

TI Designs: TIDA-00484

湿度和温度传感器节点，适用于低于 **1GHz** 的星形网络，可以实现 **10 年** 以上的纽扣电池寿命



设计概述

此 TI 设计使用德州仪器 (TI) 的纳米级功耗系统计时器、升压转换器、SimpleLink™ 超低功耗低于 1GHz 无线微控制器 (MCU) 平台和湿度感应技术，展示了传感器终端节点占空比调节的超低功耗方法，可实现极长的电池寿命。

设计资源

TIDA-00484	工具文件夹 (包含设计文件)
HDC1010	产品文件夹
HDC1080	产品文件夹
CC1310	产品文件夹
TPL5111	产品文件夹
TPS61291	产品文件夹
TPS22860	产品文件夹
TPD1E10B06	产品文件夹

设计特性

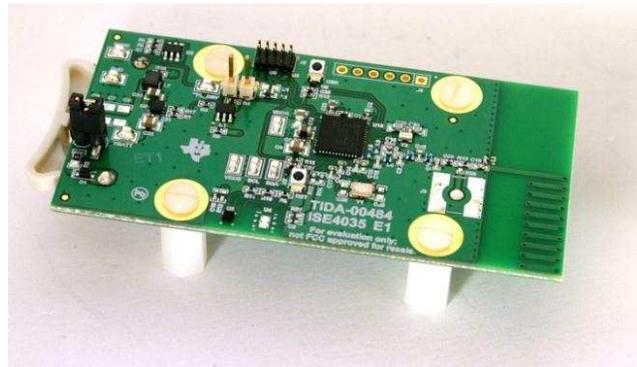
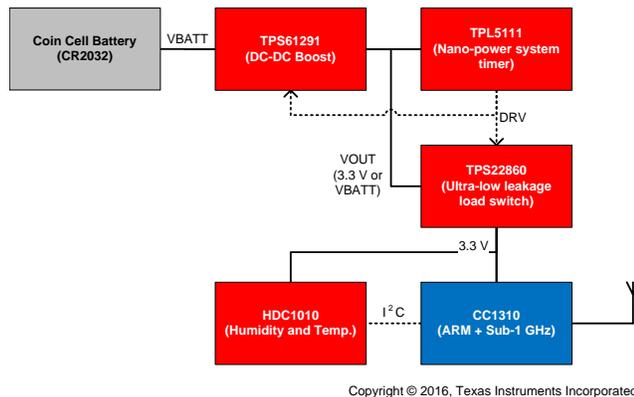
- 使用超低功耗系统计时器来驱动系统，从而通过 CR2032 纽扣电池实现 10 年以上的电池寿命
- 可配置的系统唤醒间隔
- 极低关闭状态电流 (270nA, 持续 59.97 秒)
- 由于处理器工作电流和无线电发射电流较低，因此可实现超低的开启状态电流 (3.376mA, 持续 30ms)
- 相对湿度精度为 $\pm 3\%$
- 温度精度为 $\pm 0.2^{\circ}\text{C}$

特色应用

- 工业
- 物联网 (IoT)
- 楼宇自动化
- 入侵检测
- HVAC 传感器
- 智能温度调节装置和室温监视器
- 电池供电系统



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1 Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Input power source	CR2032 Lithium-ion coin cell battery (3.0-V nominal voltage)	2.6 节
Sensor type	Humidity and temperature	2.1 节
Measurement interval	One measurement per minute	2 节
Average on-state current consumption	3.376 mA	节 6.2.1
On-state duration	30.0 milliseconds	节 6.2.1
Average off-state current consumption	269.75 nA	节 6.2.2
Off-state duration	59.97 seconds	节 6.2.2
Estimated battery life	11.90 years	节 6.2.3
Operating temperature	-30°C to 60°C (limited by CR2032 coin cell operating range)	2.6 节
Working environment	Indoor and outdoor	2.6 节
Form factor	1.5 inch x 3.0 inch rectangular PCB	5.1 节

2 System Description

Many industrial, building automation, and IoT systems require increasing numbers of wireless sensor end-nodes. However, one of the major constraints of adding many wireless sensor end-nodes to a system is power. Typical sensor end-nodes are powered by batteries, which last from several months to several years depending on the power consumption of the end node. Replacing batteries can be a very expensive system-level cost, because each end node requires a periodic manual battery replacement.

Enabled by Texas Instruments' nano-power system timer, DC-DC boost converter, SimpleLink™ ultra-low power wireless microcontroller (MCU) platform, and humidity sensing technologies, the Humidity and Temperature Sensor Node for Sub-1GHz Star Networks Enabling 10+ Year Coin Cell Battery Life TI Design demonstrates an ultra-low power method to duty-cycle sensor end-nodes leading to extremely long battery life.

At a high level, this TI Design system consists of a CR2032 coin cell battery, a nano-power system timer, a low IQ boost converter, an ultra-low power wireless MCU, and a combined humidity and temperature sensor. The nano-power system timer, which consumes tens of nanoamps when operating, controls power to all the remaining circuitry. The nano-power system timer switches on power to the system and enables the boost converter at a programmable interval (one measurement per minute in this system); when the wireless MCU has finished reading and transmitting the sensor data, a signal to the system timer shuts down the entire system and puts the boost converter in bypass mode. By duty-cycling the entire system in this manner, this TI Design achieves more than ten years of battery life from a CR2032 coin cell.

This design guide addresses component selection, design theory, and test results of the TI Design system. The scope of this design guide gives system designers a head-start in integrating TI's nano-power system timer, boost converter, SimpleLink ultra-low power wireless microcontroller (MCU) platform, and humidity sensing technologies into their end-equipment systems.

The following sub-sections describe the various blocks within the TI Design system and what characteristics are most critical to best implement the corresponding function.

2.1 Humidity and Temperature Sensor

In this TI Design, a digital humidity sensor with an integrated temperature sensor was chosen to demonstrate the ultra-low power, duty-cycling power scheme. Humidity and temperature are both common measurements required for many end-equipment systems in industrial and building automation applications. For example, home heating and cooling systems of the future are likely to include humidity and temperature measurements in each individual room. With the wireless functionality of the system, this environmental information is sent back to a smart thermostat, which then controls the various air ducts connecting to each room, providing a much more intelligent home environment by providing individual comfort settings and increasing energy savings.

With a relative humidity accuracy of $\pm 2\%$ and a temperature accuracy of $\pm 0.2^\circ\text{C}$, the HDC1010 device from Texas Instruments is ideally suited to accurately sense environmental information. The innovative placement of the HDC1010 sensing element on the bottom of the device provides resistance to dust, dirt, and other environmental contaminants, which improves system reliability for applications like heating, ventilation, and air conditioning (HVAC) systems, smart thermostats, and room monitors. Furthermore, the power consumption of the HDC1010 is extremely low, averaging $1.2\ \mu\text{A}$ at a one sample per second measurement rate. Interfacing to the device is straightforward with any microcontroller platform using the I²C communication protocol.

This TI Design also includes provisions for installing the HDC1080, which has the same performance specifications as the HDC1010 device, but comes in an industrial-friendly WSON package. Any further reference to the HDC1010 device in this document can be construed to be either HDC1010 or HDC1080. Only one of the HDC devices is intended to be populated at a time.

2.2 Ultra-Low Power Wireless Microcontroller (MCU)

In this TI Design, transmitting the sensor information to some central location for processing is necessary. However, because power consumption is always a concern in battery-based applications, the radio and processor must be low power. Also, the wireless protocol required for the end-equipment system is an important consideration for the selection of the radio device.

With TI's SimpleLink™ ultra-low power wireless microcontroller (MCU) platform, low power with a combined radio and microcontroller enables extremely long battery life for sensor end-nodes. Furthermore, the CC1310 device is a multi-standard device, with software stack support for wM-Bus and TI's SimpliciTI™ (star network) network protocol. In this TI Design, a generic proprietary protocol is the protocol of choice, but the hardware as built can work with other protocols as well.

2.3 Nano-Power System Timer

This TI Design is able to achieve extremely long battery life by means of a nano-power system timer. The use of this type of device replaces the internal timer of any standard microcontroller with a discrete analog system timer that consumes much less power than the microcontroller's internal timer. A nano-power system timer can be used either to bring an MCU out of sleep mode by means of a pin interrupt, or to completely shut off power to the system, in whole, or in part.

In this TI Design, the TPL5111 device was chosen to control both the boost converter mode and load switch, which reduces the off-state current drawn from the battery to the tens and hundreds of nanoamps. The timer interval is user-selectable by means of a resistor and can range from 100 ms up to two hours, with a typical time base accuracy of 1%. The TPL5111 device controls the operating mode of a boost converter, as the following 2.4 节 describes, and a low leakage load switch, as 2.5 节 describes.

2.4 Boost Converter

Some sensor end-nodes require a regulated voltage rail to operate at their highest levels of sensing performance. To provide a well-regulated voltage rail over the entire lifetime of the battery, a boost converter is necessary. However, to reduce the battery life loss due to converter inefficiency, an extremely high-efficiency boost converter is required.

In this TI Design, the TPS61291 device was chosen to regulate the battery voltage to 3.3 V. With a battery voltage of 3.0 V, the TPS61291 maintains an efficiency level greater than 95% at the load currents typical of a sensor end-node: 1 mA to 100 mA. Even at the depleted coin cell voltage of 2.0 V, the TPS61291 device maintains an efficiency level greater than 90% over the typical load current range of 1 mA to 100 mA.

Furthermore, the TPS61291 device has a bypass mode that connects the input voltage source directly to the output pin, while bypassing the boost inductor. This low-loss bypass mode only consumes 15 nA (typical), which when combined with a low-leakage load switch, enables ultra-low off-state currents.

2.5 Low-Leakage Load Switch

In conjunction with a nano-power system timer (see 2.3 节), this TI Design uses a low-leakage load switch to shut off power to the wireless MCU and humidity sensor. The most important characteristic of this switch is the off-state leakage, because that leakage significantly affects the overall battery life of the system.

In this TI Design, the TPS22860 device was chosen as the switch used to disconnect the system from the battery. The TPS22860 has a rated leakage current of ± 20 nA at 25°C, which enables extremely long battery life in this system.

2.6 Coin Cell Battery

The power source for this TI Design is a CR2032 lithium-ion coin cell. The selection of the CR2032 coin cell battery as the power source was due to the ubiquity of that battery type, particularly in small form factor systems, such as a sensor end-node.

