used for this application report.

The Windows software used in this application report is based on the software that is supplied with the eZ430-TMS37157. An additional tab was inserted to control the wireless sensor application.

Prior to using this application report, make sure that you have the right firmware, corresponding to this application report, loaded onto your PaLFI Wireless Sensor target board. The related software can be downloaded from http://www.ti.com/lit/zip/swra395.

3.1 Windows Software

Prior to using the Wireless Sensor tab, make sure that you have selected the correct COM port on the Expert Mode tab (see Figure 6).

1. Go to the Expert Mode tab.
2. Connect the ADR2 reader to the PC, and click Refresh to view a list of available COM ports.
3. Select the COM port of the ADR2 reader.

In the Expert Mode tab, every free configurable user page of the PaLFI EEPROM can be read, written, or locked.

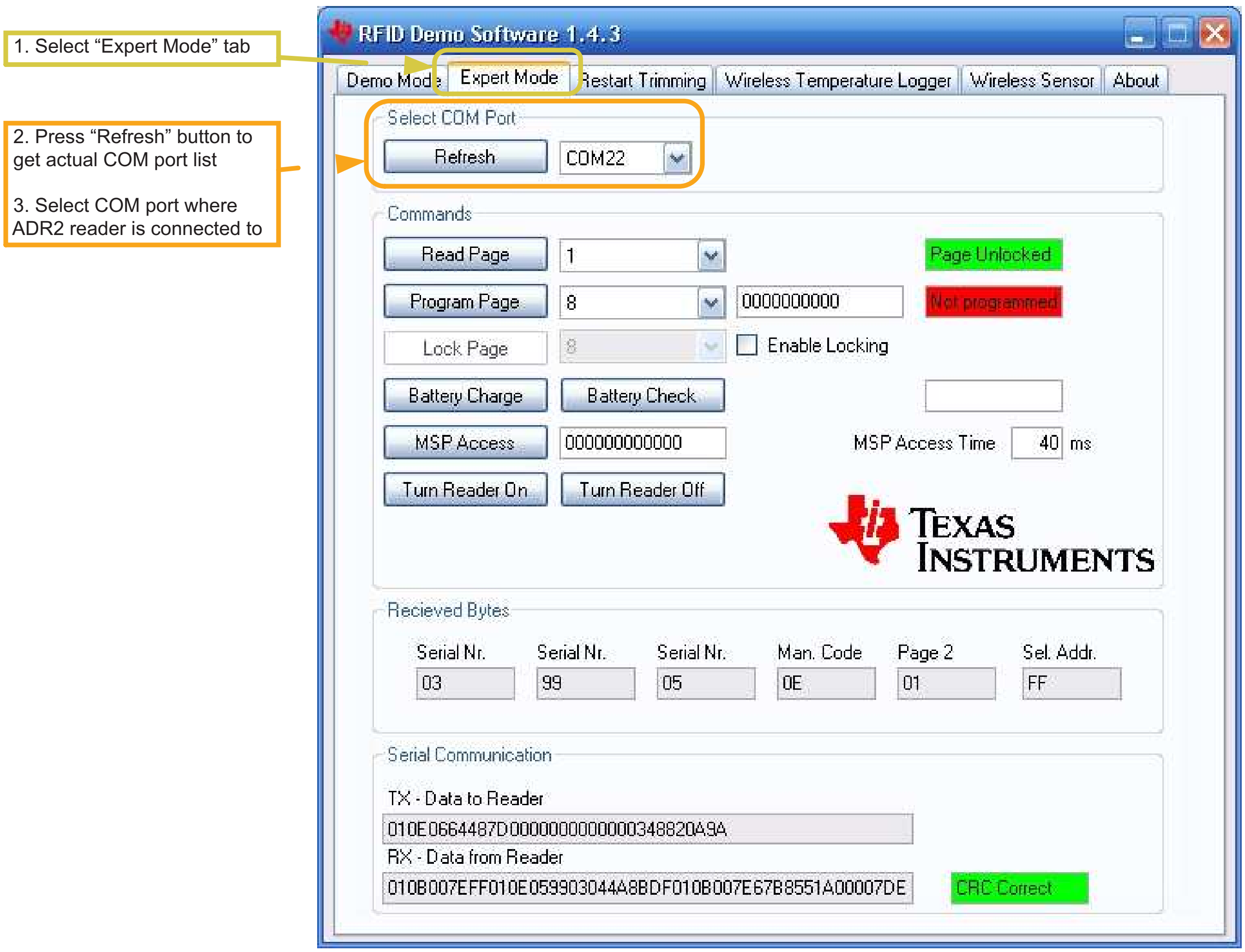

Figure 6. Expert Mode Tab

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Figure 7 shows the PaLFI demo software of the eZ430-TMS37157 with active Wireless Sensor tab. To start a single measurement, click Single. To start continuous measurements, click Loop. To stop the measurements, click Stop. To clear the graph, click Reset.

