AMC-ADC-1PH-EVM Evaluation Module

Description

The AMC-ADC-1PH-EVM is a single-phase energy meter using standalone isolated multichannel analog to-digital converters (ADC) to sample a shunt current sensor. The evaluation module (EVM) achieves 0.5% accuracy across the input range (50mA–15A) with a 4kHz sampling rate and uses a TI Arm® Cortex®-M0+ host microcontroller (MCU) for calculating the metrology parameters. The necessary software functionality is implemented in MSPM0-SDK and can be compiled with TI's Code Composer Studio™.

Get Started

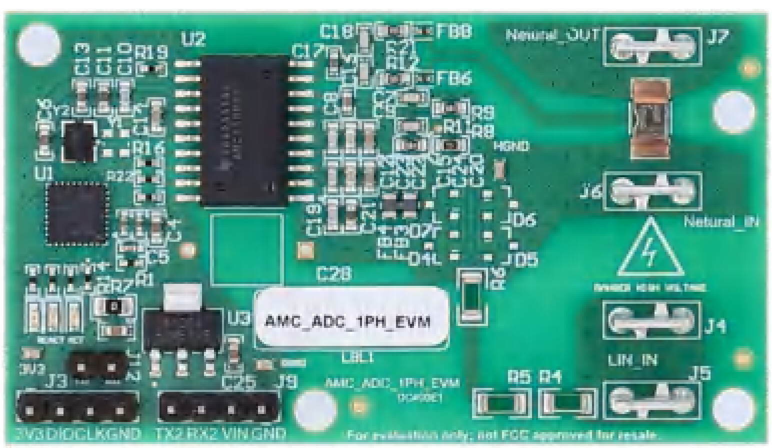
1. Order the AMC-ADC-1PH-EVM.
2. Download the Energy Metrology Library software and Microsoft®Windows® PC GUI.
3. Evaluate performance on the bench.

Features

- Single-phase class 0.5% accuracy across the input range (50mA–15A) with 4kHz sampling rate
- Calculated parameters include active and reactive energy and power, root mean square (RMS) current, RMS voltage, power factor, and line frequency
- Energy metrology software with pulsed outputs to a reference test system including results displaying on a Microsoft® Windows® PC GUI
- Flexibility in combining metrology MCU and ADC for various performance points

Applications

- Electricity meter
- Major appliances
- Small home appliances
- Heat pump
- Lighting



1 Evaluation Module Overview

1.1 Introduction

Throughout this document, the abbreviation *EVM* and the term *evaluation module* are synonymous with the AMC-ADC-1PH-EVM. This document includes how to set up and evaluate the EVM, the printed circuit board (PCB) layout, schematics, and bill of materials (BOM).

1.2 Kit Contents

The contents included in the AMC-ADC-1PH-EVM kit are:

- (1) AMC-ADC-1PH-EVM

1.3 System Description

The AMC-ADC-1PH-EVM has the properties described in Section 1.3.1 through Section 1.3.3.

1.3.1 Key System Specifications

FEATURES	DESCRIPTION
Number of phases	1 phase (current measured through a SHUNT), single voltage through a resistor divider
Accuracy class	< 0.5%
Dynamic range	50mA to 15A
Current Sensor	SHUNT
Tested current range	50mA to 15A
Tested voltage range	100V to 240V
AMC130M02 CLKIN frequency	8.192MHz
Oversampling ratio (OSR)	1024
Digital filter output sample rate	4000 samples per second (default) (adjustable per register setting)
Phase compensation implementation	Software
Selected central processing unit (CPU) clock frequency	79.87MHz
System nominal frequency	50Hz or 60Hz
Measured parameters	• Active, reactive, apparent power and energy • Root mean square (RMS) current and voltage • Power factor • Line frequency
Update rate for measured parameters	Approximately equal to 1 second
Communication options	PC graphical user interface (GUI) with a universal asynchronous receiver-transmitter (UART)
Utilized light emitting diodes (LED)	2 LEDs: Active energy and reactive energy
Board power supply	3.3V to 16V

1.3.2 End Equipment

As industries transition to clean, net-zero electricity systems, governments are taking important steps towards creating smart and flexible electricity systems, by helping unlock the potential for consumers to benefit from using smart technology to shift *when* electricity is used. The decisions help make sure consumers can use a wider range of services and devices in homes and small businesses to manage electricity consumption and reduce bills. For example, HVAC system heat pumps can be used or heated during the times when electricity is cheapest. An electricity meter can be used here for the following benefits:

- Use electricity meter to calculate the power consumption of the end equipment, show the data to the consumer, thus allowing the consumer to know the basic power information of the end equipment.
- Electricity meter with real-time clock (RTC) function: automatically heat or charge the end equipment when electricity is cheapest
- Electricity meter is also a power monitor, to inform the consumer if the end equipment is working normally

1.3.3 Electricity Meter

Different end equipments have different requirements for electricity meters; for example, multiphase or single-phase, accuracy, and isolated or non-isolated. This reference design is developed for an isolated single-phase design using isolated ADC AMC130M02, and integrates power and data isolation, with the following advantages:

- Meets the most stringent of accuracy requirements
- Meets minimum sample rate requirements (without compromising on accuracy) that is sometimes not obtainable with application-specific products or metrology systems on a chip (SoC)
- Enables flexibility in selecting the host MCU, based on the application requirements, such as the following:
  - Processing capability in million instructions per second (MIPS)
  - Minimum random access memory (RAM) and flash area
  - Number of communications modules:
    - Serial peripheral interface (SPI)
    - Universal asynchronous receiver - transmitter (UART)
    - Inter-integrated circuit (I2C)
    - Real-time clock (RTC)
    - Continuously transposed conductors (CRC) module

AMC-ADC-1PH-EVM is a high-accuracy one-phase SHUNT electricity meter design, using two channels for standalone isolated AMC130M02 ADC and cost-effective MSPM0C1105 MCU. One channel is for SHUNT resistor current sensing and another channel is for voltage sensing.

The AMC-ADC-1PH-EVM firmware specifically supports calculation of various metrology parameters for single-phase with Neural line energy measurement. These parameters can be viewed from the calibration GUI or through the ACT and REACT pulsed outputs, connected to a reference metrology test system.

- Phase active (kWh), reactive (kvarh), and apparent energy (kVAh) with pulse-generation outputs
- Phase active (kW), reactive (kvar), and apparent power (kVA)
- Phase voltage and current root mean square (RMS)
- Power factor
- Line frequency

1.4 Device Information

The AMC-ADC-1PH-EVM is designed to provide ease-of-use and high accuracy electricity metering. The AMC130M02 is an isolated ADC intended for e-metering applications with reinforced isolation and an integrated DC/DC converter. This isolated ADC has two channels that can measure voltage and current for a single phase. This EVM also features a low cost MSPM0C1105 with metrology firmware, as well as other TI components for clocking (LMK6C and CDC6CE) and power regulation (TLV76133).

2 Hardware

2.1 System Overview

2.1.1 Block Diagram

Figure 2-1 shows that for voltage sensing, the choice of voltage divider resistors for the voltage channel is selected to make sure the Mains voltage is divided down to adhere to the normal input ranges of the AMC130M02 device. Since the AMC130M02 ADCs have a large dynamic range and a large dynamic range is not needed to measure voltage, the voltage front-end circuitry is purposely selected so that the maximum voltage seen at the inputs of the voltage channel ADCs are only a fraction of the full-scale voltage. By reducing the voltage fed to the AMC130M02 voltage ADC, voltage-to-current crosstalk, which actually affects metrology accuracy more than voltage ADC accuracy, is reduced at the cost of voltage accuracy. For current sensing, a SHUNT resistor is selected based on the current range required for energy measurements and also the minimization of the maximum power dissipation of the shunt.

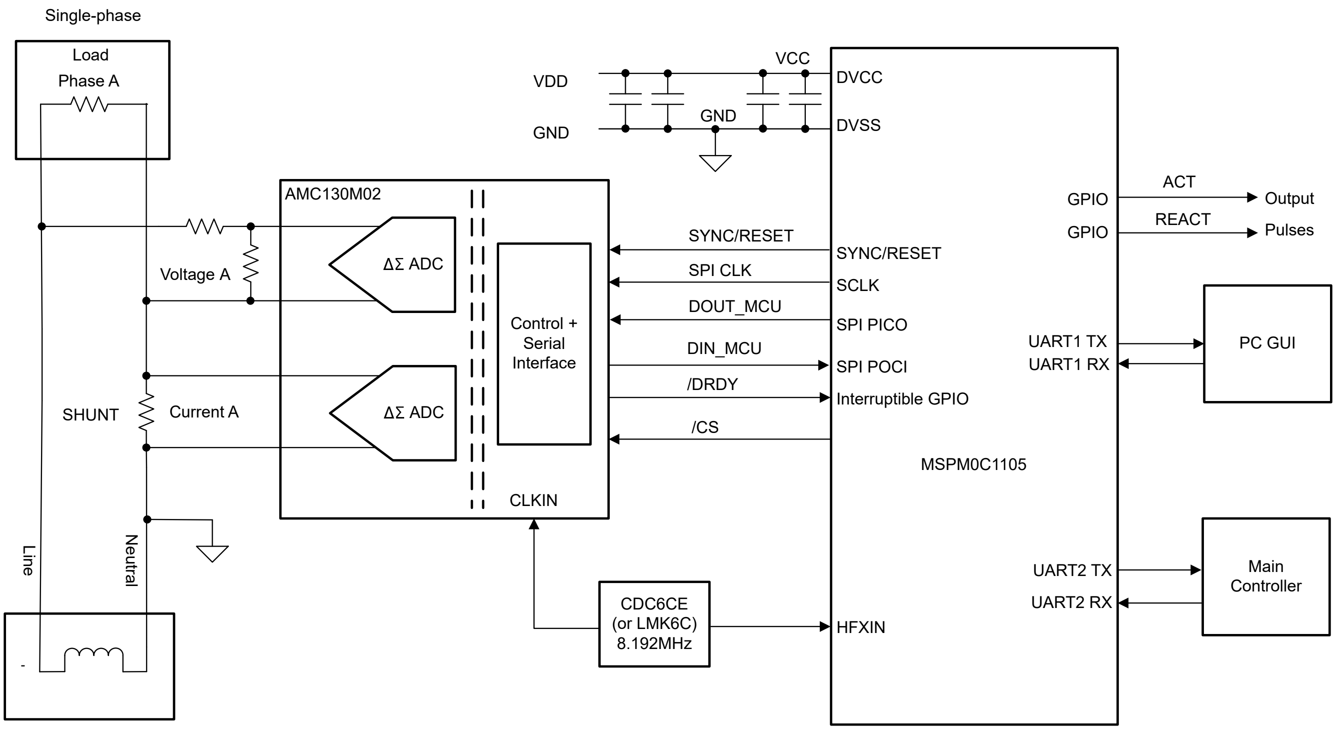


Figure 2-1. AMC-ADC-1PH-EVM Block Diagram

In this design, the AMC130M02 device interacts with MSPM0 MCU in the following manner:

1. The clock for both MSPM0 and AMC130M02 are from the same oscillator.
2. When new ADC samples are ready, the AMC130M02 device asserts the DRDY pin, which alerts the MSPM0 MCU that new samples are available.
3. After being alerted of new samples, the MSPM0 MCU uses one of the SPIs and the DMA to get the voltage and current samples from the AMC130M02 device
4. In addition, the MCU also communicates to a PC GUI through UART connection on J12.
5. ACT and REACT output signals from the MCU represent the active and reactive energy pulses used for measuring energy consumption.