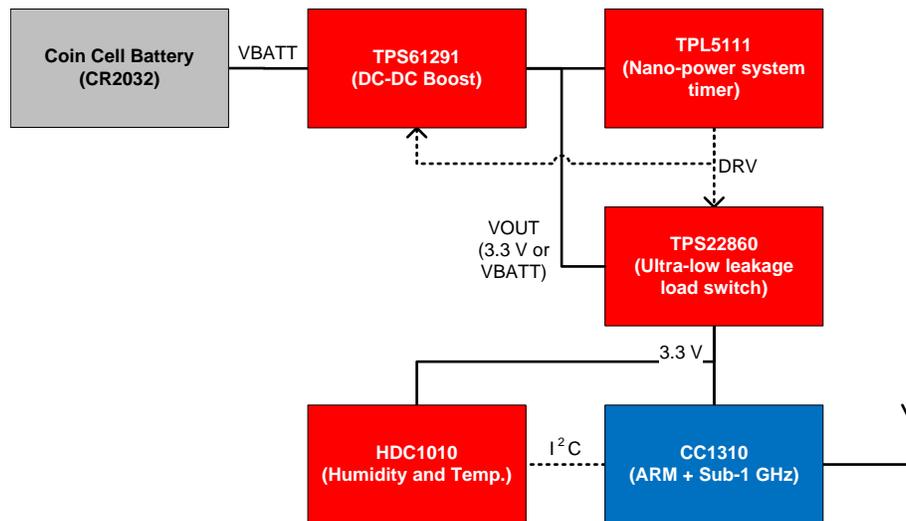
The voltage characteristics of a lithium-ion CR2032 coin cell battery are also ideal. The output voltage remains relatively flat throughout the discharge life, until the cell is nearly depleted. When the remaining charge in the coin cell battery is nearly depleted, the output voltage drops off relatively quickly.

The temperature characteristics of lithium-ion batteries are also superior to that of alkaline cells, particularly at lower temperatures. This superiority is due to lithium-ion cells having a non-aqueous electrolyte that performs better than aqueous electrolytes commonly found in alkaline batteries.

However, the CR2032 coin cell battery is still the limiting component in terms of the operating temperature range; all of the integrated circuits and other electrical components are specified to operate at a wider temperature range than the battery. Therefore, the specified operating temperature range of the TI Design system is -30°C to 60°C . Given an appropriate weather-proof enclosure, this TI Design system is suited for both indoor and outdoor use.

Immediately following the battery is a low forward voltage Schottky diode and a bulk capacitor. The Schottky diode prevents damage to the hardware if the coin cell battery is inserted backwards. This TI Design also uses a coin cell battery tray that prevents an end-user from inserting the battery backwards, which may eliminate the need for the Schottky diode. The bulk capacitor is sized to prevent too much voltage sag, particularly during the initial transition into the on-state.

3 Block Diagram



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图 1. Humidity and Temperature Sensor Node for Sub-1GHz Star Networks Enabling 10+ Year Coin Cell Battery Life System Block Diagram

3.1 Highlighted Products

The Humidity and Temperature Sensor Node for Sub-1GHz Star Networks Enabling 10+ Year Coin Cell Battery Life Reference Design features the following devices:

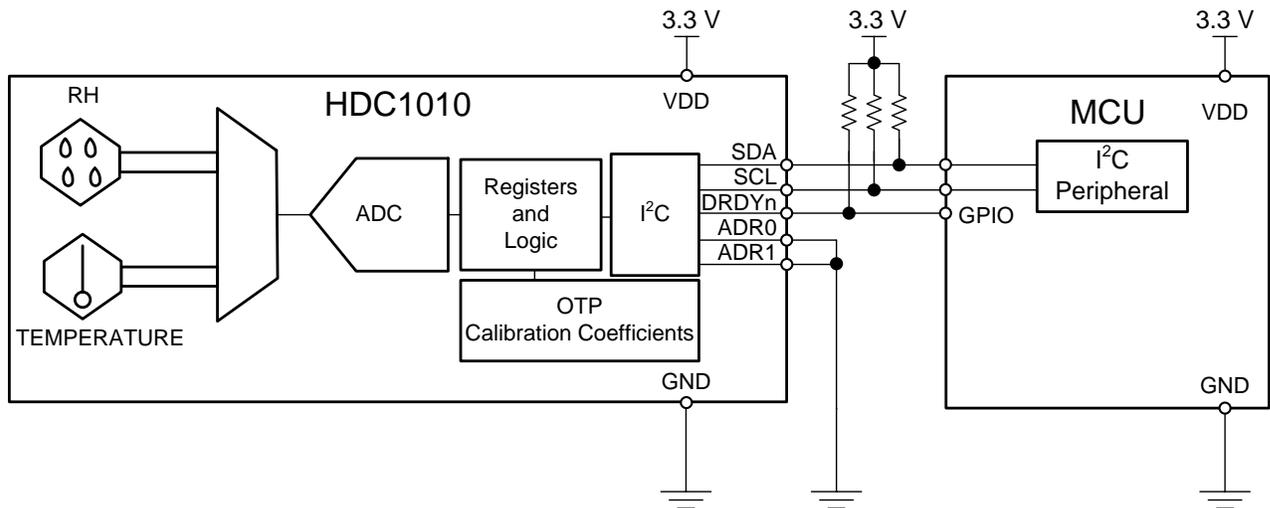
- HDC1010: Low power, high accuracy, digital humidity sensor with integrated temperature sensor (节 3.1.1)
- HDC1080: Low power, high accuracy, digital humidity sensor with integrated temperature sensor (节 3.1.2)
- CC1310: SimpleLink™ sub-1 GHz ultra-low power wireless MCU (节 3.1.3)
- TPL5111: Ultra-low power timer with MOS driver and MOSFET power ON (节 3.1.4)
- TPS61291: Low I_Q boost converter with bypass operation (节 3.1.5)
- TPS22860: Ultra-low leakage load switch (节 3.1.6)
- TPD1E10B06: Single-channel electro-static discharge (ESD) in a 0402 package with 10-pF capacitance and 6-V breakdown (节 3.1.7)

For more information on each of these devices, see the respective product folders at www.ti.com.

3.1.1 HDC1010

Features

- Relative humidity accuracy $\pm 2\%$ (typical)
- Temperature accuracy $\pm 0.2^\circ\text{C}$ (typical)
- Excellent stability at high humidity
- 14-bit measurement resolution
- 100-nA sleep mode current
- Average supply current:
 - 710 nA at 1 sps, 11-bit RH measurement
 - 1.3 μA at 1 sps, 11-bit RH and temperature measurement
- Supply voltage 2.7 to 5.5 V
- Tiny 2-mm \times 1.6-mm device footprint
- I²C interface



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图 2. HDC1010 Functional Block Diagram

Description

The HDC1010 is a digital humidity sensor with integrated temperature sensor that provides excellent measurement accuracy at very low power. The HDC1010 operates over a wide supply range, and is a low cost, low power alternative to competitive solutions in a wide range of common applications. The innovative Wafer Level Chip Scale Package (WLCS) simplifies board design with the use of an ultra-compact package. The sensing element of the HDC1010 is placed on the bottom part of the device, which makes the HDC1010 more robust against dirt, dust, and other environmental contaminants. The humidity and temperature sensors are factory calibrated and the calibration data is stored in the on-chip non-volatile memory.

3.1.2 HDC1080

Features

- Relative humidity accuracy $\pm 2\%$ (typical)
- Temperature accuracy $\pm 0.2^\circ\text{C}$ (typical)
- Excellent stability at high humidity
- 14-bit measurement resolution
- 100-nA sleep mode current
- Average supply current:
 - 710 nA at 1 sps, 11-bit RH measurement
 - 1.3 μA at 1 sps, 11-bit RH and temperature measurement
- Supply voltage 2.7 to 5.5 V
- Small 3-mm \times 3-mm device footprint
- I²C interface

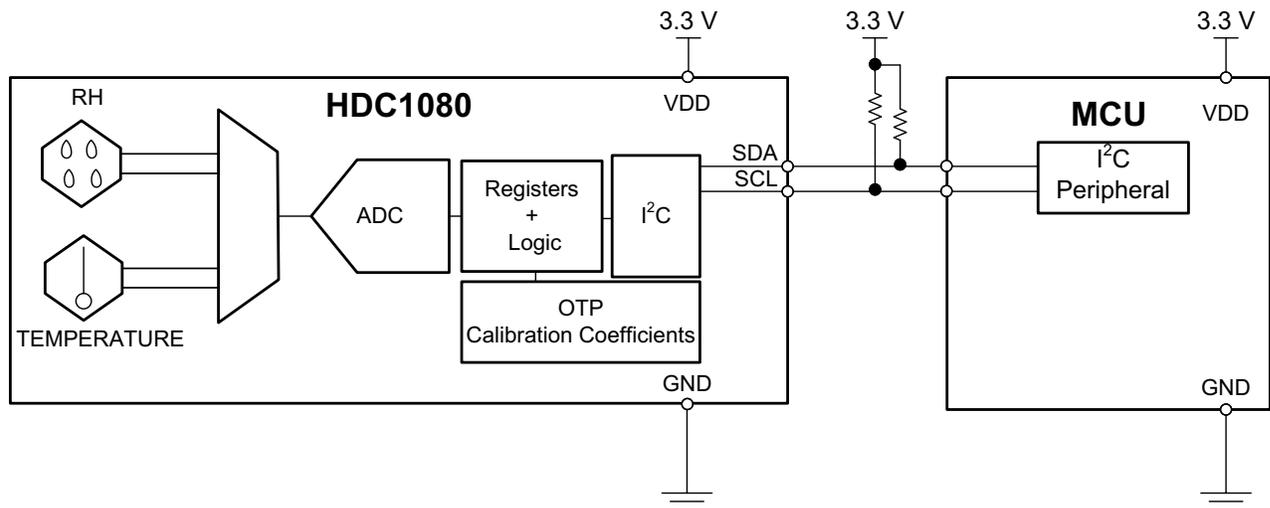


图 3. HDC1080 Functional Block Diagram

Description

The HDC1080 is a digital humidity sensor with integrated temperature sensor that provides excellent measurement accuracy at very low power. The HDC1080 operates over a wide supply range, and is a low cost, low power alternative to competitive solutions in a wide range of common applications. The humidity and temperature sensors are factory calibrated.

