TI Designs
Single-Phase Electric Meter With Isolated Energy Measurement

TI Designs

TI Designs provide the foundation that you need including methodology, testing and design files to quickly evaluate and customize the system. TI Designs help *you* accelerate your time to market.

Design Resources

TIDM-METROLOGY-HOST	Design Page
MSP430AFE253	Product Folder
MSP430F6638	Product Folder
ISO7420	Product Folder
ISO7421	Product Folder
TPS77033	Product Folder
TPD4E004	Product Folder
CC2530	Product Folder

TI E2E™ Community

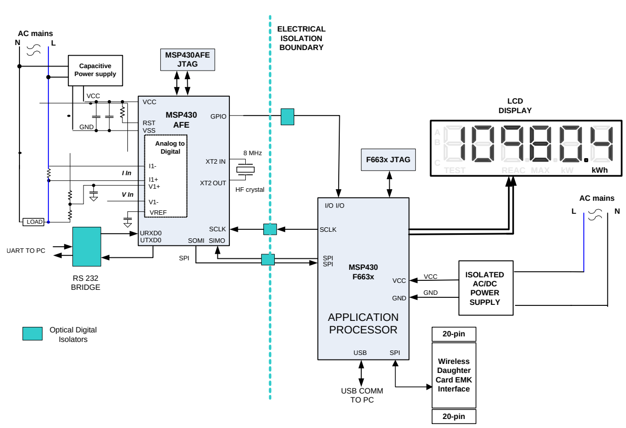
ASK Our E2E Experts
WEBENCH® Calculator Tools

Design Features

- Simplified Meter Calibration by Using USB Connection
- Isolated Communications Between Metrology AFE and Host MCU
- TI Energy Library for Metrology Calculates All Energy Measurement Parameters
- Host MCU Application Controls Onboard LCD and Meter Calibration
- Single-Phase Energy Measurement Achieves Class 0.2 Accuracy
- Segment LCD on Board

Featured Applications

- Metering
- Street Lighting



All trademarks are the property of their respective owners.

Copyright © 2014–2016, Texas Instruments Incorporated

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

1 System Description

Electric meter developers often prefer to separate the energy measurement function from the host processor functions such as ANSI/IEC data tables, DLMS/COSEM, tariff management, and communications. This design demonstrates a method for keeping these meter functions separated by using the MSP430AFE253 as the metrology processor and the MSP430F6638 as the host processor. The design also demonstrates how to isolate communications between the two processors to achieve the necessary safety requirements. Finally, this design demonstrates a method for meter calibration using the USB interface on the F6638 MCU.

The MSP430AFE25x devices belong to the MSP430F2xx family of devices. These devices find their application in energy measurement and have the necessary architecture to support it. The MSP430AFE25x, mentioned as MSP430AFE from this point forward, has a powerful 12-MHz CPU with MSP430 architecture. The analog front end (AFE) consists of up to three analog-to-digital converters (ADC) based on a second-order sigma-delta architecture that supports differential inputs. The sigma-delta ADCs (SD24_A) have capabilities to output 24-bit results and can be grouped together for simultaneous sampling of voltage and currents on the same trigger. In addition, each ΣΔ has an integrated gain amplifier (with gains up to 32) for amplification of low-output sensors. A 16×16-bit hardware multiplier on this chip is used to further accelerate math intensive operations required for metrology parameters. The programmable software on the MSP430AFE supports calculation of various parameters for single phase energy measurement with tamper detection. The key parameters calculated during energy measurements are RMS current and voltage, active, reactive, and apparent power and energies, power factor, and frequency.

The MSP430F663x, the host processor in this two-chip architecture, has a powerful 20-MHz CPU with an MSP430 architecture. The MSP430F663x contains a full-speed Universal Serial Bus (USB), integrated LCD driver with contrast control for up to 160 segments, a hardware real-time clock with battery back-up system, multiple timers, and serial communication interfaces. With large a on-chip memory, this device is best suited as an application processor to interface to any low-cost metrology processor such as the MSP430AFE. The host-processor related portions of this design are isolated from the metrology-processor related portions, thereby isolating the host processor from mains high voltage. Isolated inter-processor communication between the metrology and host processor is made possible using the ISO7420 and ISO7421 isolators on the SPI/UART pins.

This design guide has a complete metrology and application source code provided as a downloadable zip file.

Copyright © 2014–2016, Texas Instruments Incorporated

2 Design Features

This section describes the front-end passives and other components required for the design of an energy meter using the MSP430AFE.

2.1 Hardware Implementation

2.1.1 Power Supply

The MSP430 family of microcontrollers support a number of low-power modes in addition to low-power consumption during active (measurement) mode when the CPU and other peripherals are active. Since an energy meter is always interfaced to the AC mains, the DC supply required for the measuring element (MSP430AFE) can be easily derived using an AC-to-DC conversion mechanism.

The reduced power requirements of this device family allow design of power supplies to be small, extremely simple, and cost-effective. The power supply allows the operation of the energy meter by being powered directly from the mains. The next sub-sections discuss the various power supply options that are available to users to support their design.

2.1.1.1 Resistor Capacitor (RC) Power Supply

Figure 1 shows a simple capacitor power supply that supplies a regulated output voltage of 3.3 V using the mains AC voltage of 110 to 230 V.

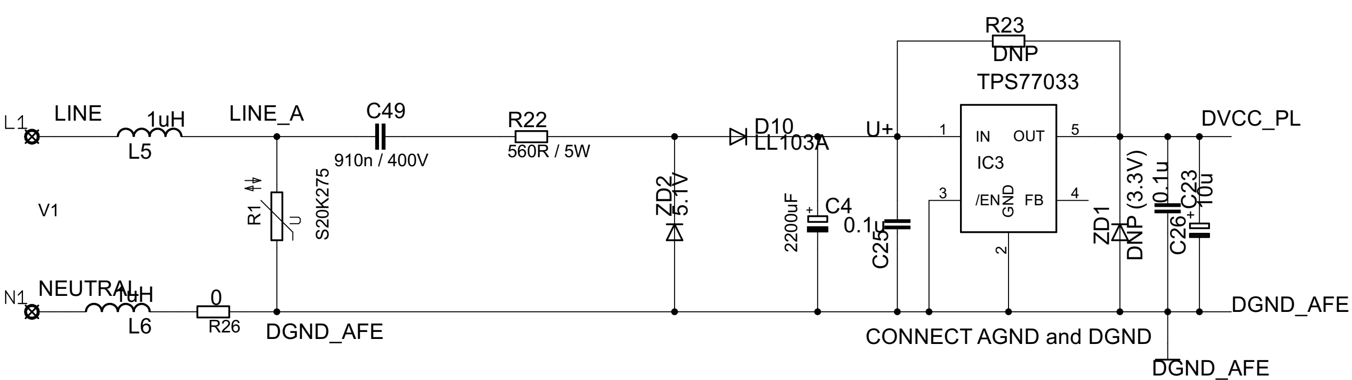


Figure 1. Simple Capacitive Power Supply for the MSP430 Energy Meter

Appropriate values of resistor R22 and capacitor C49 are chosen based on the required output current-drive of the power supply. Voltage from mains is directly fed to a RC based circuit followed by a rectification circuitry to provide a DC voltage for the operation of the MSP430. This DC voltage is regulated to 3.3 V for full speed operation of the MSP430. For the circuit above, the drive provided is approximately 25 mA. The design equations for the power supply are given in the MSP Family Mixed-Signal Microcontroller Application Notes (SLAA024, Section 3.8.3.2). If an additional drive is required, use either an NPN output buffer or a transformer- or switching-based power supply.

Copyright © 2014–2016, Texas Instruments Incorporated

2.1.1.2 Switching-Based Power Supply

When high current drive is required to drive RF transceivers, a simple capacitive power supply will not provide enough peak-current. Therefore, a switching-based power supply is required. A separate power supply module on the board may be used to provide 3.3-V DC from the AC mains of 110 to 230-V AC. Figure 2 shows the use of an SMPS module to provide a 3.3-V rail with increased current drive. This module is used on the EVM430-AFE253 to provide an isolated voltage to drive only the MSP430F663x and its associated interfaces.

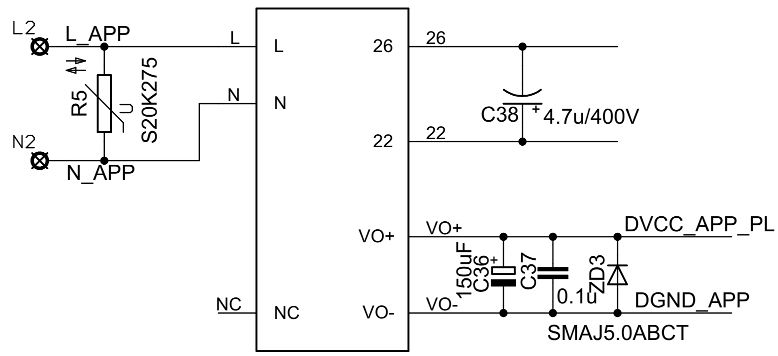


Figure 2. Switching-Based Power Supply for the MSP430 Applications Processor

2.1.2 Analog Inputs

The MSP430AFE's AFE, which consists of the ΣΔ ADC, is differential and requires that the input voltages at the pins do not exceed ±500 mV (gain = 1). To meet this specification, the current and voltage inputs need to be scaled down. In addition, since the SD24_A allows negative voltage of up to –1 V; AC mains signals can be directly interfaced without the need for level shifters. This sub-section describes the AFE used for voltage and current channels.

2.1.2.1 Voltage Inputs

The voltage from the mains is usually 230 or 110 V and needs to be scaled down to a range of 500 mV. The AFE for voltage consists of spike protection varistors (not shown) followed by a simple voltage divider and a RC low-pass filter that acts like an anti-alias filter.

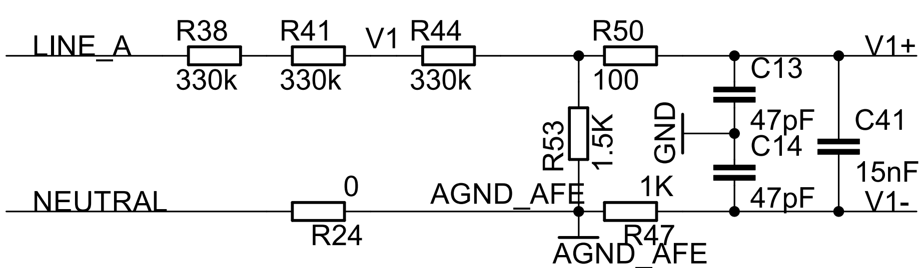


Figure 3. AFE for Voltage Inputs

Figure 3 shows the AFE for the voltage inputs for a mains voltage of 230 V. The voltage is brought down to approximately 350 mV_{RMS}, which is a 495-mV peak and fed to the positive input, adhering to the MSP430 ΣΔ analog limits. A common mode voltage of zero can be connected to the negative input of the ΣΔ.

NOTE: The anti-alias resistors on the positive and negative sides are different because the input impedance to the positive terminal is much higher; therefore, a lower value resistor is used for the anti-alias filter. If this filter is not maintained, a relatively large phase shift would result between voltage and current samples.

Copyright © 2014–2016, Texas Instruments Incorporated

2.1.2.2 Current Inputs

The AFE for current inputs is a little different from the AFE for the voltage inputs. Figure 4 shows the AFE used for current channel I1 and I2.

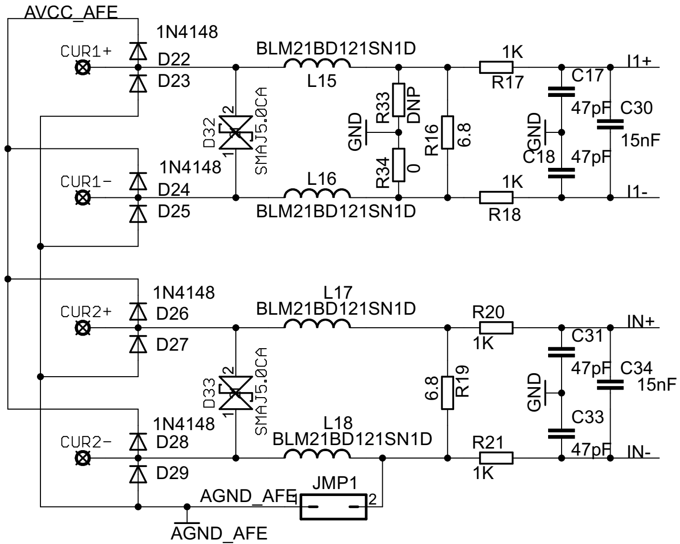


Figure 4. AFE for Current Inputs

Resistor R16 is the burden resistor that would be selected based on the current range used and the turns-ratio specification of the CT (not required if shunt resistors are used as current sensors). The value of the burden resistor for this design is around 6.8 Ω. The anti-aliasing circuitry consisting of R and C follows the burden resistor. The input signal to the converter is a fully differential input with a voltage swing of ±500-mV maximum with gain of the converter set to 1.

