Application Note

Implementation of a Single-Phase Electronic Watt-Hour Meter Using the MSP430AFE2xx

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ABSTRACT

This application report describes the implementation of a single-phase electronic electricity meter using the Texas Instruments MSP430AFE2xx metering processors. It 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. Texas Instruments is not responsible or liable in any way for shock, injury, or damage caused due to negligence or failure to heed advice.

Project collateral and source code discussed in this application report can be downloaded from the following URL: http://www.ti.com/lit/zip/slaa494.

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1 Trademarks

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2 Introduction

The MSP430AFE2xx devices belong to the MSP430F2xx family of devices. These devices find their application in energy measurement and have the necessary architecture to support it. The MSP430AFE2xx devices have a powerful 12-MHz central processing unit (CPU) with MSP430 CPUX architecture. The analog front end consists of up to three analog-to-digital converters (ADCs) based on a second-order sigma-delta (ΣΔ) architecture that supports differential inputs. The ΣΔ ADCs (SD24) can output 24-bit results. They can be grouped together for simultaneous sampling of voltage and current on the same trigger. Each SD24 converter supports a common-mode voltage of up to -1 V and enables all sensors to be referenced to ground. In addition, it has an integrated gain stage that supports gains up to 32 for amplification of low-output sensors. A 16-bit x 16-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 single-phase energy measurement. The key parameters calculated during energy measurements are root mean square (RMS) current and voltage, active and reactive power and energy, power factor, and frequency. This application report has the complete metrology source code provided as a zip file. For new designs, download the Energy Measurement Design Center (EMDC) and software library from MSP-EM-DESIGN-CENTER.

3 Block Diagram

Figure 3-1 shows the system block diagram of the EVM. The EVM is divided into the metrology portion that has the MSP430AFE and the application portion that has the MSP430F6638. The MSP430AFE is a slave metrology processor and the MSP430F6638 is the host/application processor. The two MSP430 devices communicate through digital isolators via serial peripheral interface (SPI) or universal asynchronous receiver/transmitter (UART).

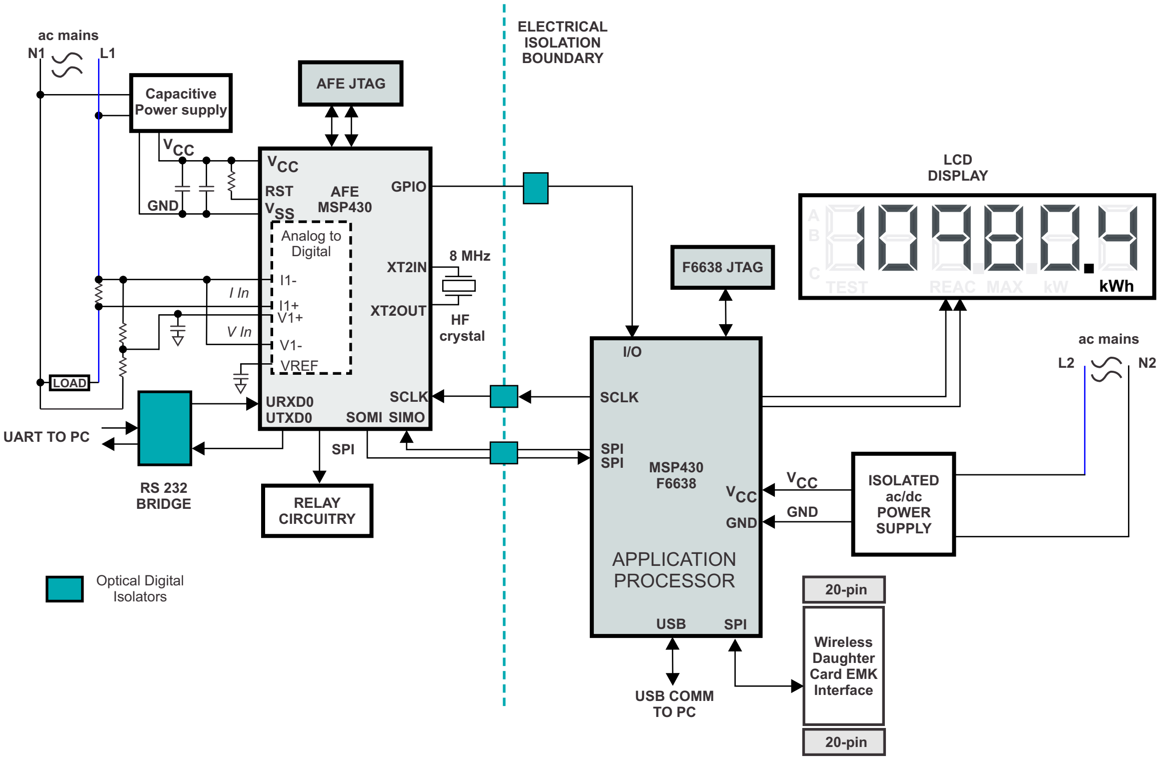


Figure 3-1. Energy Meter EVM System Block Diagram

Figure 3-2 shows the high-level interface for a single-phase energy-meter application. 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 voltage divider is used for corresponding voltages. The current transformer (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 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 on the AFE, and the tolerance of the power dissipation. The choice of voltage divider resistors for the voltage channel is selected to ensure the mains voltage is divided down to adhere to the normal input ranges that are valid for the MSP430 SD24. For these details, see the *MSP430x2xx Family User's Guide* and the device-specific data sheet.

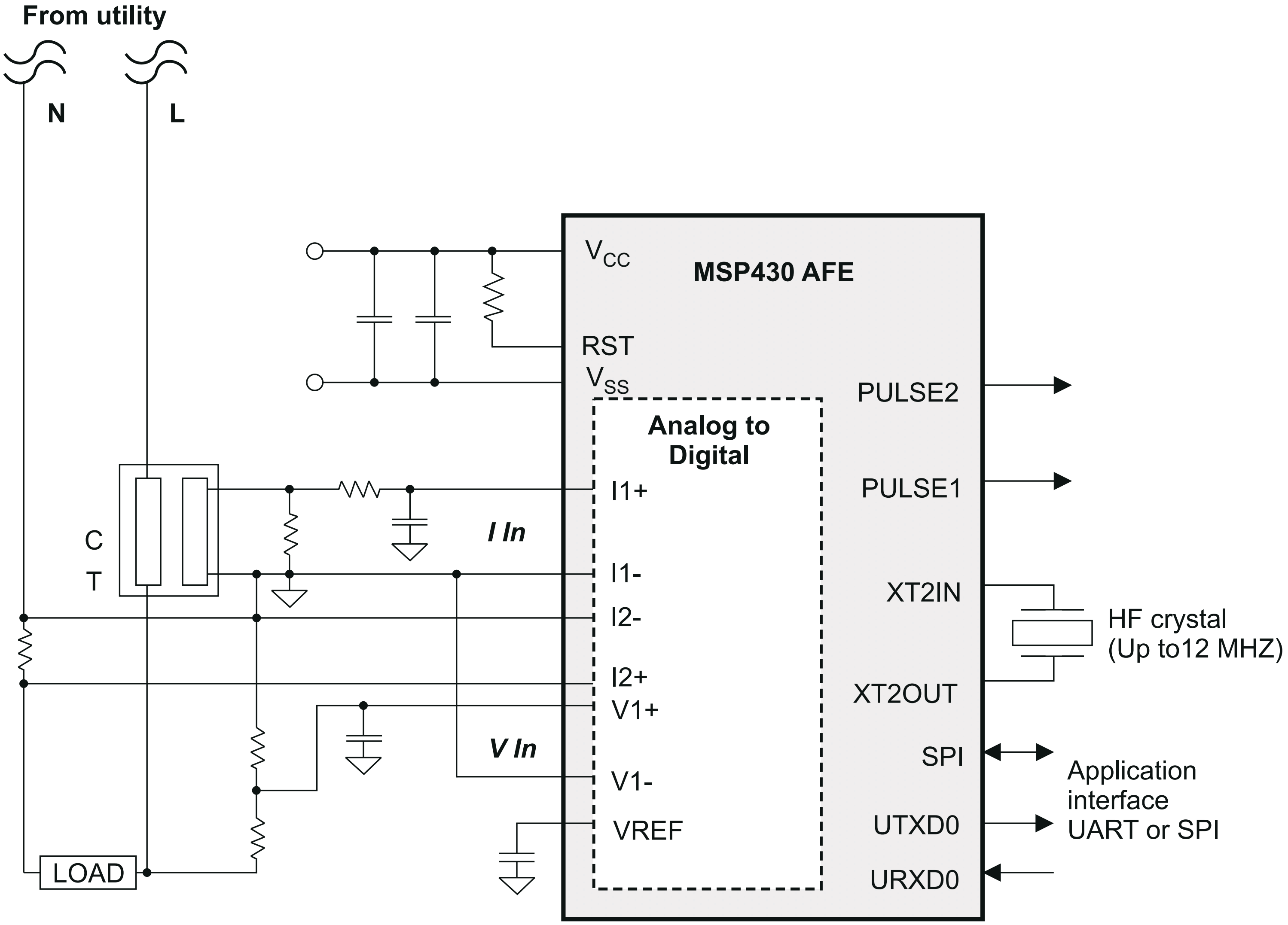


Figure 3-2. One-Phase Two-Wire Star Connection Using MSP430AFE2x3

4 Hardware Implementation

This section describes the hardware that is required for an energy meter using the MSP430AFE2xx.

4.1 Power Supply

The MSP430 family of devices is ultra-low-power microcontrollers from Texas Instruments. These devices support a number of low-power modes and also have low-power consumption during active mode when the CPU and other peripherals are active. The low-power feature of this device family allows design of the power supply to be simple and inexpensive. The power supply allows the operation of the energy meter powered directly from the mains. The following sections discuss the various power supply options that are available to support your design.

4.1.1 Resistor Capacitor (RC) Power Supply

Figure 4-1 shows a simple capacitor power supply for a single output voltage of 3.3 V directly from the mains voltage of 110/220 V_{RMS} alternating current (ac).

