# TI Designs
# Power Solution for Battery Operated Meters With 30-dBm wM-Bus at 169 MHz

TEXAS INSTRUMENTS

## TI Designs

Smart gas and water meters in Italy and France require both an ultra-low-power metrology solution combined with a wM-Bus 169-MHz RF subsystem of 25 to 30-dBm transmit power at the antenna port. This power solution is able to supply currents of up to 800 mA at 3.6 V, needed for 30-dBm transmit power from different battery types. The included software example enables periodical transmission of the flow meter reading while using an optimized power solution, which eliminates the costly HLC through the step-down charging of a SuperCap and boosting the high current. Using this design, customers can quickly design a gas or water meter compliant with the technical requirements in Italy and France.

## Design Resources

| | |
|---|---|
| TIDA-00676 | Design Folder |
| TPS62740 | Product Folder |
| TPS61030 | Product Folder |
| CC1120 | Product Folder |
| MSP430FR6989 | Product Folder |
| PMP9753 | Tool Folder |
| CC112XSKY65367EM-RD | Tool Folder |
| TPS61030EVM-208 | Tool Folder |

TI E2E™ Community

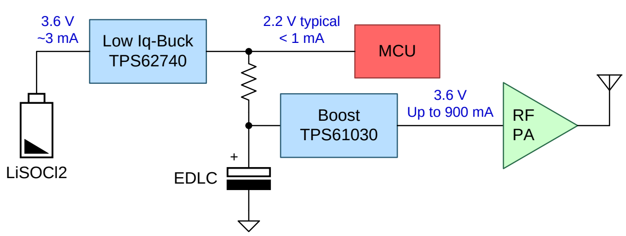
ASK Our E2E Experts
WEBENCH® Calculator Tools

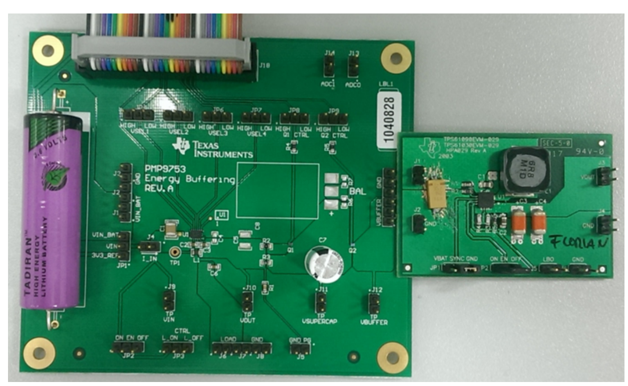
## Design Features

- Up to 1 A at 3.6-V Current Supply From Multiple Battery Types, Configurations, and Chemistries
- Ultra-Low-Power Smart Flow Meters With LCD and Rotation Detection
- Up to 30-dBm wM-Bus at 169-MHz Subsystem, Compliant With Italian UNI-TS11291-11-4 Specification and French 169-MHz Technical Requirements
- Market Leading Blocking, Selectivity, and RX Sensitivity RF Solution for all N-Modes
- Example Source Code for Nabcdefg-Mode Transmit

## Featured Applications

- Battery-Powered Smart Flow Meters (Gas, Water, and Heat) With wM-Bus at 169 MHz and up to 30-dBm Transmit Output Power
- Data Collectors, Mobile Reader Units, and In-Home Displays With wM-Bus at 169 MHz
- E-Meters With wM-Bus at 169 MHz



An IMPORTANT NOTICE at the end of this TI reference design addresses authorized use, intellectual property matters and other important disclaimers and information.

# 1 Key System Specifications

The CC1120 operates from 2.0 to 3.6 V with 3.9 V as the absolute maximum value allowed. The MSP430FR6989 operates from 1.8 to 3.6 V with 4.1 V as the absolute maximum rating. The SKY65357 operates from 2.0 to 3.6 V with 3.8 V as the absolute maximum rating. Therefore, a common supply voltage of 2.0 through 3.6 V is the common range for these three devices.

The TPS62740 has a $V_{IN}$ range from 2.2 to 5.5 V and handles the very efficient charging of the SuperCap1 with a 3-F capacity and maximum voltage of 2.7 V, by using its dynamic voltage scaling output feature. The device limits the maximum battery current to at least 4 mA and allows the usage of LiSoCl2 primary batteries. By adding some margin to the lower operating voltage for the full flow meter system, the 3-F SuperCap will be discharged from the maximum 2.7 V down to 2.2 V, which is also the voltage supply for the MSP430 + CC1120 subsystem.

The TPS61030 provides currents up to 1 A by boosting the voltage of the SuperCap up to the optimum 3.6 V for the SKY65367. Prior to any transmit operation, the MSP430 initiates the charging of the SuperCap up to 2.7 V, such that the 800-mA and 500-ms long current pulse can be delivered by the SuperCap without drawing current from the battery.

For handling three transmissions within just a few seconds of delay, the SuperCap can be selected with a triple capacity, resulting in 9 F (where a 10-F device is available).

The operating ambient temperature for all devices is $T_A$ = –40 to 85°C.

## 2 System Description

With the adoption of the wM-Bus N-mode protocol for the smart residential gas meters deployment in Italy as well as for gas and water meters in France, there is a huge demand for 169-MHz N-mode compliant solutions with the best possible RF performance and optimized battery lifetime of up to 20 years.

All residential flow meters are battery-operated, meaning its peak current and energy capacity is quite limited by the physical dimensions of the water or heat meter and a bit less so in gas meters. The transmit power allowance of up to 500-mW ERP as defined in the *wM-Bus Standard Document* [4] and the high losses of small sized 169-MHz antennas that fit in a flow meter's plastics enclosure necessitate the use of an external, high efficiency power amplifier or front end module (FEM) such as the SKY65367. The latter was specifically designed to meet the ETSI requirements for the 169-MHz metering applications by delivering up to 30-dBm transmit power.

The combination of CC1120 and SKY65367-11 is a wM-Bus at 169-MHz RF subsystem, which exceeds the requirements for both Italian and French gas metering specifications and is targeted at systems with ETSI Category 1 Compliance in the 169-MHz band without a SAW filter or external LNA. Adding a 15-dB attenuator device with bypass functionality, such as the AA116_72LF, extends the dynamic power range down to –27 dBm, as per UNI-TS-11291-11-4 in Italy. For the French market, this component is not required and should be removed.

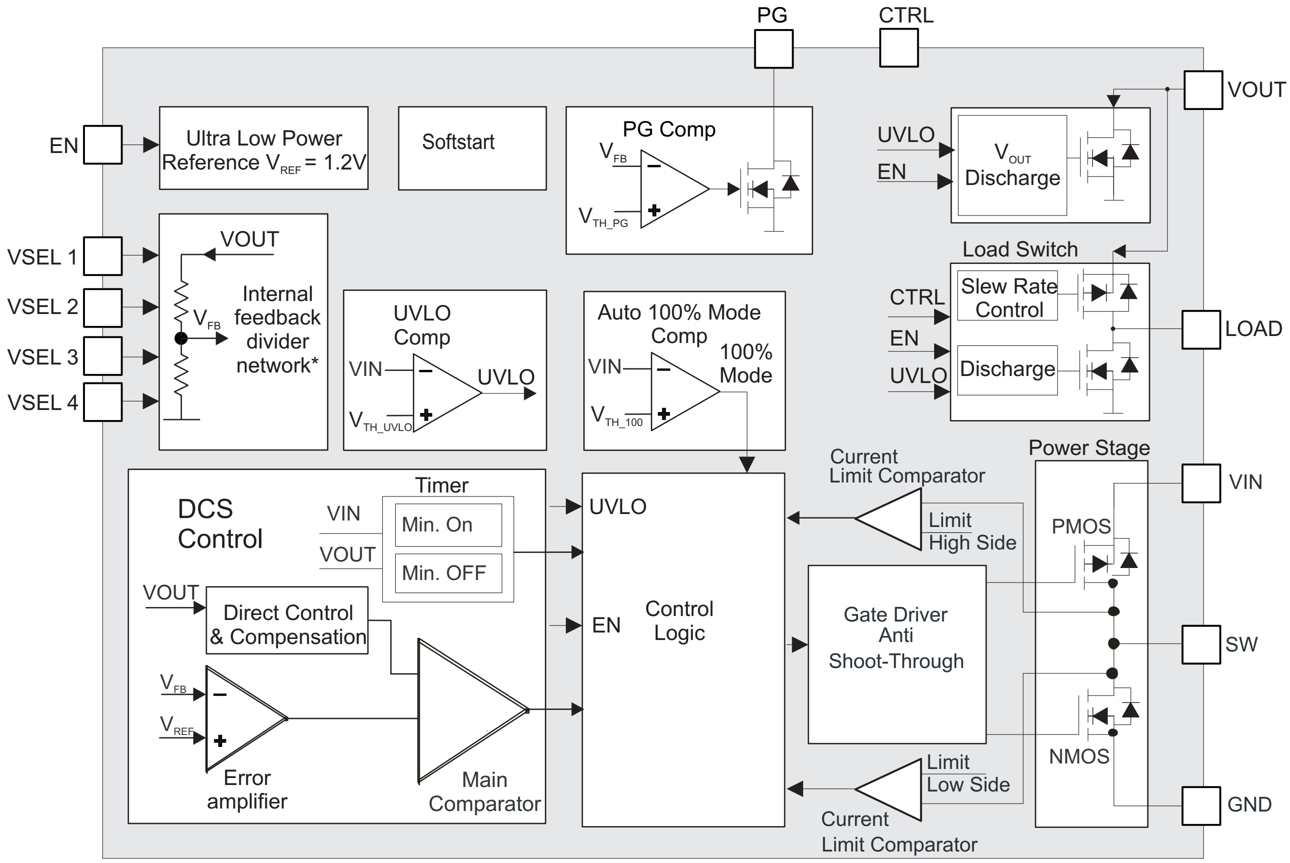
This TI Design proposes a complete flow meter system, which consists of:

- battery management solution for 30-dBm (or 1 W) RF systems from LiSoCl2 or LiMnO2 primary cells
- wM-Bus ETSI Category 1 receiver compliant RF subsystem
- Ultra-low-power metrology MCU (FRAM-based) with a hardware engine for rotation detection and integrated 320-segment LCD controller

The MSP430 uses its ESI engine for rotation detection and periodically will transmit the number of rotations (also displayed on the LCD) through a wM-Bus N-mode compliant packet. A special test mode in the firmware allows the user to put the CC1120 in unmodulated transmit carrier mode, which is useful to measure the peak transmit power and harmonics as required for RF certification testing.

## 2.1 TPS62740 — 360-nA $I_Q$ DC/DC With Dynamically Selectable Output Voltage

The TPS62740 is the first step-down converter with an ultra-low quiescent current consumption (360 nA typ.) and features TI's DCS-Control™ topology while maintaining a regulated output voltage. The device extends a high efficiency operation to output currents down to a few micro-amperes, which is the range that utility flow meters typically have.




* typical 50MΩ

**Figure 1. TPS62740 Block Diagram**

## 2.2 TPS61030 — 96% Efficient Synchronous Boost Converter

The TPS61030 provides a power supply1solution for products powered by either a one-cell Li-Ion or Li-Polymer or a two to three-cell alkaline, NiCd, or NiMH battery. The converter generates a stable output voltage that is either adjusted by an external resistor divider or fixed internally on the chip. The device provides high efficient power conversion and is capable of delivering output currents up to 1 A at 5 V at a supply voltage down to 1.8 V.

