TI Designs：TIDA-010012
工业无线状态监控参考设计

![Texas Instruments]

说明

此参考设计可用于快速建立无线网络，从而将用于状态监控的各种传感器直接连接到云端。为了进行状态监控，需要定期或永久记录机器状态，这是预测性维护所必需的信息。此设计中包括 RS-232、RS-485、IO-Link 或电阻式温度检测器 (RTD) 等输入器件，用于监控不同的传感器和机器。

资源

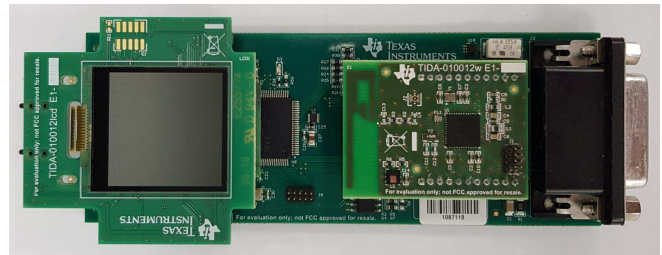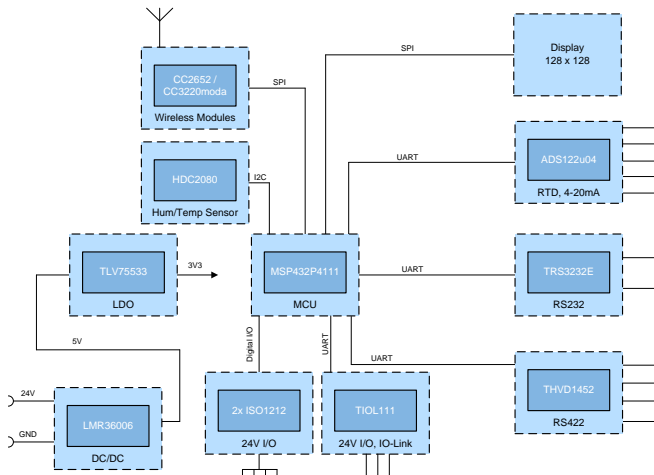|		
TIDA-010012		设计文件夹
CC2652R	ISO1212	产品文件夹
MSP432P4111	LMR36006	产品文件夹
CC3220MODA	TLV755P	产品文件夹
ADS122U04	HDC2080	产品文件夹
TRS3232E	LMZM23600	产品文件夹
THVD1452	TIOL111	产品文件夹

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特性

- 通过一个器件实现双重多协议支持
- Wi-Fi® Internet-on-a chip™
- 数字传感器接口带有集成保护功能，便于评估
- 适用于 CC2652、MSP432 和 CC3220 的 TI SimpleLink™SDK 可简化开发

应用

- 工厂自动化和过程控制
- 工业 4.0
- 状态监控传感器
- 状态监控模块
- 状态监控网关

⚠ 该 TI 参考设计末尾的重要声明表述了授权使用、知识产权问题和其他重要的免责声明和信息。

1 System Description

Condition monitoring is used to monitor the condition of machines and systems in a wide variety of application areas. Compared to the frequently used preventive maintenance, Condition Monitoring is a more efficient and safe alternative. Preventive maintenance means that parts of the engine, such as bearings or shafts, are replaced too early due to fixed maintenance intervals on machines. As a result, terms are shortened unnecessarily, capital is given away. Likewise, this method is not able to detect and accurately locate defective components before failure. Defective components can cause considerable damage and downtime during machine operation. With condition monitoring or condition-based maintenance, both can be realized. Component faults are detected early, and residual storage lives are maximized. This way costly downtime can be avoided, as well as cost savings through full utilization of the runtimes of critical machine components. Thanks to intelligent sensor technology, condition-relevant machine parameters such as machine vibrations, vibrations or temperatures are recorded directly at the system during condition monitoring. Using mathematical analysis methods and corresponding software, these parameters can be permanently analyzed. The general machine status as well as individual components can be monitored almost in real time online. The sensors used for the data collection are often housed in hard-to-access locations, and the sensors may not be accessible through ordinary wired connections. As the sensors usually must communicate with upstream data-gathering nodes, wireless communication is required. With the onboard, multistandard 2.4-GHz wireless CC2652 MCU and the CC3220 Wi-Fi MCU, this reference design can support different wireless protocols like Thread, Zigbee®, Bluetooth® low energy (BLE), Wi-Fi® or proprietary solutions.

## 1.1 Key System Specifications

表 1. Key System Specifications

PARAMETER	SPECIFICATIONS AND FEATURES
POWER SUPPLY	
Operating supply voltage	Typically 24 V
MCUs	
CC3220	ARM® Cortex®-M4 core at 80 MHz, optional 1-MB Flash, 256-KB RAM
MSP432P4111	ARM Cortex-M4F core at 48-MHz, 2-MB Flash, 256-KB RAM, 14-bit ADC
CC2652	ARM Cortex-M4F core at 48-MHz, 352-KB Flash, 80-KB RAM
INTERFACES	
Wireless interfaces	Wi-Fi, Bluetooth Low Energy (BLE), 6LoWPAN, IEEE 802.15.4
RS-232	Up to 250 kbps
RS-485, RS-422	Low EMI 500 kbps and 50 Mbps Data Rates
IO-Link	COM1, COM2 and COM3 Data Rate Support
Digital Input	24-V to 60-V Digital Inputs
TEMPERATURE MEASUREMENT	
Sensor type	PT100 (three-wire mode)
Temperature range	–200ºC to 850ºC
Current excitation	Programmable (10, 50, 100, 250, 500, 1000, 1500 µA)
Reference resistor	3.24 kΩ, Tol = 0.1%, TC = 10 ppm/°C
Resolution	24-bit ADC

2 System Overview

2.1 Block Diagram

图 **1. TIDA-010012 Block Diagram**
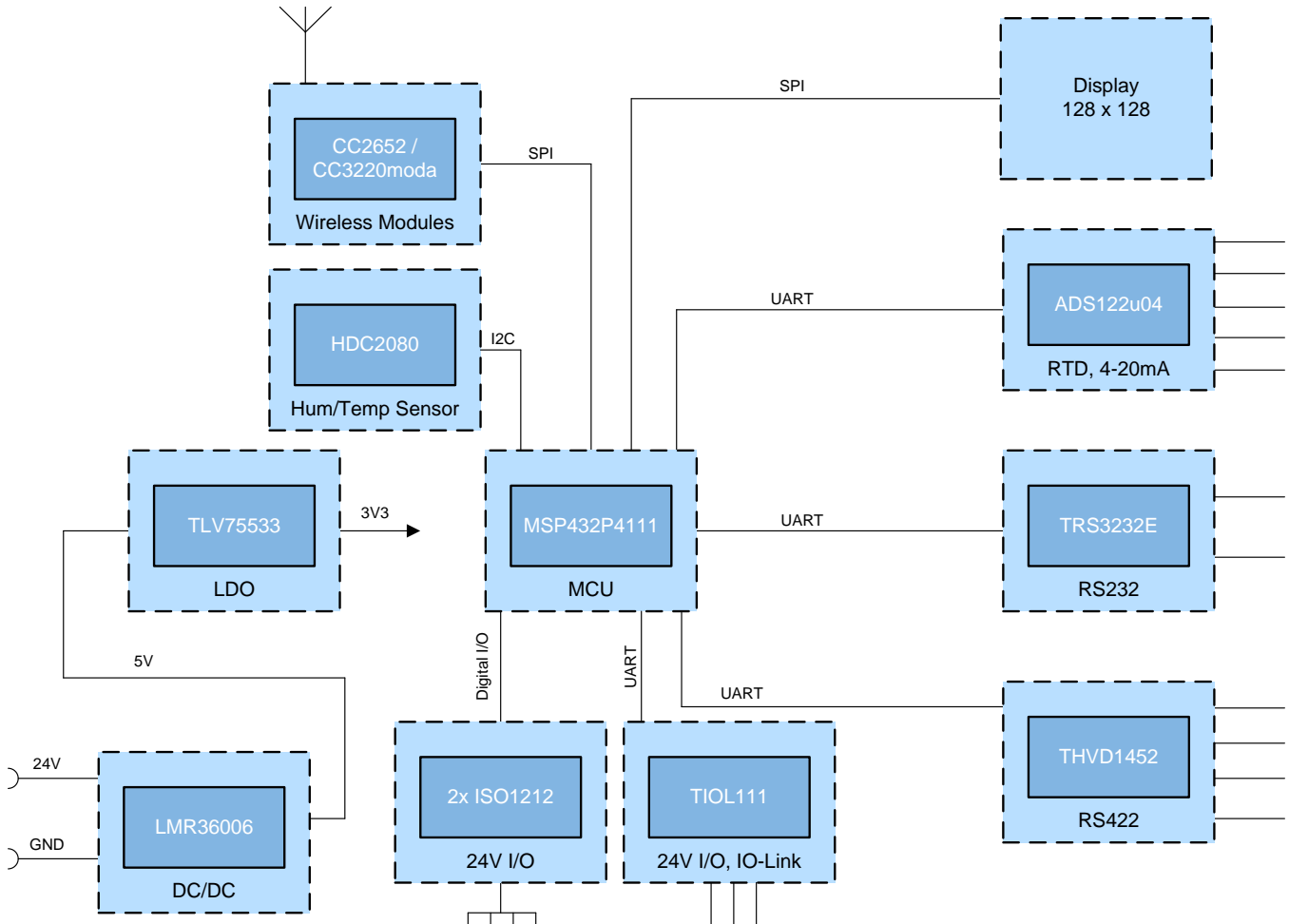
图 2. TIDA-010012 Wi-Fi and Display Module Block Diagram
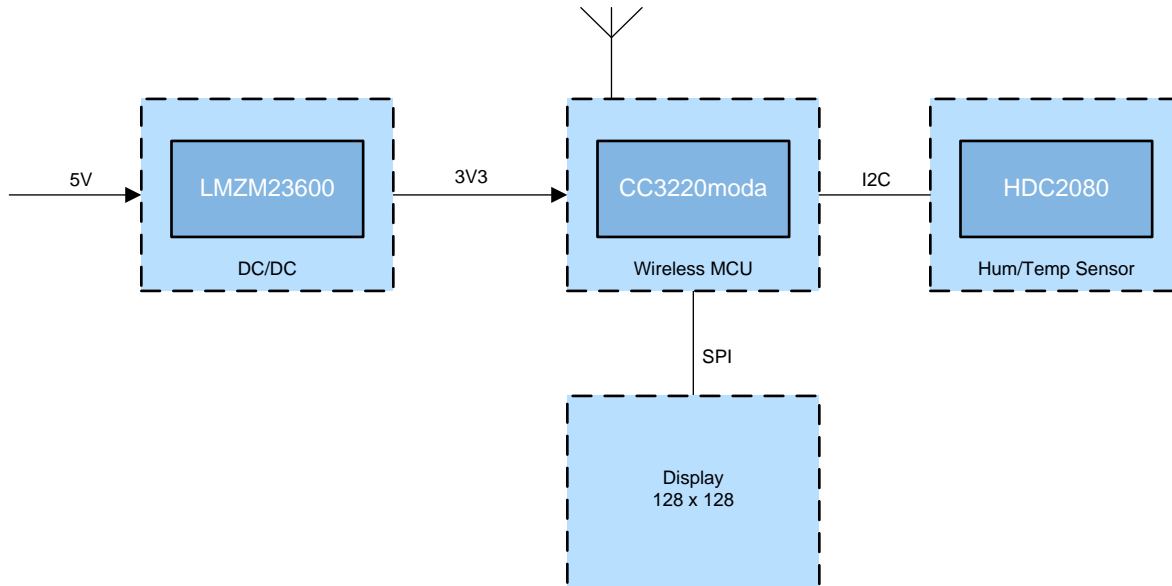
图 3. TIDA-010012 CC2652 Module Block Diagram
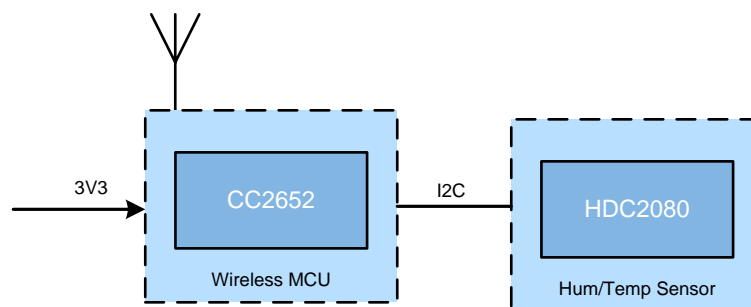
2.2 *Highlighted Products*

This reference design features the following devices:

- CC3220MODA: SimpleLink™ Wi-Fi CERTIFIED™ wireless module solutions with antenna

- CC2652R: SimpleLink™ multiprotocol 2.4-GHz wireless MCU

- MSP432P4111: SimpleLink™ ultra-low-power 32-bit ARM Cortex-M4F MCU with precision ADC, 2 MB Flash, and 256 KB RAM

- ADS122U04: 24-bit, 2 kSPS, 4-ch, low-power delta-sigma ADC with PGA, Vref, 2 × IDACs, and UART Interface

- THVD1452: 3.3-V to 5-V RS-485 Transceivers With ±16-kV IEC ESD Protection

- TRS3232E: 3-V to 5.5-V Multichannel RS-232 Line Driver/Receiver With ±15-kV ESD Protection

- ISO1212: Isolated 24-V to 60-V Digital Input Receivers for Digital Input Modules

- HDC2080: Low Power Humidity and Temperature Digital Sensor

- LMR36006: 4.2-V to 60-V, 0.6-A Synchronous Step-Down Converter in HotRod™ Package

- TLV755P: 500-mA low-Iq small-size low-dropout (LDO) regulator

- LMZM23600: 36-V, 0.5-A Step-Down DC/DC Power Module in 3.8-mm × 3-mm Package

- TVS3300: 33-V precision surge protection clamp

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

2.2.1 CC3220MODA

Start your design with the fully programmable FCC, IC, CE, MIC, and SRRC certified wireless microcontroller (MCU) module with built-in Wi-Fi connectivity. Created for the IoT, the SimpleLink CC3220MODx and CC3220MODAx module family from TI is a wireless module that integrates two physically separated on-chip MCUs.

- An application processor—ARM Cortex-M4 MCU with a user-dedicated 256KB of RAM, and an optional 1MB of Serial Flash.
- A network processor MCU to run all Wi-Fi® and internet logical layers. This ROM-based subsystem includes an 802.11b/g/n radio, baseband, and MAC with a powerful crypto engine for fast, secure internet connections with 256-bit encryption.