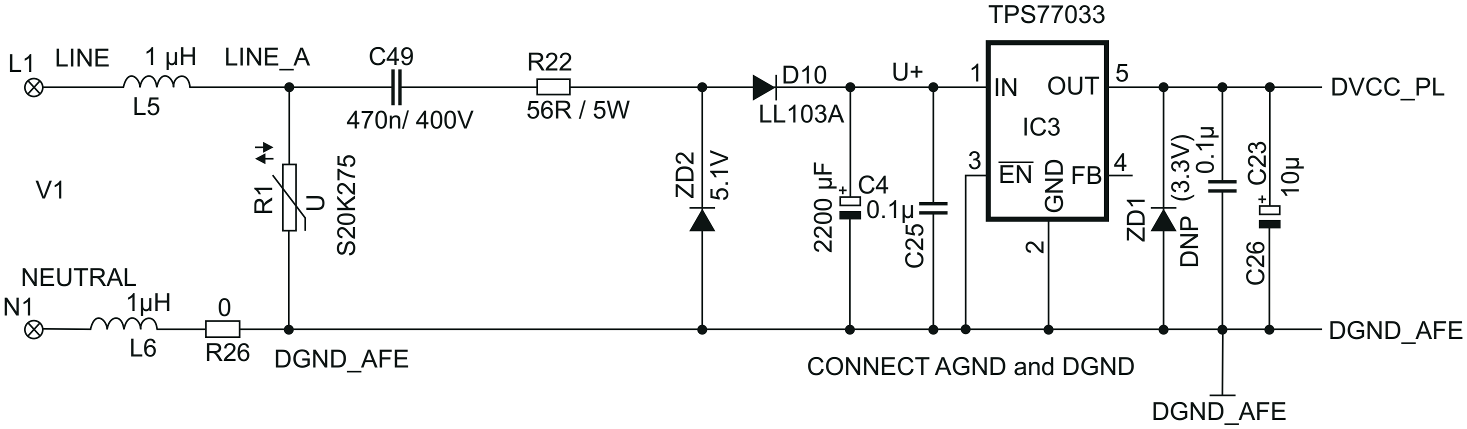


Figure 4-1. A Simple Capacitive Power Supply for the MSP430 Energy Meter

Appropriate values of resistor R22 and capacitor C49 are chosen based on the required output current drive of the power supply. Voltage from the mains is fed directly to an RC-based circuit followed by rectification circuitry to provide a direct current (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 4-1, the approximate drive provided approximately 12 mA. If additional drive is required, either an NPN output buffer or a transformer-/switching-based power supply may be used.

4.1.2 Switching-Based Power Supply

The simple capacitive power supply does not provide enough current for the MSP430F6638 to drive RF transceivers. Therefore, a switching-based power supply is required. An additional power supply module on the board provides 3.3-V dc from the ac mains of 110-V or 220-V ac. The internal circuitry for this module is not provided with this application report.

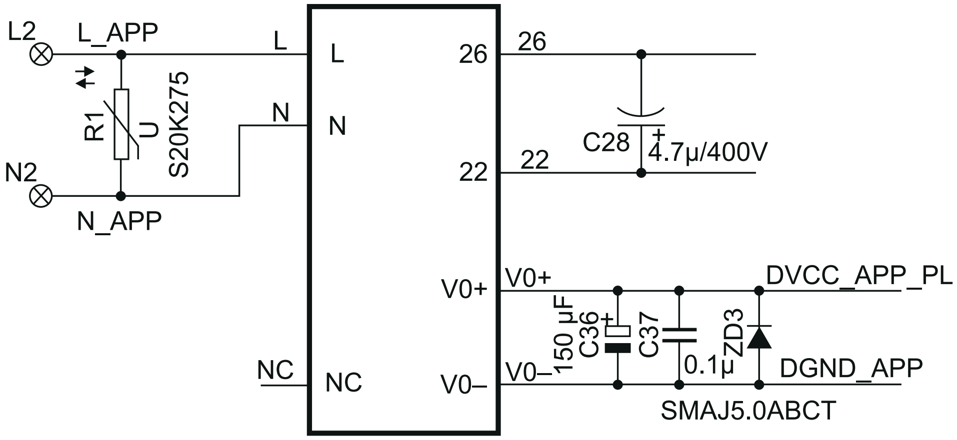


Figure 4-2. Switching-Based Power Supply for the MSP430 Energy Meter

4.2 Analog Inputs

The MSP430 analog front end that consists of the SD24 ADC is differential and requires that the input voltages at the pins do not exceed ±500 mV (gain = 1). To meet this specification, the current and voltage inputs must be divided down. In addition, the SD24 allows a maximum negative voltage of -1 V; therefore, the ac signals from the mains can be directly interfaced without the need for level shifters. The following sections describe the analog front end used for voltage and current channels.

4.2.1 Voltage Inputs

The voltage from the mains is usually 230 V or 110 V and must be brought down to a range of 500 mV (see Figure 4-3). The analog front end for voltage consists of spike protection varistors (not shown) followed by a simple voltage divider and an RC low-pass filter that acts as an anti-alias filter.

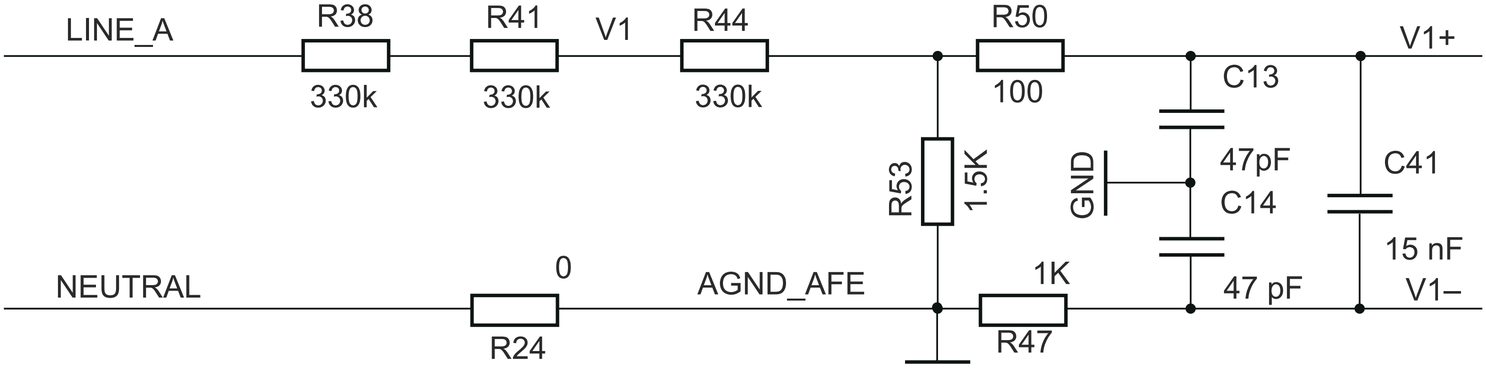


Figure 4-3. Analog Front End for Voltage Inputs

Figure 4-3 shows the analog front end for the voltage inputs for a mains voltage of 230 V. The voltage is brought down to approximately 350 mV RMS, which is 495 mV peak, and fed to the positive input. This level meets the MSP430 SD24 analog limits. A common-mode voltage of zero can be connected to the negative input of the SD24. In addition, the SD24 has an internal reference voltage of 1.2 V that can be used externally and also as a common-mode voltage, if needed.

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 difference is not maintained, a relatively large phase shift of several degrees would result.

4.2.2 Current Inputs

The analog front end for the current inputs is different from the analog front end for the voltage inputs. Figure 4-4 shows the analog front end used for current channel I1 and I2.