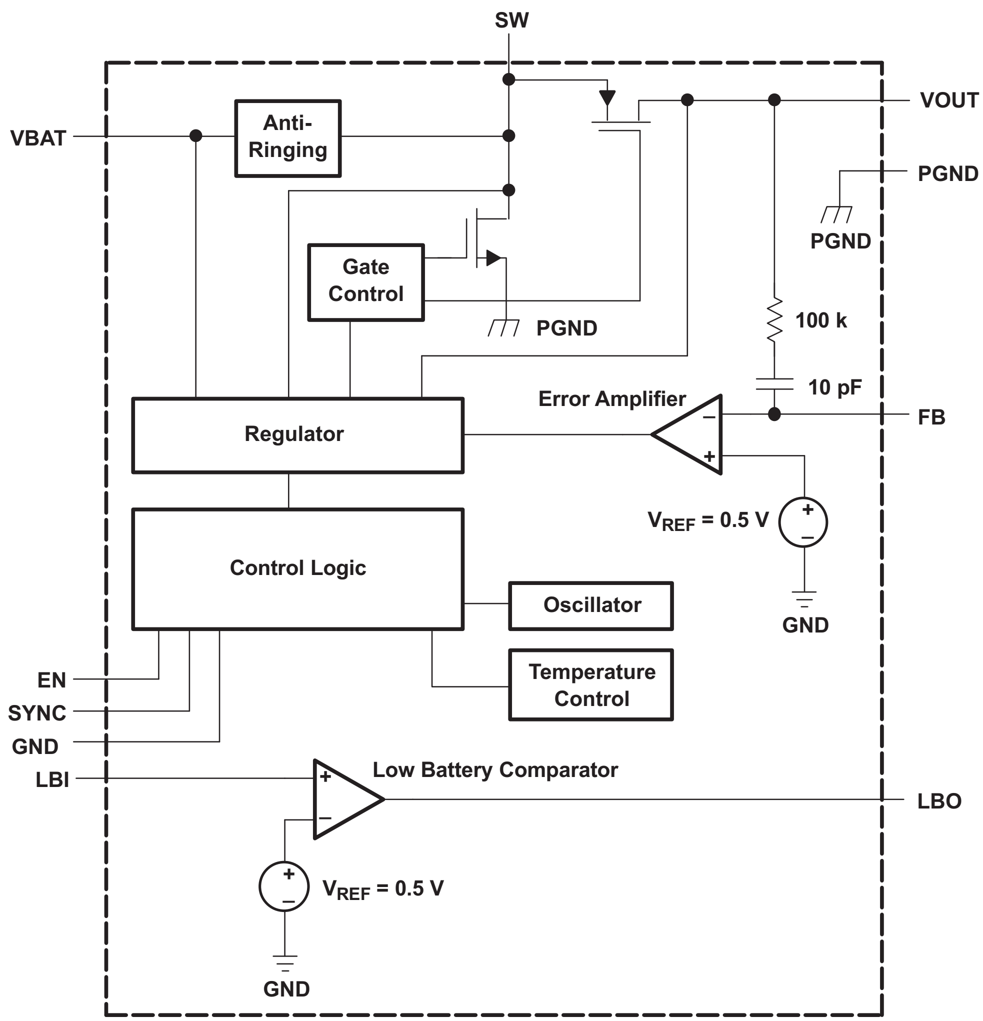



**Figure 2. TPS61030 Block Diagram**

## 2.3 MSP430FR6989 — Ultra-Low-Power FRAM MCU for Flow Meters

The MSP430FR6989 is a 16-bit embedded MCU with optimized low-power modes, an active current of 100 µA/MHz and standby mode of 350 nA with real-time clock (RTC) counter clocked by a 3.7-pF crystal. The 128-KB Ferroelectric RAM (FRAM) non-volatile and unified memory of program code, constants, and storage area offers sufficient space for complex metering applications combined with the wM-Bus RF stack. A dedicated peripheral module, named Extended Scan Interface (ESI), is optimized for background water, heat, and gas volume measurement with minimum energy consumption.

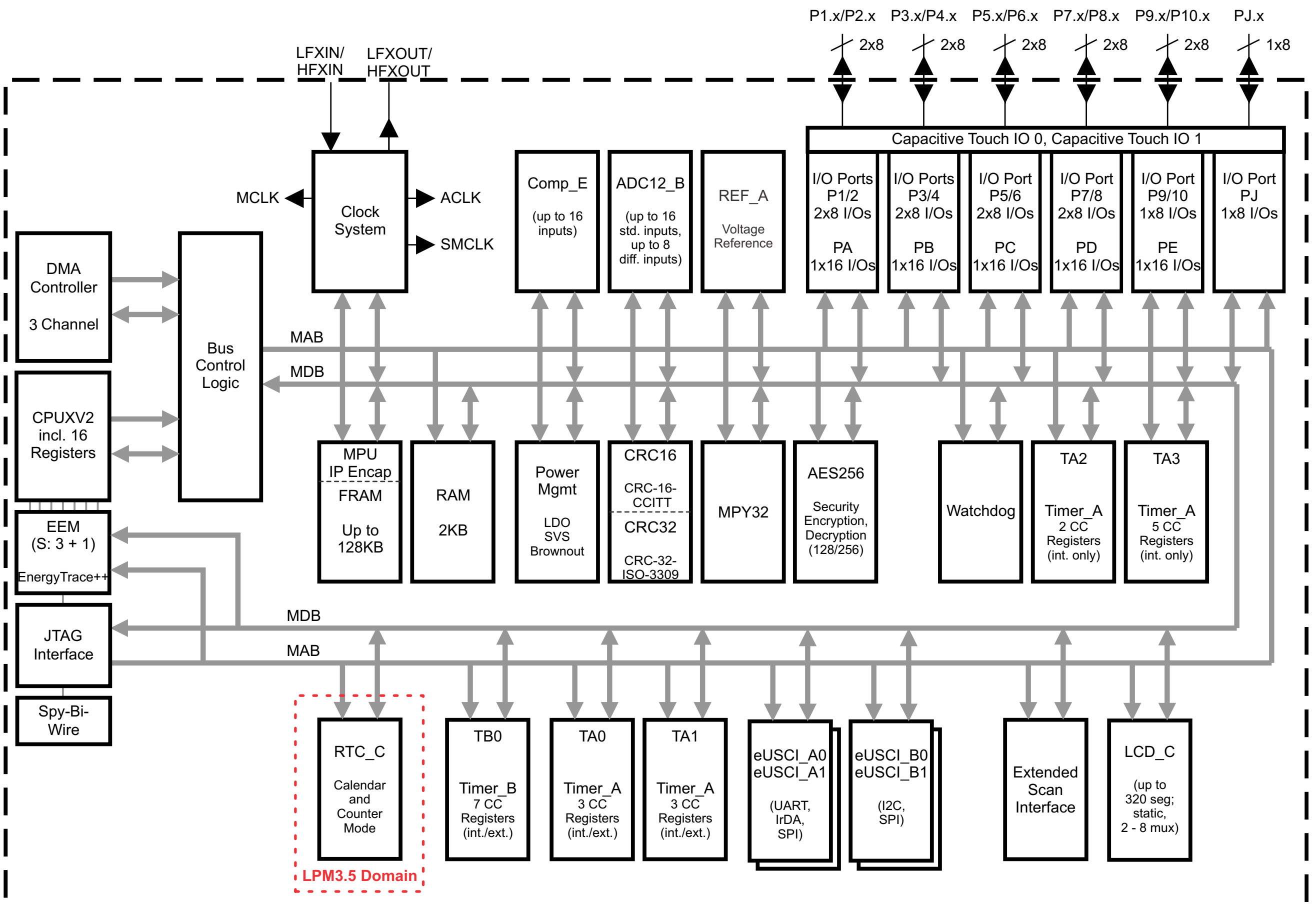



**Figure 3. MSP430FR6989 Block Diagram**

## 2.4 CC1120 — High-Performance RF Transceiver for Narrowband Systems

The CC1120 transceiver features an adjacent channel selectivity of 64 dB at a 12.5-kHz offset and blocking performance of 91 dB at a 10-MHz offset in combination of excellent receiver sensitivity of –123 dBm at 1.2 kbps. This enables ETSI Category 1 receiver performance without an external SAW filter, TCXO, or an additional LNA component in the 169-MHz band and offers transmit power range adjustment of –11 to 16 dBm in fine (< 0.5 dB) steps.

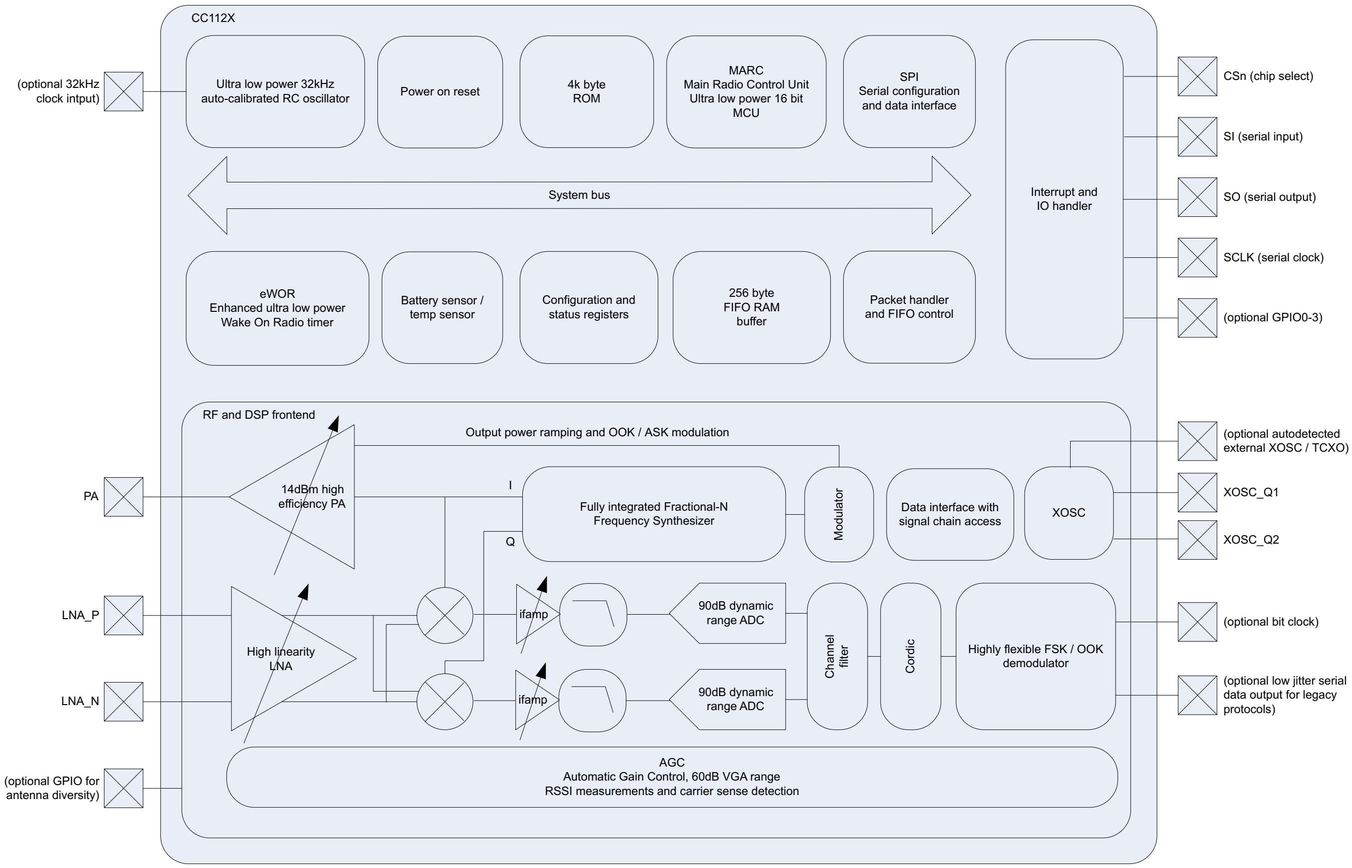



**Figure 4. CC1120 Functional Block Diagram**

## 2.5 169 to 170-MHz Transmit/Receive FEM SKY65367-11 With Bypass Mode

The SKY65367-11 is a high performance, transmit and receive (TX/RX) FEM. The device includes a power amplifier (PA) capable of 30 dBm of transmit output power (when VCC = 3.6 V) at more than 43 percent PAE for the module and 63 percent for the standalone PA. For current-sensitive applications or when high transmit power is not required, the PA can be bypassed to save battery current. All functionality can be controlled by a three-wire interface. The FEM can be placed in a deep "sleep" mode, drawing less than 1 µA of current. The receive chain consists of a low-loss single-pole, triple-throw (SP3T) switch, which provides an insertion loss of approximately 0.4 dB. Three separate VCC pins enable maximum RF isolation. The SKY65367-11 is packaged in a 16-pin, 4×4-mm multi-chip module (MCM), which allows for a low-cost solution that is easy to manufacture.