2.2 Software Implementation

The software for the implementation of one-phase metrology is discussed in this section. The first sub-section discusses the setup of various peripherals of the metrology and application processors. In the second sub-section, the metrology software is described as two major processes: the foreground process and background process. In the third sub-section, the application software is described in detail. Subsequently, the process of how the MSP430F663x receives metering parameters from the AFE is described.

2.2.1 Peripherals Setup

The major peripherals of the MSP430AFE are the 24-bit sigma delta (SD24_A) ADC, clock system, watchdog timer (WDT), and so on. For the MSP430F663x, the major peripherals of are the clock system, timer, USB, LCD, WDT, and SPI (USCI).

Copyright © 2014–2016, Texas Instruments Incorporated

2.2.1.1 AFE SD24_A Setup

The MSP430AFE has up to three independent sigma delta data converters. For a single phase system, at least two ΣΔs are necessary to independently measure one voltage and current. The code accompanying this application note will address the metrology for a 1-phase system with limited discussion to anti-tampering. The clock to the SD24_A is derived from an external crystal 8-MHz external crystal (ACLK). The sampling frequency is defined as $f_s = f_M$ / OSR, the OSR is chosen to be 256, and the modulation frequency is chosen as 1 MHz, resulting in a sampling frequency of 3906 Hz. The SD24_As are configured to generate regular interrupts every sampling instant.

The following are the ΣΔ channels associations:

- A0.0+ and A0.0–: Current I1
- A1.0+ and A1.0–: Current I2 (Neutral)
- A2.0+ and A2.0–: Voltage V1

2.2.1.2 AFE Main Clock Setup

The MSP430AFE supports an external high-frequency crystal with frequencies of up to 12 MHz. In this EVM, an 8-MHz crystal is used, and MCLK is sourced from this external crystal.

2.2.1.3 AFE UART/SPI Setup

The MSP430F6638, the master, and MSP430AFE, the slave, communicate via SPI. In this application, the SPI is configured in 8-bit, 3-wire mode with SPI clock set at 1 MHz.

2.2.1.4 F6638 Main Clock Setup

The MSP430F6638 supports external low-frequency or external high-frequency crystals. In this EVM, an 8-MHz high frequency crystal is used and MCLK is sourced from this crystal. In addition, a low-frequency 32,768-Hz crystal is used as ACLK to source the real time clock and LCD.

2.2.1.5 F6638 Real-Time Clock (RTC_B)

The RTC_B is a real-time clock module that is configured to give precise one-second interrupts. Based off these one-second interrupts, the time and date are updated in the software as necessary.

2.2.1.6 F6638 LCD Controller (LCD_B)

The LCD controller on the MSP430F6638 can support up to 4-mux displays and 160 segments. In the current design, the LCD controller is configured to work in 4-mux mode using 88 segments with a refresh rate set to ACLK/64, which is 512 Hz. For information about the parameters displayed on the LCD, see Section 5.1.

Copyright © 2014–2016, Texas Instruments Incorporated

2.2.2 Metrology Foreground Process

The metrology foreground process includes the initial setup of the MSP430AFE hardware and software immediately after a device reset. Figure 5 shows the flowchart for this process.

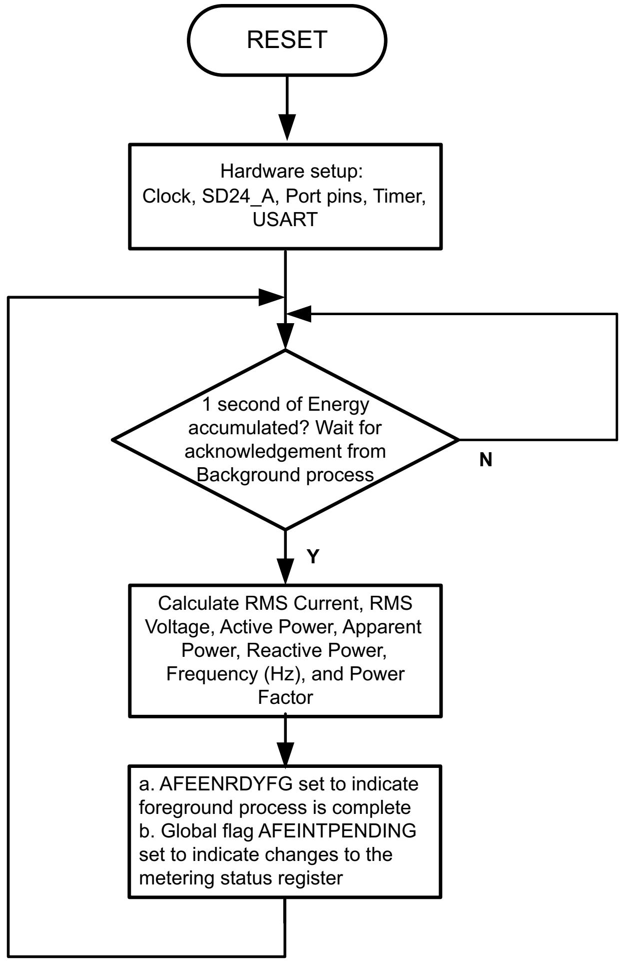


Figure 5. Metrology Foreground Process

The setup routines involve the initialization of the ADC, clock system, general purpose input/output (I/O port) pins, timer, and the USART SPI communication. The MSP430AFE is configured as an 8-bit, 3-wire SPI slave.

NOTE: Since the USART is configured for SPI, the RS-232 communication using UART cannot be used simultaneously.

After the hardware is setup, the foreground process waits for the background process to notify it to calculate new metering parameters. This notification is done through a status flag every time a frame of data is available for processing. The data frame consists of processed current, voltage, active, and reactive quantities accumulated for one second. This frame is equivalent to accumulation of 50 or 60 cycles of data synchronized to the incoming voltage signal. In addition, a sample counter keeps tracks of how many samples have been accumulated over this frame period. This count can vary as the software synchronizes with the incoming mains frequency.

Copyright © 2014–2016, Texas Instruments Incorporated

All values are accumulated in separate 48-bit registers to further process and obtain the RMS and mean values during the foreground process. Using the foreground's calculated values of active and reactive power, the apparent power is calculated. The frequency (in Hertz) and power factor are also calculated using parameters calculated by the background process and the formulas in Section 4.3. After all the metering parameters are calculated, the AFEENRDYFG metering interrupt flag is asserted high to indicate the completion of the foreground's calculation of the metrology parameters for the current frame.

2.2.2.1 Formulae

This section briefly describes the formulae used for the voltage, current, and energy calculations. As discussed in the previous sections, simultaneous voltage and current samples are obtained from three independent ΣΔ converters at a sampling rate of 3906 Hz. Track of the number of samples that are present in one second is kept and used to obtain the RMS values for voltage and for each current via the following formulas:

$$V_{RMS} = K_v \times \sqrt{\frac{\sum_{n=1}^{\text{Sample count}} v(n) \times v(n)}{\text{Sample count}}} \qquad I_{RMS,ph} = K_{i,ph} \times \sqrt{\frac{\sum_{n=1}^{\text{Sample count}} i_{ph}(n) \times i_{ph}(n)}{\text{Sample count}}}$$

where

- ph = Live or Neutral
- $v(n)$ = Voltage sample at a sample instant 'n'
- $i_{ph}(n)$ = Each current sample at a sample instant 'n'
- Sample count = Number of samples in one second
- K_v = Scaling factor for voltage
- $K_{i,ph}$ = Scaling factor for line or neutral current (1)

Power and energy are calculated for a frame's worth of active and reactive energy samples. These samples are phase corrected and passed on to the foreground process, which uses the number of samples (sample count) to calculate total active and reactive powers via the following formulas:

$$P_{ACT,ph} = K_{ACT,ph} \frac{\sum_{n=1}^{\text{Sample count}} v(n) \times i_{ph}(n)}{\text{Sample count}} \qquad P_{REACT,ph} = K_{REACT,ph} \frac{\sum_{n=1}^{\text{Sample count}} v_{90}(n) \times i_{ph}(n)}{\text{Sample count}}$$

where

- $v_{90}(n)$ = Voltage sample at a sample instant *n* shifted by 90 degrees
- $K_{ACT,ph}$ = Scaling factor for active power
- $K_{REACT,ph}$ = Scaling factor for reactive power (2)

Active energy is calculated from the active power by the following equations:

$$E_{ACT,ph} = P_{ACT,ph} \times \text{Sample count}$$

$$E_{REACT,ph} = P_{REACT,ph} \times \text{Sample count} \qquad (3)$$

For reactive energy, the 90° phase shift approach is used for two reasons:

1. The approach allows accurate measurement of the reactive power for very small currents.
2. The approach conforms to the measurement method specified by IEC and ANSI standards.

The calculated mains frequency is used to calculate the 90°-shifted voltage sample. Since the frequency of the mains varies, first measure the mains frequency accurately to phase shift the voltage samples accordingly (see Section 2.2.3.3).

Implementing the application's phase shift consists of an integer part and a fractional part. The integer part is realized by providing an *n* samples delay. The fractional part is realized by a fractional delay filter (see Section 2.2.3.2).

Copyright © 2014–2016, Texas Instruments Incorporated

After calculating the active and reactive power, the apparent power is calculated by the following formula:

$$P_{APP,ph} = \sqrt{P_{ACT,ph}^{2} + P_{REACT,ph}^{2}} \quad (4)$$

The background process calculates the frequency in terms of samples per mains cycle. The foreground process then converts this to Hertz by the following formula:

$$\text{Frequency (Hz)} = \frac{\text{Sampling Rate}}{\text{Frequency}}$$

where

- Sampling rate in units of samples per second
- Frequency in units of samples per mains cycle (5)

After the active and apparent powers have been calculated, the absolute value of the power factor is calculated. In the meter's internal representation of power factor, a positive power factor corresponds to a capacitive load and a negative power factor corresponds to an inductive load. The sign of the internal representation of power factor is determined by whether the current leads or lags voltage, which is determined in the background process. Therefore, the internal representation of power factor is calculated by the following formula:

$$\text{Internal Representation of Power Factor} = \begin{cases} \frac{P_{Act}}{P_{Apparent}}, \text{if capacitive load} \\ -\frac{P_{Act}}{P_{Apparent}}, \text{if inducitive load} \end{cases} \quad (6)$$

2.2.3 Metrology Background Process

The metrology background process uses the ΣΔ interrupt as a trigger to collect voltage and current samples (up to three values). These samples are used to calculate intermediate results in dedicated 48-bit accumulation registers for parameters explained in Section 4.2. The background function deals mainly with time critical events in software. Once sufficient samples (one second's worth) have been accumulated, the foreground process is triggered to calculate final values of V_{RMS}, I_{RMS}, active, reactive and apparent powers, active, reactive and apparent energy, frequency, and power factor. The background process is also wholly responsible for the calculation of energy proportional pulses, frequency (in samples per cycle), and the sign of the power factor. Figure 6 shows the flow diagram of the background process.

Copyright © 2014–2016, Texas Instruments Incorporated

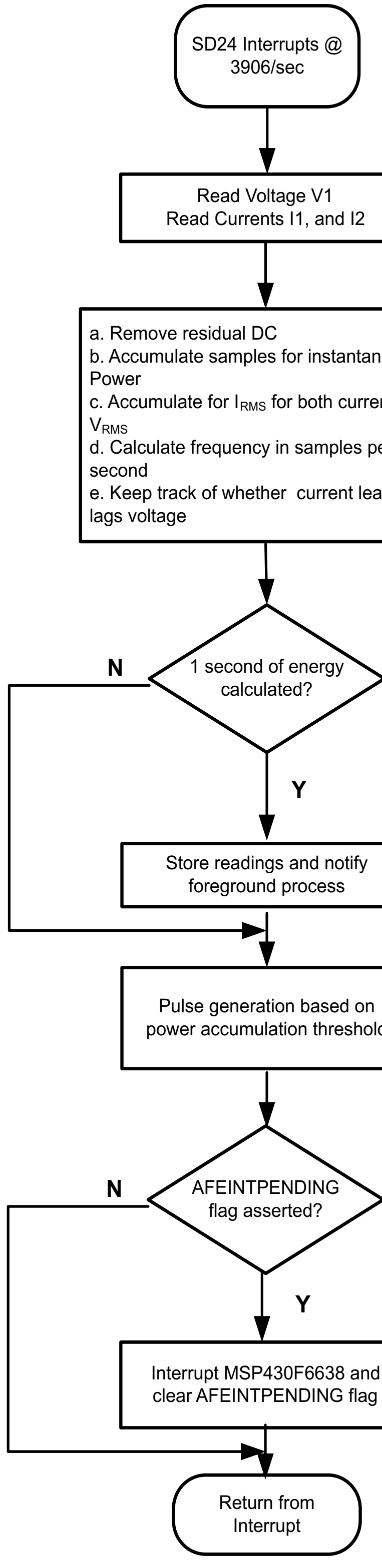


Figure 6. Background Process

The following sections discuss the various elements of electricity measurement in the background process.

Copyright © 2014–2016, Texas Instruments Incorporated

2.2.3.1 Voltage and Current Signals

The ΣΔ converter has a fully differential input architecture, and each ΣΔ pin can accept negative inputs; therefore, no level-shifting is necessary for the incoming AC voltage (unlike single-ended or pseudo-differential converters).