3.1.3 CC1310

Features

- Microcontroller
 - Powerful ARM® Cortex®-M3
 - EEMBC CoreMark Score: 142
 - Up to 48-MHz Clock Speed
 - 128KB of In-System Programmable Flash
 - 8-KB SRAM for Cache
 - Up to 20-KB of Ultra-Low Leakage SRAM
 - 2-Pin cJTAG and JTAG Debugging
 - Supports Over-the-Air Upgrade (OTA)
- Ultra-Low Power Sensor Controller
 - 16-Bit Architecture
 - 2KB of Ultra-Low Leakage SRAM for Code and Data
- Efficient Code Size Architecture, Placing Peripheral Drivers, RTOS, RF Drivers, and Bootloader in ROM
- RoHS-Compliant Packages
 - 4-mm x 4-mm RSM QFN32 (10 GPIOs)
 - 5-mm x 5-mm RHB QFN32 (15 GPIOs)
 - 7-mm x 7-mm RGZ QFN48 (30 GPIOs)
- Peripherals
 - All Digital Peripheral Pins Can Be Routed to Any GPIO
 - 4 General-Purpose Timer Modules (8 x 16 Bit or 4 x 32 Bit Timer, PWM Each)
 - 12-Bit ADC, 200-ksamples/s, 8-Channel Analog MUX
 - Continuous Comparator
 - Ultra-low Power Analog Comparator
 - Programmable Current Source
 - UART
 - 2 x SSI (SPI, μ W, TI)
 - I²C
 - I2S
 - Real-Time Clock (RTC)
- AES-128 Security Module
- True Random Number Generator (TRNG)
- Support for Eight Capacitive Sensing Buttons
- Integrated Temperature Sensor
- External System
 - World's Smallest Sub-1 GHz Wireless MCU: 4-mm x 4-mm
 - On-Chip Internal DC-DC Converter
 - Very Few External Components
 - Seamless Integration With the SimpleLink CC1190 Range Extender
 - Pin Compatible With the SimpleLink CC26xx
- Low Power
 - Wide Supply Voltage Range
 - Normal Operation: 1.8 V to 3.8 V
 - External Regulator Mode: 1.65 V to 1.95 V
 - Active-Mode RX: 5.5 mA
 - Active-Mode TX at +10 dBm: 12 mA, +14 dBm: 25 mA
 - Active-Mode MCU: 61 μ A/MHz
 - Active-Mode MCU: 48.5 CoreMark/mA
 - Active-Mode Sensor Controller: 8.2 μ A/MHz
 - Standby: 0.7 μ A (RTC Running and RAM/CPU Retention)
 - Shutdown: 100 nA (Wakeup on External Events)
- RF Section
 - Excellent Receiver Sensitivity:
 - -121 dBm at 2.4 kbit/s
 - -111 dBm at 50 kbit/s

- Very Good Selectivity and Blocking Performance
- Data Rate up to 4 Mbit/s
- Modulation Support: MSK, FSK, GFSK, OOK, ASK, 4GFSK, CPM (Shaped-8 FSK)
- Highly Flexible RF Modem (Software-Defined Radio) to Also Cover Legacy and Proprietary Communication Protocols
- Programmable Output Power up to +15 dBm With Shared RX and TX RF Pins (Regulated Power Supply)
- Antenna Diversity
- Coding Gain
- RF Section (continued)
 - Suitable for Systems Targeting Compliance With Worldwide Radio Frequency Regulations
 - ETSI EN 300 220, EN 303 131, EN 303 204 (Europe)
 - FCC CFR47 Part 15 (US)
 - ARIB STD-T108 (Japan)
- Tools and Development Environment
 - Full-Feature and Low-Cost Development Kits
 - Multiple Reference Designs for Different RF Configurations
 - Packet Sniffer PC Software
 - Sensor Controller Studio
 - SmartRF™ Studio
 - SmartRF Flash Programmer 2
 - IAR Embedded Workbench® for ARM
 - Code Composer Studio™

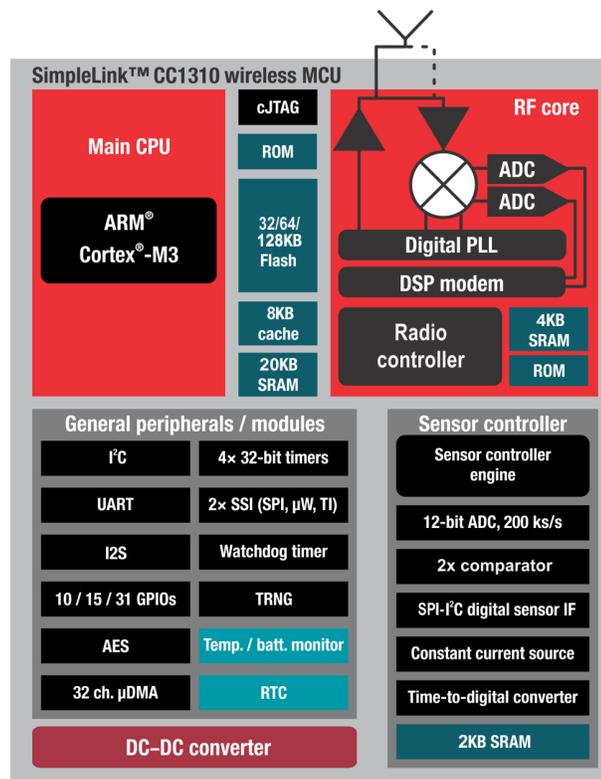


图 4. CC1310 Functional Block Diagram

Description

The CC1310 device is the first part in a Sub-1 GHz family of cost-effective, ultra-low power wireless MCUs. The CC1310 device combines a flexible, very-low power RF transceiver with a powerful 48-MHz Cortex-M3 microcontroller in a platform supporting multiple physical layers and RF standards. A dedicated Cortex®-M0 MCU is handling low-level RF protocol commands that are stored in ROM or RAM, thus ensuring ultra-low power and flexibility. The low-power consumption of the CC1310 device does not come at the expense of RF performance; the CC1310 device has excellent sensitivity and robustness (selectivity and blocking) performance. The CC1310 device is a highly integrated solution offering a complete RF system solution, which includes an on-chip DC-DC converter into a true single-chip solution down to a 4-mm x 4-mm package.

Sensors can be handled in a very low power manner by a dedicated autonomous ultra-low power MCU that can be configured to handle analog and digital sensors; thus, the main MCU (Cortex-M3) sleeps for as long as possible. Software stack support for this device is as follows:

- wM-Bus
- SimpliciTI (Star Network)

3.1.4 TPL5111

Features

- Selectable Time Intervals: 100 ms to 7200 s
- Timer Accuracy: 1% (typ)
- Current Consumption at 2.5 V: 35 nA (typ)
- Resistor Selectable Time Interval
- Manual Power-On input
- One-shot Feature
- Supply Voltage range: 1.8 V to 5.5 V

Applications

- Duty Cycle Control of Battery Powered Systems
- Internet of Things (IoT)
- Intruder Detection
- Tamper Detection
- Home Automation Sensors
- Thermostats
- Consumer Electronics
- Remote Sensor
- White Goods

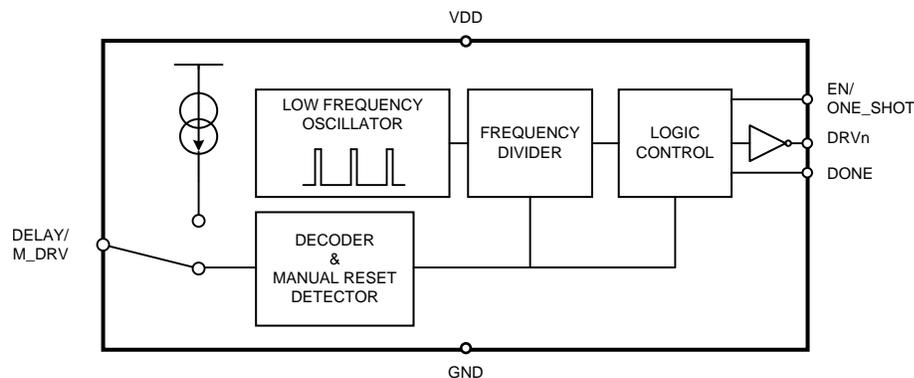


图 5. TPL5111 Functional Block Diagram

Description

The TPL5111 Nano Timer is a low power system timer, ideal for power gating in duty cycled or battery powered applications. Consuming only 35 nA, the TPL5111 can be used to enable and disable the power supply for a micro-controller or other system device, drastically reducing the overall system stand-by current during the sleep time. This power saving enables the use of significantly smaller batteries and makes the TPL5111 well suited for energy harvesting or wireless sensor applications. The TPL5111 provides selectable timing intervals from 100 ms to 7200 s. In addition, the TPL5111 has a unique One-shot feature where the timer will only assert its enable pulse for one cycle. The TPL5111 is available in a 6-pin SOT23 package.

3.1.1.5 TPS61291

Features

- Input Voltage Range 0.9V to 5V
- Startup Voltage 1.5V at 20mA Load
- Pin Selectable Output Voltages: 3.3V, 3V, 2.5V
- 15nA typical Quiescent Current in Bypass Mode
- 5.7 μ A typical Quiescent Current in Boost Mode
- Bypass Switch from VIN to VOUT
- $I_{OUT} > 200\text{mA}$ at 3.3V V_{OUT} , $V_{IN} = 1.8\text{V}$
- Internal Feedback Divider Disconnect (Bypass Mode)

- Controlled Bypass Transition Prevents Reverse Current into Battery
- Power-Save Mode at Light Loads
- Overtemperature Protection
- Redundant Overvoltage Protection
- Small 2mm x 2mm SON 6-pin package

Applications

- Metering (Gas, Water, Smart Meters)
- Remote Controls
- Home Security / Home Automation
- Single 3V Li-MnO₂ or 2 x 1.5V Alkaline Cell Powered Applications

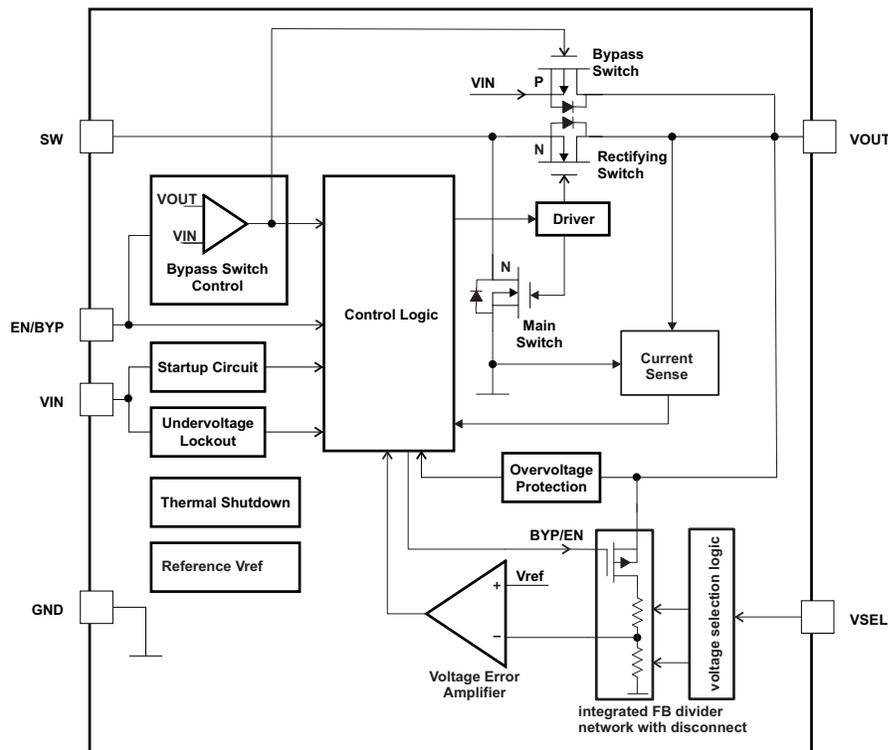


图 6. TPS61291 Functional Block Diagram

Description

The TPS61291 is a boost converter with pin selectable output voltages and an integrated bypass mode. In bypass operation, the device provides a direct path from the input to the system and allows a low power micro controller (MCU) such as the MSP430 to operate directly from a single 3V Li-MnO₂ battery or dual alkaline battery cells.