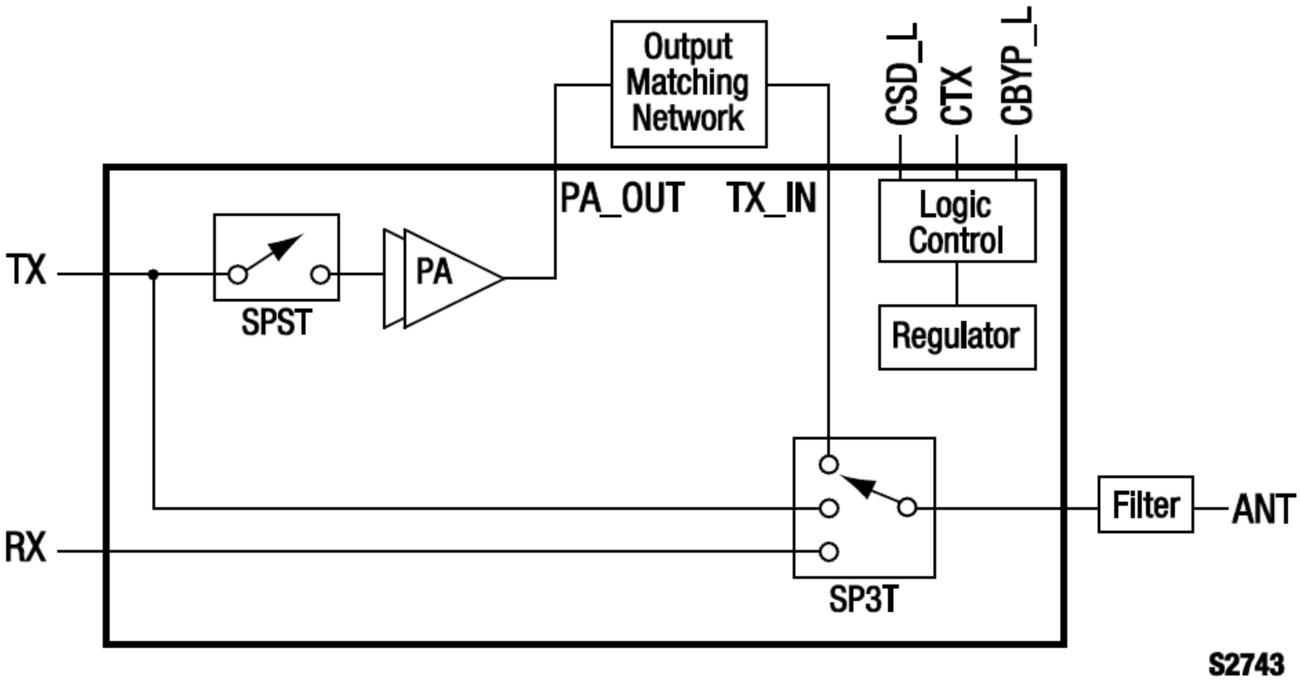



**Figure 5. SKY65367-11 Block Diagram**

# 3 Block Diagram

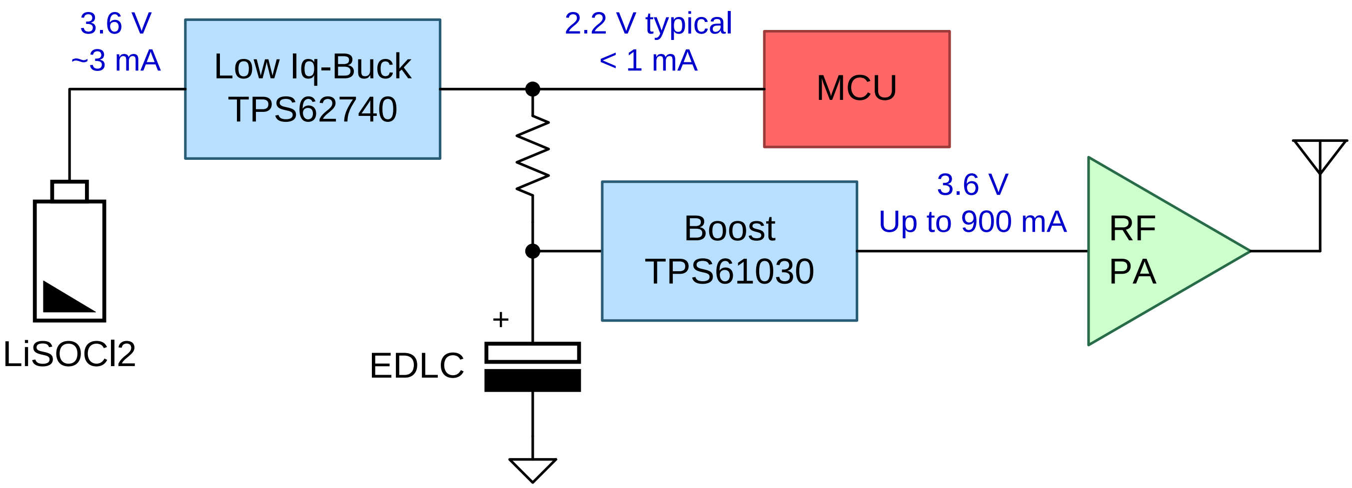



**Figure 6. High Current Power Solution for Battery-Operated Meters Block Diagram**

## *3.1 Highlighted Products*

This TI Design describes a complete smart flow meter (water or gas) with an ultra-low power rotation detection peripheral and operating a wM-Bus compliant RF link at 169 MHz with high transmit power of up to 30 dBm, supplied by a dedicated power management solution for batteries with limited peak current.

The focus of this TI Design is on both the power management solution and the wM-Bus at 169-MHz RF subsystem, as the metrology portion is covered in EVM430-FR6989 sample source code [7].

### 3.1.1 TPS62740

The TPS62740 features low output ripple voltage and low noise with a small output capacitor. The device operates from rechargeable Li-Ion batteries, Li-primary battery chemistries such as Li-SOCl2, Li-MnO2, and two- or three-cell alkaline batteries. The 16 selectable voltage levels are user selectable by four VSEL pins within a range from 1.8 to 3.3 V in 100-mV steps. The RF friendly DCS-Control TM with up to 2-MHz switching frequency is an excellent fit for wireless applications, such as wM-Bus in all 169-, 433-, and 868-MHz bands.

### 3.1.2 TPS61030

This 96% Efficient Synchronous Boost Converter With 4-A Switch can be disabled to minimize battery drain. During shutdown, the load is completely disconnected from the battery. A low-EMI mode is implemented to reduce ringing and, in effect, lower radiated electromagnetic energy when the converter enters the discontinuous conduction mode.

### 3.1.3 MSP430FR6989

The MSP430FR6989 offers multiple differentiated features such as ultra-low power consumption for rotation sensing combined with cost effective and power efficient LCD functionality. These are essential in smart flow meters, which add a RF subsystem to the metrology function. The ULP architecture of the MSP430 showcases seven low-power modes, which are optimized to achieve extended battery life in energy-challenged applications. Some of the differentiating features of the MSP430FR6989 are:

- ESI for background water, heat, and gas volume measurement
- Up to 128KB of ultra-low-power FRAM nonvolatile memory with ultra-low-power and extremely fast writes at 125 ns per word (64KB in 4 ms)
- Unified Memory = Program + Data + Storage in one single space with 1015 write cycle endurance, radiation resistant, and nonmagnetic
- Active mode: approximately 100 µA/MHz; RTC mode (LPM3.5): 0.35 µA (typical); RTC is clocked by a 3.7-pF crystal
- 128-bit or 256-bit AES security encryption and decryption coprocessor with true random number seed for random number generation algorithm
- Integrated LCD driver with contrast control for up to 320 segments

### 3.1.4 CC1120

The CC1120 is a fully integrated single-chip radio transceiver designed for high performance at very low-power and low-voltage operation in wM-Bus enabled wireless systems. All filters are integrated, thus removing the need for costly external SAW and IF filters. The device supports the ISM (Industrial, Scientific, and Medical) and SRD (Short Range Device) frequency bands at 164 to 192 MHz, 274 to 320 MHz, 410 to 480 MHz, and 820 to 960 MHz and is fully compatible with the wM-Bus standard, defined in the 169-, 433-, and 868-MHz sub-bands [9].

The separate 128-Byte deep FIFOs in TX and RX direction enable an easy processing of the wM-Bus packets and sufficient time for handling the data bytes over SPI, avoiding FIFO over- or underflow conditions while transmitting or receiving data over the air. The main operating parameters of the CC1120 are controlled through a set of registers, written or read out thru an SPI directly connected to the MSP430FR6989.

### 3.1.5 SKY65367-11 FEM With 30-dBm Output Power Level

The SKY65367 needs a 3.6-V power supply and only a –6-dBm input signal level to achieve its maximum output level. This FEM includes a PA capable of more than 30 dBm of transmit output power (VCC = 3.6 V) at more than 43 percent PAE for the module (63 percent for the standalone PA).

### 3.1.6 SKY66100-11 FEM (Pin-Compatible to SKY65367-11 FEM for 27-dBm Output Power Level)

For applications requiring optimized current consumption at a 27-dBm transmit power at 169 MHz, the pin-compatible SKY66100-11 in a 16-pin, 4×4-mm MCM should be used. This is a high performance, Tx/Rx FEM, including a PA capable of more than 27 dBm of transmit output power at more than 50 percent PAE for the module (60 percent for the standalone PA). All functionality can be controlled by a three-wire interface, and this FEM can be placed in a deep sleep mode, drawing less than 1 µA of current. The receive chain consists of a low-loss SP3T switch, which provides an insertion loss of approximately 0.4 dB. Three separate VCC pins enable maximum RF isolation and allow for a dedicated power supply for the PA, separated from the rest of the smart meter system.

# 4 System Design Theory

Several considerations were taken into account when defining this RF subsystem with the main focus on the following:

- Battery management solution replacing a hybrid layer capacitor (HLC) through a SuperCap-based approach
- Multiple battery chemistries for system cost savings and more design flexibility
- Maximizing the output current at 3.6 V to the RF FEM
- ETSI Category 1 receiver performance capability
- Full compliance with UNI-TS11291-11-4 dynamic range from –27 dBm up to 30 dBm
- Full compliance with the RF requirements for gas and water meters in France

## *4.1 Battery Management Solution With TPS62740 and TPS61030*

The solution presented in this TI Design eliminates the need of a HLC and supports either LiSoCl2 or a LiMnO2 primary battery, which cannot deliver the 1-A peak current directly without being damaged. Replacing the costly HLC provides designers with many additional battery options and thus enables cost savings on the system level. The TPS62740 DC/DC handles the charging of the SuperCap in the range of 2.2 to 2.7 V with 90% efficiency, controlled by MSP430FR6989. During normal low-power mode operation of the Metrology section (MSP439FR6989 and ESI block active) and in RF receive mode where only the CC1120 is active, the current is provided from the SuperCap, charged to 2.2 V.

As the transmission period is known and is typically a few times per day, the MSP430 enables charging of the SuperCap at the appropriate time in advance and controls the $V_{OUT}$ level of the TPS62740 step-by-step to fully charge the SuperCap up to a 2.7-V level. The MSP430 then enables the TPS61030, allowing the booster's output to settle to a 3.6-V level and only then the RF transmission operation is started.

If the FEM is used, then the 3.6-V voltage as the "high current" supply rail is activated, while the MSP430FR6989, the LCD and where needed the CC1120 are continuously operated on the common "low current" supply rail directly from the SuperCap. This means that only during an RF transmission with the SKY65367, the MSP430, and the CC1120 will be supplied with a voltage of up to 2.7 V.

## *4.2 wM-Bus RF Subsystem at 169 MHz*

The design files for the RF communication subsystem are described in found in CC112XSKY65367EM-RD. Several EM boards have been tested; Section 7.3 documents these results.

## *4.3 Flow Meter Metrology System With LCD*

This part is implemented by the EVM430-FR6989, described in the EVM430-FR6989 sample source code [7] and used here as the main MCU for running the wM-Bus N-mode example code.

