A Power Meter Reference Design Based on the ADE7756

by Stephen English

INTRODUCTION
This application note describes a high-accuracy, low-cost power meter based on the ADE7756. This design is for use in the North American three wire/single phase application. This meter may be used in a single phase, two wire distribution system with a minimum amount of changes*. The reference design is comprised of the ADE7756, a microcontroller, LCD display, serial interface and power supply.

The ADE7756 is designed to interface to a microcontroller through a serial interface (SPI). The SPI port allows the user to calibrate various components of the meter including gain, offset and phase errors. The purpose of the microcontroller is to send display data to the LCD and control the various functions of the meter. An EEPROM is used to store various calibration parameters of the meter and store meter’s data during a brown-out.

The ADE7756 is comprised of two ADCs, a reference circuit and all the signal processing necessary for the calculation of real (active) power. Circuitry is provided to null out various system errors including gain, phase, and offset errors. Additional circuitry provides waveform sampling, programmable interrupts and power line monitoring. All registers of the ADE7756 are available through the SPI port. See the ADE7756 data sheet for their descriptions. The data sheet provides detailed information on the functionality of the ADE7756 and will be referenced several times in this application note.

The entire meter is calibrated through an external calibration routine by a PC through an external SPI interface. This application note should be used in conjunction with the ADE7756 data sheet.

DESIGN GOALS
The goal for this meter is to comply with the ANSI C12.16 specifications. The reference design is for a single element, Class 100 meter in a form 2S designation. This designation complies with the wiring arrangements as defined in ANSI C12.16-1991. Although the design in this application is limited to the ANSI standard, the accuracies achieved are well within the accuracy requirements of the IEC1036 standards for a class 1 meter. For reference, see the section at the end of this application comparing the IEC1036 and ANSI C12.16 standards. This section explains the key IEC1036 specifications in terms of their ASNI equivalents.

This design greatly exceeds the definition for many of the accuracy requirements, e.g., accuracy at unity power factor and at low (PF = ±0.5) power factor. In addition the dynamic range performance of the meter has been extended to 500. The ANSI standard defines the maximum current of a Class 100 watt-hour meter as 100 Amps with a reference current (IREF) of 15 amps. The Accuracy Class is defined in Table 1 for both the Accuracy Class 0.5 and Class 0.2 static watt-hour meters. The current range (dynamic range) for accuracy is specified in terms of IREF.

<table>
<thead>
<tr>
<th>Current Value</th>
<th>PF</th>
<th>Percentage Error Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1IREF ≤</td>
<td>I</td>
<td>1</td>
</tr>
<tr>
<td>1 Amps</td>
<td>±1.0%</td>
<td>±0.4%</td>
</tr>
<tr>
<td>3 Amps</td>
<td>±1.0%</td>
<td>±0.5%</td>
</tr>
<tr>
<td>50 Amps</td>
<td>±0.6%</td>
<td>±0.3%</td>
</tr>
<tr>
<td>100 Amps</td>
<td>±0.6%</td>
<td>±0.3%</td>
</tr>
</tbody>
</table>

NOTES
1 The current ranges for specified accuracy shown in table 1 are expressed in accordance with Load performance test, ANSI C12.20-1998 Section 5.4.2.3, Table 4, in terms of the reference current.
2 Power Factor (PF) in Table 1 relates the phase relationship between the fundamental (65Hz to 65Hz) voltage and current waveforms. PF in this case can be simply defined as PF = cos(f), where f is the phase angle between pure sinusoidal current and voltage.
3 Accuracy Class is defined as the limits of the permissible percentage error. The percentage error is defined as:

\[
\text{Percentage Error} = \frac{\text{energy registered by meter} - \text{true energy}}{\text{true energy}} \times 100\%
\]
OPERATION MODES
This section describes the operation of the reference meter. The meter itself is comprised two boards, the meter board and the power supply board. The operation of the meter board is described in four parts; initialization, normal operation mode, calibration mode and power down. Another section describes the power supply for the meter.

The meter board is comprised of the ADE7756, a microprocessor or uC, an EEPROM and a LCD display. The ADE7756 provides the measurement for the system. The uC provides the control for the meter as well as communications. The EEPROM provides nonvolatile storage of various coefficients as well as energy.