In bypass mode the integrated feedback divider network for boost mode operation is disconnected from the output and the quiescent current consumption drops down to only 15nA (typical).

In boost mode the device provides a minimum output current of 200mA at 3.3V V_{OUT} from 1.8V V_{IN} . The boost mode is used for system components which require a regulated supply voltage and cannot directly operate from the input source. The boost converter is based on a current-mode controller using synchronous rectification to obtain maximum efficiency and consumes typically 5.7uA from the output. During startup of the boost converter, the VSEL pin is read out and the integrated feedback network sets the output voltage to 2.5V, 3V or 3.3V.

Bypass mode or boost mode operation is controlled by the system via the EN/BYP pin.

The device integrates an enhanced bypass mode control to prevent charge, stored in the output capacitor during boost mode operation, from flowing back to the input and charging the battery.

The device is packaged in a small 6-pin SON package (DRV) measuring 2.0mm x 2.0mm x 0.75mm.

3.1.6 TPS22860

Features

- Integrated Single Channel Load Switch
- Bias Voltage Range (V_{BIAS}): 1.65 V to 5.5 V
- Input Voltage Range: 0 V to V_{BIAS}
- ON-Resistance (R_{ON})
 - $R_{ON} = 0.73 \Omega$ at $V_{IN} = 5 V$ ($V_{BIAS} = 5 V$)
 - $R_{ON} = 0.68 \Omega$ at $V_{IN} = 3.3 V$ ($V_{BIAS} = 5 V$)
 - $R_{ON} = 0.63 \Omega$ at $V_{IN} = 1.8 V$ ($V_{BIAS} = 5 V$)
- 200 mA Maximum Continuous Switch Current

- Ultra-Low Leakage Current
 - V_{IN} Leakage Current = 2 nA
 - V_{BIAS} Leakage Current at 5.5 V = 10 nA
- 6-pin SOT-23 or SC70 Package
- ESD Performance Tested per JESD 22
 - 2 kV HBM and 1 kV CDM

Applications

- Wearables
- Internet of Things
- Wireless Sensor Networks

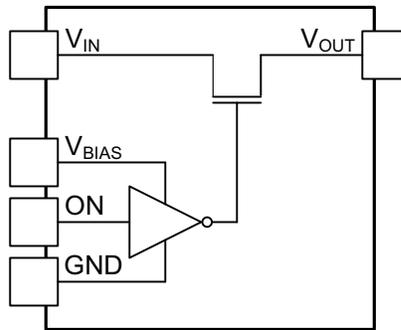


图 7. TPS22860 Functional Block Diagram

Description

The TPS22860 is a small, ultra-low leakage current, single channel load switch. The device requires a V_{BIAS} voltage and can operate over an input voltage range of 0 V to V_{BIAS} . It can support a maximum continuous current of 200 mA. The switch is controlled by an on/off input (ON), which is capable of interfacing directly with low-voltage control signals. The TPS22860 is available in two small, space-saving 6-pin SOT-23 and SC70 packages. The device is characterized for operation over the free-air temperature range of -40°C to 85°C .

3.1.7 TPD1E10B06

Features

- Provides System-Level ESD Protection for Low-Voltage I/O Interface
- IEC 61000-4-2 Level 4 ESD Protection
 - ± 30 kV Contact Discharge
 - ± 30 kV Air-Gap Discharge
- IEC 61000-4-5 Surge: 6 A (8/20 μ s)
- I/O Capacitance 12 pF (Typical)
- R_{DYN} 0.4 Ω (Typical)
- DC Breakdown Voltage ± 6 V (Minimum)
- Ultralow Leakage Current 100 nA (Maximum)
- 10-V Clamping Voltage (Max at $I_{PP} = 1$ A)
- Industrial Temperature Range: -40°C to 125°C

- Space-Saving 0402 Footprint (1 mm \times 0.6 mm \times 0.5 mm)

Applications

- End Equipment:
 - Tablets
 - Remote Controllers
 - Wearables
 - Set-Top Boxes
 - Electronic Point of Sale (EPOS)
 - ebooks
- Interfaces:
 - Audio Lines
 - Pushbuttons
 - General-Purpose Input/Output (GPIO)

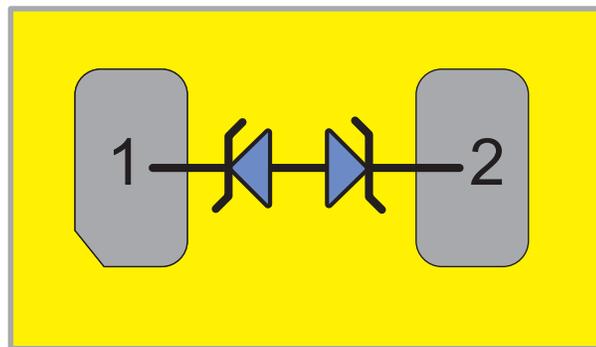


图 8. TPD1E10B06 Functional Block Diagram

Description

The TPD1E10B06 device is a single-channel electrostatic discharge (ESD) transient voltage suppression (TVS) diode in a small 0402 package. This TVS protection product offers ± 30 -kV contact ESD, ± 30 -kV IEC air-gap protection, and has an ESD clamp circuit with a back-to-back TVS diode for bipolar or bidirectional signal support. The 12-pF line capacitance of this ESD protection diode is suitable for a wide range of applications supporting data rates up to 400 Mbps. The 0402 package is an industry standard and is convenient for component placement in space-saving applications.

Typical applications of this ESD protection product are circuit protection for audio lines (microphone, earphone, and speakerphone), SD interfacing, keypad or other buttons, VBUS pin and ID pin of USB ports, and general-purpose I/O ports. This ESD clamp is good for the protection of the end equipment like ebooks, tablets, remote controllers, wearables, set-top boxes, and electronic point of sale equipment.

4 System Design Theory and Considerations

The Humidity and Temperature Sensor Node for Sub-1GHz Star Networks Enabling 10+ Year Coin Cell Battery Life TI Design measures the ambient relative humidity and temperature and achieves an extremely long battery life through the use of duty-cycling with a nano-power system timer. The TPL5111 device controls when the TPS61291 boost converter enters and exits its bypass mode and when the TPS22860 device disconnects the CC1310 and HDC1010 devices from the output of the boost converter. Because the on-state is very short (the time when the CC1310 and HDC1010 have power), and the off-state current consumption from the coin cell battery is very low, the estimated battery life is very long.

4.1 Duty-Cycled Power Design Theory

The main parameters that affect the estimated battery life of the entire system are:

- Capacity rating of the battery in milliamp-hours (mAh)
- Average off-state current consumption (nA)
- Off-state duration (s)
- Average on-state current consumption (mA)
- On-state duration (s)

The following 公式 1 describes the estimated battery life in units most convenient to this TI Design:

$$\text{Battery life [years]} = \frac{\text{Battery capacity [mAh]}}{\left(\frac{I_{\text{ON}} [\text{mA}] \times T_{\text{ON}} [\text{s}] + I_{\text{OFF}} [\text{nA}] \times T_{\text{OFF}} [\text{s}] \times 10^{-6}}{T_{\text{ON}} [\text{s}] + T_{\text{OFF}} [\text{s}]} \right)} \times \frac{1 [\text{year}]}{8760 [\text{hours}]} \times 85\% \text{ Derating factor} \quad (1)$$

Based on this equation that estimates battery life, optimizing several factors leads to a longer battery life:

- Longer T_{OFF}
- Shorter T_{ON}
- Lower I_{ON}
- Lower I_{OFF}

T_{OFF} is completely controllable by the end user. In this TI Design, a value of 1 minute was chosen for the TPL5111 wakeup interval, leading to T_{OFF} of the following form in 公式 2:

$$T_{\text{OFF}} = 1 \text{ minute} - T_{\text{ON}} \quad (2)$$

公式 2 indicates that the system wakes up once every minute to measure the ambient relative humidity and temperature and transmit an RF packet with that data.

T_{ON} is somewhat less controllable because there is a minimum amount of time required to power up the system, take the measurement from the HDC1010 device, transmit the packet, and shut down again. The HDC1010 device has a specified T_{WAIT} period after power up before anything can be done, along with a T_{CONV} , which is the time it takes to convert the humidity and temperature measurements. The I²C transactions between the CC1310 and HDC1010 devices require time to successfully complete, as well as transmitting the data packet from the CC1310 device.

I_{OFF} is defined as the average current consumed from the battery during the off-state. This current is comprised primarily of the leakage through the TPS22860 load switch, the operating current of the TPL5111 nano-power system timer, and the current required to re-charge the bulk capacitor that is placed near the CR2032 coin cell battery, as well as the steady-state leakage current through that same bulk capacitor.

6.2 节 has more details about the battery life performance of this TI Design.

4.2 Wireless Network Design Theory

Because the power is completely cut off from the CC1310 wireless MCU, the use of this TI Design is intended for a star network configuration. This configuration means that each sensor end-node connects directly to a central receiver, which receives the data from each end-node and then performs any necessary processing and connection to the cloud. This configuration implies that this TI Design is not intended for use in smart mesh networks, because the wireless microcontroller does not retain its state or have any control over when it wakes up.

The TI Design as released sends out non-connectable data packets that contain four bytes of data: two bytes of temperature data and two bytes of relative humidity data. This data is transmitted directly as the HDC1010 device outputs it; no post-processing or correction is implemented on the CC1310 device itself. However, if the sensor data requires any pre-processing, the CC1310 device is more than capable of completing any processing task in a short time with the powerful ARM® Cortex® -M3 processor.

The antenna on this TI Design is the miniature helical PCB antenna for 868 MHz or 915MHz. See the application note DN038 ([SWRA416](#)) for more details about layout and performance.

4.3 Firmware Control

The firmware for this TI Design is built on TI-RTOS and has been modified to send out non-connectable data packets. These packets contain four bytes of data directly from the HDC1010 device. I²C drivers have also been added to the firmware to enable communication with the HDC1010 device.

After the packet with the HDC1010 data has been sent, the CC1310 device is programmed to pull a general-purpose input or output (GPIO) pin high; this GPIO is connected to the DONE pin of the TPL5111 device. When the TPL5111 device receives a high level on the DONE pin, the TPS61291 boost converter is signaled to enter bypass mode and the TPS22860 device is signaled to open the connection between the boost converter output and the rest of the circuit.

During periods where the CC1310 device is required to wait, which is primarily for the HDC1010 device to start up and to complete humidity and temperature conversions, a one-shot timer is used. This method of waiting enables the CPU of the CC1310 device to shut down, which lowers the average on-state current significantly.

