Application Note

Single Phase AC Shunt Power Monitor with Low Cost MSPM0

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Abstract

This application note implements a single-phase AC power energy measurement subsystem using a low cost MCU MSPM0C1104 and an external OPA TLV9062.(Or just used a MSPM0L1304 include two internal OPAs, but not tested in this document) It uses a shunt sensor for current sensing and resistors divider for voltage sensing. This design achieves <2% accuracy test based on current input range (340mA~3.44A) with 4kHz sampling rate and uses a TI Arm® Cortex®-M0+ low cost microcontroller for calculating the metrology parameters.

Key features supported in this design:

- Low cost solution
- Single-phase two-wire (1P2W) <2% shunt metrology subsystem for power monitor
- Root mean square (RMS) current and voltage, Active, reactive and apparent power, power factor calculation
- Energy metrology software with pulsed outputs to a reference test system including results displaying on a Microsoft® Windows® PC GUI

Software and evaluation board design resources can be download here[Downloadlink]

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1 System Introduction

This document discuss an application of a single-phase AC power monitor using a simple, low-cost Texas Instruments MCU MSPM0C1104. The MSPM0C1104 is a mixed signal microcontroller that integrates with a 12-bit SAR ADC for voltage and current sensing and UART communication interface to communicate with the GUI that running at PC. TLV9062 also a low cost two channel OPA that to used for the current and voltage differential signal sensing. (Also can just used a MSPM0L1304 include two internal OPAs)

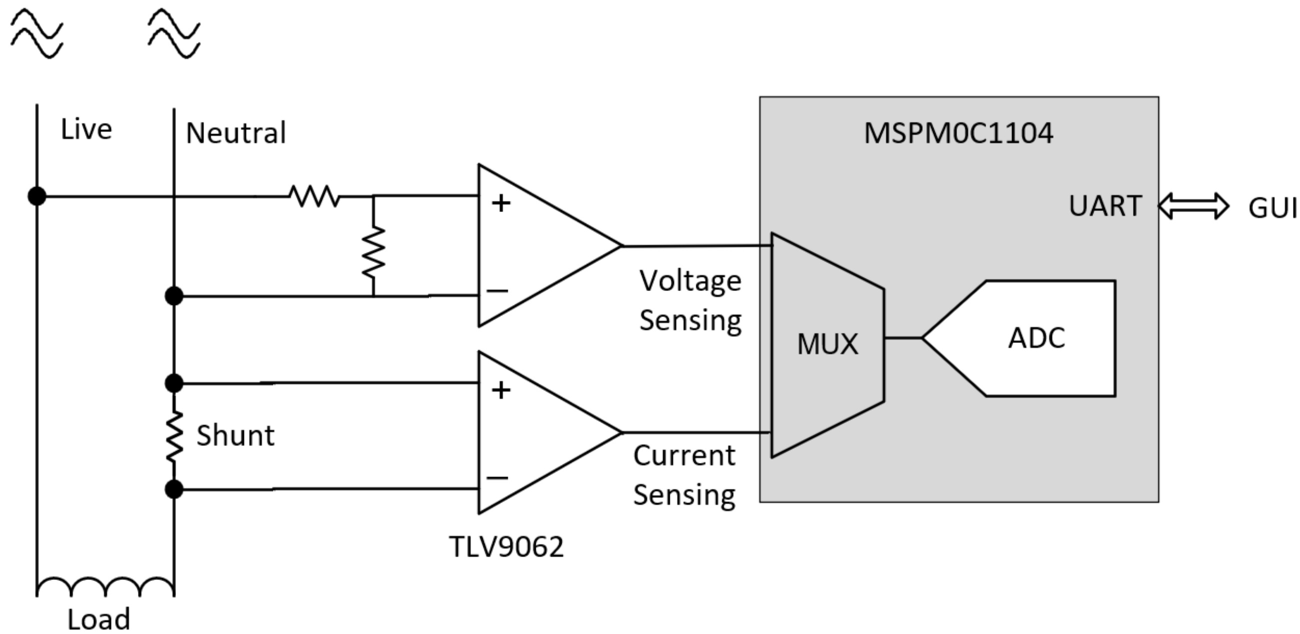

Figure 1-1. Diagram of power monitor with MSPM0C1104

2 Hardware Implementation

2.1 Power Supply

In this demo, MSPM0C1104 and TLV9062 are both powered from a LDO TLV76133 that can input from 3.3V to 18V and output 3.3V.