Initialization
Upon power-up, the uC senses the voltage at pin 28 (RB7) to determine the selected mode of operation. If the voltage sensed is low, the uC goes into the calibration mode. If the level sensed is high, the meter goes into the initialization routine prior to the normal mode of operation. The initialization routine loads the coefficients from the EEPROM in to the various registers of the ADE7756. This data is transferred through the uC. See the EEPROM memory mapping for addresses of the various registers. In addition, two parameters are read into the uC. This includes previously stored energy and the conversion coefficient. A detailed description of the calibration routine is discussed in a later section. The previously stored energy is read from the EEPROM and placed in an 11-byte register in the uC. The conversion coefficient in the uC converts the AENERGY reading from the ADE7756 into KWH. Upon completion of this routine, it begins to function as a meter.

Normal Mode
The uC continually reads the data from the ADE7756. See the ADE7756 data sheet for a detailed description of the power measurement and register descriptions. The energy read from the AENERGY register of the ADE7756 is multiplied by the conversion constant in the uC, and accumulated with the previously stored data. This result is the total KWH measured by the meter. The results are updated to the LCD every second. In addition, the uC monitors both the IRQb and SAGb pin from the ADE7756. If during the normal operation, a power out or SAG is detected, the ADE7756 will send an interrupt to the uC. This puts the uC into the power down mode.

Calibration Mode
In calibration mode, the output pins of the uC go in to tri-state. An external interface to the SPI port provides communication to a PC, the ADE7756 and the EEPROM. Calibration coefficients are calculated in the PC based on the ADE7756 measurements and transferred to the EEPROM through the SPI port. Although the control of the meter is done through the SPI port, an external RS232 port is also provided. This allows the user to write a routine to communicate to the meter through a different communication bus.

During calibration, the PC controls all signal sources and provides the calculations necessary to calibrate the meter. This minimizes the size of the uC’s program. Upon completion of the meter calibration, the PC writes all the necessary coefficients to the EEPROM (See EEPROM memory mapping table for memory addresses). At the completion of the meter calibration, the meter is powered off. Upon power up, with pin 28 (of the uC) high, the meter goes in to the initialization routine, loads the coefficients and begins to operate in normal mode.

Power Down Mode
The uC continually monitors the interrupt pin as well as the SAG pin of the ADE7756. The ADE7756 provides an interrupt under several conditions. If a power loss is de-
tected by the ADE7756, an interrupt occurs. This interrupt now places the uC into the power down mode of operation. The power down mode takes 1.4 ms to store all data prior to the loss of power. Data includes the energy stored in the uC accumulated energy register as well as the energy in the ADE7756's register. Upon power up, the initialization sequence restores the data in the ADE7756 registers along with the accumulated energy reading from the previous data. All calibration coefficients are restored in the system, the system returns to normal mode.

DETAILED DESCRIPTION

This section describes the meter's hardware and purpose of each section in the overall design.

The front end of the meter is comprised of the voltage and current input networks. The line voltage is attenuated and filtered through an anti-aliasing filter. This filter is described in the section Channel 2 Input Network. The current channels are converted from a current to a voltage through a current transformer (See Item 24, BOM, Meter board) and a burden resistor. The output of this network is filtered before being applied to the inputs V1P and V1N. The ADE7756 multiplies the two current signals with the voltage signal and accumulates the results in the AENERGY register. An LED is used to display the energy measured in IMP/KWH. See the ADE7756 for a detailed description of this operation.

The uC is used to read the AENERGY register of the ADE7756 through the SPI communication port. A data transfer occurs when CSb becomes active. The uC sends the read AENERGY command and reads the data back from the register. This data is then multiplied within the uC and converted to BCD. Results are sent to the LCD display. Additional data from the ADE7756 can be read through the SPI port including waveform samples, temperature and various interrupts.

DESIGN EQUATIONS

The ADE7756 contains a register that is proportional to the total accumulated energy. In addition, the ADE7756 has an output pin with a frequency proportional to the product of the voltages. This section describes the equations necessary to calibrate the meter. Results from these calculations are used to set the coefficients in the ADE7756 and uC registers.