5 Getting Started

5.1 Hardware Overview

图 9 显示了用于 Sub-1GHz Star Networks 湿度和温度传感器节点的硬件，该设计旨在实现 10+ 年纽扣电池寿命。印刷电路板 (PCB) 采用 1.5- x 3.0-英寸矩形封装，并配有 0.5-英寸尼龙 standoff 以确保使用时的便利性。

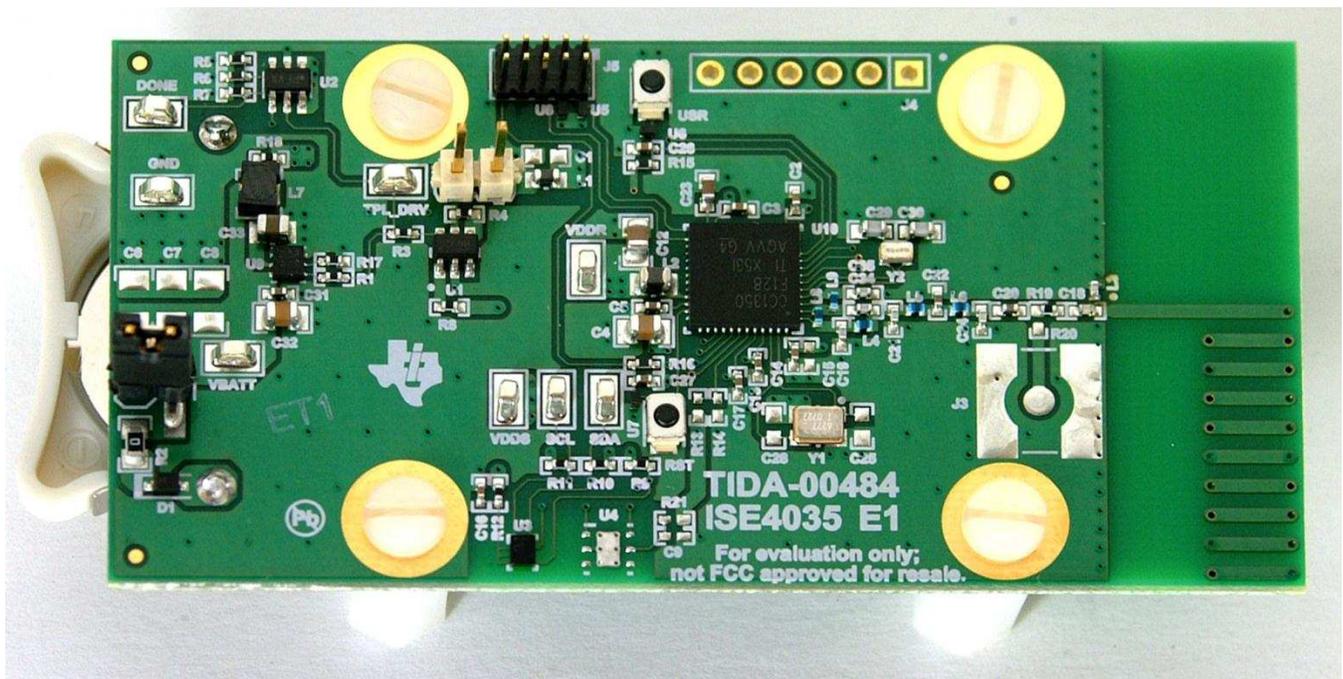


图 9. Humidity and Temperature Sensor Node for Sub-1GHz Star Networks Enabling 10+ Year Coin Cell Battery Life Reference Design Hardware

All of the integrated circuits (CC1310, TPL5111, TPS22860, and HDC1010), several test points and jumpers, as well as the ESD protection devices for the programming header are located on the top side of the PCB. The 2.4-GHz antenna is also located on the top side of the PCB.

The bottom side of the PCB contains the CR2032 coin cell battery holder.

There are four unused GPIOs that have been brought out from the CC1310 device to an unpopulated header to facilitate future prototyping and debugging.

5.2 Loading Firmware

The firmware used on this TI Design was developed using TI's [Code Composer Studio™](#) software (version 6.1.0).

The IAR Embedded Workbench for ARM () also supports the CC13xx line of SimpleLink™ products.

To program or debug the TI Design hardware, closing J2 with a jumper shunt is necessary; this bypasses the TPS22860 load switch. If J2 is left open, then the TPL5111 device continues to control the power of the CC1310 device, preventing proper programming and debugging.

Powering the board from 3.0 V is also necessary and is supplied at the test point labeled VBATT. Connecting the external power source at this location bypasses the Schottky diode.

注: For programming the TI Design hardware, it is necessary to shunt J2 and provide 3.0 V at the VBATT test point.

The TI Design hardware is programmed by connecting the 10-pin mini ribbon cable from J5 to the SmartRF06 Evaluation Board (10-pin ARM Cortex Debug Connector, P418). See [图 10](#) for a photo of the correct setup for connecting the TI Designs hardware to the SmartRF06 evaluation board.

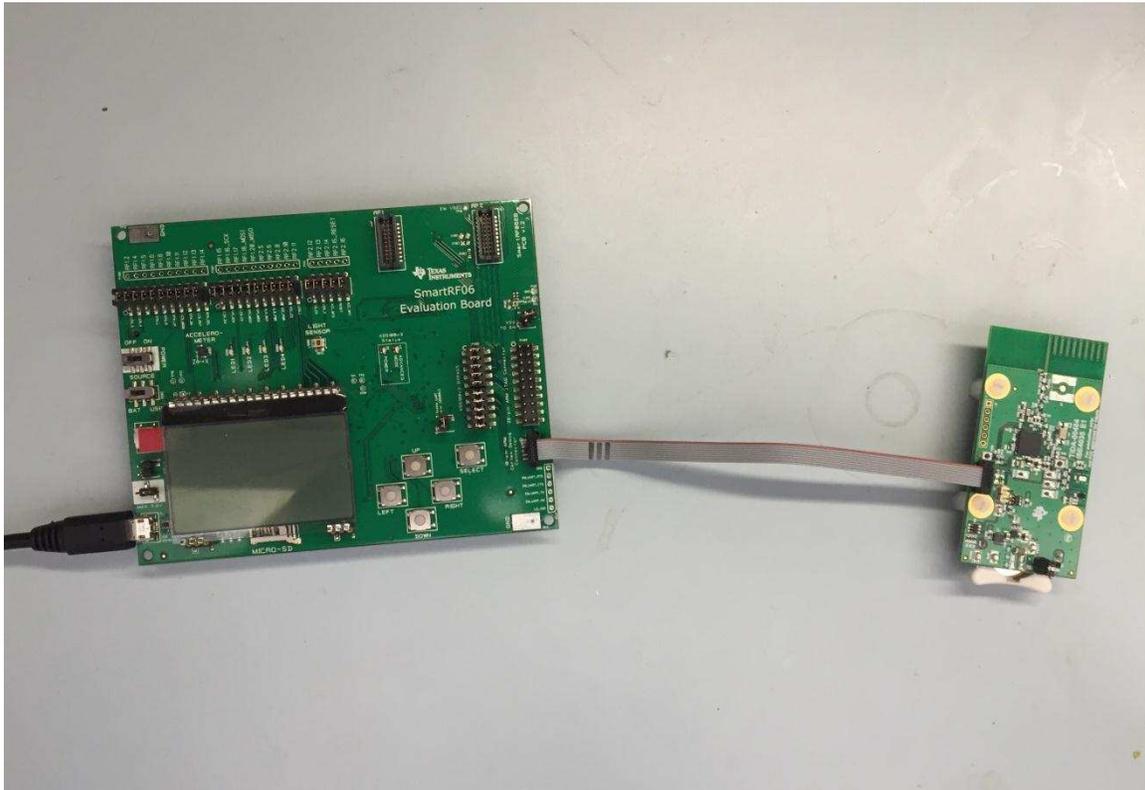


图 10. Connection of SmartRF06 Evaluation Board and TI Designs Hardware for Programming and Debugging

5.3 Receiving Data Packets Using CC1111 USB Dongle and SmartRF Protocol Packet Sniffer

As this reference guide previously describes, this TI Design is programmed to read the relative humidity and temperature data from the HDC1010 device and then broadcast that data as a non-connectable data packet. The data payload consists of two bytes of temperature data, followed by two bytes of relative humidity data.

To verify the proper operation of the radio transmission, the [CC1111 USB Dongle](#) CC1111 USB EVM Kit 868/915 MHz is used to “sniff” packets using the [SmartRF™ Protocol Packet Sniffer](#) software. After installing the packet sniffer software (v2.18.1 at the time of writing), the procedure is as follows to detect the data transmissions:

1. Plug the CC1111 USB dongle into an unused USB port on the computer with the packet sniffer software installed.
2. Open the packet sniffer software; choose *Generic* as the protocol and click the *Start* button.

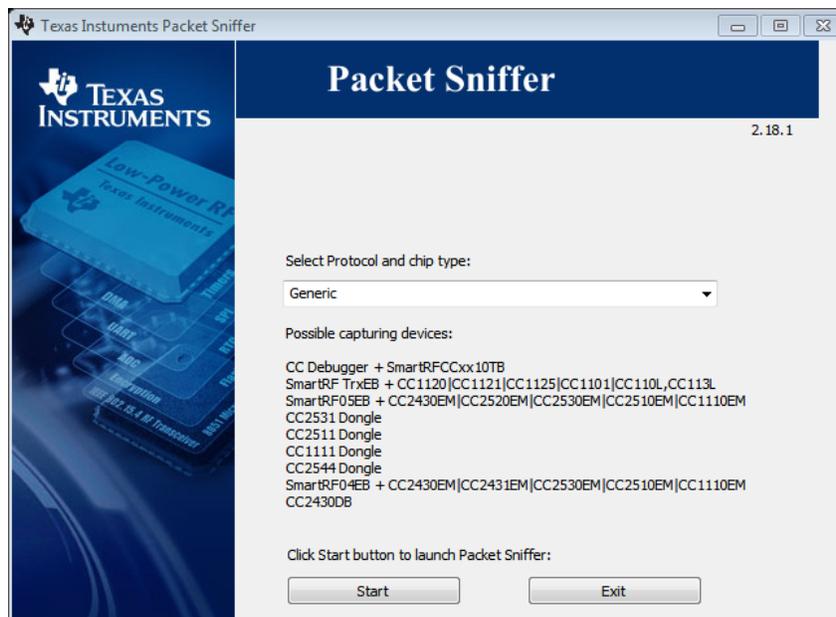


图 11. SmartRF™ Protocol Packet Sniffer Software Interface

3. CC1111 must be configured correctly to see the packets. Select the *Radio Configuration* tab. Under the *Register settings* sub tab, click on the “Browse...” button. Open the *TIDA-00484_CC1111.prs* file. Highlight and double-click on “TIDA-00484_CC1111” to apply the register settings (see [图 12](#)).

注: If long data acquisition periods are expected, please increase the *Cache Buffer* size in the packet sniffer software to prevent possible crashes. Take this action by opening the *Settings* menu and clicking “Cache buffer size...”.

4. Press the *Play* button on the top toolbar to initiate the packet capture process.
5. The packet sniffer software is likely to detect many other packets. To view only the valid data packets, to the user must apply a display filter. The following screen capture from [图 12](#) shows a sample display of what records without a filter applied. The highlighted row shows an undesired data packet.

