参考資料

TI Designs
低コスト単相/二相絶縁電気測定回路リファレンス・デザイン

TI Designs リファレンス・デザイン

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デザイン・リソース

TIDM-TWOPHASEMETER-I2040	デザイン・ページ
MSP430I2041	プロダクト・フォルダ
MSP430F6638	プロダクト・フォルダ
ISO7220A	プロダクト・フォルダ
ISO7221A	プロダクト・フォルダ
TPS5401	プロダクト・フォルダ
TPD4E004	プロダクト・フォルダ

TI E2E™ Community

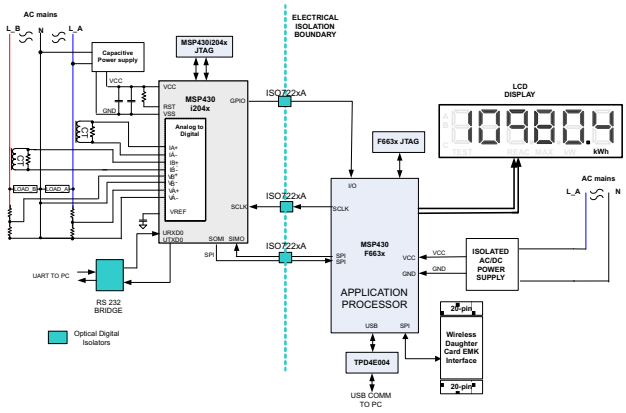
E2Eエキスパートに質問
WEBENCH®設計支援ツール

デザインの特長

- クラス1の精度を持つ低コスト二相電気計器
- TIのエネルギー・ライブラリ・ファームウェアにより、アクティブ/リアクティブな電力とエネルギー、RMS電流と電圧、力率、ライン周波数など、各種のエネルギー測定パラメータを計算
- PCベースのGUIにより較正と、エネルギー測定パラメータの確認が可能
- ホストMCUへの絶縁型通信オプション
- ホストMCUアプリケーションは、セグメントLCD、およびアドオン通信モジュールを駆動し、ZigBee®、Wi-Fi®、ワイヤレスM-Bus、IEEE-802.15.4gなどのワイヤレス通信標準に対応可能

主なアプリケーション

- メータリング
- 街路照明



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1 System Description

This design implements a low-cost, two-phase electric meter system. This two-chip solution has a metrology processor for calculating energy parameters and an additional host MCU that has the capability to communicate metrology parameters by using the on-board LCD, on-board USB interface, or add-on communication modules that are connected to the EVM's RF connector. Instead, it has the capability to act as a USB device to communicate with a computer via USB. Isolated communication between the metrology and host MCU is supported by on-board isolators.

For the metrology processor, the MSP430i2041 device is used. This chip belongs to the 16-bit MSP430i2xx platform. These devices find their application in power and energy measurement and have the necessary architecture to support it. The MSP430i20xx devices have an internal 16.384 MHz DCO, which is used to generate system clocks without an external crystal. The MSP430i204x derivatives of the MSP430i20xx devices have four independent 24-bit ΣΔ analog-to-digital converters (ADC) based on a 2nd order sigma-delta architecture that supports differential inputs. These sigma-delta ADCs (ΣΔ24) operate independently, are capable of 24-bit results, and can be grouped together for simultaneous sampling of voltages and currents on the same trigger. In addition, each converter also has an integrated gain stage for amplification of low-output current sensors. The MSP430i20xx devices also have a 16-bit x 16-bit hardware multiplier that can be used to further accelerate math intensive operations during metrology computations. The key parameters calculated during measurements are: RMS current and voltage, active and reactive power and energies, power factor, and frequency.

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

2 Design Features

This section describes the front-end passives and other components required for the design of a working meter using the MSP430i204x.

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 (MSP430i204x) can be easily derived using an AC to DC conversion mechanism.

2.1.1.1 Resistor Capacitor (RC) Power Supply

図 1 shows a capacitor power supply that provides a single output voltage of 3.3 V directly from the mains of 120/230 V RMS AC at 50/60 Hz. In this figure, appropriate values of resistor R54 and capacitor C60 are chosen based on the required output current drive of the power supply

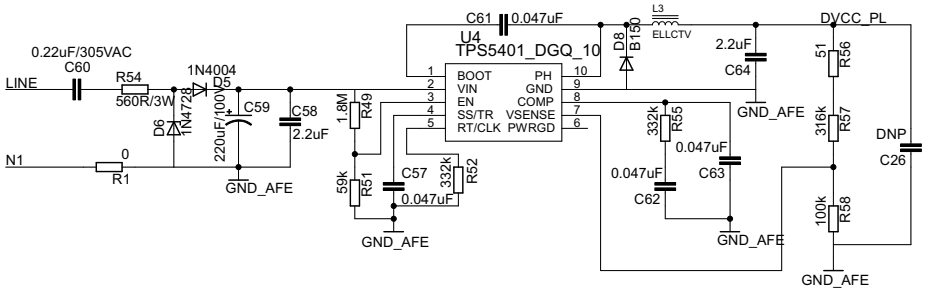

図 1. Simple Capacitive Power Supply for the MSP430 Energy Meter

As shown in 図 1, voltage from mains is directly fed to a RC based circuit followed by a rectification circuit 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. The design equations for the power supply are given in the application report *Improved Load Current Capability for Cap-Drop Off-Line Power Supply for E-Meter* (SLVA491). If even higher output drive is required, the same circuitry can be used followed by an NPN output buffer. Another option would be to replace the above circuitry with a transformer-based or switching-based power supply.

2.1.1.2 Switching Based Power Supply

When a high current drive is required to drive RF transceivers, a simple capacitive power supply will not provide enough peak-current. Hence, a switching-based power supply is required. A separate power supply module on the board may be used to provide 3.3V DC from the AC mains of 110V – 230V AC. 図 2 shows the use of an SMPS module to provide a 3.3V rail with increased current drive. This module can be used on the EVM430-i2040 to provide an isolated voltage to drive only the MSP430F663x and its associated interfaces.

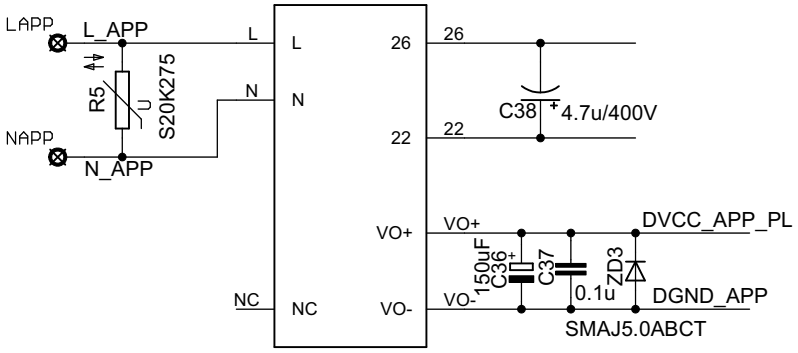

図 2. Switching-Based Power Supply for the MSP430 Energy Meter

2.1.2 Analog Inputs

The MSP430i204x's analog front end, which consists of the ΣΔ ADC, is differential and requires that the input voltages at the pins do not exceed ±928 mV (gain = 1). To meet this specification, the current and voltage inputs need to be scaled down. In addition, the ΣΔ24 allows a maximum negative voltage of -1 V. Therefore, the AC current signal from mains can be directly interfaced without the need for level shifters. This section describes the analog front end used for the voltage and current channels.

2.1.2.1 Voltage Inputs

The voltage from the mains is usually 230 V or 120 V and must be scaled down within 928 mV. The analog front end for voltage consists of spike protection varistors followed by a voltage divider network, and a RC low-pass filter that acts like an anti-alias filter. For the EVM430-i2040, footprints for suppressant inductors are also available. These inductor footprints are shown in 図 3 as L4 and L6, and by default are populated with 0-ohm resistors.

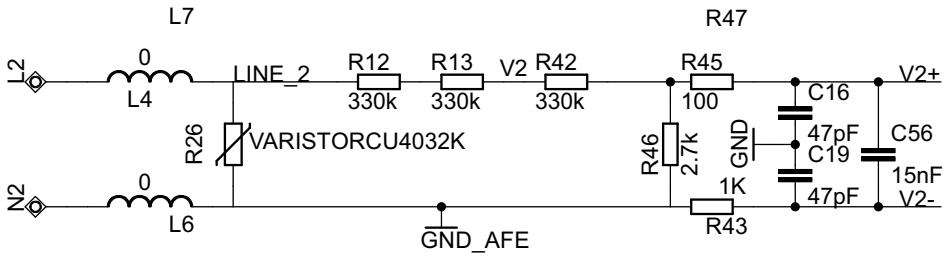

図 3. Analog Front End for Voltage Inputs

図 3 shows the analog front end for the voltage inputs for a mains voltage of 230 V. In this circuitry, the voltage is brought down to approximately 626mV RMS, which is 885mV peak, and fed to the positive input of the convertor. It is important to note that 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 is not maintained, a relatively large phase shift would result between voltage and current samples.

2.1.2.2 Current Inputs

The analog front-end for current inputs is slightly different from the analog front end for the voltage inputs. 図 4 shows the analog front end used for a current channel.

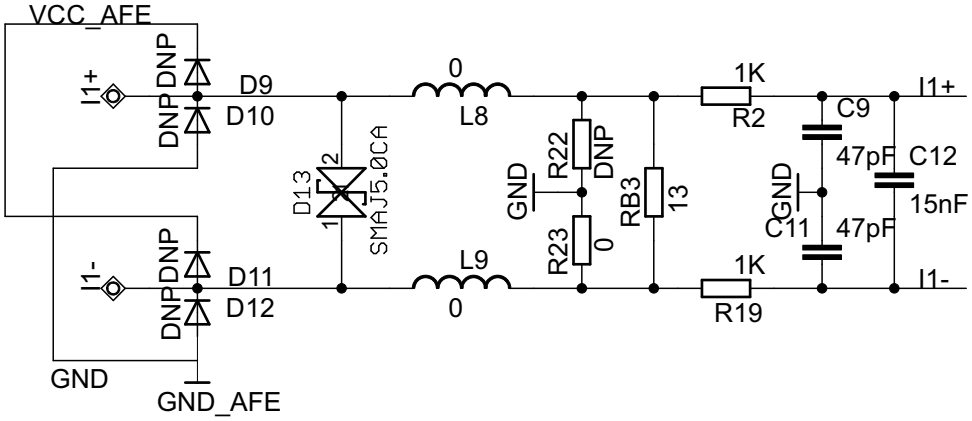

図 4. Analog Front End for Current Inputs

In the figure, resistor RB3 is the burden resistor that is selected based on the current range used and the turns ratio specification of the CT(CTs with a turns ratio of 2000:1 are used for this design). The value of the burden resistor for this design is 13 Ω. The antialiasing circuitry, consisting of resistors and capacitors, follows the burden resistor. Based on this EVM's maximum current of 100 A, CT turns ratio of 2000:1, and burden resistor of 13 Ω, the input signal to the converter is a fully differential input with a voltage swing of ±919 mV maximum when the maximum current rating of the meter(100 A) is applied.

For the EVM430-i2040, footprints for suppressant inductors are also available. These inductor footprints are shown below as L8 and L9 and by default are populated with 0-ohm resistors.

2.1.3 External Resistor/Oscillator For Clock

The i20xx internal DCO supports two modes of operation. It can operate with an internal resistor or an external resistor that is connected to ROSC pin of the device. For achieving Class 1% target accuracy, the external resistor option must be used. In this option, a recommended 20kΩ, ±50 ppm, resistor with 0.1% tolerance is recommended. This resistor is populated on this EVM and the software is configured to use this resistor. If there is an issue with the external resistor, the i204x switches to internal resistor mode automatically.

In addition to sourcing the clocks from the internal DCO, the i204x could also run from a 16.384 MHz external clock. In the EVM430-i2040, although an external clock is not used or needed, a footprint for a clock generator is provided to support this option.

2.2 Software Implementation

The software for the implementation of 2-phase metrology is discussed in this section. The first subsection discusses the setup of various peripherals of the metrology and application processors. Subsequently, the metrology software is described as two major processes: the foreground process and background process

2.2.1 Peripherals Setup

The major peripherals are the 24-bit sigma delta (ΣΔ24) ADC, clock system, timer, and watchdog timer (WDT).

2.2.1.1 Start Up Code for Device Security and Peripheral Calibration

In each i20xx device's info memory, device-specific calibration values are stored in INFO memory. These values affect items such as clock accuracy, SD24 operation, and reference voltage operation. For proper functionality of this device, these values need to be loaded into the proper calibration and trim registers, as mentioned in the TLV and Start-Up Code chapter of the *MSP430i2xx family User's Guide* (SLAU335) In addition, a decision whether to secure or unsecure the i204x must be made in the first 64 MCLK cycles after RESET. Both of these functions is accomplished in the low_level_init function (in low_level_init.c), which runs before even the main function is called.

CAUTION

Since the device-specific peripheral calibration is stored in INFO memory, please make sure not to change the project settings to erase INFO memory since it would erase these values. Please also note that meter calibration data is stored in the same segment as the peripheral calibration information. As a result, care must be taken to not delete the peripheral calibration values if performing meter calibration by using custom-written code that is outside the normal code of the energy library.

2.2.1.2 ΣΔ24 Setup

The i204x has four sigma delta data converters, which are used to measure the voltage and currents in the system. For the i20xx, the clock to the ΣΔ24 ADCs (f_M) is fixed at 1.024000 MHz. In the software, an OSR of 256 is chosen, which results in a sampling frequency of 4.000 ksps for the converters. At every sampling instance, the ΣΔ24s are configured to generate regular interrupts.

In the software, the following channel associations are used:

A0.0+ and A0.0- → Voltage VA
A1.0+ and A1.0- → Voltage VB
A2.0+ and A2.0- → Current IA
A3.0+ and A3.0- → Current IB

2.2.2 Metrology Foreground Process

The foreground process includes the initial setup of the MSP430 hardware and software immediately after a device RESET. 図 5 shows the flowchart for this process.

