

Implementation of a Single-Phase Electronic Watt-Hour Meter Using the MSP430F6736

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ABSTRACT

This application report describes the implementation of a single-phase electronic electricity meter using the Texas Instruments MSP430F673x metering processor. It also includes the necessary information with regard to metrology software and hardware procedures for this single-chip implementation.

WARNING

Failure to adhere to these steps and/or not heed the safety requirements at each step may lead to shock, injury, and damage to the hardware.

The project collateral and source code that is described in this application report can be downloaded from <http://www.ti.com/lit/zip/slaa517>.

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1 Introduction

The MSP430F6736 device is the latest metering system-on-chip (SoC), that belongs to the MSP430F67xx family of devices. This family of devices belongs to the powerful 16-bit MSP430F6xxx platform and includes new features and flexibility to support robust 1-phase, 2-phase, and 3-phase metrology solutions. This application report, however, discusses the implementation of a 1-phase solution only. These devices find their application in energy measurement and have the necessary architecture to support them.

The F6736 has a powerful 25-MHz CPU with MSP430CPUX architecture. The analog front end consists of up to three 24-bit $\Sigma\Delta$ analog-to-digital converters (ADC) based on a second-order sigma-delta architecture that supports differential inputs. The sigma-delta ADCs ($\Sigma\Delta 24$) operate independently and can output 24-bit results. They can be grouped together for simultaneous sampling of voltage and currents on the same trigger. In addition, the ADCs have an integrated gain stage that supports gains up to 128 for amplification of low-output sensors. A 32-bit x 32-bit hardware multiplier on this chip can be used to further accelerate math-intensive operations during energy computation. The software supports calculation of various parameters for 1-phase energy measurement. The key parameters calculated during energy measurements are: RMS current and voltage, active and reactive power, active and reactive energy, power factor, and frequency. Complete metrology source code is provided and can be downloaded from <http://www.ti.com/lit/zip/slaa517>.

2 System Diagrams

Figure 1 shows typical connections of electronic electricity meters (also called energy meters or e-meters) in real-life applications. The supported ac voltages and associated currents are 230 V or 120 V at 50 Hz or 60 Hz. The labels LINE and NEUTRAL indicate low-voltage ac coming from the utilities.

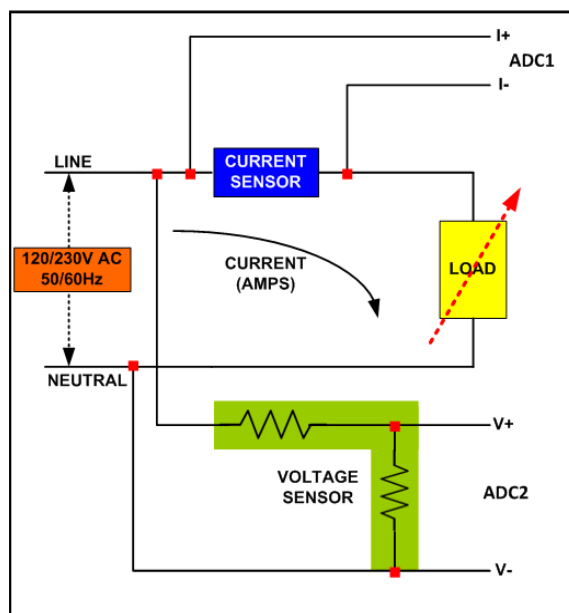


Figure 1. Typical Connections Inside Electronic Meters

More information on the current and voltage sensors, ADCs, and other hardware is provided in the following sections.

Figure 2 shows a block diagram of the high-level interface that is used for a single-phase energy meter application using the F6736. A single-phase two-wire star connection to the mains is shown with tamper detection. Current sensors are connected to each of the current channels, and a simple voltage divider is used to measure the 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, and the power dissipation at the sensors. The voltage divider resistors for the voltage channel are selected to make sure that the mains voltage is divided down to the normal input ranges that are valid for the MSP430™ SD24. For these values, see the *MSP430x5xx and MSP430x6xx Family User's Guide* (SLAU208) and the device-specific data sheet (SLAS731 for the MSP430F6736).

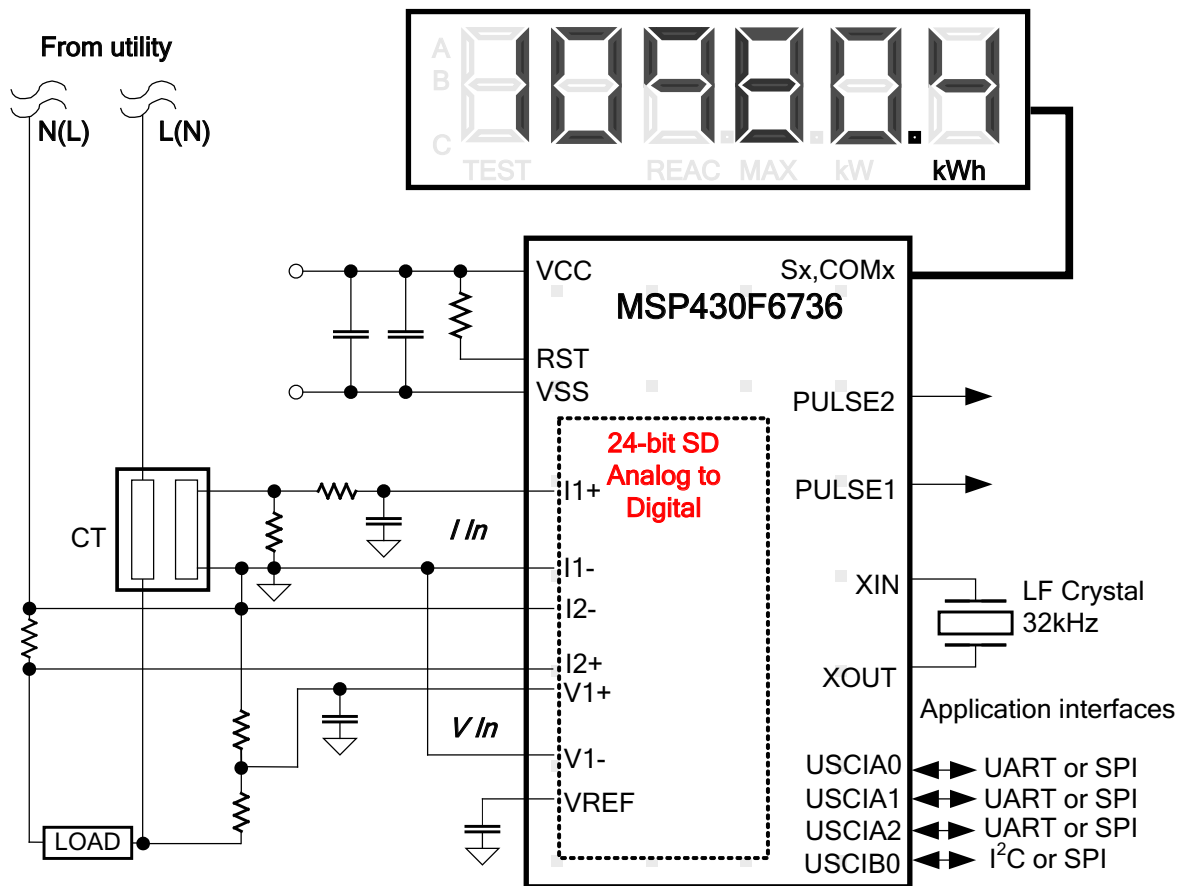


Figure 2. 1-Phase 2-Wire Star Connection Using MSP430F6736

L and N refer to the line and neutral voltages, respectively, and are interchangeable as long as the device is subject to only one voltage and not both simultaneously at its pins. The other signals of interest are the PULSE1 and PULSE2. They are used to transmit active and reactive energy pulses used for accuracy measurement and calibration.

3 Hardware Implementation

This section describes the hardware for the design of a working 1-phase energy meter using the F6736.

3.1 Power Supply

The MSP430 devices are ultralow-power microcontrollers from Texas Instruments. These devices support a number of low-power modes and improved power consumption during active mode when the CPU and other peripherals are active. The low-power features of this device family allow the design of the power supply to be extremely simple and cheap. The power supply allows the energy meter to be powered directly from the mains. The following sections describe the various power supply options that are available to support your designs.

3.1.1 Resistor Capacitor (RC) Power Supply

Figure 3 shows a simple capacitor power supply for a single output voltage of 3.3 V directly from the mains voltage of 110 V and 220 V and 50 Hz and 60 Hz VRMS ac.

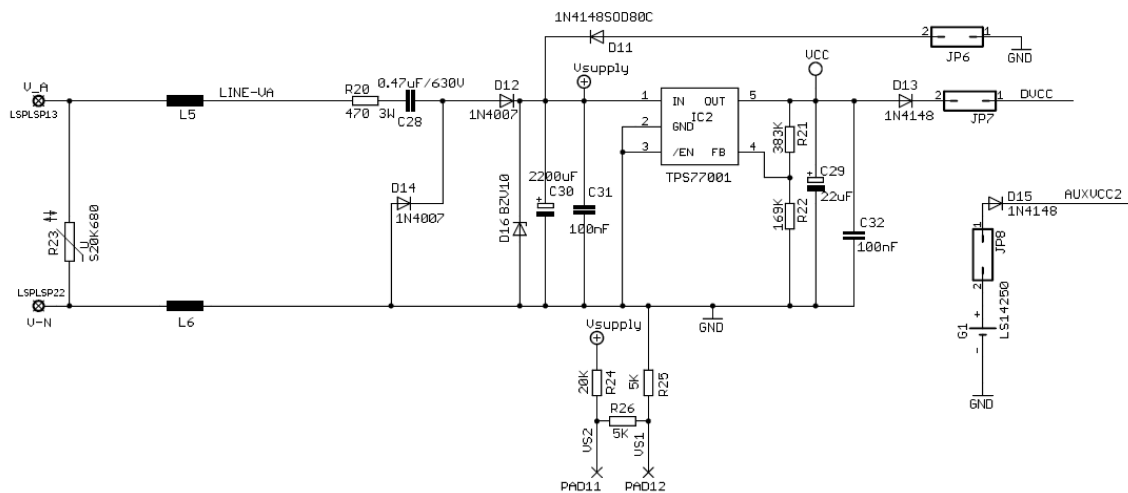


Figure 3. A Simple Capacitive Power Supply for the MSP430 Energy Meter

Appropriate values of resistor R20 and capacitor C28 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 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 in Figure 3, the drive provides approximately 12 mA. The design equations for the power supply are shown in the *Capacitor Power Supplies* section of *MSP430 Family Mixed-Signal Microcontroller Application Reports (SLAA024)*. If there is a need to slightly increase the current drive (up to 20 mA), the capacitor values of C28 can be increased. If drive higher than 20 mA is required, especially to drive RF technology, additional drive can be used either with an NPN output buffer or a transformer and switching-based power supply.