The meter is calibrated by setting V1 and V2 to the calibration signal and reading the accumulated energy register (in the calibration mode). This measurement is used to calculate total power over an integral number of power line cycles. The results are used to calibrate both the output frequency at CF and the accumulated energy. The detailed functionality of the ADE7756 is explained in the ADE7756 data sheet. Equation 1 is used to calculate the average word from the multiplication of V1 and V2.

\[
\text{Avg Word} = \frac{\text{Line Freq} \times \text{Energy} \times 8}{\# \text{ of Power Line Cycles} \times \text{Osc Freq}} \quad (\text{Eq. 1})
\]

The Avg word (LPF2) is used to calibrate the front end of the ADE7756. The output frequency of CF is set by adjusting various registers within the ADE7756. A coefficient is then calculated to determine the accumulated energy register values. Equation 2 calculates the CF output frequency for the given inputs.

\[
CF (Hz) = \frac{\text{Average LPF 2 output \times CLKIN}}{2^{23}} \quad (\text{Eq. 2})
\]

The output frequency of CF (from Eq 2) is used to calibrate the CFDIV register. This calibration is used to set the number of impulses per kilowatt-hour for the meter, the meter constant. Setting the frequency to the proper range is accomplished through the equation 3.

\[
\text{CFDIV} = \frac{\text{Frequency(CFDIV = 0)}}{\text{Desired Frequency}} - 1 \quad (\text{Eq. 3})
\]

An additional error still exists in the system and is calibrated out through the APGAIN register. The error is nulled out by adjusting the power gain in the APGAIN register. In order to adjust the APGAIN register, the error for the frequency at CF is calculated. This error is calculated from the ratio of CF at 00hex and CF at the setting from equation 3. Equation 4 calculates the CF Ratio.

\[
\text{CF out} = \frac{\text{CF}}{\text{CFDIV} + 1} \quad (\text{Eq. 4})
\]

The CF ratio is then used to calculate the error in the output frequency compared to the desired value. The desired value is defined as the meter constant (IMP/KWH) x calibration power. This result is used to adjust the APGAIN register. Error is equal to 100% \times (CF_{desired} - CF_{out}) / CF_{out}. Equation 5 calculates the new setting for the APGAIN register.

\[
\text{APGAIN setting} = \text{Error} \times 2^{12} \quad (\text{Eq. 5})
\]

Upon calibrating the CF channel, the coefficient for the energy is now calculated. While in calibration mode, the meter is allowed to accumulate power for SAGCYCLE register number of power cycles. The accumulated energy register is read once more. This new reading accounts for the adjustment made in the APGAIN
Additional calibration coefficients may be calculated for current and voltage. These coefficients are used in the waveform sampling mode to calibrate the waveform samples. This design does not use this mode however, the information concerning these coefficients is included.

In order to correct for a phase error, the ADE7756 has a phase adjust register PHCAL. Calibrating the phase error is accomplished by setting the meter to a current and voltage reference value then adjusting the PF to 0.5. A small error at 60 degrees (PF=0.5) will cause a large error in the power calculation. Using the Equation 7, the meter error is calculated in measured power versus the calculated power. Since calculated power is the calibration power times the power factor, the error is a result of the phase difference between the two quantities. The phase error is then calculated by the equation 8.

\[
\text{Error} = \frac{\text{Measured Power} - \text{Calculated Power}}{\text{Calculated Power}} \quad (\text{Eq. 7})
\]

\[
\text{Phase Error} = -\arcsin\left(\frac{\text{Error}}{\sqrt{3}}\right) \quad (\text{Eq. 8})
\]

The phase error (in degrees) is then nulled out by writing the phase error in to the PHCAL register. The phase calibration register introduces a time delay in channel 2 at the rate of 4.47 us/LSB. At 50 Hertz, the resolution of the system is 0.08 degrees/LSB, at 60 Hertz it is 0.096 degrees/LSB.

The ADE7756 has a waveform sampling mode for current, voltage and power. This sampling mode allows the user a method of measuring various parameters including RMS. In order to calculate the coefficients for power, voltage and current, the mode register in the ADE7756 is placed in the waveform sampling mode. (See ADE7756 data sheet) Two hundred samples are read from the ADE7756 and the RMS value of the code is calculated. Calibration power divided by the RMS of the waveform samples is equal to KW/LSB. The mode register is set to Channel 1 waveform select and 200 samples are taken. The RMS of the waveform samples is divided in to the calibration current to calculate the AMPSRMS/LSB. The mode register is then set to channel 2 waveform select and 200 waveform samples are taken. The resulting number is a calibration coefficient to convert the waveform to VOLTSRMS/LSB.