2.1.2 Design Considerations

2.1.2.1 Voltage Measurement - Analog Front End

The nominal voltage from the mains in many regions of the world varies from 100V to 240V, so the voltage needs to be scaled down to be sensed by an ADC. Figure 2-2 shows the analog front end for the voltage scaling.

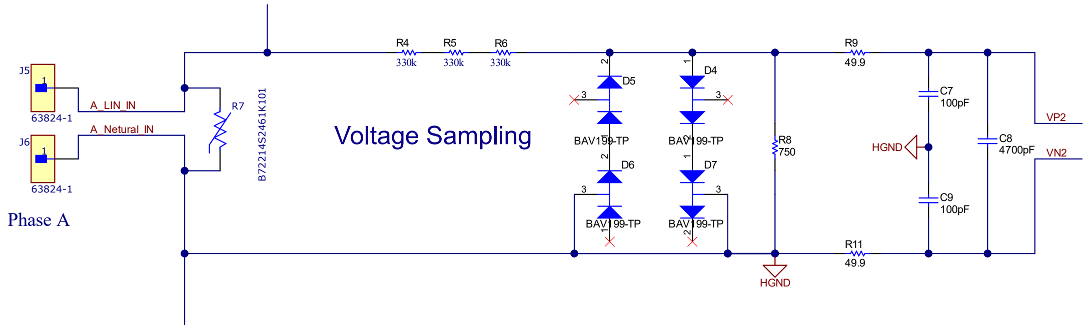


Figure 2-2. Analog Front End for Voltage Input

The analog front end for voltage input has a voltage divider network (R4, R5, R6, R8), and RC low-pass filter (R9, R11, C7, C9, and C8).

If offset calibration is not performed, the voltage-to-current crosstalk affects active energy accuracy much more than voltage accuracy when the current is low. To maximize the accuracy at lower currents, in this design the entire ADC range is not used for the voltage channel. The reduced ADC range for the voltage channels in this design still provide more than enough accuracy for measuring voltage. Equation 1 shows how to calculate the range of differential voltages fed to the voltage ADC channel for a given Mains voltage and selected voltage divider resistor values.

$$V_{ADC_{Swing}, Voltage} = \pm V_{RMS} \times \sqrt{2}\left(\frac{R_8}{R_4 + R_5 + R_6 + R_8}\right) \quad (1)$$

Based on this formula and selected resistor values in Figure 2-2, for a main voltage of 230V, the input signal to the voltage ADC has a voltage swing of ±246mV (174mV$_{RMS}$). The ±246mV voltage ranges are well within the AMC130M02's input range.

2.1.2.2 Current Measurement - Analog Front End

Figure 2-3 shows how the current input analog front end is different from voltage analog front end.

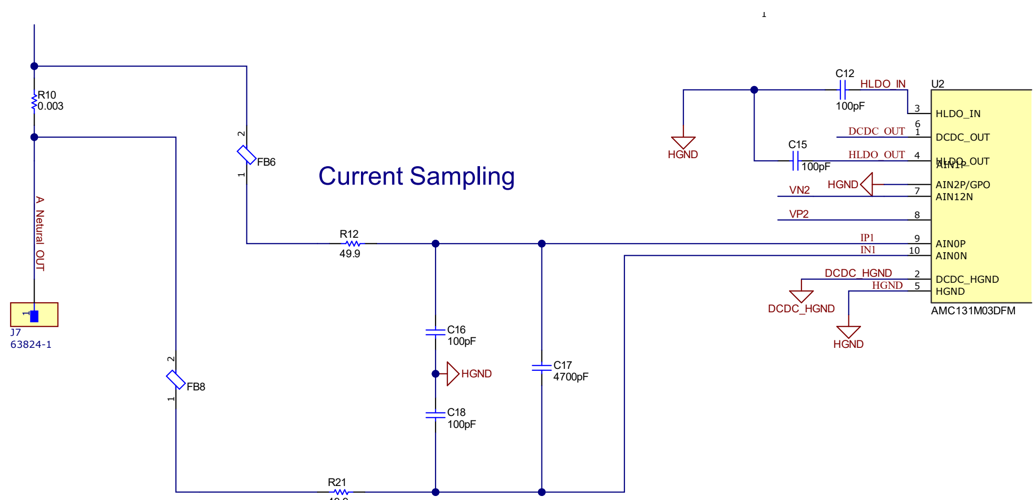


Figure 2-3. Analog Front End for Current Input

The analog front end for current consists of footprints for electromagnetic interference filter beads (FB6 and FB8), and a RC low-pass filter (R12, R21, C16, C18).

Equation 2 shows how to calculate the range of differential voltages fed to the current ADC channel for a given maximum current, and shunt resistor value.

$$V_{ADC_{Swing}, Current, Shunt} = \pm \sqrt{2} R_{shunt} I_{RMS, max} \quad (2)$$

A SHUNT value of 3mΩ is used, the input signal to the current ADC has a voltage swing of ±63.6mV, 63.6mV when the current rating of the meter (15A) is applied. This relatively low voltage, when using GAIN = 16 is well within the required Full-Scale Range of ±75mV. See also the *full-scale range table* in the *AMC130M02 2-Channel, 64kSPS, Simultaneous-Sampling, 16-Bit, Reinforced Isolated Delta-Sigma ADC With Integrated DC/DC Converter* data sheet.

Table 2-1. Full-Scale Range

GAIN SETTING	FSR
1	±1.2V
2	±600mV
4	±300mV
8	±150mV
16	±75mV
32	±37.5mV
64	±18.75mV
128	±9.375mV

2.1.2.3 Input Voltage

Figure 2-4 shows the input power supply to meet a wider input power rail from the main controller, this design uses a linear voltage regulator TLV76133, which supports 2.5V to 16V input voltage and provides a stable 3.3V output to MSPM0 and AMC130M02.

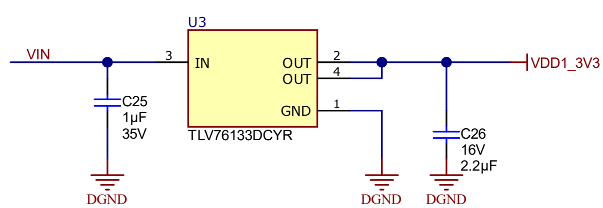


Figure 2-4. Input Power Supply

3 Software

This section discusses the features of the test software and provides insight on how the calculation of many metrology parameters are implemented. The metrology software used for testing the AMC-ADC-1PH-EVM is derived from the TIDA-010960 middleware example in the latest MSPM0 SDK, *Version 2.01.00.03 or later*.

The middleware contains hardware abstraction layers which enable communication between the standalone ADCs and an Arm Cortex-M0+ MCU and a library of metrology calculations for energy measurements. A Microsoft Windows PC GUI software is used to display metrology parameters from the EVM and can be found in MSPM0-SDK, see the /tools directory under C:\ti\mspm0_sdk_2_01_00_03\tools\metrology_gui.

The resource utilization of the middleware code example, using optimization setting of 2 are:

- 33232 Bytes FLASH for Application code
- 256 Bytes FLASH for calibration data
- 9090 Bytes RAM memory

3.1 Metrology Overview

3.1.1 Metrology Formulas

This section briefly describes the formulas used for the voltage, current, power, and energy calculations. As previously described, voltage and current samples are obtained at a sampling rate of 4kHz. All of the samples that are taken in approximately one second frames are kept and used to obtain the RMS values for voltage and current. The RMS values are obtained with the following formulas.

$$V_{RMS,\,ph} = K_{v,\,ph} \times \sqrt{\frac{\sum_{n=1}^{\text{Sample count}} V_{ph}(n) \times V_{ph}(n)}{\text{Sample Count}}} - V_{offset,\,ph} \quad (3)$$

$$I_{RMS,\,ph} = K_{i,\,ph} \times \sqrt{\frac{\sum_{n=1}^{\text{Sample count}} I_{ph}(n) \times I_{ph}(n)}{\text{Sample Count}}} - I_{offset,\,ph} \quad (4)$$

where

- $V_{ph}(n)$ = 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 *n*
- $I_{offset,ph}$ = Offset used to subtract effects of the additive white Gaussian noise from the current converter
- Sample count = Number of samples within the present frame
- $K_{v,ph}$ = Scaling factor for voltage
- $K_{i,ph}$ = Scaling factor for current

Power and energy are calculated for active and reactive energy samples of one frame. These samples are phase-corrected and passed on to the foreground process, which uses the number of samples (sample count) to calculate phase active and reactive powers through the following formulas:

$$P_{ACT,\,ph} = K_{ACT,\,ph}\frac{\sum_{n=1}^{\text{Sample count}} V_{ph}(n) \times I_{ph}(n)}{\text{Sample Count}} - P_{ACT_{Offset},\,ph} \quad (5)$$

$$P_{REACT,\,ph} = K_{REACT,\,ph}\frac{\sum_{n=1}^{\text{Sample count}} V_{90,\,ph}(n) \times I_{ph}(n)}{\text{Sample Count}} - P_{REACT_{Offset},\,ph} \quad (6)$$

$$P_{APP,\,ph} = \sqrt{P_{ACT,\,ph}^2 + P_{REACT,\,ph}^2} \quad (7)$$

where

- $V_{90}(n)$ = Voltage sample at a sample instant *n* shifted by 90°
- $K_{ACT,ph}$ = Scaling factor for active power
- $K_{REACT,ph}$ = Scaling factor for reactive power
- $P_{ACT\_offset,ph}$ = Offset used to subtract effects of crosstalk on the active power measurements

- $P_{REACT\_offset,ph}$ = Offset used to subtract effects of crosstalk on the reactive power measurements

Note

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

1. This approach allows accurate measurement of the reactive power for very small currents
2. This approach 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. Because the frequency of the mains varies, the mains frequency is first measured accurately to phase shift the voltage samples accordingly.

To get an exact 90° phase shift, interpolation is used between two samples. For these two samples, a voltage sample slightly more than 90 degrees before the most recent voltage sample and a voltage sample slightly less than 90 degrees before the most recent voltage sample are used. The phase shift implementation of the application 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 one-tap FIR filter. In the test software, a lookup table provides the filter coefficients that are used to create the fractional delays.