3.2 Analog Inputs

The MSP430 analog front end that consists of the $\Sigma\Delta$ ADC is differential and requires that the input voltages at the pins do not exceed ± 920 mV (gain = 1). To meet this specification, the current and voltage inputs need to be divided down. In addition, the SD24 allows a maximum negative voltage of -1 V, therefore, ac signals from mains can be directly interfaced without the need for level shifters. Section 3.2.1 and Section 3.2.2 describe the analog front end used for voltage and current channels, respectively.

3.2.1 Voltage Inputs

The voltage from the mains is usually 230 V or 110 V and needs to be brought down to a range of 1 V. The analog front end for voltage consists of spike protection varistors (not shown in this figure) followed by a simple voltage divider and a RC low-pass filter that acts like an anti-alias filter.

Figure 4 shows the analog front end for the voltage inputs for a mains voltage of 230 V. The voltage is brought down to approximately 700 mV RMS, which is 990 mV peak and fed to the positive input, adhering to the MSP430 $\Sigma\Delta$ analog limits. A common-mode voltage of zero can be connected to the negative input of the $\Sigma\Delta$. In addition, the $\Sigma\Delta$ has an internal reference voltage of 1.2 V that can be used externally and also as a common-mode voltage if needed. GND is referenced to the neutral voltage or line voltage, depending on the placement of the current sensor.

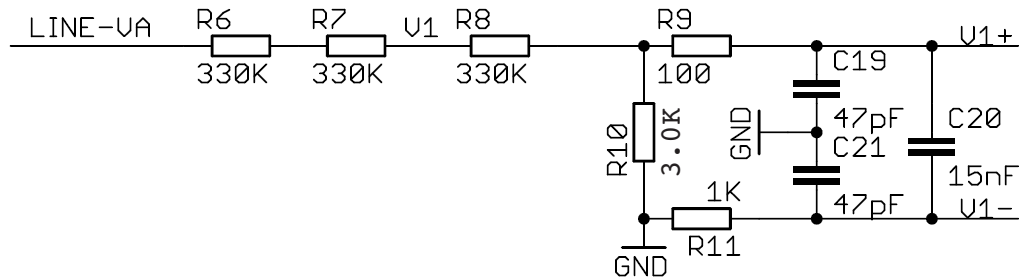


Figure 4. Analog Front End for Voltage Inputs

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 and, therefore, a lower value resistor is used for the anti-alias filter. If this is not maintained, a relatively large phase shift of several degrees would result.

3.2.2 Current Inputs

The analog front-end for current inputs is a little different from the analog front end for the voltage inputs. [Figure 5](#) shows the analog front end used for the current channels I1 and I2.

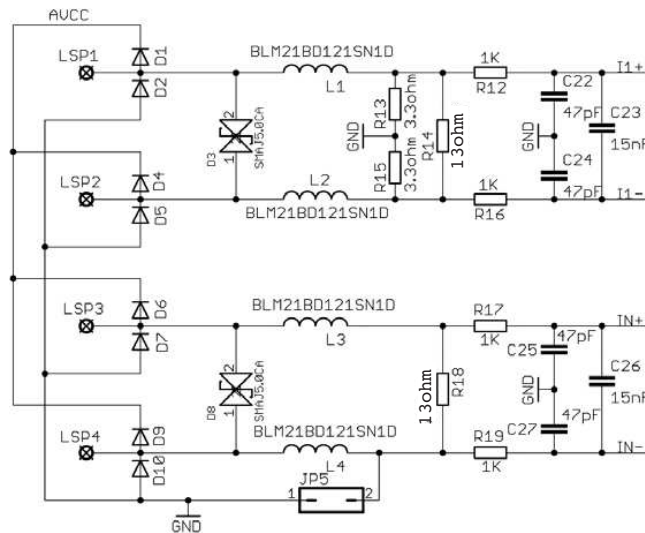


Figure 5. Analog Front End for Current Inputs

Resistors R14 and R18 are the burden resistors that would be selected based on the current range used and the turns-ratio specification of the CT (not required for shunt). The value of the burden resistor for this design is around 13 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 ± 920 mV maximum with gain of the converter set to 1. Similar to the voltage channels, the common mode voltage is selectable to either analog ground (GND) or internal reference on channels connected to LSP3 and LSP4.

4 Software Implementation

The software for the implementation of 1-phase metrology is discussed in this section. The first subsection discusses the set up of various peripherals of the MSP430. Subsequently, the entire metrology software is described as two major processes: foreground process and background process.

4.1 Peripherals Setup

The primary peripherals used for this application are the 24-bit sigma delta (SD24) ADC, clock system, timer, LCD, and watchdog timer (WDT).

4.1.1 SD24 Setup

The F673x family has up to three independent sigma delta data converters. For a single phase system at least two $\Sigma\Delta$ s are necessary to independently measure one voltage and current. The code accompanying this application report addresses the metrology for a 1-phase system with limited discussion to anti-tampering, however, the code supports the measurement of the neutral current. The clock to the SD24

(f_M) is derived from DCO running at 16 MHz. The sampling frequency is defined as $f_s = \frac{f_m}{OSR}$, the OSR is chosen to be 256 and the modulation frequency, f_M , is chosen as 1.1 MHz, resulting in a sampling frequency of 4.096 ksp/s. The SD24s are configured to generate regular interrupts every sampling instant.

The following are the $\Sigma\Delta$ channels associations:

- SD0P0 and SD0N0 → Voltage V1
- SD1P0 and SD1N0 → Current I1
- SD2P0 and SD2N0 → Current IN (Neutral)

4.2 Foreground Process

The foreground process includes the initial set up of the MSP430 hardware and software immediately after a device reset. [Figure 6](#) shows the flowchart for this process.

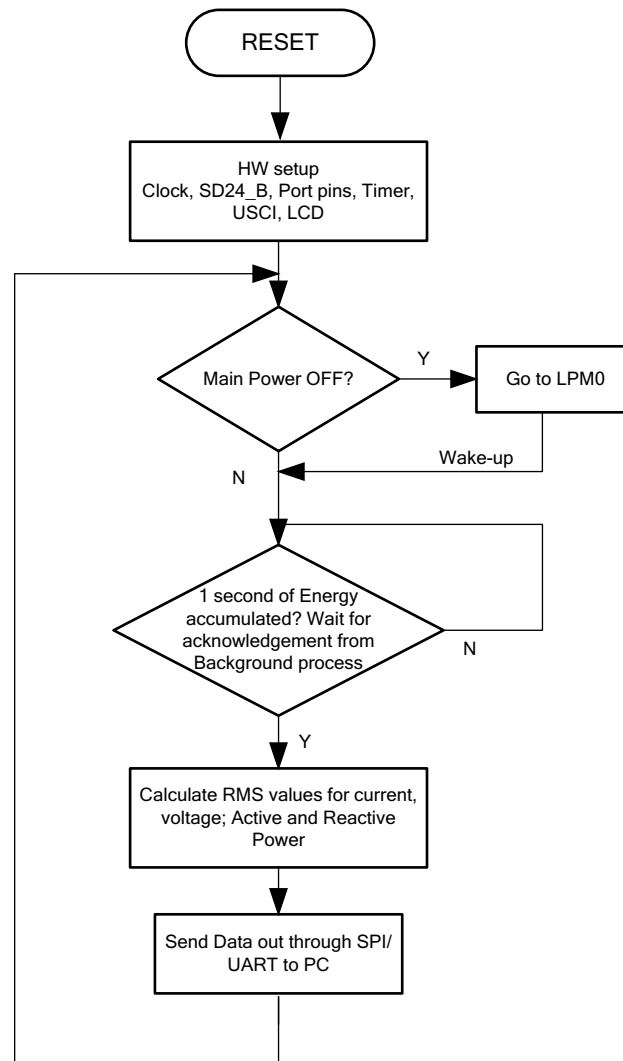


Figure 6. Foreground Process

The initialization routines involves the set up of the analog to digital converter, clock system, general purpose input/output (GPIO) port pins, timer, LCD and the USCI_A1 for universal Asynchronous receiver/transmitter (UART) functionality. A check is made to see if the main power is OFF and the device goes into LPM0. During normal operation, the background process notifies the foreground process through a status flag every time a frame of data is available for processing. This data frame consists of accumulation of energy for 1 second. This is equivalent to accumulation of 50 or 60 cycles of data samples synchronized to the incoming voltage signal. In addition, a sample counter keeps track of how many samples have been accumulated over the frame period. This count can vary as the software synchronizes with the incoming mains frequency. The data samples set consist of processed current, voltage, active and reactive energy. All values are accumulated in separate 48-bit registers to further process and obtain the RMS and mean values.

4.2.1 Formulas

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

4.2.1.1 Voltage and Current

As discussed in the previous sections simultaneous voltage and current samples are obtained from three independent $\Sigma\Delta$ converters at a sampling rate of 4096 Hz. Track of the number of samples that are present in 1 second is kept and used to obtain the RMS values for voltage and current for each phase.

$$V_{RMS} = K_V * \sqrt{\frac{\sum_{n=1}^{\text{Sample count}} v^2(n)}{\text{Sample count}}}$$

$$I_{RMS} = K_I * \sqrt{\frac{\sum_{n=1}^{\text{Sample count}} i^2(n)}{\text{Sample count}}}$$

$v(n)$ = Voltage sample at a sample instant 'n'

$i(n)$ = Current sample at a sample instant 'n'

Sample count= Number of samples in 1 second

K_V = Scaling factor for voltage

K_I = Scaling factor for current

4.2.1.2 Power and Energy

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 that uses the number of samples (sample count) and use the formulae listed below to calculate total active and reactive powers.

$$P_{ACT} = K_P * \sqrt{\frac{\sum_{n=1}^{\text{Sample count}} v(n) \times i(n)}{\text{Sample count}}}$$

$$P_{REACT} = K_P * \sqrt{\frac{\sum_{n=1}^{\text{Sample count}} v_{90}(n) \times i(n)}{\text{Sample count}}}$$

$v_{90}(n)$ = Voltage sample at a sample instant 'n' shifted by 90°

K_P = Scaling factor for power

The consumed energy is then calculated based on the active power value for each frame in similar way as the energy pulses are generated in the background process except that:

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

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

- This allows us to measure the reactive power accurately down to very small currents.
- This conforms to international specified measurement method.