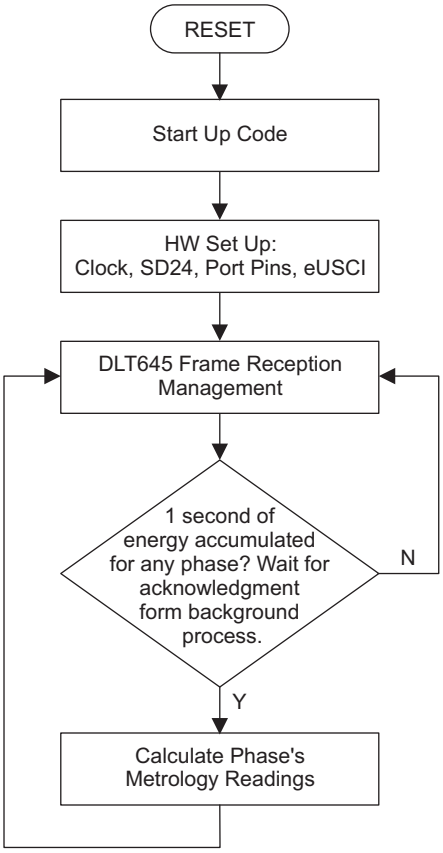

図 5. Foreground Process

The initialization routines involve the setup of the analog to digital converter, clock system, general purpose input/output (port) pins, and the USCI_A0 for UART functionality. After the hardware is setup, any received frames from the GUI are processed. Subsequently, the foreground process checks whether the background process has notified it to calculate new metering parameters. This notification is done through the assertion of the “PHASE_STATUS_NEW_LOG” status flag whenever a frame of data is available for

processing. The data frame consists of the processed dot products that were accumulated for one second in the background process. This is equivalent to accumulation of 50 or 60 cycles of data synchronized to the incoming voltage signal. In addition, a sample counter keeps track of how many samples have been accumulated over this frame period. This count can vary as the software synchronizes with the incoming mains frequency.

The processed dot products include the VRMS, IRMS, active power, and reactive power. These dot products are used by the foreground process to calculate the corresponding metrology readings in real-world units. Processed voltage dot products are accumulated in 48-bit registers. In contrast, processed current dot products, active energy dot products, and reactive energy dot products are accumulated in separate 64-bit registers to further process and obtain the RMS and mean values. 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 using the formulas in 2.2.2.1.

2.2.2.1 Formulae

This section briefly describes the formulas used for the voltage, current, and energy calculations.

As described in the previous sections, voltage and current samples are obtained from the ΣΔ converters at a sampling rate of 4000 Hz. All of the samples that are taken in 1 second are kept and used to obtain the RMS values for voltage and current for each phase. The RMS values are obtained by the following formulas:

$$V_{RMS,ph} = K_{v,ph} * \sqrt{\frac{\sum_{n=1}^{Sample\ count} v_{ph}(n) * v_{ph}(n)}{Sample\ count}} - v_{offset,ph} \qquad I_{RMS,ph} = K_{i,ph} * \sqrt{\frac{\sum_{n=1}^{Sample\ count} i_{ph}(n) * i_{ph}(n)}{Sample\ count}} - i_{offset,ph}$$

Where

ph = The phase whose parameters are being calculated. That is, Phase A(=1) and Phase B(=2).

$v_{ph}(n)$ = Voltage sample at a sample instant n

$V_{offset,\ ph}$ = Offset used to subtract effects of the Additive White Gaussian Noise from the voltage converter

$i_{ph}(n)$ = Each current sample at a sample instant

$i_{offset,\ ph}(n)$= Offset used to subtract effects of the Additive White Gaussian Noise from the current converter

Sample count = Number of samples in one second

$K_{v,\ ph}$ = Scaling factor for voltage

$K_{i\ ,ph}$ = Scaling factor for each current

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 active, reactive, and apparent powers via the following formulas:

$$P_{ACT,ph} = K_{ACT,ph} \frac{\sum_{n=1}^{Sample\ count} v(n) \times i_{ph}(n)}{Sample\ count} \qquad P_{REACT,ph} = K_{REACT,ph} \frac{\sum_{n=1}^{Sample\ count} v_{90}(n) \times i_{ph}(n)}{Sample\ count} \qquad P_{APP,ph} = \sqrt{P_{ACT,ph}^2 + P_{REACT,ph}^2}$$

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

In addition to calculating the per-phase active, reactive and apparent powers, the cumulative sum of these parameters are also calculated by the below equations:

$$P_{ACT,Cumulative} = \sum_{ph=1}^{2} P_{ACT,ph} \quad P_{REACT,Cumulative} = \sum_{ph=1}^{2} P_{REACT,ph} \quad P_{APP,Cumulative} = \sum_{ph=1}^{2} P_{APP,ph}$$

Please note that for reactive energy, the 90° phase shift approach is used for two reasons:

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

The calculated mains frequency is used to calculate the 90 degrees-shifted voltage sample. Since the frequency of the mains varies, it is important to first measure the mains frequency accurately in order to phase shift the voltage samples accordingly (refer to: Frequency measurement and cycle tracking). The application's phase shift implementation 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 (refer to: Phase compensation).

Using the calculated powers, energies are calculated by the following equations:

$$E_{ACT,\ ph} = P_{ACT,\ ph} \times Samplecount$$

$$E_{REACT,\ ph} = P_{REACT,\ ph} \times Samplecount$$

$$E_{APP\ ph} = P_{APP\ ph} \times Samplecount$$

From there, the energies are also accumulated to calculate the cumulative energies, by the below equations:

$$E_{ACT,Cumulative} = \sum_{ph=1}^{2} E_{ACT,ph} \rightarrow E_{REACT,Cumulative} = \sum_{ph-1}^{2} E_{REACT,ph} \; E_{APP,Cumulative} = \sum_{ph-1}^{2} E_{APP,ph}$$

The calculated energies are then accumulated into buffers that store the total amount of energy consumed since meter reset. Please note that these energies are different from the working variables used to accumulate energy for outputting energy pulses. Also, there is one set of buffers for each phase and one set for the cumulative of the phases. Within each set of buffers, the following energies are accumulated:

1. Active import energy (active energy when active energy >= 0)
2. Active export energy (active energy when active energy <0)
3. React. Quad I energy (reactive energy when reactive energy >=0 and active power >=0; inductive load)
4. React. Quad II energy (reactive energy when reactive energy >=0 and active power <0; capacitive generator)
5. React. Quad III energy (reactive energy when reactive energy <0 and active power <0; inductive generator)
6. React. Quad IV energy (reactive energy when reactive energy <0 and active power >=0; capacitive load)
7. App. import energy (apparent energy when active energy>=0)
8. App. export energy (apparent energy when active energy <0)

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:

$$Frequency\ (\boldsymbol{Hz}) = \frac{Sampling\ Rate\ \ (samples\ /\ second)}{Frequency\ (samples\ /\ cycle)}$$

After the active power and apparent power 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:

$$Internal\ Representation\ of\ Power\ Factor\ = \begin{cases} \dfrac{P_{Act}}{P_{Apparent}}, if\ capacitive\ \ load \\ -\dfrac{P_{Act}}{P_{Apparent}}, if\ inductive\ \ load \end{cases}$$

2.2.3 Background Process

The background function deals mainly with timing critical events in software. It uses the ΣΔ interrupt as a trigger to collect voltage and current samples. The ΣΔ interrupt is generated when a new voltage sample is ready. Once the voltage sample is obtained, sample processing is done on the previously obtained voltage and current samples. This sample processing is done by the "per_sample_dsp()" function. After sample processing, the background process uses the "per_sample_energy_pulse_processing()" for the calculation and output of energy-proportional pulses. 図 6 shows the flowchart for this process.

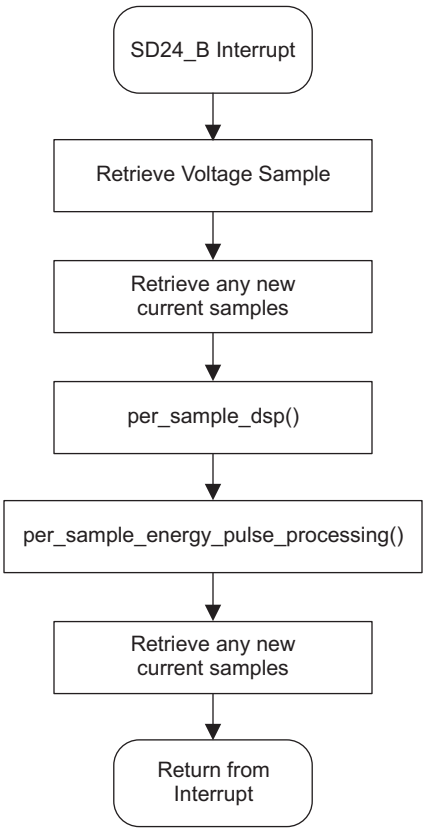

図 6. Background Process

2.2.3.1 *per_sample_dsp*

The flowchart for the per_sample_dsp function is shown in 図 7. In this function, the per_sample_dsp function is used to calculate intermediate dot product results that are fed into the foreground process for the calculation of metrology readings. Since 16-bit voltage samples are used, the voltage samples are further processed and accumulated in dedicated 48-bit registers. In contrast, since 24-bit current samples are used, the current samples are processed and accumulated in dedicated 64-bit registers. Per-phase active power and reactive power are also accumulated in 64-bit registers.

After sufficient samples (approximately one second's worth) have been accumulated, the foreground function is triggered to calculate the final values of VRMS, IRMS, active, reactive, and apparent powers, active, reactive, and apparent energy, frequency, and power factor. In the software, there are two sets of dot products: at any given time, one is used by the foreground for calculation and the other used as the working set by the background. After the background process has sufficient samples, it swaps the two dot products so that the foreground uses the newly acquired dot products that the background process just calculated and the background process uses a new empty set to calculate the next set of dot products.

Whenever there is a leading-edge zero-crossing (- to + voltage transition) on a voltage channel, the per_sample_dsp function is also responsible for updating the corresponding phase's frequency (in samples/cycle) and voltage sag/swell conditions. For the sag conditions, whenever the RMS voltage is below a certain user-defined threshold percentage, the number of mains cycles where this condition persists is logged as the sag duration. The number of periods in time where there was a sag condition is logged as the sag events count. Please note that the sag duration corresponds to the total number of cycles in a sag condition since reset, and is therefore, not cleared for every sag event. Also, when the RMS voltage is above a certain threshold percentage, swell events and duration are logged in a similar way.

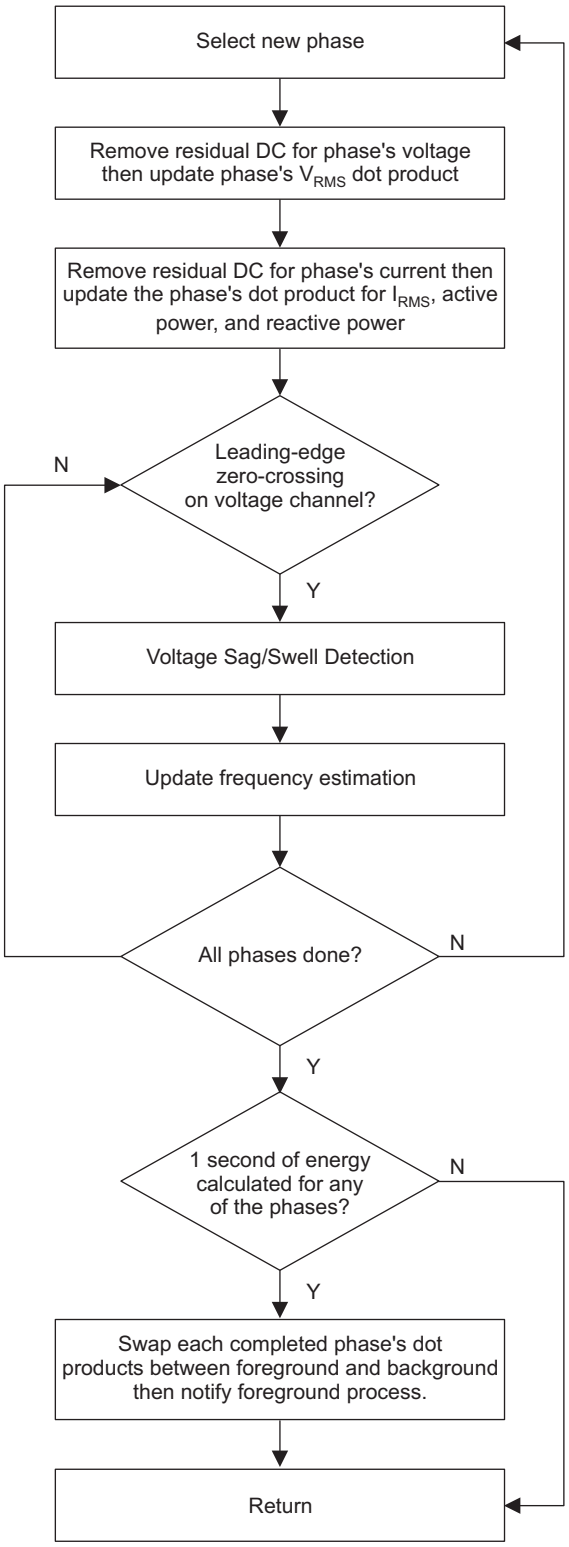

図 7. per_sample_dsp()

2.2.3.1.1 Voltage and Current Signals

The output of each ΣΔ converter is a signed integer and any stray dc or offset value on these converters is removed using a dc tracking filter. Separate dc estimates for all voltages and currents are obtained using the filter and voltage and current samples, respectively. These estimates are then subtracted from each voltage and current sample.

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

- Accumulated squared values of voltages and currents, which is used for VRMS and IRMS calculations, respectively.
- Accumulated energy samples to calculate active energies.
- Accumulated energy samples using current and 90° phase shifted voltage to calculate reactive energies.

These accumulated values are processed by the foreground process.