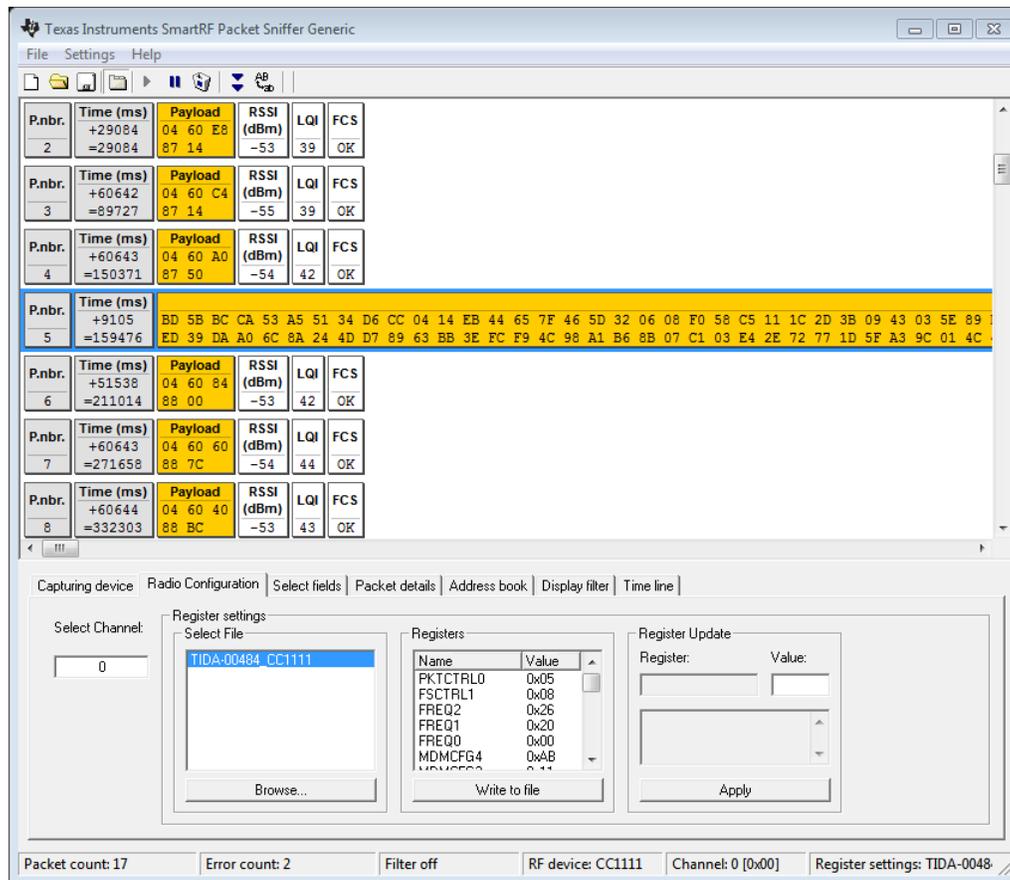


图 12. Sample Display—No Filter Applied

6. The appropriate filter checks for only valid packets. In the *Field Name* field, select “FCS” from the drop-down options. Click the button labeled *First*. Modify the filter condition to only show “OK” packets by typing “FCS=OK” in the *Filter condition* field, click the *Add* button, and then click the *Apply filter* button. The following screen capture in 图 13 shows an example filtered view.

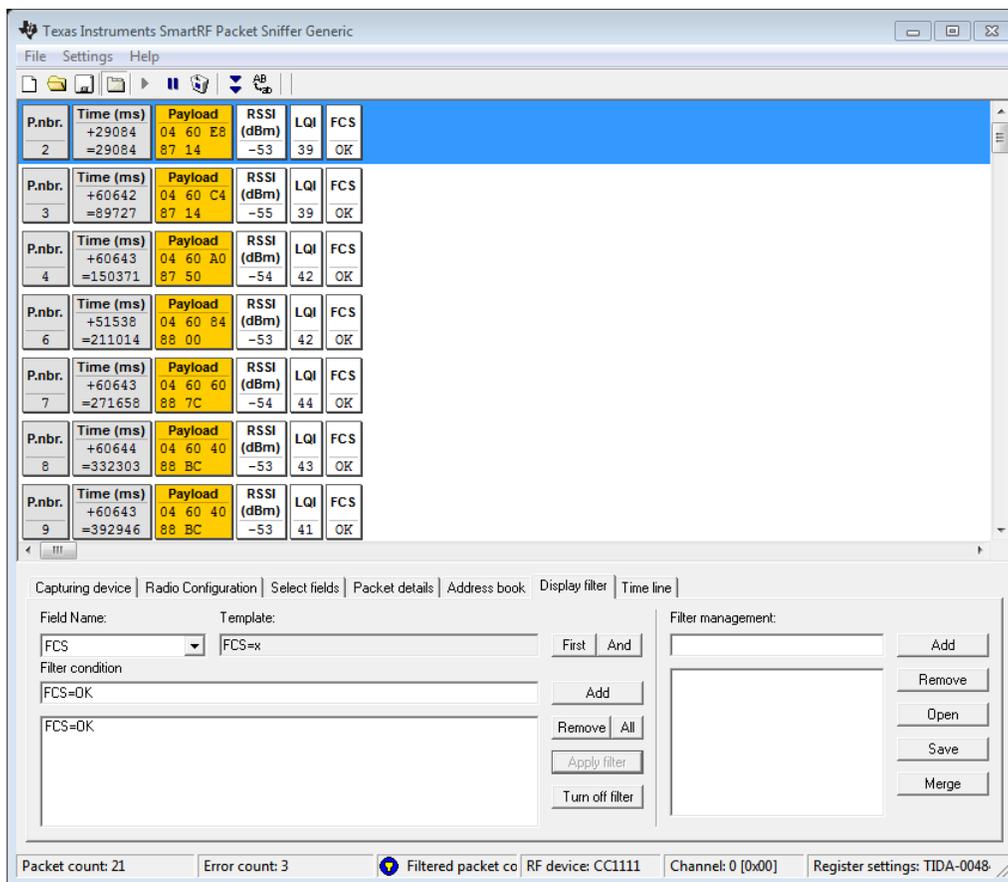


图 13. Sample Display—With Filter Applied

- To export the captured, filtered packets, click the "Save the current session" button on the toolbar (appears as a floppy disk), or pause the packet capture and click *File*→ *Save data...* from the file context menu; either of these choices prompts to save the displayed data as a packet sniffer data (.psd) file.
- HexEdit software (<http://www.hexedit.com/>) is used to convert the .psd file to readable hex values. A different hex editor may perform this function as well; however, the authors of this document have not verified any other options.
- Open the .psd file in the HexEdit software. Click on *Tools*→ *Options*. In the HexEdit *Options* window, click on *Document*→ *Display* and change the *Columns* value to "2066". Click *Edit*→ *Select All* and *Edit*→ *Copy As Hex Text*. Open a text editor program (for example, Notepad), paste the hex text, and save the text file. This text file can then be imported into Microsoft Excel® spreadsheet software for further analysis. For more information on the sniffer data packet format, click *Help*→ *User Manual* on the packet sniffer software.

6 Test Data

注: The test data in the following sections was measured with the system at room temperature, unless otherwise noted.

All of the measurements in this section were measured with calibrated lab equipment.

6.1 Overview

The Humidity and Temperature Sensor Node for Sub-1GHz Star Networks Enabling 10+ Year Coin Cell Battery Life TI Design has been characterized for functional usage including power consumption, relative humidity performance, temperature performance, and radio transmission range.

The following subsections show the results of testing and characterization. Any plots of the HDC1010 device's output data was produced using data packets captured using a CC1111 USB Dongle EVM kit and SmartRF Protocol Packet Sniffer software, as 5.3 节 describes in further detail, with data formatting and analysis performed using Microsoft Excel.

6.2 Power Consumption

Because the primary purpose of this TI Design is to showcase a power topology for battery-powered wireless sensor end-nodes, characterization of the system's power consumption is critical.

As 4.1 节 describes, there are two states that this TI Design system is in: on-state and off-state. Both the duration and the average current of each state are factors in estimating the total battery life of the TI Design system.

The on-state consists of the TPL5111 device's timer interval expiring, resulting in the TPS61291 boost converter regulating its output to 3.3 V and the TPS22860 load switch connecting the boost output voltage to the rest of the system. The CC1310 device receives power, communicates with the HDC1010 device using I²C, receives the current temperature and relative humidity information, transmits a non-connectable data packet with that data, and then signals the TPL5111 device that the system can be shut back down.

The off-state consists of completely disconnecting the rest of the system (CC1310 and HDC1010 devices) from the coin cell battery by means of the TPS22860 load switch. The sources of off-state current consumption from the coin cell battery are the recharging and leakage currents due to the bulk capacitor near the coin cell, the operating current of the TPL5111 nano-power system timer device, the quiescent current of the TPS61291 boost in bypass mode, and the leakage current due to the TPS22860 load switch.

6.2.1 On-State Power Characterization

The on-state duration and average current was characterized with the use of a Tektronix MDO3024 Mixed Domain oscilloscope and a Tektronix TCP0030A current probe. The oscilloscope was connected directly to a laptop through a USB cable and uses the corresponding software to directly export the recorded data points. 图 14 shows the current drawn from the coin cell battery, as measured through jumper J1.

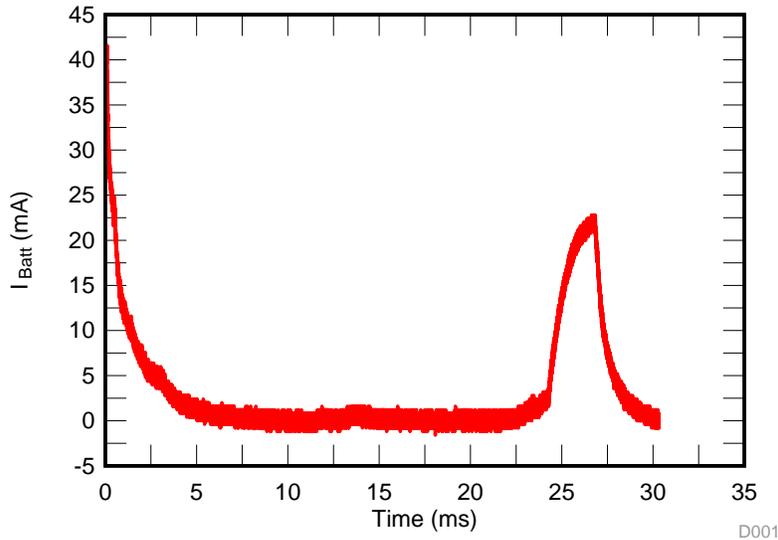


图 14. On-State Current Versus Time

At time $t = 0$ ms, the TPL5111 device activates and immediately the current jumps up to about 42 mA. The current draw then quickly settles to less than 1 mA before spiking again at time $t = 25$ ms, before decaying to less than 1 mA again.