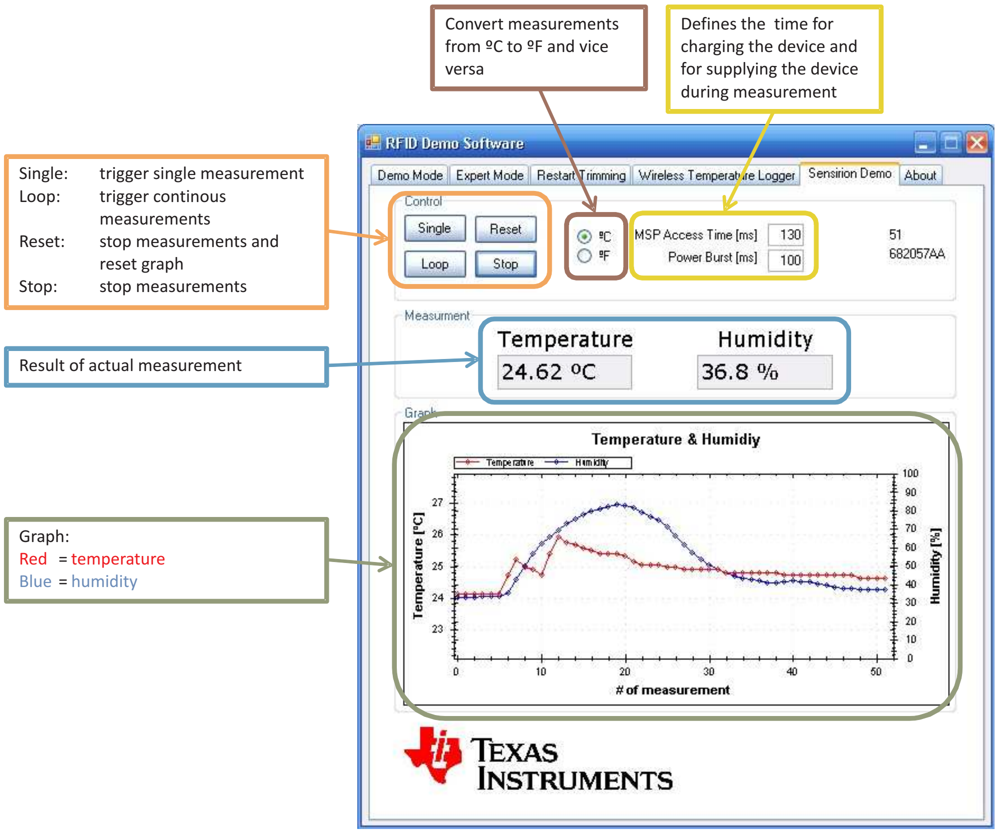

Figure 7. Wireless Sensor Tab

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3.2 MSP430F2274 Firmware

Use the zip file provided with this application report (http://www.ti.com/lit/zip/swra395) and import the project either into a Code Composer Studio workspace or an IAR Embedded Workbench workspace.

3.2.1 Program Flow

Figure 8 shows the main program flow for the firmware.

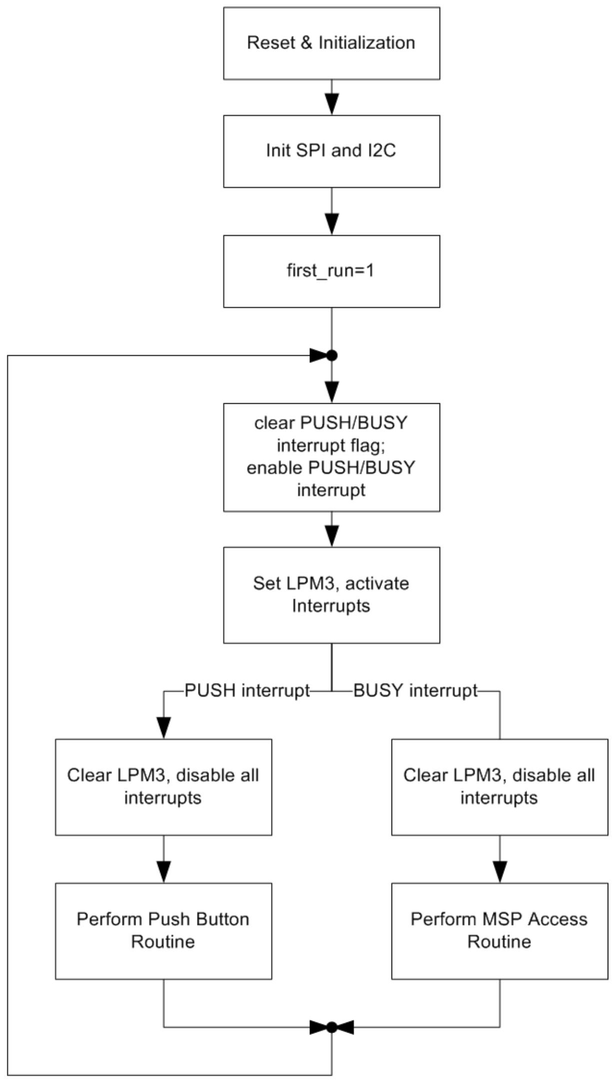

Figure 8. Main Program Flow of MSP430F2274 Software

After reset and initialization of the microcontroller (including ports, timers, SPI, and I2C), it enables interrupts for the PUSH and BUSY pins. Then it enters LPM3, waiting for a PUSH button interrupt or a BUSY interrupt.

A press on the PUSH button (see Figure 9) activates the PaLFI, reads the PCU state and page 2. If page 2 is 0x00, the autotrim routine is executed to trim the resonance circuit of the PaLFI to 134.2 kHz (see Figure 11). If page 2 is 0x01, nothing is done, and the microcontroller returns to LPM3.

In case of a BUSY interrupt, an MSP Access Command is executed (see Figure 10). In this case, the 6 bytes transmitted from the reader to TMS37157 are read via SPI command. This is followed by temperature and humidity measurements.