2.2.3.1.2 Frequency Measurement and Cycle Tracking

The instantaneous voltage of each phase is accumulated in 48-bit registers. In contrast, the instantaneous current, active power, and reactive power are accumulated in 64-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 switches the foreground and background then 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, a straight line interpolation is used between the zero crossing voltage samples. 図 8 shows the samples near a zero cross and the process of linear interpolation.

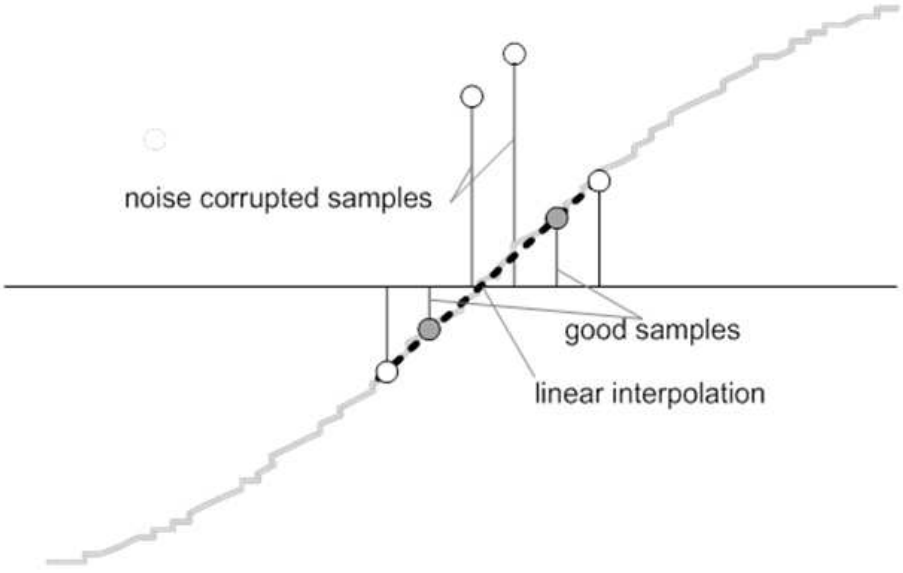

図 8. Frequency Measurement

Because noise spikes can also cause errors, the application uses a rate of change check to filter out the possible erroneous signals and make sure that the two points are interpolated from are 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 pair looks as if there is a zero crossing.

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

2.2.3.2 LED Pulse Generation (per_sample_energy_pulse_processing)

In electricity meters, the active energy consumed is normally measured in fraction of kilowatt-hour (kWh) pulses. This information can be used to calibrate any meter for accurate measurement. Typically, the measuring element (the MSP430 microcontroller) is responsible to generate pulses proportional to the energy consumed. To serve both these tasks efficiently, pulse generation must be accurate with relatively little jitter. Although, time jitters are not an indication of bad accuracy, they give a negative indication on the overall accuracy of the meter. Hence the jitter must 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, thereby spreading the accumulated energy from the previous 1 second time frame evenly for each interrupt in the current 1 second time frame. This is equivalent to converting it to energy. When 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. Because the average power tends to be a stable value, this way of generating energy pulses are very steady and free of jitter.

The threshold determines the energy "tick" specified by meter manufacturers and is a constant. It is usually defined in pulses per kWh or just in kWh. One pulse is generated for every energy "tick". For example, in this application, the number of pulses generated per kWh is set to 6400 for active and reactive energies. The energy "tick" in this case is 1 kWh/6400. Energy pulses are generated and available on a header and also via LEDs on the board. General-purpose I/O (port) pins are used to produce the pulses.

In the EVM, the LEDs that are labeled “LED_ACT” and “LED_REACT” correspond to the aggregate active energy consumption and aggregate reactive energy consumption, respectively. The number of pulses per kWh and each pulse duration can be configured in software. 図 9 shows the flow diagram for pulse generation. This flow diagram is valid for active and reactive energy.

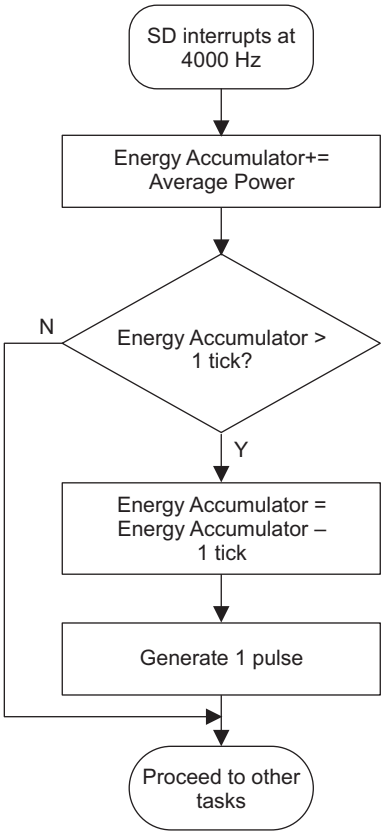

図 9. Pulse Generation for Energy Indication

The average power is in units of 0.001 W and the 1 kWh threshold is defined as:

1 kWh threshold = (1 / 0.001) × 1 kW × (number of interrupts per second) × (number of seconds in one hour) = 1000000× 4000 × 3600 = D18C2E28000

2.2.3.3 Phase Compensation

When a current transformer (CT) is used as a sensor, it introduces additional phase shift on the current signals. Also, the voltage and current input circuit's passive components may introduce additional phase shift. The relative phase shift between voltage and current samples must be compensated to ensure accurate measurements. The ΣΔ converters have programmable delay registers (ΣΔ24PREx) that can be applied to any current or voltage channel. This built-in feature (PRELOAD) is used to provide the phase compensation required.

The fractional delay resolution of the preload register is a function of input frequency (f_{IN}), OSR, and the sampling frequency (f_S):

$$Delay\ resolution_{Deg} = \frac{360° \times f_{IN}}{OSR \times f_S} = \frac{360° \times f_{IN}}{f_M}$$

In this application, for input frequency of 50 Hz, OSR of 256, and sampling frequency of 4000, the resolution for every bit in the preload register is approximately 0.02° with a maximum of 4.48° (maximum of 255 steps). When using CTs that provide a larger phase shift than this maximum, sample delays along with fractional delay must be provided. This phase compensation can also be modified while the application is running to accommodate temperature drifts in CTs, but conversions on the ΣΔ must be stopped while changes are made to the phase compensation.

3 Block Diagram

図 10 shows a high-level system block diagram of the reference EVM (EVM430-i2040) from Texas Instruments, which is divided into a metrology portion that has the MSP430i204x and the Application portion that has the MSP430F663x. The MSP430i204x is a slave metrology processor and the MSP430F663x is the host/application processor. Isolated inter-processor communication can be made possible using the digital isolators on the SPI/UART pins.

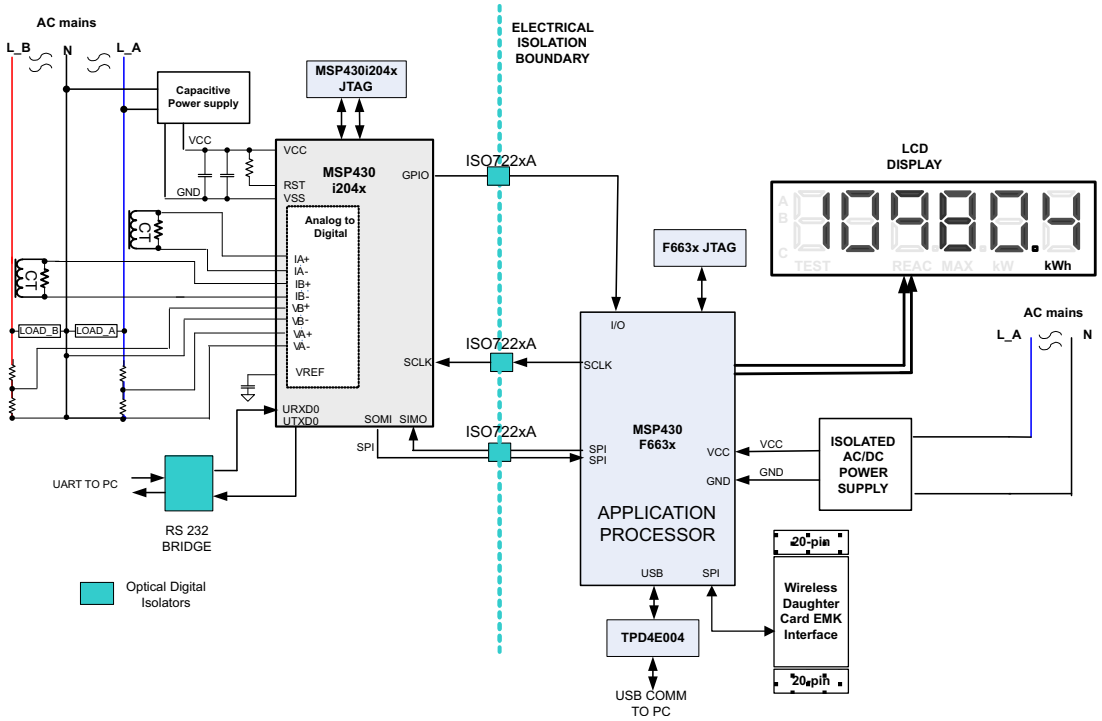

図 10. EVM430-i204x System Block Diagram

In the design, 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 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. Refer to the i2xx user's guide and MSP430i20xx datasheet for these limits.

4 Energy Meter_Demo

The energy meter evaluation module (EVM) associated with this application report specifically uses the MSP430i2041 device of the MSP430i204x and the MSP430F6638 of the MSP430F663x chips. The complete demonstration platform consists of the EVM that can be easily hooked to any test system, metrology software and a PC GUI, which is used to view results and perform calibration.

4.1 EVM Overview

The following figures of the EVM show the hardware. 図 11 is the top view of the energy meter. 図 12. 図 12 shows the location of various pieces of the EVM based on functionality.

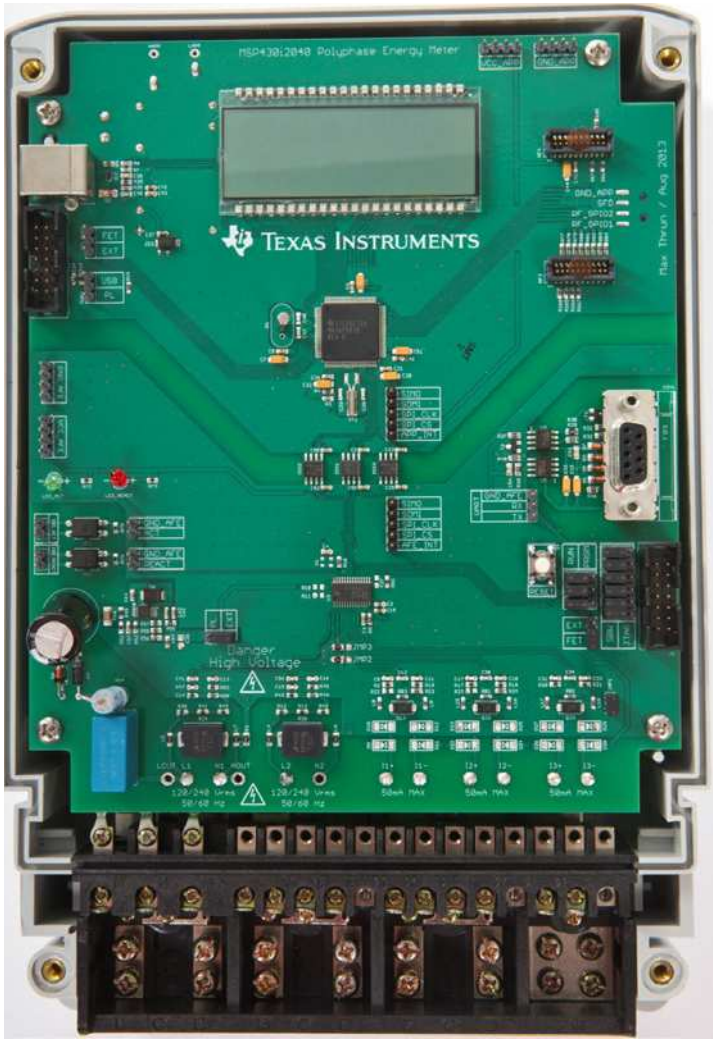

図 11. Top View of the Energy Meter EVM

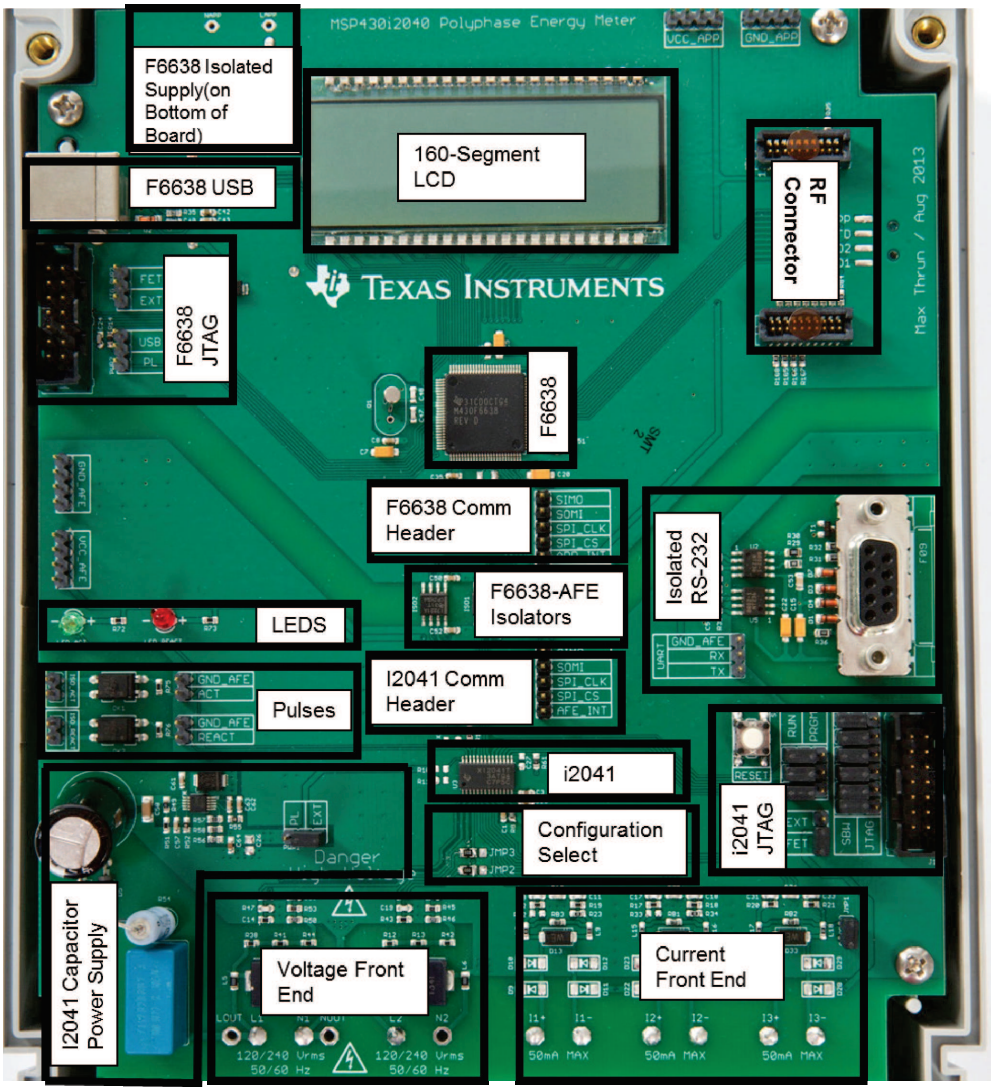

図 12. Top View of the EVM With Components Highlighted

	Danger High Voltage	Electric shock possible when conecting the board to live wires. The board should be handled with care by a professional. For safety, use of isolated test equipment with overvoltage and overcurrent protection is highly recommended.