Using the calculated powers, energies are calculated with the following formulas:

$$E_{ACT,\,ph} = P_{ACT,\,ph} \times \text{Sample Count} \tag{8}$$

$$E_{REACT,\,ph} = P_{REACT,\,ph} \times \text{Sample Count} \tag{9}$$

$$E_{APP,\,ph} = P_{APP,\,ph} \times \text{Sample Count} \tag{10}$$

The calculated energies are then accumulated into buffers that store the total amount of energy consumed since system reset. These energies are different from the working variables used to accumulate energy for outputting energy pulses. There are three sets of buffers that are available: one for each V-I mapping. Within each set of buffers, the following energies are accumulated:

1. Active import energy (active energy when active power ≥ 0)
2. Active export energy (active energy when active power < 0)
3. Fundamental active import energy (fundamental active energy when fundamental active power ≥ 0)
4. Fundamental active export energy (fundamental active energy when fundamental active power < 0)
5. React. Quad I energy (reactive energy when reactive power ≥ 0 and active power ≥ 0; inductive load)
6. React. Quad II energy (reactive energy when reactive power ≥ 0 and active power < 0; capacitive generator)
7. React. Quad III energy (reactive energy when reactive power < 0 and active power < 0; inductive generator)
8. React. Quad IV energy (reactive energy when reactive power < 0 and active power ≥ 0; capacitive load)
9. Apparent import energy (apparent energy when active power ≥ 0)
10. Apparent export energy (apparent energy when active power < 0)

The background process also calculates the frequency in terms of samples-per-mains cycle. The foreground process then converts this samples-per-mains cycle to Hertz with Equation 11:

$$\text{Frequency (Hz)} = \frac{\text{Sample Rate (samples/second)}}{\text{Frequecy (sample/cycle)}} \tag{11}$$

After the active power and apparent power have been calculated, the absolute value of the power factor is calculated. In the internal representation of power factor of the system, a positive power factor corresponds to a capacitive load; 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 with Equation 12:

$$\text{Internal Representation of Power Factor} = \begin{cases} \frac{P_{ACT}}{P_{App}}, if\ capacitive\ load \\ -\frac{P_{ACT}}{P_{APP}}, if\ inductive\ load \end{cases} \quad (12)$$

3.1.2 UART for PC GUI Communication

The MSPM0+ MCU is configured to communicate to the PC GUI through an UART interface on J12 in this reference design. The PC GUI polls data from the MSPM0C1105 using a UART module configured for 9600 baud with 8N1. The UART protocol for formatting the UART data is named DLT-645 and the UART module utilizes two DMA Channels: Channel 2 for data receive and Channel 3 for data transmit. See also the *Single Phase and DC Embedded Metering (Power Monitor) Using MSP430I2040* application note.

UART data is processed in the HAL_startUARTDMAReceive() function, by setting a trigger at 14 bytes, as this is the byte which codes the packet length (which can change dynamically from packet to packet). After decoding the byte 14, the UART DMA transfer length value gets updated to a new length, which equals the rest of the DLT-645 protocol packet, transmitted by the PC GUI.

3.1.3 Direct Memory Access (DMA)

The MCU DMA module transfers data packets between the MSPM0C1105 MCU and AMC130M02 devices with minimal hardware resources and timing overhead over the SPI bus. Two DMA channels are utilized for the SPI data transfer: DMA Channel 0 sends SPI data (0x00) to the ADC and DMA Channel 1 receives the measurements data from ADC over the SPI bus. AMC130M02 transfers 12 bytes packet due to 2 analog input, once a complete SPI data packet has been received from the ADC, an DMA Ready interrupt is generated and the CRC16 verification of the data packet starts. After the CRC16 check was successful, the data packet is disassembled into voltage and current values for Phase A.

3.1.4 ADC Setup

The AMC130M02 device register must be initialized to deliver proper measurement data on all relevant analog input channels. Figure 3-1 is followed at every start of the metrology application.

The SPI module of the MSPM0+ MCU is configured as a controller device that uses 4-wire mode. After the SPI is set up, all interrupts are disabled and a reset pulse on the SYNC_RESET line is sent from the MSPM0+ MCU. Interrupts are then re-enabled and the MSPM0+ MCU sends SPI write commands to AMC130M02:

- MODE register settings: 16-bit CCITT CRC used, 24-bit length for each word in the AMC130M02 data packet, the DRDY signal is asserted on the most lagging enabled channel, DRDY is asserted high when the conversion value is not available, DRDY is asserted low when the conversion values are ready.
- GAIN1 register settings for Voltage and Current: PGA gain = 1 used for the voltage channel, measuring the line-to-neutral, PGA gain = 16 for the current channels on Phase A and Neutral.
- CHx_CFG register settings (where x is the channel number: 0, 1): two ADC channel inputs connected to external ADC pins and the channel phase delay set to 0 for each channel (the software phase compensation in the SDK middleware is used instead of hardware phase compensation)
- CLOCK register settings: 1024 OSR, all channels enabled, and high-resolution modulator power mode

The MSPM0+ MCU is configured at start-up to generate a port interrupt whenever a falling edge occurs on the DRDY pins, which indicate that new measurement samples are available.

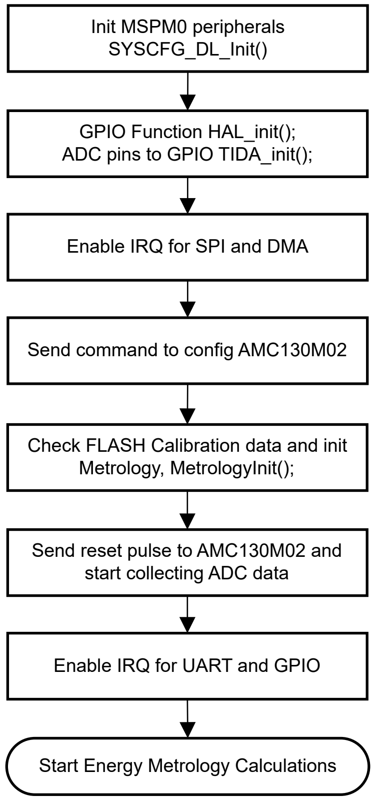


Figure 3-1. ADC Initialization Procedure

The ADC modulator clock is derived from the clock fed to the CLKIN pin which gets internally divided by two, to generate the ADC modulator clock. Equation 13 shows the definition of the sampling frequency of the ADC.

$$f_S = \frac{f_M}{OSR} = \frac{f_{CLKIN}}{2 \times OSR} \quad (13)$$

where

- f_S is the sampling rate
- f_M is the modulator clock frequency
- f_{CLKIN} is the clock fed to the AMC130M02 CLKIN pin
- OSR is the selected oversampling ratio

In this design, the CLKIN pin gets Clock from an external oscillator at a fixed frequency of 8.192MHz. The oversampling ratio is selected to be 1024 with the appropriate register setting. The sample rate is set to 4000 samples per second.

This design uses the following AMC130M02 channel mappings:

- AIN0P and AIN0N AMC130M02 ADC channel pins → Voltage
- AIN1N and AIN1P AMC130M02 ADC channel pins → Shunt Current (this can measure either the neutral or line current)

3.1.5 Foreground Process

The foreground process includes the initial setup of the MSPM0+ MCU hardware and software and AMC130M02 registers immediately after a device RESET. Figure 3-2 shows the flow chart for this process

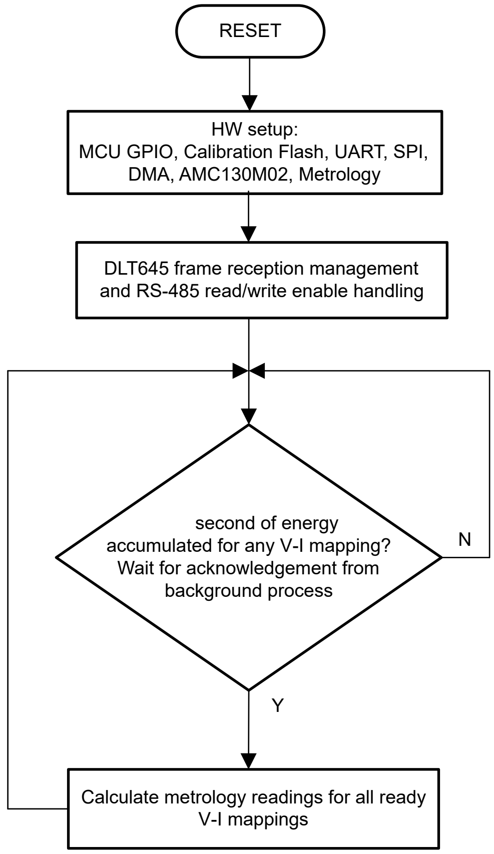


Figure 3-2. Foreground Process

The initialization routines involve the setup of the MSPM0C1105:

- General purpose input/output (GPIO) port pins
- Clock system (MCLK or CPU clock, RTC clock, SPI clock, CLK_OUT pin)
- 2 UART port
- 3AMC130M02 registers

  DMA channels, for SPI and UART
- Metrology variables

After the hardware is set up, any received frames from the GUI are processed. Next, the foreground process checks whether the background process has notified the foreground process to calculate new metrology parameters for any voltage-current mappings. This notification is accomplished 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 CYCLES_PER_COMPUTATION number of cycles of data. The value for CYCLES_PER_COMPUTATION is 10 cycles when the nominal frequency setting in the software is 50Hz and 12 cycles when the nominal frequency setting in the software is set to 60Hz. When the measured line frequency is equal to the nominal frequency of the design, this is equivalent to 200 milliseconds of accumulated data.

The processed dot products include the V_{RMS}, I_{RMS}, active power, reactive power, fundamental voltage, fundamental active power, and fundamental reactive power. These dot products are used by the foreground process to calculate the corresponding metrology readings in real-world units. All the processed dot products are accumulated in separate 64-bit registers to further process and obtain the RMS and mean values. The apparent power is calculated using the calculated values of active and reactive power of the foreground process.

Similarly, using the calculated values of the foreground for the fundamental voltage, fundamental reactive power, and fundamental active power, the fundamental current, fundamental apparent power – voltage THD, and current THD are calculated. Additionally, voltage underdeviation and voltage overdeviation are calculated using the value of the calculated RMS voltage and the defined nominal voltage of the design. The frequency (in Hz) and power factor are also calculated using parameters calculated by the background process using the formulas in Section 3.1.1.

3.1.6 Background Process

Figure 3-3 shows the different events that occur when sampling voltage and current, where the items in green are done by the MSPM0G1106 hardware modules.

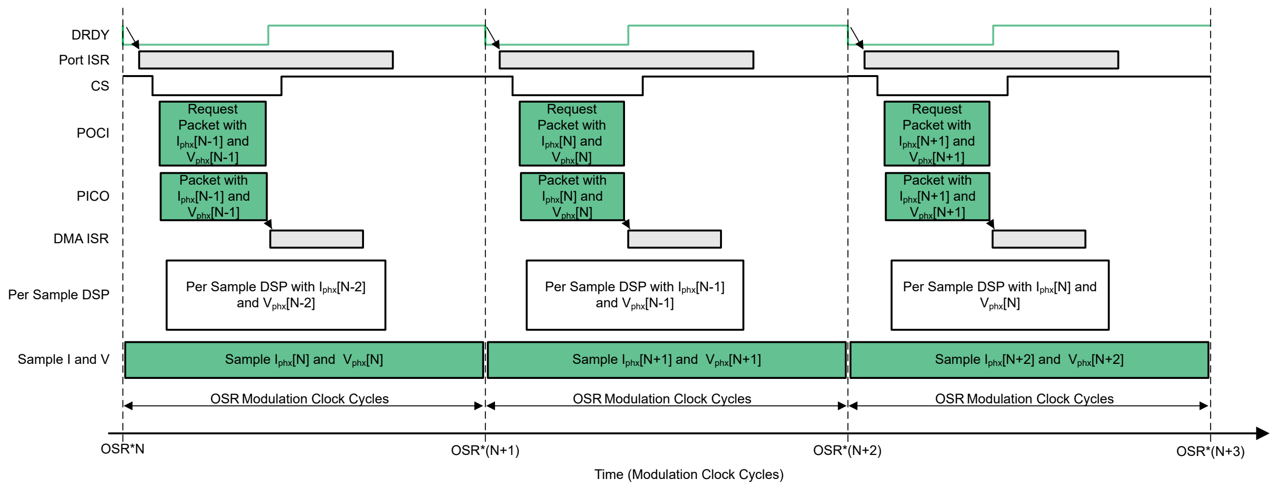


Figure 3-3. Voltage and Current Sampling Events

New current samples for each phase are ready every OSR, or 1024 modulation clock cycles for this design, thus resulting in 4000 samples per second over the SPI bus to MSPM0+ MCU. Once new samples are ready, the DRDY pin causes a GPIO interrupt on the MSPM0+ MCU, which triggers the Port ISR, and the background process is run within the Port ISR.