2.2 Voltage sensing

The voltage from the mains is usually 230 V and needs to be brought down to a range of 3.3 V (ADC reference). The analog front end for voltage consists of a simple voltage divider and an OPA to add bias of the voltage signal that make it can be sensing by a single-ended ADC. A protection diode parallel with R8 is recommended added to limited the input voltage signal in a safe range (it not implemented in this demo).

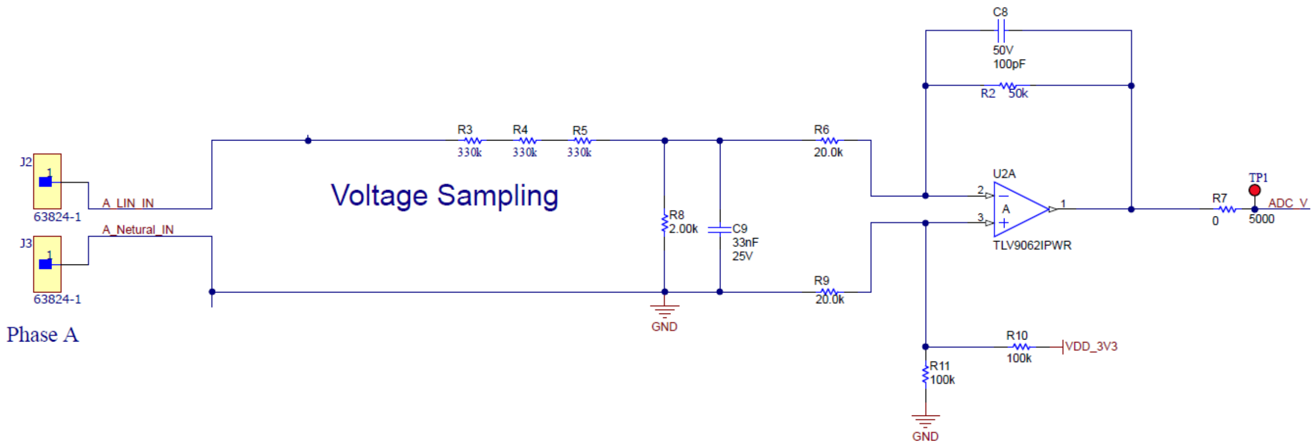

Figure 2-1. Analog Front End for Voltage Inputs

For the bias is recommend to make it ½ ADC reference voltage, in this demo the ADC reference using VDD as reference. So select proper value of R10 and R11 to make the bias about to 1.65V.

2.3 Current Inputs

In the current sensor interface circuit with R12 being the shunt sensor and an OPA to convert the differential signal to single-ended signal. A protection diode parallel with R12 is recommended added to limited the input voltage signal in a safe range (it not implemented in this demo). For the bias circuit is the same with the voltage sensing.