The output of each ΣΔ is a signed integer and any stray DC or offset value on these ΣΔs are removed using a DC tracking filter in software. Separate DC estimates for voltage and current are obtained using the filter for voltage and current samples respectively. This estimate is then subtracted from subsequent voltage and current samples.

The resulting instantaneous voltage and current samples are used to generate the following intermediate results:

- Accumulated squared values of voltage and current, which is used for V_{RMS} and I_{RMS} calculations, respectively.
- Accumulated energy samples to calculate active energy.
- Accumulated energy samples using current and 90° phase-shifted voltage to calculate reactive energy.

These accumulated values are processed by the foreground process.

2.2.3.2 Phase Compensation

When a current transformer (CT) is used as a sensor, it introduces a phase shift between the current and voltage signals. Also, the voltage and current input circuit's passive components may introduce another phase shift. The relative phase shift between voltage and current samples need to be compensated to ensure accurate measurements. The ΣΔ converters have programmable delay registers (SD24PREx) that can be applied to a particular channel. This built-in feature (PRELOAD) is used to provide the phase compensation required. Figure 7 shows the usage of PRELOAD to delay sampling on a particular channel.

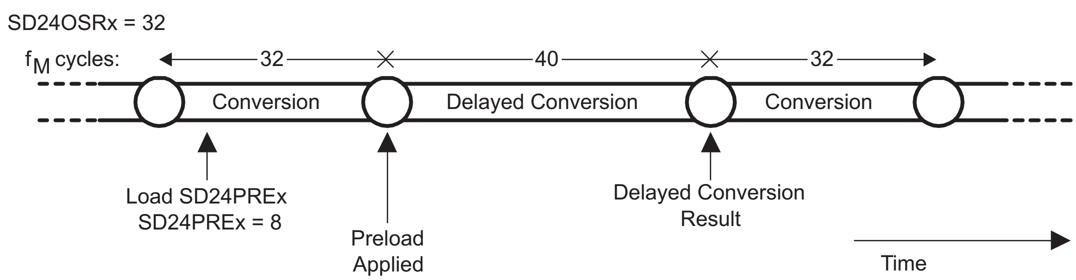


Figure 7. Phase Compensation Using PRELOAD Register

The fractional delay resolution is a function of input frequency (f_{in}), OSR, and the sampling frequency (f_s).

$$\text{Delay resolution}_{Deg} = \frac{360° \times f_{in}}{OSR \times f_s} = \frac{360° \times f_{in}}{f_m} \quad (7)$$

In this application, for an input frequency of 60 Hz, OSR of 256, and sampling frequency of 3906, the PRELOAD register resolution (one step) is about 0.02° and the maximum PRELOAD delay (a maximum of 255 steps) is 5.25°. When using CTs that provide a larger phase shift than this maximum, entire sample delays along with fractional delay must be provided. This phase compensation can also be modified on the fly to accommodate temperature drifts in CTs, but one must ensure that the conversions on the ΣΔ have been stopped.

Copyright © 2014–2016, Texas Instruments Incorporated

2.2.3.3 Frequency Measurement and Cycle Tracking

The instantaneous current and voltage samples for each phase are accumulated in 48-bit registers. A cycle-tracking counter and sample counter keep track of the number of samples accumulated. When approximately one second's worth of samples have been accumulated, the background process stores these 48-bit registers and notifies the foreground process to produce the average results such as RMS and power values. Cycle boundaries are used to trigger the foreground averaging process since it produces very stable results.

For frequency measurements, do a straight-line interpolation between the zero crossing voltage samples. Figure 8 depicts the samples near a zero cross and the process of linear interpolation.

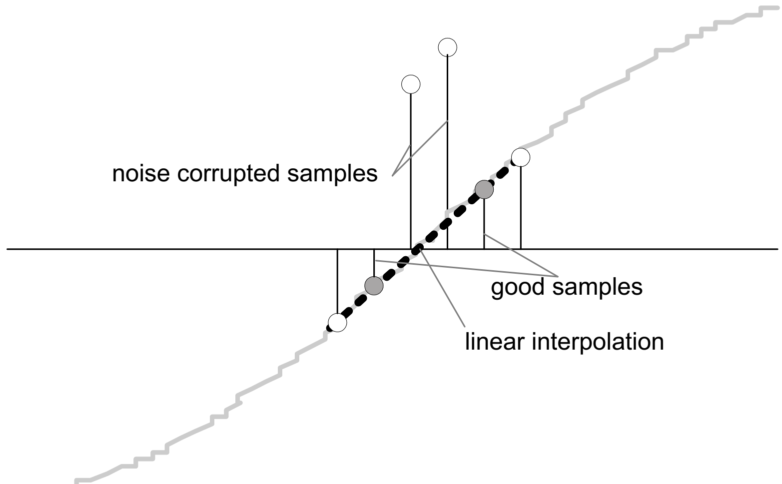


Figure 8. Frequency Measurement

Since noise spikes can cause errors, the application uses a rate-of-change check to filter out the possible erroneous signals and make sure points interpolated are from genuine zero-crossing points. For example, with two negative samples, a noise spike can make one of them positive and, therefore, make the negative and positive pairs look as if there is a zero crossing.

The resultant cycle-to-cycle timing goes through a simple low-pass filter to further smooth out cycle-to-cycle variations. This results in a stable and accurate frequency measurement tolerant of noise.

2.2.3.4 LED Pulse Generation

In electricity meters, the energy consumed is normally measured in fraction of kilowatt hour (KWh) pulses. This information can be used to accurately calibrate any meter or for accuracy measurement. Typically, the measuring element (MSP430) is responsible to generate pulses proportional to the energy consumed, typically defined as *pulses per kWh*. To serve both these tasks efficiently pulse generation has to be accurate with relatively little jitter. Although, time jitters are not an indication of bad accuracy, they would give a negative indication on the overall accuracy of the meter. Therefore, the jitter has to be averaged out.

This application uses average power to generate these energy pulses. The average power (calculated by the foreground process) is accumulated every ΣΔ interrupt, spreading the accumulated energy from the previous one-second time frame evenly for each interrupt in the current one-second time frame. This time frame is equivalent to converting power to energy. Once the accumulated energy crosses a threshold, a pulse is generated. The amount of energy above this threshold is kept and new energy value is added on top of it in the next interrupt cycle. Since the average power tends to be a stable value, this way of generating energy pulses is very steady and free of jitter.

Copyright © 2014–2016, Texas Instruments Incorporated

The threshold determines the energy "tick" specified by meter manufacturers and is a constant. The tick is usually defined in "pulses per kWh" or just in KWh. One pulse's needs to beg generates for every energy tick. For example, in this application, the number of pulses generated per KWh is set to 1600 for active and reactive energies. The energy tick in this case is 1 KWh per 1600 pulses. Energy pulses are generated and available on a header and also through LEDs on the board. General purpose I/O pins are used to produce the pulses. The number of pulses per kWh and each pulse-width can be configured in the software. Figure 9 shows the flow diagram for pulse generation.

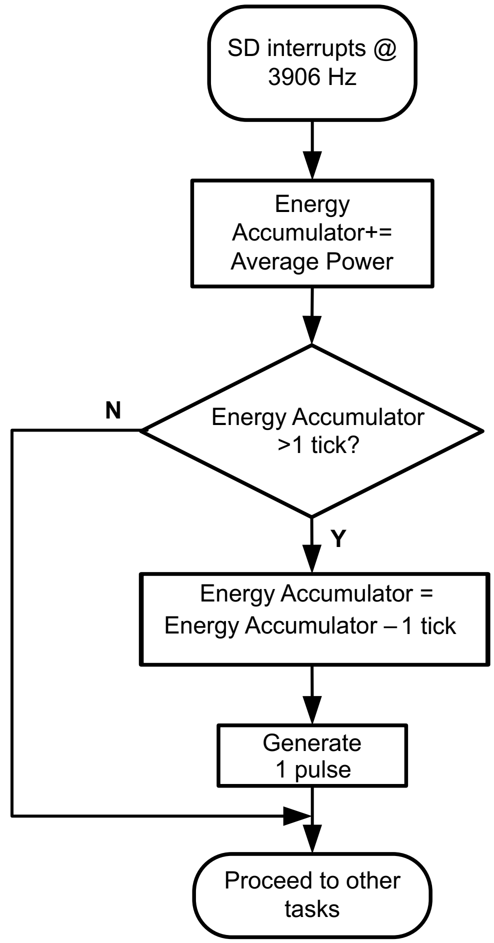


Figure 9. Pulse Generation for Energy Indication

In this application, the average power is represented in units of 0.01 W; therefore, the corresponding value of the 1-KWh threshold is defined as:

$$\text{1-KWh Threshold} = \frac{1}{.01} \times 1\,\text{KW} \times \text{Number of interrupts per second} \times \text{Number of seconds per hour}$$
$$= 100{,}000 \times 3906 \times 3600 = 0\text{x}14765\text{AAD}400 \quad (8)$$

Copyright © 2014–2016, Texas Instruments Incorporated

2.2.4 Application Processor Software

The application processor is a proxy between the AFE and various types of external communication and LCD display. It is responsible for responding to port (I/O) and SPI (receive) interrupts from the AFE and USB interrupts from a PC GUI. Figure 10 shows the flowchart of the main components of the software that runs on the MSP430F663x.

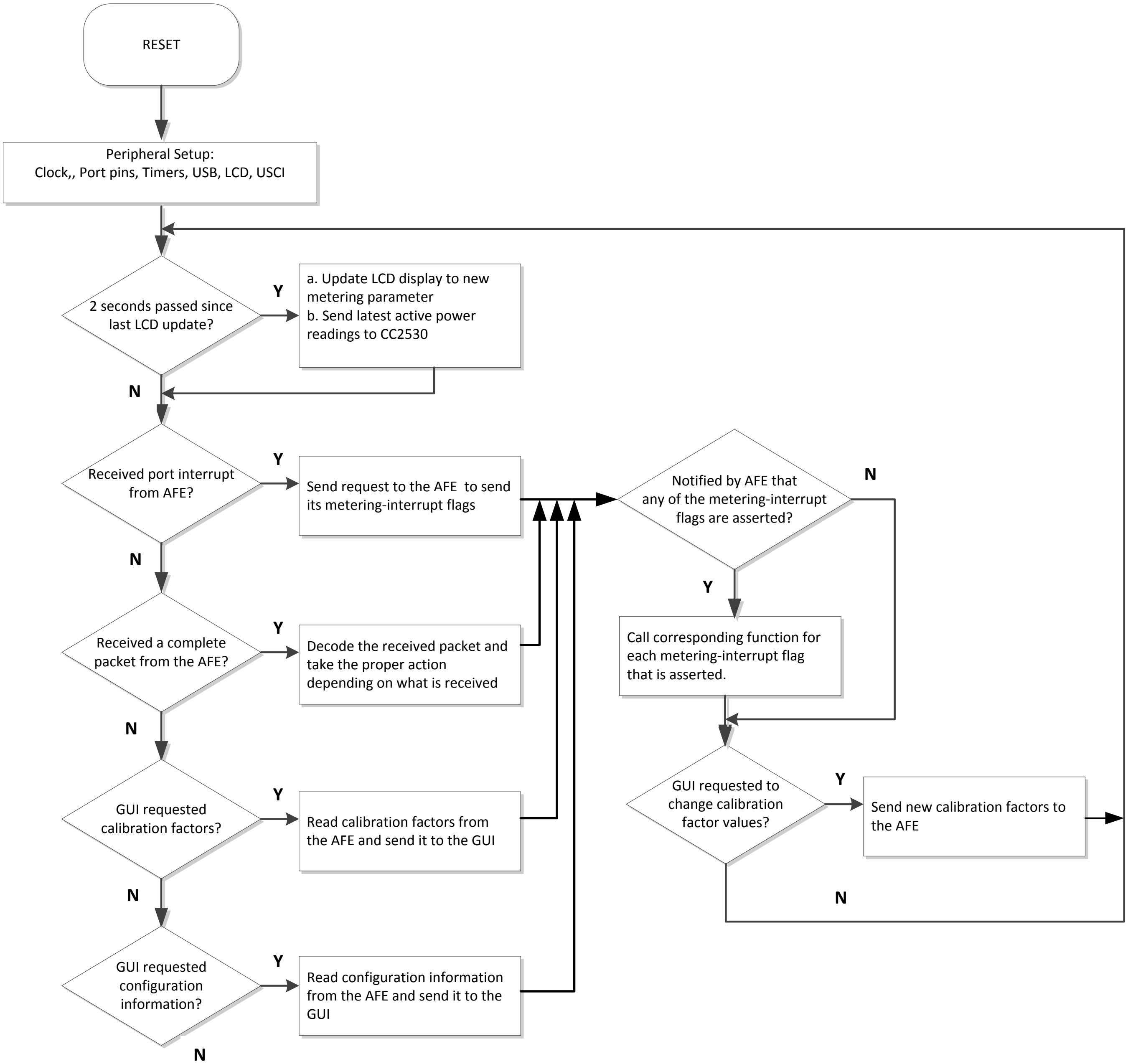


Figure 10. Application Software

After a device reset, the MSP430F663x sets up the peripherals and initializes the CPU and SMCLK clock (at 8 MHz), port pins, timers, USB, USCI, and LCD. One USCI module is configured for SPI communication to the MSP430AFE and another module is configured for UART for wireless communication. In this application, the USCI module for SPI communication is configured as a 3-pin, 8-bit SPI master with a SPI clock of 1 MHz. The USCI module that is configured for UART communication is connected to a ZigBee network processor (CC2530) and is configured for 8N1 with a baud rate of 115200.