The CC3220MODx and CC3220MODAx wireless MCU family is a part of the second generation of the Internet-on-a chip™ family of solutions from TI. This generation introduces new features and capabilities that further simplify the connectivity of things to the internet. The new capabilities include:

- IPv6
- Enhanced Wi-Fi provisioning
- Optimized low-power management
- Enhanced file-system security
- Wi-Fi AP connection with up to four stations
- More concurrently opened BSD sockets—up to 16 BSD sockets (6 are secure HTTPS support)
- HTTPS support
- RESTful API support
- Asymmetric keys crypto library

The CC3220MODx and CC3220MODAx wireless MCU family supports the following modes: station, AP, and Wi-Fi Direct®. The CC3220MODx and CC3220MODAx modules also supports WPA2™ personal and enterprise security. This subsystem includes embedded TCP/IP and TLS/SSL stacks, HTTP server, and multiple internet protocols. The module supports a variety of Wi-Fi provisioning methods, including HTTP based on AP mode, SmartConfig™ technology, and WPS2.0.

The power-management subsystem includes integrated DC/DC converters that support a wide range of supply voltages. This subsystem enables low-power consumption modes for extended battery life, such as low-power deep sleep, hibernate with RTC (consuming only 5 μA), and shutdown mode (consuming only 1 μA).

The module includes a wide variety of peripherals, including a fast parallel camera interface, I2S, SD, UART, SPI, I2C, and a 4-channel ADC.
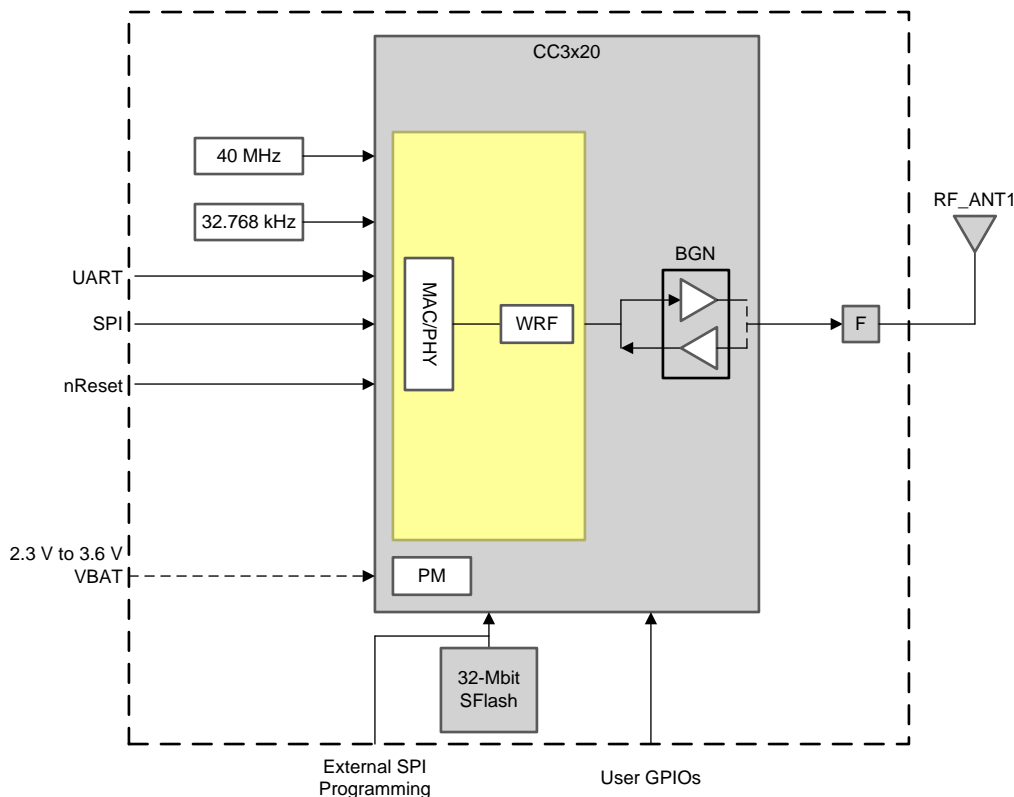
The SimpleLink CC3220MODx and CC3220MODAx module family come in four different module variants: CC3220MODS, CC3220MODSF, CC3220MODA, and CC3220MODASF

- The CC3220MODS and CC3220MODAS modules include 256KB on application-dedicated embedded RAM for code and data. In addition, the CC3220MODAS includes an integral antenna.
- The CC3220MODSF and CC3220MODASF modules include application-dedicated 1MB of Serial

Flash and 256KB of RAM for code and data. In addition, the CC3220MODASF includes an integral antenna.

The four modules integrate the 40-MHz crystal, 32.768-kHz RTC clock, 32-Mb SPI serial Flash, RF filter, and passive components. The modules also have additional security features, such as encrypted and authenticated file systems, user IP encryption and authentication, secured boot (authentication and integrity validation of the application image at Flash boot time), and more.

图 4. CC3220MODAx Functional Block Diagram

Features

- CC3220MODx is a Family of Wireless MCU Modules Consisting of SimpleLink Wi-Fi Single Chip Wireless MCUs—the CC3220MODS and CC3220MODAS Modules Consist of the CC3220SM2ARGK Wireless MCU, while the CC3220MODSF and CC3220MODASF Modules Consist of the CC3220SF12ARGK Wireless MCU. Fully Integrated, Industrial Temperature-Grade, Green Modules Include All Required Clocks, SPI Flash, and Passives

- CC3220MODAx Modules Include an Integral Antenna for Easy Integration Into the Host System

- CC3220MODx and CC3220MODAx SimpleLink Wi-Fi Wireless MCU System-on-Chip (SoC) Contains a Single Chip With Two Separate Execution Environments:
    – User Application Dedicated ARM Cortex-M4 MCU
    – Network Processor MCU to Run All Wi-Fi and Internet Logical Layers

- FCC, IC, CE, MIC, and SRRC certified

- Wi-Fi Alliance Members Can Request Certificate Transfer of Wi-Fi CERTIFIED Modules

- 1.27-mm Pitch QFM Package for Easy Assembly and Low-Cost PCB Design

- Applications MCU Subsystem

- – ARM Cortex-M4 Core at 80 MHz
- – Embedded Memory
  - CC3220MODS and CC3220MODAx Variants Include 256KB of RAM
  - CC3220MODSF and CC3220MODASF are Flash-Based MCUs With An Integrated 1MB of Flash and 256KB of RAM
  - Peripheral Drivers in ROM
- – McASP Supports Two I2S Channels
- – SD
- – SPI
- – I2C
- – UART
- – 8-Bit Synchronous Image Interface
- – Four General-Purpose Timers (GPTs) With 16-Bit PWM Mode
- – One Watchdog Timer Module
- – 4-Channel, 12-Bit Analog-to-Digital Converters (ADCs)
- – Debug Interfaces: JTAG, cJTAG, and SWD
- Wi-Fi Network Processor Subsystem
  - – Wi-Fi Internet-on-a chip Dedicated ARM MCU Completely Offloads Wi-Fi and Internet Protocols from the Application MCU
  - – Wi-Fi Modes
    - 802.11b/g/n Station
    - 802.11b/g/n Access Point Supports up to Four Stations
    - Wi-Fi Direct® Client and Group Owner
    - WPA2 Personal and Enterprise Security: WEP, WPA™, WPA2 PSK, and WPA2 Enterprise (802.1x)
    - IPv4 and IPv6 TCP and IP Stack
    - Industry-Standard BSD Socket Application Programming Interfaces (APIs)
    - 16 Simultaneous TCP or UDP Sockets
    - 6 Simultaneous TLS and SSL Sockets
    - IP Addressing: StaticIP, LLA, DHCPv4, DHCPv6 With Duplicate Address Detection (DAD)
    - SimpleLink Technology Connection Manager for Autonomous and Fast Wi-Fi Connections
    - Flexible Wi-Fi Provisioning With SmartConfig Technology, AP Mode, and WPS2 Options
    - RESTful API Support Using Internal HTTP Server
    - Embedded Network Applications Running on Dedicated Network Processor
    - Wide Set of Security Features
      - Hardware Features:
        - Separate Execution Environments
        - Device Identity

- Hardware Crypto Engine for Advanced Fast Security, Including: AES, DES, 3DES, SHA2, MD5, CRC, and Checksum
  - Initial Secure Programming
    - Debug Security
    - JTAG and Debug Ports are Locked
  - Personal and Enterprise Wi-Fi Security
  - Secure Sockets (SSLv3, TLS1.0, TLS1.1, TLS1.2)
- Networking Security
  - HTTPS Server
  - Trusted Root-Certificate Catalog
  - TI Root-of-Trust Public Key
- SW IP Protection
  - Secure Key Storage
  - File System Security
  - Software Tamper Detection
  - Cloning Protection
  - Secure Boot: Validate Integrity and Authenticity of Runtime Binary During Boot
- Embedded Network Applications Running on Dedicated Network Processor
  - HTTP and HTTPS Web Server With Dynamic User Callbacks
  - mDNS, DNS-SD, and DHCP Servers
  - Ping
- Recovery Mechanism: Can Recover to Factory Defaults or to Complete Factory Image
- Wi-Fi TX Power
  - 17.0 dBm at 1 DSSS
  - 13.5 dBm at 54 OFDM
- Wi-Fi RX Sensitivity
  - −95.0 dBm at 1 DSSS
  - −73.5 dBm at 54 OFDM
- Application Throughput
  - UDP: 16 Mbps
  - TCP: 13 Mbps
- Power-Management Subsystem
  - Integrated DC/DC Converter With a Wide-Supply Voltage
  - VBAT: 2.3 to 3.6 V
  - Advanced Low-Power Modes:
    - Shutdown: 1 µA
    - Hibernate: 5 µA
    - Low-Power Deep Sleep (LPDS): 135 µA (Measured on CC3220MODS and CC3220MODSF

With 256KB RAM Retention)

- • RX Traffic (MCU Active): 59 mA (Measured on CC3220MODS; CC3220MODSF and CC3220MODASF Consume an Additional 15 mA) at 54 OFDM
- • TX Traffic (MCU Active): 223 mA (Measured on CC3220MODS; CC3220MODSF and CC3220MODASF Consume an Additional 15 mA) at 54 OFDM, Maximum Power
- • Idle Connected (MCU in LPDS): 710 µA (Measured on CC3220MODS and CC3220MODSF With 256KB RAM Retention) at DTIM = 1

- • Additional Integrated Components
  - – 40.0-MHz Crystal
  - – 32.768-kHz Crystal (RTC)
  - – 32-Mbit SPI Serial Flash o RF Filter and Passive Components
- • Footprint Compatible QFM Package
  - – CC3220MODx: 1.27-mm Pitch, 63-Pin, 20.5-mm × 17.5-mm
  - – CC3220MODAx: 1.27-mm Pitch, 63-Pin, 20.5-mm × 25.0-mm
- • Operating Temperature o Ambient Temperature Range: –40°C to +85°C
- • Module Supports SimpleLink Developer's Ecosystem

2.2.2 CC2652R

The CC2652R device is a multiprotocol wireless 2.4-GHz MCU targeting Thread, Zigbee®, Bluetooth® 5 low energy, IEEE 802.15.4g, IPv6-enabled smart objects (6LoWPAN), Wi-SUN®, and proprietary systems.

The CC2652R device is a member of the CC26xx and CC13xx family of cost-effective, ultra-low power, 2.4-GHz and Sub-1 GHz RF devices. Very low active RF and microcontroller (MCU) current, in addition to sub-µA sleep current with up to 80KB of RAM retention, provide excellent battery lifetime and allow operation on small coin-cell batteries and in energy-harvesting applications.

The CC2652R device combines a flexible, very low-power RF transceiver with a powerful 48-MHz ARM Cortex-M4F CPU in a platform supporting multiple physical layers and RF standards. A dedicated Radio Controller (ARM Cortex-M0) handles low-level RF protocol commands that are stored in ROM or RAM, thus ensuring ultra-low power and great flexibility. The low power consumption of the CC2652R device does not come at the expense of RF performance; the CC2652R device has excellent sensitivity and robustness (selectivity and blocking) performance.

The CC2652R device is a highly integrated, true single-chip solution incorporating a complete RF system and an on-chip DC/DC converter.

Sensors can be handled in a very low-power manner by a programmable, autonomous ultra-low power Sensor Controller CPU with 4KB of SRAM for program and data. The Sensor Controller, with its fast wake-up and ultra-low-power 2-MHz mode is designed for sampling, buffering, and processing both analog and digital sensor data; thus the MCU system can maximize sleep time and reduce active power.

The CC2652R device is part of the SimpleLink microcontroller (MCU) platform, which consists of Wi-Fi®, Bluetooth® low energy, Thread, Zigbee, Sub-1 GHz MCUs, and host MCUs, which all share a common, easy-to-use development environment with a single core software development kit (SDK) and rich tool set. A one-time integration of the SimpleLink platform enables you to add any combination of the portfolio's devices into your design, allowing 100 percent code reuse when your design requirements change. For more information, visit www.ti.com/simplelink.

图 5. CC2652R Functional Block Diagram
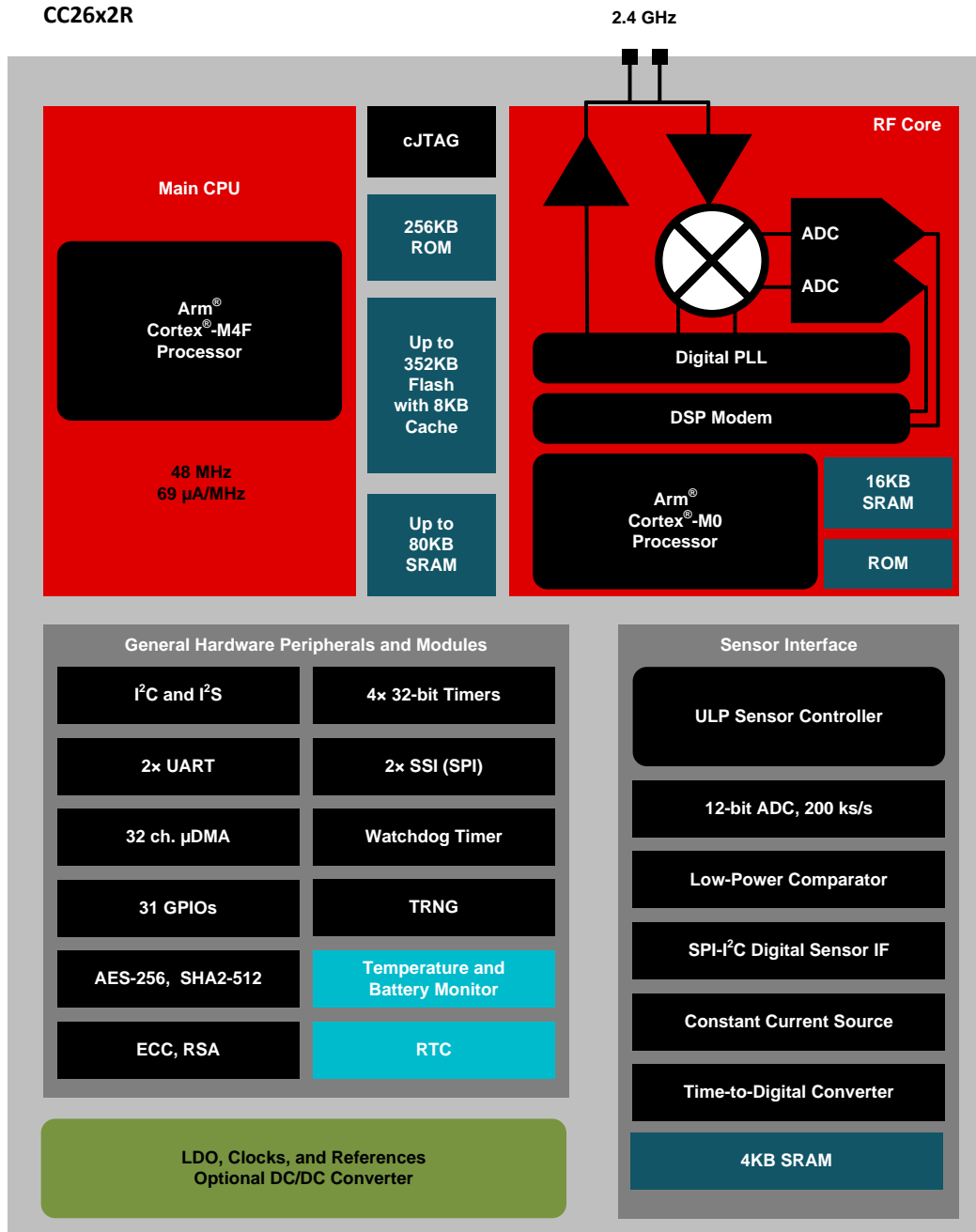
Features