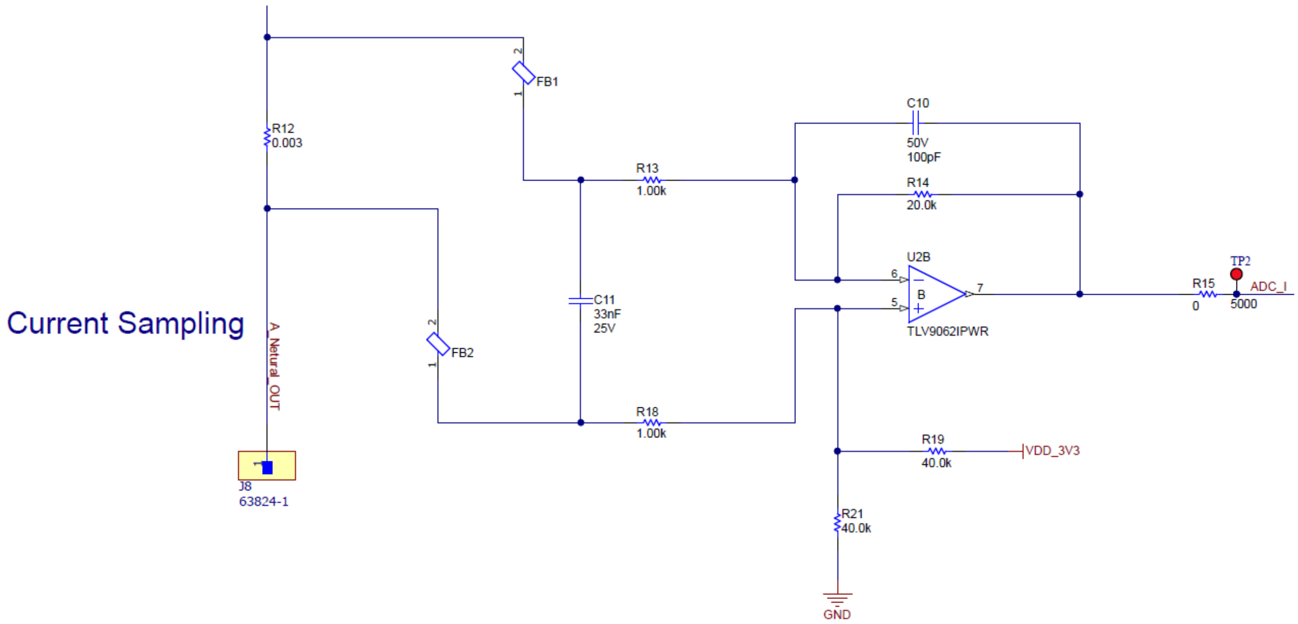

Figure 2-2. Analog Front End for Current Inputs

3 Software Introduction

3.1 Peripherals Setup

The primary peripherals used for this application are the 12-bit ADC, internal REF (optional), timer, and UART.

For the ADC is configured as sequence conversion mode and the sample-hold time as 1us.The ADC refence in this demo is used VDD. A timer is used to trigger the ADC with sample rate 4Ksps. For the UART is used to communicate with the GUI that using baud rate 115200, no parity and one stop bit.

3.2 Metrology Computation Engine

The metrology computation engine performs the actual sampling and computation based on the information collected from the voltage and current ADC channels. The engine acts in a time-critical background process and a less time-critical foreground process.

The background process is triggered by the ADC at the sample rate. This process runs in the interrupt services routine of the ADC and is processed automatically.

The foreground process is triggered by the completion of background process at the reporting and update rate. The background process sets the flag HAL_ADC_PHASE_A_DATA_READY

in the variable phaseDataReady to indicate that data is ready to be processed by the foreground. The application then needs to monitor this flag to trigger the foreground process by calling to EM_processForegroundData(). In the actual computation, use the following formulas in the metrology computation

$$V_{\mathrm{RMS}} = \mathrm{VGAIN} \times \sqrt{\frac{1}{N} \times \sum_{i=1}^{N} V_{\mathrm{samp}(i)} \times V_{\mathrm{samp}(i)}} \tag{1}$$

$$I_{\mathrm{RMS}} = \mathrm{IGAIN} \times \sqrt{\frac{1}{N} \times \sum_{i=1}^{N} I_{\mathrm{samp}(i)} \times I_{\mathrm{samp}(i)}} \tag{2}$$

$$P_{\mathrm{active}} = \mathrm{PGAIN} \times \frac{1}{N} \times \sum_{i=1}^{N} V_{\mathrm{samp}(i)} \times I_{\mathrm{samp}(i)} \tag{3}$$

$$P_{\mathrm{reactive}} = \mathrm{PGAIN} \times \frac{1}{N} \times \sum_{i=1}^{N} V_{\mathrm{samp},90(i)} \times I_{\mathrm{samp}(i)} \tag{4}$$

$$P_{\mathrm{apparent}} = V_{\mathrm{RMS}} \times I_{\mathrm{RMS}} \tag{5}$$

$$\mathrm{PF} = \cos\varphi = \frac{P_{\mathrm{active}}}{P_{\mathrm{apparent}}} \tag{6}$$