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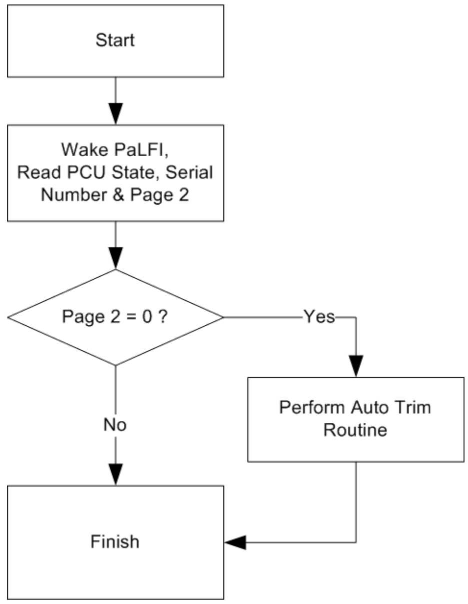

Figure 9. PUSH Interrupt Service Routine

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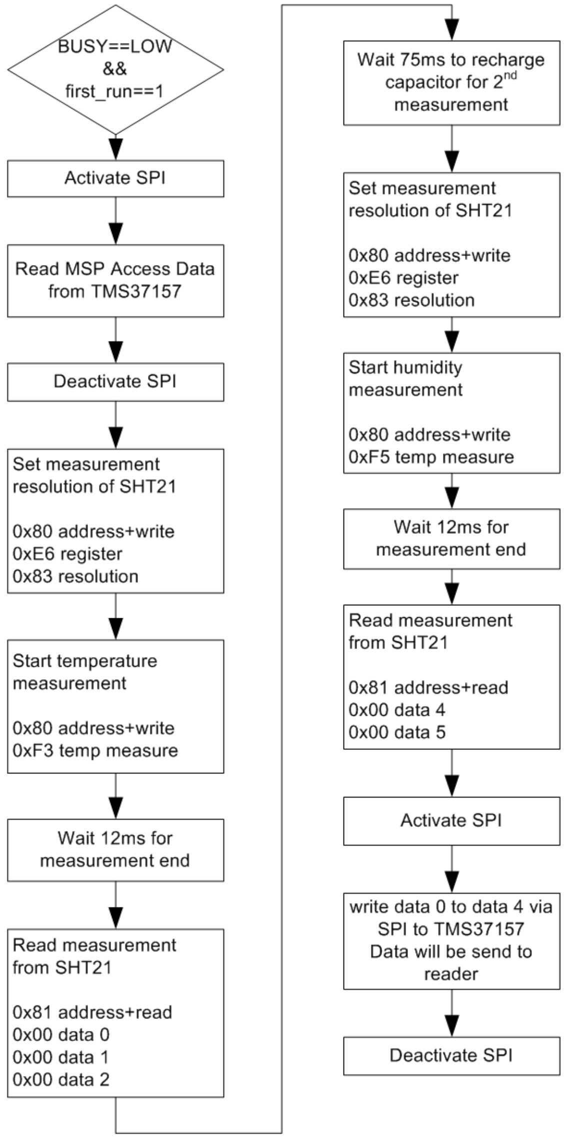

Figure 10. BUSY Interrupt Service Routine

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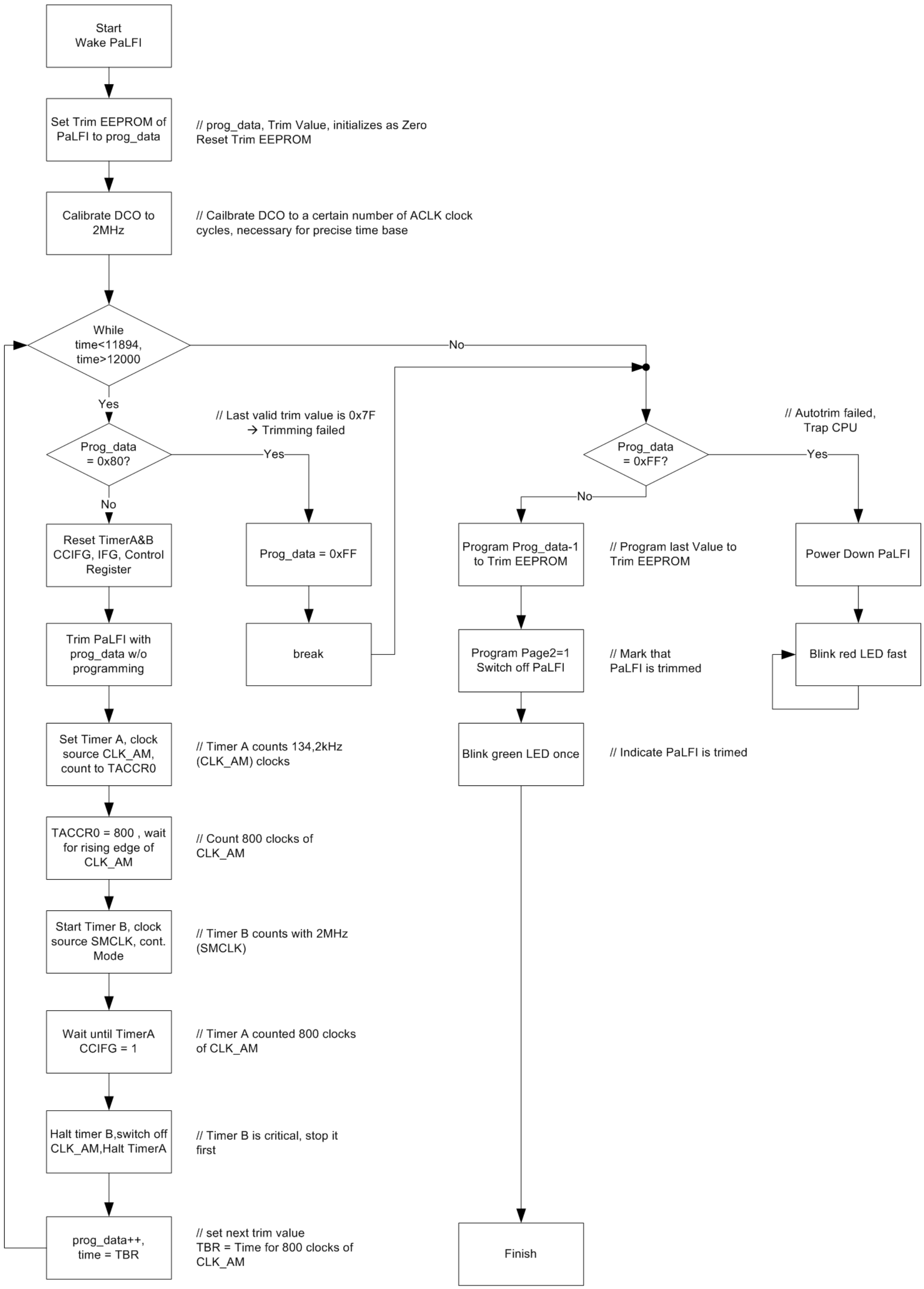