The first current spike at turn on is due to the output capacitor being charged from VBATT up to 3.3 V after the TPS61291 boost converter transitions from bypass mode to normal switching operation. The second current spike is due to the CC1310 device transmitting a sub-1 GHz radio packet.

The on-state is considered complete at 30 ms when the current level drops below the accuracy of the current probe in use, and the V_SWITCH voltage net stops decreasing, which indicates that the CC1310 wireless MCU has fully shut down.

By exporting the data into Microsoft Excel for analysis, the design team was able to determine that the average current over the first 30 ms of system operation was 3.376 mA. This current is considered the average on-state current of the TI Design system.

6.2.2 Off-State Power Characterization

The off-state duration and average current was characterized with the use of a Keysight (formerly Agilent) 34401A digital multimeter (DMM) with 6½ digits of resolution. The DMM was connected directly to a laptop with the corresponding software to directly export the recorded data points. 图 15 shows the current drawn from the coin cell battery, as measured through jumper J1.

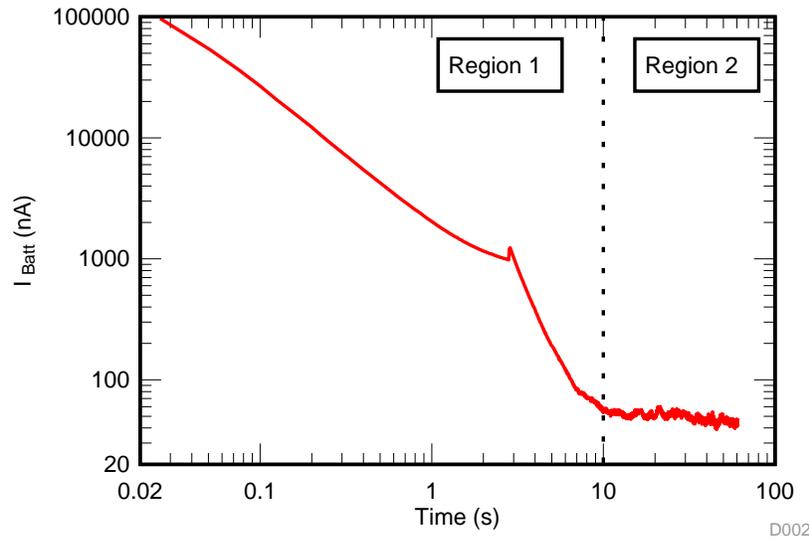


图 15. Off-State Current Versus Time

The data has been plotted logarithmically on both the x- and y-axes because the first portion of the plot, labelled “Region 1”, has a much higher current and shorter time duration than that of “Region 2”.

“Region 1” is actually the portion of the off-state where the bulk capacitor continuously recharges directly from the coin cell. The first data point occurs at approximately 25 ms after the system first powers up and then is essentially complete after ten seconds. The average current over Region 1 is 1.4325 μA .

The off-state current during Region 2 is dominated by the operating current of the TPL5111 device (35 nA typical), and the quiescent current of the TPS61291 boost converter in bypass mode (15 nA). The supply current in this TI Design system is nominally 3.0 V; in practice, the supply current can be somewhat higher (3.2 V to 3.3 V) depending on the age of the coin cell in use. As 6.2 节 previously mentions, the leakage current of the bulk capacitor (approximately 8.33 nA), the TPS61291 boost converter in bypass mode (15 nA), and the TPS22860 load switch (± 20 nA) also contribute to the off-state current during Region 2. Given the expected values of the sources of off-state current, the measured average value of 48.70 nA during Region 2 is quite reasonable.

The off-state current is equal to 269.75 nA, which is averaged over the entire duration of Regions 1 and 2 and lasts for a duration of 1 minute – 30 ms = 59.970 seconds.

6.2.3 Estimated Battery Life Calculations

As 4.1 节 shows, the equation used for estimating battery life of the TI Design system has five parameters:

- Capacity rating of the battery in milliamp-hours (mAh)
- Average off-state current consumption (nA)
- Off-state duration (s)
- Average on-state current consumption (mA)
- On-state duration (s)

As previously stated, the battery used in this TI Design is a CR2032 lithium-ion coin cell that has a capacity rating of 240 mAh. The battery life equation has a built-in de-rating factor of 85%, which attempts to model the effects of varying temperatures, as well as battery self-leakage.

When using the measured values for the remaining parameters, 公式 3 shows the following battery life calculation:

$$\text{Battery life} = \frac{240 \text{ mAh}}{\left(\frac{3.376 \text{ mA} \times 0.030 \text{ s} + 269.75 \text{ nA} \times 59.970 \text{ s} \times 10^{-6}}{(0.030 \text{ s} + 59.970 \text{ s})} \right)} \times \frac{1 \text{ year}}{8760 \text{ hours}} \times 85\% = 11.9 \text{ Years} \quad (3)$$

Because the estimated battery life for this TI Design system is above the specified shelf life of typical coin cell batteries, it is possible to increase the transmit power of the CC1310 device to increase range. Alternatively, more processing of the sensor data can be done on the sensor end-node to decrease the burden on the up-stream data processing units.

6.2.4 Duty-Cycled System Tradeoffs

This TI Design is based around the concept that by duty-cycling the system with a nano-power system timer, the off-state current can be lowered beyond that of what any inherent sleep mode of the remaining components can achieve. A comparison between a system using this duty-cycling concept and one that does not use this concept can be valuable, because there are various situations where either system topology could make sense.

With the assumption that the on-state current and duration remain fixed for both types of system topologies, comparing the two is possible. By varying the wakeup interval, certain scenarios exist where using the built-in standby mode of the CC1310 device makes more sense, rather than using the TPL5111 device. The assumption is that by using the built-in standby mode of the CC1310 device, the off-state current goes from 269.75 nA up to approximately 2 μ A. Also, a reference line is displayed with a level of ten years, a common shelf life of coin cell batteries.

However, as 图 16 shows, the system using the TPL5111 device to duty-cycle the system always has a better estimated battery life, particularly at longer system wakeup intervals. The only scenario where the use of a TPL5111 device to create a duty-cycled sensor end-node is not practical is if the wireless network is a sleeping mesh network. In the case of a sleeping mesh network, the CC1310 device must be in control of its own sleep state to maintain network communications. Furthermore, utilizing additional load switches to the system is a likely requirement to ensure that quiescent or standby currents of any other sensors or devices in the system are minimized during the off-state. Adding additional load switches can potentially increase the system cost and complexity.

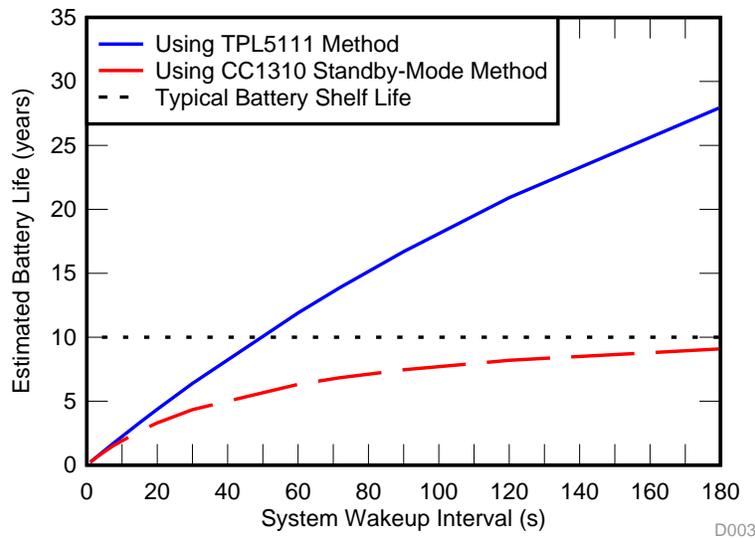


图 16. Estimated Battery Life Comparison: TPL5111 Nano-Power System Timer Versus CC1310 Standby Mode

If the end-equipment system has different requirements for the on-state current and duration, this calculation can vary significantly. Re-run these calculations to determine what sort of system topology makes the most sense to achieve the longest battery life possible.

6.3 Relative Humidity Characterization

This TI Design exemplifies the concept of a duty-cycled sensor end-node through the use of the HDC1000 device, which measures both relative humidity and temperature.

To better understand how the TI Design system responds to varying relative humidity levels, the hardware was placed in a Thunder Scientific® Model 2500 Benchtop Humidity Generator (<http://www.thunderscientific.com/>) with a new Energizer® brand CR2032 lithium-ion coin cell battery. The CC1111 USB Dongle EVM Kit was plugged into a USB extension cord and placed next to the TI Design hardware for optimal data packet reception performance. A Rotronic® HC2-S precision humidity and temperature probe (<http://www.rotronic.com>) and Rotronic Hygro Flex HF53 transmitter was used to provide reference relative humidity and temperature measurements. 图 17 shows the test setup.

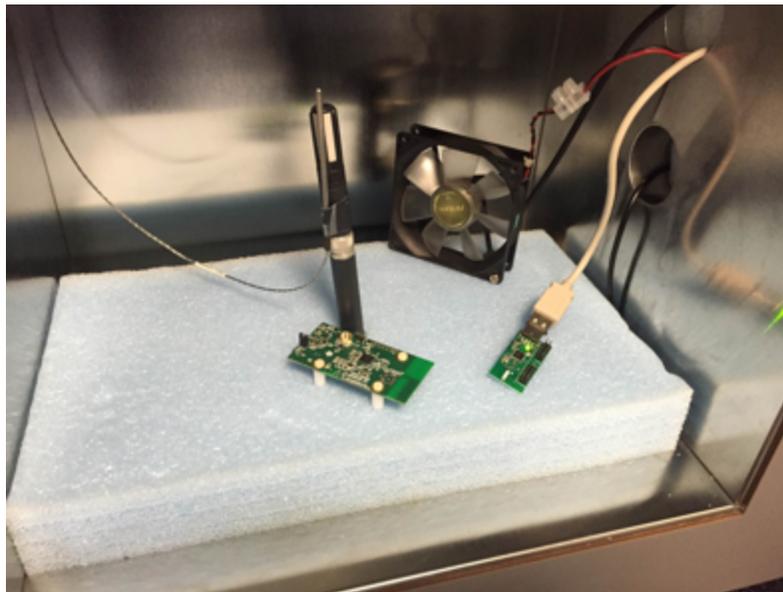


图 17. Relative Humidity Test Setup

The relative humidity was then programmed to run a pre-defined profile. This profile set the initial chamber humidity to 20% and soaked the TI Design hardware for an initial 40 minutes. The relative humidity was then ramped up to 30% at a controlled rate over 10 minutes and then soaked at that humidity level for 20 minutes. This process was repeated up to the maximum tested relative humidity of 70%, then decreased similarly to the minimum humidity level of 20%, and finally soaked for 40 minutes to end the test. The temperature during this profile was held to a set-point of 45°C.