Figure 3-4 shows the background process, which mainly deals with timing-critical events in the test software.

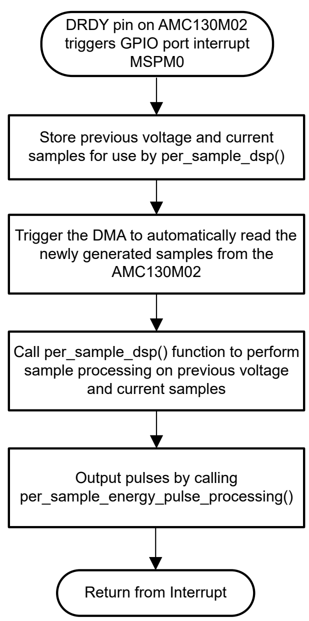


Figure 3-4. Background Process

3.1.7 Software Function per_sample_dsp ()

Figure 3-5 shows the flowchart for the per_sample_dsp() 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. Both voltage and 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.

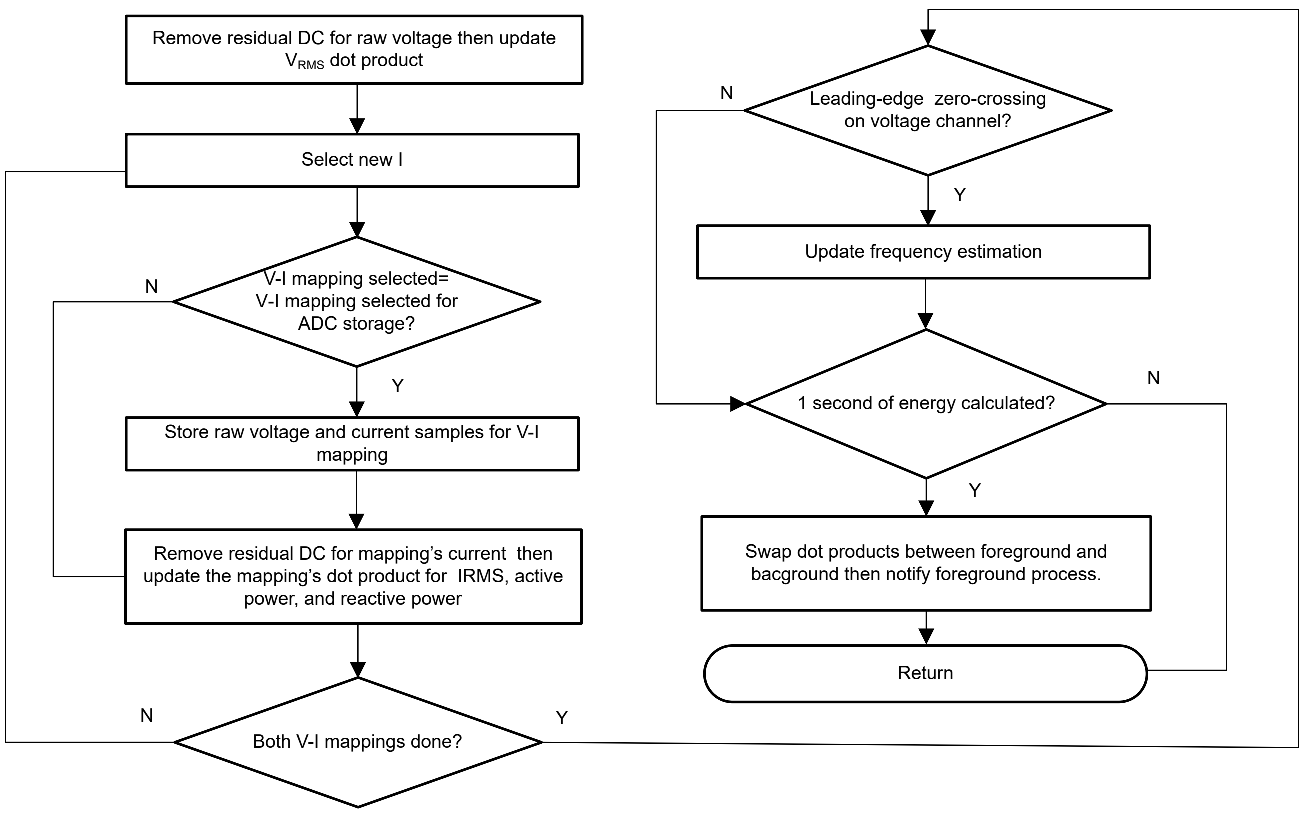


Figure 3-5. per_sample_dsp () Function

3.1.8 Frequency Measurement and Cycle Tracking

The instantaneous voltage, currents, active powers, and reactive powers are accumulated in 64-bit registers. A cycle tracking counter keeps track of the number of cycles accumulated. When CYCLES_PER_COMPUTATION number of cycles have been accumulated, the background process stores these accumulation registers and notifies the foreground process to produce the average results, such as RMS and power values. Cycle boundaries are used to trigger the foreground averaging process because this process produces very stable results.

For frequency measurements, a straight line interpolation is used between the zero crossing voltage samples. 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 genuine zero crossing points. For example, with two negative samples, a noise spike can make one of the samples positive, thereby making the negative and positive pair appear as if there is a zero crossing.

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

3.1.9 LED Pulse Generation

In electricity meters, the energy consumption of the load is normally measured in a fraction of kilowatt-hour (kWh) pulses. This information can be used to accurately calibrate any meter for accuracy measurement. Typically, the measuring element (the MSPM0+ MCU) is responsible for generating pulses proportional to the energy consumed.

This application uses average power to generate these energy pulses. The average power accumulates at every DRDY port ISR interrupt, thereby spreading the accumulated energy from the previous one-second time frame evenly for each interrupt in the current one-second time frame. This accumulation process is equivalent to converting power to energy. When the accumulated energy crosses a threshold, a pulse is generated. The amount of energy above this threshold is kept and a new energy value is added on top of the threshold in the next interrupt cycle. Because 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 meter manufacturers and is a constant. The tick is usually defined in pulses-per-kWh or just in kWh. One pulse must be 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 1kWh / 6400. Energy pulses are generated and available on the ACT and REACT pin headers and also through light-emitting diodes (LEDs) on the board. GPIO pins are used to produce the ACT and REACT energy pulses.

Figure 3-6 shows the flow diagram for pulse generation with a pulse constant of 6400, though TI recommends reducing this value to 3600 or even lower if the energy meter supports currents beyond 80A.

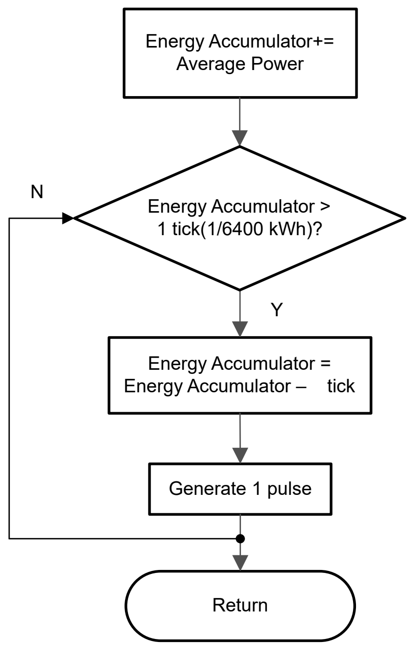


Figure 3-6. Pulse Generation for Energy Indication

The average power is in units of 0.001W and a 1kWh threshold is defined in Equation 14.

$$1\text{kWh threshold} = \frac{1}{0.001} \times 1\text{kW} \times \left(\text{Number of interrupts per second}\right) \times \left(\text{Number of seconds in one hour} = 1000000 \times 8000 \times 3600 = 0\text{x}1\text{A}3185\text{C}50000 \tag{14}$$

4 Implementation Results

4.1 Evaluation Procedure

To evaluate the function of the board, TI recommends to run a test procedure - Section 4.1.2.

4.1.1 Equipment Setup

Figure 4-1shows the location of various components of the reference design on the top layer of the PCB. The bottom layer has no soldered components.

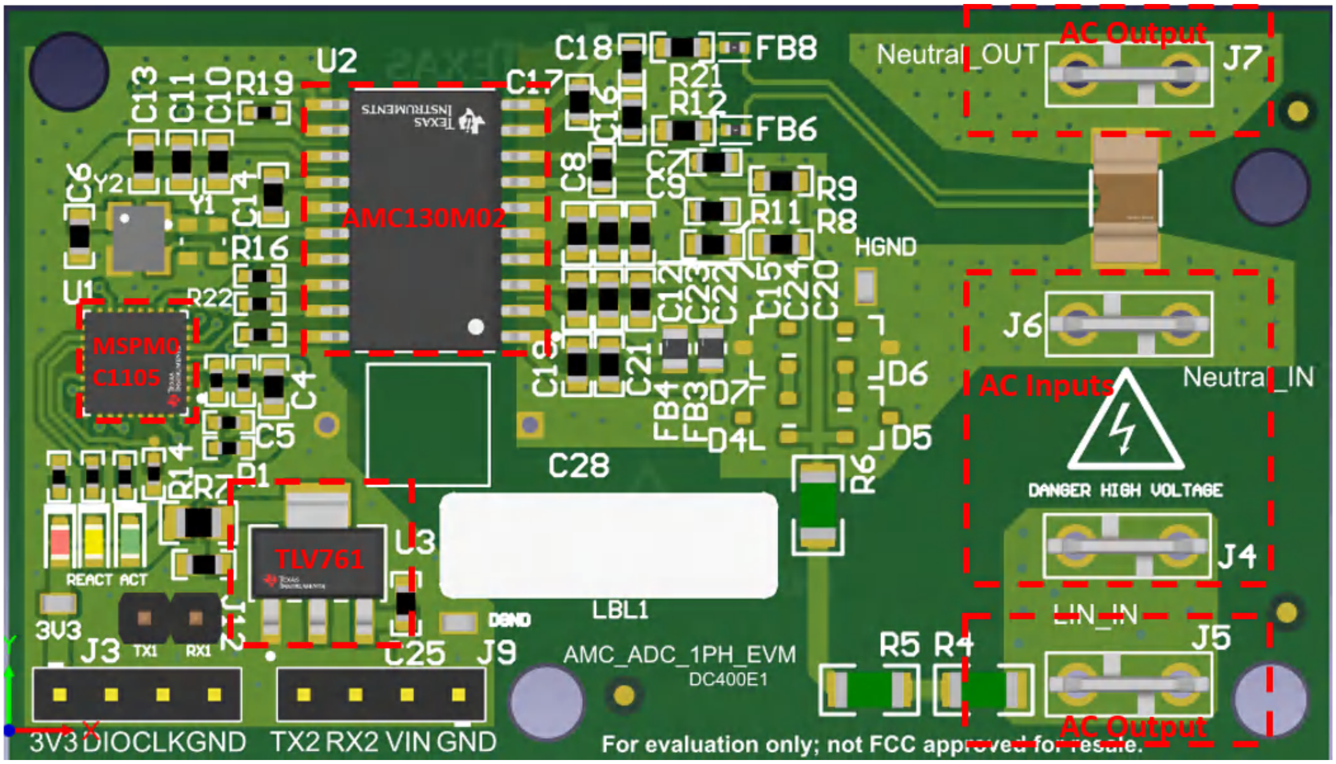


Figure 4-1. AMC-ADC-1PH-EVM Hardware 3D View

Table 4-1 lists the jumper settings.