Since the frequency of the mains varies, it is important to first measure the mains frequency accurately and then phase shift the voltage samples accordingly. This is discussed in [Section 4.3.3](#).

The 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 (refer to: Phase compensation).

4.3 Background Process

The background process uses the $\Sigma\Delta$ interrupt as a trigger to collect voltage and current samples (three values in total). These samples are further processed and accumulated in dedicated 48-bit registers. The background function deals mainly with timing critical events in software. Once sufficient samples (1 second worth) have been accumulated then the foreground function is triggered to calculate the final values of V_{RMS} , I_{RMS} , power and energy. The background process is also wholly responsible for energy proportional pulses, frequency and power factor calculation for each phase. Figure 7 shows the flow diagram of the background process.

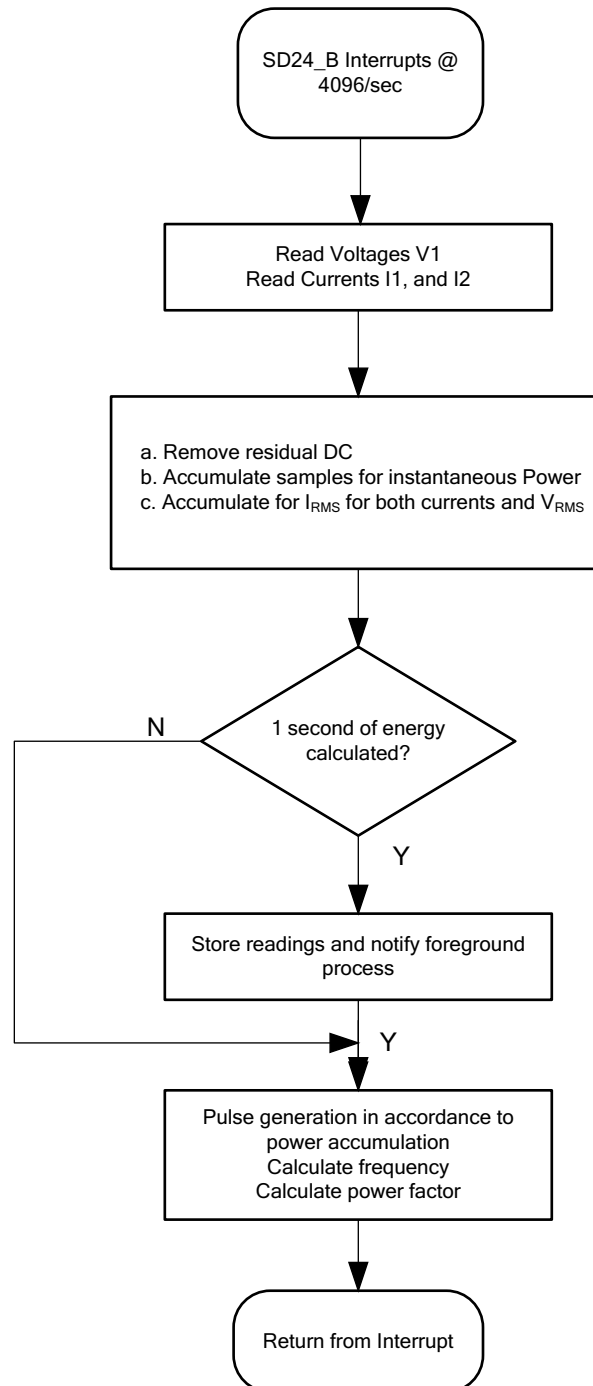


Figure 7. Background Process

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

4.3.1 Voltage and Current Signals

The Sigma-Delta Converter has a fully differential input; therefore, no added dc offset is needed to precondition a signal, which is the case with most single ended converters.

The output of the Sigma Delta is a signed integer. Any stray dc offset value is removed independently for V and I by subtracting a long term dc tracking filter's output from each $\Sigma\Delta$ sample. This long term dc tracking filter is synchronized to the mains cycle to yield a highly stable output.

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

- Accumulated squared values of voltage and current for V_{RMS} and I_{RMS} calculations.
- Accumulated energy samples to calculate Active Energy.
- Accumulated energy samples with current and 90° phase shifted voltage to calculate Reactive Energy.

These accumulated values are processed by the foreground process.

4.3.2 Phase Compensation

The Current Transformer (CT) when used as a sensor and the input circuit's passive components together introduces an additional phase shift between the current and voltage signals that needs compensation. The $\Sigma\Delta$ converter has built in hardware delay that can be applied to individual samples when grouped. This can be used to provide the phase compensation required. This value is obtained during calibration and loaded on to the respective PRELOAD register for each converter. Figure 8 shows the application of PRELOAD (SD24PREx).

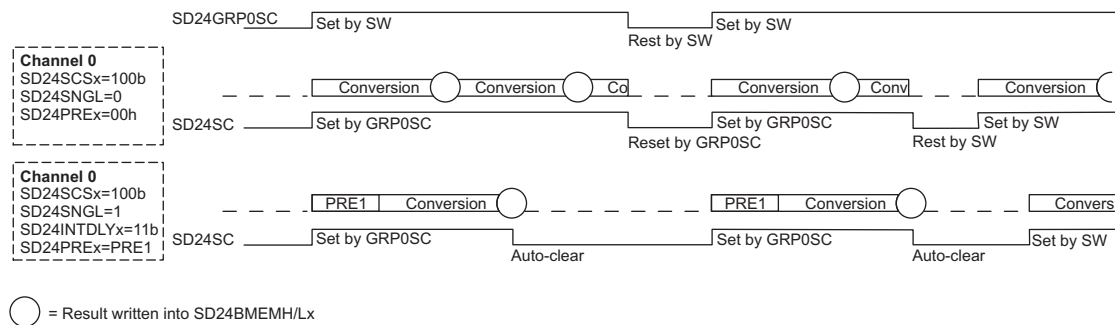


Figure 8. Phase Compensation Using PRELOAD Register

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

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

In the current application for input frequency of 60 Hz, OSR of 256 and sampling frequency of 4096, the resolution for every bit in the preload register is about 0.02° with a maximum of 5.25° (maximum of 255 steps). Since the sampling of the 3 channels are group triggered, an often method used is to apply 128 steps of delay to all channels and then increasing or decreasing from this base value. This allows \pm delay timing to compensate for phase lead or lag. This puts the practical limit in the current design to $\pm 2.62^\circ$. When using CTs that provide a larger phase shift than this maximum, an entire sample delay along with fractional delay must be provided. This phase compensation can also be modified on the fly to accommodate temperature drifts in CTs.

4.3.3 Frequency Measurement and Cycle Tracking

The instantaneous I and V signals 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 like RMS and power values. Cycle boundaries to trigger the foreground averaging process are used since it gives very stable results.

For frequency measurements, a straight line interpolation is created between the zero crossing voltage samples. Figure 9 depicts the samples near a zero cross and the process of linear interpolation.

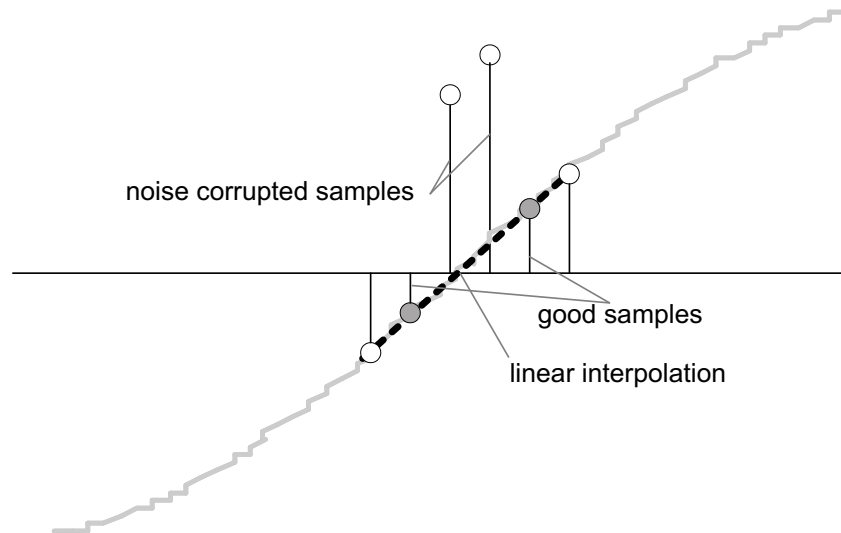


Figure 9. Frequency Measurement

Because noise spikes can also cause errors, therefore, the rate of change check to filter out the possible erroneous signals is used and make sure that the two points interpolated from are genuine zero crossing points. For example, if you have two negative samples, a noise spike can make one of them positive and therefore making 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 tolerant of noise.

4.3.4 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 to report measurement during normal operation. To serve both these tasks efficiently, the microcontroller has to accurately generate and record the number of these pulses. It is a general requirement to generate these pulses with relatively little jitter. Although, time jitters are not an indication of bad accuracy, as long as the jitter is averaged out it would give a negative indication on the overall accuracy of the meter.

The average power to generate the energy pulses is used. The average power (calculated by the foreground process) is accumulated every $\Sigma\Delta$ interrupt. This is equivalent to converting it 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 amount 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.

The threshold determines the energy "tick" specified by the power company and is a constant. For example, this can be in kWh. In most meters, the pulses per kWh decide this 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 or 6400. Energy pulses are generated and also indicated via LEDs on the board. Port pins are toggled for the pulses with control over the pulse width for each pulse.

Figure 10 shows the flow diagram for pulse generation.