Copyright © 2014–2016, Texas Instruments Incorporated

Once the hardware has been configured, the MSP430F663x enters a while loop. At the beginning of each iteration of the loop, a timer flag is checked to determine the start of a new 2-second interval. Every two-second interval, the LCD display is updated with a different metering parameter. Additionally, updated active power readings received from the MSP430AFE are sent to a RF transceiver (CC2530, configured as transmitter). Section 2.2.5 discusses how the MSP430F663x receives the active power readings and other metering parameters from the MSP430AFE.

After determining if it is a new two-second interval, as shown in Figure 10, appropriate actions are taken.

2.2.5 Transferring New E-Meter Parameters from AFE to MSP430F663x

Although the MSP430F663x calls a function for each asserted metering-interrupt flag, only one of these functions actually has code to deal with its corresponding metering-interrupt flag being asserted. This function deals with the case the AFE has just calculated new e-meter parameters and has alerted the MSP430F663x via the corresponding metering-interrupt flag. For the other functions, the user may add code to customize the performed actions for each metering interrupt. Figure 11 shows the process used to calculate the metering parameters and transfer the newly calculated parameters from the AFE to the MSP430F663x.

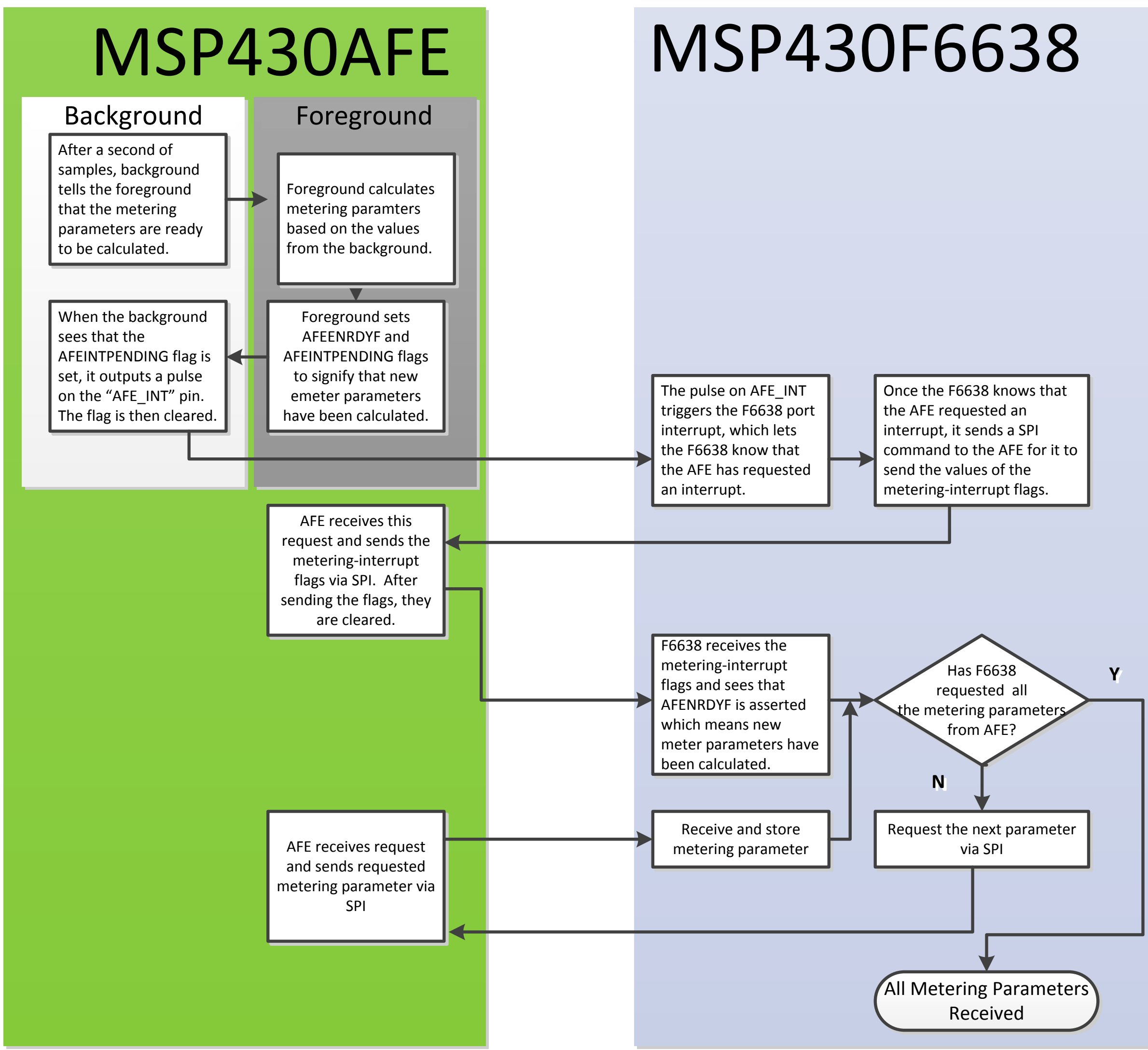


Figure 11. Transference of Meter Parameters from AFE to MSP430F663x

Copyright © 2014–2016, Texas Instruments Incorporated

3 Block Diagram

Figure 12 shows a high-level system block diagram of the reference EVM (EVM430-AFE253) from Texas Instruments, which is divided into a metrology portion that has the MSP430AFE and the application portion that has the MSP430F663x. The MSP430AFE is a slave metrology processor and the MSP430F663x is the host/application processor. Isolated inter-processor communication is made possible using digital isolators on the SPI/UART pins.

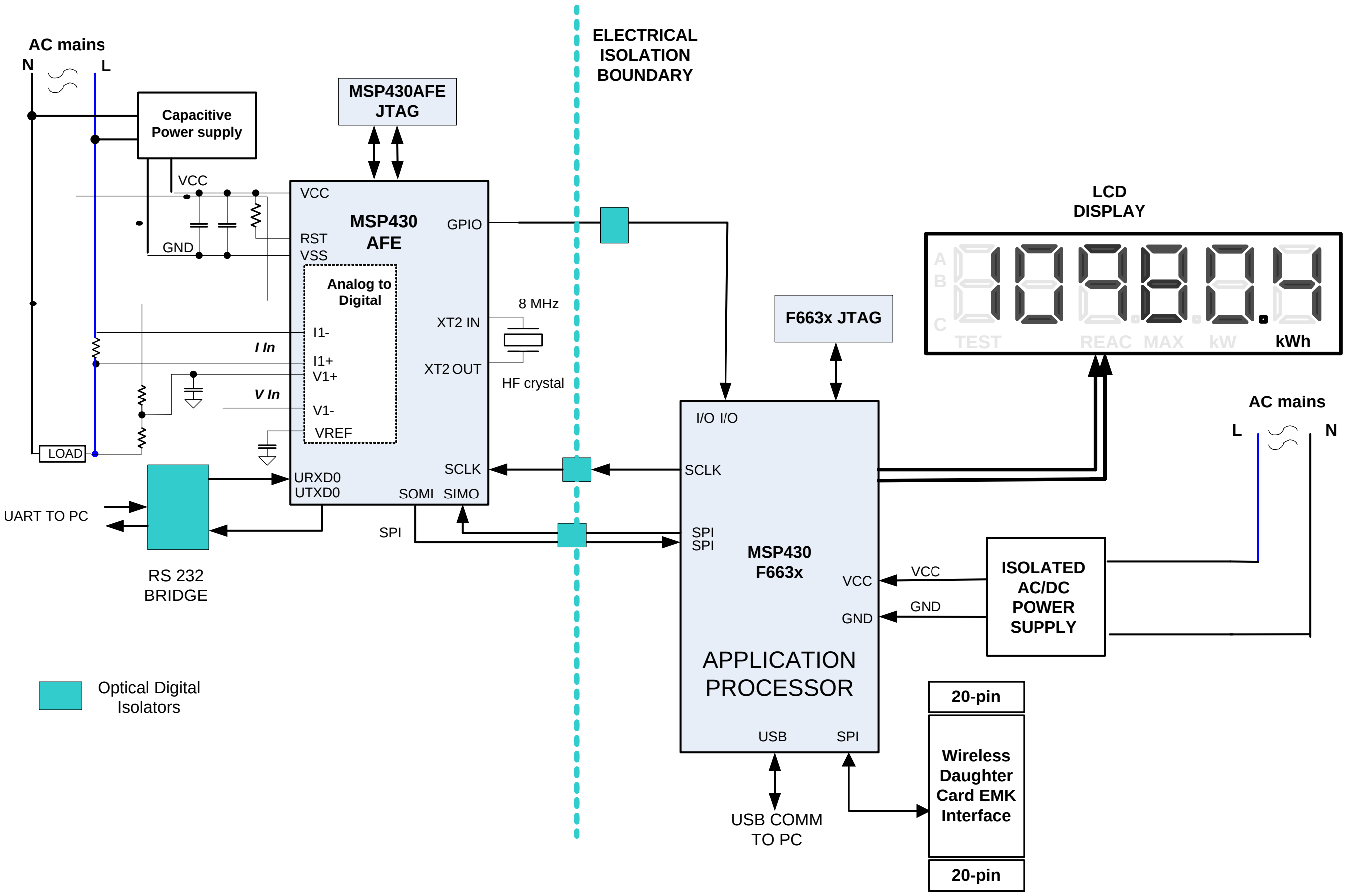


Figure 12. EVM430-MSP430AFE253 System Block Diagram

Copyright © 2014–2016, Texas Instruments Incorporated

Figure 13 shows the high level interface with MSP430 used for a single-phase energy meter application. A single-phase, two-wire connection to the mains is shown in this case with tamper detection. Current sensors are connected to each of the current channels and a simple voltage divider is used for corresponding voltages. The CT has an associated burden resistor that must be connected at all times to protect the measuring device. The choice of the CT and the burden resistor is done based on the manufacturer and current range required for energy measurements. The choice of the shunt resistor value is determined by the current range, gain settings of the SD24_A on the AFE and the tolerance of the power dissipation. The choice of voltage divider resistors for the voltage channel is selected to ensure the mains voltage is divided down to adhere to the normal input ranges that are valid for the MSP430 SD24_A. Refer to the MSP430x2xx user's guide and MSP430AFE datasheet for these limits.

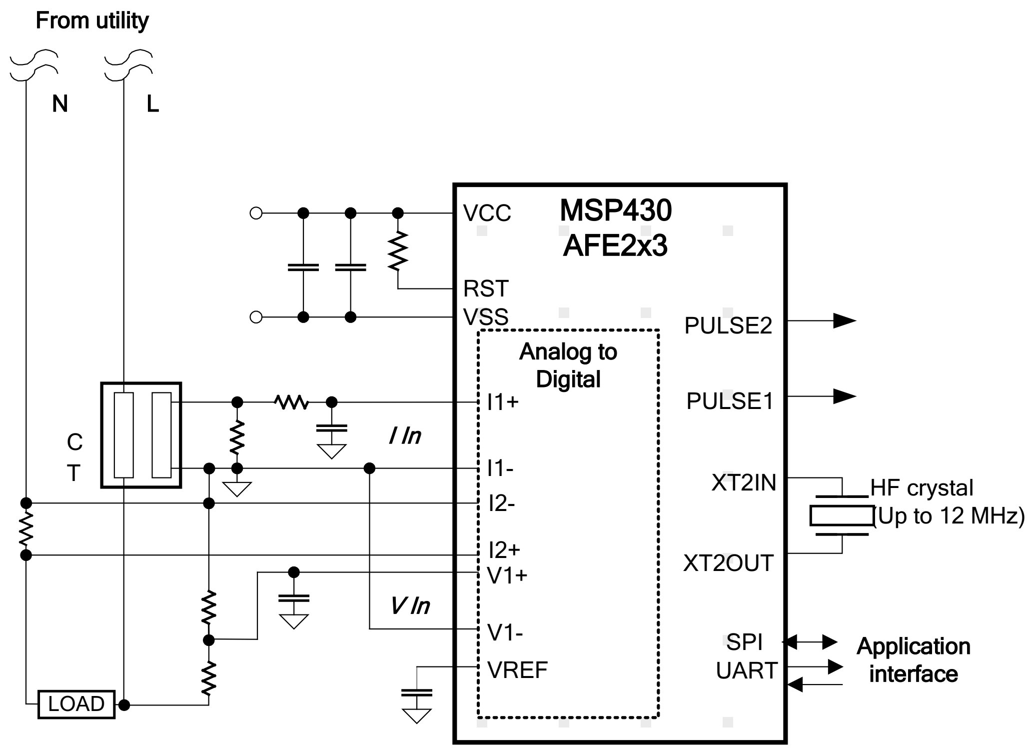


Figure 13. Single-Phase, Two-Wire Connection Using MSP430AFE2x3

Copyright © 2014–2016, Texas Instruments Incorporated

4 Energy Meter Demo

The following figures of the EVM best describe the hardware. Figure 14 is the top view of the energy meter. Figure 15 then shows the location of various pieces of the EVM.