Figure 11. Autotrim Routine

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4 Application

4.1 Description of Analog Signals

Figure 12 shows the complete telegram of the application. The telegram includes the following phases.

1. Charge Phase
2. Downlink Phase
3. Measurement Phase
4. Uplink Phase

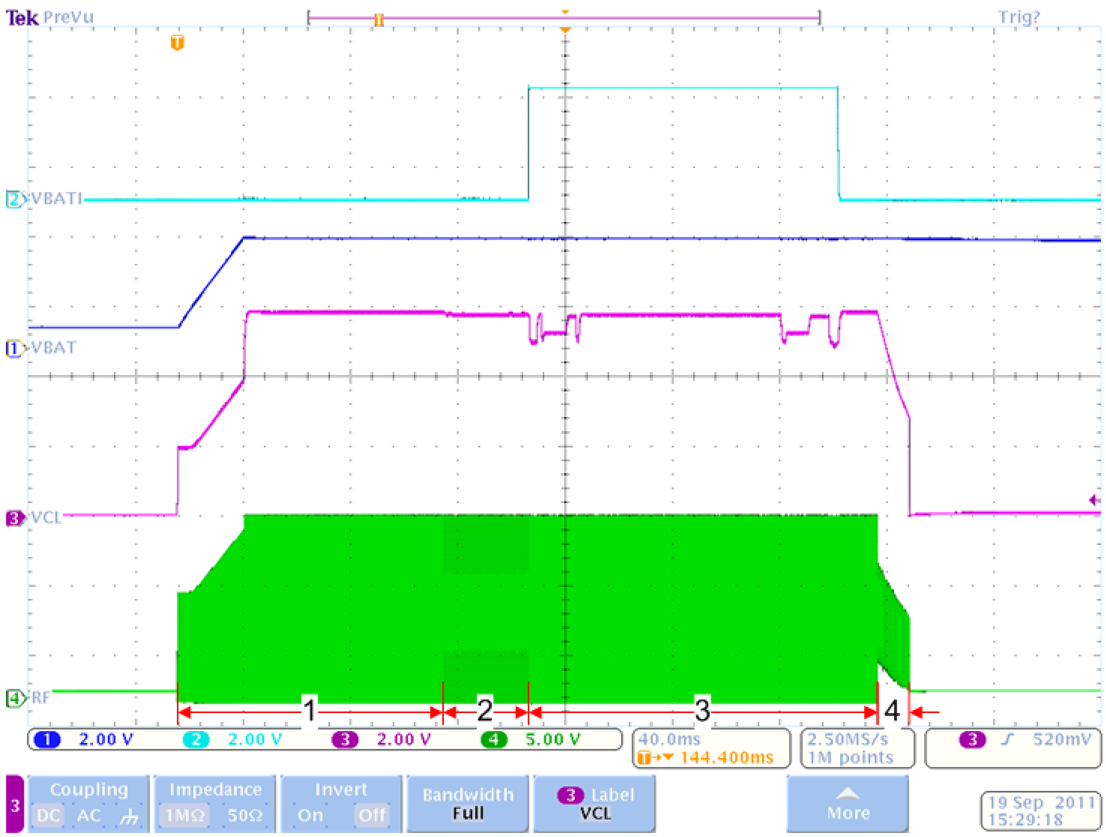

Figure 12. Overview of Complete Telegram

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4.1.1 Charge Phase

Figure 13 shows the charge up phase. During this phase the capacitors at VBAT and VCL are charged. The blue line shows the linear rising VBAT voltage. During time period 1 VCL is almost flat as the DC/DC regulator (TPS74133) drains the maximum available power out of the RF field until voltage U_{in} is equal or higher than U_{out} (see Figure 14).

Current consumption is lower and VCL is rising again during time period 2.

When the capacitors connected to VBAT are charged, current consumption again decreases and VCL is charged to its end voltage of approximately 6 V (time period 3).