# 5 Getting Started Hardware

The hardware kit comprised several boards:

- EVM430-FR6989 with motor board
- RF evaluation module based on the CC112XSKY65367EM-RD
- PMP9753 board with a SuperCap of 3 F

The EVM430-FR6989 is powered through a USB cable; the same USB connection allows for source code development and debugging. The SKY65367 FEM is separately powered through the PMP9753 board, populated with the 3-F SuperCap device.

For capturing the transmitted wM-Bus data packets, using the SRF7 Studio tool, and the provided XML configuration files, obtain the TRXEB + CC1120EM-169.

## 5.1 Setting up the Hardware System

Different test setups are used, depending on which hardware portion is being tested.

Test 1: For the transmit power and current consumption in Table 1, Table 2, and Table 3 the EVM430 is programmed with the firmware and powered through the USB cable or external power supply unit. For receiving the transmitted N-mode data, the TRXEB + CC1120EM-169 and SRF7 Studio were used.

Test 2: For the power management solution testing, the PMP9753 and the TPS61030-EVM-208 are combined as in Figure 7, with Section 7.2 listing the results. The test setup and software were done with LabVIEW™; the EVM430 was not used.

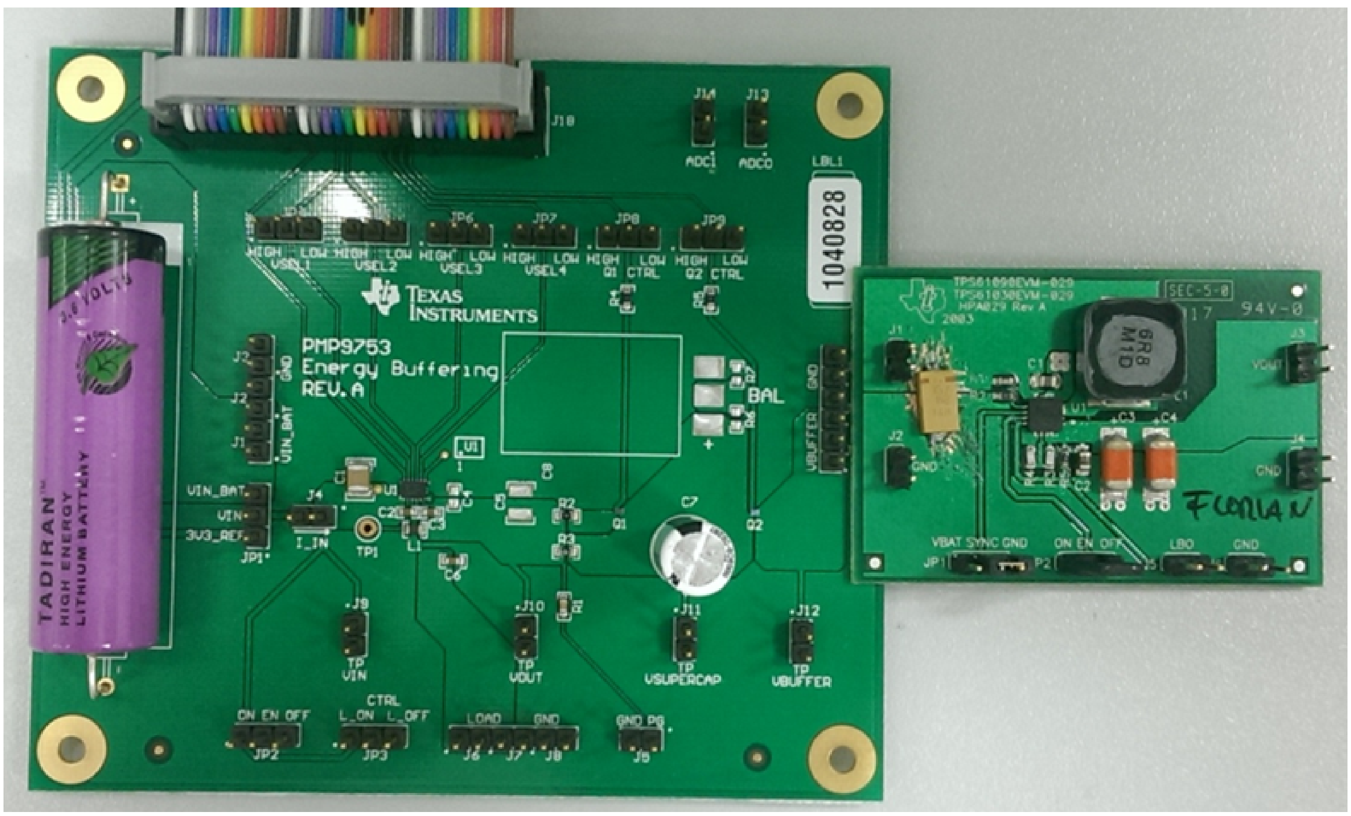



**Figure 7. Power Management Solution (PMP9753 + TPS61030 EVM)**

Test 3) The RF tests with CC112XSKY65367EM-RD boards were done in an automated RF test system, where any frequency offsets between the signal generator unit and the Device Under Test (DUT) is automatically calibrated away. The EVM430 was not used. Section 7.3 summarizes these results.

## 5.2 Testing Conditions

All measurements for Test 1 and Test 3 were done at room temperature. Ncd-mode used 169.437 MHz while Nabef- and Ng-mode used 169.4063 MHz.

### 5.2.1 Installing the Firmware

Power supply for Test 1:

1. HP E3631A bench supply to SKY65367 ($V_{IN}$ = 3.6 V, 3.0 V, and 2.1 V)

   or

2. HP E3631A bench supply to EVM430-FR6989 – connected to TARGET_VCC pin, bypassing the ezFET hardware

**NOTE:** The HP E3631A unit has not been calibrated.

Test 3 was also done at –25°C and 55°C, see Section 7.3.4.

# 6 Getting Started Firmware

The source code project can be compiled and downloaded, using CCS v6.0.1 or later development tool version, into the EVM430-FR6989 over a USB cable. The CC112XSKY65367EM-RD board is plugged into the EVM and will periodically transmit packets in the preconfigured (per firmware image) N-sub mode. The example code was can be used for further modifications and improvements, as the focus of the code development has been to implement the wM-Bus protocol physical layer; thus no specific code optimizations for the MSP430 and CC1120 low-power modes have been done. The software code examples are based on source code examples from TIDC-MULTIBAND-WMBUS and EVM430-FR6989. For simplification reasons, maximal packet length is fixed per firmware to 128 Bytes, which is the FIFO depth of the CC1120.

## 6.1 SmartRF7 Studio Files — Visualizing the wM-Bus N-Mode Transmit Data

Three configuration files for SmartRF7 have been tested and are provided as a reference for Nabef, Ncd, and Ng modes, respectively. Using these files, the transmitted packets can be captured by another piece of hardware, consisting of a CC1120EM–169-MHz board mounted onto a TRXEB, connected to a PC running TI's SmartRF7 Studio software. The correct wM-Bus N-sub mode configuration file has to be loaded into SRF7 Studio through the File → Open Cfg menu item and after starting the Reception process all received data packets will be shown in SRF7 in HEX format inside the Packet RX tab.

The SRF7 configuration files use the "fixed" packet length setting for the CC1120 FIFO, though in all N-modes SRF7 studio with "variable packet length" should work, as the first byte (= length byte) indicates the exact number of data bytes following itself as supported by CC1120's packet engine.

## 6.2 Open Source Software Example

The source code CCS project enables only TX functionality; therefore, the RF subsystem will send periodically data packets based on an RTC timer and the current reading of the rotation counter inside the MCU. This is the regular operating mode and the wM-Bus packets can be captured with the SRF7 Studio as described in Section 6.1 to ensure that they are transmitted and the packet content is correct.

A second operation mode is enabled by a push button on EVM430, putting the CC1120 into an RF test mode. For the latter, a special routine has been implemented to enable Continuous transmit mode with an unmodulated carrier (also called CW for "carrier wave") on the CC1120.

## 6.3 Power Management Control Software

To feature the load decoupling from the battery, the power management buffers energy in a storage capacitor and extracts the required transmission energy from the capacitor without drawing current from the battery. This sequence is implemented in software whereas the MCU controls the low $I_Q$ buck converter TPS62740 and enables the boost converter TPS6130.

Figure 8 shows a scheme of how the software control-sequence operates, including charging of the storage capacitor and energy extraction for the radio transmission. Figure 9 demonstrates an excerpt of the LabVIEW-based test software program.