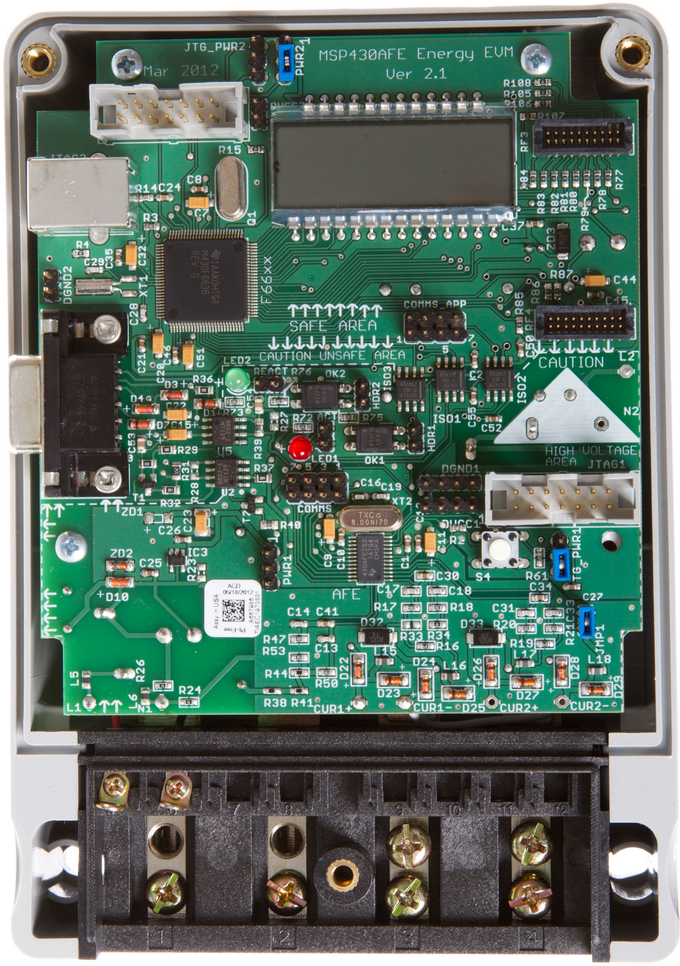


Figure 14. Top View of the EVM

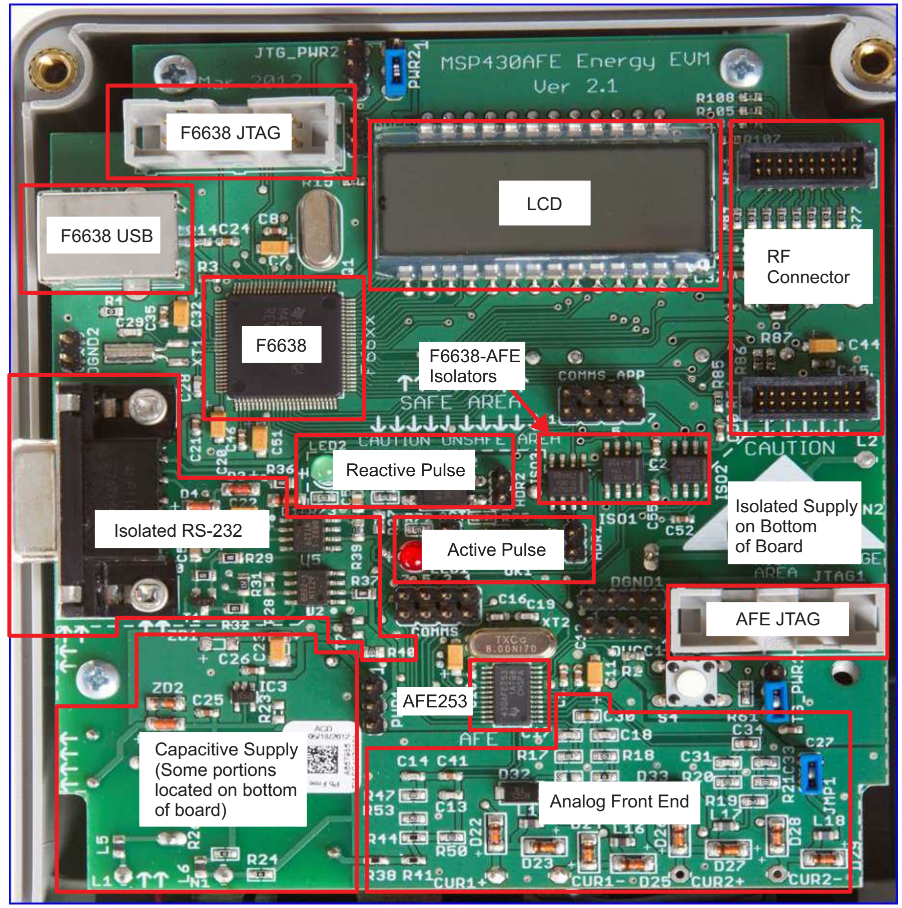


Figure 15. Top View of the EVM with Blocks and Jumpers

Copyright © 2014–2016, Texas Instruments Incorporated

4.1 Connections to the Test Setup or AC Voltages

NOTE: This is a single-phase system and any reference to secondary currents and voltages should not be confused with a dual-phase system.

AC voltage or currents can be applied to the board for testing purposes at these points:

- Pads L1 and N1 correspond to the line and neutral voltage inputs. The EVM can measure up to 230-V AC, 50 or 60 Hz from the AC line. This line voltage can also be used to power the MSP430AFE from AC mains.
- Pads CUR1+ and CUR1–, which are the current inputs after the sensors (secondary AC current for CT or AC voltage across shunt). Care must be taken that the AC peak amplitude fed to the corresponding ΣΔ not exceed 500 mV.
- CUR2+ and CUR2– can also be used as current inputs to measure another current (typically used to measure return current for tamper detection). Care must be taken that the AC peak amplitude fed to the corresponding ΣΔ not exceed 500 mV.
- Pads L2 and N2 correspond to the same Line and Neutral voltage inputs. The AC mains line and neutral voltages should be connected to these pads to provide isolated power to the host MSP430F6638 and its associated components. On this EVM, this connection has not been made.

Figure 16 and Figure 17 shows the various connections that need to be made to the test set up for proper functionality of the EVM.

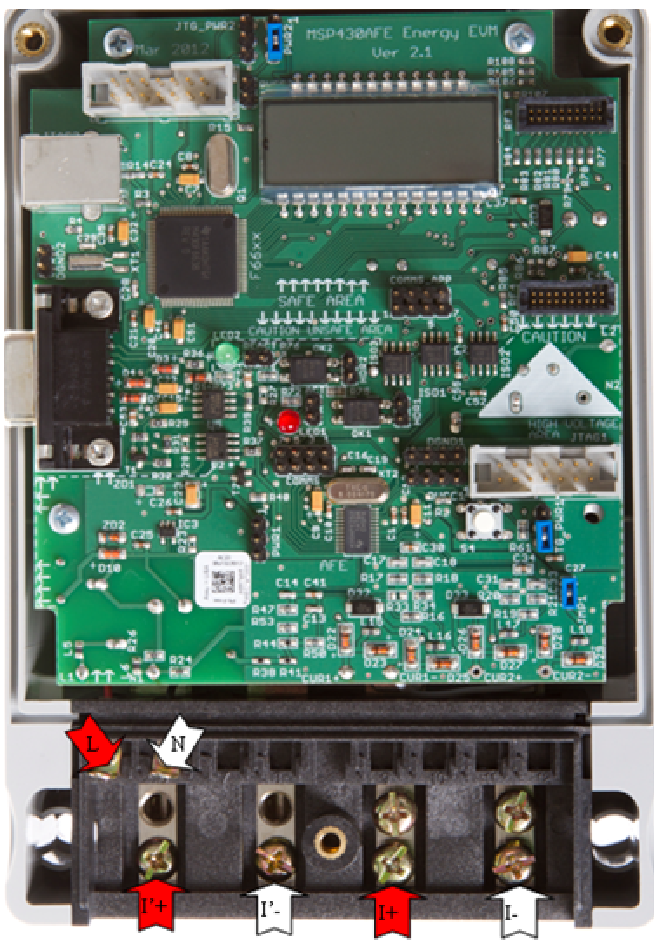


Figure 16. Top View of the EVM with Test Setup Connections

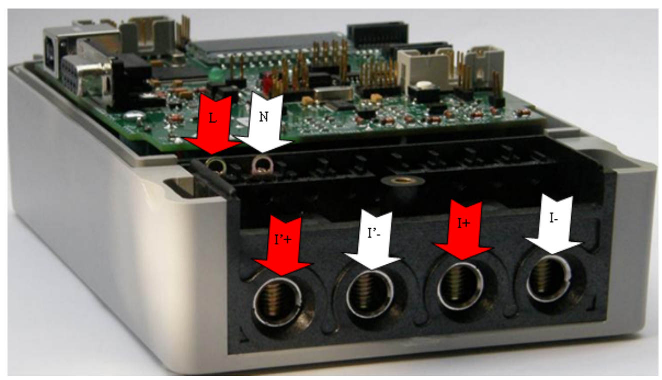


Figure 17. Side View of the EVM with Test Setup Connections

Copyright © 2014–2016, Texas Instruments Incorporated

With an AC test setup, the connections have to be made according to Figure 16 and Figure 17 that show the connections from the top and side view respectively. L and N correspond to the voltage inputs from the AC test setup. I+ and I– corresponds to one set of current inputs and I'+ and I'– corresponds to the second set of current inputs.

Although the EVM hardware and software support measurement for the second current, the EVM obtained from Texas Instruments does not have the second sensor. The current outputs from the AC test source must be connected to I+ and I– only. If an additional sensor needs to be placed, use the two bottom left slots corresponding to terminals I'+ and I'–. Additional wired connections need to be made to connect the output of these sensors to points CUR2+ and CUR2– on the EVM.

Copyright © 2014–2016, Texas Instruments Incorporated

4.2 Jumper Settings

Table 1. Header Names and Jumper Settings on the EVM

NAME	TYPE	MAIN FUNCTIONALITY	VALID USE-CASE	COMMENTS
ACT	2-pin header	Active Energy Pulses + GND (WARNING)	Probe here for active energy pulses. The pin under the "ACT" label corresponds to the Active Energy Pulse and the other pin corresponds to ground.	This header is not isolated from AC voltage so do not connect measuring equipments unless isolators external to the EVM are available. See HDR1 instead.
COMMS	4×2-pin header	Communication header for MSP430AFE (WARNING)	This contains the SPI and UART lines of the MSP430AFE isolated from the MSP430F6638. This header also contains the non-isolated active and reactive energy pulse outputs (Duplicated on ACT and REACT headers).	The SPI pins on this header are interfaced to the MSP430F663x via on board isolators (ISO1/ISO2/ISO3). The UART pins correspond to the UART signals and are not the associated translated RS-232 signals; therefore, they have UART voltage levels and not RS232 voltage levels. Do not connect the active and reactive pulse pins on this header to a scope or other measuring equipment if external isolators are not present. See HDR1 and HDR2 instead.
COMMS_APP	4×2-pin header	Communication header for MSP430F663x	This contains the SPI lines and the application interrupt pin (APP_INT) and other signals connected to the RF connector: RF_GPIO1, RF_GPIO2, and SFD.	The SPI pins on this header are interfaced to the MSP430AFE via on board isolators (ISO1/ISO2/ISO3). The APP_INT is an isolated input from the MSP430AFE used to alert the MSP430F6638 that updated metering parameters are ready. All pins on this header are isolated from the AC mains
DGND1	Header	Ground voltage header for MSP430AFE (WARNING)	Probe here for GND voltage of the MSP430AFE (DGND_AFE). Connect negative terminal of bench or external power supply when powering the MSP430AFE externally.	Do not probe here if the MSP430AFE is connected to AC mains unless when using an isolated AC test setup.
DGND2	Header	Ground Voltage Header for MSP430F663x	Probe here for GND voltage of the MSP430F663x (DGND_APP). Connect negative terminal of bench or external power supply when powering the MSP430F663x externally.	Note that DGND_APP is not isolated with USB GND voltages on the EVM.