3.3 Foreground Process

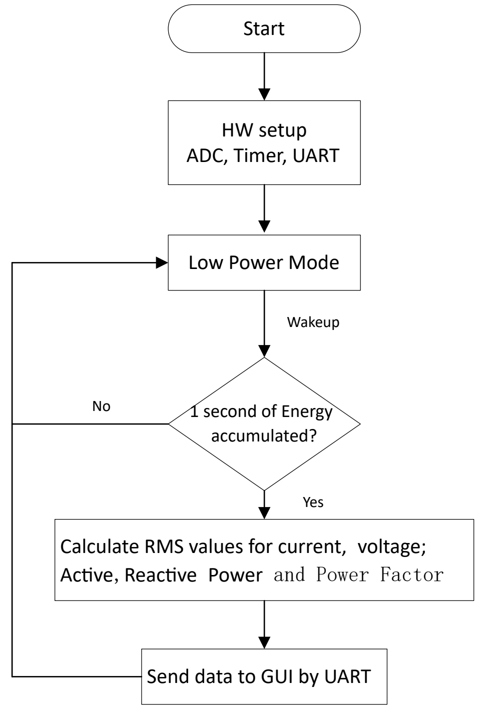

Figure 3-1. Foreground Process Diagram

The initialization routines involve the setup of the ADC, Timer, general purpose input/output (GPIO) port pins and UART. The device will go into low power mode in the while(1) loop. During normal operation, the background process that the ADC interrupts every 256 us/4KHz will wakeup the CPU and the foreground process will to check 1 second of energy accumulated flag. This is equivalent to accumulation of 50 or 60 cycles of data samples synchronized to the incoming voltage signals and current signals. 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 variables in ADC interrupt to further process and obtain the RMS and mean values in the foreground process.

3.4 Background Process

The background process is the ADC's interrupts with 4KHz. In the interrupt, it will read the ADC results of voltage and current and then remove residual DC and accumulate the samples for Irms, Vrms, active power and reactive power. It will also calculate the frequency and then check 1 second of energy accumulated is meet or not.

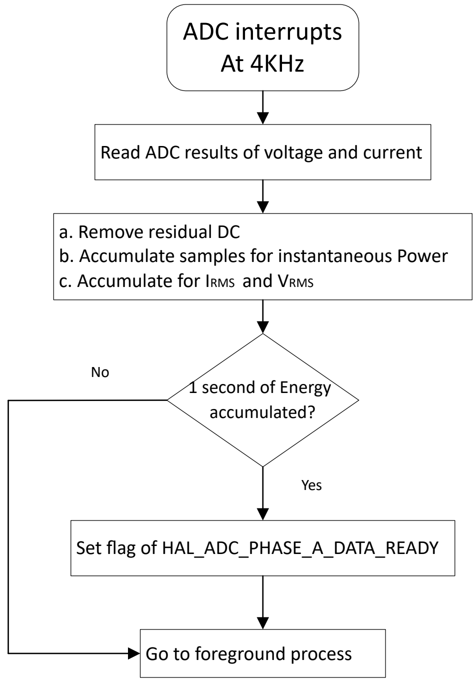

Figure 3-2. Background Process Diagram

3.5 PC GUI Introduction

There is a GUI that write by python QT5 and can help to show the test results easily. The GUI also can save the results automatically in a excel file when needed.