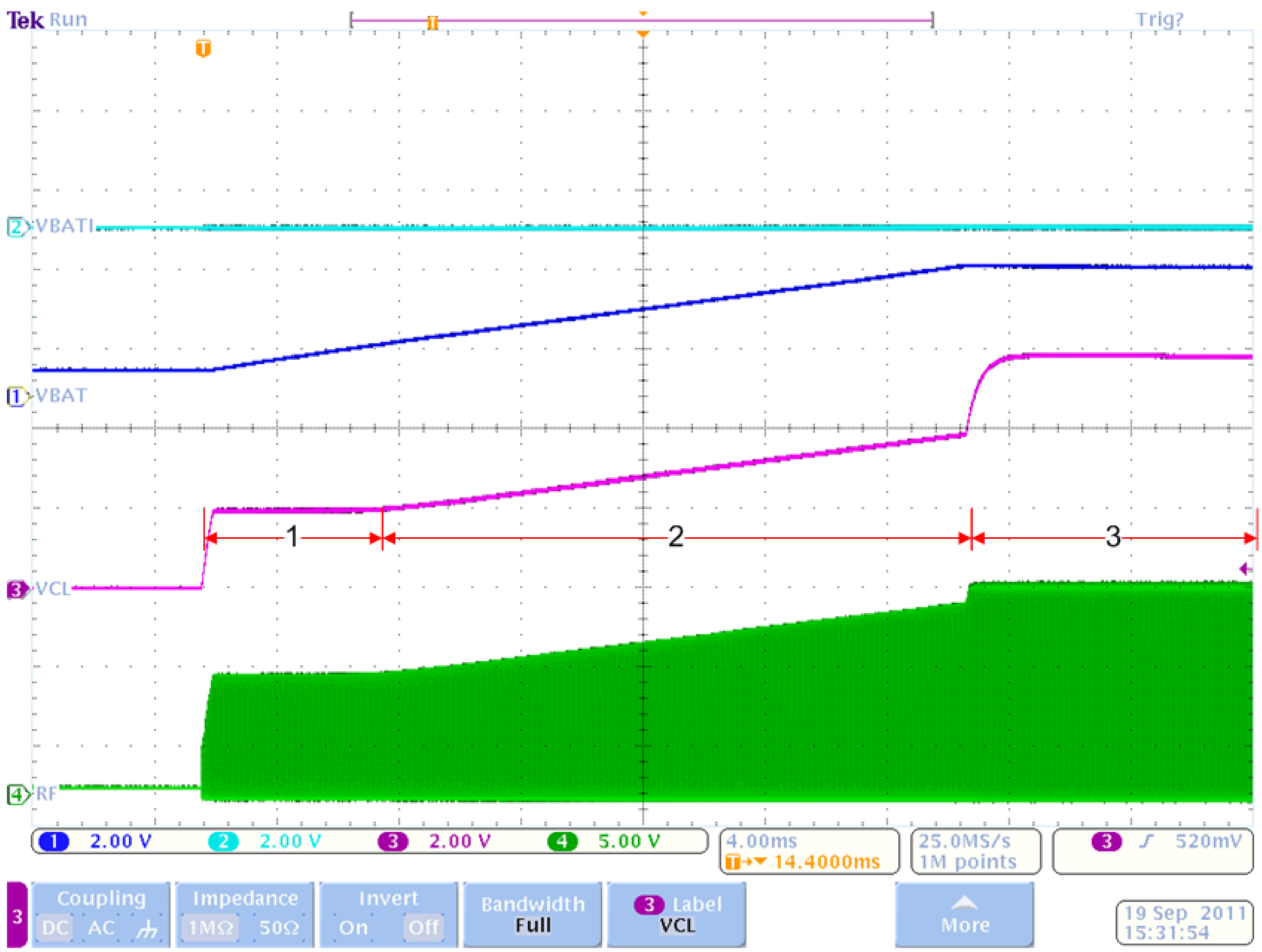

Figure 13. Charge-Up Phase

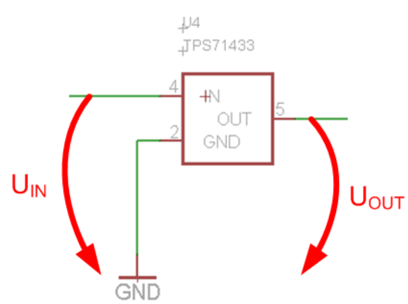

Figure 14. U_{IN} and U_{OUT} Voltage at DC/DC Regulator

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4.1.2 Downlink and Measurement Phase

Figure 15 shows the end of the downlink phase and the beginning of the measurement phase. During downlink the reader sends commands (here the MSP Access command) amplitude modulated to the PaLFI. Upon receive of a valid MSP Access command PaLFI is activated indicated by setting VBATI (light blue line) to VBAT level. At the same time a short BUSY=HIGH pulse is issued to wake the MSP430F2274 (see Figure 10).

The ripples that can be seen on the VCL voltage after rising VBATI are due to activating the MSP430F2274 and the SHT21 and starting the measurement.