Copyright © 2014–2016, Texas Instruments Incorporated

Table 1. Header Names and Jumper Settings on the EVM (continued)

NAME	TYPE	MAIN FUNCTIONALITY	VALID USE-CASE	COMMENTS
DVCC1	Header	VCC Voltage Header for MSP430AFE (WARNING)	Probe here for VCC supply voltage of the MSP430AFE (DVCC_AFE). Connect positive terminal of bench or external power supply when powering the MSP430AFE externally.	Do not probe here if the MSP430AFE is connected to AC mains unless when using an isolated AC test setup.
DVCC2	Header	VCC Voltage Header for MSP430F663x (WARNING)	Probe here for VCC supply voltage of the MSP430F663x (DVCC_APP). Connect positive terminal of bench or external power supply when powering the MSP430F663x externally.	Note that DGND_APP is not isolated with USB GND voltages on the EVM.
HDR1	Header	Isolated Active Energy Pulses	Probe here for isolated active energy pulses.	This is isolated from AC mains voltage so it is safe to connect a scope or other measuring equipments since isolators are already present on the EVM.
HDR2	Header	Isolated Reactive Energy Pulses	Probe here for reactive energy pulses.	This is isolated from AC mains voltage so it is safe to connect a scope or other measuring equipments since isolators are already present on the EVM.
JMP1	Jumper	"CUR2" Current Sensor Reference	Place a jumper here to reference the negative terminal of the "CUR2" ΣΔ to analog ground (AGND_AFE).	**Conditions based on sensor:** CT: Always have a jumper Shunt: Do not connect a jumper
JTG_PWR1	Jumper	JTAG Power Selection for MSP430AFE	Jumper placed during JTAG programming.	See Section 4.3 for configuration information.
JTG_PWR2	Jumper	JTAG Power Selection for MSP430F663x	Jumper placed during JTAG programming.	See Section 4.3 for configuration information.
PWR1	Jumper	Power Option Select for MSP430AFE	Jumper placed when powering the MSP430AFE either via AC mains or external power.	See Section 4.3 for configuration information
PWR2	Jumper	Power Option Select for MSP430F663x	Jumper placed when powering the MSP430F663x either via mains or external power.	See Section 4.3 for configuration information
REACT	Header	Reactive Energy Pulses + GND (WARNING)	Probe here for reactive energy pulses. The pin next to the LED corresponds to the Reactive Energy Pulse pin and the other pin corresponds to ground.	This header is not isolated from AC voltage so do not connect measuring equipments unless isolators external to the EVM are available. See HDR2 instead.

Copyright © 2014–2016, Texas Instruments Incorporated

4.3 Power Supply Options

The EVM can be configured to operate with different sources for power specific to the MSP430AFE and the MSP430F663x. The various sources of power to the MSP430s are JTAG, AC mains voltage, and external bench supply and battery. Table 2 lists the header settings for the power options of the MSP430AFE only.

Table 2. AFE Power Selection Headers

POWER OPTION	JTG_PWR1	PWR1
JTAG	Jumper on bottom two pins when board is oriented as in Figure 16	No jumper
AC Mains Voltage	No jumper if debugging is not desired.	Jumper on [1-2]
(WARNING)	Do not debug using JTAG unless AC source or JTAG is isolated from each other. Jumper on the top two pins (when the board is oriented as shown in Figure 16) if debugging is desired.	
External bench supply/battery	No jumper if debugging is not desired; Jumper on the top two pins (when the board is oriented as shown in Figure 16) if debugging is desired.	Jumper on [2-3]

When powered by the AC mains voltage, the PWR1 header can also be treated as a current consumption header by placing an ammeter across it.

Table 3 lists the header settings for the power options of the MSP430F663x only.

Table 3. F663x Power Selection Headers

POWER OPTION	JTG_PWR2	PWR2
JTAG	Jumper on [1-2]	No jumper
AC Mains voltage	No jumper if debugging is not desired; Jumper on [2-3] if debugging is desired.	Jumper on [1-2]
External bench supply/battery	No jumper if debugging is not desired; Jumper on [2-3] if debugging is desired.	Jumper on [2-3]
USB power	R15 must be populated (default)	Jumper on [2-3]

When powered by the mains supply, PWR2 header can also be treated as a current consumption header by placing an ammeter across it.

Copyright © 2014–2016, Texas Instruments Incorporated

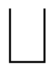
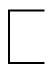
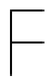
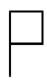
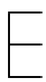
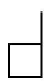
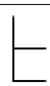
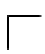
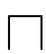
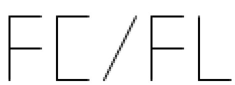
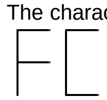
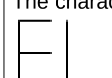
5 Results and Calibration

When the MSP430F6638 and MSP430AFE are turned on, the results will be available through LCD and the PC GUI.

5.1 *Viewing Results via LCD*

Table 4 shows the different metering parameters that are displayed on the LCD. If the AFE is not turned on, then the metering parameters (with the exception of day and time) will not be updated from their respective initial values. The initial values for the metering parameters are shown in the *Initial LCD Value* column of Table 4. The LCD display scrolls between metering parameter every two seconds. To distinguish metering parameters from each other, one or two characters are displayed on the LCD to the left of the actual reading. The *Symbol* column shows which characters correspond to which metering parameter. The *Comments* column provides a brief interpretation of the displayed metering parameters.

Table 4. LCD Metering Parameters

PARAMETER NAME	SYMBOL	UNITS	INITIAL LCD VALUE	COMMENTS
Voltage		Volts (V)	0.08	—
Current		Amps (A)	0.009	The ':' symbol represents the decimal point '.'
Frequency		Hertz (Hz)	0	—
Active Power		Watt (W)	0	—
Total consumed Active Energy		100 “Tick”	0	Every 10 ticks increments the tenths place by 1.
Date		Year/Month/Day (yymmdd)	110321	—
Time		Hour/Minute/Second (hhmmss)	10203	—
Reactive Power		Volt-Ampere Reactive (var)	0	—
Apparent Power		Volt-Ampere (VA)	0	—
Power Factor		Constant between 0 and 1	0	The characters  are used if the load is determined to be a capacitive load. The characters  are used if the load is determined to be an inductive load.

Copyright © 2014–2016, Texas Instruments Incorporated

5.2 Viewing Results via GUI

To open the GUI, follow these steps:

1. Once the MSP430F663x is turned on and the EVM's USB connector is connected to the PC, open the device manager to find the COM port assigned to the EVM. In this example, COM19 is used.
2. Enter the */Source/GUI* folder and open *calibration-config.xml* in a text editor.
3. Change the port name field within the *<meter>* tag to the COM port of the meter. In Figure 18, this field is changed to COM19.

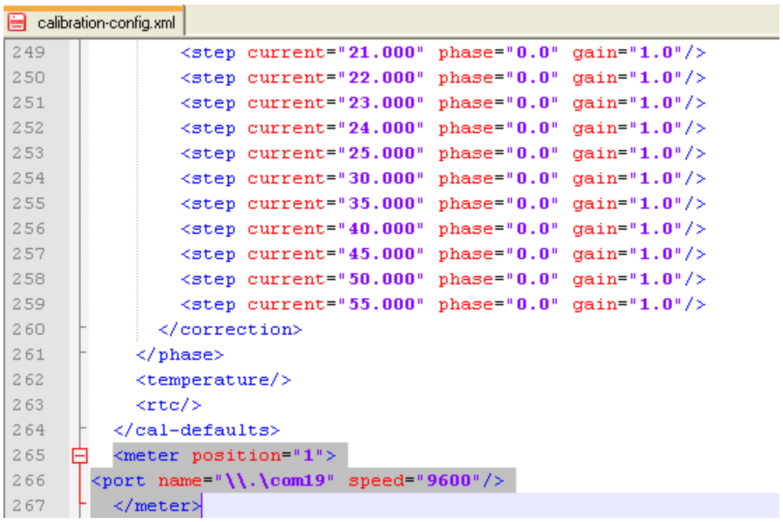


Figure 18. GUI Config File Changed with to EVM COM Port

4. Open *calibrator.exe*, which is located in the */Source/GUI* folder. If the COM port in *calibration-config.xml* was changed in the previous step to the com port of the enumerated EVM, the GUI should pop up.

Under correct connections, a top-left button will be green. If there are problems with connections or if the code is not configured correctly, the button will be red. Once the GUI is executing, the results can be viewed by pressing the green button as shown in Figure 19.

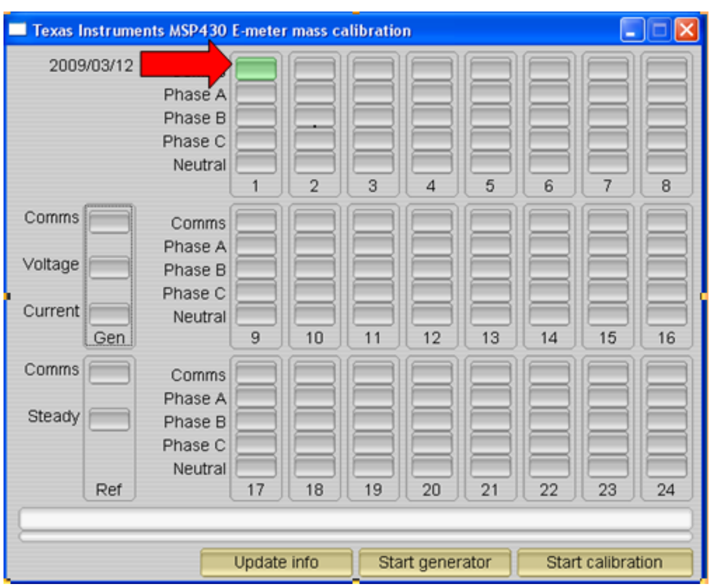


Figure 19. GUI Startup Window

Copyright © 2014–2016, Texas Instruments Incorporated

Once the green button is clicked, the results window pops up, as shown in Figure 20. Note that, unlike the LCD, the GUI power factor is displayed as a constant from 0 to 10 instead of a constant from 0 to 1. Also, there is a trailing 'L' or 'C' to indicate an inductive or capacitive load respectively.

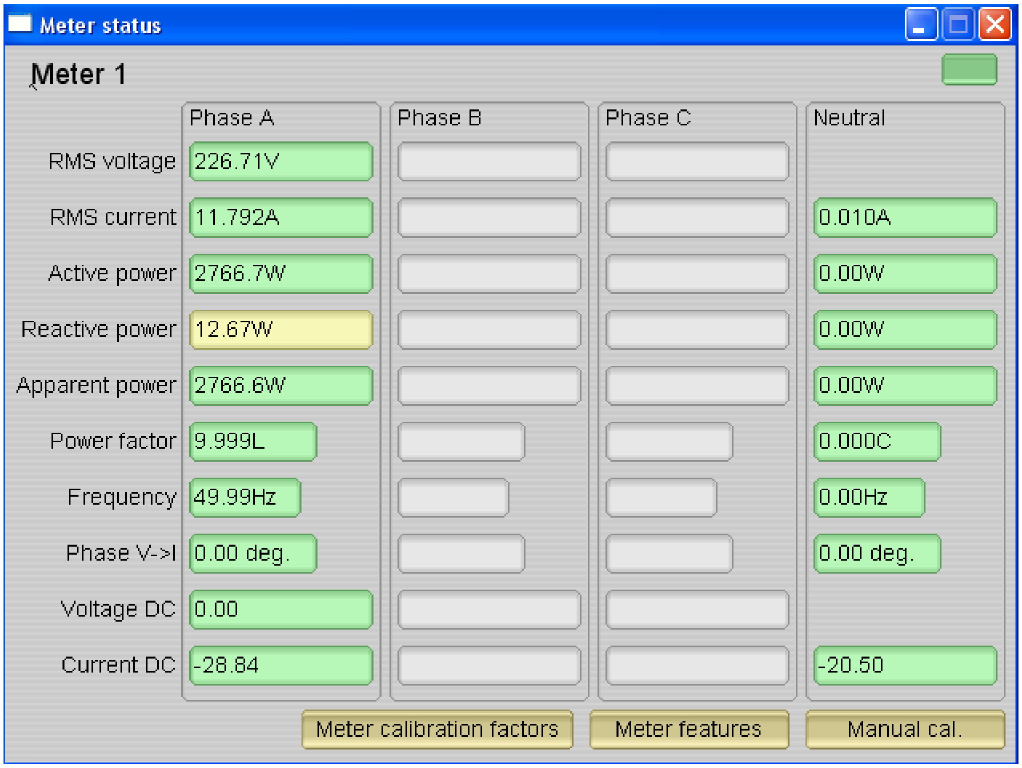


Figure 20. Results Window

Copyright © 2014–2016, Texas Instruments Incorporated

6 Design Files

6.1 Schematics

To download the schematics, see TIDM-METROLOGY-HOST.

