Application Report
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Energy Measurement Results for CTs and Shunts on a TI Designed Meter Using MSP430AFE2xx Devices

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ABSTRACT

This application report describes the results obtained on a single phase electronic electricity meter using the Texas Instruments MSP430AFE2xx metering processors. These tests are indicative of the performance of a meter designed by Texas Instruments and is subject to differ based on sensor selection, board layouts and other design considerations. The results include energy accuracies for active and reactive energy for 50 mA to 100A, a dynamic range of 2000:1.

WARNING

Failure to adhere to these steps 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.

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1 Sensors

Any metering application requires that the sensors to be selected up front, depending on the accuracies required and the current ranges. In this document, current transformers (CT) and shunt resistors were selected as part of the testing. The current transformer selected is rated for 100A with a turns-ratio of 2000:1 and the shunt resistors selected are 100 μΩ, 200 μΩ and 400 μΩ.

1.1 Voltage Inputs

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

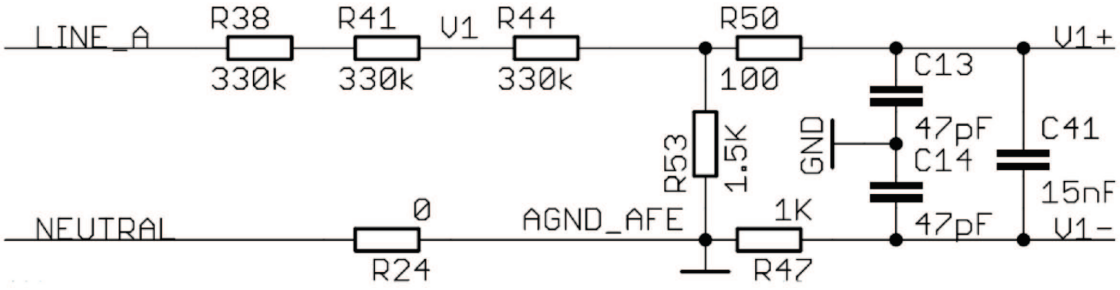

Figure 1. Analog Front End for Voltage Inputs

1.2 Current Inputs

The analog front end for current inputs is a little different from the analog front end for the voltage inputs. Figure 2 shows the analog front end used for current channel I1 and I2.