Table 4-1. Hardware Jumper Settings

HEADER NAME	TYPE	MAIN FUNCTIONALITY	COMMENTS
J3	4 pin	JTAG: MSPM0 programming header	
J4, J6	1 pin	Positive and negative AC input header	Connect AC Line and Neutral to J5 J6
J5, J7	1 pin	Positive and negative AC output header	Connect load the J4 J7
J9	4 pin	UART output to connect to main controller and External power supply	
J12	2 pin	UART to connect with PC GUI	

4.1.2 Test Procedure

Note

Verify that the outputs of the connected supplies are disabled before connecting or disconnecting equipment.

4.1.2.1 Working with the Metrology GUI

To view the metrology parameter values from the GUI, perform the following steps:

1. Select UART connection for communication to the PC GUI. Connect J12 to PC USB and a COM port is created on the PC. The testing was done using UART with 9600, 8N1 setting.
2. Open the 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 system. As Figure 4-2 shows, this field is changed to COM7.

Figure 4-2. GUI Configuration File Changed to Communicate With Energy Measurement System

4. Run the calibrator.exe file, which is located in the GUI folder. If the COM port in the calibration-config.xml was changed in the previous step to the COM port connected to the reference design, the GUI opens (see Figure 4-3). If the GUI connects to the design properly, 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.

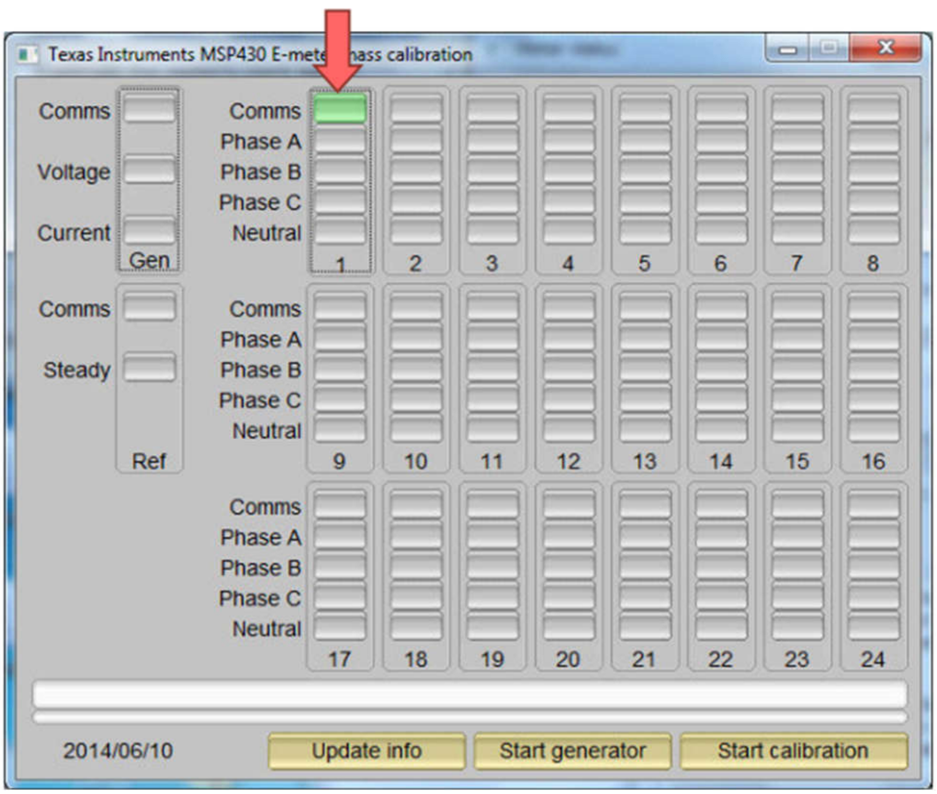


Figure 4-3. GUI Start-Up Window

The results window opens after clicking on the green button (see Figure 4-4).

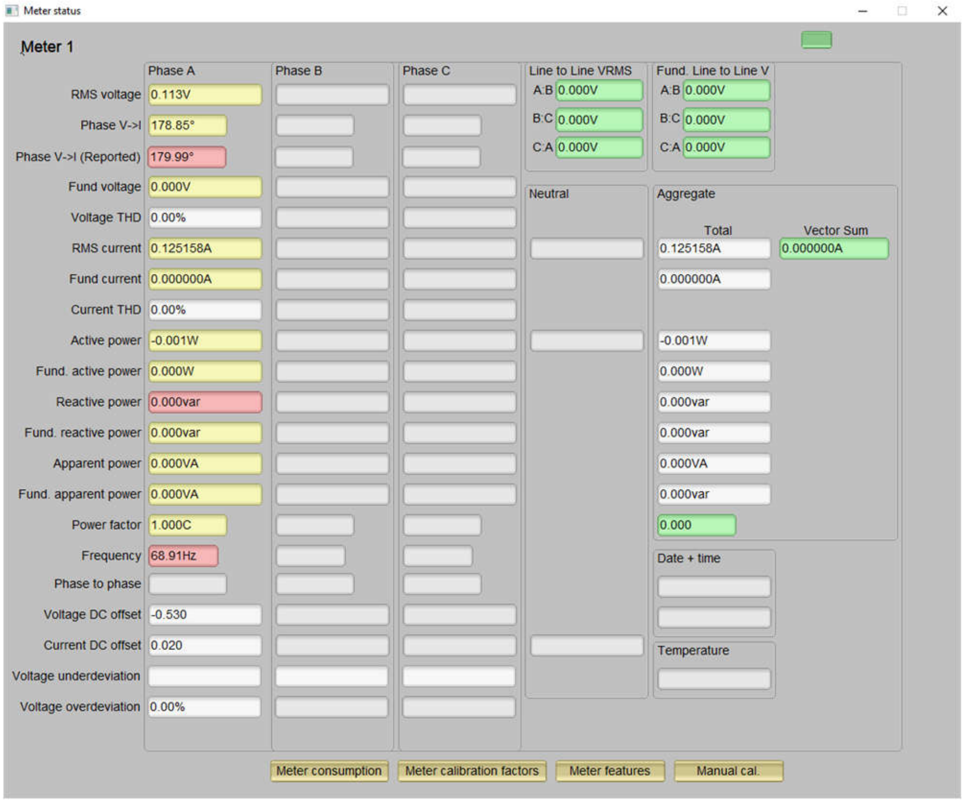


Figure 4-4. GUI Results Window

4.1.2.2 Calibration

4.1.2.2.1 Voltage and Current Offset Calibration

To calibrate the voltage and current offset, perform the following steps:

1. Connect the GUI to view results for voltage and current.
2. Configure the test source to supply the desired voltage and current.
   - Using a low but non-zero value is recommended; for example, 120V and 0.5A.
3. Click on the *Manual cal.* button.
4. Input the difference from the expected input versus what the GUI is reading into the appropriate fields.

Note

AC current offset is in microamps and AC voltage offset is in millivolts.

4.1.2.2.2 Voltage and Current Gain Calibration

To calibrate the voltage and current readings, perform the following steps:

1. Connect the GUI to view results for voltage, current, active power, and the other metering parameters.
2. Configure the test source to supply the desired voltage and current for all phases. Make sure that these are the voltage and current calibration points with a zero-degree phase shift between each phase voltage and current. For example, for 120V, 10A, 0° (PF = 1). Typically, these values are the same for every phase.
3. Click on the *Manual cal.* button as illustrated in Figure 4-4.

   The screen in Figure 4-5 pops up:

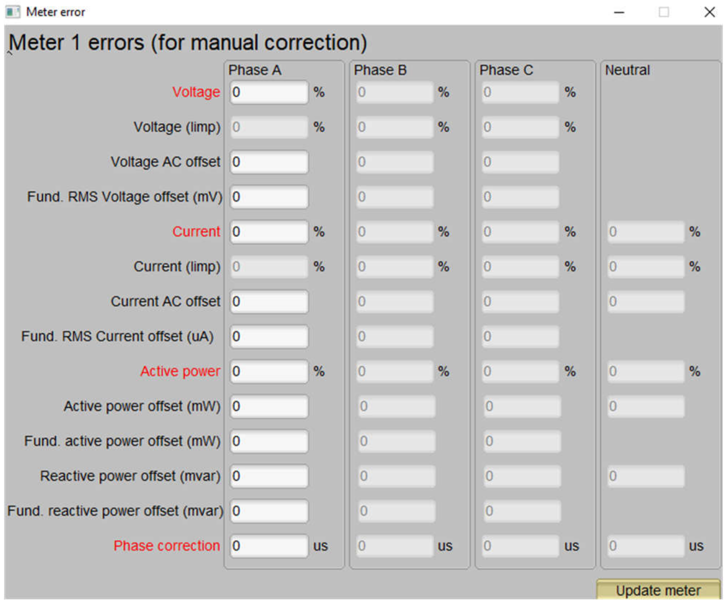


Figure 4-5. Manual Calibration Window

4. Calculate the correction values for each voltage and current. The correction values that must be entered for the voltage and current fields are calculated using Equation 15.

$$\text{Correction (\%)} = \left(\frac{\text{value}_{\text{observed}}}{\text{value}_{\text{desired}}} - 1\right) \times 100 \tag{15}$$

where

- $\text{value}_{\text{observed}}$ is the value measured by the TI meter
- $\text{value}_{\text{desired}}$ is the calibration point configured in the AC test source

4.1.2.2.3 Active Power Gain Calibration

After performing gain correction for voltage and current, gain correction for active power must be completed. Gain correction for active power is done differently in comparison to voltage and current. Although, conceptually, calculating the active energy % error as is done with voltage and power can be done, this method is not the most accurate.

The best option to get the Correction (%) is directly from the reference meters measurement error of the active power. This error is obtained by feeding energy pulses to the reference meter. To perform active power calibration, complete the following steps:

1. Turn off the system and connect the energy pulse output of the system to the reference meter. Configure the reference meter to measure the active power error based on these pulse inputs.
2. Turn on the AC test source.
3. Repeat steps 1 to 3 from Section 4.1.2.2.2 with the identical voltages, currents, and 0° phase shift that were used in the same section.
4. Obtain the % error in measurement from the reference meter.