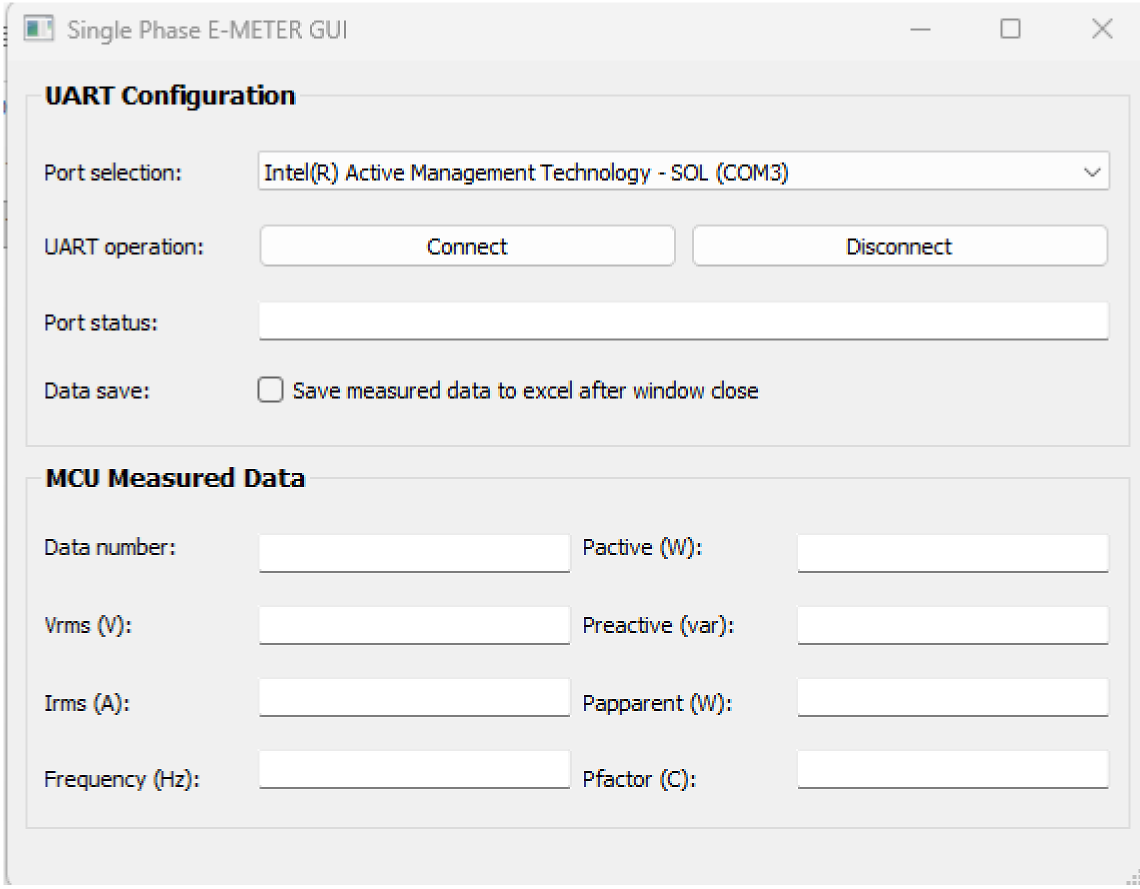

Figure 3-3. PC GUI

To use the GUI need to connect the MSPM0C1104 with a USB to UART tool, for this demo use a XDS110 UART back channel on a launchpad. Open the GUI and select correct COM port that the USB to UART tool used and click “Connect”. When click the connect the GUI will send one byte “0x22” to notice MSPM0C start to send meter results data every 1s. The data format as below

Harder(0x80) + data(38 bytes)

Table 3-1. Data section detials

Item	length(LSB byte first)	format
VRMS	4 bytes	IQ14
IRMS	4 bytes	IQ14
Frequency	2 bytes	actual frequency*100
Active power	8 bytes	IQ8
Reactive power	8 bytes	IQ8
Apparent power	8 bytes	IQ8
Power factor	4 bytes	Actual PF*10000

For IQ14 or IQ8, to get the actual data just need to divided by 2^14 or 2^8.