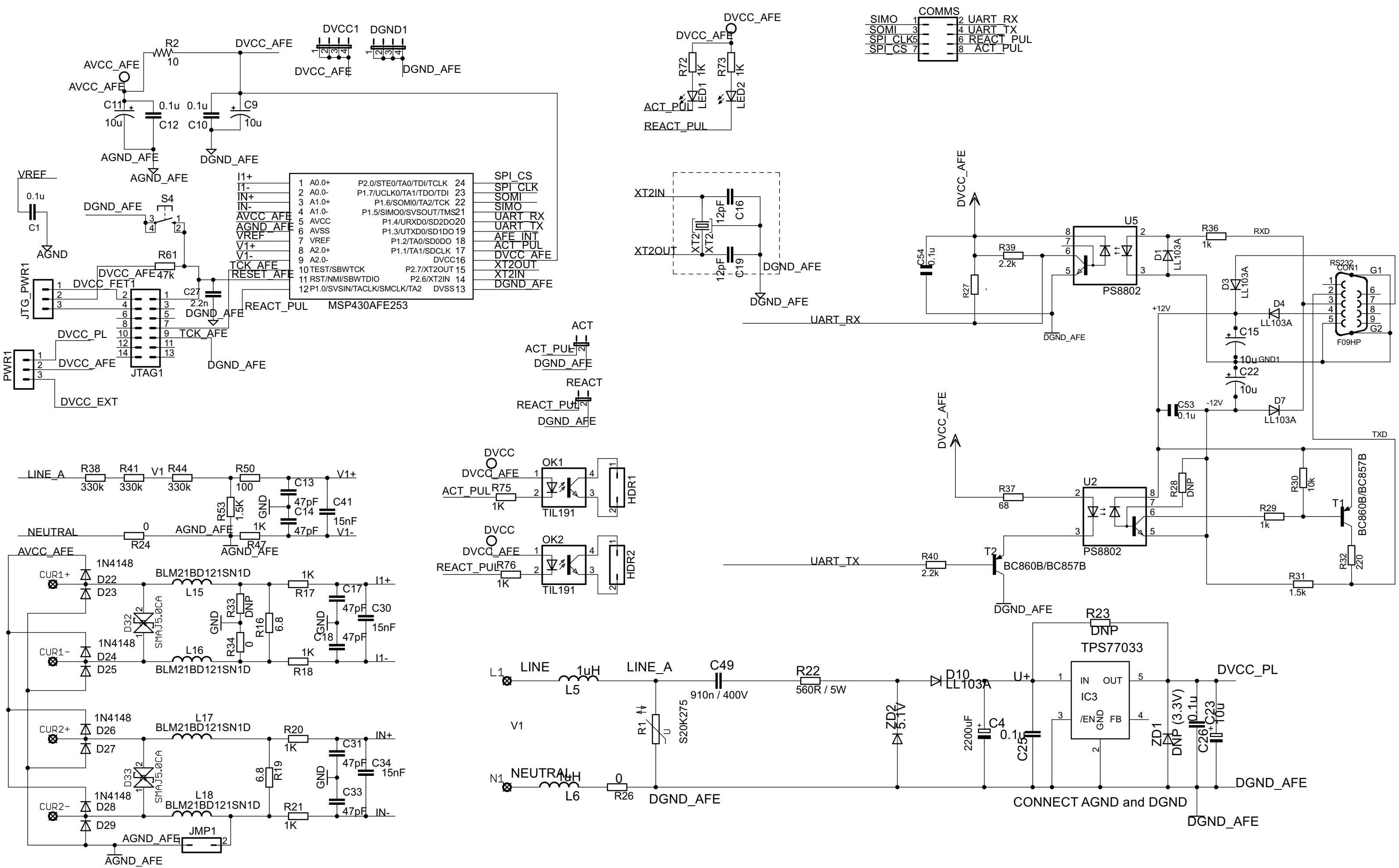


Figure 21. TIDM-METROLOGY-HOST Schematic Page 1

Copyright © 2014–2016, Texas Instruments Incorporated

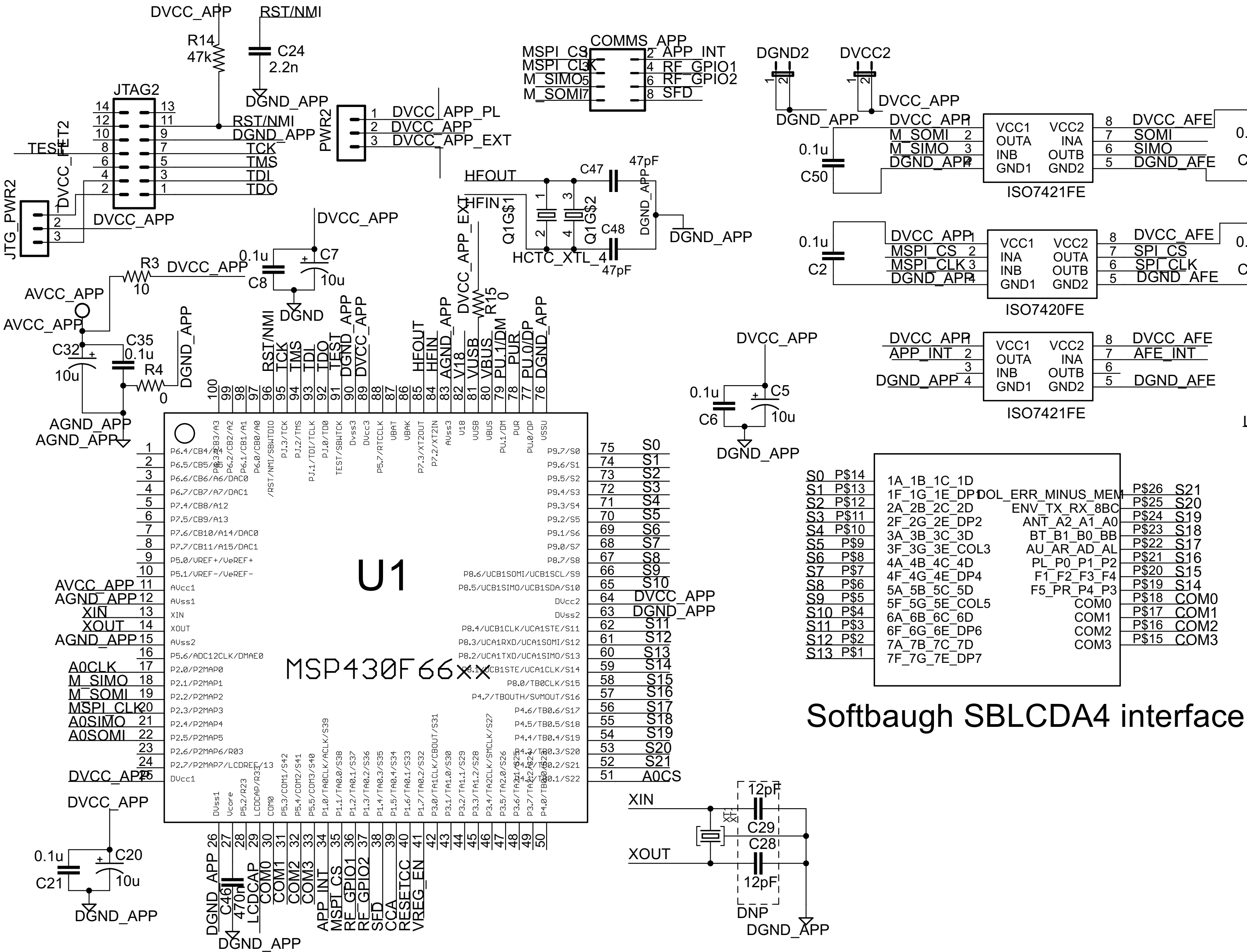


Figure 22. TIDM-METROLOGY-HOST Schematic Page 2

Copyright © 2014–2016, Texas Instruments Incorporated

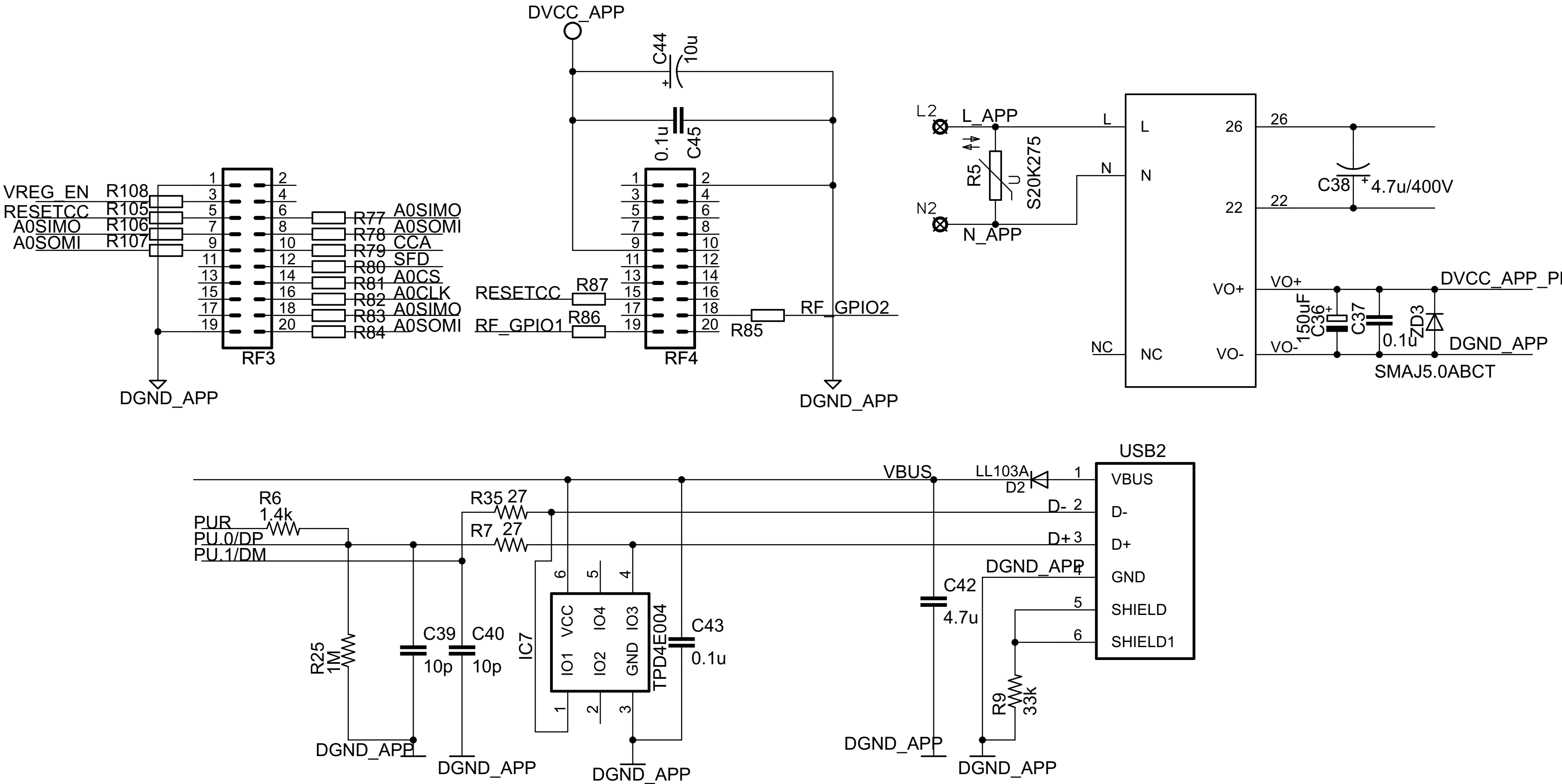


Figure 23. TIDM-METROLOGY-HOST Schematic Page 3

Copyright © 2014–2016, Texas Instruments Incorporated

6.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDM-METROLOGY-HOST.