- Microcontroller
  - Powerful ARM Cortex-M4F Processor
  - EEMBC CoreMark® Score: 148
  - Clock Speed Up to 48 MHz
  - 352KB of In-System Programmable Flash
  - 256KB of ROM for Protocols and Firmware
  - 8KB of Cache SRAM (Available as General-Purpose RAM)

- – 80KB of Ultra-Low Leakage SRAM

- – 2-Pin cJTAG and JTAG Debugging

- – Supports Over-the-Air Upgrade (OTA)

• Ultra-Low Power Sensor Controller With 4KB of SRAM

- – Sample, Store, and Process Sensor Data

- – Operation Independent From System CPU

- – Fast Wake-Up for Low-Power Operation

• TI-RTOS, Drivers, Bootloader, Bluetooth® 5 low energy Controller, and IEEE 802.15.4 MAC in ROM for Optimized Application Size

• RoHS-Compliant Package

- – 7-mm × 7-mm RGZ VQFN48 (31 GPIOs)

• Peripherals

• Digital Peripherals Can be Routed to Any GPIO

- – 4× 32-Bit or 8× 16-Bit General-Purpose Timers

- – 12-Bit ADC, 200 kSamples/s, 8 Channels

- – 2× Comparators With Internal Reference DAC (1× Continuous Time, 1× Ultra-Low Power)

- – Programmable Current Source

- – 2× UART

- – 2× SSI (SPI, MICROWIRE, TI)

- – I2C

- – I2S o Real-Time Clock (RTC)

- – AES 128- and 256-bit Crypto Accelerator

- – ECC and RSA Public Key Hardware Accelerator

- – SHA2 Accelerator (Full Suite Up to SHA-512)

- – True Random Number Generator (TRNG)

- – Capacitive Sensing, Up to 8 Channels

- – Integrated Temperature and Battery Monitor

• External System

- – On-Chip Buck DC/DC Converter

• Low Power

- – Wide Supply Voltage Range: 1.8 V to 3.8 V

- – Active-Mode RX: 6.83 mA

- – Active-Mode TX: 7.5 mA

- – Active-Mode MCU 48 MHz (CoreMark): 3.3 mA (69 µA/MHz)

- – Sensor Controller 16-Hz Flow Metering: 1.7 µA

- – Sensor Controller 100-Hz Comp A Reading: 1.5 µA

- – Sensor Controller, 1-Hz ADC Sampling: 1 µA

- – Standby: 0.92 µA (RTC on, 80KB RAM and CPU Retention)

- – Shutdown: 125 nA (Wakeup on External Events)
- • Radio Section
    - – 2.4-GHz RF Transceiver Compatible With Bluetooth 5 low energy and IEEE 802.15.4 PHY and MAC
    - – Excellent Receiver Sensitivity: –100 dBm for 802.15.4 (2.4 GHz), –103 dBm for Bluetooth 5 low energy Coded
    - – Programmable Output Power Up to +5 dBm
    - – Suitable for Systems Targeting Compliance With Worldwide Radio Frequency Regulations
        - • EN 300 328, (Europe)
        - • EN 300 440 Class 2 (Europe)
        - • FCC CFR47 Part 15 (US)
        - • ARIB STD-T66 (Japan)
- • Development Tools and Software
    - – LAUNCHXL-CC26X2R1 Development Kit
    - – SimpleLink CC26X2 Software Development Kit
    - – SmartRF™ Software Studio for Simple Radio Configuration
    - – Sensor Controller Studio for Building Low-Power Sensing Applications

2.2.3   MSP432P4111

The SimpleLink MSP432P411x and MSP432P401x microcontrollers (MCUs) are optimized wireless host MCUs with an integrated 16-bit precision ADC, delivering ultra-low-power performance including 100 µA/MHz in active power and 820 nA in standby power with FPU and DSP extensions. As an optimized wireless host MCU, the MSP432P411x and MSP432P401x let developers add high-precision analog and memory extension to applications based on SimpleLink wireless connectivity solutions.

The MSP432P411x and MSP432P401x devices are part of the SimpleLink MCU platform, which consists of Wi-Fi, Bluetooth low energy, Sub-1 GHz, and host MCUs. All share a common, easy-to-use development environment with one core software development kit (SDK) and a rich tool set. A one-time integration of the SimpleLink platform lets you add any combination of devices from the portfolio into your design. The ultimate goal of the SimpleLink platform is to achieve 100 percent code reuse when your design requirements change. For more information, visit www.ti.com/simplelink.

MSP432P411x and MSP432P401x MCUs are supported by a comprehensive ecosystem of tools, software, documentation, training, and support to get your development started quickly. The LaunchPad™ development kit or MSP-TS432PZ100 target socket board (with additional MCU sample) along with the free SimpleLink MSP432 SDK are all you need to get started.

图 **6. MSP432P411x Functional Block Diagram**
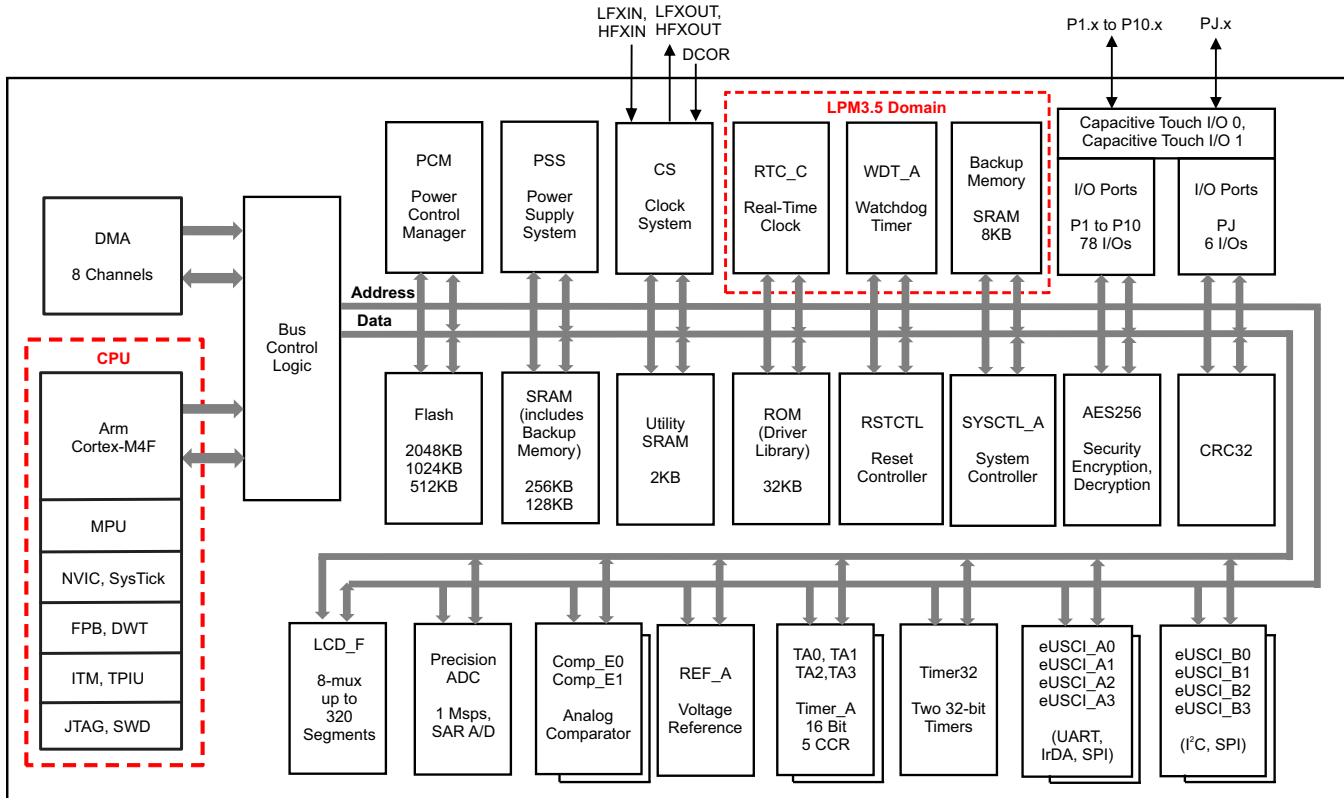
Features

- Core
  - ARM 32-Bit Cortex-M4F CPU With Floating Point Unit and Memory Protection Unit
  - Frequency up to 48 MHz
  - ULP Benchmark
    - 150.6 ULPBench™ CP Performance Benchmark
    - 3.41 CoreMark/MHz
    - 1.22 DMIPS/MHz (Dhrystone 2.1)
- Advanced Low-Power Analog Features
  - SAR Analog-To-Digital Converter (ADC) With 16-Bit Precision and up to 1 Msps
    - Differential and Single-Ended Inputs
    - Two Window Comparators
    - Up to 24 Input Channels
  - Internal Voltage Reference With 25-ppm/°C Typical Stability
  - Two Analog Comparators
  - Integrated LCD Driver With Contrast Control for up to 320 Segments
- Memories
  - Up to 2048KB of Flash Main Memory (Organized Into Two Banks Enabling Simultaneous Read or Execute During Erase)

- – 32KB of Flash Information Memory (Including area used for BSL, TLV, and Flash Mailbox)

- – Up to 256KB of SRAM (Including 8KB of Backup Memory)

- – 2KB of Utility SRAM

- – 32KB of ROM with MSP432™ Peripheral Driver Libraries

- Ultra-Low-Power Operating Modes

  - – Active: 100 µA/MHz

  - – Low-Frequency Active: 95 µA (at 128 kHz)

  - – LPM3 (With RTC): 820 nA

  - – LPM3.5 (With RTC): 820 nA

  - – LPM4: 690 nA

  - – LPM4.5: 22 nA

- SimpleLink Platform

  - – Support for Bluetooth® Low Energy, Wi-Fi, and Sub-1 GHz

  - – Single Development Environment

  - – 100% Code Reuse Across SimpleLink SDK

- Operating Characteristics

  - – Wide Supply Voltage Range: 1.62 V to 3.7 V

  - – Temperature Range (Ambient): –40°C to 85°C

- • Flexible Clocking Features

  - – Programmable Internal DCO (up to 48 MHz)

  - – 32.768-kHz Low-Frequency Crystal (LFXT)

  - – High-Frequency Crystal (HFXT) up to 48 MHz

  - – Low-Frequency Trimmed Internal Reference Oscillator (REFO)

  - – Very-Low-Power Low-Frequency Internal Oscillator (VLO)

  - – Module Oscillator (MODOSC)

  - – System Oscillator (SYSOSC)

- Code Security Features

  - – JTAG and SWD Lock

  - – IP Protection (up to Four Secure Flash Zones, Each With Configurable Start Address and Size)

- Enhanced System Options

  - – Programmable Supervision and Monitoring of Supply Voltage

  - – Multiple-Class Resets for Better Control of Application and Debug

  - – 8-Channel DMA

  - – RTC With Calendar and Alarm Functions

- Timing and Control

  - – Up to Four 16-Bit Timers, Each With up to Five Capture, Compare, PWM Capability

  - – Two 32-Bit Timers with Interrupt Generation Capability

- Serial Communication

- – Up to Four eUSCI_A Modules
  - • UART With Automatic Baud-Rate Detection
  - • IrDA Encode and Decode
  - • SPI (up to 16 Mbps)
- – Up to Four eUSCI_B Modules
  - • I2C (With Multiple-Slave Addressing)
  - • SPI (up to 16 Mbps)
- • Flexible I/O Features
  - – Ultra-Low-Leakage I/Os (±20 nA Maximum)
  - – All I/Os With Capacitive Touch Capability
  - – Up to 48 I/Os With Interrupt and Wake-up Capability
  - – Up to 24 I/Os With Port Mapping Capability
  - – Eight I/Os With Glitch Filtering Capability
- • Encryption and Data Integrity Accelerators
  - – 128-, 192-, or 256-Bit AES Encryption and Decryption Accelerator
  - – 32-Bit Hardware CRC Engine
- • JTAG and Debug Support
  - – 4-Pin JTAG and 2-Pin SWD Debug Interfaces
  - – Serial Wire Trace
  - – Power Debug and Profiling of Applications

2.2.4 ADS122U04

The ADS122U04 is a precision, 24-bit, analog-to-digital converter (ADC) that offers many integrated features to reduce system cost and component count in applications measuring small sensor signals. The device features two differential or four single-ended inputs through a flexible input multiplexer (MUX), a low-noise, programmable gain amplifier (PGA), two programmable excitation current sources, a voltage reference, an oscillator, and a precision temperature sensor.

The device can perform conversions at data rates up to 2000 samples-per-second (SPS) with single-cycle settling. At 20 SPS, the digital filter offers simultaneous 50-Hz and 60-Hz rejection for noisy industrial applications. The internal PGA offers gains up to 128. This PGA makes the ADS122U04 ideally suited for applications measuring small sensor signals, such as resistance temperature detectors (RTDs), thermocouples, thermistors, and resistive bridge sensors.

The ADS122U04 features a 2-wire, UART-compatible interface. In applications that require galvanic isolation this universal asynchronous receiver/transmitter (UART) interface minimizes the number of digital isolation channels, thus saving cost, board space, and power.

The ADS122U04 is offered in a leadless 16-pin WQFN or a 16-pin TSSOP package and is specified over a temperature range of –40°C to +125°C.