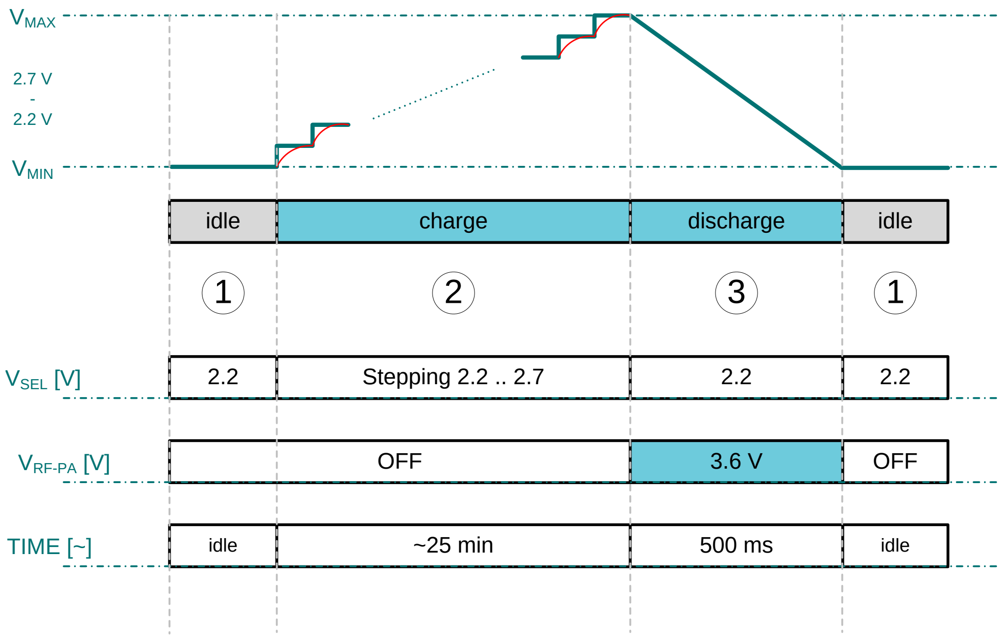



**Figure 8. Control Sequence Scheme**

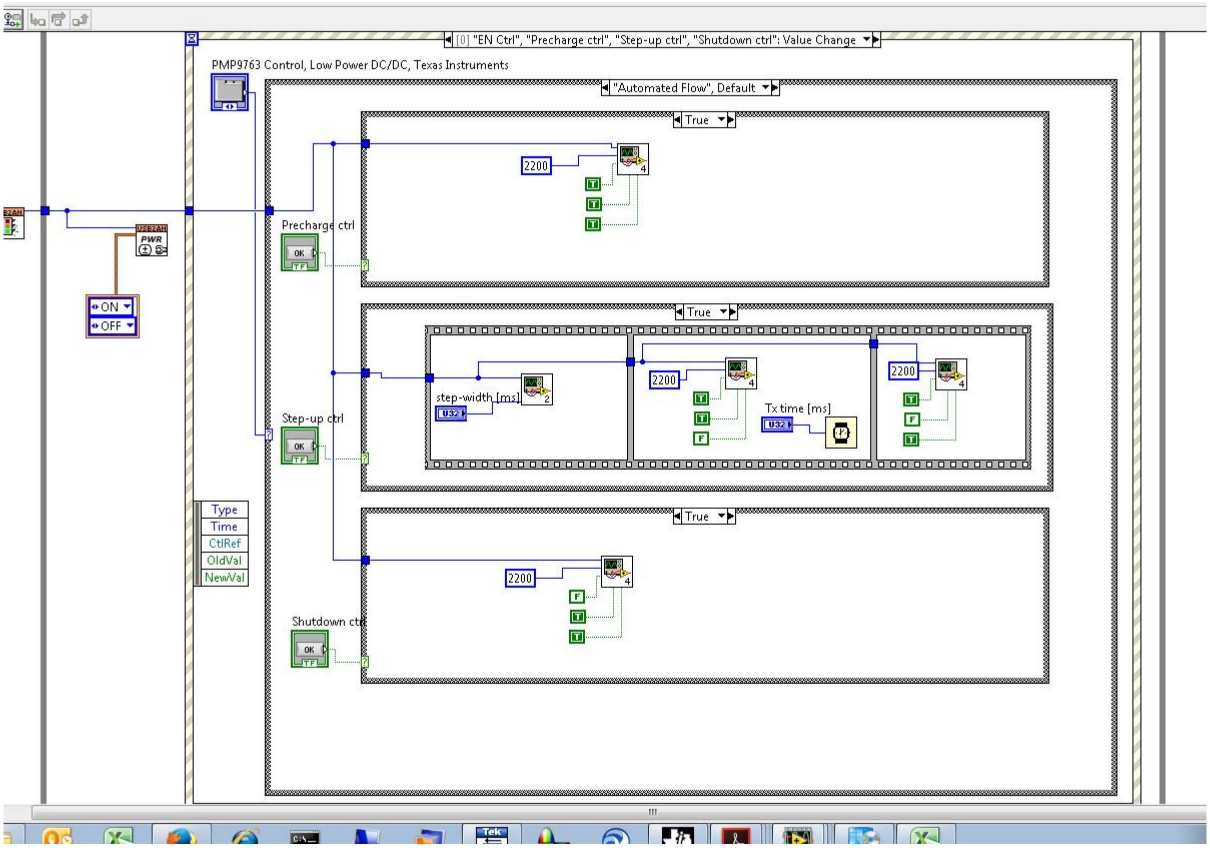



**Figure 9. LabVIEW Control Setup Excerpt**

# 7 Test Data

Detailed test results have been collected for both the battery management solution and the wM-Bus at 169-MHz RF subsystem.

## 7.1 Transmit Current

For this test, the full flow meter reference system, comprising the EVM430-FR6989 and the CC1120+SKY65367 hardware module, was powered through the USB cable (and thus through the TPS62237 device with 3.3-V fixed output voltage). On the CC1120+SKY65367 hardware module, the attenuator was set to 0 dB and the VCC jumper was set to 3.3 V (1-2) to use the supply of the TPS62237.

**Table 1. TX Current Plot for CW Unmodulated TX Carrier Signal in Nc Mode at 169.431 MHz**

| TPS62237 VOLTAGE (V) | CC1120 PA_CFG2 REGISTER VALUE | SKY65367-11 IN BYPASS MODE | ATTENUATOR AA116_72LF | FSIQ7 PEAK POWER (dBm) |
|---|---|---|---|---|
| 3.3 | 0x7F | YES | 0 dB (OFF) | 13.6 |
| 3.3 | 0x7A | YES | 0 dB (OFF) | 12.1 |
| 3.3 | 0x75 | YES | 0 dB (OFF) | 10.4 |
| 3.3 | 0x6F | YES | 0 dB (OFF) | 8.3 |
| 3.3 | 0x68 | YES | 0 dB (OFF) | 5.8 |
| 3.3 | 0x5F | YES | 0 dB (OFF) | 2.9 |
| 3.3 | 0x59 | YES | 0 dB (OFF) | 0.1 |
| 3.3 | 0x4F | YES | 0 dB (OFF) | –4.0 |
| 3.3 | 0x49 | YES | 0 dB (OFF) | –6.3 |
| 3.3 | 0x43 | YES | 0 dB (OFF) | –8.8 |
| 3.3 | 0x5F | YES | 15 dB (ON) | –11.7 |
| 3.3 | 0x58 | YES | 15 dB (ON) | –14.5 |
| 3.3 | 0x4F | YES | 15 dB (ON) | –18.4 |
| 3.3 | 0x49 | YES | 15 dB (ON) | –21.0 |
| 3.3 | 0x43 | YES | 15 dB (ON) | –23.3 |

Table 1 shows only some of the possible transmit power levels for the CC112xSKY65367EM-RD board, with the SKY65367 in bypass mode, covering a dynamic range from –24 to 14 dBm. Further test results with an external supply are shown in Table 2; here, a power supply E3631A was connected to the TARGET_VCC and GND pins of Jumper 401 of the MSP430 and measurements were taken for the TX power level settings 0x43, 0x4B, and 0x4D.

**Table 2. TX Current for CW Unmodulated TX Carrier With External VCC and PA_CFG2=0x43/4B/4D**

| EXTERNAL VOLTAGE (TARGET _VCC) | CC1120 PA_CFG2 REGISTER VALUE | SKY65367-11 IN BYPASS MODE | ATTENUATOR AA116_72LF | FSIQ7 PEAK POWER (dBm) | CURRENT (mA) |
|---|---|---|---|---|---|
| 2.1 V | 0x43 | NO | 0 dB (OFF) | 23.4 | 380 |
| 2.6 V | 0x43 | NO | 0 dB (OFF) | 24.9 | 460 |
| 2.7 V | 0x43 | NO | 0 dB (OFF) | 25.0 | 470 |
| 3.0 V | 0x43 | NO | 0 dB (OFF) | 2.0 | 510 |
| 3.3 V | 0x43 | NO | 0 dB (OFF) | 23.4 | 560 |
| 3.6 V | 0x43 | NO | 0 dB (OFF) | 24.9 | 610 |
| 2.1 V | 0x4B | NO | 0 dB (OFF) | 23.8 | 400 |
| 2.5 V | 0x4B | NO | 0 dB (OFF) | 25.1 | 480 |
| 2.7 V | 0x4B | NO | 0 dB (OFF) | 25.7 | 510 |
| 3.0 V | 0x4B | NO | 0 dB (OFF) | 26.5 | 560 |
| 3.3 V | 0x4B | NO | 0 dB (OFF) | 27.4 | 630 |
| 3.6 V | 0x4B | NO | 0 dB (OFF) | 28.1 | 680 |
| 2.1 V | 0x4D | NO | 0 dB (OFF) | 23.8 | 410 |
| 2.5 V | 0x4D | NO | 0 dB (OFF) | 25.3 | 480 |
| 2.7 V | 0x4D | NO | 0 dB (OFF) | 25.7 | 520 |
| 3.0 V | 0x4D | NO | 0 dB (OFF) | 26.6 | 580 |
| 3.3 V | 0x4D | NO | 0 dB (OFF) | 27.4 | 640 |
| 3.6 V | 0x4D | NO | 0 dB (OFF) | 28.2 | 700 |

The current numbers in the last column include the current consumption of the complete flow meter system, with the MSP430FR6989, the LCD display, and the RF subsystem. For comparison, one more measurement was made by connecting the external power supply to the Skyworks FEM only while the rest of the system was supplied through the TPS62237 at 3.3 V.

**Table 3. TX Current for CW Unmodulated TX Carrier With External VCC to Skyworks FEM, 0x4D**

| EXTERNAL VOLTAGE (TARGET _VCC) | CC1120 PA_CFG2 REGISTER VALUE | SKY65367-11 IN BYPASS MODE | ATTENUATOR AA116_72LF | FSIQ7 PEAK POWER (dBm) | CURRENT (mA) |
|---|---|---|---|---|---|
| 2.1 V | 0x4D | NO | 0 dB (OFF) | 23.8 | 390 |
| 2.7 V | 0x4D | NO | 0 dB (OFF) | 25.8 | 480 |
| 3.0 V | 0x4D | NO | 0 dB (OFF) | 26.7 | 530 |
| 3.3 V | 0x4D | NO | 0 dB (OFF) | 27.5 | 580 |
| 3.6 V | 0x4D | NO | 0 dB (OFF) | 28.1 | 630 |

Note that in Table 1, Table 2, and Table 3, the FSIQ7 device has not been calibrated and cable loss (of around 0.8dB) is not included; therefore, the conducted power measurement for the RF subsystem is approximately 29 dBm. Also note that the 15-dB attenuator in OFF mode reduces the maximum achievable transmit power of the CC112xSKY65367EM-RD board due to its 0.45-dB insertion loss.

## 7.2 Power Management Sequence Performance Results

This section shows the test results of the power management block, including energy buffering, to decouple RF load pulses from the primary battery. Figure 10 shows one cycle for buffering the required RF amplifier energy and extracting it from the storage capacitor for transmission. The green trace shows the current drawn from the battery. The current is just required during the charging phase and is not present during transmission (indicated by the radio power amplifier voltage, yellow trace). The current during the charging phase is limited to ~4 mA by the 100-mV voltage increments to achieve highest available capacity from a LiSoCl2 battery.

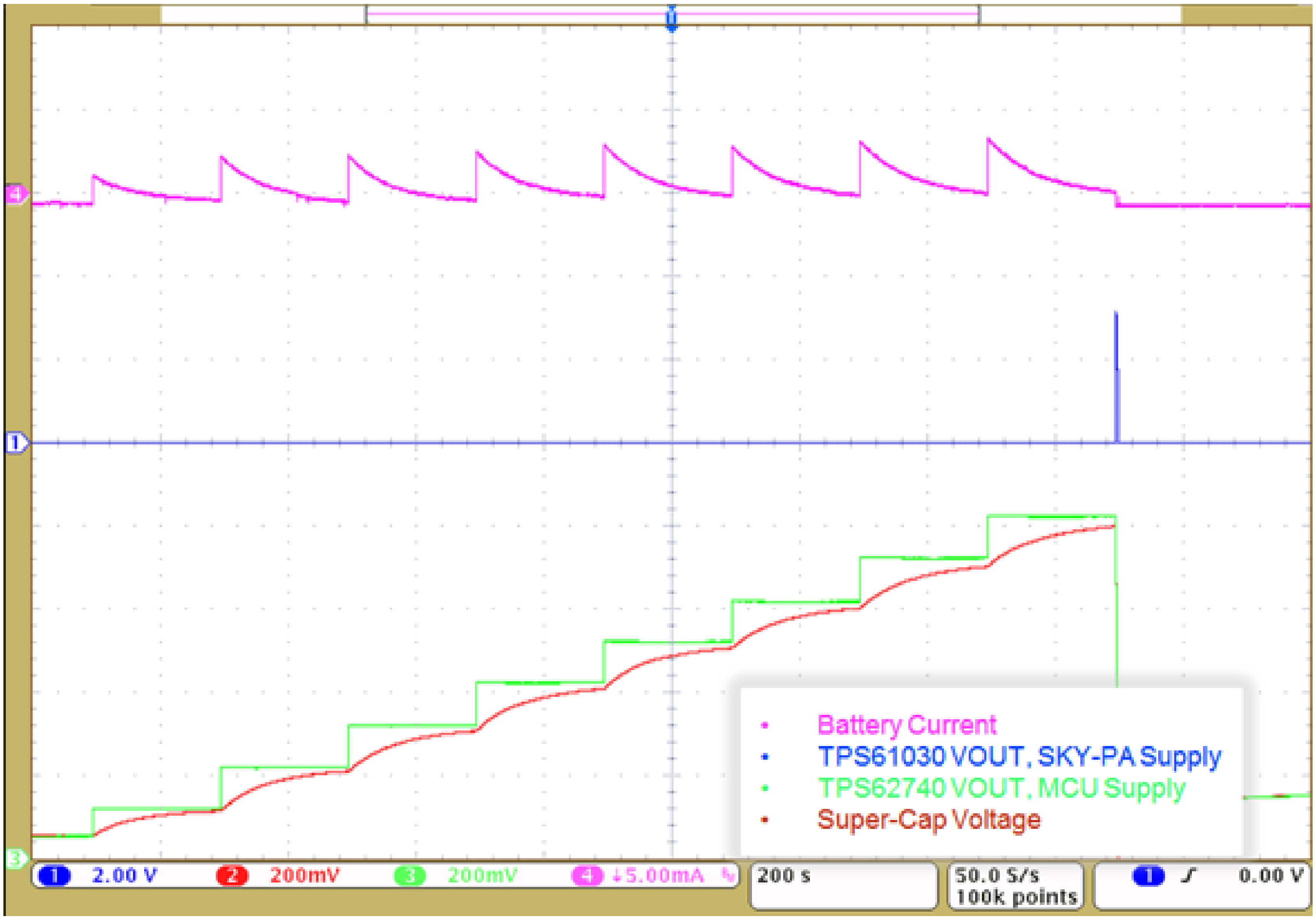



**Figure 10. Transmission Sequence Including Energy Buffering**

Figure 11 shows the waveforms during the transmission event. The yellow trace shows the power amplifier voltage, which is just active during transmission. The magenta curve shows the transmission current. The green trace shows the discharge of the storage capacitor, which provides the energy.