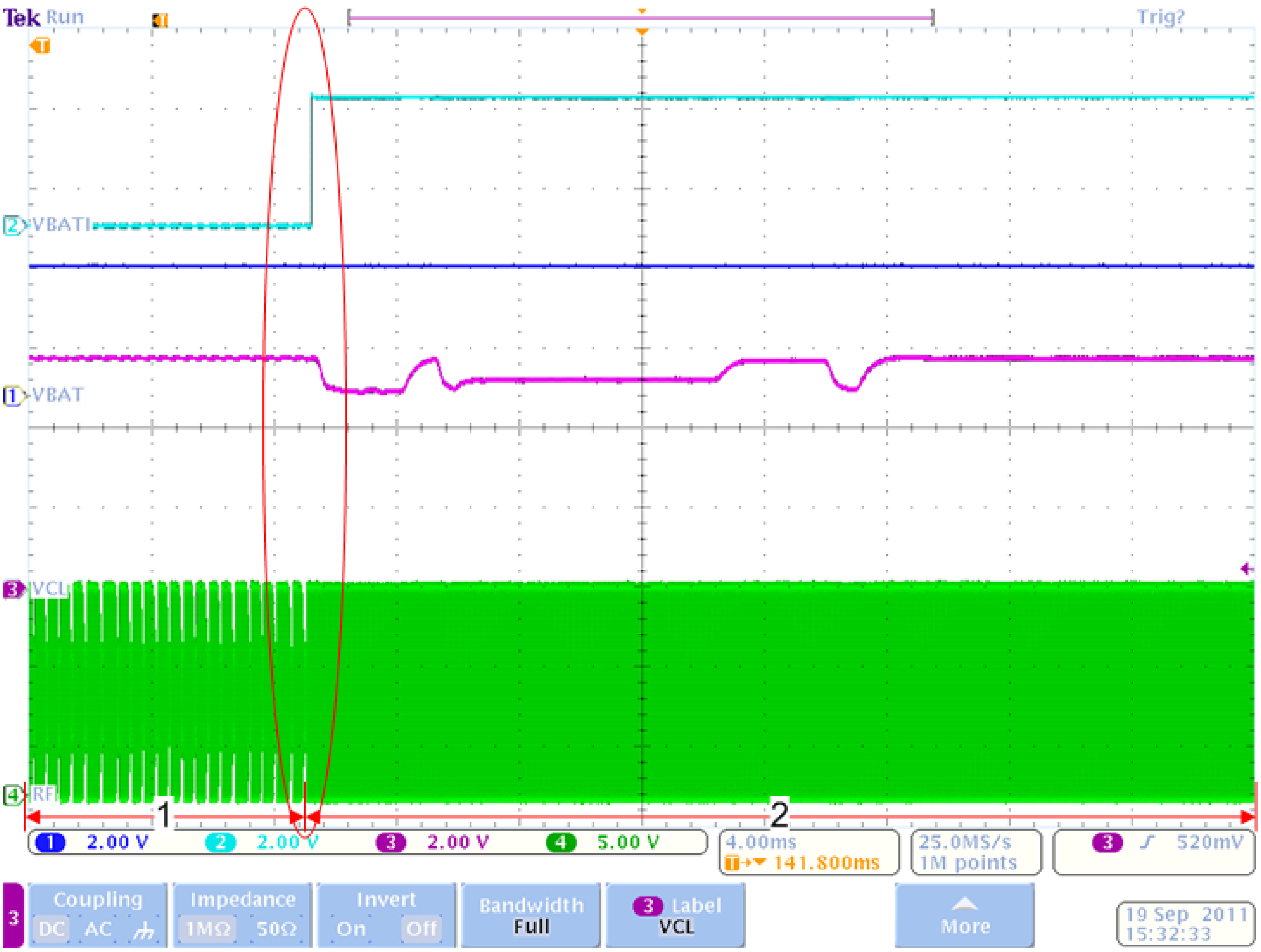

Figure 15. Downlink and Measurement Phase

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4.1.3 Uplink Phase

Figure 16 shows the end of the measurement phase (time 1) and the uplink phase (3). At the end of time period 1 measurement data is shifted from MSP430F2274 to TMS37157 via MSP Access Data Out command. After finishing this command PaLFI is deactivated indicated by setting VBATI=LOW.

Switching off the reader causes the PaLFI to start the uplink. During this phase the measurement results are sent to the ADR2 reader. At the end of the uplink phase a discharge of the CL capacitor is performed to proper reset the device.