图 7. ADS122U04 Functional Block Diagram
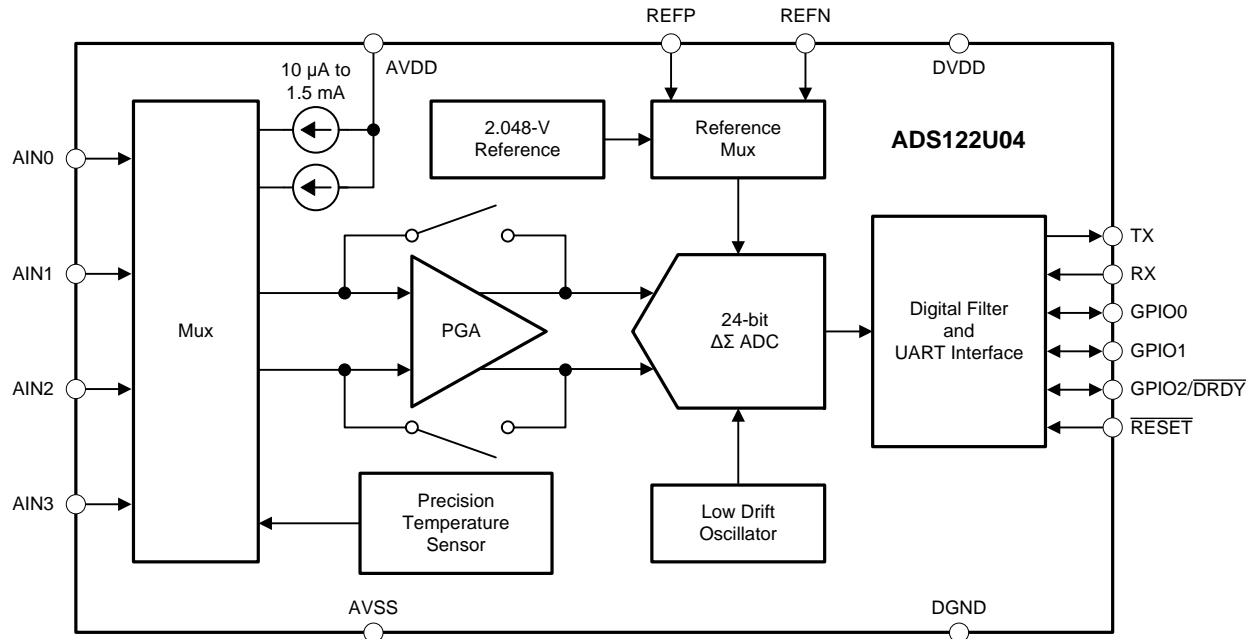
Features

- Current Consumption as Low as 315 µA (typ)
- Wide Supply Range: 2.3 V to 5.5 V
- Programmable Gain: 1 to 128
- Programmable Data Rates: Up to 2 kSPS
- Up to 20 Bits Effective Resolution
- Simultaneous 50-Hz and 60-Hz Rejection at 20 SPS With Single-Cycle Settling Digital Filter
- Two Differential or Four Single-Ended Inputs
- Dual-Matched Programmable Current Sources: 10 µA to 1.5 mA
- Internal 2.048-V Reference: 5 ppm/°C (typ) Drift
- Internal 2% Accurate Oscillator
- Internal Temperature Sensor: 0.5°C (typ) Accuracy
- Three General-Purpose Inputs/Outputs
- 2-Wire UART Compatible Interface (8-N-1 Format) With Baud Rates up to 120 kBaud and Auto-Baud-Rate Detection
- Package: 3.0-mm × 3.0-mm × 0.75-mm WQFN

2.2.5 THVD1452

THVD14xx is a family of noise-immune RS-485/RS-422 transceivers designed to operate in rugged industrial environments. The bus pins of these devices are robust to high levels of IEC electrical fast transients (EFT) and IEC electrostatic discharge (ESD) events, eliminating the need for additional system level protection components.

Each of these devices operates from a single supply from 3 V to 5.5 V. The devices in this family feature an extended common-mode voltage range which makes them suitable for multi-point applications over long cable runs.

THVD14xx family of devices is available in small VSON and VSSOP packages for space constrained applications. These devices are characterized over ambient free-air temperatures from –40°C to 125°C.

图 **8. THVD1452 Functional Block Diagram**
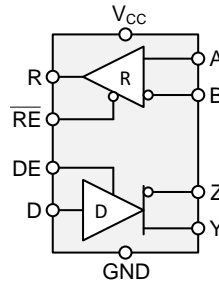
Features

- Meets or Exceeds the Requirements of the TIA/EIA-485A Standard
- 3 V to 5.5 V Supply Voltage
- Bus I/O ESD Protection
    - ±30 kV HBM
    - ±18 kV IEC 61000-4-2 Contact Discharge
    - ±18 kV IEC 61000-4-2 Air-Gap Discharge
    - ±4 kV IEC 61000-4-4 Fast Transient Burst
- Extended Operational Common-mode Range: ±15 V
- Low EMI 500 kbps and 50 Mbps Data Rates
- Large Receiver Hysteresis for Noise Rejection
- Low Power Consumption
    - Standby Supply Current: < 1 µA
    - Current During Operation: < 3 mA
- Extended Ambient Temperature Range: –40°C to 125°C
- Glitch-Free Power-Up/Down for Hot Plug-in Capability
- Open, Short, and Idle Bus Failsafe
- 1/8 Unit Load (Up to 256 Bus Nodes)
- Small-Size VSON and VSSOP Packages Save Board Space or SOIC for Drop-in Compatibility

2.2.6 TRS3232E

The TRS3232E device consists of two line drivers, two-line receivers, and a dual charge-pump circuit with ±15-kV IEC ESD protection pin to pin (serial-port connection pins, including GND).

The device meets the requirements of TIA/EIA-232-F and provides the electrical interface between an asynchronous communication controller and the serial-port connector. The charge pump and four small external capacitors allow operation from a single 3-V to 5.5-V supply. The devices operate at data signaling rates up to 250 kbps and a maximum of 30-V/µs driver output slew rate.

图 **9. TRS3232E Functional Block Diagram**
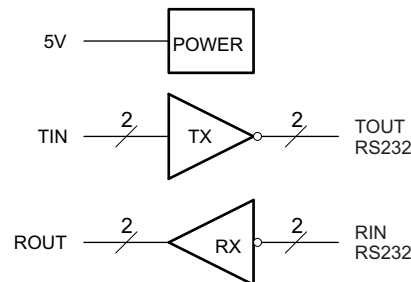
Features

- ESD Protection for RS-232 Bus Pins
    - ±15 kV (HBM)
    - ±8 kV (IEC61000-4-2, Contact Discharge)
    - ±15 kV (IEC61000-4-2, Air-Gap Discharge)
- Meets or Exceeds the Requirements of TIA/EIA-232-F and ITU V.28 Standards
- Operates With 3-V to 5.5-V VCC Supply
    - Interoperable with RS-232 down to 2.7-V VCC
- Operates up to 250 kbps × Two Drivers and Two Receivers
- Low Supply Current: 300 µA (Typical)
- External Capacitors: 4 × 0.1 µF
- Accepts 5-V Logic Input With 3.3-V Supply
- Pin Compatible to Alternative High-Speed Devices (1 Mbps)
    - SN65C3232E (–40°C to +85°C)
    - SN75C3232E (0°C to 70°C)

2.2.7 ISO1212

The ISO1211 and ISO1212 devices are isolated 24-V to 60-V digital input receivers, compliant to IEC 61131-2 Type 1, 2, and 3 characteristics. These devices enable 9-V to 300-V DC and AC digital input modules in programmable logic controllers (PLCs), motor-control, grid infrastructure, and other industrial applications. Unlike traditional optocoupler solutions with discrete, imprecise current limiting circuitry, the ISO121x devices provide a simple, low-power solution with an accurate current limit to enable the design of compact and high-density I/O modules. These devices do not require field-side power supply and are configurable as sourcing or sinking inputs.

The ISO121x devices operate over the supply range of 2.25 V to 5.5 V, supporting 2.5-V, 3.3-V, and 5-V controllers. A ±60-V input tolerance with reverse polarity protection helps ensure the input pins are protected in case of faults with negligible reverse current. These devices support up to 4-Mbps data rates passing a minimum pulse width of 150 ns for high-speed operation. The ISO1211 device is ideal for designs that require channel-to-channel isolation and the ISO1212 device is ideal for multichannel space-constrained designs.

图 **10. ISO1212 Functional Block Diagram**
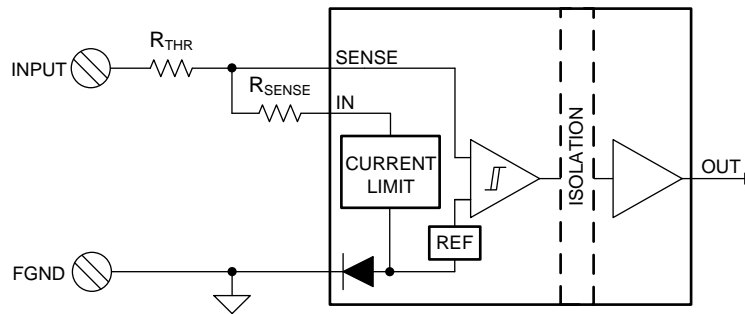
Features

- Compliant to IEC 61131-2; Type 1, 2, 3 Characteristics for 24-V Isolated Digital Inputs
- Supports 9-V to 300-V DC and AC Digital Input Designs Using External Resistors
- Accurate Current Limit for Low-Power Dissipation:
  - 2.2 mA to 2.47 mA for Type 3
  - Adjustable up to 6.5 mA
- Eliminates the Need for Field-Side Power Supply
- High Input-Voltage Range With Reverse Polarity Protection: ±60 V
- Wire-Break Detection (Refer to TIDA-01509)
- Configurable as Sourcing or Sinking Input
- High Data Rates: Up to 4 Mbps
- Enable Pin to Multiplex Output Signals
- High Transient Immunity: ±70-kV/µs CMTI
- Wide Supply Range (VCC1): 2.25 V to 5.5 V
- Ambient Temperature Range: –40°C to +125°C
- Compact Package Options:
  - Single-Channel ISO1211, SOIC-8
  - Dual-Channel ISO1212, SSOP-16
- Safety-Related Certifications:
  - Basic Insulation per DIN V VDE V 0884-10
  - UL 1577 Recognition, 2500-V_{RMS} Insulation
  - CSA, CQC, TUV Certificates Available

2.2.8 HDC2080

The HDC2080 device is an integrated humidity and temperature sensor that provides high accuracy measurements with very low power consumption in a small DFN package. The capacitive-based sensor includes new integrated digital features and a heating element to dissipate condensation and moisture. The HDC2080 digital features include programmable interrupt thresholds to provide alerts and system wake-ups without requiring a microcontroller to be continuously monitoring the system. Combined with programmable sampling intervals, a low power consumption, and a support for a 1.8-V supply voltage, the HDC2080 is designed for battery-operated systems.

The HDC2080 provides high accuracy measurement capability for a wide range of environmental monitoring and internet of things (IoT) applications such as smart thermostats and smart home assistants. For designs where printed-circuit board (PCB) area is critical, a smaller CSP package option is available thru the HDC2010 with complete software compatibility with the HDC2080.

For applications with strict power-budget restrictions, Auto Measurement Mode enables the HDC2080 to automatically initiate temperature and humidity measurements. This feature allows users to configure a microcontroller into deep sleep mode because the HDC2080 is no longer dependent upon the microcontroller to initiate a measurement.

Programable temperature and humidity thresholds in the HDC2080 allow the device to send a hardware interrupt to wake up the microcontroller when necessary. In addition, the power consumption of the HDC2080 is significantly reduced, which helps to minimize self-heating and improve measurement accuracy.

The HDC2080 is factory-calibrated to 0.2°C temperature accuracy and 2% relative humidity accuracy.

图 11. HDC2080 Functional Block Diagram
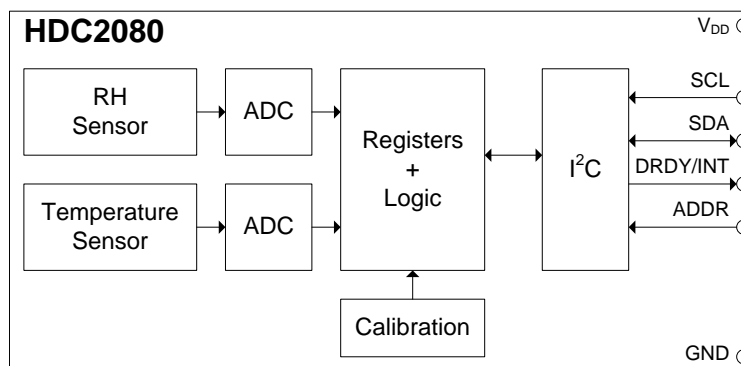
Features

- Relative Humidity Range: 0% to 100%

- Humidity Accuracy: ±2% (Typical), ±3% (Maximum)

- Temperature Accuracy: ±0.2°C (Typical), ±0.4°C (Maximum)

- Sleep Mode Current: 50 nA (Typical), 100 nA (Maximum)

- Average Supply Current (1 Measurement/Second)
  - 300 nA: RH% Only (11 Bit)
  - 550 nA: RH% (11 Bit) + Temperature (11 Bit)

- Temperature Range:
  - Operating: –40°C to 85°C
  - Functional: –40°C to 125°C

- Supply Voltage Range: 1.62 V to 3.6 V

- Available Auto Measurement Mode

- I2C Interface Compatibility

2.2.9 LMR36006

The LMR36006 regulator is an easy-to-use, synchronous, step-down DC/DC converter. With integrated high-side and low-side power MOSFETs, up to 0.6 A of output current can be delivered over a wide input voltage range of 60 V, with transient tolerance up to 66 V. The transient tolerance reduces the necessary design effort to protect against overvoltages and meets the surge immunity requirements of IEC 61000-4-5.

The LMR36006 employs peak-current-mode control to provide optimal efficiency and output voltage accuracy. Precision enable provides flexibility by enabling a direct connection to the wide input voltage or precise control over device start-up and shutdown. The power-good flag, with built-in filtering and delay, offers a true indication of system status, and negates the requirement for an external supervisor.

The device requires few external components and has a pinout designed for simple PCB layout. The small solution size and feature set of the LMR36006 is designed to simplify implementation for a wide range of end equipment, including space critical applications of ultra-small field transmitters and vision sensors.