Note

The error can be negative.

---

5. Enter the error obtained in 4 into the *Active power* field under the corresponding phase in the GUI window. This error is already the value and does not require calculation.
6. Click the *Update meter* button and the error values on the reference meter immediately settle to a value close to zero.

4.1.2.2.4 Offset Calibration

After performing gain calibration, if the accuracy at low currents is not acceptable, offset calibration can be done. Offset calibration removes any crosstalk, such as the crosstalk to the current channels of a phase from the line voltages.

To perform active power offset calibration for a phase, add the offset to be subtracted from the active power reading (in units of mW) to the current value of the active power offset (labeled *Active power offset (mW)* in the meter calibration factors window) and then enter this new value in the Active power offset (mW) field in the Manual Calibration window. As an example, if the *Active power offset (mW)* has a value of 200 (0.2W) in the meter calibration window, and subtracting an additional 0.300mW is desired, then enter a value of 500 in the *Active power offset (mW)* field in the *Manual Calibration* window. After entering the value in the *Active power offset (mW)* field in the *Manual Calibration* window, press the *Update meter* button.

To perform reactive power offset calibration for a phase, a similar process is followed as the process used to perform active power offset calibration.

4.1.2.2.5 Phase Calibration

After performing power gain correction, do the phase calibration. To perform phase correction calibration, complete the following steps:

1. If the AC test source has been turned OFF or reconfigured, perform steps 1 through 3 from Section 4.1.2.2.2 using the identical voltages and currents used in that section.
2. Modify only the phase-shift to a non-zero value; typically, +60° is chosen. The reference meter now displays a different % error for active power measurement.

   Note

   This value can be negative.

   ---
3. If the error from 2 is not close to zero, or is unacceptable, perform phase correction by following these steps:
   a. Enter a value as an update for the *Phase correction* field for the phase that is being calibrated. Usually, a small ± integer must be entered to bring the error closer to zero. Additionally, for a phase shift greater than 0 (for example: +60°), a positive (negative) error requires a positive (negative) number as correction.
   b. Click on the *Update meter* button and monitor the error values on the reference meter.
   c. If this measurement error (%) is not accurate enough, fine-tune by incrementing or decrementing by a value of 1 based on 1. After a certain point, the fine-tuning only results in the error oscillating on either side of zero. The value that has the smallest absolute error must be selected.
   d. Change the phase now to –60° and check if this error is still acceptable. In best practice, errors must be symmetric for the same phase shift on lag and lead conditions.

After performing phase calibration, calibration is complete. Figure 4-6 shows the new calibration factors.

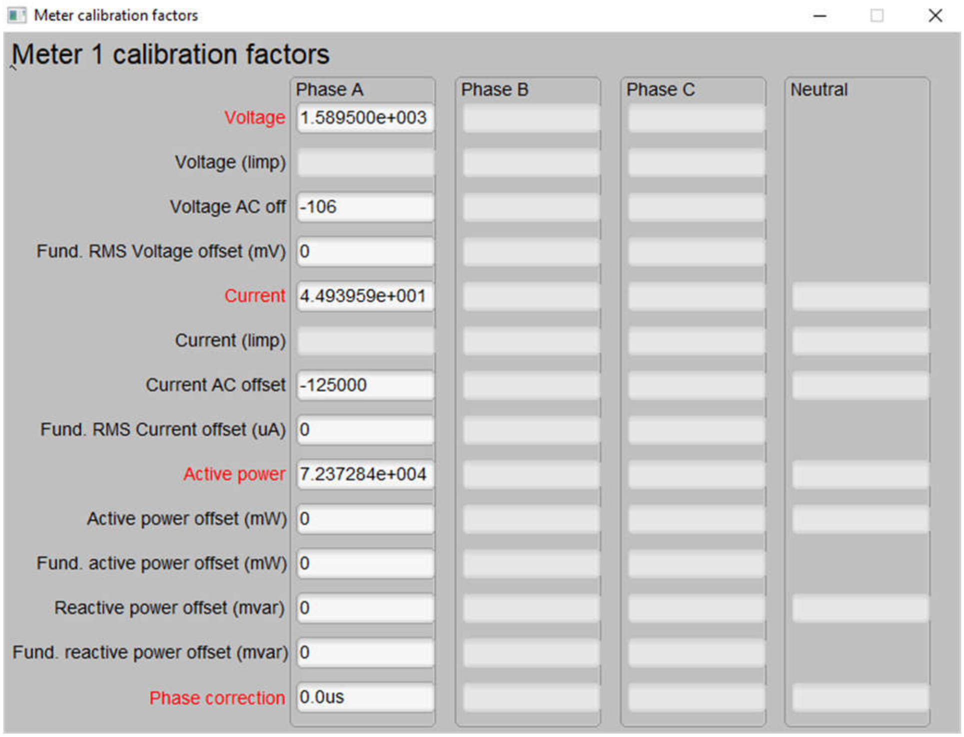


Figure 4-6. Calibration Factors Window

4.2 Performance Data and Results

For cumulative active energy and individual phase error testing, current is varied from 50mA to 15A, a phase shift of 0° (PF = 1), PF = 0.5i (inductive) and PF = 0.8c (capacitive) is applied between the voltage and current waveforms fed to the reference design. Based on the error from the active energy output pulse, a plot of active energy % error versus current is created for the three PF values.

For cumulative reactive energy error testing, a similar process is followed except that a phase shift of 90° (sin ϕ = 1i), sin ϕ = 0.5i (inductive) and sin ϕ = 0.8c (capacitive) are used, and cumulative reactive energy error is plotted instead of cumulative active energy error.

4.2.1 Electricity Meter Metrology Accuracy Results

After gain, phase, and offset calibration, the test results are shown in the following tables. Table 4-2 and Figure 4-7 show the active energy test results.

Table 4-2. Active Energy % Error Versus Current, 3mΩ Shunt, 230V

CURRENT (A)	AVG ERROR% PF=1 Cos PHI = 1 (0°)	AVG ERROR% PF=0.5i Cos PHI = 0.5i (60°)	AVG ERROR% PF=0.8c Cos PHI = 0.8c (–36.87°)
0.05	0.368	0.413	0.605
0.15	0.111	0.098	0.29
5	0.026	-0.374	0.141
10	0.073	-0.311	0.21
15	0.096	-0.242	0.29

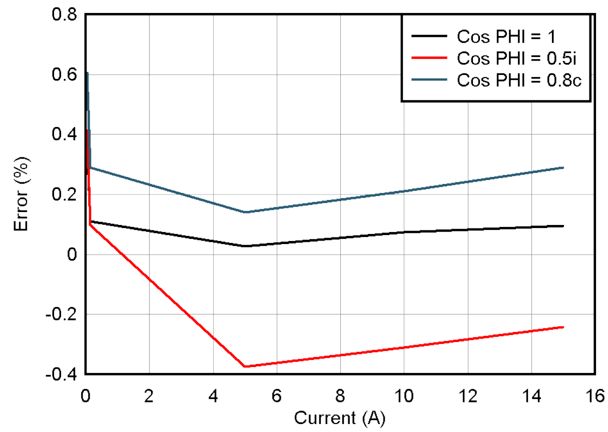


Figure 4-7. Active Energy % Error Versus Current, 3mΩ Shunt, 230V

Table 4-3 and Figure 4-8 show the reactive energy test results.

Table 4-3. Reactive Energy % Error Versus Current, 3mΩ Shunts

CURRENT (A)	AVG ERROR% Sin PHI = 1i (90°)	AVG ERROR% Sin PHI = 0.5i (30°)	AVG ERROR% Sin PHI = 0.8c (–53.13°)
0.05	0.494	1.316	-0.644
0.15	0.086	0.486	-0.097
5	0.172	0.549	-0.049
10	0.202	0.607	0.053
15	0.264	0.682	0.141

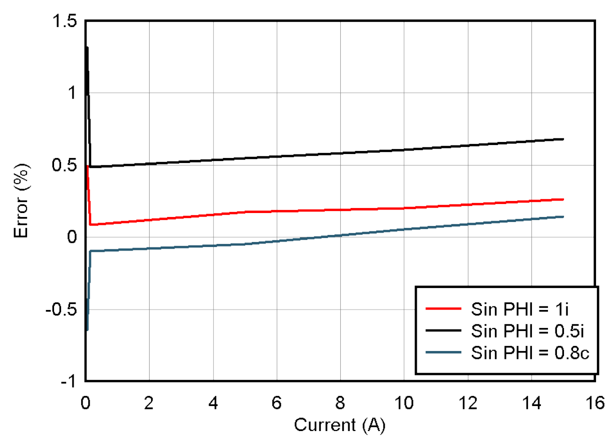


Figure 4-8. Reactive Energy % Error Versus Current, 3mΩ Shunts

5 Hardware Design Files

5.1 Schematics

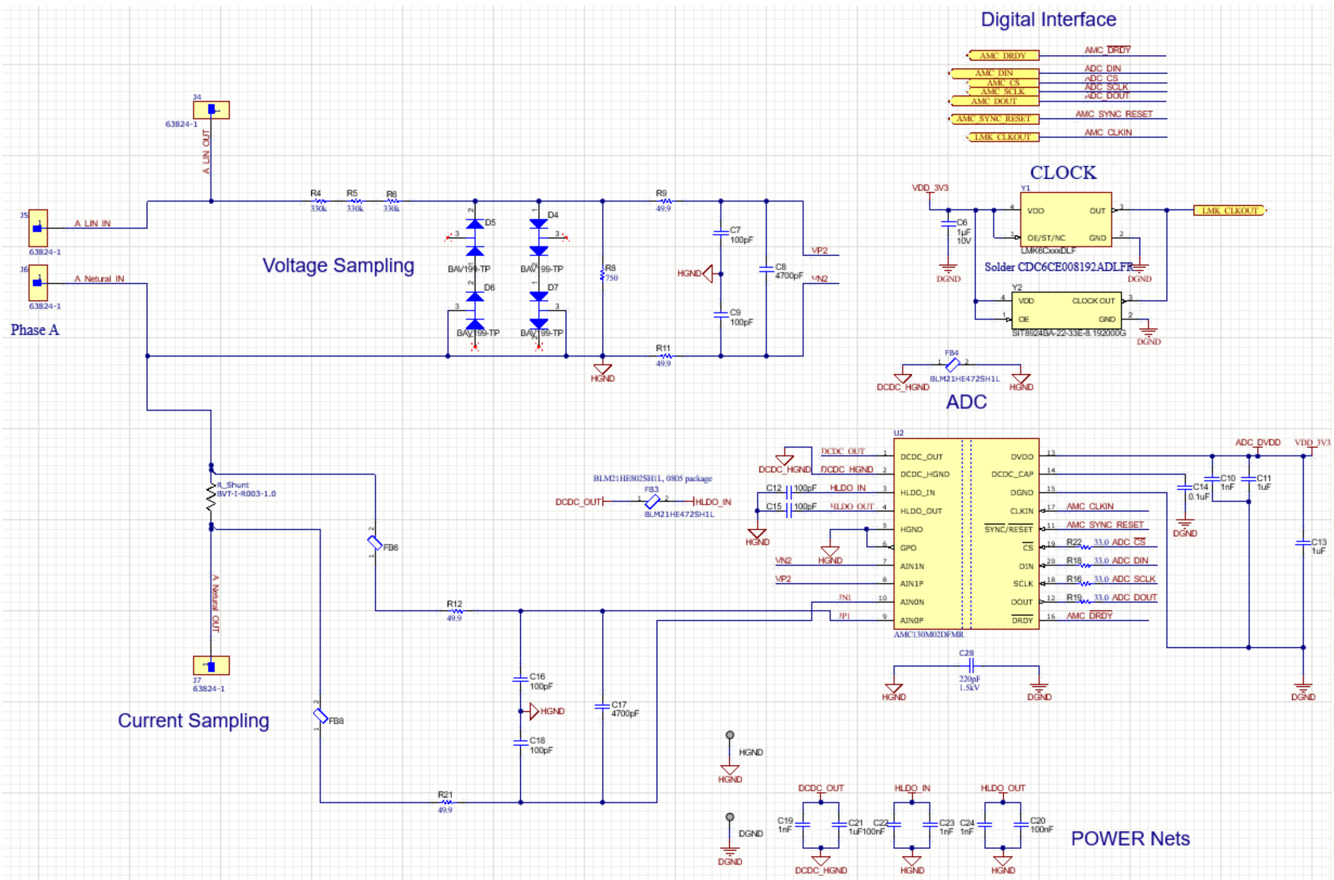


Figure 5-1. AMC-ADC-1PH-EVM Schematic (ADC and Front End)