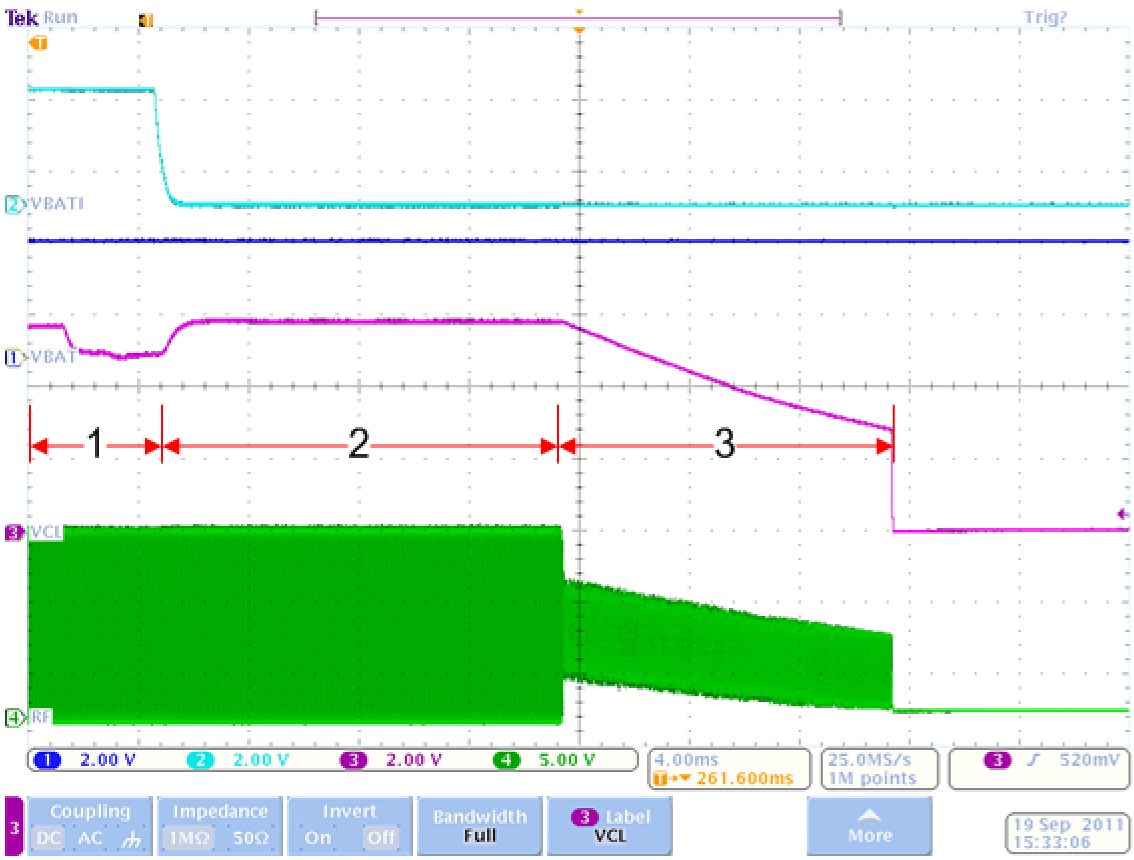

Figure 16. Uplink Phase

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4.2 Overview of Used I2C Commands

Figure 17 shows the complete I2C telegrams used to measure temperature and humidity. The telegram consists of the following phases.

1. Set up SHT21 and start temperature measurement
2. Temperature measurement
3. Transfer temperature results from SHT21 to MSP430F2274
4. Recharge CBAT capacitor for humidity measurement
5. Set up SHT21 and start temperature measurement
6. Humidity measurement
7. Transfer humidity results from SHT21 to MSP430F2274

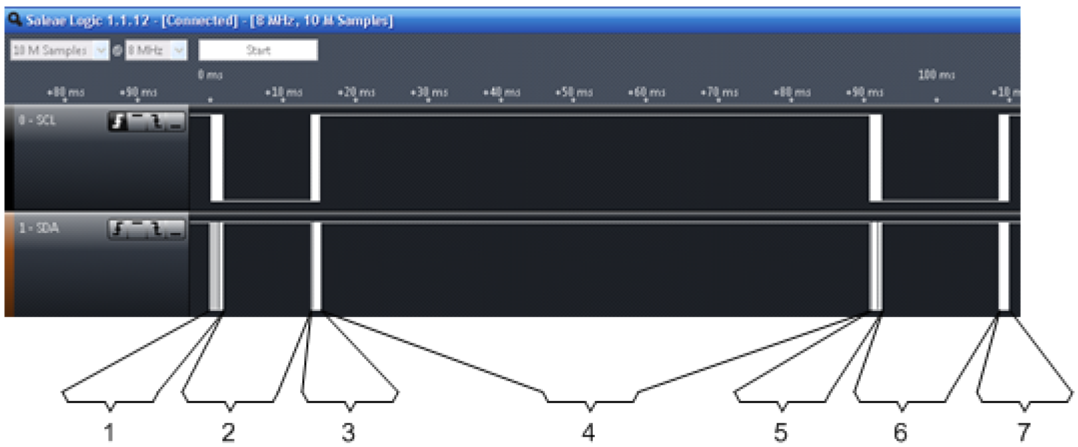

Figure 17. I2C Telegram Overview

4.2.1 Start Temperature Measurement

Figure 18 shows the I2C commands how to set up and start the temperature measurements of the SHT21. For detailed descriptions, see the SHT21 data sheet, Figure 10, and the MSP430F2274 firmware.

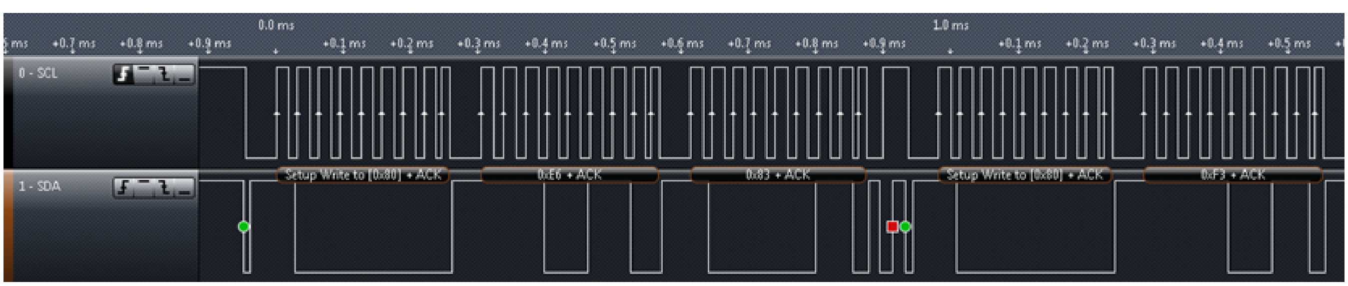

Figure 18. I2C Set Up and Start Temperature Measurement

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4.2.2 Read Temperature Measurement Results

Figure 19 shows an example of temperature measurement results and the commands needed to read them from the SHT21.