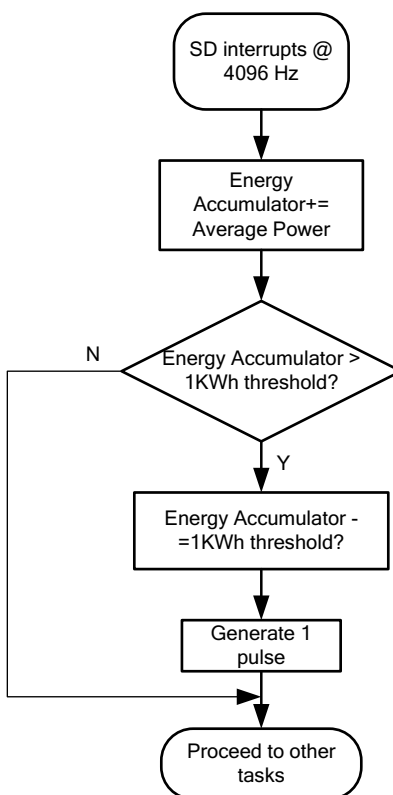


Figure 10. Pulse Generation for Energy Indication

The average power is in units of 0.01 W and 1 kWh threshold is defined as:

$$\begin{aligned}
 1 \text{ kWh threshold} &= 1/0.01 * 1 \text{ kW} * (\text{Number of interrupts/second}) * (\text{number of seconds in 1 hour}) \\
 &= 100000 * 4096 * 3600 = 0x15752A00000
 \end{aligned}$$

5 Energy Meter Demo

The energy meter evaluation module (EVM) associated with this application report has the MSP430F6736 and demonstrates energy measurements. The complete demonstration platform consists of the EVM that can be easily hooked to any test system, metrology software, and a PC GUI that is used to view results and perform calibration.

5.1 EVM Overview

The following figures of the EVM describe the hardware. [Figure 11](#) is the top view of the energy meter. [Figure 12](#) discusses the location of various pieces of the EVM based on functionality.

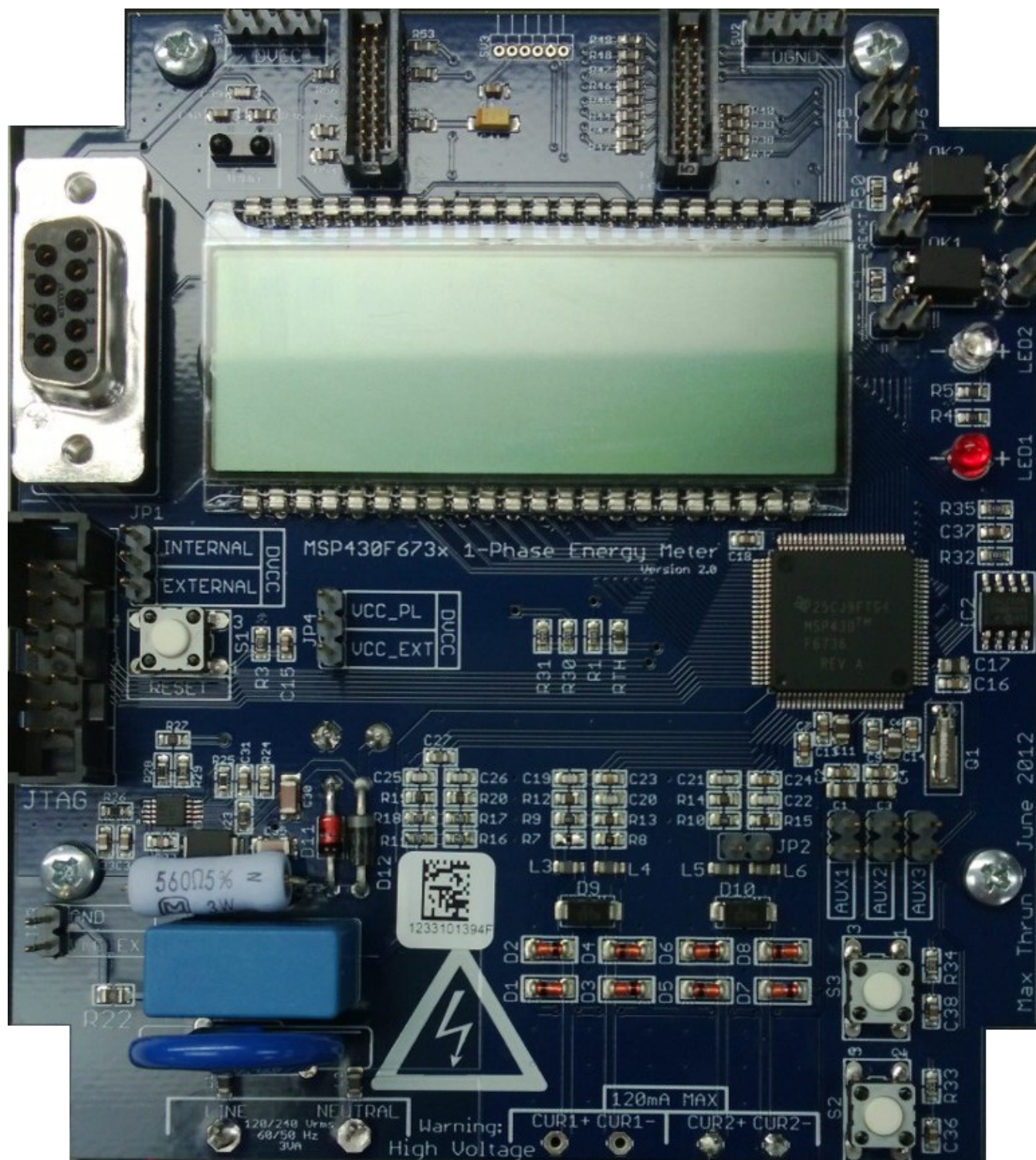


Figure 11. Top View of the Single Phase Energy Meter EVM

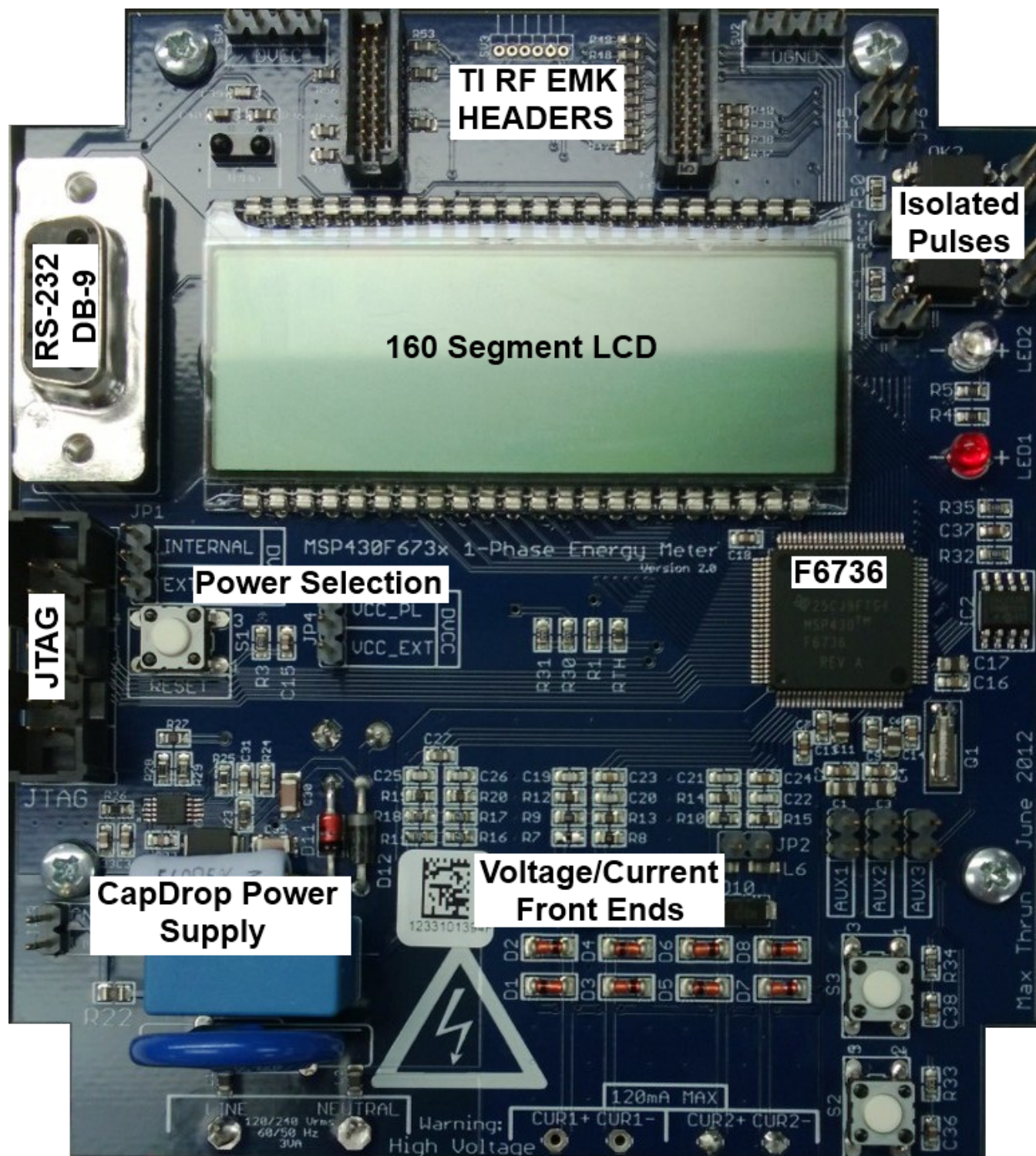


Figure 12. Top View of the EVM With Blocks and Jumpers

5.1.1 Connections to the Test Setup for AC Voltages

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

- LINE and NEUTRAL for voltage inputs, connect to Line and Neutral voltages, respectively. This can be up to 240 V ac, 50 Hz and 60 Hz. Currently available on top of the terminal block.

- CUR1+ and CUR1- are the current inputs after the sensors. When CT or shunts are used, make sure the voltages across CUR1+ and CUR1- does not exceed 920 mV. Not currently used on the EVM.
- CUR2+ and CUR2- can also be used as current inputs after the sensors. When CT or shunts are used, make sure the voltages across CUR2+ and CUR2- does not exceed 920 mV. Currently connected to a CT.

To read active energy pulses for accuracy measurements, there are several options available on the board. The related pulse rate is 6400 pulses per kWh by default, but is configurable via the energy library.