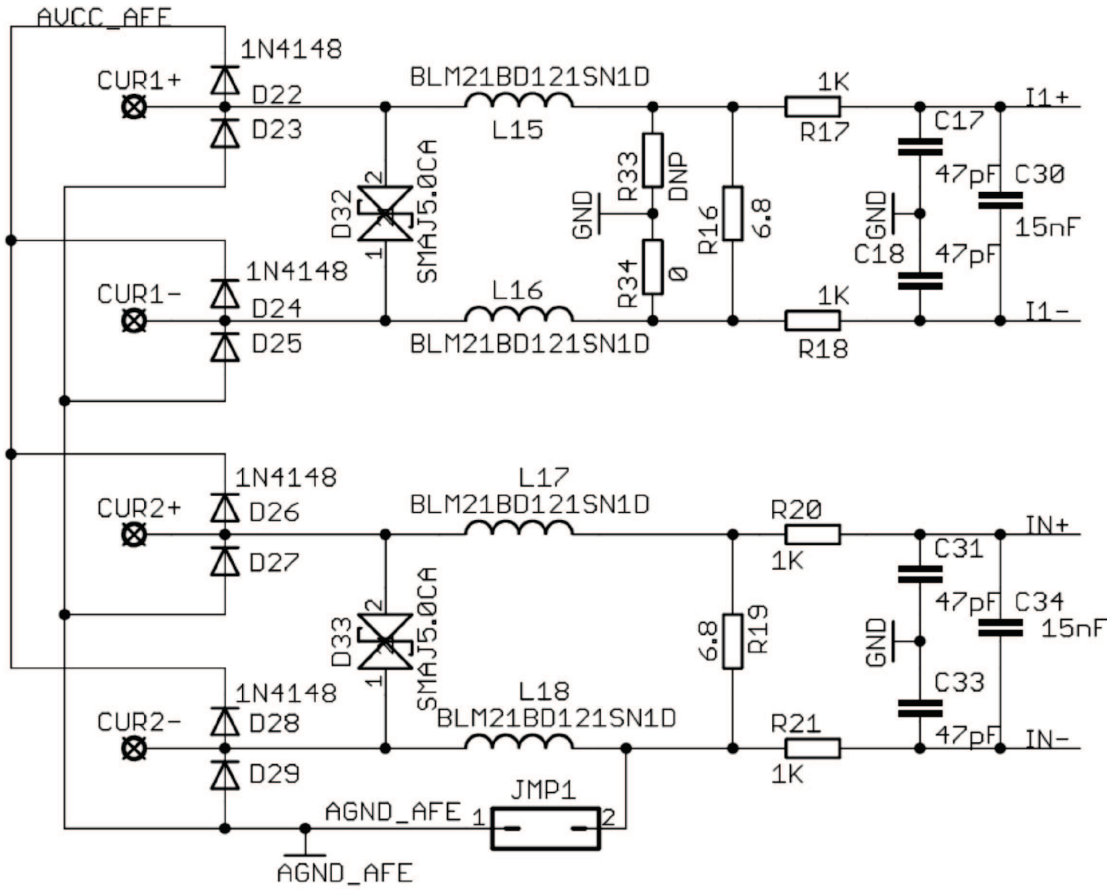

Figure 2. Analog Front End for Current Inputs

Resistor R16 is the burden resistor that would be selected based on the current range used and the turns-ratio specification of the CT (not required for shunt). The value of the burden resistor for this design is around 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. If a shunt resistor is used, you can place it between CUR1+ and CUR1- pins of the EVM. Note that the burden resistor can still exist for this condition and will not affect performance.

2 Current Transformer Results

The results obtained by the Current transformer are shown in this section. The gain selected on both the voltage and the current ΣΔ converter is 1.

Table 1. CT Results for Active and Reactive Energy Error [(1)]

	Active for CT			Reactive for CT	
	0 Deg	60 Deg	-60 Deg	60 Deg	-60 Deg
Current	(% error)	(% error)	(% error)	(% error)	(% error)
0.05	-0.045	-0.051	-0.16	-0.247	0.148
0.1	-0.025	-0.013	-0.118	-0.185	0.099
0.25	0.016	0.048	-0.045	0.019	0.083
0.5	0.029	0.067	-0.013	0.058	0.074
1	0.032	0.0077	0.01	0.08	0.061
2	0.016	0.067	-0.009	0.083	0.055
5	0.026	0.045	0.032	0.055	0.083
10	0.005	0.012	0.049	0.003	0.008
20	-0.021	-0.043	0.053	-0.0073	-0.014
30	-0.021	-0.053	0.075	-0.0107	-0.019
40	-0.043	-0.064	0.053	0.00037	-0.0557
50	-0.032	-0.075	0.086	0.0177	-0.0497
70	-0.053	-0.17	0.107	0.032	-0.0607
80	-0.049	-0.17	0.096	0.0283	-0.039
90	-0.05	-0.18	0.104	0.0393	-0.018
100	-0.051	-0.178	0.102	0.04	-0.03

(1) Performed with a 100A customized CT with a turns ratio of 2000:1.

Results summary:

- Results are measured at room temperature
- Results easily pass <0.1% error in accuracy for active energy measurements
- The results show consistency of the error performance over a dynamic range of 2000:1
- The same results can be achieved for any current ranges as long as they fall under this dynamic range

3 Shunt Results

The results obtained by the shunt resistor are shown in this section. The gain selected on the voltage converter is maintained at 1 and the current ΣΔ converter gain is varied depending on the shunt resistor value chosen.

Case 1: Shunt of 400 µΩ

When the shunt value of 400 µΩ is chosen, the gain of the current ΣΔ converter is set to 8. This is line with the adherence to the voltage at the inputs of the ΣΔ converter do not cross 500 mV at the maximum current of 100A. The results for this configuration are shown in Table 2.

Table 2. 400µΩ Shunt Results for Active and Reactive Energy Error [(1)]

	Active for 400 µΩ Shunt			Reactive for 400 µΩ Shunt	
Current	Zero Deg (% error)	60 Deg (% error)	-60 Deg (% error)	60 Deg (% error)	-60 Deg (% error)
0.05	0.205	0.237	0.263	-0.217	0.282
0.1	0.08	0.055	-0.004	-0.118	0.093
0.25	0.058	-0.07	0.2	-0.019	0.067
0.5	0.048	-0.09	0.18	0.055	0.055
1	0.0333	0.133	0.069	0.064	0.047
2	0.016	0.081	-0.088	-0.025	0.103
5	0.028	0.0345	0.0267	0.0517	0.0907
10	0.007	-0.02	0.0123	0.0203	0.0593
20	0.0073	-0.0073	-0.0177	0.0107	0.053
30	0.014	0	-0.0073	0.0213	0.064
40	0.0177	0	-0.0073	0.0287	0.075
50	0.0357	0.011	0.0247	0.0497	0.0823
70	0.0567	0.025	0.043	0.0677	0.0927
80	0.075	0.046	0.0603	0.0857	0.114
90	0.0823	0.0567	0.082	0.1073	0.1353
100	0.1033	0.0688	0.107	0.1247	0.1463

(1) Vishay Meter Shunt Resistor WSMS3124 family: http://www.vishay.com/docs/30173/wsms3124.pdf

Results summary:

- Results are measured at room temperature
- Results easily pass <0.1% error in accuracy for active energy measurements except for lowest current
- The results show consistency of the error performance over a dynamic range of 2000:1
- The same results can be achieved for any current ranges as long as they fall under this dynamic range

Case 2: Shunt of 200 µΩ

When the shunt value of 200 µΩ is chosen, the gain of the current ΣΔ converter is set to 16. This is line with the adherence to the voltage at the inputs of the ΣΔ converter do not cross 500 mV at the maximum current of 100A. The results for this configuration are shown in Table 3.