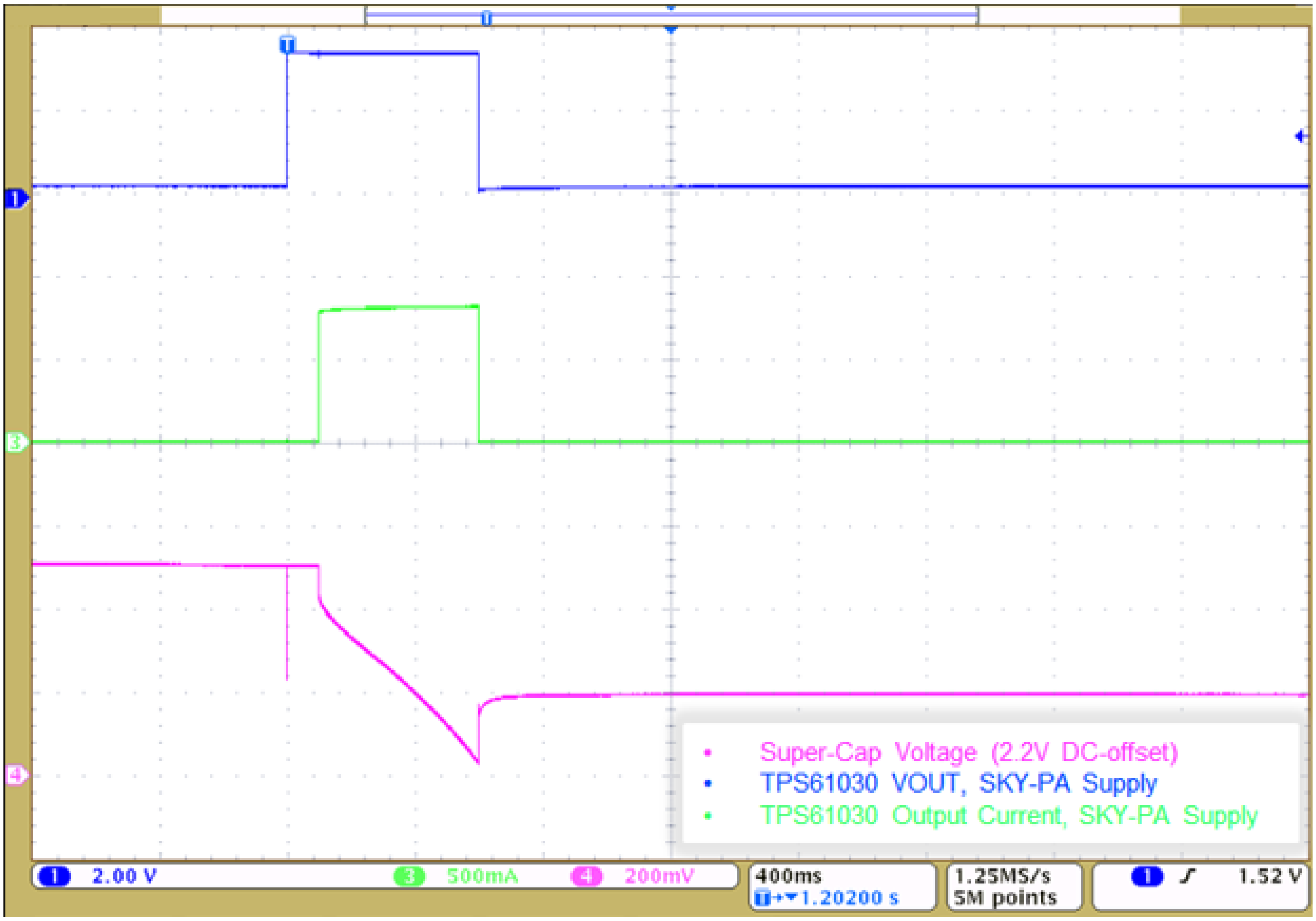



**Figure 11. Active Radio Waveforms**

Figure 12 shows the initialization of the whole system. The blue curve indicates the charging state of the storage capacitor, whereas the system voltage is present immediately (magenta curve). The capacitor is charged while the battery current is limited to 4 mA (green trace).

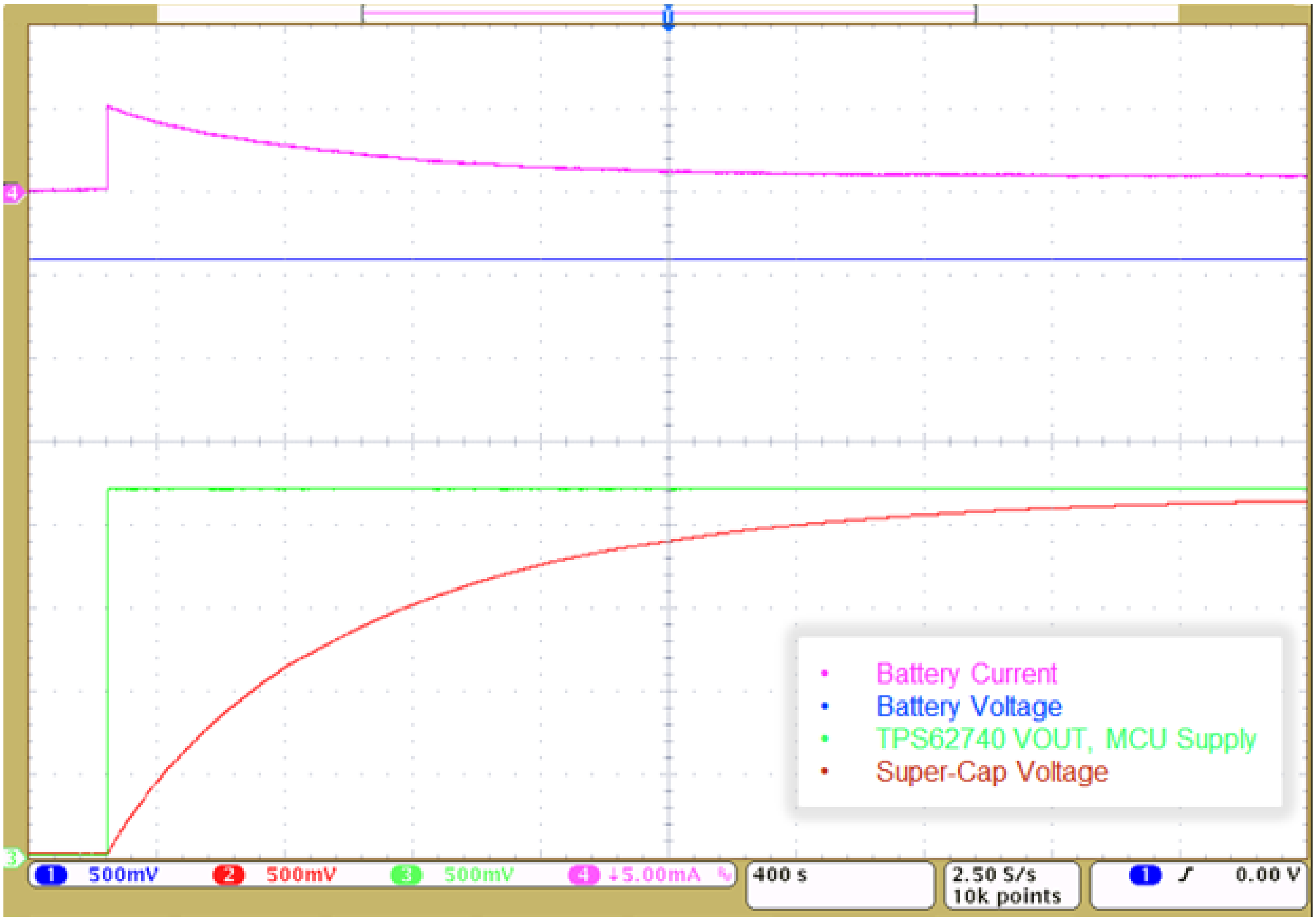



**Figure 12. Startup Waveform for Initialization**

## 7.3 Performance Results for 169-MHz RF Subsystem

This section summarizes the RF performance of the CC112xSKY65367EM-RD board as a wM-Bus RF subsystem at 169 MHz for all three EN13757-4 N-modes. To achieve ETSI Category 1 blocking performance, consider these recommended register improvements for the CC1120:

- AGC_CFG2 = 0x3
- AGC_CFG1 = 0xAB
- AGC_CFG0 = 0x4F

For even better RX sensitivity, it is recommended to test with:

- Enable FB2PLL (Feedback-to-PLL): FREQOFF_CFG register = 0x32 (extended RX BW of ±¼ for Ncd or FREQOFF_CFG register = 0x36 for Nabef)
- LNA = 0x3

### 7.3.1 Nabef-Mode Sensitivity, Blocking, and PER

Four units were tested in an automated RF test system, where any frequency offset between a signal generator and EM under test is calibrated away before testing begins.

Nabef parameters: 2-GFSK, 4.8 kbps, Devv = v2.4vkHz:

**Table 4. Nabef Sensitivity (Measured at Na Channel)**

| LIMIT (%) | PAYLOAD (BYTES) | DEVIATION | FREQUENCY (MHz) | AVERAGE OF 4 BOARDS (dBm) |
|---|---|---|---|---|
| 80 | 20 | Nominal | 169.4063 | –119.9 |
| 20 | 8 | Nominal | 169.4063 | –118.8 |
| 1 | 8 | Nominal | 169.4063 | –117.1 |
| 80 | 20 | Low | 169.4063 | –118.3 |
| 80 | 20 | High | 169.4063 | –118.7 |

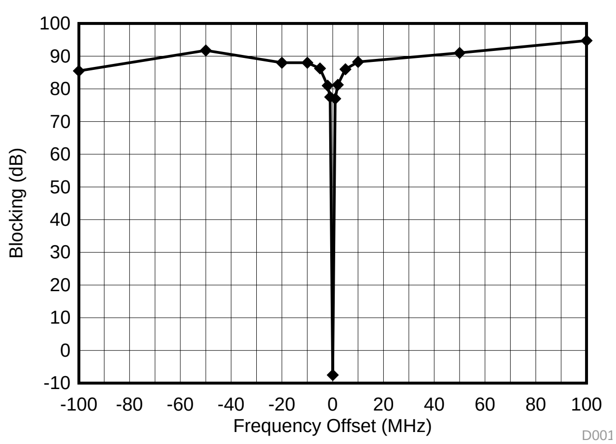



**Figure 13. Nabef Blocking (Measured at Na Channel)**

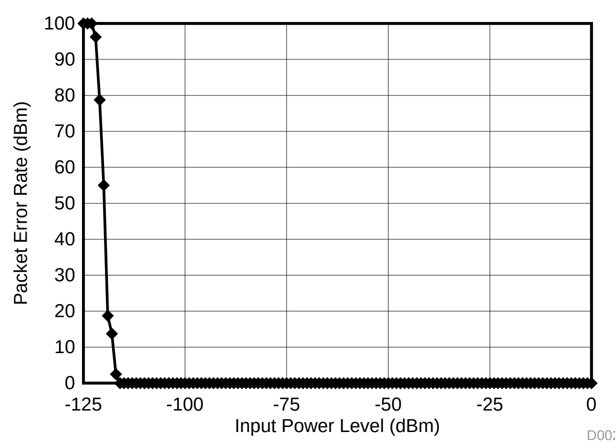



**Figure 14. Nabef PER Plot (Measured at Na Channel)**

### 7.3.2 Ncd-Mode Sensitivity, Blocking, and PER

Ncd parameters: 2-GFSK, 2.4 kbps, Dev = 2.4 kHz:

**Table 5. Ncd Sensitivity (Measured at Nc Channel)**

| LIMIT (%) | PAYLOAD (BYTES) | DEVIATION | FREQUENCY (MHz) | AVERAGE OF 4 BOARDS (dBm) |
|---|---|---|---|---|
| 80 | 20 | Nominal | 169.4313 | –121.4 |
| 20 | 8 | Nominal | 169.4313 | –120.6 |
| 1 | 8 | Nominal | 169.4313 | –118.5 |
| 80 | 20 | Low | 169.4313 | –119.7 |
| 80 | 20 | High | 169.4313 | –121.2 |

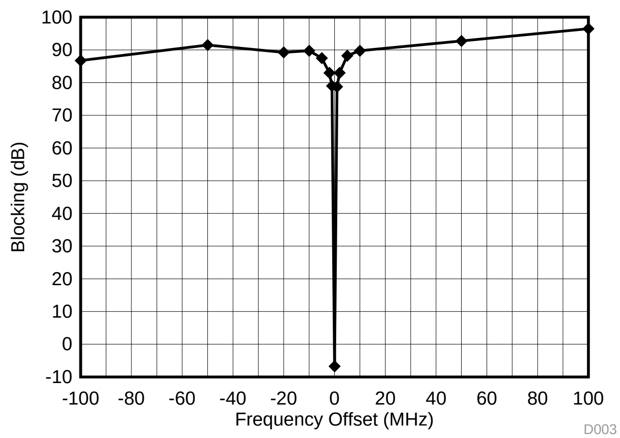



**Figure 15. Ncd Blocking (Measured at Nc Channel)**

Blocking performance has been tested at the ±1, 2, 5, 10, 50, and 100-MHz frequency offset, where ±2 and ±10 MHz are relevant for the ETSI Category 1 receiver compliance. For increased blocking performance, modify the registers AGC_CFG0/1/2 as suggested in Section 7.2.

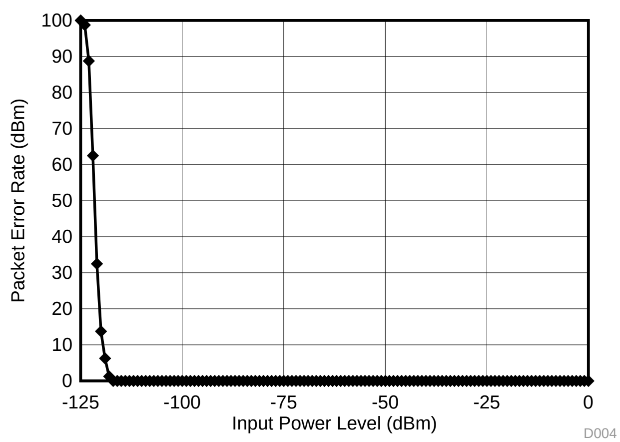



**Figure 16. Ncd PER Plot (Measured at Nc Channel)**

The packet error test was run in 1-dB steps for the input level signal from the 0-dB level (very strong RF signal down to the sensitivity limit).

### 7.3.3 Ng-Mode Sensitivity, Blocking, and PER

The Ng-mode uses 4-GFSK modulation, 50-kHz bandwidth, and 19.2 kbps.

**Table 6. Ng Sensitivity**

| LIMIT (%) | PAYLOAD (BYTES) | DEVIATION | FREQUENCY (MHz) | AVERAGE OF 4 BOARDS (dBm) |
|---|---|---|---|---|
| 80 | 20 | Nominal | 169.4063 | –114.8 |
| 20 | 8 | Nominal | 169.4063 | –113.7 |
| 1 | 8 | Nominal | 169.4063 | –111.9 |

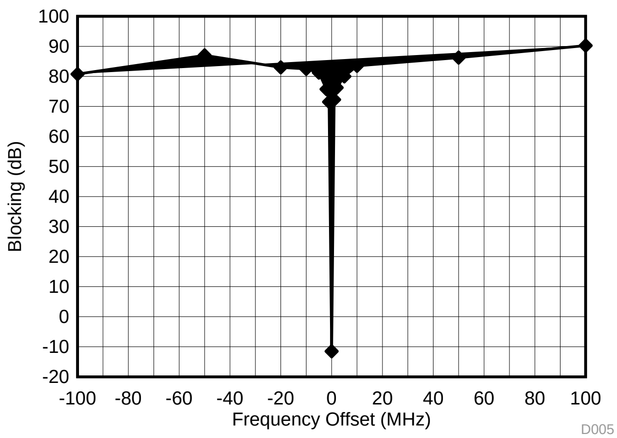



**Figure 17. Ng Blocking**

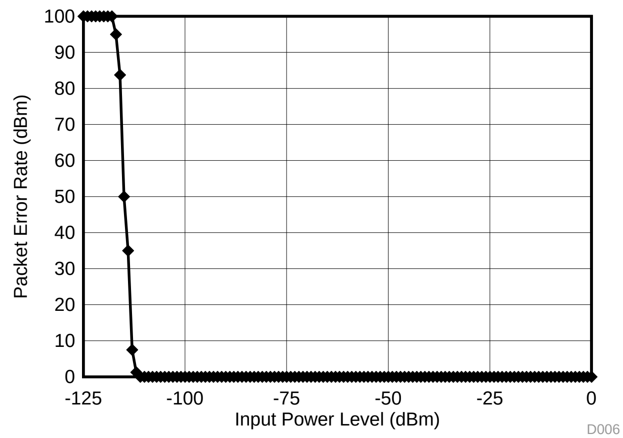



**Figure 18. Ng PER Plot (Measured at Nc Channel)**

### 7.3.4 Dynamic Range of Transmit Power

The hardware test setup can test up to six boards simultaneously. Table 7 displays data for Board 6, tested at 25°C. To determine the full dynamic range multiple combinations of the CC1120, output power values (see first column of Table 7) have been tested with or without SKY65367 (PA active or in bypass = byp). In addition, the switchable attenuator AA116_72LF was set either in a 0-dB or 15-dB position, resulting in a range of usable power levels, which are highlighted in Green ($V_{CC}$ = 3.3 V for Table 7):

**Table 7. Output Power and CC1120 Settings (With or Without Attenuator) for Maximized Dynamic Range**

| | | | | |
|---|---|---|---|---|
| Max recommended range | 27.5 | 23.5 | 13.6 | –11.8 |
| Min recommended range | 24.4 | 14.1 | –10.9 | –26.4 |
| Board 6 | 0 dB | 15 dB | 0 dB byp | 15 dB byp |
| 3F | –8.7 | –29.3 | 13.6 | –0.3 |
| 3D | –0.8 | –21.2 | 13.0 | –1.1 |
| 3B | 7.4 | –13.6 | 12.4 | –1.9 |
| 39 | 15.4 | –5.7 | 11.7 | –2.7 |
| 37 | 23.3 | 2.2 | 11.0 | –3.5 |
| 35 | 27.1 | 10.4 | 10.3 | –4.3 |
| 33 | 27.1 | 18.8 | 9.5 | –5.2 |
| 31 | 27.2 | 26.6 | 8.7 | –6.0 |
| 2F | 27.2 | 26.7 | 7.8 | –6.9 |
| 2D | 27.3 | 26.5 | 7.0 | –7.7 |
| 2B | 27.3 | 26.2 | 6.2 | –8.5 |
| 29 | 27.3 | 25.8 | 5.5 | –9.3 |
| 27 | 27.4 | 25.4 | 4.7 | –10.1 |
| 25 | 27.4 | 24.9 | 3.9 | –10.9 |
| 23 | 27.4 | 24.3 | 3.1 | –11.8 |
| 21 | 27.4 | 23.5 | 2.2 | –12.7 |
| 1F | 27.4 | 22.7 | 1.3 | –13.6 |
| 1D | 27.5 | 21.8 | 0.5 | –14.4 |
| 1B | 27.5 | 20.8 | –0.4 | –15.3 |
| 19 | 27.4 | 19.9 | –1.2 | –16.2 |
| 17 | 27.4 | 18.8 | –2.1 | –17.2 |
| 15 | 27.3 | 17.6 | –3.0 | –18.1 |
| 13 | 27.2 | 16.4 | –4.0 | –19.1 |
| 11 | 27.1 | 15.3 | –4.8 | –20.0 |
| F | 26.9 | 14.1 | –5.8 | –21.0 |
| D | 26.6 | 12.9 | –6.7 | –21.9 |
| B | 26.3 | 11.8 | –7.5 | –22.8 |
| 9 | 26.0 | 10.8 | –8.3 | –23.7 |
| 7 | 25.6 | 9.7 | –9.1 | –24.5 |
| 5 | 25.0 | 8.5 | –10.0 | –25.4 |
| 3 | 24.4 | 7.5 | –10.9 | –26.4 |

The last column shows how the 15-dB attenuator shifts the minimum power level by roughly 15 dB.

The power steps were also verified at two more temperature points: –25°C and 55°C. At –25°C, the transmit power levels are always either equal or higher than at 25°C (Table 7), and the maximum delta measured is 0.8 dB (at lower temperature the output power is higher). For 55°C, the levels measured are very similar to Table 7; the worst case difference measured is only –0.3 dB (meaning at 55°C, the power level is slightly less than at 25°C).

# 8 Design Files

## 8.1 Schematics

To download the schematics, see the design files at TIDA-00676.