4 Demo Board Quick Start and Calibration

4.1 Evaluation Board Introduction

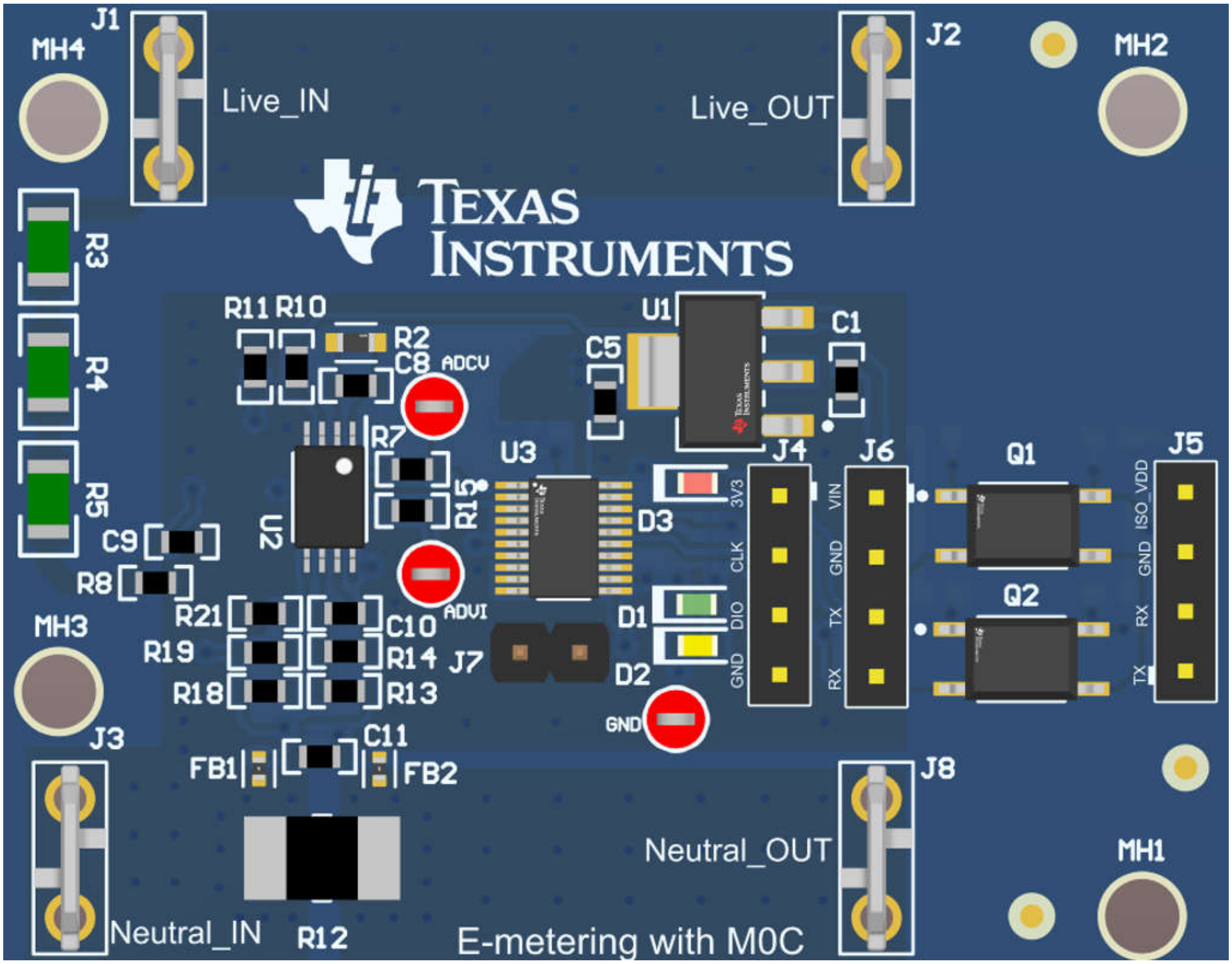

Figure 4-1. Evaluation Board

Table 4-1. Evaluation Board Connectors

Header Name	Main Function	Comments
J1	Live line input	
J2	Live line output	
J3	Neutral line input	
J8	Neutral line output	
J4	SWD program port	Can supply 3.3v directly
J6	DC Power supply and communication port	DC power supply and the UART port, for the DC voltage can be suppled from 3.3v~18v
J5	Isolation communication port	Isolation VDD is needed here