4.1.1 Connections to the Test Setup or AC Voltages

CAUTION

Do note leave the EVM powered when unattended.

In order to properly connect the EVM430-i2040 to a voltage/current source, the proper connections must be made. These necessary connections are dependent on which of the three measurement configurations are selected. In this EVM, the JMP2 and JMP3 jumper resistors must be placed on the two left-most positions of these three-pad jumpers to connect the voltage front-end circuitry for pad L2 the i2041 to enable two-phase operation.

CAUTION

All three pads of the JMP2 and JMP3 jumper-pads should never be shorted together.

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

- Pad L1 corresponds to the line connection for phase A.
- Pad L2 corresponds to the line connection for phase B. To enable this, the resistor for JMP2 and JMP3 resistors should be placed on the two left-most positions.
- Pad N1 corresponds to the Neutral voltage. The voltage between any of the two possible line connections to the neutral connection can be up to 230 V AC at 50/60 Hz.
- I1+ and I1- are not used for this two-phase configuration and should not have anything connected to it
- I2+ and I2- are the current inputs after the sensors for phase A. Please note that when a current sensor is used, make sure that the voltage across I2+ and I2- does not exceed 928 mV.
- I3+ and I3- are the current inputs after the sensors for phase B. Please note that when a current sensor is used, make sure that the voltage across I3+ and I3- does not exceed 928 mV

When a test AC source needs to be connected, the connections must be made according to the EVM design. 図 13 shows the connections from the top view. In the figures, V_A+ , V_B+, correspond to the line voltage for phases A and B, respectively. V_N corresponds to the neutral voltage from the test AC source. 図 14 shows the connections from the front view. In this figure, I_A+ and I_A- correspond to the current inputs for phase A while I_B+ and I_B- correspond to the current inputs for phase B.

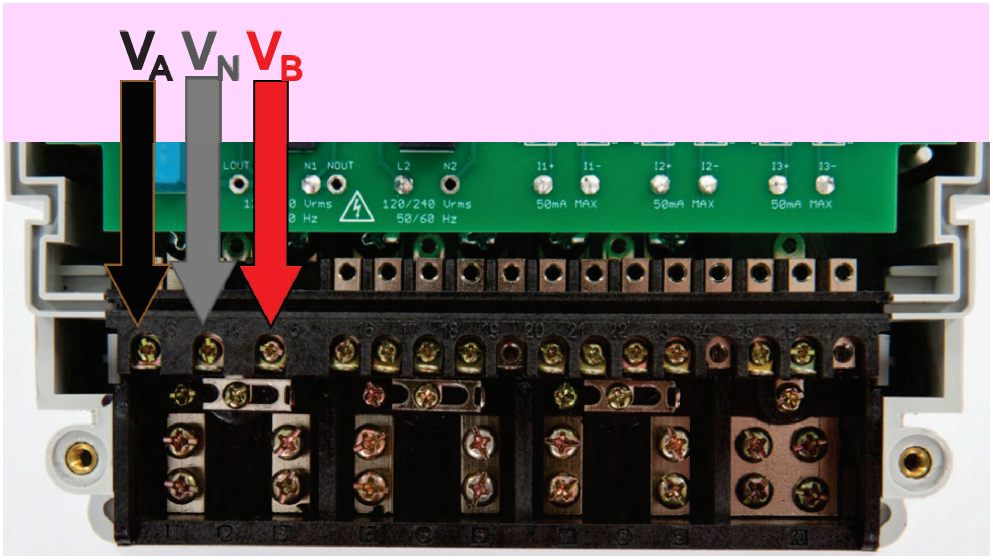

図 13. Top View of EVM with Test Setup Connections

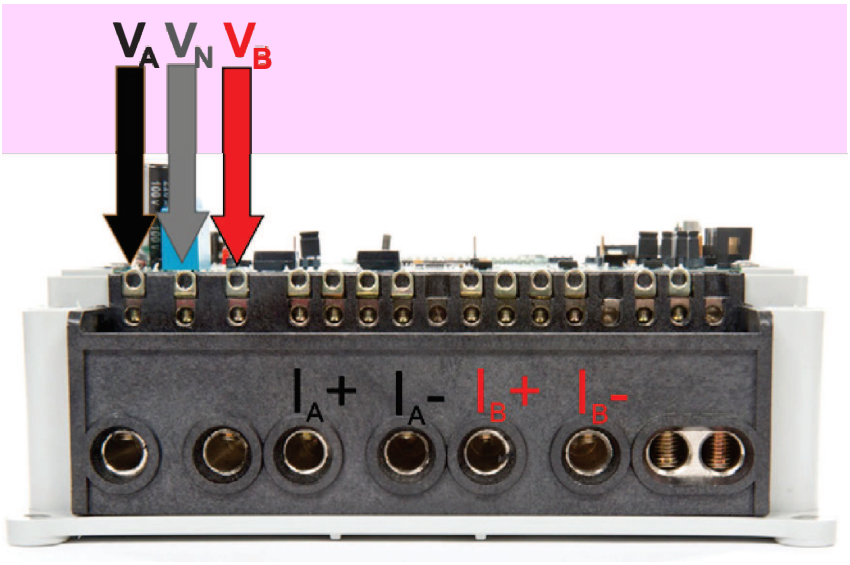

図 14. Front View of the EVM With Test Setup Connections, Two-Phase

4.1.2 Power Supply Options and Jumper Settings

This EVM provides various jumper settings and headers that can be used for debugging. 表 1 shows the different header names and jumper setting on this EVM.

表 1. Header Names and Jumper Settings on the EVM

Header, Header Option Name	Type	Main Functionality	Valid Use Case	Comments
ACT(Not isolated, do not probe)	2-pin Header on the i2041 portion of the EVM	Active Energy Pulses (WARNING)	Probe here for cumulative active energy pulses.	This header is not isolated from AC voltage, so do not connect measuring equipments unless isolators external to the EVM are available. See the ISO_ACT header instead.
AFE_INT (Not isolated, do not probe)	1-pin Header on the i2041 portion of the EVM	F6638 interrupt pin on the i2041's side of the F6638-i2041 isolated communication (WARNING)	This pin can be used to provide a port interrupt on the F6638. This pin is driven by the i2041.	This pin is interfaced to the MSP430F6638 via on-board isolators. The AFE_INT pin on the i2041's side is not isolated so do not probe if board is powered form ac mains, unless the ac mains are isolated. This voltage can be hot or neutral if ac wall plug is connected to the meter. The isolated version of this signal that is connected to the F6638 is called APP_INT. Also, this 1-pin header is grouped with 4 other 1-pin headers to form the i2041 Comm Header.
APP_INT	1-pin Header on the F6638 portion of the EVM	F6638 interrupt pin on the F6638's side of the F6638-i2041 isolated communication	This pin can be used to provide a port interrupt on the F6638. This pin is driven by the i2041.	This pin is interfaced to the MSP430i2041 via on-board isolators. The version of this signal that is connected to the i2041 is called AFE_INT. Also, this 1-pin header is grouped with 4 other 1-pin headers to form the F6638 Comm Header.
EXT (Do not connect JTAG if AC mains is the power source Isolated JTAG or supply is fine)	Jumper Header Option on the i2041 portion of the EVM	JTAG External Power Selection Option (WARNING)	Place a jumper at this header option to select external voltage for JTAG programming of the i2041.	This jumper option and the "FET" jumper option comprise one three-pin header used to select the voltage source for JTAG programming of the i2041. Do not probe if board is powered from AC mains, unless the AC mains are isolated. This voltage can be hot or neutral if AC wall plug is connected to the meter.

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

Header, Header Option Name	Type	Main Functionality	Valid Use Case	Comments
FET (Do not connect JTAG if AC mains is the power source).	Jumper Header Option on the i2041 portion of the EVM	JTAG Internal Power Selection Option (WARNING)	Place a jumper at this header option to power the i2041 using JTAG and to select the voltage from the USB FET for JTAG programming.	This jumper option and the “EXT” jumper option comprise one three-pin header used to select the voltage source for JTAG programming of the i2041. Do not probe if board is powered from AC mains, unless the AC mains are isolated. This voltage can be hot or neutral if AC wall plug is connected to the meter.
GND_AFE (Not isolated, do not probe)	Header on the i2041 portion of the EVM	I2041 Ground Voltage Header (WARNING)	Not a jumper header, probe here for GND voltage for the i2041. Connect negative terminal of bench or external power supply when powering the board externally.	Do not probe if board is powered form ac mains, unless the ac mains are isolated. This voltage can be hot or neutral if ac wall plug is connected to the meter.
GND_APP	Header on the F6638 portion of the EVM	F6638 Ground Voltage Header (WARNING)	Not a jumper header, probe here for GND voltage for the F6638. Connect negative terminal of bench or external power supply when powering the board externally.	Note that DGND_APP is not isolated with USB GND voltages on the EVM.
ISO_ACT	2-pin Header on the i2041 portion of the EVM	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.
ISO_REACT	2-pin Header on the i2041 portion of the EVM	Isolate Reactive Energy Pulses	Probe here for isolated 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 Header on the i2041 portion of the EVM	“I3” Current Sensor Reference	Place a jumper here to reference the negative terminal of the "I3" ΣΔ to ground (GND_AFE).	Conditions based on Sensor: CT: Always have a jumper Shunt: Do not connect a jumper
JMP2	3-pad Jumper on the i2041 portion of the EVM	A1.0+ Converter Input Select and Measurement Configuration Select (WARNING)	To enable two-phase measurement, place a 0-Ohm resistor on the two left-most pads of this 3-pad jumper.	
JMP3	3-pad Jumper on the i2041 portion of the EVM	A1.0- Converter Input Select and Measurement Configuration Select (WARNING)	To enable two-phase measurement, place a 0-Ohm resistor on the two left-most pads of this 3-pad jumper.	
JTAG (Do not connect JTAG if AC mains is the power source)	Jumper Header Option on the i2041 portion of the EVM	4-wire JTAG Programming Option (WARNING)	Place jumpers at the JTAG header options of all of the six JTAG communication headers to select 4-wire JTAG.	There are six headers that jumpers must be placed at to select the JTAG communication option. Each of these six headers has a JTAG option and an SBW option to select either 4-wire JTAG or SBW. To enable 4-wire JTAG, configure all of these headers for the JTAG option. To enable SBW, configure all of the headers for the SBW option.

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

Header, Header Option Name	Type	Main Functionality	Valid Use Case	Comments
JTG_PWR2	3-pin Jumper Header on F6638 portion of the EVM	JTAG Power Selection	Place a jumper at the FET option to power the F6638 portion of the EVM from the FET and to select the voltage from the USB FET for JTAG programming. Place a jumper at the EXT option, to select external voltage for JTAG programming of the F6638.	
PGM (Do not connect JTAG if AC mains is the power source)	Jumper Header Option on the i2041 portion of the EVM	4-wire JTAG programming Option (WARNING)	When using 4-wire JTAG mode, place jumpers at these options to enable programming the i2041.	There are three headers where jumpers must be placed. Each of these three headers has a PGM option and a RUN option. To enable programming the i2041 in 4-wire JTAG mode, configure all of these headers for the PGM option. To enable use of the UART TX, UART RX, and interrupt pin to the F6338, configure all of these headers to the PGM option. Please note that for SBW, the PGM option does not need to be selected to program the i2041. However, for the SBW case, jumpers at “RUN” are still needed to enable use of the UART TX, UART RX, and the interrupt pin for the F6638.
PWR1	Jumper Header on the i2041 portion of the EVM	Power Option Select for MSP430i2041 (WARNING)	Place a jumper at the “PL” option to power the i2041 from mains. Place a jumper at the “EXT” option to power the i2041 from an external power source such as a FET tool or a bench power supply.	If the PL option is selected, do not debug using JTAG unless ac source is isolated or JTAG is isolated. Also, note that the on-board isolators will need to be removed to allow the power supply to power the i2041.
PWR2	Jumper Header on the F6638 portion of the EVM	Power Option Select for MSP430F6638 (WARNING)	Place a jumper at the “PL” option to power the F6638 from mains. Place a jumper at the “PL” option to power the F6638 from USB.	If the “PL” option is selected, please note that the “LAPP” and “NAPP” pads must be connected to mains, which is not the default. One way of doing this is by connecting a wire from the LOUT pad to the LAPP Pad and a wire from the NOUT pad to the NAPP pad. By doing this, LAPP and NAPP get connected to the mains voltage at pad L1.
REACT(Not isolated, do not probe)	2-pin Header on the i2041 portion of the EVM	Reactive Energy Pulses (WARNING)	Probe here for cumulative reactive energy pulses.	This header is not isolated from AC voltage, so do not connect measuring equipments unless isolators external to the EVM are available. See the ISO_REACT header instead.
RUN (Do not connect JTAG if AC mains is the power source)	Jumper Header Option on the i2041 portion of the EVM	UART TX, UART RX, and AFE_INT Enable (WARNING)	Place jumpers here to enable the UART TX and UART RX signals which are interfaced to the RS-232 connector on the EVM. Also, place jumpers here to enable the interrupt pin that goes from the i2041 to the F6638.	There are three headers where jumpers must be placed. Each of these three headers has a PGM option and a RUN option. To enable programming the i2041 in 4-wire JTAG mode, configure all of these headers for the PGM option. To enable use of the UART TX, UART RX, and interrupt pin to the F6338, configure all of these headers to the PGM option. Please note that for SBW, the PGM option does not need to be selected to program the i2041. However, for the SBW case, jumpers at “RUN” are still needed to enable use of the UART TX, UART RX, and the interrupt pin for the F6638.
RX(Not isolated, do not probe)	1-pin header on the i2041 portion of the EVM	RS-232 Receive(to MSP430) (WARNING)	This is the UART RX line associated with the i2041’s RS-232 connection.	This pin correspond to the UART RX signal and is not the associated translated RS-232 signals; therefore, it has the UART voltage levels and not RS232 voltage levels. Do not probe if board is powered form ac mains, unless the ac mains are isolated. This voltage can be hot or neutral if ac wall plug is connected to the meter.