Channel Offset is another source of error in the meter that can be calibrated out. The ADE7756 has a high pass filter in the current channel that prevents any DC term from entering the power calculation. Offsets can be calibrated out to maintain the dynamic range of the 2 ADCs in the ADE7756. (See ADE7756 data sheet, Analog Inputs section). The offset is nulled by grounding the inputs to the ADCs through bits 8 & 9 of the mode register. The waveform register is read and the offset is calculated using the equation;

\[
\text{Channel Offset} = \frac{\text{CODE}(\text{ADC}) \times \text{VREF}}{396,392} \quad (\text{Eq. 9})
\]

The results of the calculation are entered in to the channel offset register as sign magnitude. See Table II for the offset correction range and LSB size in the ADE7756 data sheet.

Temperature measurement is also available through the ADE7756. Calibration of the measurement is made at room temperature. The offset of the device is measured and stored. The uC subtracts the temperature offset from all subsequent measurements to correct for the offset error. The temperature coefficient is 1 degrees C/LSB.
**LCD DISPLAY**

The LCD display will display a minimum of four digits to display energy billing quantities as per ANSI C12.16-1991 sec 4.8.3. IEC1036 section 4.2.11 specifies that the display shall register and display, starting at zero, for a minimum of 1500 hours, the energy corresponding to maximum current at reference voltage and unity power factor. A value of 1500 hours at maximum current is 33,000KWH. A display with a five plus one digits is used, i.e., 10,000's 1,000's 100's 10's 1's 1/10's. In addition, the display must indicate negative current. This is indicated by the display character "**". In addition, the ANSI specification requires that all billing quantities be displayed for 4 seconds.

**ADE7756 Reference**

This design does not include an optional reference circuit. The on-chip reference circuit of the ADE7756 has a temperature coefficient of typically 30ppm/°C. However on A grade parts this specification is not guaranteed and may be as high as 80 ppm /°C. At 80ppm /°C the ADE7756 error at -20°C/+60°C could be as high as +0.65%, assuming a calibration at 25°C.

**Current Transformer Selection**

The current transformer is the device used in this design for measuring the load current. This sensor arrangement provides isolation as the line-to-line voltage differs by more than 300 V. Along with this required isolation, the CT affords an easy, reliable and cost effective way of combining (adding) the currents in both phase wires. Figure 3 illustrates the application used in this design for a Two-wire single phase meter. When selecting a current transformer care should be taken when evaluating the linearity of the current transformer under light load.

**CALIBRATING THE METER**

The meter is calibrated through the SPI port using an external calibration routine. This program calculates the various coefficients needed by the meter. These parameters are then stored in the EEPROM.

**Design Calculations**

Design parameters:
- Line voltage =220V (nominal)
- Class 100 meter with Imax = 100A
- Meter constant =3200 imp/kWh
- CT Turns ratio =1800

Meter will be calibrated at $I_{REF} = 15A$

Power dissipation at $I_b = 220V \times 15A = 3.3kW$

$V_1=354mV_{pk}$ max or $250mV_{RMS}$ Referred to input

$R_{BURDEN} = 354mV/(100A/1800) = 6.4 \text{ Ohm}$

At test current ($I_{REF} = 15A$)

$15A \times 6.4 \text{ Ohm} /1800 = 53.733mV$ Referred to Input

The input levels to the meter must be within the design constraints of the ADE7756. The input level to the voltage channel should be set to approximately half-scale. The current channel should be approximately 1/6th of full scale at $I_{REF}$. The input voltage of $V_1$ is set by the ratio of the current transformer and the burden resistor. As seen above the input level to the current channel is set to 54.7mV or 1/6th of full scale. The voltage channel ($V_2$) is attenuated through a resistor divider network to approximately 250mV_{RMS}. This configuration is for the 220 line voltage. In order to run the meter at 120 volts, the GAIN for channel 2 is increased to a gain of 2 through the GAIN register.

Calibration mode bit set with SAGCYC=80x, the average of LPF2 is calculated by reading the multiplier output of the waveform sampling register. The results for this measurement is 1462.47. Equation 2 is used to calculate the output frequency at CFDIV=00x. The output frequency is found to be 156 Hertz. The IMP/KWH is set at 3200IMP/KWH or

\[
\frac{\text{IMP}}{\text{KWH}} = \frac{3200\text{IMP}}{3600\text{sec}} = \frac{1}{1125}\text{Hz/KWH} \quad \text{(Eq. 10)}
\]

The meter constant is 0.8888 Hertz/KW from equation 8 above. The calibration power (3.3KW) is multiplied by the meter constant to determine the desired output frequency. CF is calculated to be 2.933Hz. Using equation 3, the CFDIV register is calculated. The results (52d) are written in to the CFDIV register.