Table 3. 200 µΩ Shunt Results for Active and Reactive Energy Error (1)

	Active for 200 µΩ Shunt			Reactive for 200 µΩ Shunt	
Current	Zero Deg (% error)	60 Deg (% error)	-60 Deg (% error)	60 Deg (% error)	-60 Deg (% error)
0.05	-0.228	-0.223	-0.273	-0.379	0.397
0.1	-0.143	-0.129	-0.271	-0.366	0.369
0.25	-0.166	-0.107	-0.274	-0.339	0.294
0.5	-0.141	-0.177	-0.119	-0.2425	0.3015
1	-0.0985	0.0655	-0.131	-0.0605	0.0945
2	-0.088	-0.178	-0.0755	-0.1597	0.0547
5	-0.1107	-0.114	-0.148	-0.069	-0.001
10	-0.002	-0.014	-0.005	-0.019	0.0587
20	-0.0213	0.0037	-0.0247	-0.032	0.0533
30	-0.0143	0	-0.021	-0.032	0.051
40	-0.0177	-0.0143	-0.0497	-0.0343	0.0463
50	-0.0463	-0.0393	-0.0283	-0.0247	0.039
70	-0.0643	-0.0783	-0.1347	-0.071	0.021
80	-0.101	-0.149	-0.1527	-0.092	-0.063
90	-0.1273	-0.1277	-0.1987	-0.1773	-0.1027
100	-0.255	-0.195	-0.241	-0.209	-0.1667

(1) Vishay Meter Shunt Resistor WSMS3124 family: http://www.vishay.com/docs/30173/wsms3124.pdf

Results summary:

- Results are measured at room temperature
- Results easily pass <0.2% error in accuracy for active energy measurements except for lowest current
- Errors tend to be higher for higher gains of the PGA on the ΣΔ converter
- The results show consistency of the error performance over a dynamic range of 2000:1
- The same results can be achieved for any current ranges as long as they fall under this dynamic range

Case 3: Shunt of 100 µΩ

When the shunt value of 100 µΩ is chosen, the gain of the current ΣΔ converter is set to 32. This is line with the adherence to the voltage at the inputs of the ΣΔ converter do not cross 500 mV at the maximum current of 100A. The results for this configuration are shown in Table 4.

Table 4. 100 µΩ Shunt Results for Active and Reactive Energy Error (1)

	Active for 100 µΩ Shunt (% error)			Reactive for 100 µΩ Shunt	
Current	Zero Deg (% error)	60 Deg (% error)	-60 Deg (% error)	60 Deg (% error)	-60 Deg (% error)
0.05	-0.441	-0.362	-0.383	-0.326	0.295
0.1	-0.338	-0.308	-0.367	-0.285	0.303
0.25	-0.181	-0.2985	-0.3655	-0.559	0.2915
0.5	-0.061	-0.2285	-0.228	-0.273	0.243
1	-0.039	-0.0453	-0.005	-0.182	0.143
2	-0.012	0.0723	-0.218	-0.1497	-0.0267
5	0.013	0.127	-0.147	-0.1403	-0.086
10	0.014	0.1593	-0.1513	0.008	0.0633
20	-0.0073	0.1813	-0.1707	-0.0107	0.0533
30	-0.0107	0.146	-0.202	-0.0107	0.032
40	-0.057	0.1247	-0.223	-0.039	0.0213
50	-0.0533	0.0927	0.0787	-0.043	-0.0143
70	-0.1913	-0.3433	-0.305	-0.142	-0.0603
80	-0.2517	-0.1277	-0.4093	-0.181	-0.1843
90	-0.4457	-0.2413	-0.448	-0.333	-0.2377
100	-0.499	-0.361	-0.693	-0.4247	-0.4143

(1) Vishay Meter Shunt Resistor WSMS3124 family: http://www.vishay.com/docs/30173/wsms3124.pdf

Results summary:

- Results are measured at room temperature
- Results easily pass <0.5% error in accuracy for active energy measurements except for lowest current
- High current tends to heat the resistor; these thermal effects are prone to show worse results at high temperatures. In most cases, these are outliers.
- Errors tend to be worse for PGA gain of 32 on the ΣΔ converter
- The results show consistency of the error performance over a dynamic range of 2000:1
- The same results can be achieved for any current ranges as long as they fall under this dynamic range

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