Table 5. BOM

ITEM	QTY	REFERENCE	VALUE	PART DESCRIPTION	DIGIKEY PARTNUMBER
1	1	S4	Switch	Pushbutton Switch	P8006S-ND
2	1	C38	4.7 u/400 V	Capacitor	565-1411-ND
3	1	RS-232	9-pin connector	DB-9 Connector	A32115-ND
4	7	ACT, DGND2, DVCC2, REACT,HDR1, HDR2, JMP1	2-pin Jumper header	Jumper header	609-3296-ND Break and use
5	4	JTG_PWR1, JTG_PWR2, PWR1, PWR2	3-pin Jumper header	Jumper header	609-3296-ND Break and use
6	2	DGND1, DVCC1	4-pin Jumper header	Jumper header	609-3296-ND Break and use
7	2	COMMS, COMMS_APP	4×2 8-pin header	Jumper header	609-3296-ND Break and use
8	1	LED1	Light Emitting Diode	LED	511-1256-1-ND
9	1	LED2	Light Emitting Diode	LED	511-1254-1-ND
10	2	JTAG1, JTAG2	14-pin Connector	JTAG Connector	MHB14K-ND
11	2	RF3, RF4	20-pin Connector	RF Connector	TFM-110-02-SM-D-A-K
12	1	USB2	USB Connector	USB_RECEPTACLE	WM17113-ND
13	1	ZD1	3.6 V	Zener Diode	DNP
14	20	R4. R15. R24, R26, R34, R77, R78, R79, R80, R81, R82, R83, R84, R85, R86, R87, R105, R106, R107, R108	0	Resistor 0603	P0.0GCT-ND
15	16	C1, C2, C6, C8, C10, C12, C21, C25, C26, C35, C37, C43, C45, C50, C52, C55	0.1 u	Capacitor 0603	311-1366-1-ND
16	2	C53, C54	0.1 u	Capacitor 0805	445-1349-1-ND
17	1	R53	1.5 K	Resistor 0603	P1.5KGCT-ND
18	1	R31	1.5 K	Resistor 0805	RMCF0805JT1K50CT-ND
19	9	R17, R18, R20, R21, R47, R72, R73, R75, R76	1 K	Resistor 0603	P1.0KGCT-ND
20	2	R29, R36	1 K	Resistor 0805	P1.0KACT-ND
21	1	R25	1 M	Resistor 0603	P1.0MGCT-ND
22	8	D22, D23, D24, D25, D26, D27, D28, D29	1N4148	Diode	568-1749-1-ND
23	1	R6	1.4 k	Resistor 0603	P1.40KHCT-ND
24	2	L5, L6	EXC-ML20A390U	Inductor	P10191CT-ND
25	2	C24, C27	2.2 n	Capacitor 0603	478-6210-1-ND
26	2	R39, R40	2.2 k	Resistor 0805	P2.2KGCT-ND
27	1	ZD2	5.1 V	Zener Diode	568-4874-1-ND

Copyright © 2014–2016, Texas Instruments Incorporated

Table 5. BOM (continued)

ITEM	QTY	REFERENCE	VALUE	PART DESCRIPTION	DIGIKEY PARTNUMBER
28	1	C42	4.7 u	Capacitor 0603	490-3302-1-ND
29	2	R16, R19	6.8 Ω	Resistor 0603	P6.8GCT-ND
30	2	R2, R3	10	Resistor 0603	P10GCT-ND
31	2	C39, C40	10 p	Capacitor 0603	490-1403-1-ND
32	11	C5, C7, C9, C11, C15, C20, C22, C32, C44, C51, C23	10 u	Polarized Capacitor	399-3685-1-ND
33	4	C16, C19, C28, C29	12 pF	Capacitor 0603	445-1270-1-ND
34	3	C30, C34, C41	15 nF	Capacitor 0603	445-5102-1-ND
35	2	R7, R35	27	Resistor 0603	P27GCT-ND
36	1	R9	33 k	Resistor 0603	P33KGCT-ND
37	2	R61, R14	47 K	Resistor 0603	P47KGCT-ND
38	8	C13, C14, C17, C18, C31, C33, C47, C48	47 pF	Capacitor 0603	445-1277-1-ND
39	1	R50	100	Resistor 0603	P100GCT-ND
40	1	C36	150 µF	Polarized Capacitor	P12917-ND
41	3	R38, R41, R44	330 K	Resistor 0603	P330KHCT-ND
42	1	C49	470 n / 300 V~	Polarized Capacitor	P12275-ND
43	1	R22	470 / 5 W	Resistor	45J470E-ND
44	1	C4	2200 µF	Polarized Capacitor	P5128-ND
45	4	L15, L16, L17, L18	BLM21BD121SN1D	Inductor	490-1044-1-ND
46	1	U$2	CUI_XR	Power supply module	102-1801-ND
47	1	U1	F66XX---PZ100	MSP430F6638 100-pin	TI chip
48	1	Q1	HCTC_XTL_4	HF Crystal	887-1002-ND
49	1	ISO1	ISO7420	8-pin DW Isolator chip	296-28742-1-ND
50	2	ISO2, ISO3	ISO7421	8-pin DW Isolator chip	296-28426-ND
51	6	D1, D2, D3, D4, D7, D10	LL103A	Diode	LLSD103ADICT-ND
52	1	U$1	MSP430AFE_24TSSOP	MSP430AFE 24-pin TSSOP	TI chip
53	2	U2, U5	PS8802	8-pin TSSOP	PS8802-1-F3-AXCT-ND
54	2	R1, R5	S20K275	Varistor	495-1417-ND
55	1	LCD1	SBLCDA4	LCD Display	ACD Will provide
56	1	ZD3	SMAJ5.0ABCT	Diode	SMAJ5.0ABCT-ND
57	2	D32, D33	SMAJ5.0CA	Diode	SMAJ5.0CABCT-ND
58	2	OK1, OK2	PS2501-1-A	4-pin Isolator chip	PS2501-1A-ND
59	1	IC7	TPD4E004	6-pin Chip	296-23618-1-ND
60	1	IC3	TPS77033	6-pin Chip	296-11051-1-ND
61	1	XT1	XT1	LF Crystal	300-8341-1-ND

Copyright © 2014–2016, Texas Instruments Incorporated

Table 5. BOM (continued)

ITEM	QTY	REFERENCE	VALUE	PART DESCRIPTION	DIGIKEY PARTNUMBER
62	1	XT2	XT2	HF Crystal	887-1233-ND
63	1	R23	DNP	Resistor 0805	DNP
64	1	R37	68	Resistor 0805	P68ACT-ND
65	1	R27	DNP	Resistor 0805	DNP
66	1	R30	10 k	Resistor 0805	P10KACT-ND
67	1	R32	220	Resistor 0805	P220ACT-ND
68	1	C46	470 n	Capacitor 0603	445-3456-1-ND
69	1	R33	DNP	Resistor 0603	DNP
70	1	R28	DNP	Resistor 0603	DNP
71	2	T1, T2	BC860B/BC857B	BC857ASMD	BC857B-TPMSCT-ND

Copyright © 2014–2016, Texas Instruments Incorporated

6.3 PCB Layer Plots

To download the layer plots, see the design files at TIDM-METROLOGY-HOST.

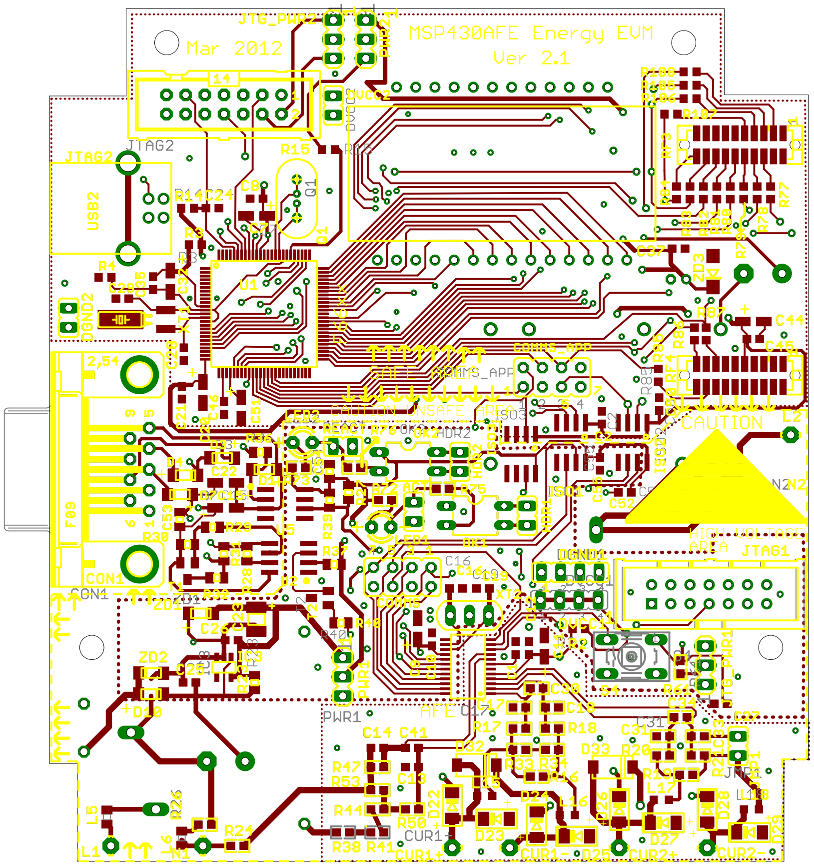


Figure 24. Top Layer Plot

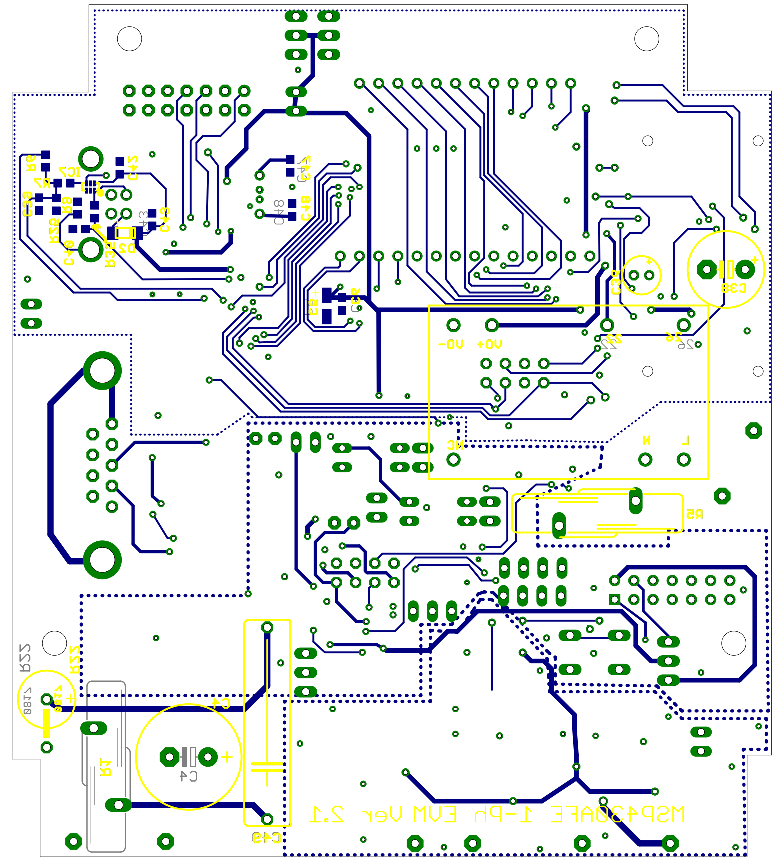


Figure 25. Bottom Layer Plot

Copyright © 2014–2016, Texas Instruments Incorporated

6.4 CAD Project Files

To download the CAD project files, see the design files at TIDM-METROLOGY-HOST.

6.5 Gerber Files

To download the Gerber files, see the design files at TIDM-METROLOGY-HOST.

6.6 Software Files

To download the software files, see the design files at TIDM-METROLOGY-HOST.

7 References

1. Energy Measurement Results for CTs and Shunts on a TI Designed Meter Using MSP430AFE2xx Devices (SLAA536)

8 About the Author

MEKRE MESGANAW is a system applications engineer in the Smart Grid and Energy group at Texas Instruments, where he primarily works on electricity metering customer support and reference design development. Mekre received his bachelor of science and master of science in computer engineering from the Georgia Institute of Technology.

Copyright © 2014–2016, Texas Instruments Incorporated

Revision History

Changes from Original (August 2014) to A Revision	Page
• Added CC2530 to Design Resources	1

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Copyright © 2014–2016, Texas Instruments Incorporated

IMPORTANT NOTICE FOR TI REFERENCE DESIGNS

Texas Instruments Incorporated ("TI") reference designs are solely intended to assist designers (“Buyers”) who are developing systems that incorporate TI semiconductor products (also referred to herein as “components”). Buyer understands and agrees that Buyer remains responsible for using its independent analysis, evaluation and judgment in designing Buyer’s systems and products.

TI reference designs have been created using standard laboratory conditions and engineering practices. **TI has not conducted any testing other than that specifically described in the published documentation for a particular reference design.** TI may make corrections, enhancements, improvements and other changes to its reference designs.

Buyers are authorized to use TI reference designs with the TI component(s) identified in each particular reference design and to modify the reference design in the development of their end products. HOWEVER, NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY THIRD PARTY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT, IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI REFERENCE DESIGNS ARE PROVIDED "AS IS". TI MAKES NO WARRANTIES OR REPRESENTATIONS WITH REGARD TO THE REFERENCE DESIGNS OR USE OF THE REFERENCE DESIGNS, EXPRESS, IMPLIED OR STATUTORY, INCLUDING ACCURACY OR COMPLETENESS. TI DISCLAIMS ANY WARRANTY OF TITLE AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, QUIET ENJOYMENT, QUIET POSSESSION, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS WITH REGARD TO TI REFERENCE DESIGNS OR USE THEREOF. TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY BUYERS AGAINST ANY THIRD PARTY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON A COMBINATION OF COMPONENTS PROVIDED IN A TI REFERENCE DESIGN. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, SPECIAL, INCIDENTAL, CONSEQUENTIAL OR INDIRECT DAMAGES, HOWEVER CAUSED, ON ANY THEORY OF LIABILITY AND WHETHER OR NOT TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES, ARISING IN ANY WAY OUT OF TI REFERENCE DESIGNS OR BUYER’S USE OF TI REFERENCE DESIGNS.

TI reserves the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques for TI components are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

Reproduction of significant portions of TI information in TI data books, data sheets or reference designs is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards that anticipate dangerous failures, monitor failures and their consequences, lessen the likelihood of dangerous failures and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in Buyer’s safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed an agreement specifically governing such use.

Only those TI components that TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components that have ***not*** been so designated is solely at Buyer's risk, and Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265

Copyright © 2016, Texas Instruments Incorporated