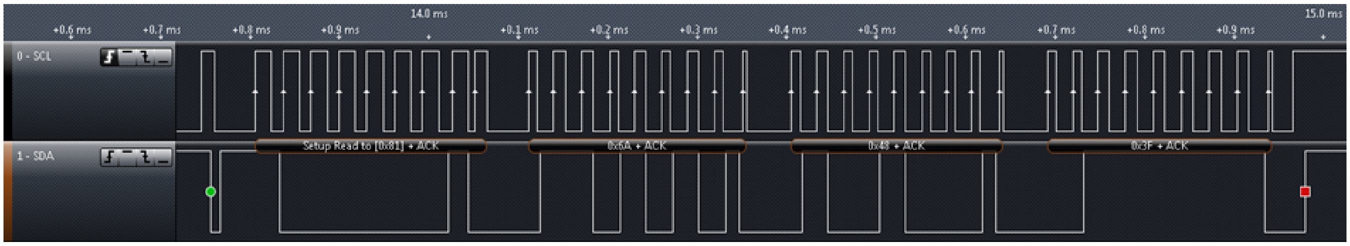

Figure 19. I2C Read Temperature Measurement Results

4.2.3 Start Humidity Measurement

Figure 20 shows the I2C commands to set up and start the temperature measurements of the SHT21. For detailed descriptions, see the SHT21 data sheet, Figure 10, and the MSP430F2274 firmware.

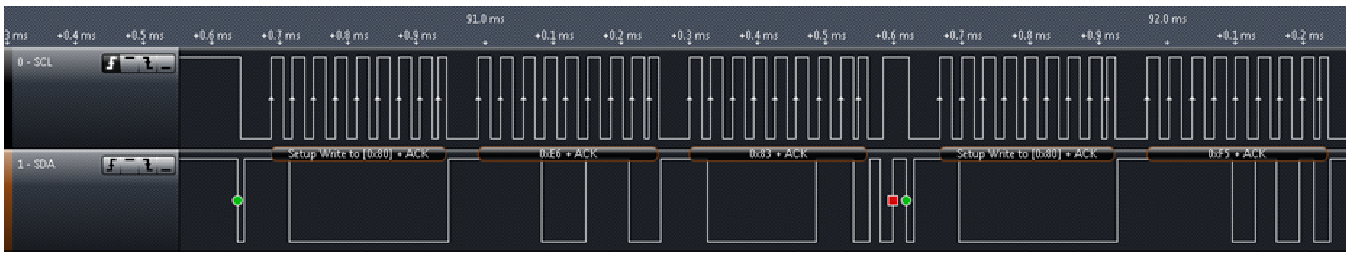

Figure 20. I2C Set Up and Start Humidity Measurement

4.2.4 Read Humidity Measurement Results

Figure 21 shows an example of humidity measurement results and the commands needed to read them from the SHT21.

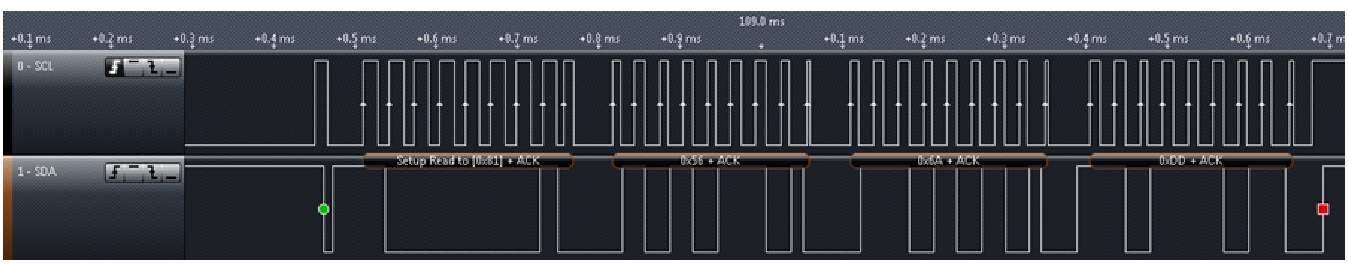

Figure 21. I2C Read Humidity Measurement Results

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5 Summary

This application report shows the concept and the implementation of a wireless and battery-less temperature and humidity sensor. It provides a reference schematic and layout, as well as the firmware for the MSP430F2274 and an example GUI. The information and guidance in this application report should help you develop a custom wireless sensor application based on the PaLFI device and an MSP430™ microcontroller.

6 References

1. *MSP430x22x2, MSP430x22x4 Mixed Signal Microcontroller* data sheet (SLAS504)
2. *MSP430x2xx Family User's Guide* (SLAU144)
3. *TMS37157 Passive Low-Frequency Interface (PaLFI) Device With EEPROM and 134.2-kHz Transponder* data sheet (SWRS083)
4. *eZ430-TMS37157 Development Tool User's Guide* (SLAU281)
5. *Using the SPI Library for TMS37157* (SWRA272)
6. *SHT21 Humidity and Temperature Sensor* data sheet (http://www.sensirion.com)
7. *TMS37157 Passive Low-Frequency Interface IC Performance With Neosid Antennas* (SWRA382)

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