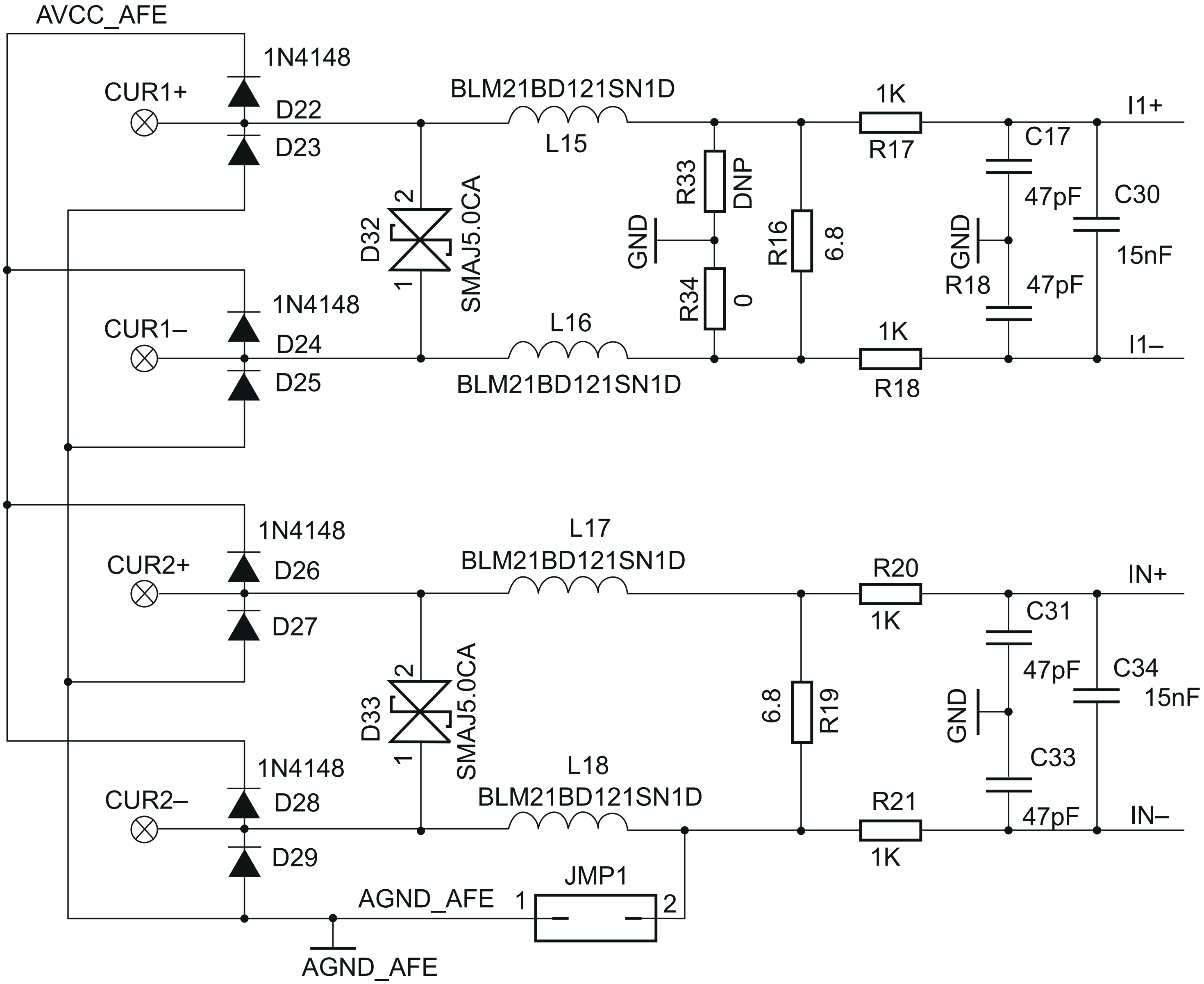


Figure 4-4. Analog Front End for Current Inputs

Resistor R16 is the burden resistor that is selected based on the current range and the turns-ratio specification of the CT (not required for shunt). The value of the burden resistor for this design is approximately 6.8 Ω. The anti-aliasing circuitry consisting of R and C follows the burden resistor. The input signal to the converter is a fully differential input with a voltage swing of ±500 mV maximum with gain of the converter set to 1. Similar to the voltage channels, the common-mode voltage is selectable to either analog ground (AGND_AFE) or internal reference.

5 Software Implementation

The software for the implementation of single-phase metrology is discussed in the following sections. Section 5.1 discusses the setup of various peripherals of the MSP430. Section 5.2 and Section 5.3 describe the metrology software as two major processes: foreground process and background process.

5.1 Peripherals Setup

The major peripherals are the 24-bit sigma delta (SD24) ADC, clock system, timer, and watchdog timer (WDT).

5.1.1 SD24 Setup

As mentioned previously, the MSP430AFE25x has up to three independent sigma-delta data converters. For a single-phase system, at least two sigma-delta converters are necessary to independently measure one voltage and one current. The code accompanying this application report addresses the metrology for a single-phase system with some anti-tampering techniques. The clock to the SD24 (f_M) is derived from an 8-MHz external crystal (ACLK). The sampling frequency is defined as $f_S = f_M/OSR$. OSR is chosen as 256, and the modulation frequency f_M, is chosen as 1 MHz, resulting in a sampling frequency of 3.906 ksps. The SD24 modules are configured to generate regular interrupts every sampling instant.

The following are the SD24 channel associations:

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

5.2 Foreground Process

The foreground process includes the initial setup of the MSP430 hardware and software immediately after a device RESET. Figure 5-1 shows the flowchart for this process.

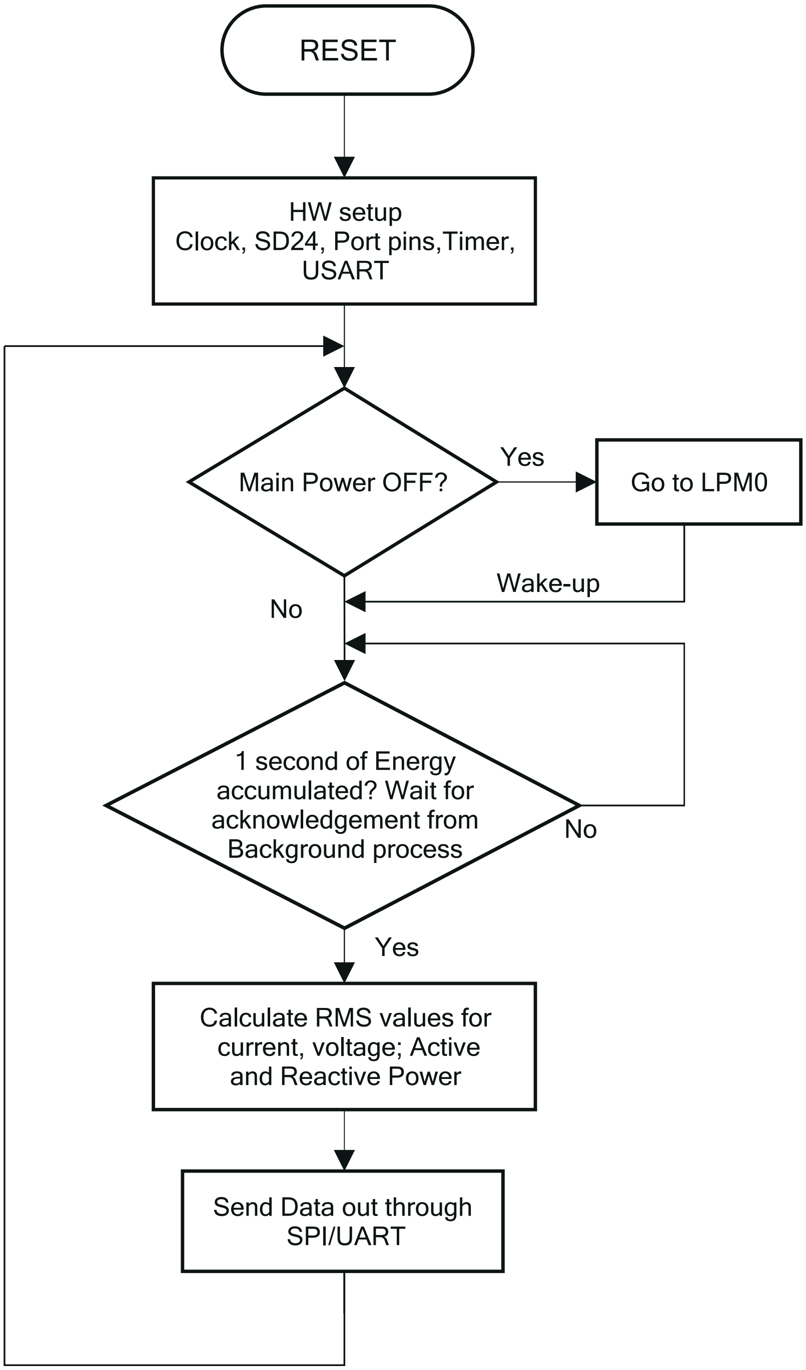


Figure 5-1. Foreground Process

The initialization routines involves the setup of the analog-to-digital converter, Clock system, general-purpose input/output (GPIO) (port) pins, timer and the USART for UART functionality. A check is made 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.

5.2.1 Formulas

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

5.2.1.1 Voltage and Current

As discussed in the previous sections, simultaneous voltage and current samples are obtained from three independent ΣΔ converters at a sampling rate of 3906 Hz. Track of the number of samples that are present in 1 second is kept and used to obtain the RMS values for voltage and current for each phase.

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

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

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

5.2.1.2 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.

$$P_{Act} = K_p \frac{\sum_{n=1}^{\text{Sample count}} v(n) \times i(n)}{\text{Sample count}}$$

$$P_{React} = K_p \frac{\sum_{n=1}^{\text{Sample count}} v_{90}(n) \times i(n)}{\text{Sample count}}$$

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, similar to the way the energy pulses are generated in the background process except that:

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

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

- It allows accurate measurement of the reactive power with very small currents.
- It conforms to international specified measurement method.

Because 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 5.3.3.

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 (see Section 5.3.2).

5.3 The Background Process

The background process uses the SD24 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. After sufficient samples (one second worth) have been accumulated, 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, and frequency and power factor calculation for each phase. Figure 5-2 shows the flow diagram of the background process.

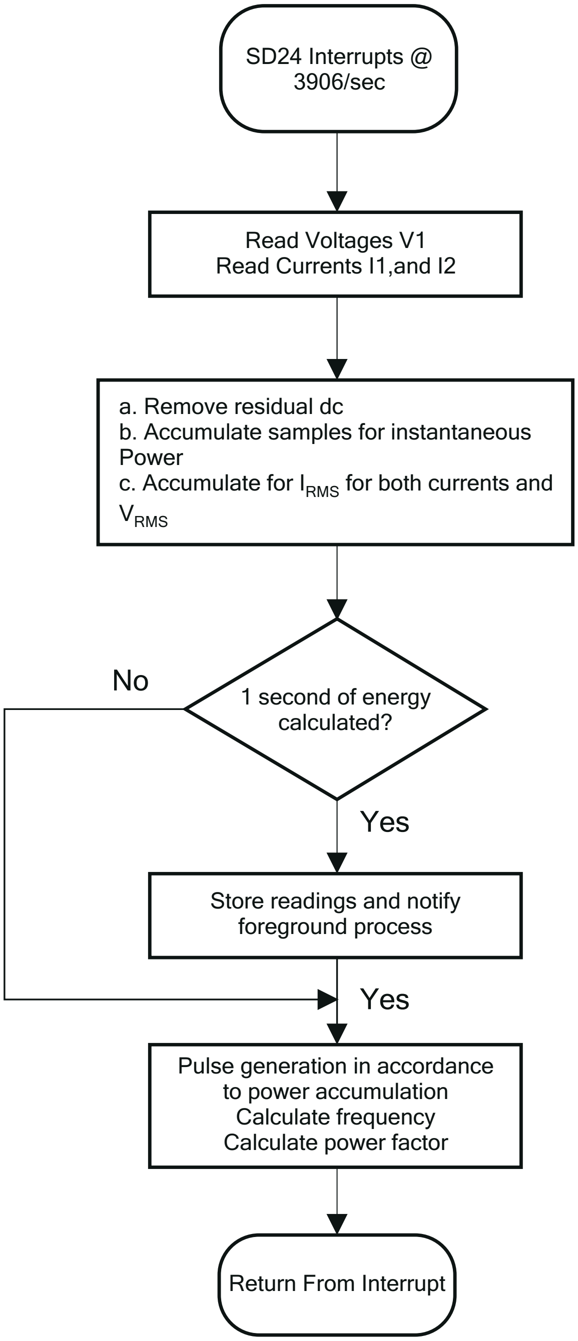


Figure 5-2. Background Process

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

5.3.1 Voltage and Current Signals

The SD24 converter has a fully differential input and, therefore, no added dc offset is needed to precondition a signal, which is the case with most single-ended converters.