CF is now calculated to be 160 HZ/(52+1) from equation 4. The result (2.9432) is used to calculate the percent error to be used in equation 5. The results (.34682%) are divided by 0.0244 (Eq 5) and written in to the APGAIN register (-14d or FF2x).

**CHANNEL 1 INPUT NETWORK**

Figure 3 shows the input stage to channel 1 of the meter. The current transformer with a turns ratio of 1800:1 is used for the design. The burden resistor is selected to give the proper input range for the ADE7756. The additional components in the input network provide filtering to the current signal. The filter corner is set to 4.8KHz for the anti-alias-filters.
From previous sections, it can be seen that the meter is simply calibrated by attenuating the line voltage down to 250mV. The line voltage attenuation is carried out by a simple resistor divider as shown in Figure 2. The topology of the network is such that the phase matching between channel 1 and channel 2 is preserved. As can be seen from Figure 2 the -3dB frequency of this network is determined by R4 and C4. This is due to R7(255kΩ) and R8(255kΩ) being much greater than R4 (1kΩ).

This meter can also be used in a 120 volt application as well. The attenuation network need not be changed as the voltage channel can be gained up internally in the ADE7756. The PGA Gain adjust register of the ADE7756 has channel 2 gains of 1, 2, 4, 8 and 16. This allows the user to program the voltage channel gain through software to match the line voltage. This maintains the dynamic performance of the meter by maintaining the SNR. It should be noted that switching the meter to 120 volt operation, the power supply transformer must be set-up to properly operate at that line voltage.

Since the ADE7756 transfer function is extremely linear a one point calibration (Ib) at unity power factor, is all that is needed in order to calibrate the meter. If the correct precautions have been taken at the design stage no calibration will be necessary at low power factor (PF = 0.5). A calibration routine for phase error is discussed earlier in this documentation in the Design Equations section. The next section discusses phase matching for correct calibration of the input networks at low power factor.

**CORRECT PHASE MATCHING BETWEEN CHANNELS**

Phase matching of the system is another critical issue. The errors induced in the system at PF=1 are minimal. A power factor of 0.5 with a phase error as little as 0.5 degrees will cause a 1.5% error in the power measurement. Some of the sources of the phase error are described later in this application note. This section describes the method used to calibrate out the phase error.

The ADE7756 has an internal phase compensation network to match the two input phases. The phase calibration register is a 2’s complement register, 6-bit, signed register which can introduce a time delay in the channel 2 signal path from +143us to -143us. This section describes some of the phase errors and how to compensate for them. Correct phase matching is important in energy metering applications since any phase mismatch between channels will translate into significant measurement error at low power factor. Proper matching reduces the amount of calibration needed for the overall accuracy of the system. This is easily illustrated with the following example. Figure 5 shows the voltage and current waveforms for a inductive load. In the example shown the current lags the voltage by 60° (PF=0.5). Assuming pure sinusoidal conditions the power is easily calculated as Vrms x Irms x cos(60°).

**ANTI-ALIAS FILTERS**

As mentioned in the previous section, one possible source of external phase errors are the anti-alias filters on channel 1 and channel 2. The anti-alias filters are low pass filters which are placed before the analog inputs of any ADC. They are required in order to prevent a possible
distortion due to sampling called aliasing. Figure 6 illustrates the effects of aliasing.

![Aliasing Effects](image)

**Figure 6— Aliasing effects**

Figure 6 shows how aliasing effects could introduce inaccuracies in an ADE7756 based meter design. The ADE7756 uses two Σ-∆ ADCs to digitize the voltage and current signals. These ADCs have a very high sampling rate, i.e., 900kHz. Figure 6 shows how frequency components (arrows shown in black) above half the sampling frequency (also known as the Nyquist frequency), i.e., 450kHz get imaged or folded back down below 450kHz (arrows shown in grey). This will happen with all ADCs no matter what the architecture. In the example shown it can be seen that only frequencies near the sampling frequency, i.e., 900kHz, will move into the band of interest for metering, i.e., 0 - 2kHz. This fact will allow us to use a very simple LPF (Low Pass Filter) to attenuate these high frequencies (near 900kHz) and so prevent distortion in the band of interest.

The simplest form of LPF is the simple RC filter. This is a single pole filter with a roll off or attenuation of -20dBs/dec.

**Choosing the filter -3dB frequency**

As well as having a magnitude response all filters also have a phase response. The magnitude and phase response of a simple RC filter (R =1kΩ, C =33nF) are shown in Figure 7 and 8. From Figure 7 it is seen that the attenuation at 900kHz for this simple LPF is greater than 40dBs. This is enough attenuation to ensure no ill effects due to aliasing.