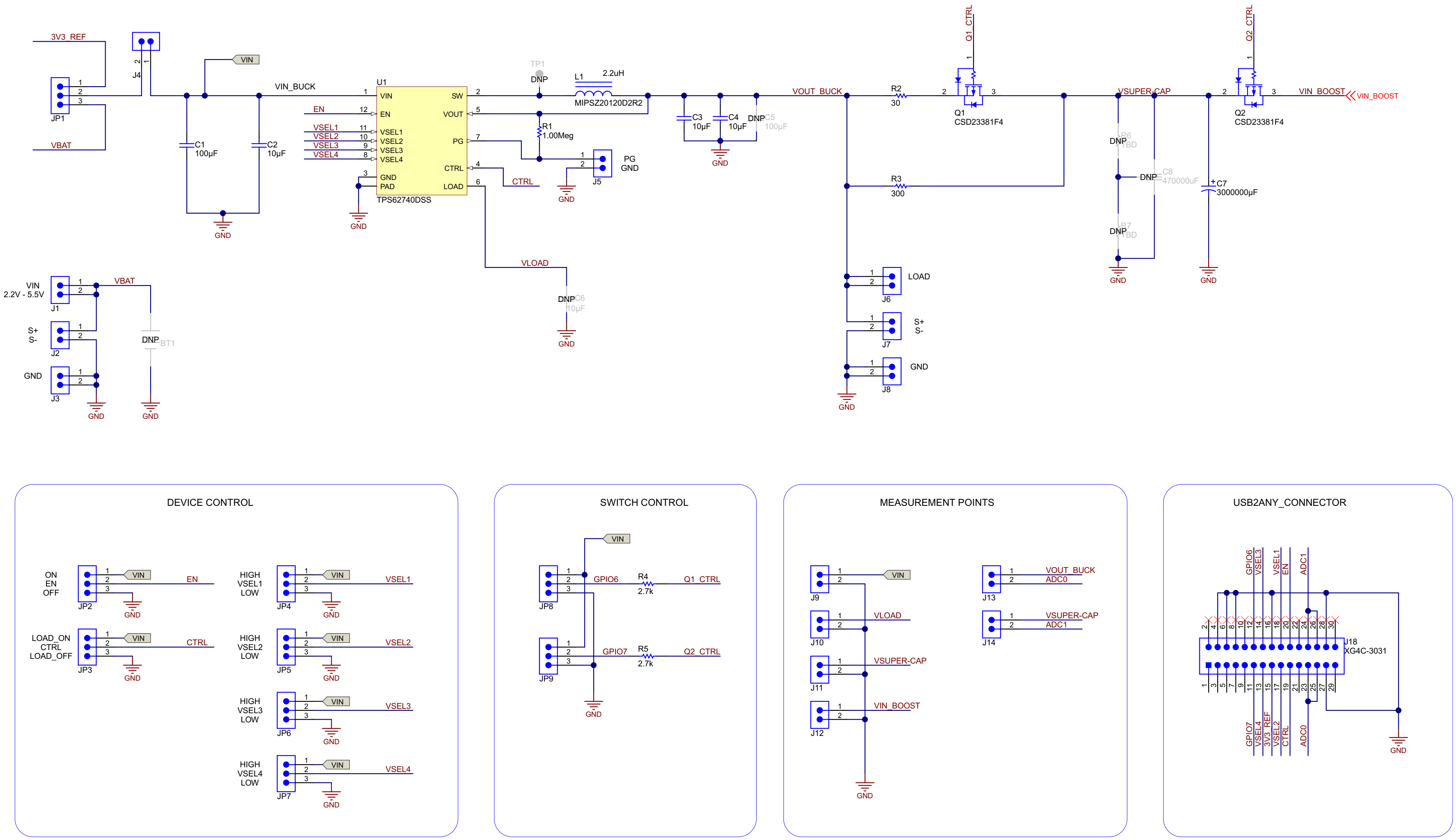



**Figure 19. TIDA-00676 Power Buck**

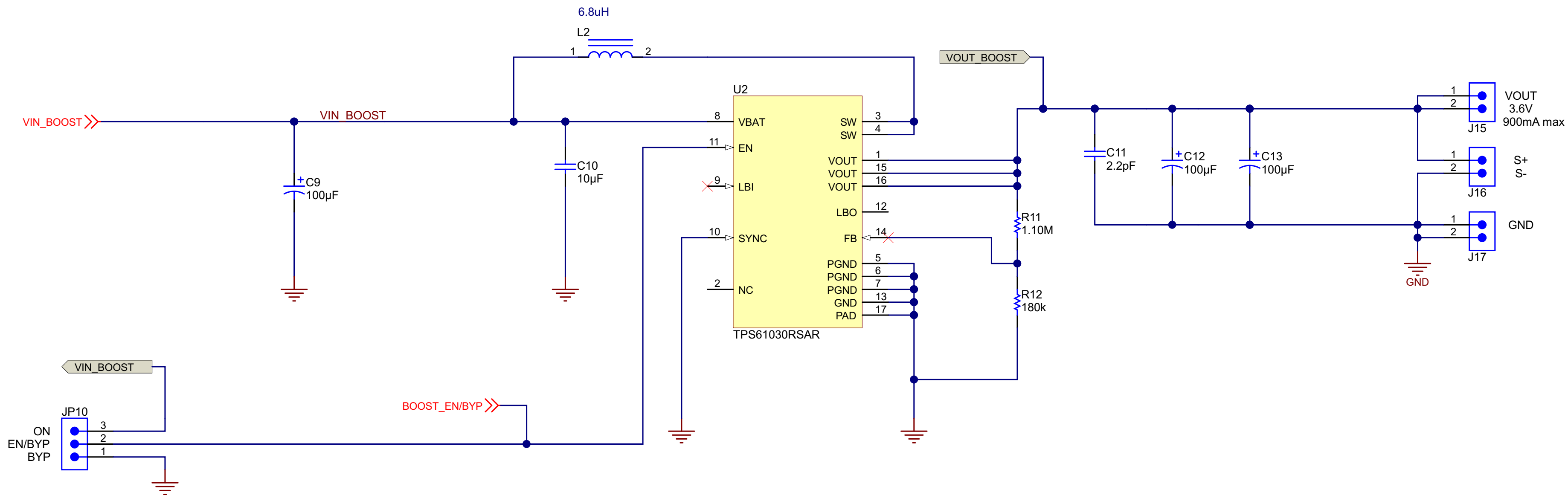



**Figure 20. TIDA-00676 Power Boost**

## 8.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00676.

**Table 8. TIDA-00676 BOM**

| ITEM | QTY | REFERENCE | VALUE | PART DESCRIPTION | MANUFACTURER | MANUFACTURER PARTNUMBER | PCB FOOTPRINT |
|---|---|---|---|---|---|---|---|
| 1 | 1 | !PCB | | Printed Circuit Board | Any | TIDA-00676/ALPS-0199 | |
| 2 | 1 | C1 | 100uF | CAP, CERM, 100uF, 6.3V, +/-20%, X5R, 1210 | MuRata | GRM32ER60J107ME20L | 1210 |
| 3 | 3 | C2, C3, C4 | 10uF | CAP, CERM, 10uF, 6.3V, +/-20%, X5R, 0603 | MuRata | GRM188R60J106ME84 | 0603 |
| 4 | 1 | C7 | 3000000uF | CAP, Electric Double Layer, 3000000uF, 2.7V, +20/-10%, 0.061 ohm, TH | NESSCAP | ESHSR-0003C0-002R7 | TH, 2-Leads, 8mm Dia, 20mm Height |
| 5 | 3 | C9, C12, C13 | 100uF | CAP, TA, 100 µF, 16 V, +/- 20%, 0.09 ohm, SMD | Vishay-Sprague | 594D107X0016D2T | Case Code D |
| 6 | 1 | C10 | 10uF | CAP, CERM, 10 µF, 6.3 V, +/- 20%, X5R, 1206 | TDK | C3216X5R0J106M | 1206 |
| 7 | 1 | C11 | 2.2pF | CAP, CERM, 2.2 pF, 50 V, +/- 11%, C0G/NP0, 0805 | AVX | 08055A2R2CAT2A | 0805 |
| 8 | 17 | J1, J2, J3, J4, J5, J6, J7, J8, J9, J10, J11, J12, J13, J14, J15, J16, J17 | | Header, TH, 100mil, 2x1, Gold plated, 230 mil above insulator | Samtec, Inc. | TSW-102-07-G-S | TSW-102-07-G-S |
| 9 | 1 | J18 | | Connector, 15x2, 3A 300V STRT DIP, TH | Omron Electronic Components | XG4C-3031 | Connector, 15x2, Pitch 2.54mm, TH |
| 10 | 10 | JP1, JP2, JP3, JP4, JP5, JP6, JP7, JP8, JP9, JP10 | | Header, TH, 100mil, 3x1, Gold plated, 230 mil above insulator | Samtec, Inc. | TSW-103-07-G-S | TSW-103-07-G-S |
| 11 | 1 | L1 | 2.2uH | Inductor, Multilayer, Ceramic, 2.2uH, 0.7A, 0.23 ohm, SMD | FDK | MIPSZ20120D2R2 | 2.2x1x1.45 mm |
| 12 | 1 | L2 | 6.8uH | Inductor, SMT, yyA, zzmilliohm | Sumida | CDRH124-6R8 | 0.485 sq inch |
| 13 | 2 | Q1, Q2 | -12V | MOSFET, P-CH, -12V, -2.3A, 1.0x0.35x0.6mm | Texas Instruments | CSD23381F4 | 1.0x0.35x0.6mm |
| 14 | 1 | R1 | 1.00Meg | RES, 1.00Meg ohm, 1%, 0.1W, 0603 | Yageo America | RC0603FR-071ML | 0603 |
| 15 | 1 | R2 | 30 | RES, 30 ohm, 5%, 0.1W, 0603 | Vishay-Dale | CRCW060330R0JNEA | 0603 |
| 16 | 1 | R3 | 300 | RES, 300 ohm, 1%, 0.1W, 0603 | Yageo America | RC0603FR-07300RL | 0603 |
| 17 | 2 | R4, R5 | 2.7k | RES, 2.7k ohm, 5%, 0.1W, 0603 | Vishay-Dale | CRCW06032K70JNEA | 0603 |
| 18 | 1 | R11 | 1.10Meg | RES, 1.10 M, 1%, 0.1 W, 0603 | Vishay-Dale | CRCW06031M10FKEA | 0603 |
| 19 | 1 | R12 | 180k | RES, 180 k, 5%, 0.1 W, 0603 | Vishay-Dale | CRCW0603180KJNEA | 0603 |

**Table 8. TIDA-00676 BOM (continued)**

| ITEM | QTY | REFERENCE | VALUE | PART DESCRIPTION | MANUFACTURER | MANUFACTURER PARTNUMBER | PCB FOOTPRINT |
|---|---|---|---|---|---|---|---|
| 20 | 1 | U1 | | 360nA IQ Step Down Converter for Low Power Applications, DSS0012A | Texas Instruments | TPS62740DSS | DSS0012A |
| 21 | 1 | U2 | | 96% Efficient Synchronous Boost Converter With 4A Switch, RSA0016B | Texas Instruments | TPS61030RSAR | RSA0016B |

## 8.3 PCB Layout Recommendations

Copy the layout exactly as shown in PMP9753 and TPS61030 EVM literature.

### 8.3.1 Layer Plots

To download the layer plots, see the design files at TIDA-00676.

## 8.4 Altium Project

To download the Altium project files, see the design files at TIDA-00676.

## 8.5 Gerber Files

To download the Gerber files, see the design files at TIDA-00676.

## 9 Software Files

To download the software files, see the design files at TIDA-00676.

## 10 References


1. Texas Instruments, *CC1120 High-Performance RF Transceiver for Narrowband Systems*, CC1120 Datasheet (SWRS112)
2. Texas Instruments, *TPS6274x 360nA $I_Q$ Step Down Converter For Low Power Applications*, TPS62740 Datasheet (SLVSB02)
3. Texas Instruments, *TPS6103x 96% Efficient Synchronous Boost Converter With 4A Switch*, TPS61030 Datasheet (SLUS534)
4. Beuth, *EN13757-4:2014-2 wM-Bus Standard Document* (www.beuth.de)
5. ETSI, *Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 25 MHz to 1 000 MHz frequency range with power levels ranging up to 500 mW*, ETSI 300220 v2.4.1 (http://www.etsi.org)
6. Texas Instruments, *MSP430FR698x(1), MSP430FR598x(1) Mixed-Signal Microcontrollers*, MSP430FR6989 Datasheet (SLAS789)
7. Texas Instruments, EVM430-FR6989 Sample Source Code (SLAC695)
8. Texas Instruments, , *EVM430-FR6989 Evaluation Kit*, EVM430-FR6989 User's Guide (SLAU611)
9. Texas Instruments, *Wireless M-Bus Implementation with CC112x / CC120x High Performance Transceiver Family*, CC1120 Application Note (SWRA423)
10. Texas Instruments, Smart RF7 Studio (http://www.ti.com/tool/smartrftm-studio)

## 11 Terminology

**wM-Bus—** The European RF Metering standard, providing solutions for 169-, 433-, and 868-MHz bands

**ETSI Cat. 2 Receiver—**Definition for a set of RF parameters in EN300 220 v2.4.1, representing the minimum requirement in wM-Bus capable RF systems at 868 MHz

**ETSI Cat. 1 Receiver—**Definition in ETSI 300 220 as "Highly reliable SRD communication media; for example, serving human life inherent systems (may result in a physical risk to a person)" and comprises the most stringent set of RF parameters for narrowband RF systems.

**Nabef-mode—** The N-mode 169-MHz mode with 4.8 kbps (using 2-GFSK) . In Italy, all six wM-Bus channels are allowed to use this data rate

**Ncd-mode—** The "longest reach" and lowest data rate N-submode with 2.4 kbps (using 2-GFSK)

**Ng-mode—** The "high-speed" N-sub mode with 19.2 kbps (using 4-GFSK)

## 12 About the Author

**MILEN STEFANOV** (M.Sc.E.E) is a System Engineer at TI, working in the field of Grid Infrastructure and an expert in RF communication technologies and metering applications. After graduating, he spent five years as a research assistant at University of Chemnitz (TUC) and 3.5 years in the semiconductor industry in high-speed optical and wired communications as a system engineer. He joined TI in 2003 to become a WiFi expert and support TI's WiFi products at major OEMs; since 2010 he is focusing on metering and sub-1GHz RF solutions for the European grid infrastructure market. Mr. Stefanov has published multiple articles on wM-Bus technology in Europe and presented technical papers at the Wireless Congress and SmartHome & Metering summits in Munich.

**FLORIAN FECKL** works as an Analog Power Application Engineer for Texas Instruments' ALPS Group. In this role, he is part of the development team, holds trainings, supports worldwide customers, and develops reference designs. Since 2013, he is focusing on ultra-low power applications. Florian received his master of engineering (embedded systems) in 2012.