The output of the SD24 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 SD24 sample. This long-term dc tracking filter is synchronized to the mains cycle to yield a 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.

5.3.2 Phase Compensation

The CT, when used as a sensor, and the input circuit's passive components together introduce an additional phase shift between the current and voltage signals that needs compensation. The SD24 converter has built-in hardware delay that can be applied to individual samples when grouped. This delay 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 5-3 shows the application of PRELOAD.

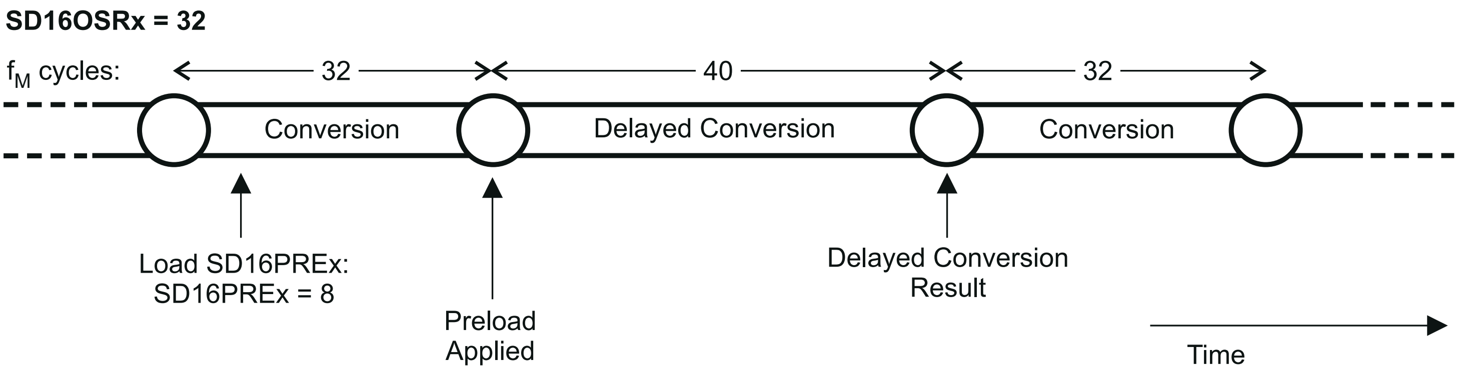


Figure 5-3. Phase Compensation Using PRELOAD Register

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

$$Delay\ resolution_{Deg} = \frac{360^o \times f_{in}}{OSR \times f_s} = \frac{360^o \times f_{in}}{f_m}$$

In this application for input frequency of 60 Hz, OSR of 256 and sampling frequency of 3906, the resolution for every bit in the preload register is approximately 0.02° with a maximum of 5.25° (maximum of 255 steps). Because the sampling of the three channels are group triggered, a method often used is to apply 128 steps of delay to all channels and then increase or decrease from this base value. This allows positive and negative delay timing to compensate for phase lead or lag. This puts the practical limit in the current design to ±2.62°. 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.

5.3.3 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 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. The sample code uses cycle boundaries to trigger the foreground averaging process, because this gives very stable results.

For frequency measurements, the sample code does a straight-line interpolation between the zero-crossing voltage samples. Figure 5-4 shows the samples near a zero crossing and the process of linear interpolation.

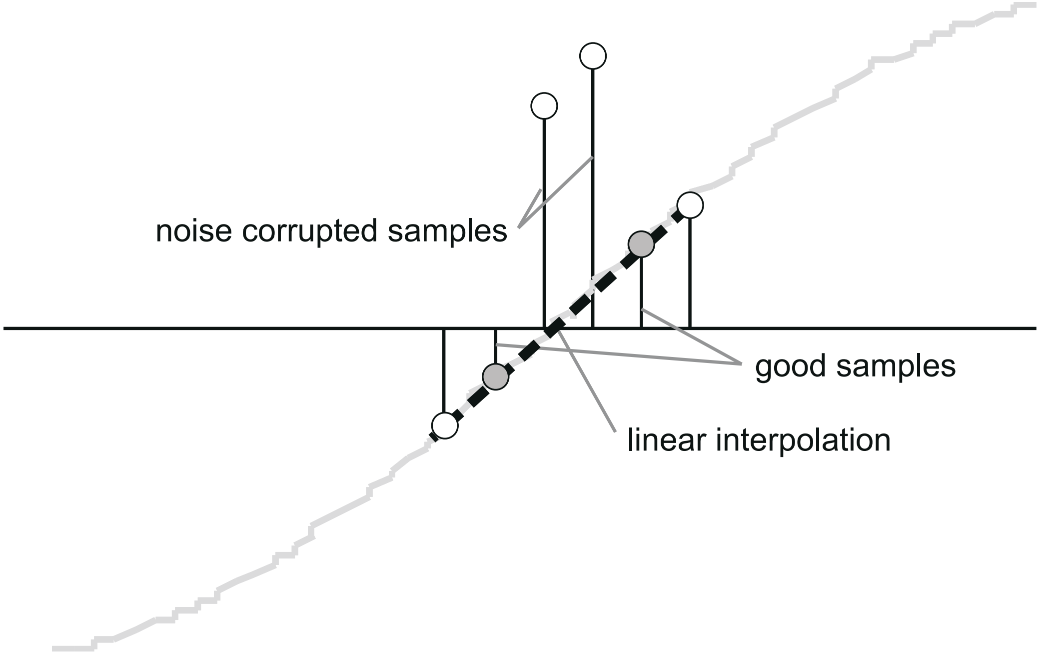


Figure 5-4. Frequency Measurement

Because noise spikes can also cause errors, the codes uses a rate-of-change check to filter out the possible erroneous signals and make sure that the points 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 were 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.

5.3.4 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 of these tasks efficiently, the microcontroller must 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 can give a negative impression of the overall accuracy of the meter.

The sample code uses the average power to generate the energy pulses. The average power (calculated by the foreground process) is accumulated every SD24 interrupt. This is equivalent to converting it to energy. After the accumulated energy crosses a threshold, a pulse is generated. The amount of energy above this threshold is stored, and new energy amount is added to 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 the power company and is a constant, for example, it 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 1600 for active and reactive energies. The energy *tick* in this case is 1 kWh/1600. 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 5-5 shows the flow diagram for pulse generation.

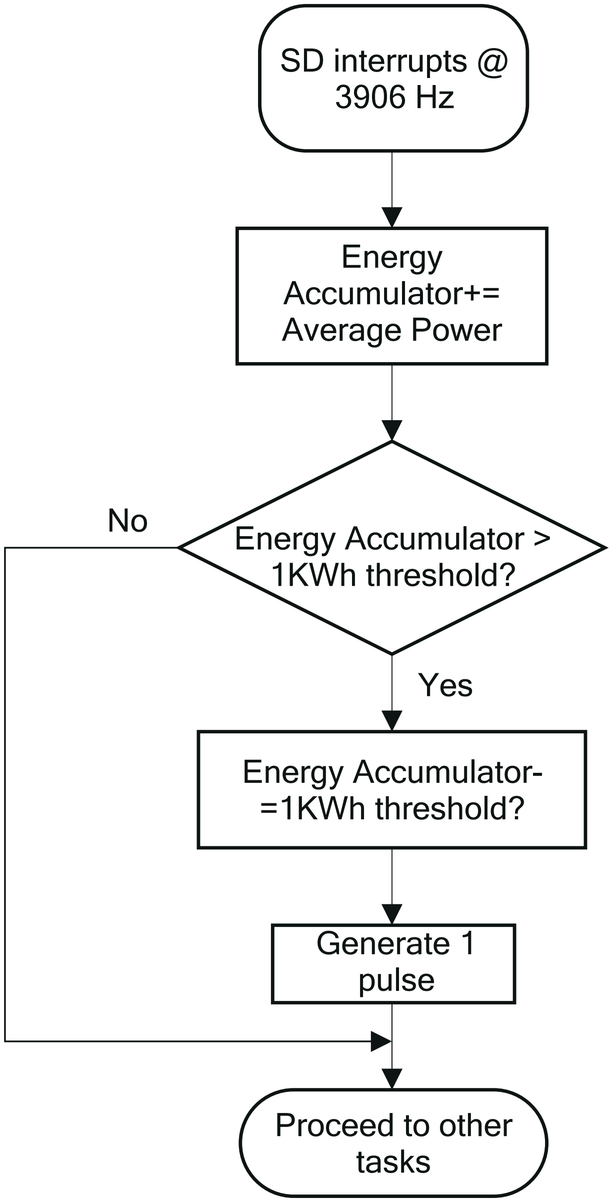


Figure 5-5. Pulse Generation for Energy Indication

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

1 kWh threshold = 1 / 0.01 × 1 kW × (number of interrupts/sec) × (number of seconds in 1 hour) = 100000 × 3906 × 3600 = 0x14765AAD400

5.4 Energy Meter Configuration

Include files are used to initialize and configure the energy meter to perform several metrology functions. Some of the user configurable options that are available are listed in this section. The file that needs modification is *emeter-1ph-bare-bones-afe.h* in the `emeter-ng` directory. It includes macro definitions that are used during the normal operation of the meter.

- MAINS_FREQUENCY_SUPPORT: The macro configures the meter to measure the frequency of the mains.
- MAINS_NOMINAL_FREQUENCY: The macro defines the default mains frequency, which is a starting point for dynamic-phase correction for nonlinear CTs or other sensors for which the phase changes with the current.