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

Header, Header Option Name	Type	Main Functionality	Valid Use Case	Comments
SBW (Do not connect JTAG if AC mains is the power source)	Jumper Header Option on the i2041 portion of the EVM	SBW JTAG Programming Option (WARNING)	Place jumpers at the SBW header options of all of the six JTAG communication headers to select SBW	There are six headers that jumpers must be placed at to select the JTAG communication option. Each of these six headers has a JTAG option and an SBW option to select either 4-wire JTAG or SBW. To enable 4-wire JTAG, configure all of these headers for the JTAG option. To enable SBW, configure all of the headers for the SBW option.
SIMO	1-pin Header on the F6638 portion of the EVM	SPI SIMO pin on the F6638's side of the F6638-i2041 isolated communication	This contains the SPI SIMO line that is connected to the F6638. It is the SPI input for the i2041.	This pin is interfaced to the MSP430i2041 via on-board isolators. The version of this signal that is connected to the i2041 is also called SIMO. This 1-pin header is grouped with 4 other 1-pin headers to form the F6638 Comm Header.
SIMO	1-pin Header on the i2041 portion of the EVM	SPI SIMO pin on the i2041's side of the F6638-i2041 isolated communication (WARNING)	This contains the SPI SIMO line that is connected to the i2041. It is the SPI input for the i2041.	This pin is interfaced to the MSP430F6638 via on-board isolators. The SIMO line on the i2041's side is not isolated so do not probe if board is powered form ac mains, unless the ac mains are isolated. This voltage can be hot or neutral if ac wall plug is connected to the meter. The isolated version of this signal, which is connected to the F6638, is also called SIMO. This 1-pin header is grouped with 4 other 1-pin headers to form the i2041 Comm Header.
SOMI	1-pin Header on the F6638 portion of the EVM	SPI SOMI pin on the F6638's side of the F6638-i2041 isolated communication	This contains the SPI SOMI line that is connected to the F6638. It is the SPI output from the i2041.	This pin is interfaced to the MSP430i2041 via on-board isolators. The version of this signal that is connected to the i2041 is also called SOMI. This 1-pin header is grouped with 4 other 1-pin headers to form the F6638 Comm Header.
SOMI	1-pin Header on the i2041 portion of the EVM	SPI SOMI pin on the i2041's side of the F6638-i2041 isolated communication (WARNING)	This contains the SPI SOMI line that is connected to the i2041. It is the SPI output from the i2041.	This pin is interfaced to the MSP430F6638 via on-board isolators. The SOMI line on the i2041's side is not isolated so do not probe if board is powered form ac mains, unless the ac mains are isolated. This voltage can be hot or neutral if ac wall plug is connected to the meter. The isolated version of this signal, which is connected to the F6638, is also called SOMI. This 1-pin header is grouped with 4 other 1-pin headers to form the i2041 Comm Header.
SPI_CLK	1-pin Header on the F6638 portion of the EVM	SPI Clock on the F6638's side of the F6638-i2041 isolated communication	This contains the SPI Clock for SPI communication between the F6638 and i2041. This pin is driven by the F6638.	This pin is interfaced to the MSP430i2041 via on-board isolators. The version of this signal that is connected to the i2041 is also called SPI_CLK. This 1-pin header is grouped with 4 other 1-pin headers to form the F6638 Comm Header.
SPI_CLK	1-pin Header on the i2041 portion of the EVM	SPI Clock on the i2041's side of the F6638-i2041 isolated communication (WARNING)	This contains the SPI Clock for SPI communication between the F6638 and i2041. This pin is driven by the F6638.	This pin is interfaced to the MSP430F6638 via on-board isolators. The SPI_CLK line on the i2041's side is not isolated so do not probe if board is powered form ac mains, unless the ac mains are isolated. This voltage can be hot or neutral if ac wall plug is connected to the meter. The isolated version of this signal, which is connected to the F6638, is also called SPI_CLK. This 1-pin header is grouped with 4 other 1-pin headers to form the i2041 Comm Header.
SPI_CS	1-pin Header on the F6638 portion of the EVM	SPI Chip Select on the F6638's side of the F6638-i2041 isolated communication	This contains a possible SPI chip select to enable communication with the i2041. This pin is driven by the F6638.	This pin is interfaced to the MSP430i2041 via on-board isolators. The version of this signal that is connected to the i2041 is also called SPI_CS. This 1-pin header is grouped with 4 other 1-pin headers to form the F6638 Comm Header.

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

Header, Header Option Name	Type	Main Functionality	Valid Use Case	Comments
SPI_CS	1-pin Header on the i2041 portion of the EVM	SPI Chip Select on the i2041's side of the F6638-i2041 isolated communication (WARNING)	This contains a possible SPI chip select to enable communication with the i2041. This pin is driven by the F6638.	This pin is interfaced to the MSP430F6638 via on-board isolators. The SPI_CS line on the i2041's side is not isolated so do not probe if board is powered form ac mains, unless the ac mains are isolated. This voltage can be hot or neutral if ac wall plug is connected to the meter. The isolated version of this signal, which is connected to the F6638, is also called SPI_CS. This 1-pin header is grouped with 4 other 1-pin headers to form the i2041 Comm Header.
TX(Not isolated, do not probe)	1-pin Header on the i2041 portion of the EVM	RS-232 Transmit(from MSP430) (WARNING)	This is the UART TX line associated with the i2041's RS-232 connection.	This pin corresponds to the UART TX signal and is not the associated translated RS-232 signals; therefore, it has the UART voltage levels and not RS232 voltage levels. Do not probe if board is powered form ac mains, unless the ac mains are isolated. This voltage can be hot or neutral if ac wall plug is connected to the meter.
VCC_AFE (Not isolated, do not probe)	Header on the i2041 portion of the EVM	I2041 VCC Voltage Header (WARNING)	Not a jumper header, probe here for VCC voltage for the i2041. Connect positive terminal of bench or external power supply when powering the board externally.	Do not probe if board is powered form ac mains, unless the ac mains are isolated. This voltage can be hot or neutral if ac wall plug is connected to the meter.
VCC_APP	Header on the F6638 portion of the EVM	F6638 VCC Voltage Header (WARNING)	Not a jumper header, probe here for VCC voltage for the F6638. Connect positive terminal of bench or external power supply when powering the board externally.	Note that DGND_APP is not isolated with USB GND voltages on the EVM.

5 Results

5.1 GUI Execution

The steps for GUI execution are as follows:

1. Connect the EVM to a PC via an RS-232 cable.
2. Open "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 connected to the meter. In図 15, this field is changed to COM7.

```
260        </correction>
261      </phase>
262      <temperature/>
263      <rtc/>
264    </cal-defaults>
265    <meter position="1">
266      <port name="com7" speed="9600"/>
267    </meter>
268    <reference-meter>
269      <port name="USB0::0x0A69::0x0835::A66200101281::INSTR"/>
270      <type id="chroma-66202"/>
271      <log requests="on" responses="on"/>
272      <scaling voltage="1.0" current="1.0"/>
273    </reference-meter>
```

図 15. GUI Config File Changed to Communicate with Meter

4. Run calibrator.exe, which is located in the GUI folder. If the COM port in calibration-config.xml was changed in the previous step to the com port connected to the EVM, the GUI opens (see 図 16). If the GUI connects properly to the EVM, the top left button is green. If there are problems with connections or if the code is not configured correctly, the button is red. Click the green button to view the results.

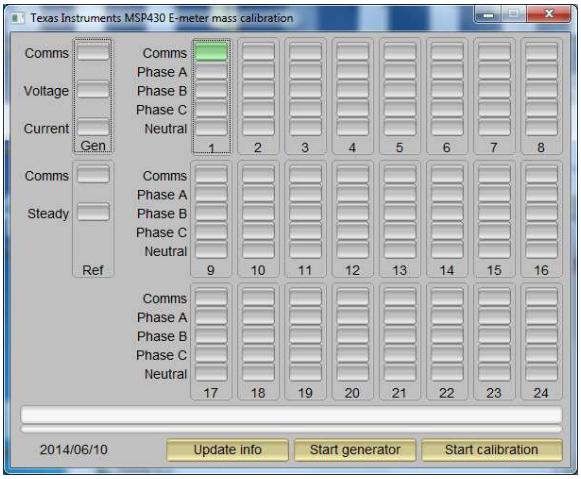

図 16. GUI Startup Window

When you click on the green button, the results window opens (see 図 17). In the figure, there is a trailing "L" or "C" on the Power factor values to indicate an inductive or capacitive load, respectively.

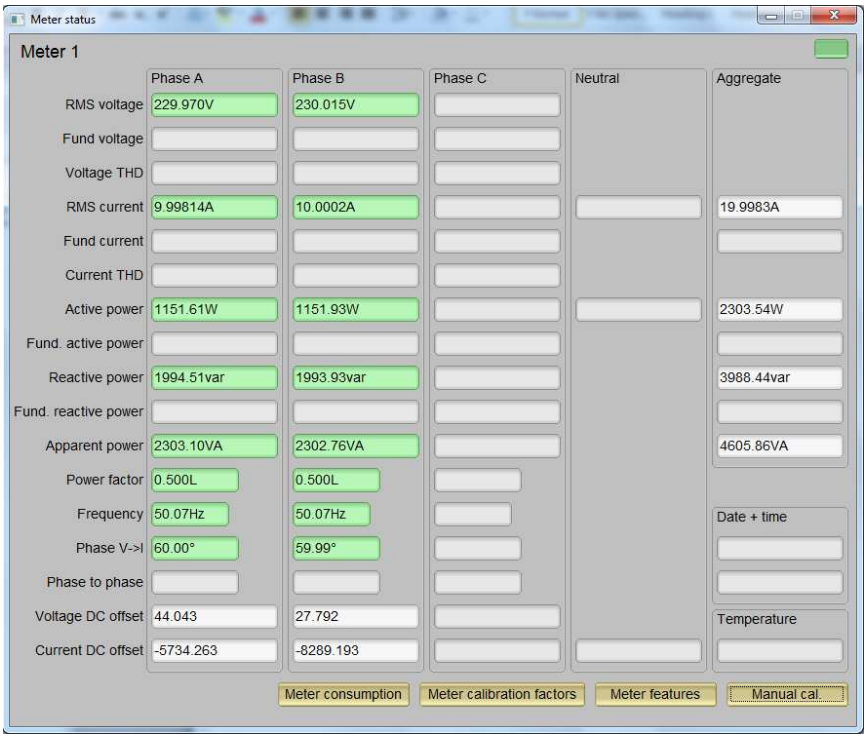

図 17. Results Window

From the results window, the total-energy consumption readings and sag/swell logs could be viewed by pressing the “Meter Consumption” button. Once this is pressed, the meter events and consumption window pops up as shown in 図 18.