- Optical output via LED1.
- Non-isolated electrical pulse via ACT header. The left pin is the signal, and the right pin is GND.
- Isolated pulses via JP7. The opto-isolator used will close the circuit between these two pins on an active pulse

Figure 13 shows the various connections that need to be made to the test set up for proper functionality of the EVM.

Figure 13. Top View of the EVM With Test Setup Connections

If a test setup needs to be connected, the connections have to be made according to the EVM design. Figure 13 shows the connections from the top view. L and N correspond to the voltage inputs from the 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 supports measurement for the second current, the EVM obtained from Texas Instruments do not have the second sensor and any current inputs must be connected to I+ and I- only. If additional sensor needs to be placed, please use the two bottom left slots close to terminals I'+ and I'-. Additional connections need to be made to connect the output of these sensors to points CUR1+ and CUR1- on the PCB.

5.1.2 Power Supply Options and Jumper Settings

The entire board and the UART communication is powered by a single dc voltage rail (DVCC). DVCC can be derived either via JTAG, external power or the ac mains through the capacitive power supply. Various jumper headers and jumper settings are present to add to the flexibility to the board. Headers JP1 to JP15 constitute the entire headers on the EVM shown above. Some of these headers require that jumpers be placed appropriately for blocks to function correctly. Table 1 indicates the functionality of each jumper on the board and the associated functionality.

Table 1. Header Names and Jumper Settings on the F6736 EVM

Header Name	Main Functionality	Valid Use-case	Comments
JP1	JTAG power selection	Jumper placed during JTAG programming	Jumper on "INTERNAL" selects JTAG voltage from the attached USB FET. Jumper on "EXTERNAL" selects JTAG voltage from an external source.
JP4	DVCC Power Selection	Jumper placed during operation	Jumper on "VCC_PL" selects voltage from the cap drop power supply on board, and jumper on "VCC_EXT" selects an external input from JP3.
JP3	External power input	Not a jumper header	When using an external source for DVCC, attach VCC and GND here.
JP2	Current Sensor Reference	Connects the -ve input of the current sensor sigma delta to AGND	Place a jumper if Current transformers are used. Do not place jumper if shunt is used. Needs to be placed on the EVM if used as provided
AUX1	AUXVCC1 selection	Connects AUXVCC1 to GND and input of external supply of AUXVCC1.	Jumper must be present if AUXVCC1 is not used. When removed, it can be used to supply an external voltage to AUXVCC1.
AUX2	AUXVCC2 selection	Connects AUXVCC2 to GND and input of external supply of AUXVCC2.	Jumper must be present if AUXVCC2 is not used. When removed, it can be used to supply an external voltage to AUXVCC2.

Table 1. Header Names and Jumper Settings on the F6736 EVM (continued)

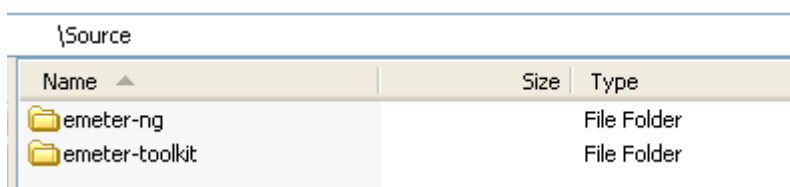
Header Name	Main Functionality	Valid Use-case	Comments
AUX3	AUXVCC3 selection	Connects AUXVCC3 to DVCC and input of external supply of AUXVCC3.	Jumper can be placed if AUXVCC3 needs to be used; when removed it can be used to supply an external voltage to AUXVCC3.
JP7	Isolated active energy pulses	Not a jumper header	Isolated output to probe the active energy output pulses using external equipment.
JP8	Isolated reactive energy pulses	Not a jumper header	Isolated output to probe the reactive energy output pulses using external equipment.
SV1	DVCC Power Tap	Not a jumper header	Used to measure DVCC or connect power to an external module.
SV2	DGND Power Tap	Not a jumper header	Used to measure DGND or connect power to an external module.
RF1 + RF2	TI EMK Headers	Not a jumper header	Used to connect a standard TI Wireless Evaluation Module Kit (EMK) such as the CC2530 or CC3000
ACT	Non-isolated active energy pulses + GND	Not a jumper header	Not isolated from ac voltage. Do not connect external equipment if external isolation is not present. The left pin is the signal, and the right pin is GND.
REACT	Non-isolated reactive energy pulses + GND	Not a jumper header	Not isolated from ac voltage. Do not connect external equipment if external isolation is not present. The left pin is the signal, and the right pin is GND.

5.2 Loading the Example Code

The source code is developed in the IAR environment using IAR compiler version 6.x. If earlier versions of IAR are used, the project files will not open. If later than 6.x versions are used when project is loaded, a prompt to create a back-up will be issued and you can click YES to proceed. There are two parts to the energy metrology software: the toolkit that contains a library of mostly mathematics routines and the main code that has the source and include files.

5.2.1 Opening the Project

The "source" folder structure is shown in [Figure 14](#).


Figure 14. Source Folder Structure

The folder "emeter-ng" contains multiple project files. For this application, the *emeter-6736.ewp* project file is to be used. The folder "emeter-toolkit" has corresponding project file *emeter-toolkit-6736.ewp*. Choose only the projects that have the succeeding terms 6736 for this application. For first time use, it is recommended that both the projects be completely rebuild.

1. Open IAR window.
2. find and load the project *emeter-toolkit-6736.ewp*.
3. Rebuild all.
4. Close the existing workspace and open the main project *emeter-6736.ewp*.
5. Rebuild all and load this on to the MSP430F6736, which is shown in [Figure 15](#)

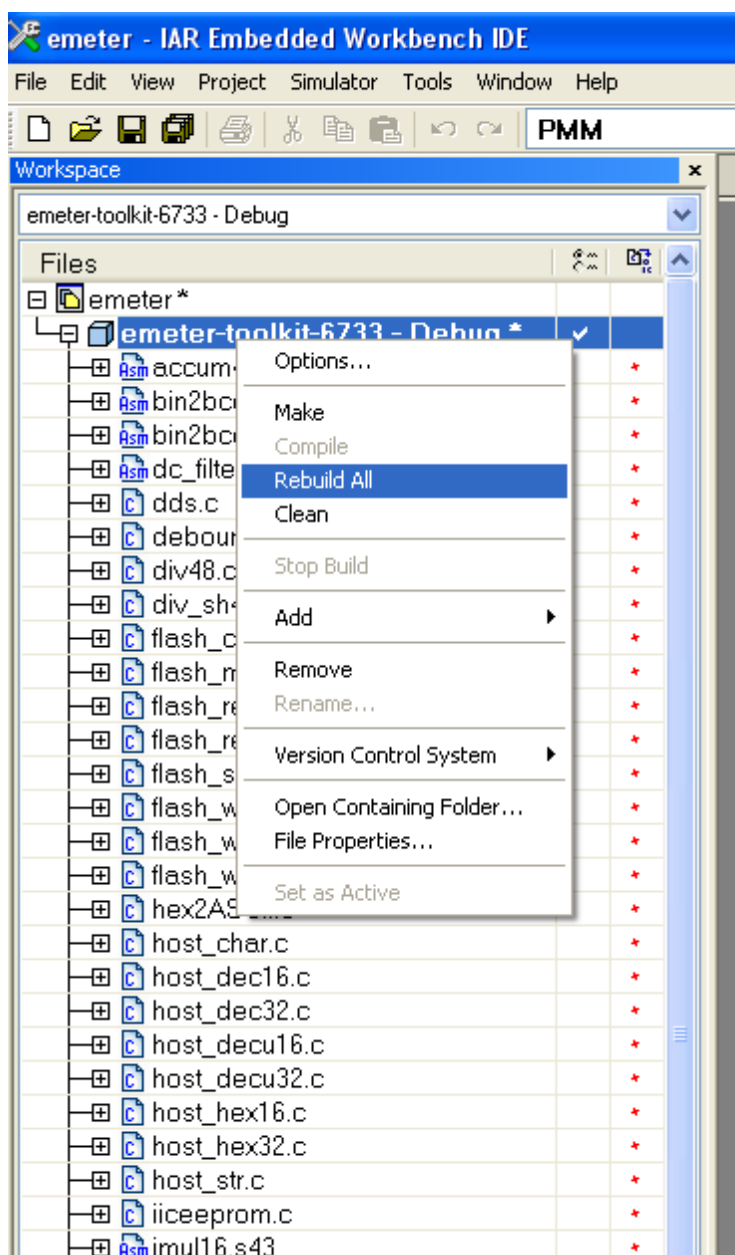


Figure 15. Toolkit Compilation in IAR

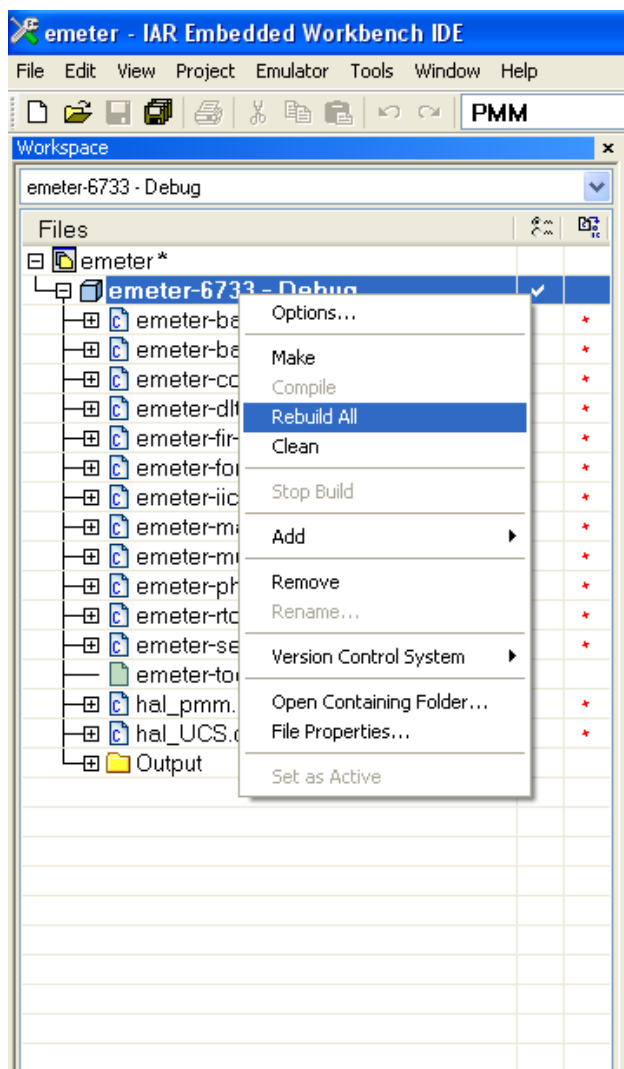


Figure 16. Metrology Project Build in IAR

6 Results and Calibration

If the procedures and configurations are complete in the previous two sections, the results can be observed and based on these; calibration can be performed. Calibration is key to any meter's performance and is absolutely necessary for every meter to go through this process. Initially every meter would exhibit different accuracies due to silicon-silicon differences, sensor accuracies and other passive tolerances. To nullify their effects, every meter should be calibrated. Simple procedures to accomplish this process are shown in this section. For any calibration to be performed accurately there should be an accurate source available. The source should be able to generate any desired voltage, current and phase shifts (between V and I) or power factors. In addition to an accurate source, there should also be a reference meter that acts as an arbitrator between the source and the meter being calibrated. This section discusses a simple and effective method of calibration of this 1-phase EVM.