- TOTAL_ENERGY_PULSES_PER_KW_HOUR: This macro defines the total number of pulses per 1 kWh of energy. In this application, it is defined as 1600. Note that this value is not a standard, but it is widely used by many meter manufacturers. There could be a practical limit set on this number due to the reference meter's ability to accept fast pulses (due to large currents).
- ENERGY_PULSE_DURATION: This macro defines the duration of the LED ON time for an energy pulse. This is measured in ADC samples (that is, increments every 1/3906 s). The maximum allowed is 255, giving a pulse of about 62.5 ms, while 163 gives a pulse of 40 m. This duration might be too large with adjacent pulses overlapping when very high currents are measured. It is recommended that this value be changed to a smaller number such as 80 if overlap is seen at the pulse outputs.
- NEUTRAL_MONITOR_SUPPORT: This macro enables the support for neutral monitoring. The third SD24 is used for this purpose.
- VRMS_SUPPORT: This macro configures the meter to calculate V_{RMS} from the voltage samples.
- IRMS_SUPPORT: This macro configures the meter to calculate I_{RMS} from the current samples.
- REACTIVE_POWER_SUPPORT: This macro configures the meter to calculate the reactive power from the voltage and current samples.
- REACTIVE_POWER_BY_QUADRATURE_SUPPORT: This macro configures the meter to calculate the reactive power from the delayed voltage samples by 90° and current samples instead of using the power triangle method.
- APPARENT_POWER_SUPPORT: This macro configures the meter to calculate the apparent power.
- POWER_FACTOR_SUPPORT: This macro configures the meter to calculate the power factor for both lead and lag. A frequency-independent method, based on the ratio of scalar dot products, is used.
- CURRENT_LIVE_GAIN: This macro defines the gain of the SD24's internal programmable gain amplifier (PGA) for the line current. In this application it is set to 1.
- CURRENT_NEUTRAL_GAIN: This macro defines the gain of the SD24's internal PGA for neutral current monitoring. In this application it is set to 16.
- VOLTAGE_GAIN: This macro defines the gain of the SD24's internal PGA for the voltage. In this application it is set to 1.
- DEFAULT_V_RMS_SCALE_FACTOR_A: This macro holds the scaling factor for voltage at phase 1. It can be set to a value that is in an acceptable range and is fine tuned during calibration.
- DEFAULT_I_RMS_SCALE_FACTOR_A: This macro holds the scaling factor for current at phase 1. It can be set to a value that is in an acceptable range and is fine tuned during calibration.
- DEFAULT_P_SCALE_FACTOR_A_LOW: This macro holds the scaling factor for active power at phase 1. It can be set to a value that is in an acceptable range and is fine tuned during calibration.
- DEFAULT_I_RMS_SCALE_FACTOR_NEUTRAL: This macro holds the scaling factor for current at neutral. It can be set to a value that is in an acceptable range and is fine tuned during calibration.

6 Energy Meter Demo

The energy meter evaluation module (EVM) uses the MSP430AFE253 and demonstrates energy measurements. The complete demonstration platform consists of the EVM that can be easily attached to a test system, metrology software, and a PC graphical user interface (GUI), which is used to view results and perform calibration.

6.1 EVM Overview

Figure 6-1 and Figure 6-2 show the EVM hardware. Figure 6-1 is the top view of the energy meter. Figure 6-2 shows the location of various pieces of the EVM based on functionality.

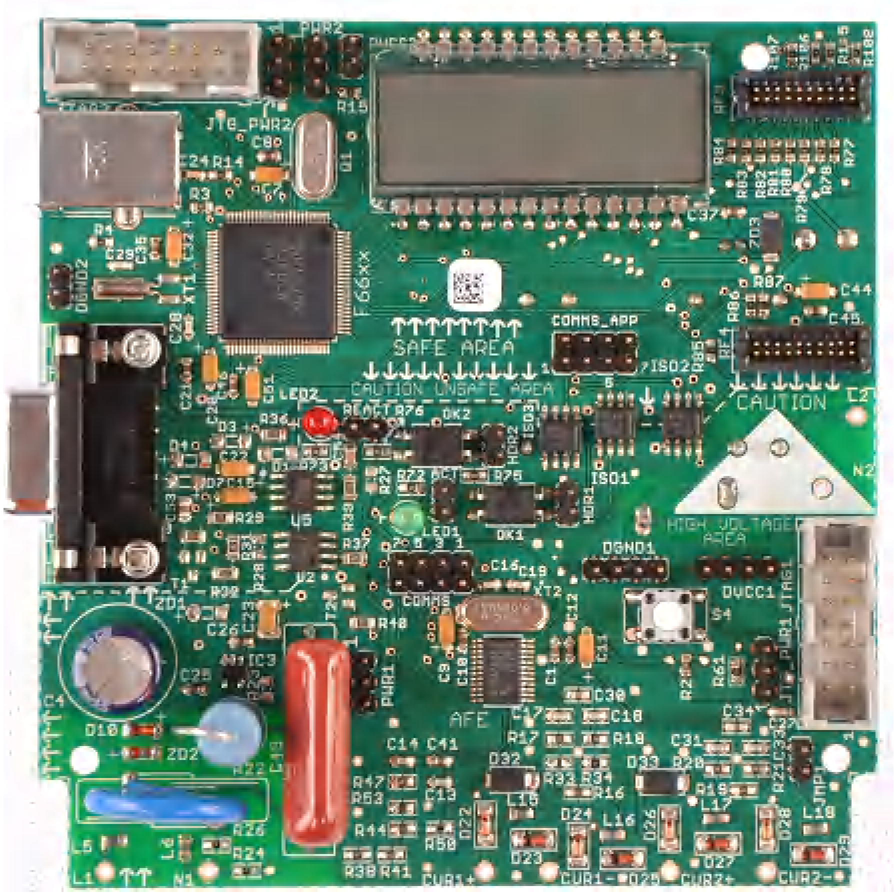


Figure 6-1. Top View of the Single-Phase Energy Meter EVM

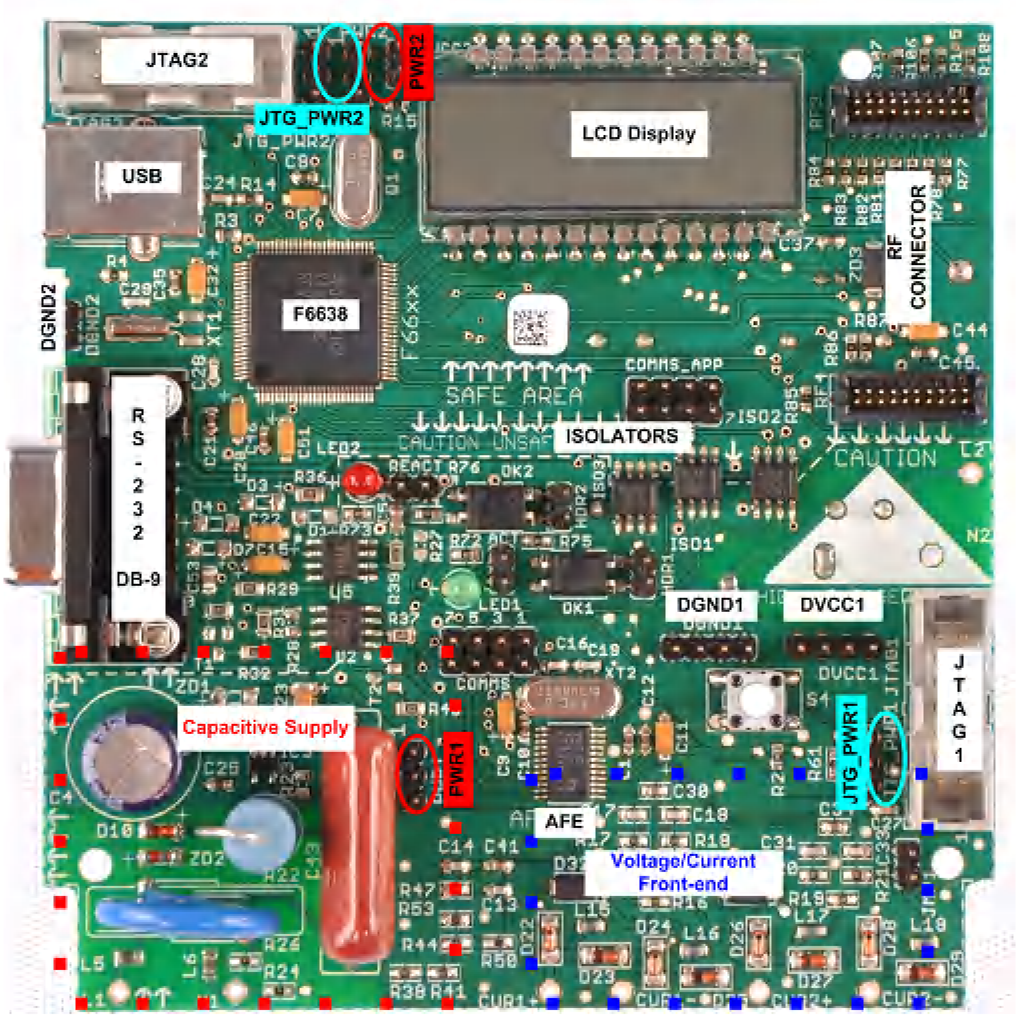


Figure 6-2. Top View of the EVM With Blocks and Jumpers

6.1.1 Connections to the Test Setup or AC Voltages

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

- L and N for voltage inputs. This can be up to 240 V ac 50/60 Hz.
- CUR1+ and CUR1- are the current inputs after the sensors. When CT or shunts are used, make sure that the voltages across CUR1+ and CUR1- do not exceed 500 mV.
- CUR2+ and CUR2- can also be used as current inputs after the sensors. When CT or shunts are used, make sure that the voltages across CUR2+ and CUR2- do not exceed 500 mV.