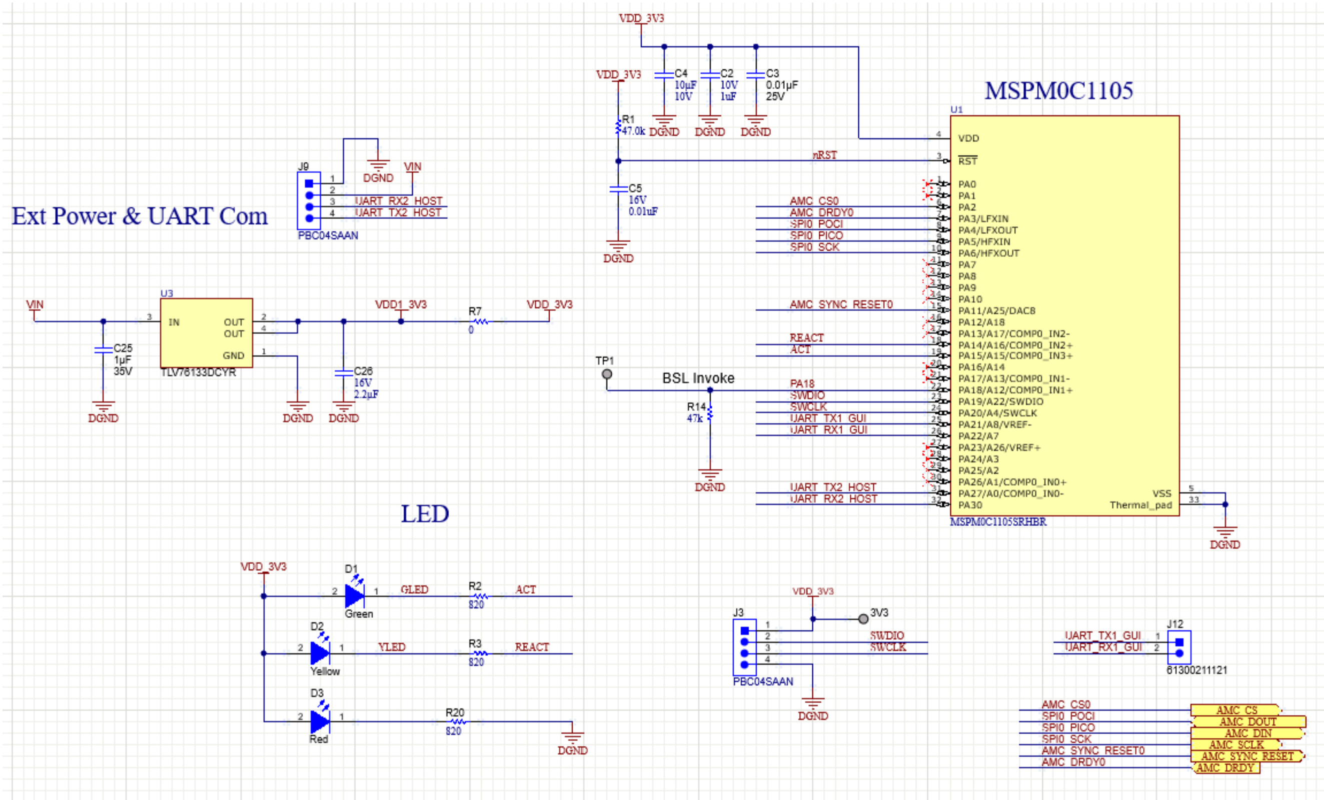


Figure 5-2. AMC-ADC-1PH-EVM Schematic (MCU, Supply, and UART)

5.2 PCB Layouts

Figure 5-3 and Figure 5-4 show the top and bottom printed circuit board (PCB) drawings of the AMC-ADC-1PH-EVM respectively.

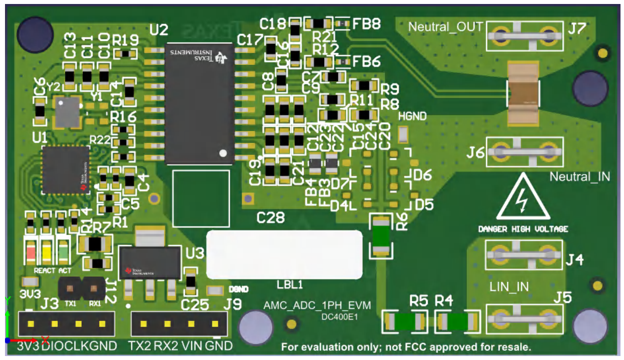


Figure 5-3. AMC-ADC-1PH-EVM Top PCB Drawing

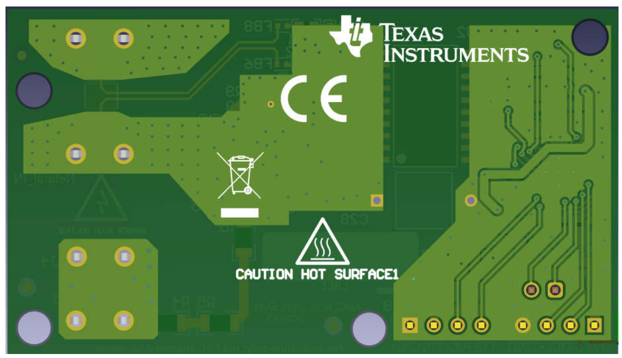


Figure 5-4. AMC-ADC-1PH-EVM Bottom PCB Drawing

5.3 Bill of Materials (BOM)

Table 5-1. Bill of Materials

DESIGNATOR	DESCRIPTION	MANUFACTURER	PART NUMBER
!PCB1	Printed Circuit Board	Any	DC400
3V3, DGND, HGND	Natural PC Test Point Brass, SMT	Harwin	S2761-46R
C2	CAP, CERM, 1uF, 10V,+/- 10%, X6S, 0402	MuRata	GRM155C81A105KA12D
C3	CAP, CERM, 0.01µF, 25V,+/- 5%, X7R, 0402	AVX	04023C103JAT2A
C4	CAP, CERM, 10µF, 10V,+/- 10%, X5R, 0603	MuRata	GRM188R61A106KAALD
C5	CAP, CERM, 0.01uF, 16V, +/- 10%, X7R, 0402	TDK	C1005X7R1C103K050BA
C6	CAP, CERM, 1µF, 10V,+/- 10%, X7R, 0603	Taiyo Yuden	LMK107B7105KA-T
C7, C9, C16, C18	CAP, CERM, 100pF, 50V, +/- 5%, C0G/NP0, 0603	Wurth Elektronik	885012006057
C8, C17	CAP, CERM, 4700pF, 100V, +/- 5%, C0G/NP0, 0603	Kemet	C0603C472J1GAC7867
C10, C19, C23, C24	CAP, CERM, 1000pF, 50V, +/- 10%, X7R, 0603	Kemet	C0603C102K5RACTU
C11, C13, C21	CAP, CERM, 1uF, 25V, +/- 10%, X7R, 0603	Kemet	C0603C105K3RACTU
C12, C15	CAP, CERM, 100pF, 50V, +/- 5%, C0G/NP0, 0603	Wurth Elektronik	885012006057
C14, C20, C22	CAP, CERM, 0.1uF, 50V, +/- 10%, X7R, 0603	TDK	C1608X7R1H104K080AA
C25	CAP, CERM, 1µF, 35V,+/- 10%, X7R, AEC-Q200 Grade 1, 0603	TDK	CGA3E1X7R1V105K080AE
C26	CAP, CERM, 2.2uF, 16V, +/- 10%, X7R, 0603	MuRata	GRM188Z71C225KE43
D1	LED, Green, SMD	Wurth Elektronik	150060VS75000
D2	LED, Yellow, SMD	Wurth Elektronik	150060YS75000
D3	LED, Red, SMD	Wurth Elektronik	150060RS75000
FB3, FB4	4.7 kOhms @ 100MHz 1 Signal Line Ferrite Bead 0805 (2012 Metric) 850mA 400mOhm	Murata	BLM21HE472SH1L
FB6, FB8	1.8 kOhms @ 100MHz 1 Power, Signal Line Ferrite Bead 0402 (1005 Metric) 210mA 2.1Ohm	Wurth Electronics	74269244182
FID3	Fiducial mark. There is nothing to buy or mount.	N/A	N/A
J3, J9	Header, 2.54mm, 4x1, Gold, TH	Sullins Connector Solutions	PBC04SAAN
J4, J5, J6, J7	Connector	TE Connectivity	63824-1
J12	Header, 2.54mm, 2x1, Gold, TH	Wurth Elektronik	61300211121
LBL1	Thermal Transfer Printable Labels, 0.650" W x 0.200" H - 10,000 per roll	Brady	THT-14-423-10
R1	RES, 47.0k, 1%, 0.0625W, 0402	Yageo America	RC0402FR-0747KL
R2, R3, R20	RES, 820, 1%, 0.063W, 0402	Yageo America	RC0402FR-07820RL
R4, R5, R6	RES, 330k, 0.1%, 1W, 1206	Vishay Draloric	TNPV1206330KBEEN
R7	RES, 0, 5%, 0.125W, AEC-Q200 Grade 0, 0805	Vishay-Dale	CRCW08050000Z0EA
R8	RES, 750, 0.1%, 0.1W, 0603	Susumu Co Ltd	RG1608P-751B-T5

Table 5-1. Bill of Materials (continued)

DESIGNATOR	DESCRIPTION	MANUFACTURER	PART NUMBER
R9, R11, R12, R21	RES, 49.9, 1%, 0.1W, AEC-Q200 Grade 0, 0603	Vishay-Dale	CRCW060349R9FKEA
R14	RES, 47k, 5%, 0.063 W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW040247K0JNED
R16, R18, R19, R22	RES, 33.0, 1%, 0.1W, 0402	Panasonic	ERJ-2RKF33R0X
R_Shunt	3 mOhms ±1% 6W Chip Resistor 2512 (6432 Metric) Automotive AEC-Q200, Current Sense, Moisture Resistant	Isabellenhuette	BVT-I-R003-1.0
U1	Mixed-Signal Microcontroller, VQFN32	Texas Instruments	MSPM0C1105SRHBR
U2	Two-channel, simultaneously-sampling, 16-bit, isolated delta-sigma ADC 20-SOIC -40 to 125	Texas Instruments	AMC130M02DFMR
U3	1A 16V high-PSRR linear voltage regulator 4-SOT-223 -40 to 125	Texas Instruments	TLV76133DCYR
Y2	Ultra-low-Power LVCMOS Oscillator	Texas Instruments	CDC6CE008192ADLFR

6 Additional Information

6.1 Trademarks

Code Composer Studio™ is a trademark of Texas Instruments.
Arm® and Cortex® are registered trademarks of Arm Limited.
Microsoft® and Windows® are registered trademarks of Microsoft Corporation.
All trademarks are the property of their respective owners.