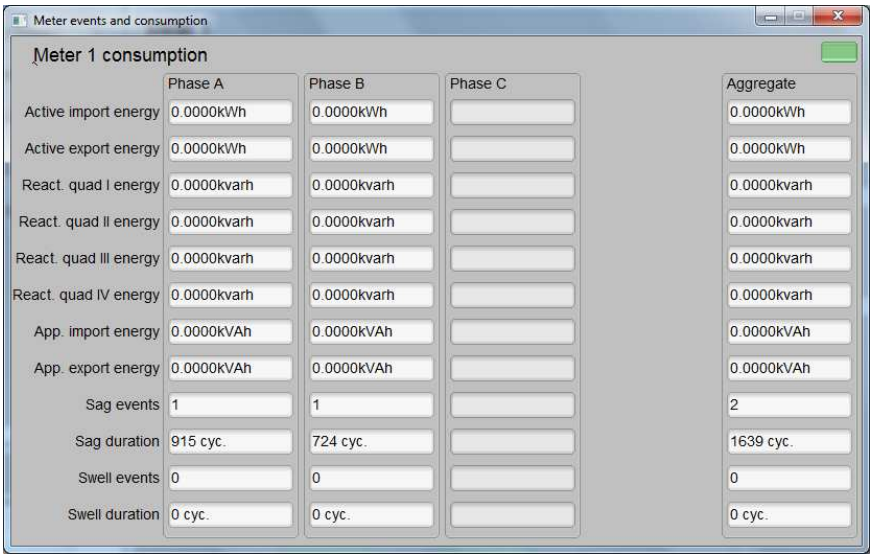

図 18. Meter Events and Consumption Window

5.2 Results

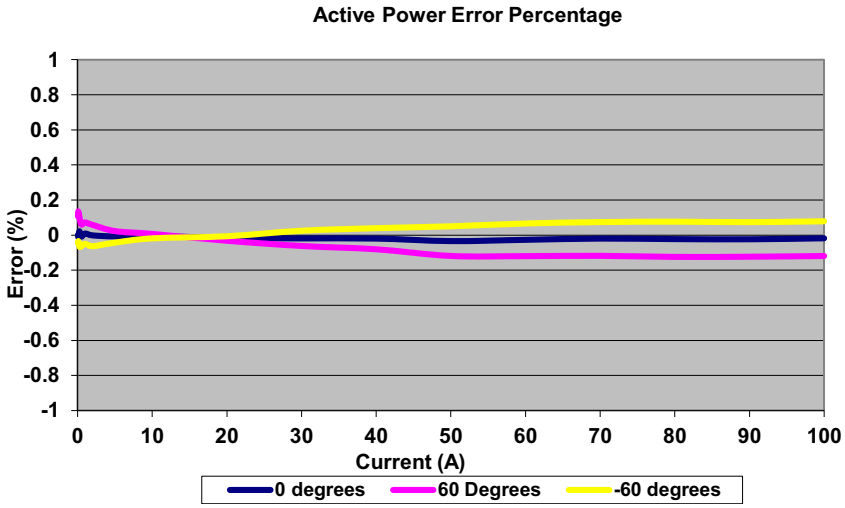

図 19. Cumulative Phase Active Energy Measurement Error

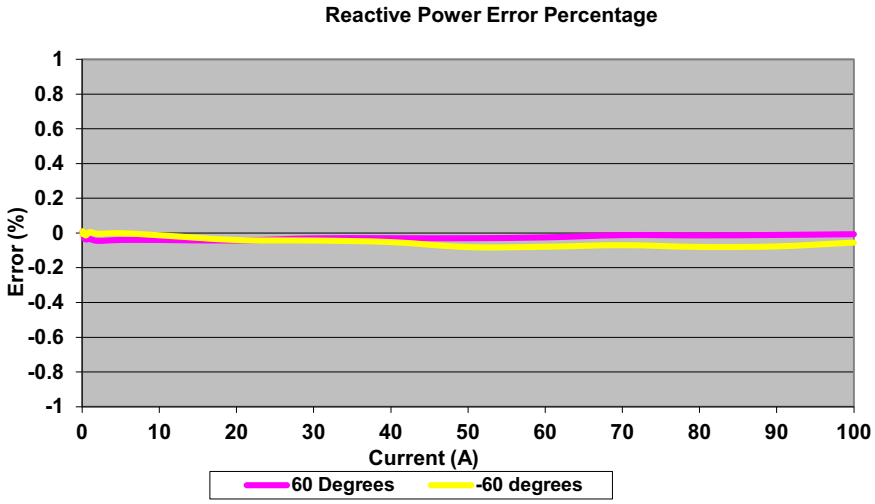

図 20. Cumulative Phase Reactive Energy Measurement Error

表 2. Cumulative Phase Energy Measurement Error (%)

	Active Power % error			Reactive Power % error	
Current(A)	0°	60°	-60°	60°	-60°
0.05	0	0.107	-0.047	0	-0.006
0.1	-0.012	0.135	-0.034	0.01	0.011
0.25	0.022	0.104	-0.066	-0.029	0
0.5	-0.009	0.06	-0.065	-0.037	-0.014
1	0.009	0.072	-0.05	-0.035	0.006
2	-0.00166667	0.0583333	-0.0633333	-0.045	-0.004
5	-0.00766667	0.0226667	-0.043	-0.04	-0.001
10	-0.00566667	0.00666667	-0.0186667	-0.04	-0.013
20	-0.016	-0.0323333	-0.00666667	-0.043	-0.04
30	-0.019	-0.062	0.0246667	-0.0307	-0.0433
40	-0.02	-0.081	0.0393333	-0.03	-0.052
50	-0.0343333	-0.119	0.05	-0.03	-0.081
60	-0.027	-0.12	0.066	-0.025	-0.079
70	-0.02	-0.118333	0.074	-0.012	-0.07
80	-0.023	-0.124333	0.0763333	-0.0135	-0.08
90	-0.024	-0.123333	0.0736667	-0.011	-0.077
100	-0.0183333	-0.119333	0.0786667	-0.0067	-0.055

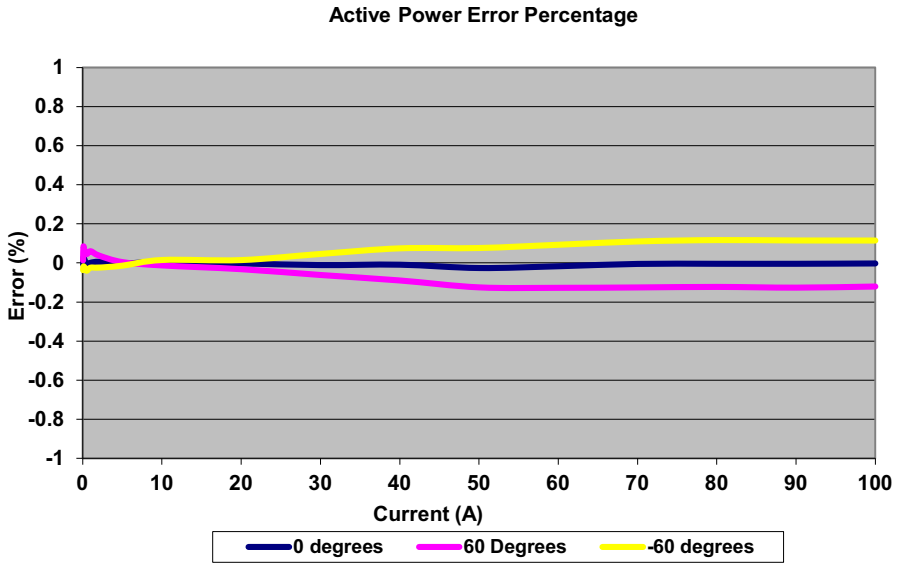

図 21. Phase A Active Energy Measurement Error

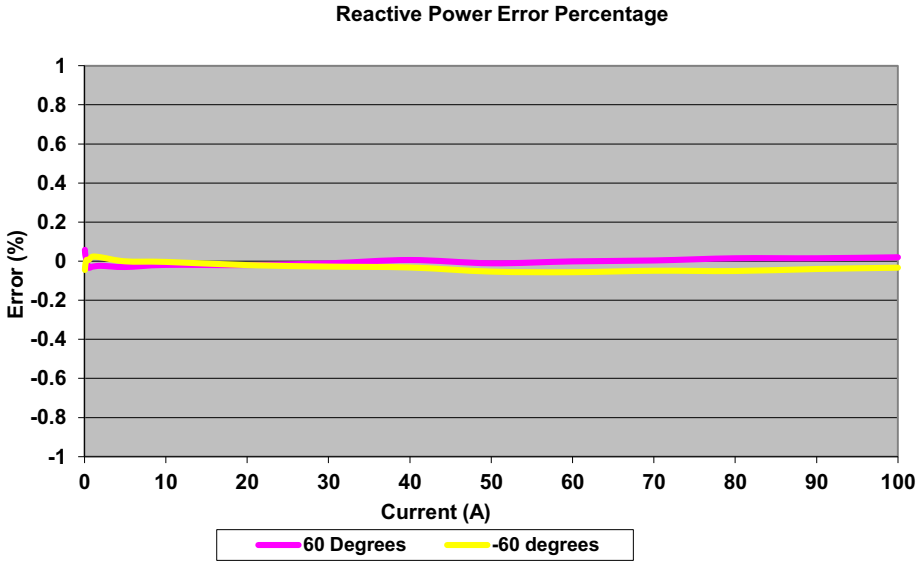

図 22. Phase A Reactive Energy Measurement Error

表 3. Phase A Energy Measurement Error

	Active Power % error			Reactive Power % error	
Current(A)	0°	60°	-60°	60°	-60°
0.05	-0.008	0.013	-0.037	0.058	-0.045
0.1	0.028	0.084	-0.018	0.032	-0.019
0.25	0.015	0.058	-0.024	0.006	0.006
0.5	-0.007	0.045	-0.04	-0.032	0.006
1	0.001	0.06	-0.024	-0.028	0.0233
2	0.006	0.0386667	-0.024	-0.0237	0.02
5	-0.00333333	0.00433333	-0.014	-0.0297	-0.0007
10	0.00633333	-0.0126667	0.015	-0.019	-0.0037
20	-0.00233333	-0.032	0.0146667	-0.02	-0.02

表 3. Phase A Energy Measurement Error (continued)

	Active Power % error			Reactive Power % error	
30	-0.011	-0.0616667	0.046	-0.011	-0.0277
40	-0.009	-0.0896667	0.0746667	0.006	-0.0323
50	-0.026	-0.125	0.0763333	-0.0107	-0.0533
60	-0.017	-0.127333	0.093	-0.001	-0.0563
70	-0.005	-0.125333	0.11	0.0037	-0.049
80	-0.00433333	-0.122667	0.117	0.015	-0.0503
90	-0.00433333	-0.126333	0.115	0.015	-0.04
100	-0.00266667	-0.120667	0.114667	0.02	-0.0333

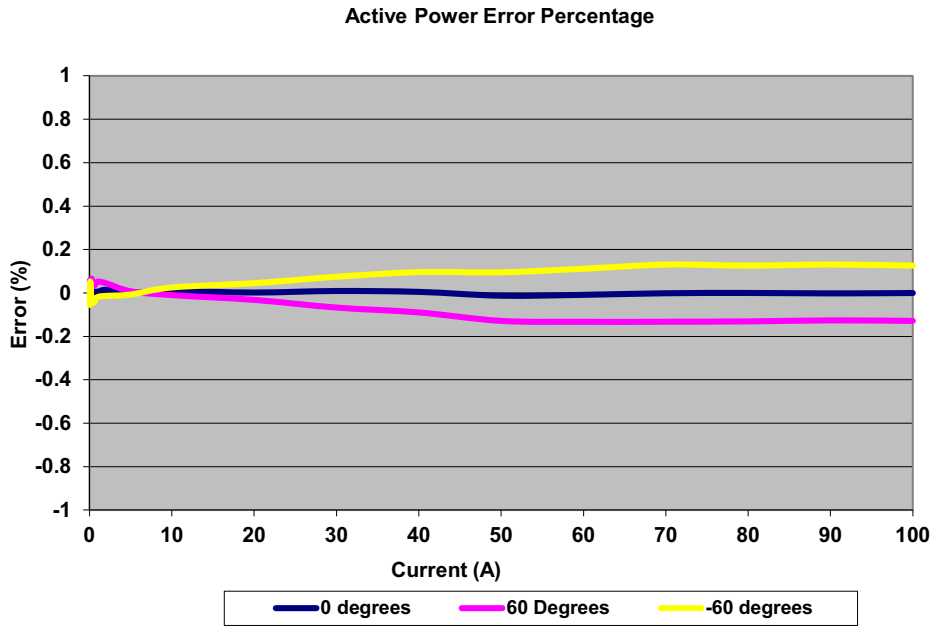

図 23. Phase B Active Energy Measurement Error

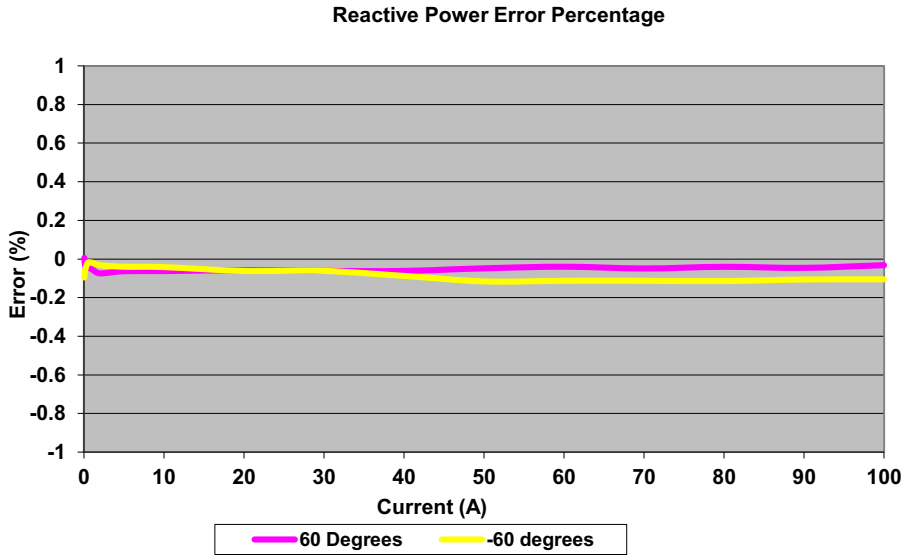

図 24. Phase B Reactive Energy Measurement Error

表 4. Phase B Energy Measurement Error

	Active Power % error			Reactive Power % error	
Current(A)	0°	60°	-60°	60°	-60°
0.05	0.024	0.059	-0.055	0.006	-0.096
0.1	0.007	0.035	0.053	-0.019	-0.07
0.25	0.018	0.066	-0.04	-0.045	-0.045
0.5	0.006	0.032	-0.045	-0.045	-0.019
1	0.006	0.052	-0.019	-0.0533	-0.019
2	0.0143333	0.045	-0.0136667	-0.0743	-0.032
5	0.000333333	0.00766667	-0.00733333	-0.0633	-0.04
10	0.00866667	-0.01	0.0253333	-0.0627	-0.042
20	0.002	-0.032	0.045	-0.058	-0.062
30	0.009	-0.0673333	0.0746667	-0.0617	-0.0617
40	0.005	-0.0896667	0.096	-0.0617	-0.0877
50	-0.0126667	-0.128667	0.095	-0.0483	-0.116
60	-0.00866667	-0.133	0.111667	-0.04	-0.113
70	-0.00133333	-0.132667	0.130667	-0.049	-0.113
80	0	-0.131	0.126	-0.0405	-0.1143
90	-0.002	-0.126333	0.131	-0.046	-0.1063
100	-0.00033333	-0.128667	0.126	-0.032	-0.1053

6 Design Files

This section provides the schematics and layout images used for this design.