6.1.2 Power Supply Options

The EVM can be configured to operate with different sources for power specific to the MSP430AFE253 and the MSP430F6638. The various sources of power to the MSP430 devices are JTAG, mains voltage, and external power. Table 6-1 lists the header settings for the power options of the MSP430AFE253 only.

Table 6-1. Power Supply Selection for MSP430AFE253

Power Option	JTG_PWR1	PWR1
JTAG	Jumper on [1-2]	No jumper
Mains supply	No jumper	Jumper on [1-2]
External power	No jumper	Jumper on [1-2]

If JTAG debugging is necessary with external power is ON, the jumper on [2-3] on JTG_PWR1 must be placed in addition to the jumper on PWR1. External power can be provided directly between the DV_{CC1} and DGND1 headers.

When powered by the mains supply, the PWR1 header can also be treated as a current consumption header by placing an ammeter across it. Also, when powered via JTAG, the current consumption header is no longer PWR1; instead, the ammeter can be connected across [1-2] of header JTAG_PWR1.

Table 6-2 lists the header settings for the power options of the MSP430F6638 only.

Table 6-2. Power Supply Selection for MSP430F6638

Power Option	JTG_PWR2	PWR2
JTAG	Jumper on [1-2]	No jumper
Mains supply	No jumper	Jumper on [1-2]
External power	No jumper	Jumper on [2-3]

JTAG debugging is necessary with external power is ON. In addition, to jumper on PWR1, jumper on [2-3] on JTG_PWR1 must be placed. External power can be provided directly between DV_{CC2} and DGND2 headers. In addition for USB power option for the entire board, R15 must be populated and jumper be placed on PWR2 at position [2-3].

When powered by the mains supply PWR2 header can also be treated as a current consumption header by placing an ammeter across. Also, when powered via JTAG, the current consumption header will be no longer PWR2, instead the ammeter can be connected across [1-2] of header JTAG_PWR2.

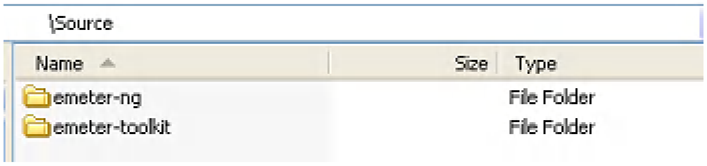
6.2 Loading the Example Code

The source code is developed in the IAR™ IDE using IAR compiler version 6.x. The project files cannot be opened in earlier versions of IAR. If the project is loaded in a version later than 6.x, a prompt to create a backup is displayed, 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.
- The main code that has the source and include files.

6.2.1 Opening the Project

The Source folder structure is shown in Figure 6-3.



\Source

Name	Size	Type
emeter-ng		File Folder
emeter-toolkit		File Folder

Figure 6-3. Source Folder Contents

The `emeter-ng` folder contains project files; for this application, use the *EVM_AFE253.ewp* project file. The `emeter-toolkit` folder has a corresponding project file named *emeter-toolkit-afe2xx.ewp*. For first time use, it is recommended that you complete rebuild of both projects:

1. Open IAR Embedded Workbench®, find and load the project *emeter-toolkit-afe2xx.ewp*, and rebuild all (see Figure 6-4).

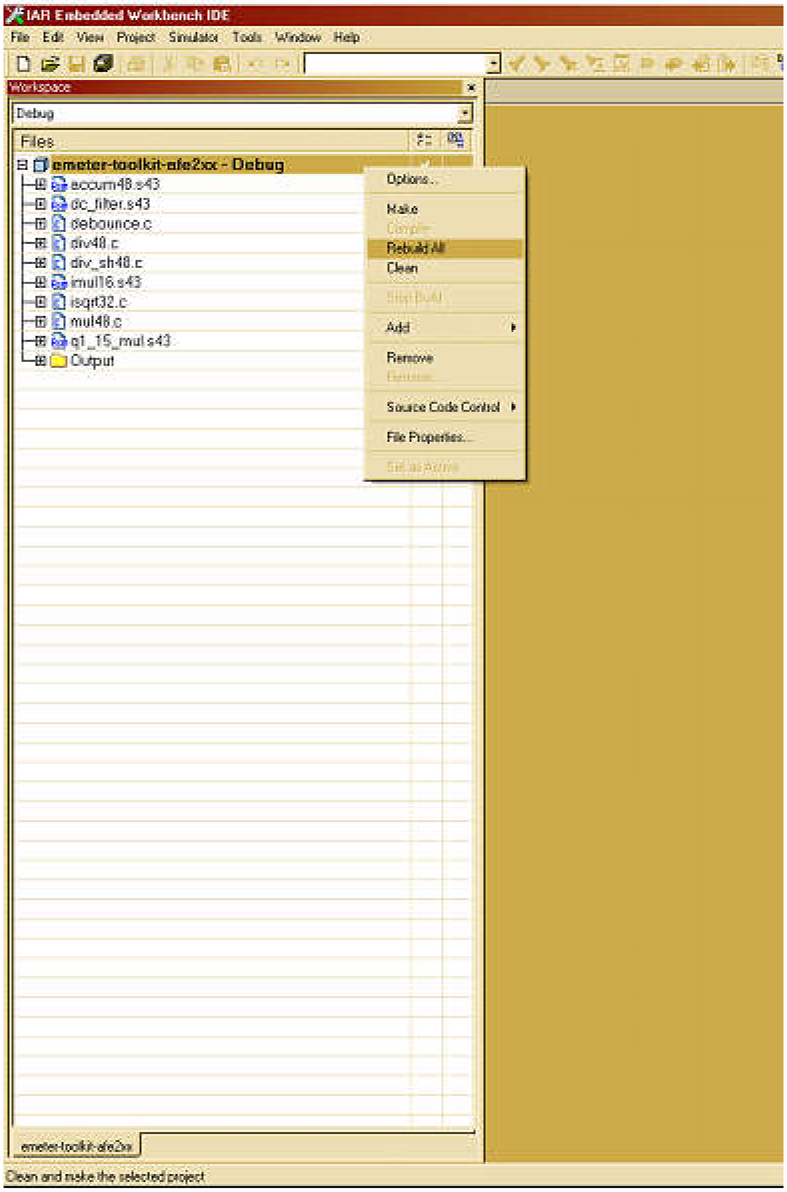


Figure 6-4. Toolkit Compilation in IAR

2. Close the existing workspace and open the main project *EVM_AFE253.ewp*, rebuild all and load this onto the MSP430AFE253 (see Figure 6-5).

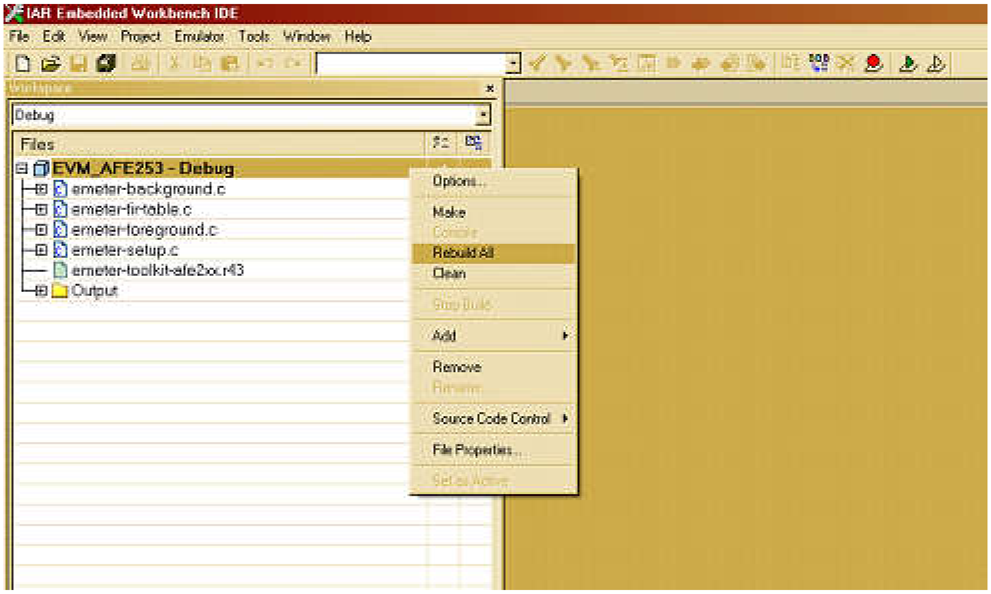


Figure 6-5. Metrology Project Build in IAR

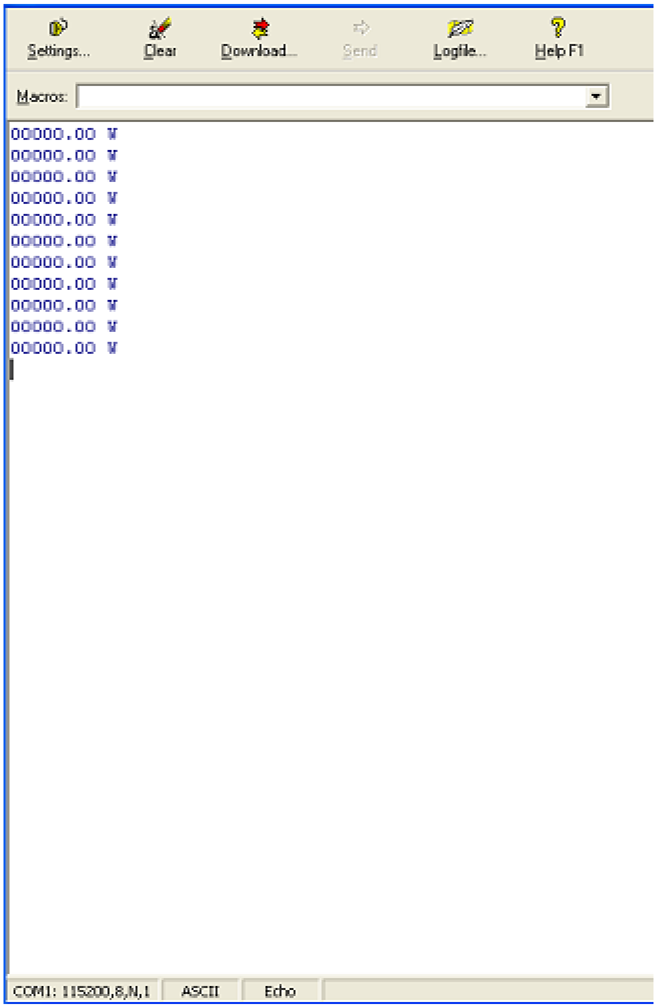
3. Load it onto the EVM and hit GO from the Debug menu, once the main project has been rebuilt.