![RC filter magnitude response](image)

**Figure 7 — RC filter magnitude response**

![RC filter phase response](image)

**Figure 8— RC filter phase response**

As explained in the last section the phase response can introduce significant errors if the phase response of the LPFs on both channel 1 and channel 2 are not matched. Phase mismatch can easily occur due to poor component tolerances in the LPF. The lower the -3dB frequency in the LPF (anti-alias filter) the more pronounced these errors will be at the fundamental frequency component or the line frequency. Even with the corner frequency set at 4.8kHz (R = 1kΩ, C =33nF) the phase errors due to poor component tolerances can be significant. Figure 7 illustrates the point. In Figure 9, the phase response for the simple LPF is shown at 50Hz for R =1kΩ ±10%, C =33nF ±10%. Remember a phase shift of 0.2° can cause measurement errors of 0.6% at low power factor. This design uses resistors of 1% tolerance and capacitors of 10% tolerance for the anti-alias filters to reduce the possible problems due to phase mismatch. Alternatively the corner frequency of the anti-alias filter could be pushed out to 10kHz - 15Hz. However the corner frequency should not be made too high, as this could allow enough high frequency components to be aliased and so cause accuracy problems in a noisy environment.
Note this is also why precautions were taken with the design of the calibration network on channel 2 (voltage channel). Calibrating the meter by varying the resistance of the attenuation network will not vary the -3dB frequency and hence the phase response of the network on channel 2—see Calibrating the Meter.

EEPROM DATA TABLE
The EEPROM is used to store all the data of the meter. The addresses and their contents are listed in Table 2.

<table>
<thead>
<tr>
<th>Add.</th>
<th>Page 1</th>
<th>Page 2</th>
<th>Page 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Energy(0-7)</td>
<td>CFDIV(0-7)</td>
<td>Econst(0-7)</td>
</tr>
<tr>
<td>1</td>
<td>Energy(8-15)</td>
<td>CFDIV (8-15)</td>
<td>Econst(8-15)</td>
</tr>
<tr>
<td>2</td>
<td>Energy(16-23)</td>
<td>APGAIN(0-7)</td>
<td>Econst(16-23)</td>
</tr>
<tr>
<td>3</td>
<td>Energy(24-31)</td>
<td>APGAIN(8-15)</td>
<td>Resolution</td>
</tr>
<tr>
<td>4</td>
<td>Energy(32-39)</td>
<td>APOS</td>
<td>Temp offset</td>
</tr>
<tr>
<td>5</td>
<td>Energy(40-47)</td>
<td>CH1OS</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Energy(48-55)</td>
<td>CH2OS</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Energy(56-63)</td>
<td>GAIN</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Energy(64-71)</td>
<td>PHCAL</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Energy(72-79)</td>
<td>SAGCYC</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Energy(80-87)</td>
<td>SAGLVL</td>
<td></td>
</tr>
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<td>11</td>
<td>IRQEN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>MODE(0-7)</td>
<td></td>
<td></td>
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<tr>
<td>13</td>
<td>MODE(8-15)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>ZXTOUT(0-7)</td>
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<td></td>
</tr>
<tr>
<td>15</td>
<td>ZXTOUT(8-15)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: EEPROM memory map

Page 1 of the EEPROM contains the accumulated energy in bytes 0-10. Page 2 of the EEPROM contains the settings for the various registers of the ADE7756. Page 3 is used to store the calibration coefficient used to translate the AENERGY register into KWH. Page 3 is used to set the resolution of the display. Address 4, page 3 is used for temperature offset.

POWER SUPPLY DESIGN
This design uses a simple low-cost power supply based on a power transformer. This scheme allows better isolation of the system. The secondary of the transformer is used to power the meter only. Although the secondary could be used as an attenuated input for channel 2, load currents can affect the overall accuracy of the system. The filter capacitor (C18) should be chosen to ensure there is enough charge stored during a brown out to power the meter for the power down mode.

The total power consumption in the voltage circuit including power supply is specified in section 4.4.1.1 of IEC1039 (1996-9). The total power consumption in each phase is 2W and 10VA under nominal conditions. The total power dissipation is approximately 0.1W. Figure 11 shows the basic power supply design.

![Figure 11— Power Supply](image)

The plot shown in figures 12 shows the power supply performance under heavy load (40A) with the line voltage at 220V. By far the biggest load on the power supply is the current required to drive the led.