图 **12. LMR36006 Functional Block Diagram**
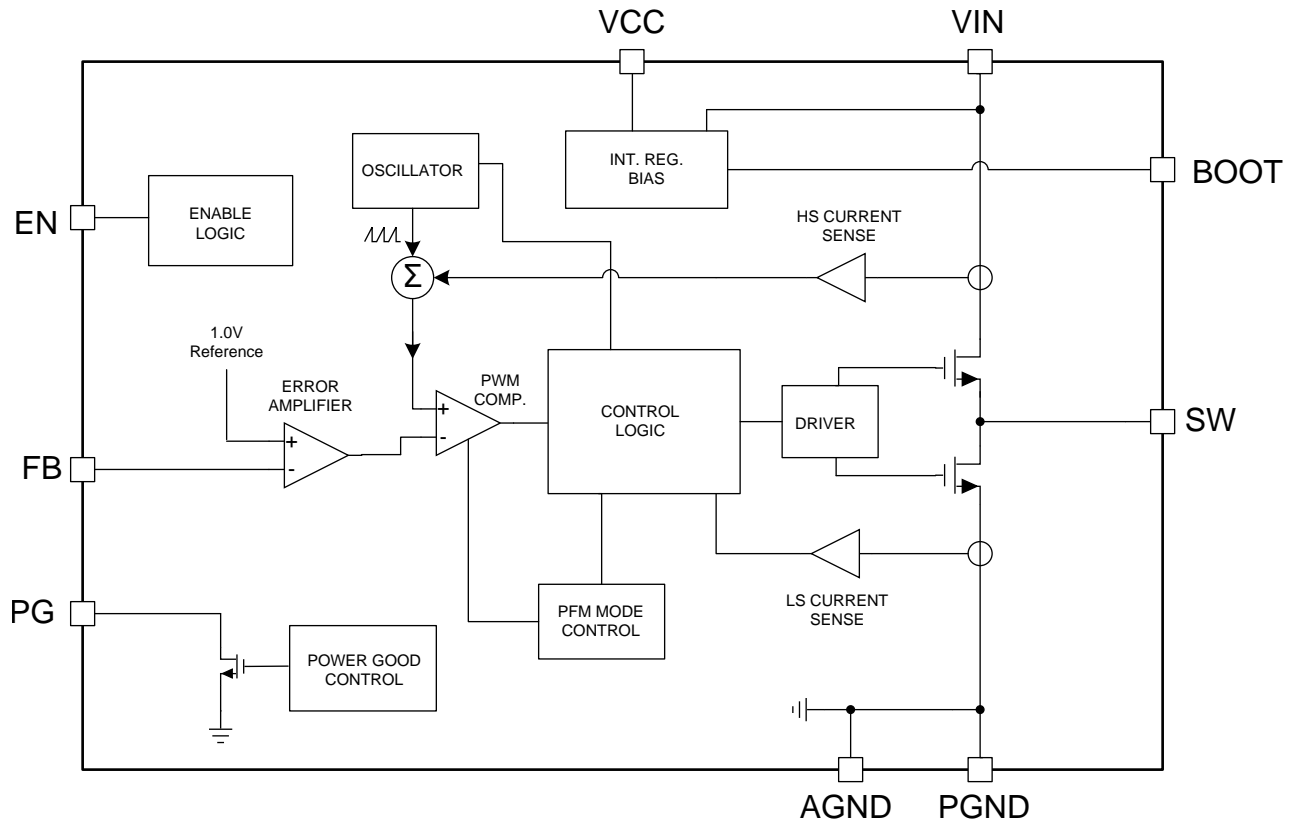
Features

- Designed for Reliable and Rugged Applications
  - Input Transient Protection up to 66 V
  - Junction Temperature Range –40°C to +150°C
  - Protection Features Like Thermal Shutdown, Input Undervoltage Lockout, Cycle-by-Cycle Current Limit, Hiccup Short-Circuit Protection
- • Suited for Scalable Industrial Power Supplies
  - Pin Compatible With LMR36015 (60 V, 1.5 A) and LMR33620/30 (36 V, 2 A / 3 A)
  - 1-MHz, 2.1-MHz Frequency Options Available
- • Integration Reduces Solution Size and Cost
  - Small, 3-mm × 2-mm HotRod Package
  - Few External Components with Integrated Rectification and Internal Compensation
- Low Power Dissipation Across Load Spectrum
  - 92% Efficiency at 1 MHz (12 VIN, 5 VOUT, 0.6 A)
  - Increased Light Load Efficiency with Automatic Transition into PFM
  - Low Shutdown Quiescent Current of 3 µA
  - Low Operating Quiescent Current of 23 µA
- AEC-Q100 version available in 400 kHz and 2.1 MHz — contact TI for details
- Create a Custom Design Using the LMR36006 with the WEBENCH® Power Designer

2.2.10 TLV755P

The TLV755P is an ultra-small, low quiescent current, low-dropout regulator (LDO) that sources 500 mA with good line and load transient performance. The TLV755P is optimized for a wide variety of applications by supporting an input voltage range from 1.45 V to 5.5 V. To minimize cost and solution size, the device is offered in fixed output voltages ranging from 0.6 V to 5 V to support the lower core voltages of modern microcontrollers (MCUs). Additionally, the TLV755P has a low IQ with enable functionality to minimize standby power. This device features an internal soft-start to lower inrush current, thus providing a controlled voltage to the load and minimizing the input voltage drop during start up. When shutdown, the device actively pulls down the output to quickly discharge the outputs and ensure a known start-up state.

The TLV755P is stable with small ceramic output capacitors allowing for a small overall solution size. A precision band-gap and error amplifier provides a typical accuracy of 1%. All device versions have integrated thermal shutdown, current limit, and undervoltage lockout (UVLO). The TLV755P has an internal foldback current limit that helps reduce the thermal dissipation during short-circuit events.

图 **13. TLV755P Functional Block Diagram**
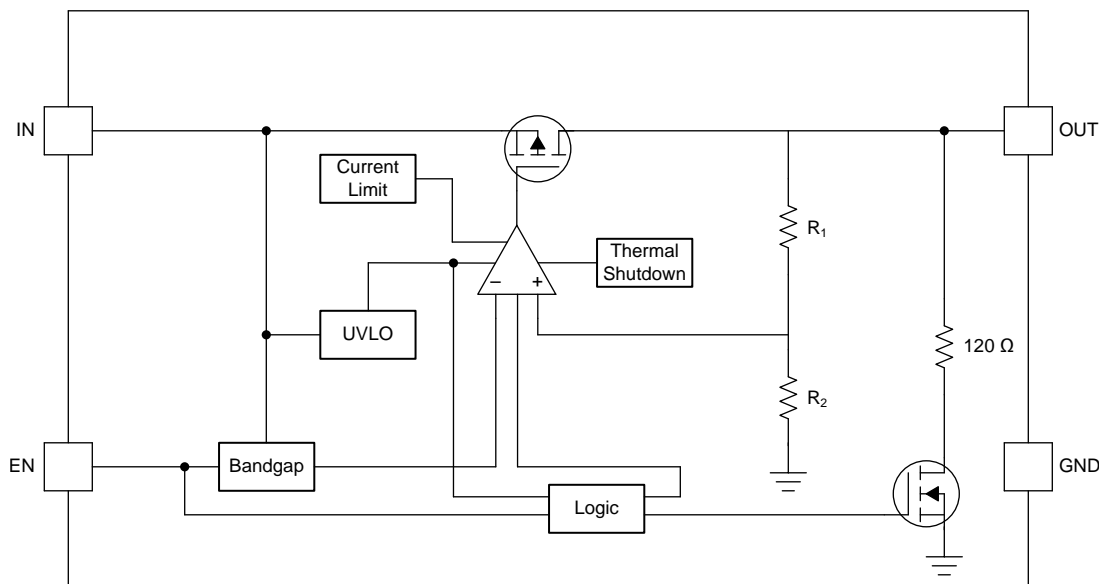
Features

- Input Voltage Range: 1.45 V to 5.5 V
- Low IQ: 25 µA (Typical)
- Low Dropout:
    - 238 mV (Maximum) at 500 mA (3.3 VOUT)
- Output Accuracy: 1% (Maximum at 85°C)
- Built-In Soft-Start With Monotonic VOUT Rise
- Foldback Current Limit
- Active Output Discharge
- High PSRR: 46 dB at 100 kHz
- Stable With a 1-µF Ceramic Output Capacitor
- Packages:

– 2.9-mm × 1.6-mm SOT-23-5

– 1-mm x 1-mm X2SON-4

– 2 mm × 2 mm WSON-6

2.2.11 LMZM23600

The LMZM23600 integrated-inductor power module is specifically designed for space-constrained industrial applications. It is available in two fixed output voltage options of 5-V and 3.3-V, and an adjustable (ADJ) output voltage option supporting a 2.5-V to 15-V range. The LMZM23600 has an input voltage range of 4-V to 36-V and can deliver up to 500-mA of output current. This power module is extremely easy to use, requiring only 2 external components for a 5-V or 3.3-V output design. All aspects of the LMZM23600 are optimized for performance driven and low EMI industrial applications with space-constrained needs. An open-drain, Power-Good output provides a true indication of the system status and negates the requirement for an additional supervisory component, saving cost and board space. Seamless transition between PWM and PFM modes along with a no-load supply current of only 28 µA ensures high efficiency and superior transient response for the entire load-current range. For easy output current scaling the LMZM23600 is pin-to-pin compatible with the 1000-mA output current capable LMZM23601.

图 **14. LMZM23601 Functional Block Diagram**
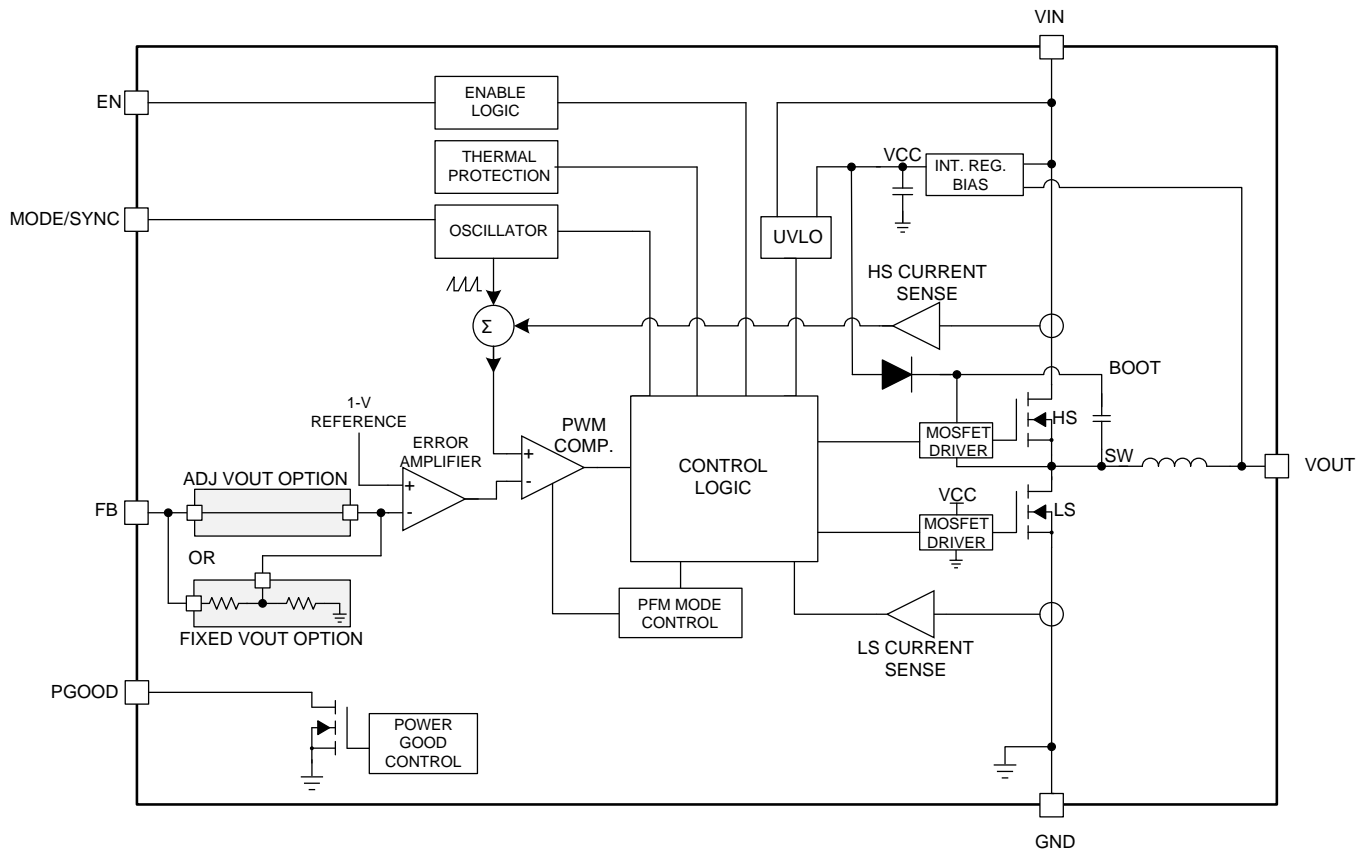
Features

• 4-V to 36-V Wide Operating Input Voltage

• 2.5-V to 15-V Adjustable, and 3.3-V or 5-V Fixed Output Voltage Options

• 0.5-A Output Current

- Only Input and Output Capacitors Needed for 5-V and 3.3-V Output Designs

- 27-mm^2 Solution Size With Single-Sided Layout

- 28-µA Supply Current at No Load

- 2-µA Shutdown Current

- Power-Good Flag

- External Frequency Synchronization

- MODE Selection Pin

  – Forced PWM Mode for Constant Frequency Operation

  – Auto PFM Mode for High Efficiency at Light Load

- Built-in Control Loop Compensation, Soft Start, Current Limit, and UVLO

- Miniature 3.8-mm × 3-mm × 1.6-mm Package

- Create a Custom Design Using the LMZM23600 With the WEBENCH® Power Designer

2.2.12 TIOL111

The TIOL111 family of transceivers implements the IO-Link interface for industrial bidirectional, point-topoint communication. When the device is connected to an IO-Link master through a three-wire interface, the master can initiate communication and exchange data with the remote node while the TIOL111 acts as a complete physical layer for the communication.

These devices are capable of withstanding up to 1.2 kV (500 Ω) of IEC 61000-4-5 surge and feature integrated reverse polarity protection.

A simple pin-programmable interface allows easy interfacing to the controller circuits. The output current limit can be configured using an external resistor.

Fault reporting and internal protection functions are provided for under voltage, over current and over temperature conditions.