6.1 Schematics

The schematics are presented in the following order:

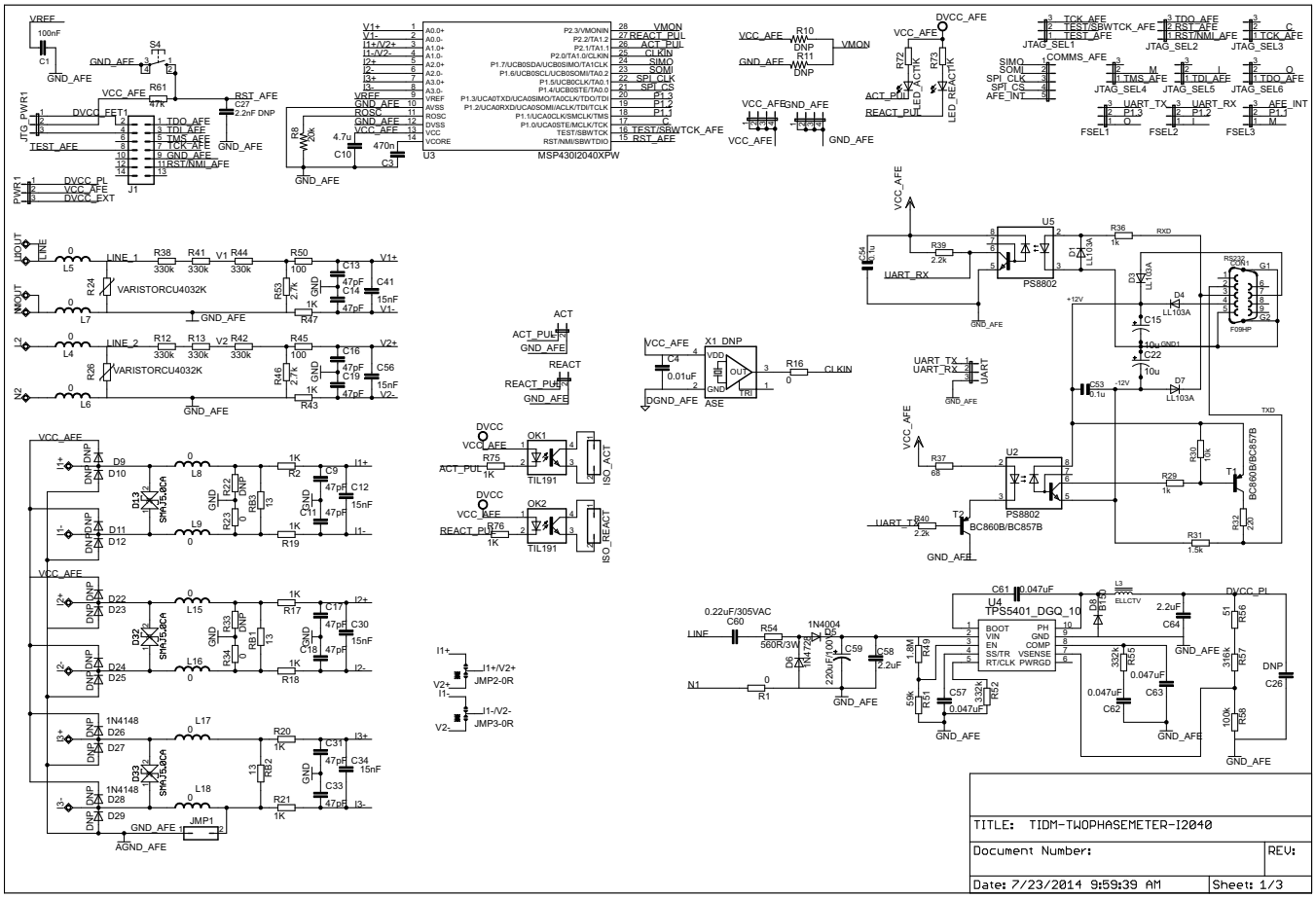

図 25. Schematics Page 1

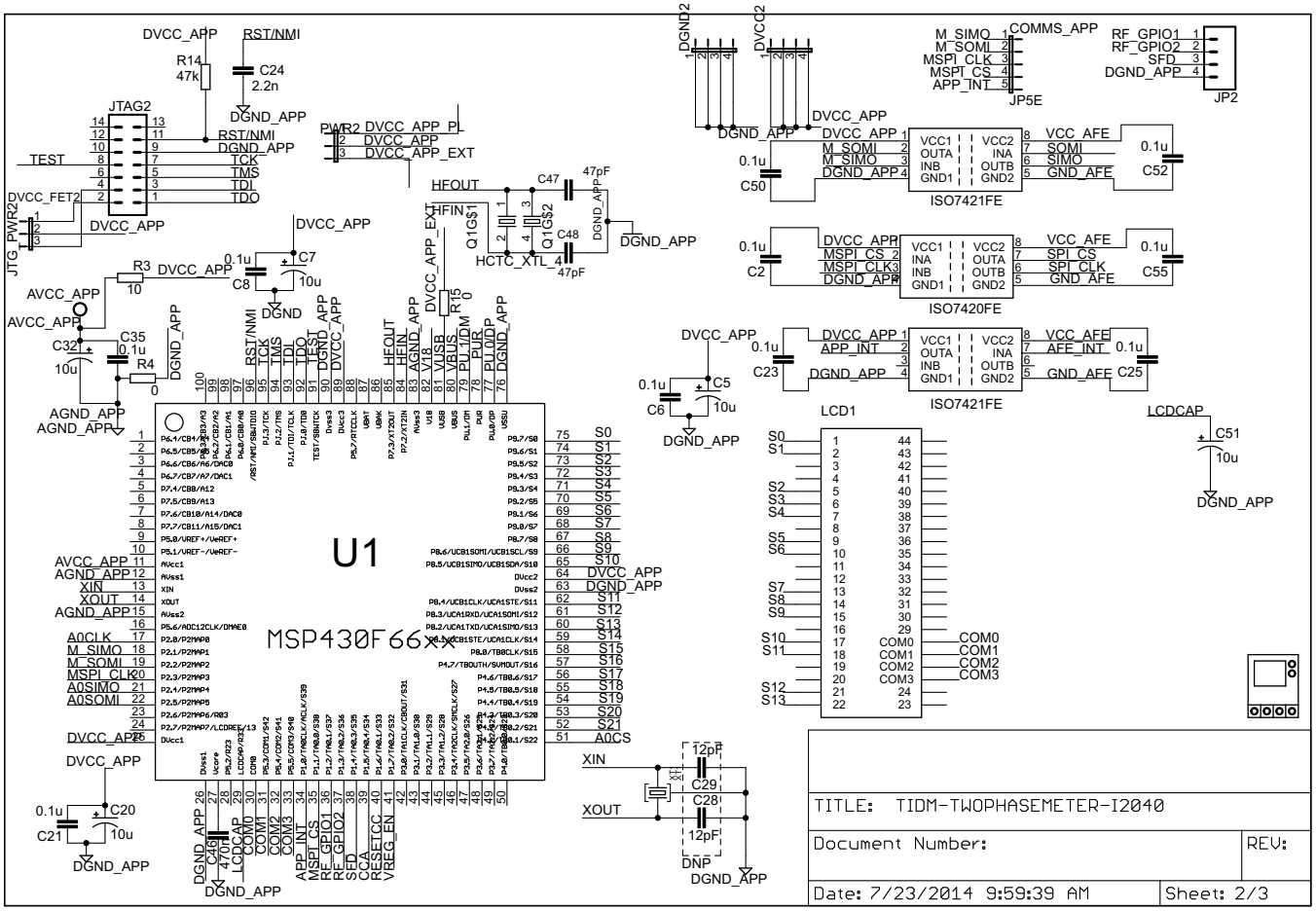

図 26. Schematics Page 2

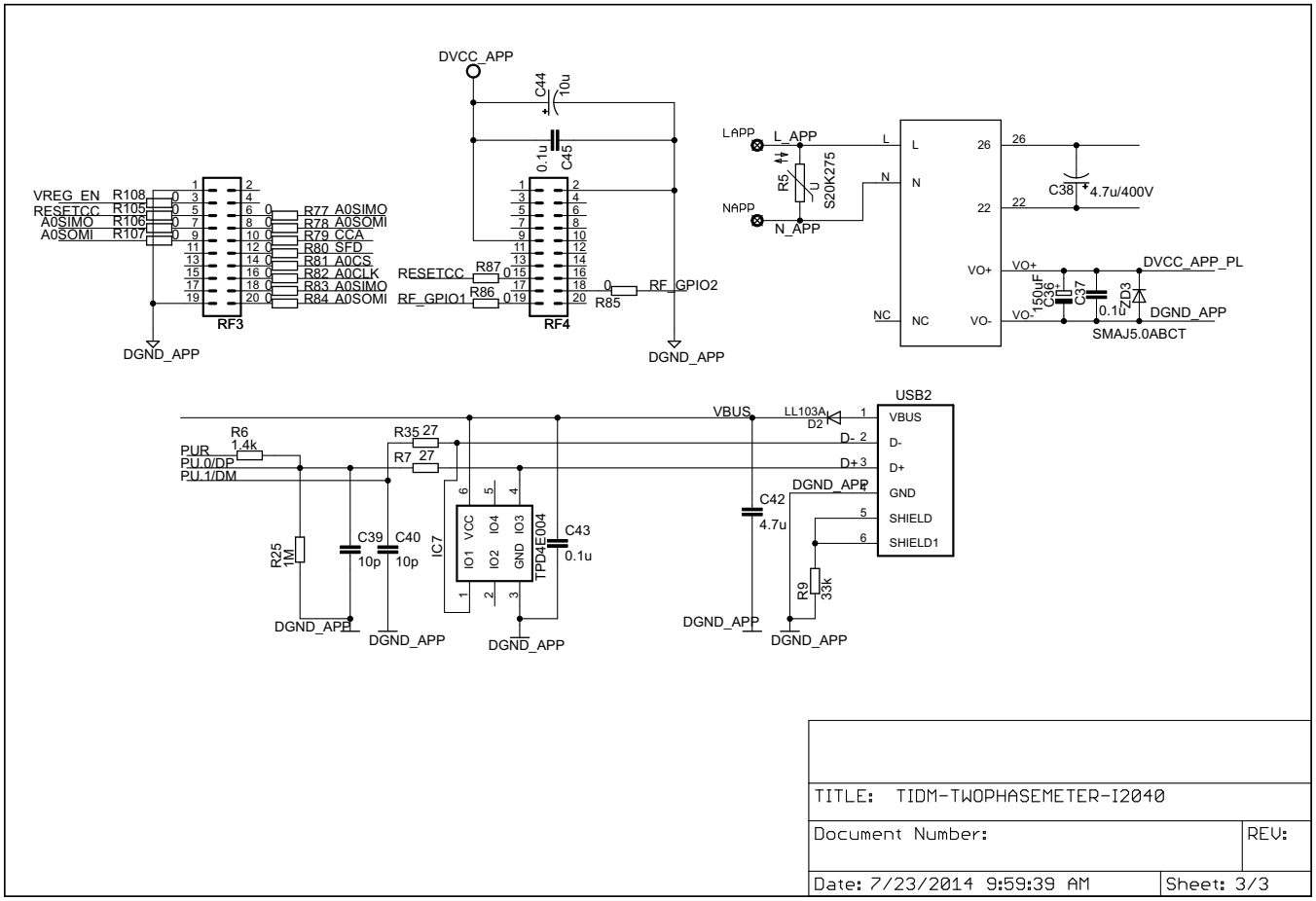

図 27. Schematics Page 3

6.2 Bill of Materials

表 5. BOM

Line	Qty	Value	Device	Parts	Vendor #	Notes
1	5		JP1E	ACT, REACT, ISO_ACT, ISO_REACT, JMP1	609-3469-ND	
2	14	HEADER0.05	JP2E	FSEL1, FSEL2, FSEL3, JTAG_SEL1, JTAG_SEL2, JTAG_SEL3, JTAG_SEL4, JTAG_SEL5, JTAG_SEL6, UART, JTG_PWR1, JTG_PWR2, PWR1, PWR2	609-3464-ND	
3	4		JP4E	DGND2, DVCC2, GND_AFE, VCC_AFE	609-3262-ND	
4	2		JP5E	COMMS_AFE, COMMS_APP	609-4303-ND	
5	2	ML14	ML14	JTAG2, J1	MHC14K-ND	
6	1	F09HP	F09HP	CON1	609-1485-ND	
7	2	0R-JUMPA	0R-JUMPA	JMP2, JMP3		Solder bridge to left side
8	1		M04SMD	JP2	DNP	
9	2		TFM-110-02-SM-D-A-K	RF3, RF4	TFM-110-02-SM-D-A-K	
10	2	BC860B/BC857B	BC857ASMD	T1, T2	568-6094-1-ND	Purchased from Samtech
11	1		USB_RECEPTACLE	USB2	AE9925-ND	
12	1		10-XX	S4	SW400-ND	
13	2	4.7u	C0603	C10, C42	445-3449-1-ND	
14	5	15nF	C0603	C12, C30, C34, C41, C56	445-1283-1-ND	
15	14	0.1u	C0603	C1, C2, C6, C8, C21, C23, C25, C35, C37, C43, C45, C50, C52, C55	445-1316-1-ND	
16	1	2.2n	C0603	C24	445-1309-1-ND	
17	1	DNP	C0805	C26	DNP	
18	1	2.2nF DNP	C0603	C27	DNP	
19	2	12pF	C0603	C28, C29	445-1270-1-ND	
20	2	470n	C0603	C3, C46	445-3454-1-ND	
21	1	150uF	CPOL-EUE2-5	C36	P14374-ND	
22	1	4.7u/400V	CPOL-USE5-10.5	C38	399-6097-ND	
23	2	10p	C0603	C39, C40	445-1269-1-ND	
24	1	0.01uF	C0603	C4	445-1311-1-ND	
25	8	10u	CPOL-USCT3216	C5, C7, C15, C20, C22, C32, C44, C51	399-3685-1-ND	
26	2	0.1u	C0805	C53, C54	445-6957-1-ND	
27	4	0.047uF	C0603	C57, C61, C62, C63	445-1313-1-ND	
28	1	2.2uF	C1206	C58	445-1382-1-ND	
29	1	220uF/100V	CPOL-USE5-13	C59	P5598-ND	