A PC GUI is included in the zip file that can be downloaded from <http://www.ti.com/lit/zip/slaa517>. After decompressing the zip file, a folder named GUI has all of the files that are necessary to run this application.

6.1 Viewing Results

Once the meter is turned ON, the results can be easily viewed using this GUI by connecting the RS-232 header to the PC. Run calibrator.exe in the GUI folder.

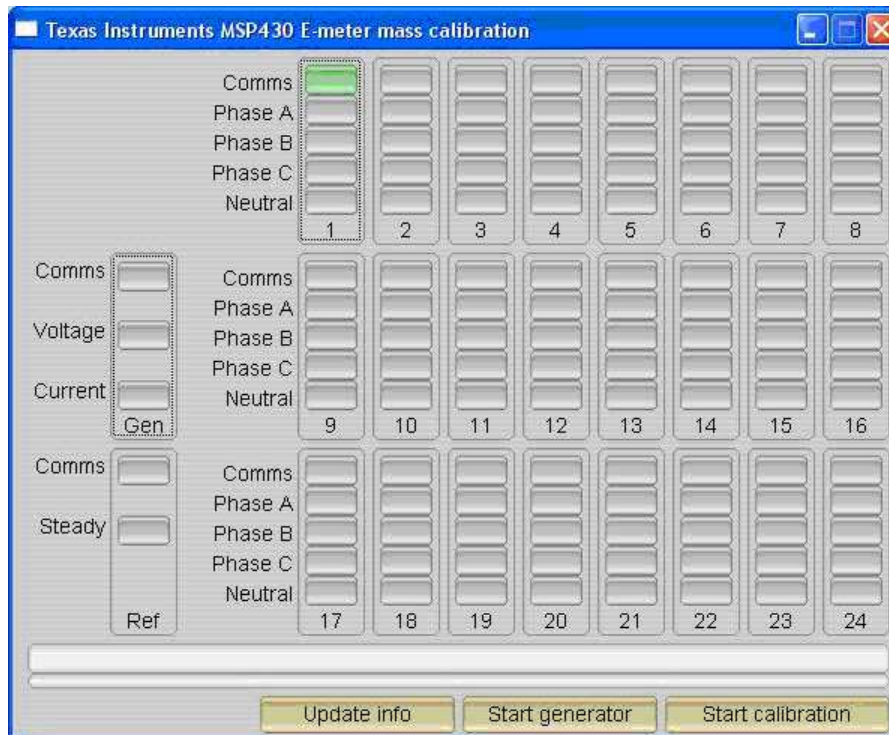


Figure 17. E-Meter Mass Calibration

Under correct connections, you should see the GREEN filled button under "Comms". If there are problems with connections or if the code is not configured correctly, the button will be RED in color. Click on the green button to see the meter results immediately on the GUI.

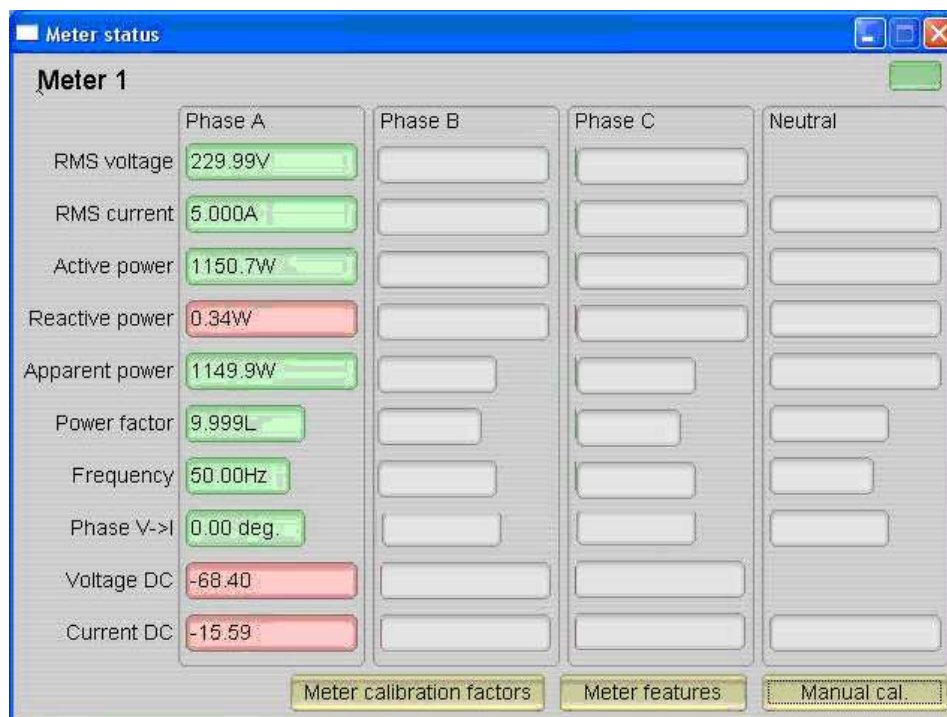


Figure 18. Meter Status

The configuration of the meter can also be viewed by clicking on "Meter features" (Example only) to get the screen shown in [Figure 19](#).

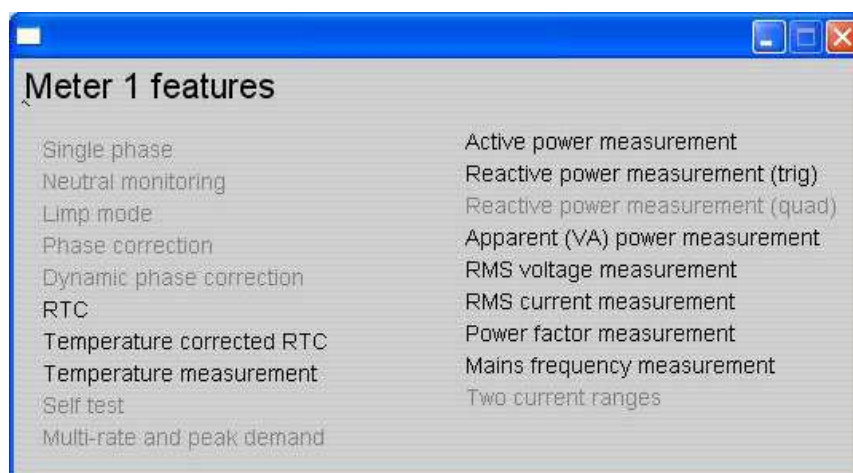


Figure 19. Meter 1 Features

Results can also be viewed as pulses fed back to any energy meter test setup. Energy pulses for total active and total reactive energies are available at JP9 and JP12 (ACT) and JP14 and JP13 (REACT). In addition, the pulses go through on-board opto-couplers that might be necessary for interface to any test equipment. Look at [Table 1](#) and choose the right header for energy pulses.

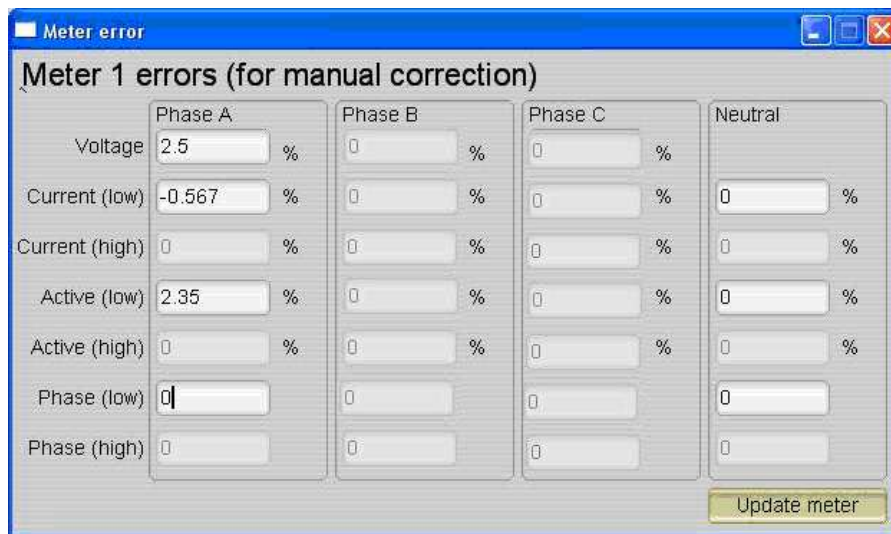
6.2 Calibrating the Meter

The meter can be calibrated easily using the included GUI. Gain correction for voltage, current and active power can be done simultaneously. However, phase correction for active power is an additional step.

6.2.1 Gain Correction

Gain correction for voltage, current and active power can be done simultaneously and the procedure is discussed below.

1. Connect the meter to the test setup with known voltage and currents.
2. Connect GUI to view results for voltage, current, active power, and so forth.
3. Click on Manual cal seen in Figure 18 to give you this screen.