图 **15. TIOL111-x Functional Block Diagram**
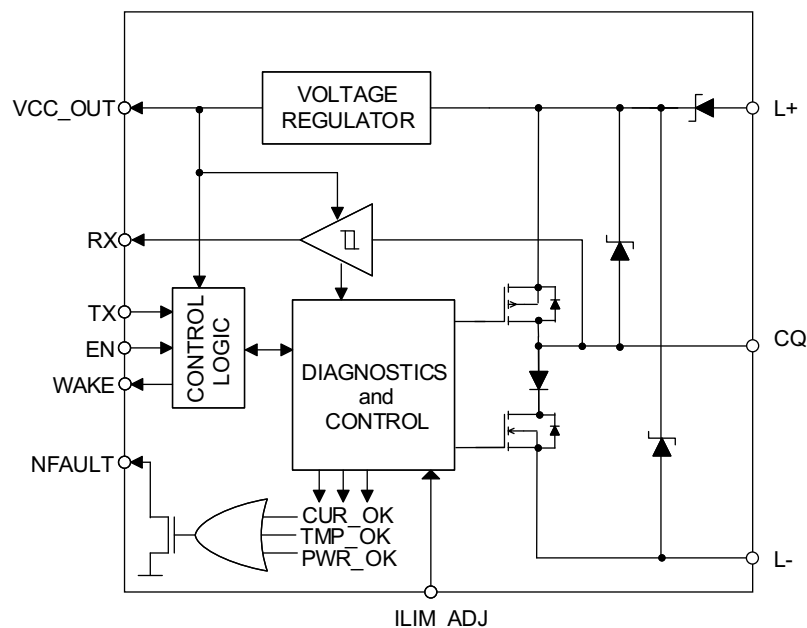
Copyright © 2016, Texas Instruments Incorporated

Features

- 7-V to 36-V Supply Voltage
- PNP, NPN or IO-Link Configurable Output
  - IEC 61131-9 COM1, COM2 and COM3 Data Rate Support
- Low Residual Voltage of 1.75 V at 250 mA
- 50-mA to 350-mA Configurable Current Limit
- Tolerant to ±65-V Transients < 100 μs
- Reverse Polarity Protection of up to 55 V on L+, CQ and L-
- Integrated EMC Protection on L+ and CQ
  - ±16 kV IEC 61000-4-2 ESD Contact Discharge
  - ±4 kV IEC 61000-4-4 Electrical Fast Transient
  - ±1.2 kV/500 Ω IEC 61000-4-5 Surge
- Fast Demagnetization of Inductive Loads up to 1.5 H
- Large Capacitive Load Driving Capability
- < 2-μA CQ Leakage Current
- < 1.5-mA Quiescent Supply Current
- Integrated LDO Options for up to 20 mA Current
  - TIOL111: No LDO
  - TIOL111-3: 3.3-V LDO
  - TIOL111-5: 5-V LDO
- Overtemperature Warning and Thermal Protection
- Remote Wake-up Indicator
- Fault Indicator
- Extended Ambient Temperature: –40°C to 125°C
- 2.5 mm x 3 mm 10-pin VSON Package

2.3 System Design Theory

Semiconductor companies manage their wafer fabrication facilities to maximize uptime, yield and throughput. Equipment engineering teams are constantly looking for new ways to get more efficiency out of the manufacturing process. In a wafer fabrication plant, hundreds of vacuum pumps are used in the wafer manufacturing process (see 图 16).

图 **16. Vacuum Pumps in a Wafer Fabrication Facility**

These vacuum pumps must be closely monitored to ensure uninterrupted wafer manufacturing. An unplanned interruption of the vacuum pumps operation would result in wafer scrappage, revenue loss and unacceptable delay in product shipments to customers. To avoid downtime, the vacuum pumps in the fab need to be continously monitored. The Busch vacuum pumps provide permanent measurement data of the casing temperature, motor current, nitrogen flow, water flow and oil status. Furthermore, the vacuum pumps also provide 24-V power. With this reference design board connected to the vacuum pumps, the permanent measurement data can be centrally collected and easily accessed through the internet. This collection enables the possibility for trend analysis and predictive maintenance. 图 17 shows the actual connection of the TIDA-010012 board to one vacuum pump. 图 18 shows some of the read out pump data on the display of the TIDA-001012 board.

图 **17. TIDA-010012 Connected to one Vacuum Pump**

图 **18. TIDA-010012 Showing Vacuum Pump Data**

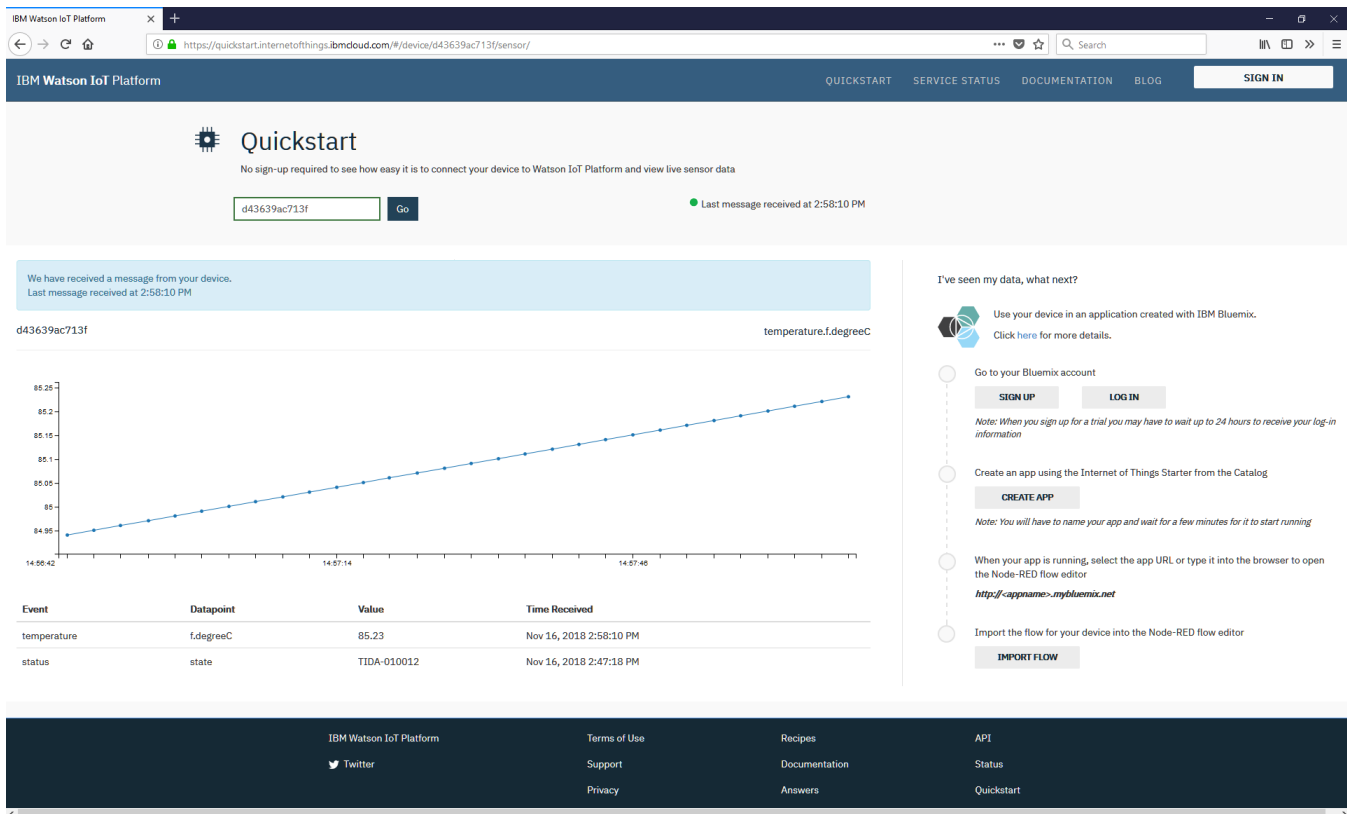### 2.3.1   Condition Monitoring With Wi-Fi® and IBM Watson IoT

The vacuum pump data are also sent to a cloud for condition monitoring. On this reference design the CC3220 is used to connect via Wi-Fi to the IBM Watson IoT service using the MQTT Client library API. The IBM Watson Platform offers a QuickStart service which allows devices to connect without being registered, to evaluate the platform and verify connection setup. It has pre-integrated support for TI evaluation boards, enabling developers to quickly begin prototyping IoT applications. In 图 19, the temperature of one vacuum pump is shown on the IBM Watson IoT Platform. More information on how to connect to the IBM Watson IoT service using the MQTT client library API is found here: *SimpleLink™ SDK plugin for IBM Watson*.

图 **19. IBM Watson IoT Platform Showing Vacuum Pump Temperature**
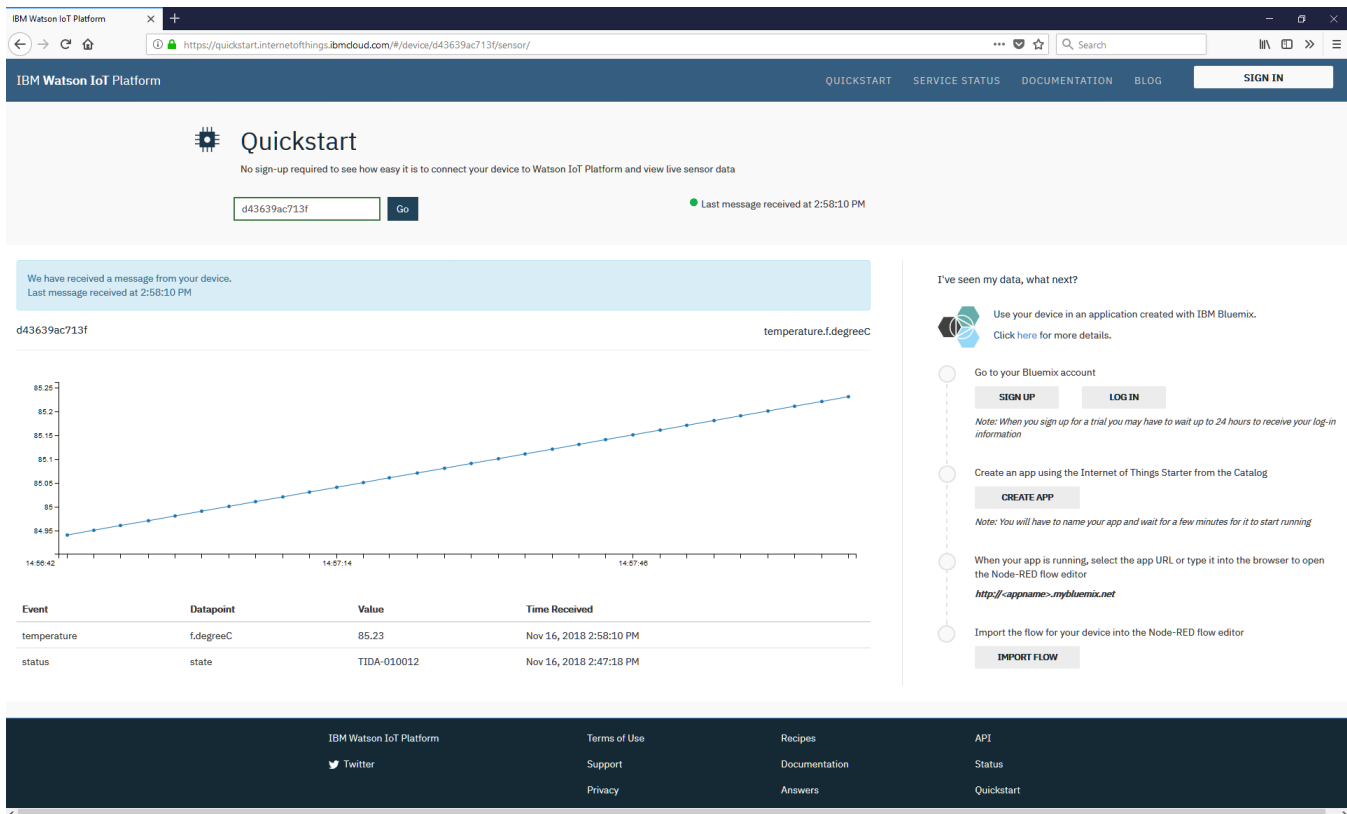

Key IBM Watson IoT features include:

- Provides connectivity for IoT devices, networks and gateways.
- Leverages robust analytics capabilities and Watson IoT APIs.
- Helps manage risk and security of applications and devices within an IoT ecosystem.
- Provides information management services for structured and unstructured data, from devices, people, and the world around us.

By centrally collecting data from the vacuum pumps and making it readily available to plant management, this system enables trend analysis which further identifies opportunities to streamline plant operations by correlating readings with specific semiconductor fab processes.

2.3.2 Condition Monitoring With a Wireless Mesh Network

In addition to the CC3220 Wi-Fi based cloud connection a mesh network using the CC2652 adapter board can also be established with this reference design. With this wireless mesh network the vacuum pumps can be connected to a central gateway and the pump data can be collected for condition monitoring. Mesh networks make radio systems more reliable by allowing radios to forward messages for other radios. For example, if a node (TIDA-010012 board) cannot send a message directly to another node, the mesh network forwards the message through one or more intermediary nodes. On this reference design 6LoWPAN protocol has been used. 6LoWPAN is an open standard defined in RFC 6282 by the *Internet Engineering Task Force* (IETF). The 6LoWPAN layer is a tiny layer in the stack located below IPv6 and above the IEEE802.15.4 MAC. The 6LoWPAN layer fragments and compresses IP frames, so the frames can be sent over the IEEE MAC layer. The main idea is to compress IPv6 headers and to not send data and information that the devices already detect. For example, sending the IPv6 destination and source address in every header is not necessary because the node detects this information once the header joins the 6LoWPAN network. The other big feature of 6LoWPAN is the fragmentation, that is the splitting of packets to fit into IEEE802.15.4 MAC frames. 6LoWPAN networks are self-healing mesh networks, which means the devices automatically connect to an edge router (gateway) with the right RF and security settings. If a node fails or drops out of the network, the routing protocol is smart enough to find a new way around the failing device.
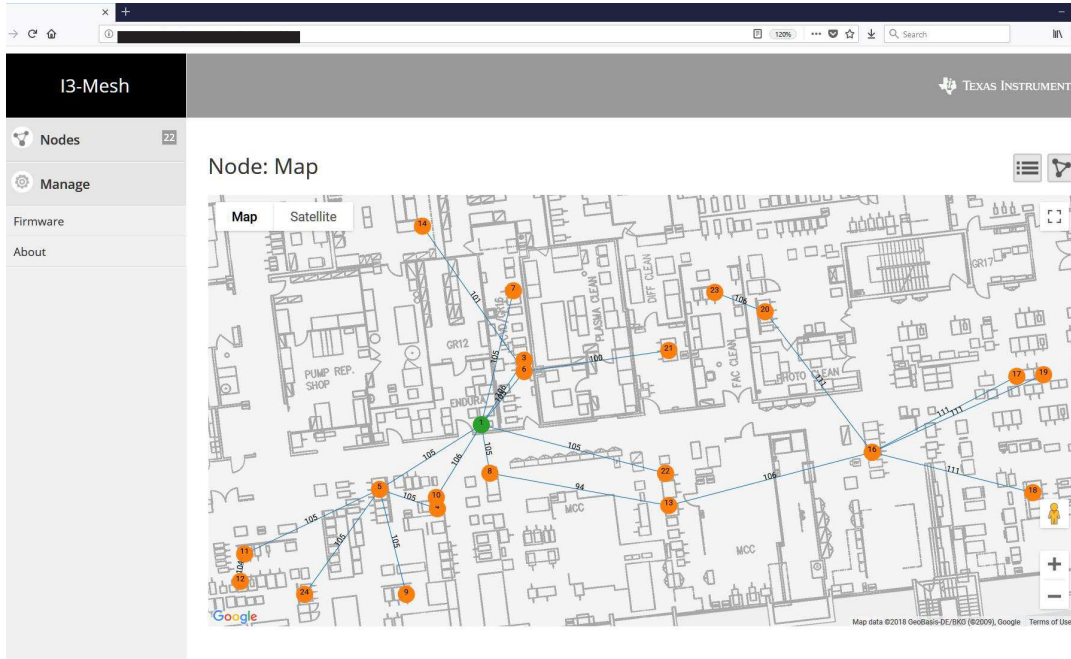
图 20. Wireless Mesh Network Overview
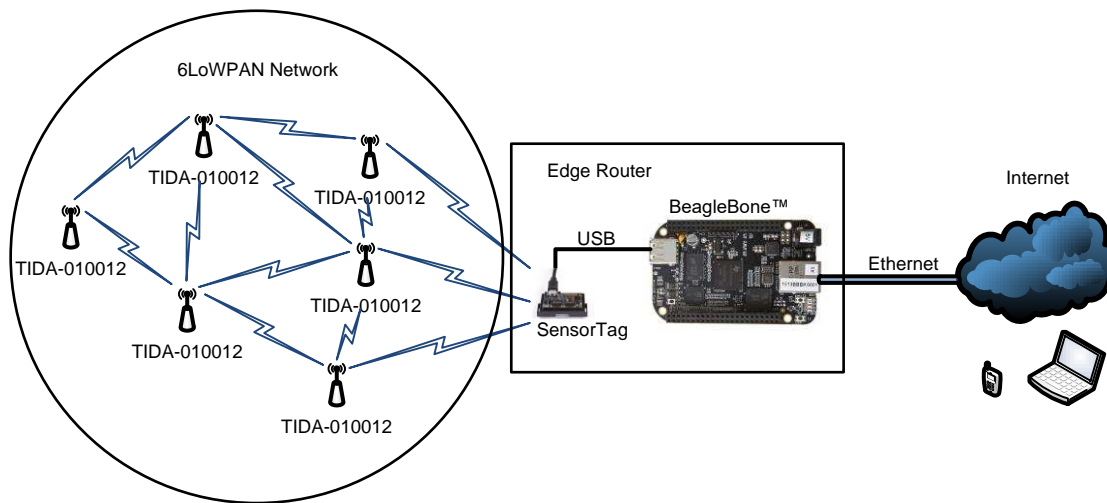
A BeagleBone™ Black board connected to a CC2650 SensorTag forms the Edge Router to the internet. The CC2650 SensorTag acts as the root node. The compressed IPv6 header requires an intermediary device to provide a conversion between 6LoWPAN and standard IP header. An edge router can be seen as this simplified gateway. The BeagleBone Black Gateway is running a web server. A standard web browser (Internet Explorer, Firefox, or Google Chrome) can be used to connect to the BeagleBone Black webserver and view the sensor nodes.