表 5. BOM (continued)

Line	Qty	Value	Device	Parts	Vendor #	Notes
30	1	0.22uF/305VAC	C15/8	C60	495-4351-ND	
31	1	2.2uF	C0603	C64	587-2983-1-ND	
32	12	47pF	C0603	C9, C11, C13, C14, C16, C17, C18, C19, C31, C33, C47, C48	445-1277-1-ND	
33	5	LL103A	D	D1, D2, D3, D4, D7	LLSD103ADICT-ND	
34	3	SMAJ5.0CA	SMAJ	D13, D32, D33	478-7058-1-ND	
35	1	1N4004	1N4004	D5	1N4007-E3/54GICT-ND	
36	1	1N4754	1N4754	D6	1N4754AVSCT-ND	
37	1	B150	DIODE-DO214BA	D8	P6SMB150A-E3/52GICT-ND	
38	12	1N4148	1N4148SOD80C	D9, D10, D11, D12, D22, D23, D24, D25, D26, D27, D28, D29	DNP	
39	1	SMAJ5.0ABCT	DIODE-DO214AC	ZD3	SMAJ5.0ABCT-ND	
40	1	TPD4E004	TPD4E004	IC7	296-23618-1-ND	
41	1	ISO742ADR	ISO7220ADR	ISO1	296-21952-1-ND	
42	2	ISO7421FE	ISO7221A	ISO2, ISO3	296-21955-1-ND	
43	2	PS2501-1-A	PS2501-1-A	OK1, OK2	PS2501-1A-ND	
44	1	HCTC_XTL_4	HCTC_XTL_4	Q1	X801-ND	
45	1	CUI_XR	CUI_XR	U$2	102-1801-ND	
46	1	F66XX---PZ100	F66XX---PZ100	U1	296-29470-1-ND	
47	2	PS8802	PS8802SO08	U2, U5	PS8802-1-F3-AXCT-ND	
48	1	MSP430i2041PW	MSP430I2040XPW	U3		
49	1	TPS5401_DGQ_10	TPS5401_DGQ_10	U4	296-28092-1-ND	
50	1	ASE	ASE	X1	DNP	
51	1	XT1	CM200T	XT1	X1045-ND	
52	1	ELLCTV	ELLCTV	L3	PCD1759CT-ND	
53	4	1uH	L-US08050805	L4, L5, L6, L7	P0.0ACT-ND	
54	6	BLM21BD121SN1D	L-USL2012C	L8, L9, L15, L16, L17, L18	P0.0GCT-ND	
55	1	TI_160SEG_LCD	TI_160SEG_LCD	LCD1	Custom-Made	
56	1		LED3MM	LED_REACT	511-1249-ND	
57	1		LED3MM	LED_ACT	511-1247-ND	
58	1	0	R0805	R1	P0.0ACT-ND	
59	2	DNP	R0603	R10, R11	DNP	
60	6	330k	R0603	R12, R13, R38, R41, R42, R44	P330KGCT-ND	
61	2	47k	R0603	R14, R61	P47KGCT-ND	

表 **5. BOM (continued)**

Line	Qty	Value	Device	Parts	Vendor #	Notes
62	12	1K	R0603	R2, R17, R18, R19, R20, R21, R43, R47, R72, R73, R75, R76	P1.0KGCT-ND	
63	2	DNP	R0603	R22, R33	DNP	
64	2	VARISTORCU4032K	VARISTORCU4032K	R24, R26	495-1467-1-ND	
65	1	1M	R0603	R25	P1.0MGCT-ND	
66	2	1k	R0805	R29, R36	P1.0KACT-ND	
67	1	10	R0603	R3	P10GCT-ND	
68	1	10k	R0805	R30	P10KACT-ND	
69	1	1.5k	R0805	R31	P1.5KACT-ND	
70	1	220	R0805	R32	P220ACT-ND	
71	1	68	R0805	R37	P68ACT-ND	
72	2	2.2k	R0805	R39, R40	P2.2KACT-ND	
73	20	0	R0603	R4, R15, R16, R23, R34, R77, R78, R79, R80, R81, R82, R83, R84, R85, R86, R87, R105, R106, R107, R108	P0.0GCT-ND	
74	2	100	R0603	R45, R50	P100GCT-ND	
75	2	2.7K	R0603	R46, R53	P2.7KGCT-ND	
76	1	1.8M	R0603	R49	P1.8MGCT-ND	
77	1	S20K275	S20K275	R5	495-1417-ND	
78	1	59k	R0603	R51	P59.0KHCT-ND	
79	2	332k	R0603	R52, R55	P332KHCT-ND	
80	1	560R/3W	R-EU_0414/5V	R54	P560W-3TR-ND	
81	1	51	R0603	R56	P51GCT-ND	
82	1	316k	R0603	R57	P316KHCT-ND	
83	1	100k	R0603	R58	P100KGCT-ND	
84	1	1.4k	R0603	R6	P1.40KHCT-ND	
85	2	27	R0603	R7, R35	P27GCT-ND	
86	1	33k	R0603	R9	P33KGCT-ND	
87	3	13	R0603	RB1, RB2, RB3	P13GCT-ND	
88	1	20K	R0603	R8	P20KDBCT-ND	

6.3 PBC Layout Prints

To download the PCB Layer Plots, see the design files at TIDM-TWOPHASEMETER-I2040.

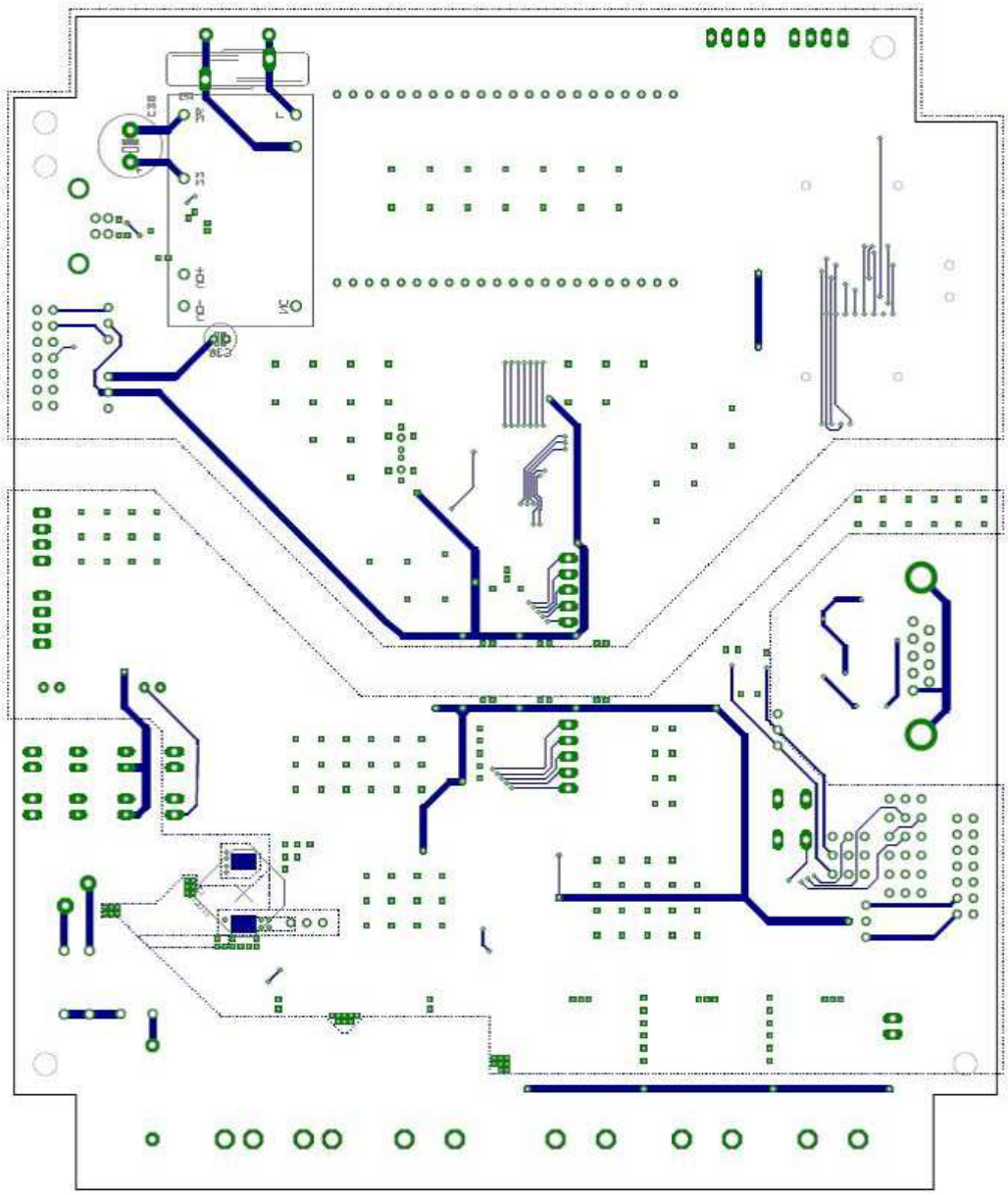

図 28. Bottom Layer Plot 1

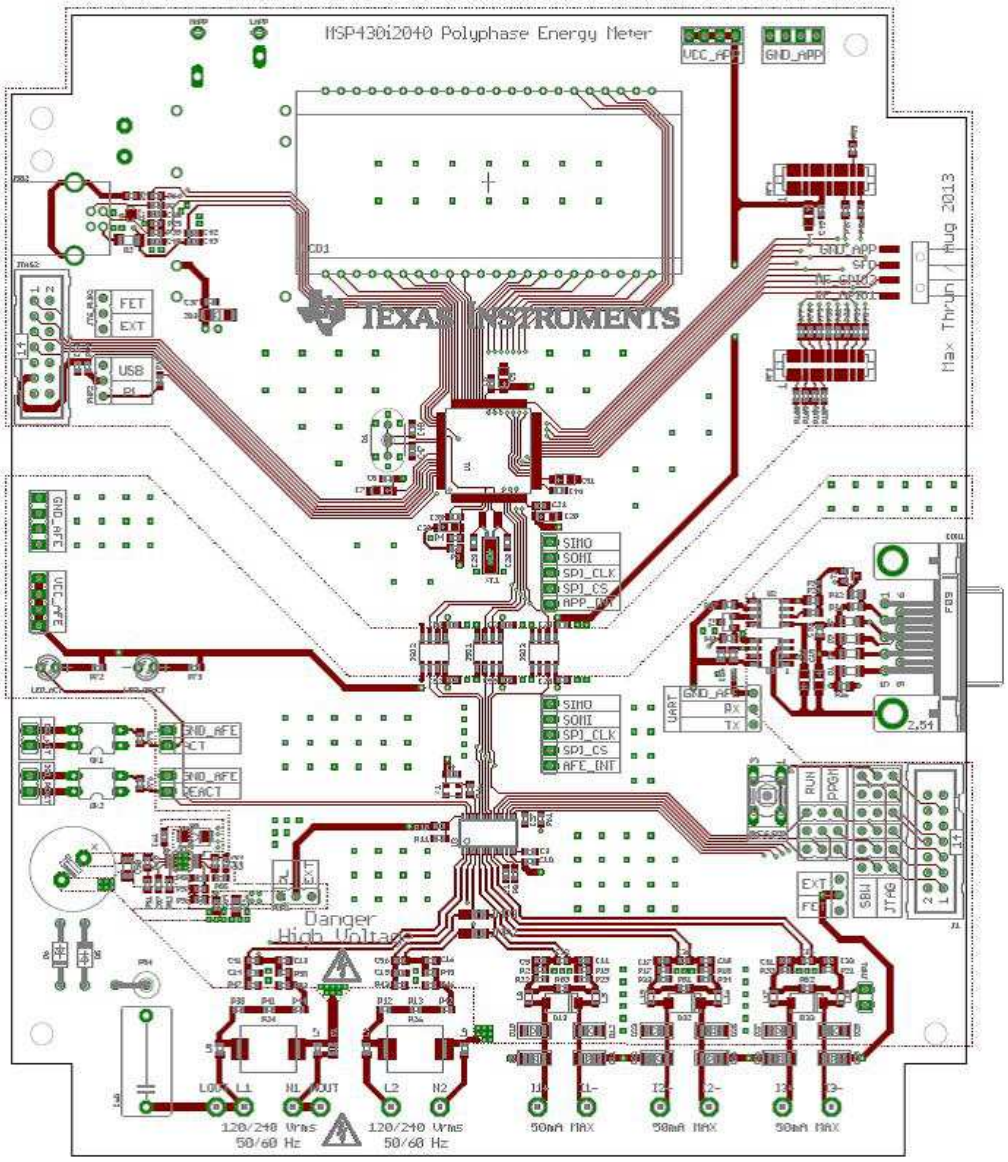

図 29. Top Layer Plot 2

6.4 CAD Project

To download the CAD project files, see the design files at TIDM-TWOPHASEMETER-I2040 .

6.5 Gerber Files

To download the Gerber files, see the design files at TIDM-TWOPHASEMETER-I2040 .

7 Software Files

To download the software files, see the design files at TIDM-TWOPHASEMETER-I2040 .

8 References

Implementation of One- or Two-Phase Electronic Watt-Hour Meter Using MSP430i20xx (SLAA637).

8.1 商標

9 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.

改訂履歴

資料番号末尾の英字は改訂を表しています。その改訂履歴は英語版に準じています。

2014年9月発行のものから更新 **Page**

- タイトルを「低コスト二相電気計器」から「低コスト単相/二相絶縁電気測定回路リファレンス・デザイン」に 変更 1

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