7 Results

If the procedures and configurations described in Section 5 and Section 6 are complete, the results can be observed.

7.1 Viewing Results on PC

After the meter is turned ON, the results can be viewed using the supplied GUI. Connect the RS-232 header on the EVM to the PC using a DB-9 RS-232 serial cable. Open a terminal program to see a report similar to Figure 7-1. The baud rate settings of the UART are user configurable and are set to 115 kbps by default.



```
00000.00 W
00000.00 W
00000.00 W
00000.00 W
00000.00 W
00000.00 W
00000.00 W
00000.00 W
00000.00 W
00000.00 W
00000.00 W
```

COM1: 115200,8,N,1 | ASCII | Echo

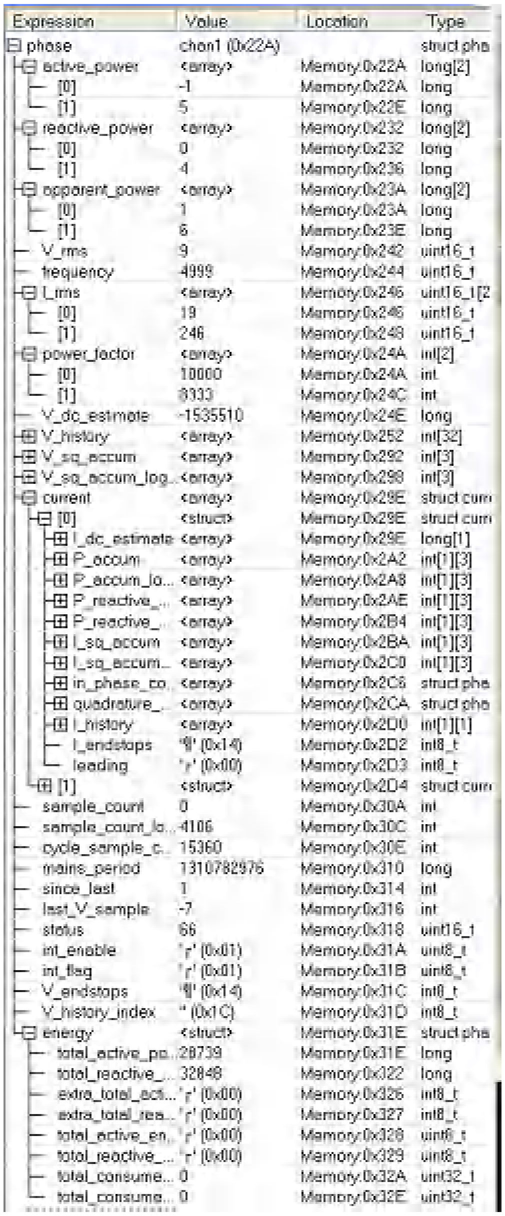
Figure 7-1. Results Via UART Communication to PC

This is the active power consumption being displayed approximately every second. When a test signal is connected, a non-zero value is reported.

7.2 Viewing Results During Debug

During debug, if a breakpoint is placed at appropriate locations in code, the results can be viewed in the watch window. A structure named phase is defined for this purpose.

The structure details are shown in Figure 7-2.



Expression	Value	Location	Type
⊟ phase	chan1 (0x22A)		struct pha
⊟ active_power	<array>	Memory:0x22A	long[2]
[0]	-1	Memory:0x22A	long
[1]	5	Memory:0x22E	long
⊟ reactive_power	<array>	Memory:0x232	long[2]
[0]	0	Memory:0x232	long
[1]	4	Memory:0x236	long
⊟ apparent_power	<array>	Memory:0x23A	long[2]
[0]	1	Memory:0x23A	long
[1]	6	Memory:0x23E	long
V_rms	9	Memory:0x242	uint16_t
frequency	4999	Memory:0x244	uint16_t
⊟ I_rms	<array>	Memory:0x246	uint16_t[2
[0]	19	Memory:0x246	uint16_t
[1]	246	Memory:0x248	uint16_t
⊟ power_factor	<array>	Memory:0x24A	int[2]
[0]	10000	Memory:0x24A	int
[1]	8333	Memory:0x24C	int
V_dc_estimate	-1535510	Memory:0x24E	long
⊞ V_history	<array>	Memory:0x252	int[32]
⊞ V_sq_accum	<array>	Memory:0x292	int[3]
⊞ V_sq_accum_log...	<array>	Memory:0x298	int[3]
⊟ current	<array>	Memory:0x29E	struct curr
⊟ [0]	<struct>	Memory:0x29E	struct curr
⊞ I_dc_estimate	<array>	Memory:0x29E	long[1]
⊞ P_accum	<array>	Memory:0x2A2	int[1][3]
⊞ P_accum_lo...	<array>	Memory:0x2A8	int[1][3]
⊞ P_reactive_...	<array>	Memory:0x2AE	int[1][3]
⊞ P_reactive_...	<array>	Memory:0x2B4	int[1][3]
⊞ I_sq_accum	<array>	Memory:0x2BA	int[1][3]
⊞ I_sq_accum...	<array>	Memory:0x2C0	int[1][3]
⊞ in_phase_co...	<array>	Memory:0x2C6	struct pha
⊞ quadrature_...	<array>	Memory:0x2CA	struct pha
⊞ I_history	<array>	Memory:0x2D0	int[1][1]
I_endstops	'¶' (0x14)	Memory:0x2D2	int8_t
leading	'ŗ' (0x00)	Memory:0x2D3	int8_t
⊞ [1]	<struct>	Memory:0x2D4	struct curr
sample_count	0	Memory:0x30A	int
sample_count_lo...	4106	Memory:0x30C	int
cycle_sample_c...	15360	Memory:0x30E	int
mains_period	1310782976	Memory:0x310	long
since_last	1	Memory:0x314	int
last_V_sample	-7	Memory:0x316	int
status	66	Memory:0x318	uint16_t
int_enable	'ŗ' (0x01)	Memory:0x31A	uint8_t
int_flag	'ŗ' (0x01)	Memory:0x31B	uint8_t
V_endstops	'¶' (0x14)	Memory:0x31C	int8_t
V_history_index	'' (0x1C)	Memory:0x31D	int8_t
⊟ energy	<struct>	Memory:0x31E	struct pha
total_active_po...	28739	Memory:0x31E	long
total_reactive_...	32848	Memory:0x322	long
extra_total_acti...	'ŗ' (0x00)	Memory:0x326	int8_t
extra_total_rea...	'ŗ' (0x00)	Memory:0x327	int8_t
total_active_en...	'ŗ' (0x00)	Memory:0x328	uint8_t
total_reactive_...	'ŗ' (0x00)	Memory:0x329	uint8_t
total_consume...	0	Memory:0x32A	uint32_t
total_consume...	0	Memory:0x32E	uint32_t

Figure 7-2. Results Structure During Debug

8 Important Notes

- This document is preliminary and is subject to change when the next board revision is made available.
- Never use the mains at the same time as debug, unless you are using isolated-FET USB FETs.
- The MSP430AFE and the MSP430F6638 have two different GND planes, and this needs to be maintained if PC communication is done via USB.
- The first revision of the software does not include any projects on the MSP430F6638, but these will be added in the future.
- Two LEDs on the board, one for active and the other for reactive, are present to test the accuracy of the meter via pulse generation.
- The same pulses are also available on headers ACT_PUL and REACT_PUL. However, these pulses on the header are not isolated. For isolated pulses, use the header HDR1 and HDR2, instead.
- The board is not supplied with current sensors. You must ensure sensors are connected before making connections to CUR1 and CUR 2 points on the lower side of the EVM.

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. Texas Instruments is not responsible or liable in any way for shock, injury, or damage caused due to negligence or failure to heed advice.