![Figure 12- Power Supply Current](image)

BROWN OUT
The ADE7756 contains circuitry to monitor the line voltages to the meter. This has a distinct advantage over other designs as it allows the meter additional time to store all necessary data before the power supplies decay. The decay is proportional to the current drawn by the meter board and the size of the storage capacitor on the supply board. Figure 13 illustrates the time between power loss and the 5 volt supply decaying. By setting the ADE7756 brownout detect registers, the part can send an interrupt to the µC and save all the data prior to the decay of the power supply. See Zero Cross detection and Line Voltage Sag Detection in the ADE7756 data sheet. Figure 13 shows the 5 volt decay with a load current of 40 amps. The line voltage in Figure 13 was measured at the secondary of the power supply. The line in voltage is 220 V_{RMS}, 50Hz.
POWER SUPPLY

In order to adjust the power supply to the line voltage, a resistor network is used. Each resistor in the network is 0 ohms. Table 2 shows the proper connections for the input line voltage.

<table>
<thead>
<tr>
<th>Component</th>
<th>220V</th>
<th>120V</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>Open</td>
<td>Open</td>
</tr>
<tr>
<td>R2</td>
<td>Open</td>
<td>Short</td>
</tr>
<tr>
<td>R3</td>
<td>Open</td>
<td>Short</td>
</tr>
<tr>
<td>R4</td>
<td>Short</td>
<td>Open</td>
</tr>
<tr>
<td>R5</td>
<td>Short</td>
<td>Short</td>
</tr>
<tr>
<td>R6</td>
<td>Open</td>
<td>Open</td>
</tr>
<tr>
<td>R7</td>
<td>Short</td>
<td>Short</td>
</tr>
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</table>

ADE7756 REFERENCE DESIGN LINEARITY ERROR

The linearity error for the meter was measured over a dynamic range of 1000:1 and found to be less than 0.1% error. An extended dynamic range of 10,000:1 was well within the specifications of an accuracy class 0.5 meter.
Figure 17: Reference Design Schematic.
<table>
<thead>
<tr>
<th>Parts(s)</th>
<th>Details</th>
<th>Comments</th>
</tr>
</thead>
</table>
| 1. C1   | 220uF 6.3V, 20% | NHE RADIAL ELECT CAP  
Panasonic ECE-A0GE221  
Digi-key Part #P5204-ND |
| 2. C2-3,C5, C9-C12 | 100nF, 50V, 10% | CERM CHIP 1206 X7R Surface Mount  
Panasonic EBJ-3VB1H104K  
Digi-Key Part #PC104BRT-N |
| 3. C4, C6-8 | 33nF, 50V, 10% | CERM CHIP 1206 Surface Mount  
Panasonic ECU-V1H333KBW  
Digi-key Part #PCC104BTR-N |
| 4. C13-16 | 22 pF, 50V, 5% | CERM CHIP 0805 Surface Mount  
Panasonic EBJ-7VC1H220J  
Digi-key Part #PCC220CNCT-N |
| 5. C17-18 | 10uF, 6.3V, 20% | Tantalum TES Surface Mount  
Panasonic ECE-T0JY106R  
Digi-key Part #PCC1106CT-N |
| 6. CR1 | LED Red | LED Red Diffused Round Short  
Panasonic LN21RPHL  
Digi-key Part #P300-N |
| 7. L1 | Ferrite bead | Bead Core Single 3.5X9MM Axial  
Panasonic EXC-ELSA39  
Digi-key Part #P9818BK-N |
| 8. L2 | 150 Ohms | Ferrite SMT 1806 Surface Mount  
Steward LI1806C151R-00  
Digi-key Part #240-1030-1-N |
| 9. R1 | 1K, 1/8W, 1% | SMD 1206 Resistor Surface Mount  
Panasonic ERJ-8ENF1001V  
Digi-key Part #P100KFCT-N |
| 10. R2 | 10K, Multi-turn trimpot | Trimmer Pot, Top Adj  
BC Components CT-94W-103  
Digi-key Part #CT94W103-N |
| 11. R3-4 | 162, 1/8W, 1% | SMD 1206 Surface Mount  
Panasonic ERJ-8ENF1620V  
Digi-key Part #P163FCT-N |
| 12. R5,R15,R17 | 10K, 1/8W, 1% | SMD 1206 Surface Mount  
Panasonic ERJ-8ENF1002V  
Digi-key Part #P100KFCT-N |
| 13. R6-7 | 255K, 1/8W, 1% | SMD 1206 Surface Mount  
Panasonic ERJ-8ENF2553V  
Digi-key Part #P255KFCT-N |
| 14. R8-10 | 1K, 1/8W, 1% | SMD 1206 Surface Mount  
Panasonic ERJ-8ENF1001V  
Digi-key Part #P100KFCT-N |
| 15. R11-13 | 10, 1/8W, 1% | SMD 1206 Surface Mount  
Panasonic ERJ-8ENF10R0V  
Digi-key Part #P100FCT-N |
| 16. R14,R16 | 00, 1/8W 5% | SMD 1206 Surface Mount  
Panasonic ERJ-8ENF10R0V  
Digi-key Part #P100FCT-N |
| 17. TP1-20 | Testpoint | Testpoint  
ECS Inc ECS-35-17-4  
Digi-key Part #X079-N |
| 18. Y1-2 | 3.579MHz Crystal | EAD7756  
Analog Devices ADE7756AN |
AN-564 Preliminary Technical Data