7 Compliance Information

7.1 Compliance and Certifications

8 Related Documentation

- Texas Instruments, *AMC130M02 2-Channel, 64-kSPS, Simultaneous-Sampling, 16-Bit, Reinforced Isolated Delta-Sigma ADC With Integrated DC/DC Converter*, data sheet
- Texas Instruments, *MSPM0C1105, MSPM0C1106 Mixed-Signal Microcontrollers*, data sheet
- Texas Instruments, *LMK6x Low Jitter, High-Performance BAW Oscillator*, data sheet
- Texas Instruments, CDC6Cx Low Power LVCMOS Output BAW Oscillator, data sheet
- Texas Instruments, *One-Phase Shunt Power Meter Reference Design With Isolated ADC*
- Texas Instruments, *One-Phase Shunt Electricity Meter Reference Design*
- Texas Instruments, *Single-Phase and Split-Phase Shunt Energy Metrology Reference Design*
- Texas Instruments, *One-Phase Shunt Electricity Meter Reference Design Using Standalone ADCs* , design guide
- Texas Instruments, *Shunt Resistor Selection for Isolated Data Converters*, application brief
- Texas Instruments, *Design Considerations for Isolated Current Sensing*, analog design journal

STANDARD TERMS FOR EVALUATION MODULES

1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, and/or documentation which may be provided together or separately (collectively, an "EVM" or "EVMs") to the User ("User") in accordance with the terms set forth herein. User's acceptance of the EVM is expressly subject to the following terms.

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   2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for a nonconforming EVM if (a) the nonconformity was caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI, (b) the nonconformity resulted from User's design, specifications or instructions for such EVMs or improper system design, or (c) User has not paid on time. Testing and other quality control techniques are used to the extent TI deems necessary. TI does not test all parameters of each EVM. User's claims against TI under this Section 2 are void if User fails to notify TI of any apparent defects in the EVMs within ten (10) business days after delivery, or of any hidden defects with ten (10) business days after the defect has been detected.

   2.3 TI's sole liability shall be at its option to repair or replace EVMs that fail to conform to the warranty set forth above, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

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User shall operate the Evaluation Kit within TI's recommended guidelines and any applicable legal or environmental requirements as well as reasonable and customary safeguards. Failure to set up and/or operate the Evaluation Kit within TI's recommended guidelines may result in personal injury or death or property damage. Proper set up entails following TI's instructions for electrical ratings of interface circuits such as input, output and electrical loads.

NOTE:

EXPOSURE TO ELECTROSTATIC DISCHARGE (ESD) MAY CAUSE DEGREDATION OR FAILURE OF THE EVALUATION KIT; TI RECOMMENDS STORAGE OF THE EVALUATION KIT IN A PROTECTIVE ESD BAG.

3 *Regulatory Notices:*

3.1 *United States*

3.1.1 *Notice applicable to EVMs not FCC-Approved:*

FCC NOTICE: This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

CAUTION

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

3.2 *Canada*

3.2.1 *For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

3.3 *Japan*

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。

https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-delivered-in-japan.html

3.3.2 *Notice for Users of EVMs Considered "Radio Frequency Products" in Japan:* EVMs entering Japan may not be certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required to follow the instructions set forth by Radio Law of Japan, which includes, but is not limited to, the instructions below with respect to EVMs (which for the avoidance of doubt are stated strictly for convenience and should be verified by User):

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

【無線電波を送信する製品の開発キットをお使いになる際の注意事項】 開発キットの中には技術基準適合証明を受けていないものがあります。 技術適合証明を受けていないもののご使用に際しては、電波法遵守のため、以下のいずれかの措置を取っていただく必要がありますのでご注意ください。

1. 電波法施行規則第6条第1項第1号に基づく平成18年3月28日総務省告示第173号で定められた電波暗室等の試験設備でご使用いただく。
2. 実験局の免許を取得後ご使用いただく。
3. 技術基準適合証明を取得後ご使用いただく。

なお、本製品は、上記の「ご使用にあたっての注意」を譲渡先、移転先に通知しない限り、譲渡、移転できないものとします。

上記を遵守頂けない場合は、電波法の罰則が適用される可能性があることをご留意ください。 日本テキサス・インスツルメンツ株式会社

東京都新宿区西新宿６丁目２４番１号

西新宿三井ビル

3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page

電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-for-power-line-communication.html

3.4 *European Union*

3.4.1 *For EVMs subject to EU Directive 2014/30/EU (Electromagnetic Compatibility Directive)*:

This is a class A product intended for use in environments other than domestic environments that are connected to a low-voltage power-supply network that supplies buildings used for domestic purposes. In a domestic environment this product may cause radio interference in which case the user may be required to take adequate measures.

4 *EVM Use Restrictions and Warnings:*

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 *Safety-Related Warnings and Restrictions:*

4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.

5. *Accuracy of Information:* To the extent TI provides information on the availability and function of EVMs, TI attempts to be as accurate as possible. However, TI does not warrant the accuracy of EVM descriptions, EVM availability or other information on its websites as accurate, complete, reliable, current, or error-free.

6. *Disclaimers:*

6.1 EXCEPT AS SET FORTH ABOVE, EVMS AND ANY MATERIALS PROVIDED WITH THE EVM (INCLUDING, BUT NOT LIMITED TO, REFERENCE DESIGNS AND THE DESIGN OF THE EVM ITSELF) ARE PROVIDED "AS IS" AND "WITH ALL FAULTS." TI DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, REGARDING SUCH ITEMS, INCLUDING BUT NOT LIMITED TO ANY EPIDEMIC FAILURE WARRANTY OR IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF ANY THIRD PARTY PATENTS, COPYRIGHTS, TRADE SECRETS OR OTHER INTELLECTUAL PROPERTY RIGHTS.

6.2 EXCEPT FOR THE LIMITED RIGHT TO USE THE EVM SET FORTH HEREIN, NOTHING IN THESE TERMS SHALL BE CONSTRUED AS GRANTING OR CONFERRING ANY RIGHTS BY LICENSE, PATENT, OR ANY OTHER INDUSTRIAL OR INTELLECTUAL PROPERTY RIGHT OF TI, ITS SUPPLIERS/LICENSORS OR ANY OTHER THIRD PARTY, TO USE THE EVM IN ANY FINISHED END-USER OR READY-TO-USE FINAL PRODUCT, OR FOR ANY INVENTION, DISCOVERY OR IMPROVEMENT, REGARDLESS OF WHEN MADE, CONCEIVED OR ACQUIRED.

7. *USER'S INDEMNITY OBLIGATIONS AND REPRESENTATIONS.* USER WILL DEFEND, INDEMNIFY AND HOLD TI, ITS LICENSORS AND THEIR REPRESENTATIVES HARMLESS FROM AND AGAINST ANY AND ALL CLAIMS, DAMAGES, LOSSES, EXPENSES, COSTS AND LIABILITIES (COLLECTIVELY, "CLAIMS") ARISING OUT OF OR IN CONNECTION WITH ANY HANDLING OR USE OF THE EVM THAT IS NOT IN ACCORDANCE WITH THESE TERMS. THIS OBLIGATION SHALL APPLY WHETHER CLAIMS ARISE UNDER STATUTE, REGULATION, OR THE LAW OF TORT, CONTRACT OR ANY OTHER LEGAL THEORY, AND EVEN IF THE EVM FAILS TO PERFORM AS DESCRIBED OR EXPECTED.

8. *Limitations on Damages and Liability:*

   8.1 *General Limitations*. IN NO EVENT SHALL TI BE LIABLE FOR ANY SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL, OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF THESE TERMS OR THE USE OF THE EVMS , REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. EXCLUDED DAMAGES INCLUDE, BUT ARE NOT LIMITED TO, COST OF REMOVAL OR REINSTALLATION, ANCILLARY COSTS TO THE PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES, RETESTING, OUTSIDE COMPUTER TIME, LABOR COSTS, LOSS OF GOODWILL, LOSS OF PROFITS, LOSS OF SAVINGS, LOSS OF USE, LOSS OF DATA, OR BUSINESS INTERRUPTION. NO CLAIM, SUIT OR ACTION SHALL BE BROUGHT AGAINST TI MORE THAN TWELVE (12) MONTHS AFTER THE EVENT THAT GAVE RISE TO THE CAUSE OF ACTION HAS OCCURRED.

   8.2 *Specific Limitations.* IN NO EVENT SHALL TI'S AGGREGATE LIABILITY FROM ANY USE OF AN EVM PROVIDED HEREUNDER, INCLUDING FROM ANY WARRANTY, INDEMITY OR OTHER OBLIGATION ARISING OUT OF OR IN CONNECTION WITH THESE TERMS, , EXCEED THE TOTAL AMOUNT PAID TO TI BY USER FOR THE PARTICULAR EVM(S) AT ISSUE DURING THE PRIOR TWELVE (12) MONTHS WITH RESPECT TO WHICH LOSSES OR DAMAGES ARE CLAIMED. THE EXISTENCE OF MORE THAN ONE CLAIM SHALL NOT ENLARGE OR EXTEND THIS LIMIT.

9. *Return Policy.* Except as otherwise provided, TI does not offer any refunds, returns, or exchanges. Furthermore, no return of EVM(s) will be accepted if the package has been opened and no return of the EVM(s) will be accepted if they are damaged or otherwise not in a resalable condition. If User feels it has been incorrectly charged for the EVM(s) it ordered or that delivery violates the applicable order, User should contact TI. All refunds will be made in full within thirty (30) working days from the return of the components(s), excluding any postage or packaging costs.

10. *Governing Law:* These terms and conditions shall be governed by and interpreted in accordance with the laws of the State of Texas, without reference to conflict-of-laws principles. User agrees that non-exclusive jurisdiction for any dispute arising out of or relating to these terms and conditions lies within courts located in the State of Texas and consents to venue in Dallas County, Texas. Notwithstanding the foregoing, any judgment may be enforced in any United States or foreign court, and TI may seek injunctive relief in any United States or foreign court.

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

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