	Phase A	Phase B	Phase C	Neutral
Voltage	2.5 %	0 %	0 %	
Current (low)	-0.567 %	0 %	0 %	0 %
Current (high)	0 %	0 %	0 %	0 %
Active (low)	2.35 %	0 %	0 %	0 %
Active (high)	0 %	0 %	0 %	0 %
Phase (low)	0	0	0	0
Phase (high)	0	0	0	0

Update meter

Figure 20. Meter 1 Errors (for manual correction)

4. The values that need to be entered are in % and these values are calculated by the following formula. For any particular voltage, the value will be:

$$\%VAL = \left(\frac{V_{Observed}}{V_{Desired}} - 1 \right) \times 100$$

5. Negative values are accepted in the voltage and current fields and the same procedure is applicable for other voltages and currents. For voltages, enter in field "Voltage" and for currents, enter in field Current (low). After these values are entered, click on Update meter.
6. Gain correction for active power is done differently; the accuracy obtained from any test system when pulses are fed from the meter is the most accurate method.
7. Measure accuracy in the reference meter of the test system. This gives the true accuracy of the meter for active energy.
8. Enter the "% accuracy" seen as-is in the Active (low) field. Click on update meter to do a gain correction on Phase A.

6.2.2 Phase Correction

Phase correction has to be done differently and the following is the procedure.

1. Set voltage and current values to the same as Gain correction and introduce a known phase shift between voltage and current to +60°.
2. See % error on the test setup. If errors are not acceptable, enter correction factors in the Phase (low) field. Only increments and decrements should be entered in this field and preferably start with 1 or -1 to determine the direction of correction. Click "Update meter".

3. Measure error again to see if error has increased or decreased. If error has decreased, continue to add desired increments until you arrive at an error close to zero, else add decrements.
4. Click on "Update meter" every time a modification is made to this field.
5. Change the phase now to -60° and check if this error is still acceptable. If not, fine tune the values of Phase (low) again. Ideally, errors should be symmetric for same phase shift on lag and lead conditions.

After the meter has been calibrated, it is possible to see these calibrated values for reference. Click "Meter calibration factors" to open this screen (sample values only).

	Phase A	Phase B	Phase C	Neutral
Voltage	9883	0 %	0 %	
Current (low)	5931	0 %	0 %	0 %
Current (high)		0 %	0 %	0 %
Active (low)	7328	0 %	0 %	0 %
Active (high)		0 %	0 %	0 %
Phase (low)	16	0	0	0
Phase (high)		0	0	0

Figure 21. Meter Calibration Factors

If the calibration procedure goes wrong, such that the calibration values are either negative or zero, further calibration of the meter should be stopped and code must be reloaded on to the device and the calibration routine repeated.

6.2.3 Metrology Results

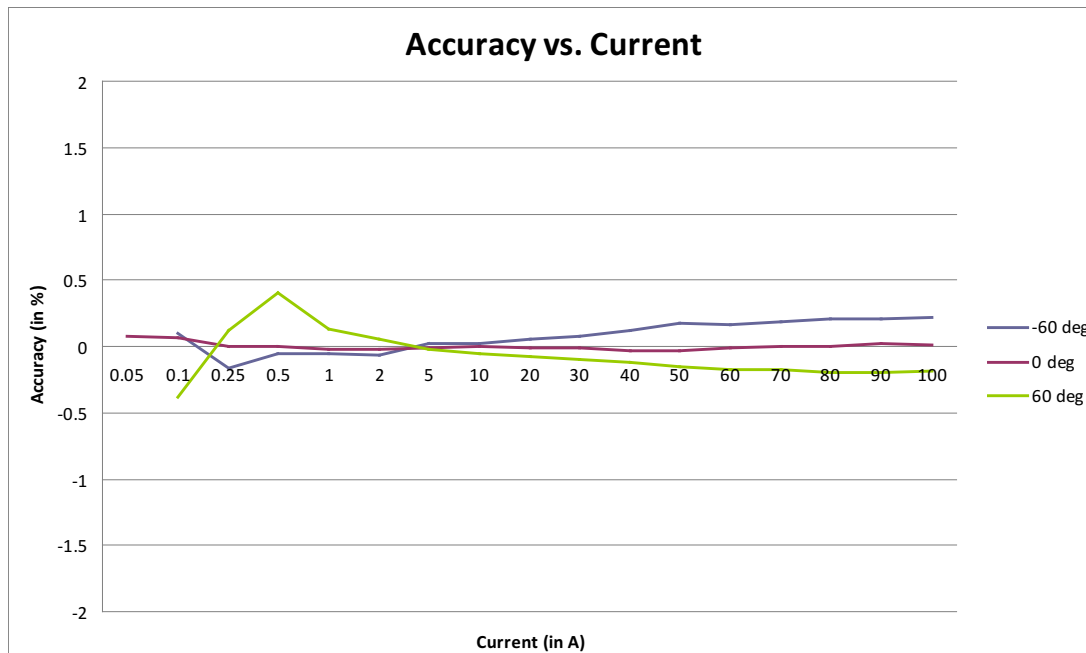
In this discussion, metrology results are shown. Current transformers have been used, however, the code supports shunt resistors as well. Figure 22 shows the results for current that is varied from 50 mA to 100 A exhibiting a 2000:1 dynamic range. Table 2 shows the values for the error at room temperature.

Table 2. Energy Measurement Accuracy With Error in (%)

Calibrated at 230 V, 15 A, 50 Hz			
Current (Amps)	-60° (PF =-0.5)	0° (PF =1)	60° (PF=0.5)
	Error (%)	Error (%)	Error (%)
0.05		0.077	
0.1	0.103	0.064	-0.382
0.25	-0.16	0	0.1231
0.5	-0.051	-0.002	0.405
1	-0.057	-0.019	0.128
2	-0.07	-0.025	0.058
5	0.026	-0.013	-0.019
10	0.025	-0.004	-0.057
20	0.0533	-0.0107	-0.075
30	0.0747	-0.0107	-0.096
40	0.1177	-0.032	-0.117
50	0.174	-0.032	-0.15

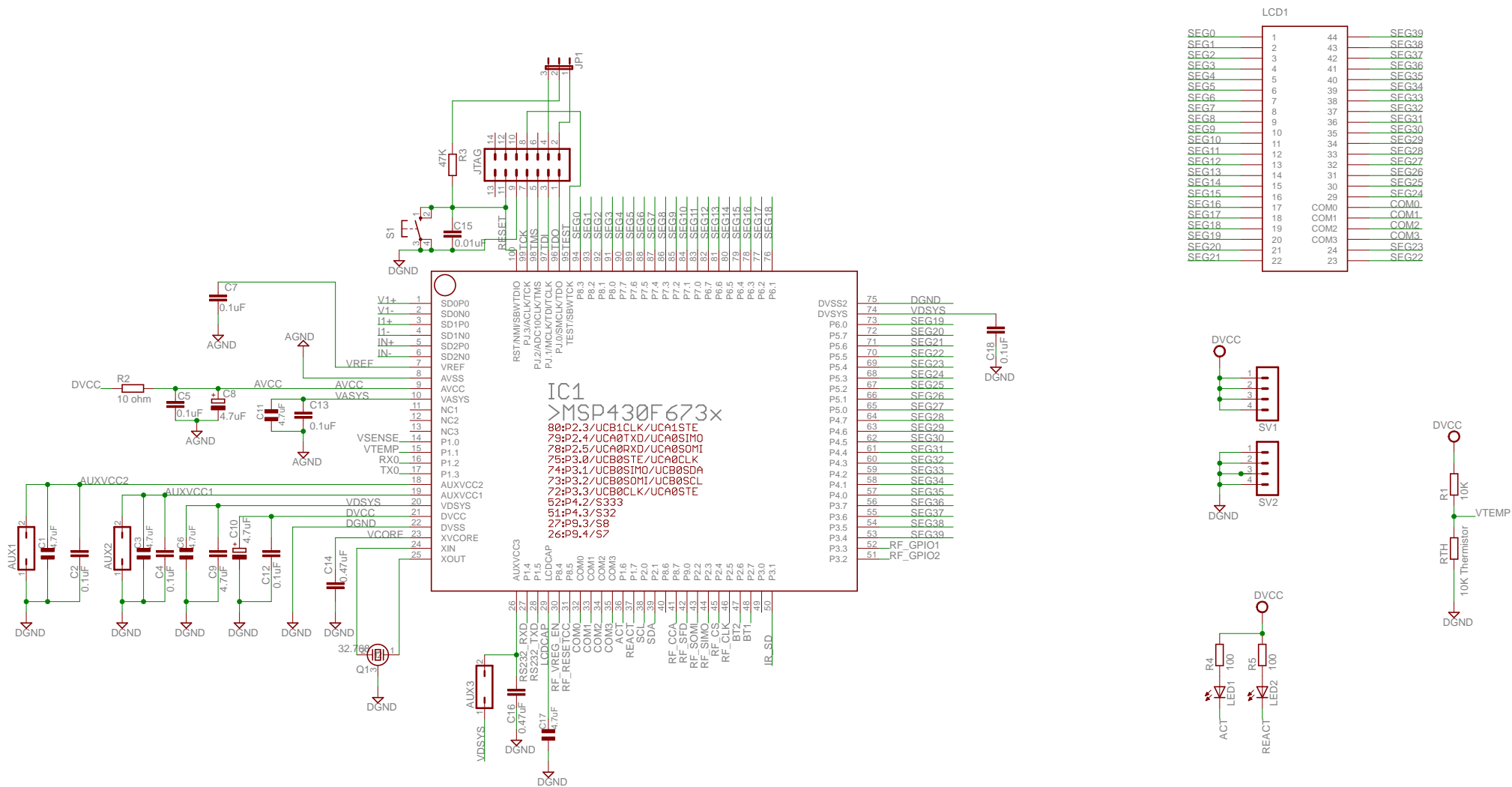
Table 2. Energy Measurement Accuracy With Error in (%) (continued)

Calibrated at 230 V, 15 A, 50 Hz			
Current (Amps)	-60° (PF =-0.5)	0° (PF =1)	60° (PF=0.5)
	Error (%)	Error (%)	Error (%)
60	0.1677	-0.01	-0.174
70	0.189	0.0037	-0.18
80	0.21	0.0037	-0.195
90	0.21	0.025	-0.195
100	0.224	0.011	-0.188


Figure 22. Measurement Accuracy Across Current

7 References

- *MSP430 Family Mixed-Signal Microcontroller Application Reports* ([SLAA024](#))
- *MSP430x5xx and MSP430x6xx Family User's Guide* ([SLAU208](#))