图 21 shows the web GUI and the actual connection of the TIDA-010012 boards (nodes) in the meshed network. The orange dots are the nodes connected to the pumps and the green dot is the gateway. For test purposes, 22 nodes have been installed.

图 **21. Map of the Connected TIDA-010012 Boards**

Clicking on the different nodes shows the actual vacuum pump data. 图 22 shows the actual vacuum pump data of node 13, for example.

图 **22. Vacuum Pump Data of Node 13**
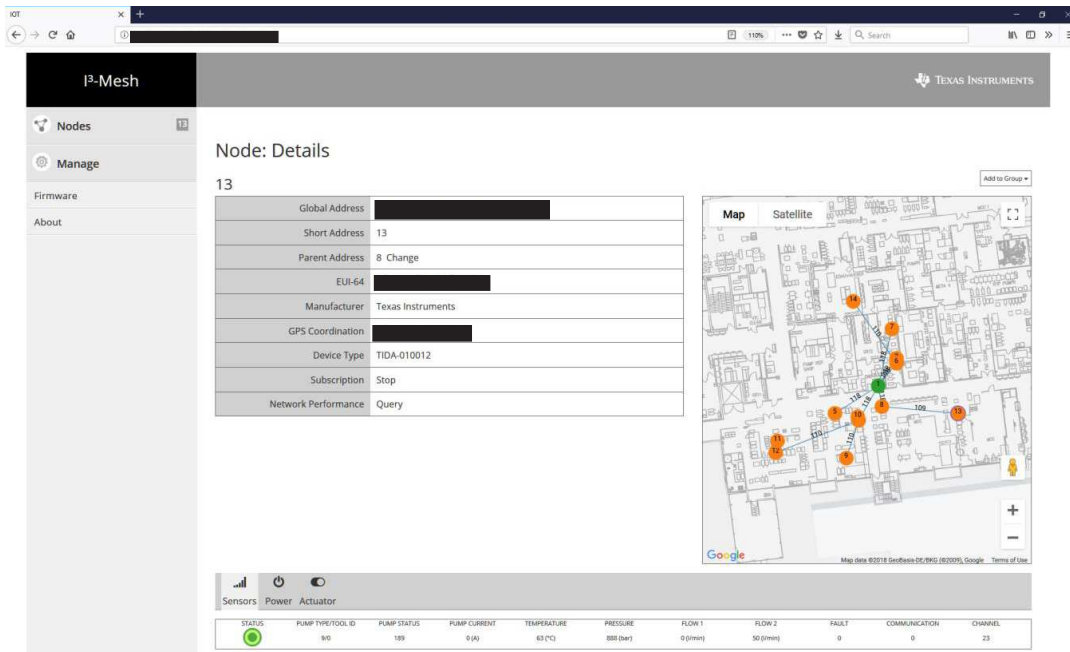
With the onboard, multistandard 2.4-GHz wireless CC2652 MCU, this reference design can also support Zigbee, Thread, Bluetooth low energy, or proprietary solutions.

2.3.3   Bluetooth® Low Energy for Configuration and Maintenance

In addition to the mesh network protocol, the CC2652 can also run BLE communication for the configuration and maintenance of the TIDA-010012. Different vacuum pumps are used in the factory with different interfaces and data types for condition monitoring. Depending on which pump the TIDA-010012 is connected to, it needs to run different protocols on RS-232 or RS-422/RS-485 to read out the data from the vacuum pumps. With the Bluetooth interface on the CC2652 adapter board, a smartphone or tablet can be used to configure the TIDA-010012 board for the different pump types. After the configuration with Bluetooth, the CC2652 will switch from BLE to the mesh network protocol to continuously send the data from the pumps for condition monitoring.
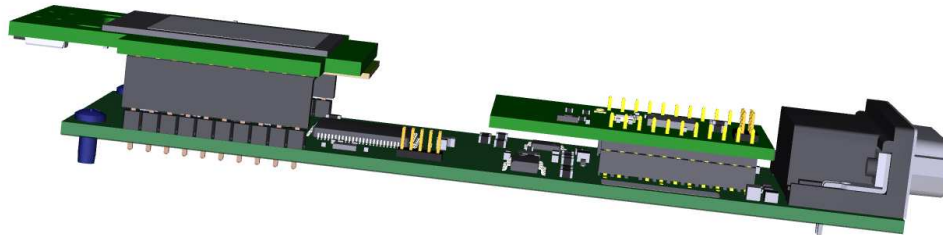
3 Hardware, Software, Testing Requirements, and Test Results

3.1 *Required Hardware and Software*

3.1.1 Hardware

图 23 is a 3D representation of the reference design board.

图 23. TIDA-010012 Reference Design 3D

This reference design consists of 3 different boards:

- The main board with the MSP432P4111
- The Wi-Fi and display board with the CC3220
- The CC2652 adapter board

图 24 shows the complete TIDA-010012 reference design with all 3 boards.

图 24. TIDA-010012 Reference Design

3.1.1.1 *Main Board*

图 25 shows the main board. All components are located on the top layer of the PCB for easy evaluation.
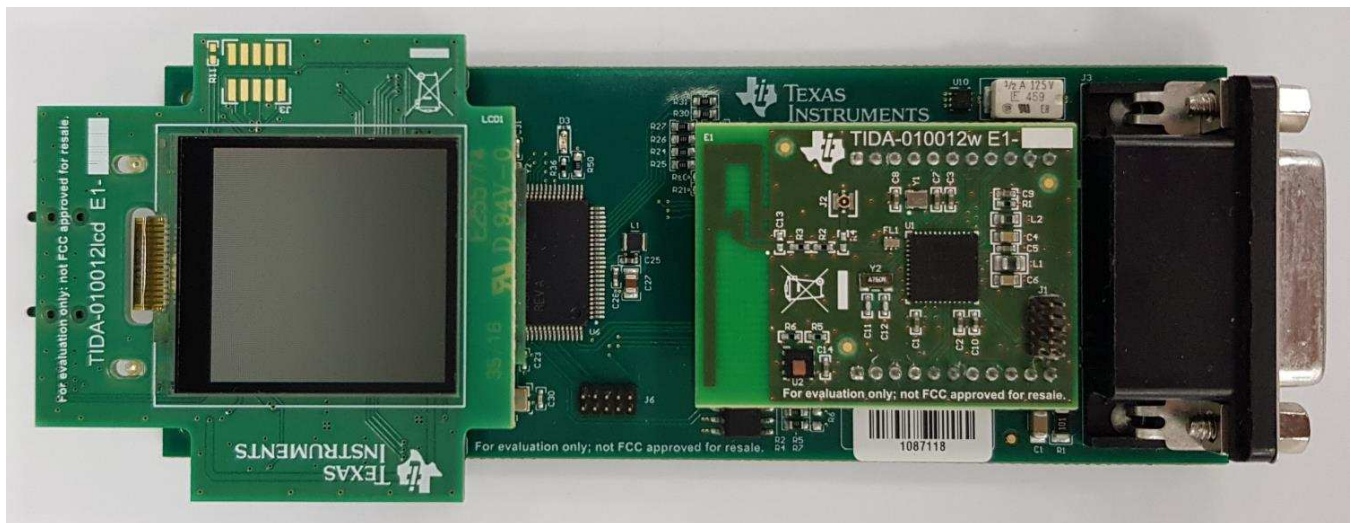
图 **25. Main Board**
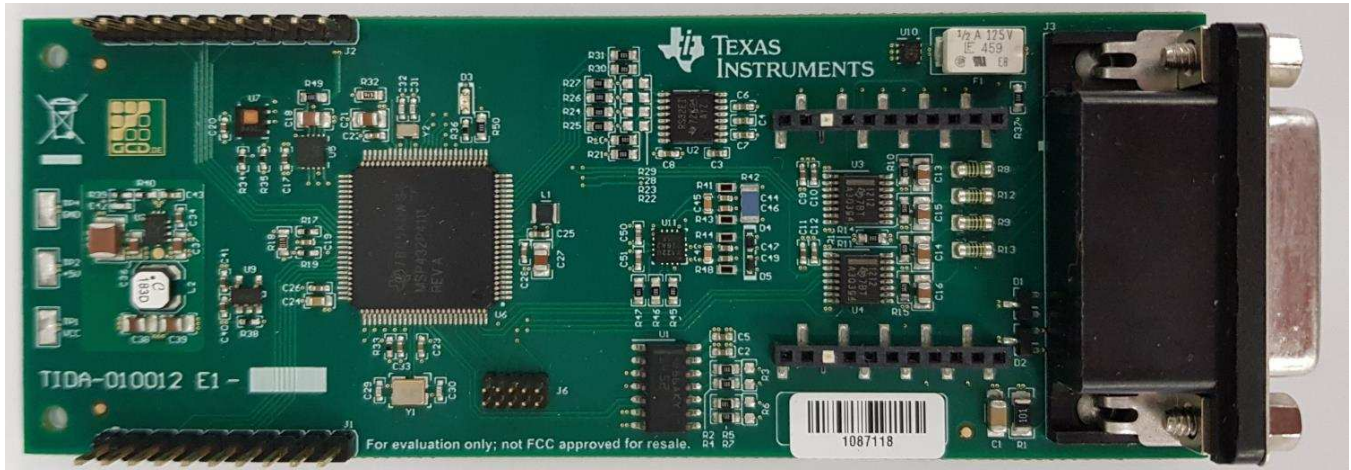
3.1.1.1.1 *RS-232 and RS-485 Interfaces*

On connector J3 on the main board there is a RS-232 and a RS-485/RS-422 interface available. 图 26 shows the pin configuration of connector J3.

图 **26. Connector J3 Pin Configuration**
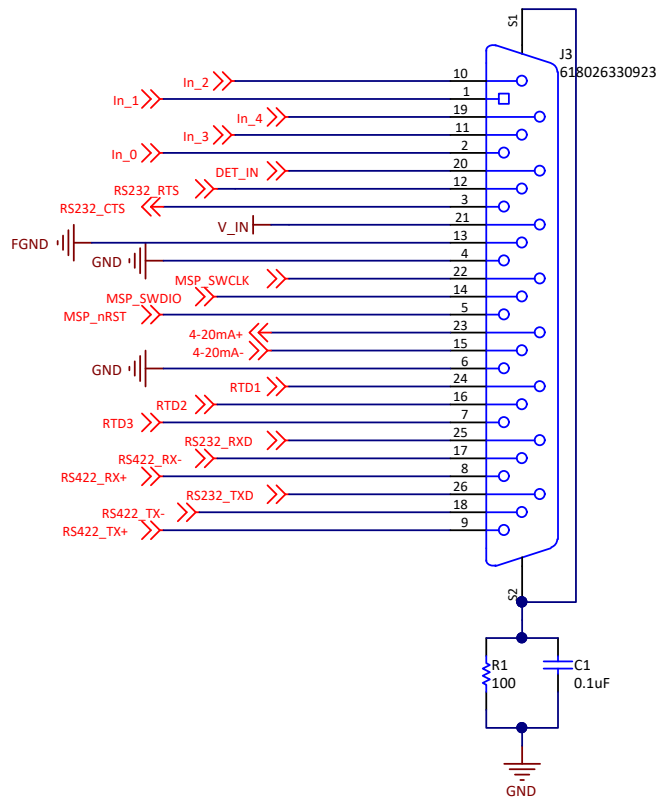
In this example, the design boards have been connected through the RS-485 interface on J3 to several vacuum pumps, like the Busch Cobra® DS, in a semiconductor fabrication plant. The interface on these pumps is RS-485-compatible and uses the GE® Fanuc® series ninety protocol (SNP) protocol. With this interface, permanent measurement data of the casing temperature, motor current, nitrogen flow, and water flow can be read out of the vacuum pumps. The reference design can also be connected to other pump types with different protocols like Modbus.

3.1.1.1.2 *Resistance Thermometer (RTD)*

The main board has the option for an RTD. For the excitation current and to measure the RTD resistance value, this references design uses the ADS122U04. 图 27 shows the implementation of a ratiometric, three-wire RTD measurement using the excitation current sources integrated in the ADS122U04. The sensor signal (that is, the voltage across the RTD) and the reference voltage for the ADC are derived from the same excitation source. Therefore, errors resulting from temperature drift or noise of the excitation source cancel out because these errors are common to both the sensor signal and the reference. The excitation current from the ADS122U04 is provided through the two diodes D4 and D5, which develop a reference voltage across R42. This 3.24-kΩ precision resistor has a 0.1% tolerance with a temperature coefficient of 10 ppm/°C and generates the reference voltage for the ADC, which enables a ratiometric measurement.