9 Schematics

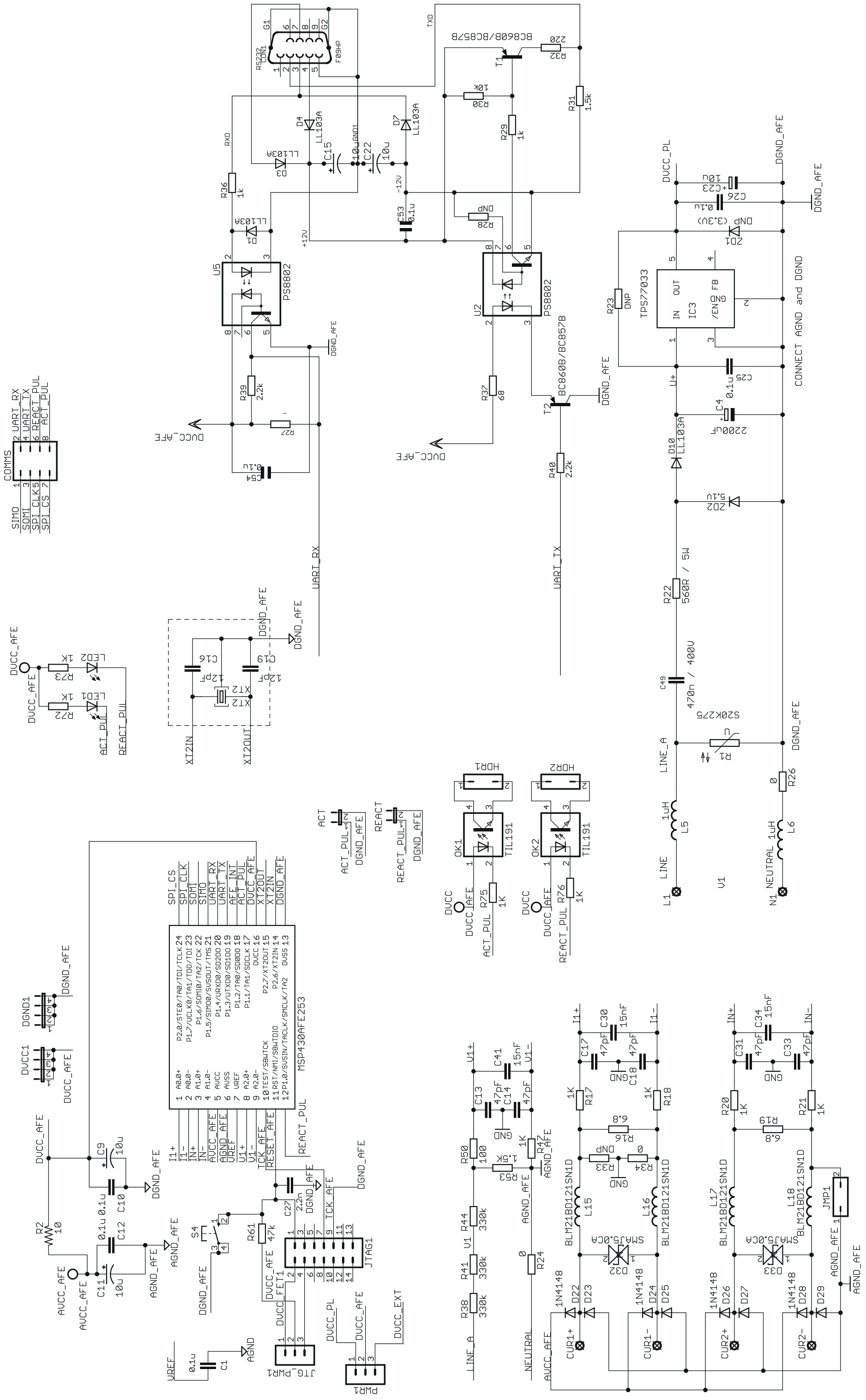


Figure 9-1. Schematic 1

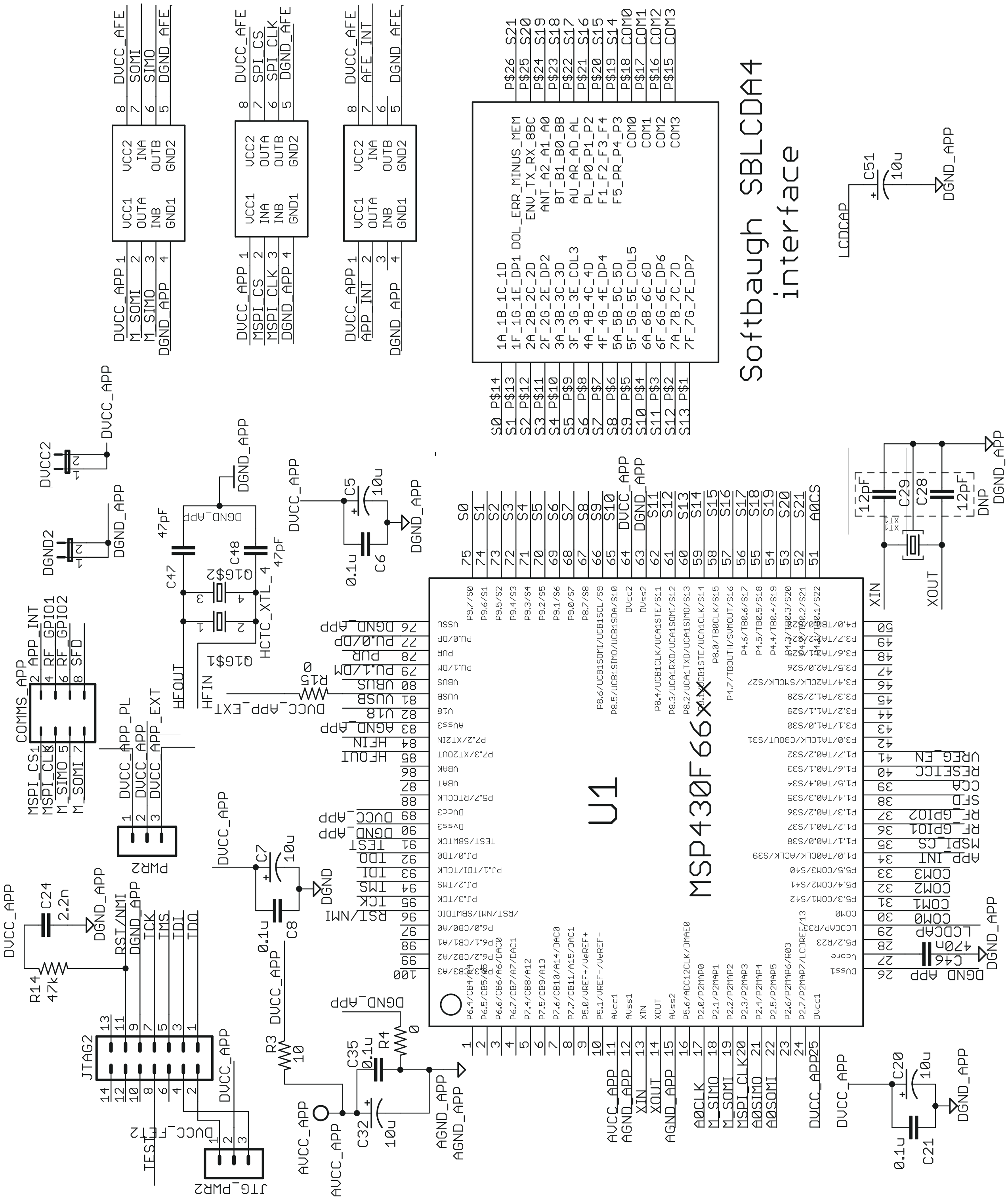


Figure 9-2. Schematic 2

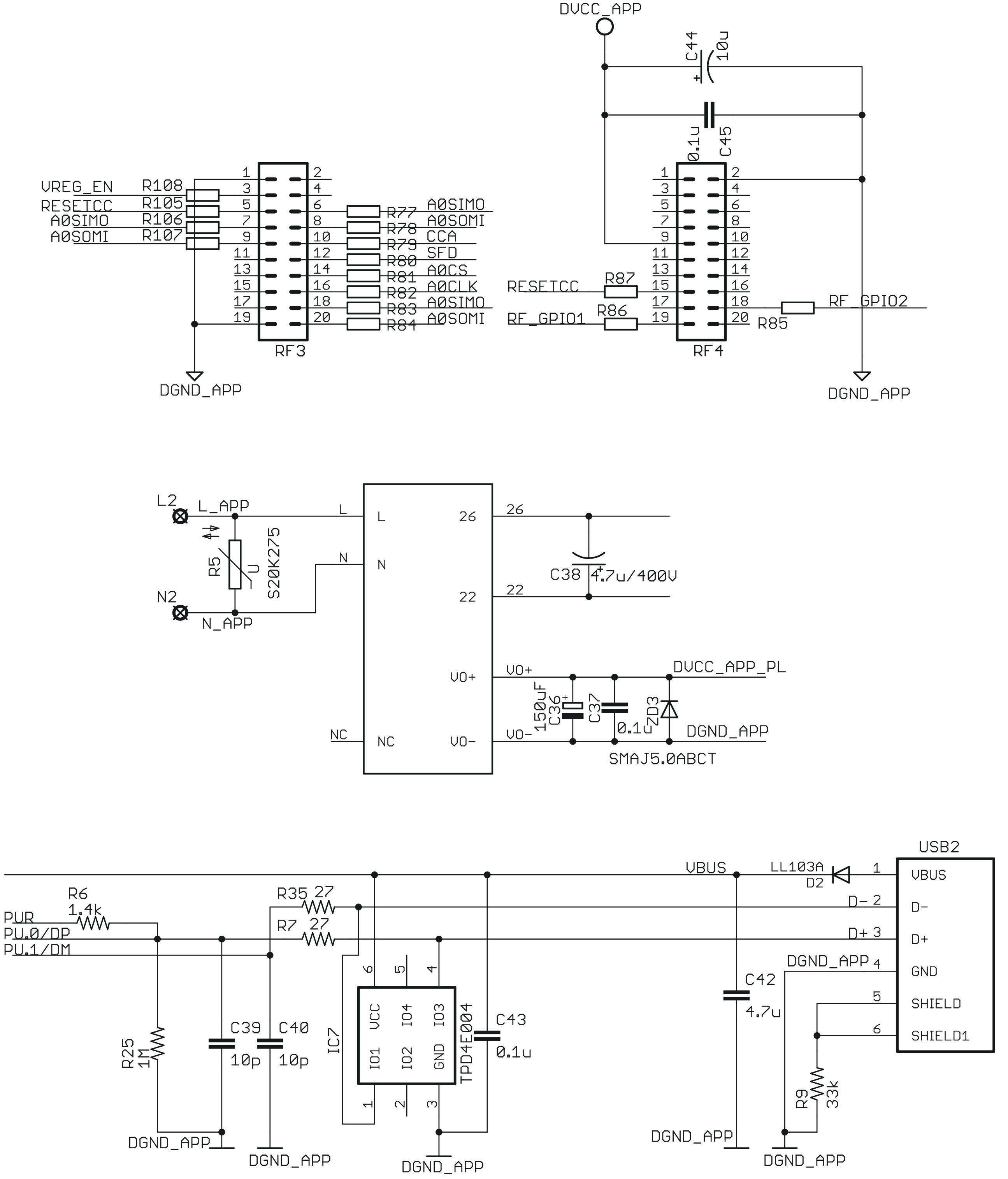


Figure 9-3. Schematic 3

10 References

- Texas Instruments, *MSP430x2xx Family User's Guide*

11 Revision History

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

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