4.2 Scaling Factor Calibration

To make the solution can be used with different AFEs, scaling factors be defined that to correct the gain error in the system. In the source code of MSPM0C1104 provide four scaling factors for Vrms, Irms, active power and reactive power. The scaling factors are defined in the file user_config.h.

5 Test Results

For this solution is tested based on the hardware below

- AC source: Chroma programmable AC source 61503(accuracy 0.2%)
- Resistor load: LINGO Dry type load bank
- Temperature test chamber: Votsch VT4002
- The accuracy of resistors on the EVM board based on 1%

Table 5-1. Different current load accuracy test- current and voltage

Current reference(A)	Current measure(A)	Current error(A)	Current error %	Voltage reference(V)	Voltage measure(V)	Voltage error(V)	Voltage error %
0.34	0.344	0.004	1.18(max)	220.1	220.42	0.32	0.15
0.69	0.698	0.008	1.16	220.1	220.29	0.19	0.09
1.04	1.0412	0.0012	0.12	220.2	220.26	0.06	0.03
1.39	1.387	-0.003	-0.22	220.1	220.04	-0.06	-0.03
1.72	1.726	0.006	0.35	220.1	219.91	-0.19	-0.09
2.07	2.073	0.003	0.14	220	219.83	-0.17	-0.08
2.42	2.422	0.002	0.08	220	219.67	-0.33	-0.15
2.76	2.759	-0.001	-0.04	220	219.56	-0.44	-0.2
3.1	3.106	0.006	0.19	220	219.53	-0.47	-0.21
3.44	3.444	0.004	0.12	220	219.39	-0.61	-0.28(max)

Table 5-2. Different current load accuracy test – Active power

Power reference(W)	Power measure(W)	Power error (W)	Power error %
76.2	75.64	-0.56	-0.73(max)
153	153.46	0.46	0.3
229	228.96	-0.04	-0.02
305.2	304.57	-0.63	-0.21
379.5	379.06	-0.44	-0.12
455.9	455.07	-0.83	-0.18
532.7	531.07	-1.63	-0.31
607	604.75	-2.25	-0.37
683.2	680.68	-2.52	-0.37
757.5	754.33	-3.17	-0.42

Table 5-3. Typical Accuracy versus Temperature

Temp(℃)	Voltage(V)			Current(A)			Active Power(W)		
	Vmeasure	Vref	Error(%)	Imeasure	Iref	Error(%)	Pmeasure	Pref	Error(%)
0	219.21	220	-0.36	2.066	2.07	-0.19	452.17	456	-0.84
10	219.55	220	-0.2	2.071	2.07	0.05	453.97	456.6	-0.58
20	219.79	220	-0.1	2.075	2.07	0.24	455.3	456.5	-0.26
25	219.89	220	-0.05	2.076	2.07	0.29	455.79	456.5	-0.16
35	220.18	220	0.08	2.08	2.07	0.48	457.34	456.5	0.18
45	220.45	220	0.2	2.084	2.07	0.68	458.69	456.5	0.48
55	220.72	220	0.33	2.087	2.07	0.82	460.04	456.6	0.75
65	220.96	220	0.44	2.091	2.07	1.01	461.41	456.6	1.05
75	221.21	220	0.55	2.095	2.07	1.21	462.7	456.6	1.34
85	221.44	220	0.65(max)	2.098	2.07	1.35(max)	463.91	456.6	1.6(max)

6 References

- Texas Instruments: MSPM0C1104 Datasheet
- Texas Instruments: Single-Phase AC and DC Power Monitor with Wire Resistance and EMI Capacitor Compensation

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