图 27. Three-Wire RTD Measurement
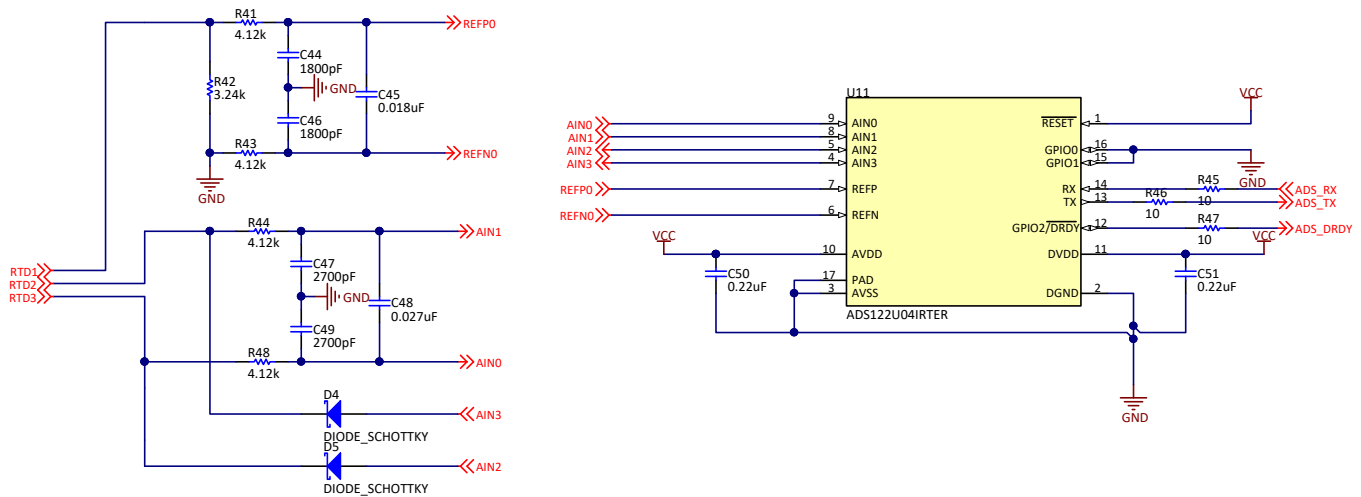
3.1.1.2   *TIDA-010012 Wi-Fi® and Display Board*

图 28 shows the Wi-Fi and display board. All components are located on the top layer of the PCB for easy evaluation.

图 28. Wi-Fi® and Display Board

The board has an onboard eight-color LCD module LS013B7DH06, which is connected to J4. The display has an SPI interface and can be either controlled from the CC3220MODASF or from the MSP432P4111 on the main board. For the Wi-Fi connection, the CC3220MODASF is on the board which is a plug and play module; no other RF components are needed.

3.1.1.3   *TIDA-010012 CC2652 Adapter Board*

图 29 shows the CC2652 adapter board. All components are located on the top layer of the PCB for easy evaluation.

图 **29. CC2652 Adapter Board**
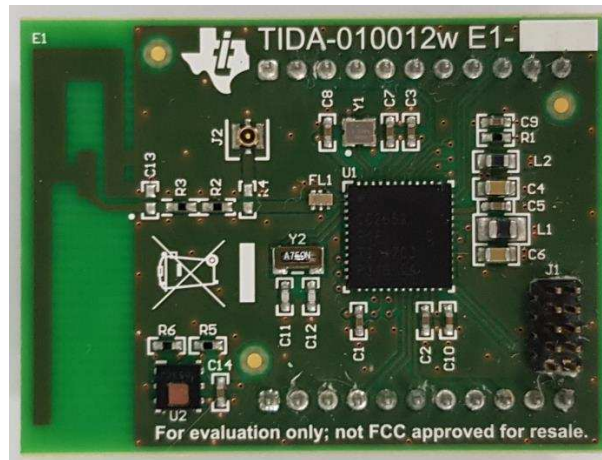
The board has an inverted-F 2.4 GHz PCB Antenna. PCB antennas are very layout sensitive. For best performance it is recommended to follow the design layout in the *2.4-GHz Inverted F Antenna* application report. This document describes a printed-circuit board (PCB) design that can be used with all 2.4-GHz transceivers and transmitters from TI.

The CC2652 adapter board has the HDC2080 device on board which is an integrated humidity and temperature sensor that provides high accuracy measurements with very low power consumption. Therefore the board can also be used stand-alone as a wireless humidity and temperature sensor. A single CR2032 coin cell is sufficient to power the board in stand-alone mode. The battery can be connected to TP1 (VCC) and TP2 (GND).

3.1.2 Software

3.1.2.1 *CC3220 SimpleLink™ SDK and IBM Watson MQTT Client*

With the CC3220 connected to the internet via Wi-Fi, this reference design can start sending data to the cloud. An ideal protocol for updating the cloud with the vacuum pump state is the Message Queue Telemetry Transport (MQTT) protocol. It is ideal for an embedded system like this reference design because it is a lightweight protocol, and is based on the publish-subscribe model.

Being based on the publish-subscribe model means that client devices using the protocol send messages to each other by publishing them to a central broker first. The broker then distributes the messages to all other clients subscribed on the topic the message was published on. This provides the benefit of allowing the network of connected clients to scale through the cloud vendor, and it is easy to add MQTT client functionality into a SimpleLink Wi-Fi-based design, because there is an MQTT client library included in the CC3220 software development kit.

The MQTT client library from the SDK can be used to quickly connect to a cloud server, such as IBM. The SimpleLink CC32XX Watson IoT Plugin delivers components that enable engineers to develop applications on the CC3220 MCU that connect to, and utilize features of, the Watson IoT platform.

3.1.2.2   CC26x2 SimpleLink™ SDK

The SimpleLink CC26x2 SDK provides a cohesive and consistent experience by packaging essential software components such as TI RTOS, peripheral drivers, TI 15.4-Stack, Bluetooth low energy, and TI OpenThread Stack examples in one easy-to-use software package along with exhaustive documentation. For more information, visit http://www.ti.com/simplelink.

3.1.2.3   MSP432P4 SimpleLink SDK

The SimpleLink MSP432P4 SDK delivers components that enable engineers to develop applications on Texas Instruments' micro-controller devices. The product is comprised of multiple software components and examples of how to use these components together. In addition, examples are provided to demonstrate the use of each functional area and each supported device and as a starting point for your own projects.

3.2 Testing and Results

3.2.1 Test Setup

To test the stability of the wireless meshed network in an industrial environment, 22 nodes and one gateway were installed in a noisy environment where hundreds of different machines, like vacuum pumps, steppers for photolithography, etching, cleaning, doping, and dicing machines, are running. 图 21 shows the mesh network which was used for the tests. The orange dots are the nodes connected to the pumps and the green dot is the gateway.

3.2.2 Test Results

As an example, the reference design boards are connected through the RS-485 interface and RS232 interface to several vacuum pumps (Busch Cobra DS) in a semiconductor fabrication plant. 图 30 shows a picture of one node, which is connected to a vacuum pump and reads out the pump data.

图 **30. TIDA-010012 Reference Design Connected to one Vacuum Pump**

The Busch vacuum pumps provide permanent measurement data of the casing temperature, motor current, nitrogen flow, water flow and other status information. Furthermore, the vacuum pumps provide the 24 V to power the reference design board. These vacuum pumps must be closely monitored to ensure uninterrupted operation. With this reference design board connected to the vacuum pumps, the permanent measurement data can be centrally collected and easily accessed through the internet.

图 31 shows an extract of the collected condition monitoring data of one vacuum pump. The oil status (oil), nitrogen flow (n2), water flow (H2o) and temperature (tamb) of the pump are shown in this case over several days. This collection enables the possibility for trend analysis and predictive maintenance.

图 31. Condition Monitoring Data of one Vacuum Pump
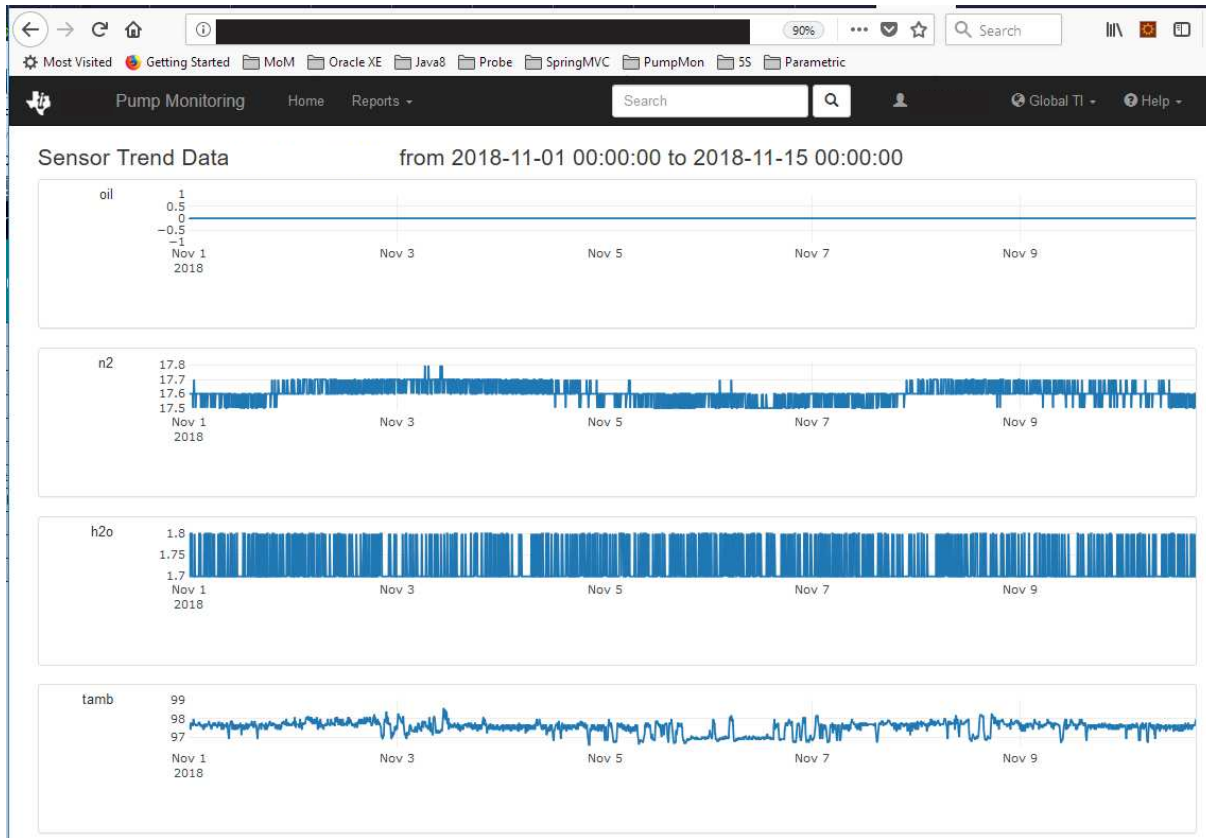
It gives operators of the pumps insight into failures before they happen. Defective components that could soon lead to a system shutdown can be identified independently of the usual maintenance schedule and replaced before damage actually occurs.

4   Design Files

4.1   Schematics

To download the schematics, see the design files at TIDA-010012.

4.2   Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-010012.

4.3   PCB Layout Recommendations

For best performance of the CC2652 PCB antenna, TI recommends following the design layout in the *2.4-GHz Inverted F Antenna* application report.

4.3.1   Layout Prints

To download the layer plots, see the design files at TIDA-010012.

4.4   Altium Project

To download the Altium Designer® project files, see the design files at TIDA-010012.

4.5   Gerber Files

To download the Gerber files, see the design files at TIDA-010012.

4.6   Assembly Drawings

To download the assembly drawings, see the design files at TIDA-010012.

5   Software Files

The TIDA-010012 software is composed of multiple elements subject to several licensing types. Most of the drivers, communication stacks, and OS kernel are included in the SimpleLink SDK. The TIDA-010012 software is an example for the hardware evaluation and have not been validated as production-ready. In the case of the mesh network protocol stack, various alternatives are available, like the open-source implementation supported by the community project Contiki-NG. Other software stacks such as BLE, ZigBee, and so forth, can be utilized for hardware evaluation as well.

6   Related Documentation

1. Texas Instruments, *CC3220MODx and CC3220MODAx SimpleLink™ Wi-Fi® CERTIFIED™ Wireless MCU Modules Data Sheet*
2. Texas Instruments, *CC3120 and CC3220 Simplelink™ Wi-Fi® Embedded Programming User's Guide*
3. Texas Instruments, *CC2652R SimpleLink™ Multiprotocol 2.4-GHz Wireless MCU Data Sheet*
4. Texas Instruments, *CC13x2, CC26x2 SimpleLink™ Wireless MCU Technical Reference Manual*
5. Texas Instruments, *MSP432P411x, MSP432P401x SimpleLink™ Mixed-Signal Microcontrollers Data Sheet*
6. Texas Instruments, *MSP432P4xx SimpleLink™ Microcontrollers Technical Reference Manual*
7. Texas Instruments, *ADS122U04 24-Bit, 4-Channel, 2-kSPS, Delta-Sigma ADC With UART Interface Data Sheet*
8. Texas Instruments, *TRS3232E 3-V to 5.5-V Multichannel RS-232 Line Driver and Receiver With ±15-kV IEC ESD Protection Data Sheet*

9. Texas Instruments, *THVD14xx 3.3-V to 5-V RS-485 Transceivers With ±18-kV IEC ESD Protection Data Sheet*

10. Texas Instruments, *ISO121x Isolated 24-V to 60-V Digital Input Receivers for Digital Input Modules Data Sheet*

11. Texas Instruments, *LMR36006 4.2-V to 60-V, 0.6-A Synchronous Step-Down Converter Data Sheet*

12. Texas Instruments, *TLV755P 500-mA, Low I_Q, Small Size, Low Dropout Regulator Data Sheet*

13. Texas Instruments, *LMZM23600 36-V, 0.5-A Step-Down DC/DC Power Module in 3.8-mm × 3-mm Package Data Sheet*

14. Texas Instruments, *HDC2080 Low Power Humidity and Temperature Digital Sensor Data Sheet*

15. Texas Instruments, *TIOL111 IO-Link Device Transceivers with Integrated Surge Protection Data Sheet*

16. Texas Instruments, *TVS3300 33-V Precision Surge Protection Clamp Data Sheet*

17. Texas Instruments, *SimpleLink™ SensorTag*

18. Beagleboard.org, *Getting Started*

19. Busch, *Vacuum Pumps and Systems: COBRA DS 0080/0160 G*

20. 6TiSCH, *IPv6 over the TSCH mode of IEEE 802.15.4e*

21. Contiki-NG, *Documentation: TSCH and 6TiSCH*

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7   Acknowledgments

The author wish to acknowledge Jianwei Zhou, Il Han Kim, Martin Gattig, and Georg Schmid for their technical contributions to this TI Design.

8   About the Author

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