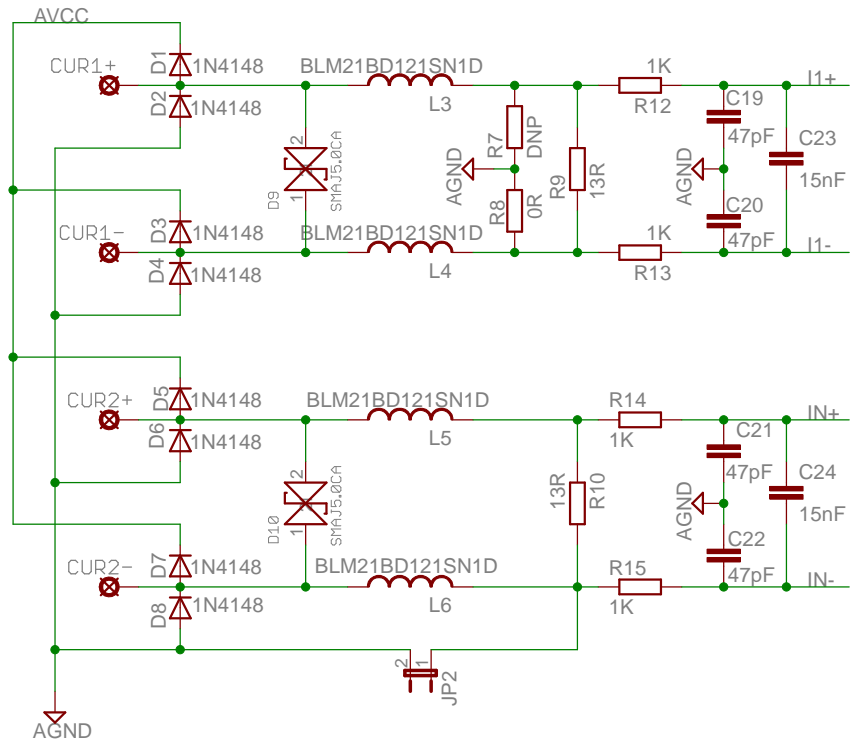
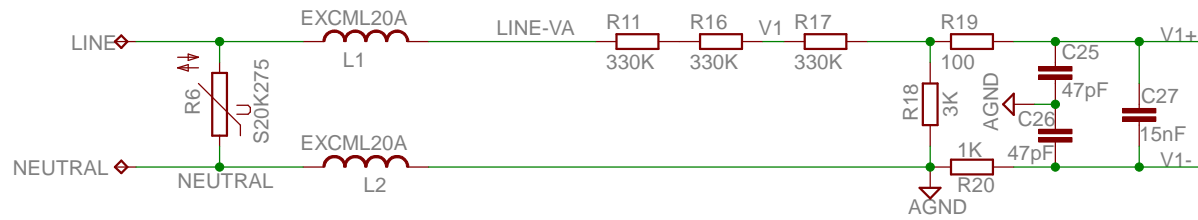
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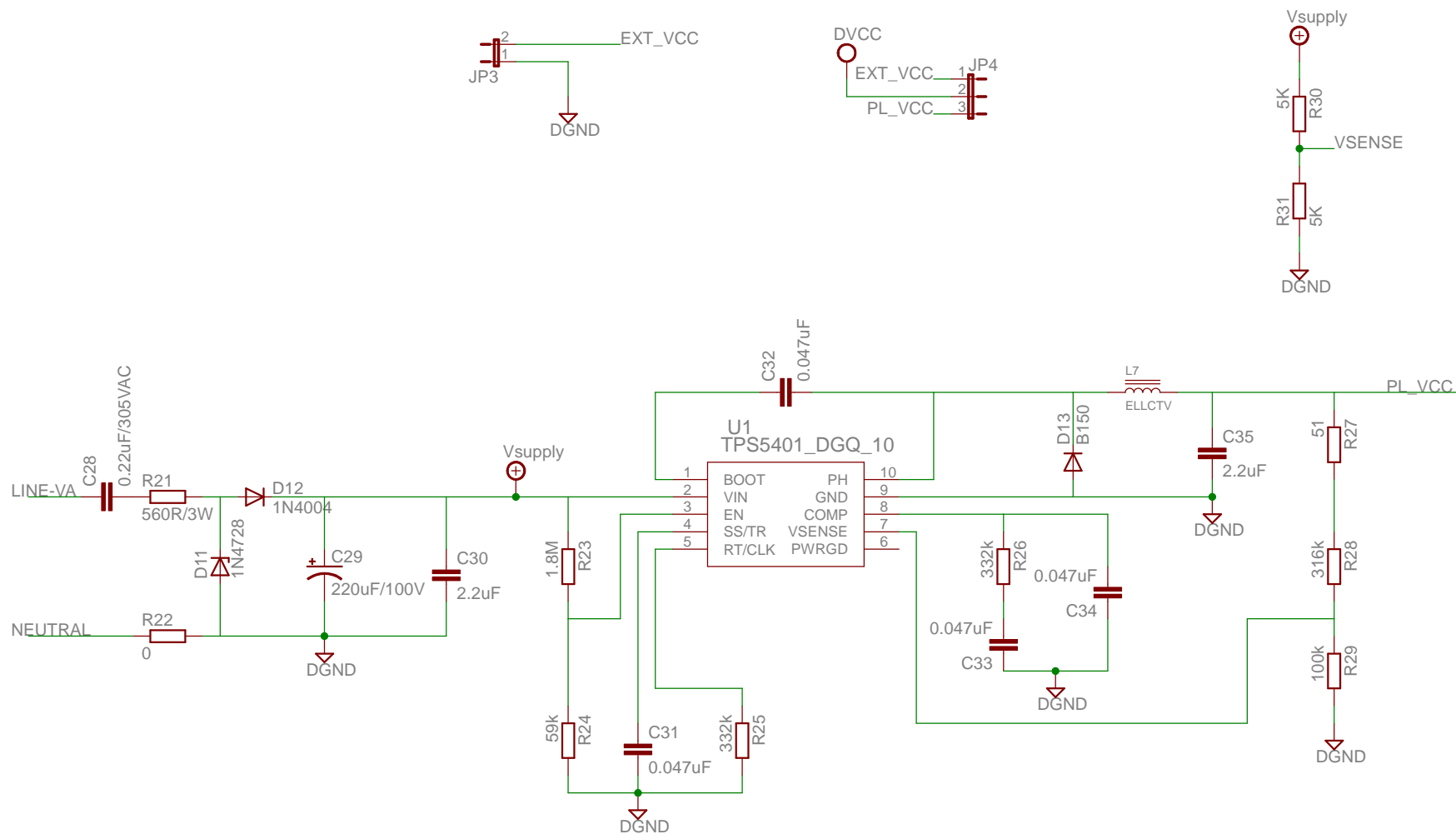
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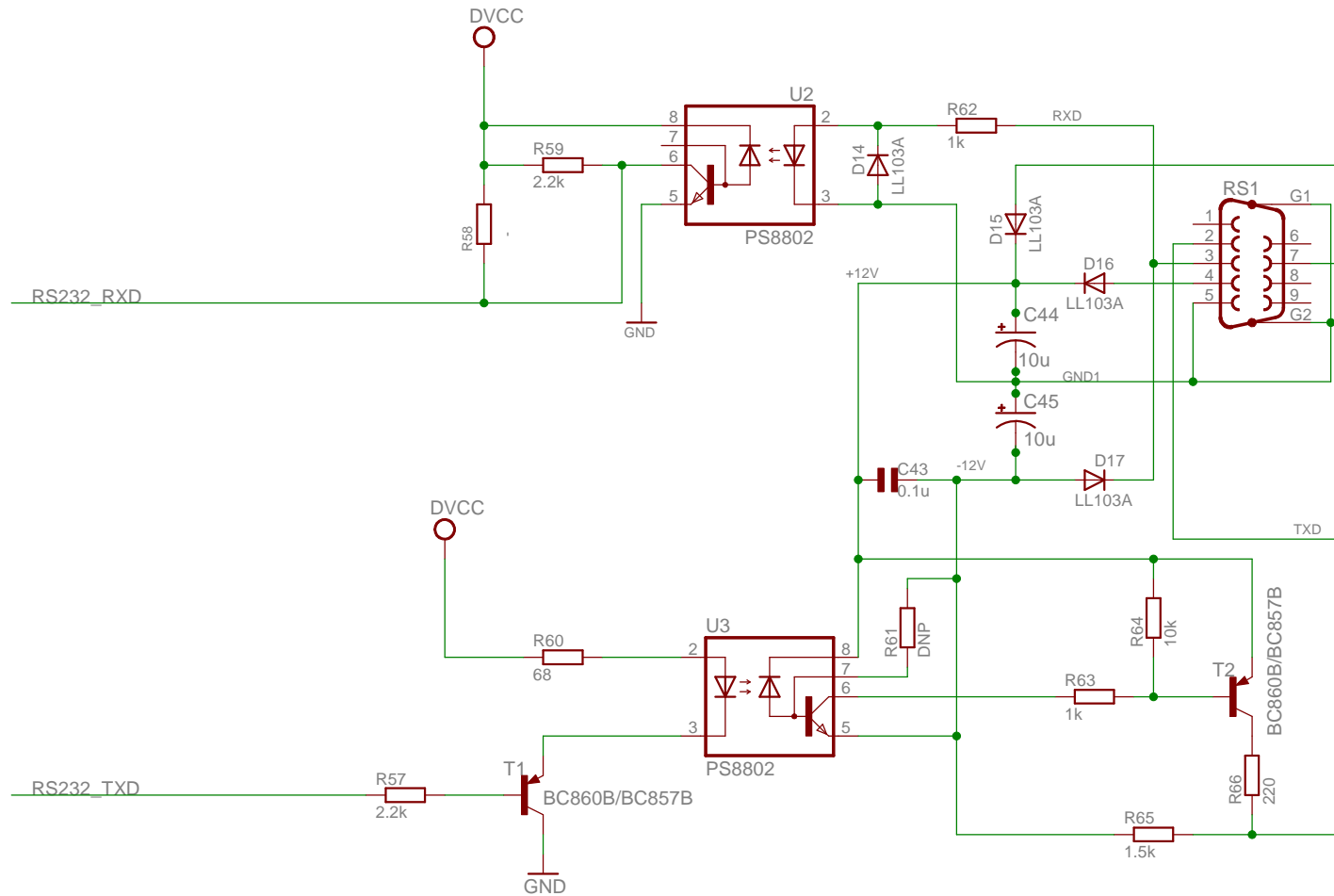
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