BOM

Meter Board (cont.)

<table>
<thead>
<tr>
<th>Part(s)</th>
<th>Details</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td>20. Z2</td>
<td>LCD Module 16X2 Char.</td>
<td>Optrex America Inc DMC-16230U Digi-key Part #73-1030-ND</td>
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<tr>
<td>21. Z3-4</td>
<td>1 Channel Opto-Coupler</td>
<td>Panasonic ECJ-3VB1H104K Digi-key Part #PC104BTR-ND</td>
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<tr>
<td>22. Z5</td>
<td>EEPROM 512 X 8</td>
<td>IC Serial 8 Pin Dip Microchip Technology 25C040/P Digi-key Part #PS2501-1-ND</td>
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<tr>
<td>24. CT</td>
<td>CT, 1800:1</td>
<td>3C SM150 Cased Current Transformer Forbes Gokak Limited Part# FG 0003 Stk #08000787A</td>
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<tr>
<td>25. PCB</td>
<td>Meter Case</td>
<td>Marwell Corp, #SP-2376-AD</td>
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<tr>
<td>26. Case</td>
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</table>

Power Supply Board

<table>
<thead>
<tr>
<th>Part(s)</th>
<th>Details</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. C1</td>
<td>100nF, 50V, 10%</td>
<td>CERM CHIP 1206 X7R Surface Mount Panasonic ECJ-3VB1H104K Digi-key Part #PC104BTR-ND</td>
</tr>
<tr>
<td>2. C2</td>
<td>220uF 6.3V, 20%</td>
<td>NHE RADIAL ELECT CAP Panasonic ECE-A0JGE221 Digi-key Part #PS204-ND</td>
</tr>
<tr>
<td>3. C3</td>
<td>330uF, 50V, 20%</td>
<td>NHE RADIAL ELECT CAP Panasonic ECE-A1HGE331 Digi-key Part #PS278-ND</td>
</tr>
<tr>
<td>4. MOV1</td>
<td>Metal Oxide Varistors</td>
<td>AC 275V, 140 Joules Farnel No. 580-284, Siemens, S20K275</td>
</tr>
<tr>
<td>5. R1-7</td>
<td>0 Ohm, 1/8W 5%</td>
<td>SMD 1206 Surface Mount Resistor Panasonic ERJ-8GEY001V Digi-key Part #P0.080CT-ND</td>
</tr>
<tr>
<td>6. T1</td>
<td>Transformer</td>
<td>10VCT .110A DUAL Tamura/Microtran 3FD-210 Digi-key Part #MT2096-ND</td>
</tr>
<tr>
<td>7. TP1-7</td>
<td>Testpoints</td>
<td></td>
</tr>
<tr>
<td>8. VR1</td>
<td>5 Volt Regulator</td>
<td>IC +5V REGULATOR TO220F NJM NJM7805FA Digi-key Part #NJM7805FA-ND</td>
</tr>
<tr>
<td>9. Z1</td>
<td>Bridge Rectifier</td>
<td>BRIDGE RECTIFIER 1A 100V DB-1 Microsem Corp DB102 Digi-key Part #DB102MS-ND Stk #08007088A</td>
</tr>
<tr>
<td>10. PCB</td>
<td></td>
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Rev. PrB1
Figure 17 Meter Board Silk Screen
Figure 18 - Power Supply Supply Silk Screen