The HDC1000 output data was recorded using the CC1111 USB dongle and packet sniffer software combination that 5.3 节 describes.

图 18 显示了测试期间从 HDC1000 设备测得的相对湿度，以及来自 Rotronic HC2-S 精密湿度和温度探头参考相对湿度的数据。这些结果表明，HDC1000 设备非常精确地跟踪了参考相对湿度。

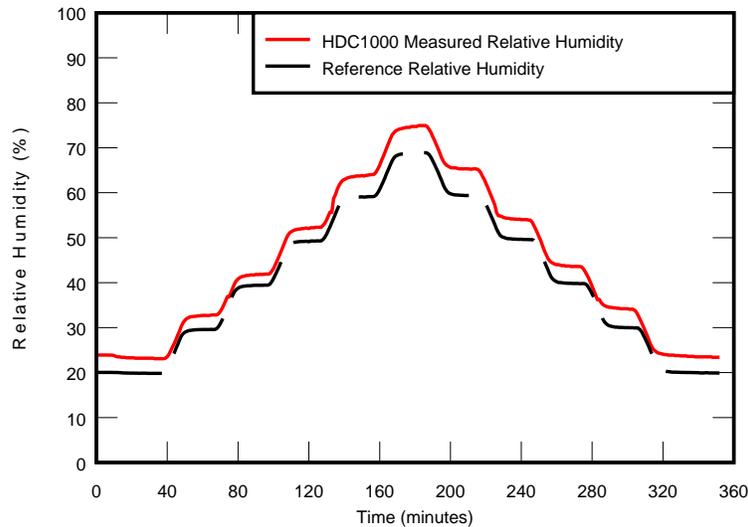


图 18. HDC1000 Measured Relative Humidity Data

注：The HDC1000 用于相对湿度测试。HDC1010 具有与 HDC1000 相同的功能和引脚，但不是完全等效。

使用 HDC1010 进行测试将在稍后日期进行。

6.4 Temperature Characterization

This TI Design exemplifies the concept of a duty-cycled sensor end-node through the use of the HDC1000 device, which measures both relative humidity and temperature.

To better understand how the TI Design system responds to varying temperatures, the hardware was placed in a TestEquity 1007H Temperature/Humidity Chamber (<http://www.testequity.com/products/1104/>) with a new Energizer CR2032 lithium-ion coin cell battery. Two test wires were routed outside the chamber to a Keysight (formerly Agilent) 34401A DMM with 6½ digits of resolution for monitoring of the V_BATT voltage net. The CC1111 USB Dongle CC2540 USB EVM Kit was plugged into a USB port near the TI Design hardware for optimal data packet reception performance. 图 19 shows the test setup.



图 19. Temperature Test Setup

The temperature was then programmed to run a pre-defined profile. This profile set the initial chamber temperature to 25°C and soaked the TI Design hardware for 10 minutes. The temperature then ramped up to 35°C at a controlled rate over five minutes and then soaked at that temperature for 10 minutes. This process was repeated up to the maximum temperature of 60°C and then decreased similarly to the minimum temperature of -30°C. Finally, the temperature was increased back to 25°C using the same controlled method. Relative humidity was allowed to vary during the temperature test to best emulate the response of a real-world environment.

The HDC1000 output data was recorded using the CC1111 USB dongle and packet sniffer software combination that 5.3 节 describes.

图 20 shows the environmental chamber set-point and the measured temperature from the HDC1000 device over the duration of the test. As is clearly visible, the HDC1000 device tracks the chamber temperature very closely.

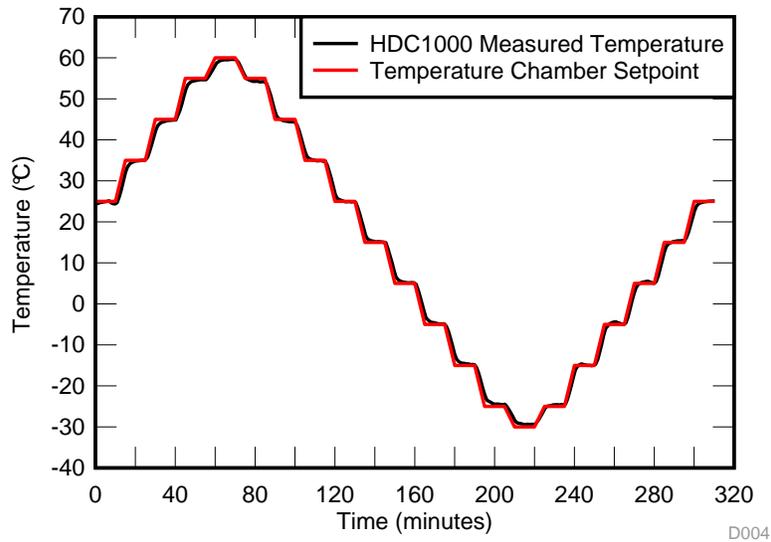


图 20. HDC1000 Measured Temperature Data and Environmental Chamber Set-Point

Due to the nature of CR2032 lithium-ion coin cell battery chemistry, the output voltage can drop slightly (tens to hundreds of millivolts) at lower temperatures. However, if all components in the system work throughout the lifetime operating voltage of the coin cell, this output voltage drop should not be an issue for proper operation.

注: The HDC1000 was used for the Relative Humidity testing. The HDC1010 has the same functionality and pinout as the HDC1000 but is *not* an exact equivalent.

Testing using the HDC1010 will be done at a later date.

7 Design Files

7.1 Schematics

To download the schematics, see the design files at [TIDA-00484 Schematics](#).

7.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-00484 BOM](#).

7.3 Layer Plots

To download the layer plots, see the design files at [TIDA-00484 Layer Plots](#).

7.4 Altium Project

To download the Altium project files, see the design files at [TIDA-00484 Altium](#).

7.5 Layout Guidelines

To ensure high performance, the Humidity and Temperature Sensor Node for Sub-1GHz Star Networks Enabling 10+ Year Coin Cell Battery Life TI Design was laid out using a four-layer PCB. The second layer is a solid GND pour, and the third layer is used for power rail routing with GND fills in unused areas. The top and bottom layers are used for general signal routing and also have GND fills in unused areas. For all of the TI products used in this TI Design, ensure that care is taken to adhere to the layout guidelines detailed in the respective datasheets.

7.6 Gerber Files

To download the Gerber files, see the design files at [TIDA-00484 Gerber](#).

7.7 Assembly Drawings

To download the assembly drawing files, see the design files at [TIDA-00484 Assembly Drawing](#).

7.8 Software Files

To download the software files, see the design files at [TIDA-00484](#).

8 References

1. Texas Instruments, *HDC1010 Low Power, High Accuracy Digital Humidity Sensor with Temperature Sensor*, HDC1010 Datasheet, ([SNAS685](#))
2. Texas Instruments, *HDC1080 Low Power, High Accuracy Digital Humidity Sensor with Temperature Sensor*, HDC1080 Datasheet ([SNAS672](#))
3. Texas Instruments, *CC1310 Simplelink™ Ultra-Low Power Sub-1GHz Wireless MCU*, CC1310 Datasheet ([SWRS184](#))
4. Texas Instruments, *TPL5111 Nano-power System Timer for Power Gating*, TPL5111 Datasheet ([SNAS659](#))
5. Texas Instruments, *TPS61291 Low IQ Boost Converter with Bypass Operation*, TPS61291 Datasheet ([SLVSBX9](#))
6. Texas Instruments, *TPS22860 Ultra-Low Leakage Load Switch*, TPS22860 Datasheet ([SLVSD04](#))
7. Texas Instruments, *TPD1E10B06 Single-Channel ESD Protection Diode in 0402 Package*, TPD1E10B06 Datasheet ([SLLSEB1](#))
8. Texas Instruments, *Miniature Helical PCB Antenna for 868 MHz or 915/920 MHz*, DN038 Application

Report (SWRA416)

8.1 商标

IAR Embedded Workbench is a registered trademark of IAR Systems AB. SmartRF, Code Composer Studio are trademarks of Texas Instruments. ARM, Cortex are registered trademarks of ARM Limited (or its subsidiaries). All other trademarks are the property of their respective owners.

9 About the Author

EVAN D. CORNELL is a systems architect at Texas Instruments where he is responsible for developing reference design solutions for the industrial segment. Evan brings to this role experience in system-level analog, mixed-signal, and power management design. Evan earned his Master of Electrical and Computer Engineering (M.Eng.) and Bachelor of Science (BS) in electrical engineering from the Rose-Hulman Institute of Technology in Terre Haute, IN. Evan is a member of the Institute of Electrical and Electronics Engineers (IEEE).

CHRISTINA S. LAM is a systems architect at Texas Instruments where she is responsible for developing firmware for reference design solutions in the industrial segment. Christina has broad experience with applications processors, microcontrollers, and digital-signal processors with specialties in embedded firmware. Christina earned her Bachelor of Science (BS) in electrical and computer engineering from the University of Texas at Austin.

修订版本 E 历史记录

注：之前版本的页码可能与当前版本有所不同。

Changes from D Revision (May 2016) to E Revision	Page
• 已删除 schematic images.....	35

修订版本 D 历史记录

Changes from C Revision (December 2015) to D Revision	Page
• 已更改 从 HDC1000 更改为 HDC1010.....	1
• 已更改 从 HDC1050 更改为 HDC1080.....	1
• 已更改 相对湿度精度从 $\pm 3\%$ 更改为 $\pm 2\%$	1
• 已更改 relative humidity accuracy from $\pm 3\%$ to $\pm 2\%$	3
• 已更改 all references of HDC1000 to HDC1010.....	3
• 已更改 all references of HDC1050 to HDC1080.....	4
• 已更改 all references of HDC1000 to HDC1010.....	8
• 已更改 from HDC1050 to HDC1080.....	8
• 已更改 all references of HDC1000 to HDC1010.....	9
• 已更改 all references of HDC1050 to HDC1080.....	10
• 已更改 all references of HDC1000 to HDC1010.....	19
• 已更改 all references of HDC1000 to HDC1010.....	20
• 已更改 from HDC1000 to HDC1010.....	21
• 已更改 from HDC1000 to HDC1010.....	23
• 已更改 all references of HDC1000 to HDC1010.....	26
• 已添加 note.....	32
• 已添加 note.....	34
• 已更改 the schematics.....	35
• 已更改 the schematics.....	35
• 已更改 from HDC1000 datasheet to HDC1010 datasheet.....	35
• 已更改 from HDC1050 datasheet to HDC1080 datasheet.....	35

修订版本 C 历史记录

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• 已更改 公式 2 from $T_{OFF} = 1 \text{ minute} - T_{OFF}$	19

修订版本 B 历史记录

Changes from A Revision (July 2015) to B Revision	Page
• 已更改 the schematics.....	35
• 已更改 the schematics.....	35

修订版本 A 历史记录

Changes from Original (June 2015) to A Revision	Page
• 已更改 text	14
• 已添加 note between Steps 3 and 4.....	23
• 已更改 to an updated figure.	31
• 已更改 to an updated figure.	32

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