LOW-COST ENERGY METER USING ADE7757

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CERTIFICATE

This is to certify that the work entitled, "A low-cost energy meter using ADE7757" submitted by Sanyam Khurana (021050) & Nikhil Sharma (021008) in partial fulfillment for the award of degree of Bachelor of Technology in Electronics & Communication Engineering of Jaypee University of Information Technology has been carried out under my supervision. This work has not been submitted partially or wholly to any other University or Institute for the award of this or any other degree or diploma.

Kedia.

Jyoti Kedia

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Nikhil Sharma
Sanyam Khurana

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LIST OF ABBREVIATIONS

kWh	Kilowatt Hour
Hz	Hertz
mA	milli-Ampere
A	Ampere
V	Volts
IC	Integrated Circuit
CMOS	Complementary Metal-oxide Semiconductor
IEC	International Electro technical Commission
ADC	Analog to Digital Converter
DAC	Digital to Analog Converter
RTC	Real Time Controller
LCD	Liquid crystal display
SOIC	Small Outline Plastic Packages Integrated Circuit
PCB	Printed Circuit Board
AC	Alternating Current
DC	Direct Current

ABSTRACT

Electromechanical energy meters have been the standard for billing the electricity since billing began. These are now being gradually replaced by digital signal processor-based energy meters or Kilo-watt (kWh) hour meters.

More accurate energy measurements and additional features are in fact accelerating the adoption of digital kWh meters These meters have additional features like more accurate energy measurement and additional features like power quality monitoring, recording of current voltage peaks, power factor information etc.

We designed the low cost energy meter using Analog Devices' ADE7757 chip for single phase, 2-wire (phase and neutral) systems used in households. IC ADE7757 is a solution for electrical energy measurement. The IC ADE7757 is a highly integrated system comprised of two ADC's, a reference circuit and a fixed DSP function for the calculation of real power. A highly stable oscillator is integrated into the design to provide the necessary clock for the IC. It includes high frequency pulse output for both calibration and system communication.

The salient features of the meter designed are that it can read up to 999,999.99 units (kWh) with a resolution of 0.01,designed for a nominal 230 V, 45-65 Hz and maximum line current of 30 amps with a dynamic range of 400 (75mA to 30A) and the meter has count of 100 impulses which register one unit.

INTRODUCTION

An **Energy meter** or an **Electric meter** is a device that measures the amount of electrical energy supplied to a residence or business. These are customers of an electric company.

The most common type is more properly known as a (kilo)watt-hour meter. Utilities record the values measured by these meters to generate an invoice for the electricity.

The most common unit of measurement on the electricity meter is the kilowatt-hour which is equal to the amount of energy used by a load of one kilowatt over a period of one hour, or 3,600,000 joules.

Demand is normally measured in Watts, but averaged over a period, most often a quarter or half hour. Reactive power is measured as "volt-amps, reactive", (VARh) also in kilowatt-hours. It may help to think of reactive power as power that is "reflected" from a load, because the load cannot immediately use all the power provided by the distribution system. A "lagging" or "inductive" load such as a motor will have positive reactive power. A "leading" or "capacitive" load will have negative reactive power.

Volt-Amps measures all power passed through the distribution network, whether reactive or actual. This is equal to the product of root-mean-square volts and amps. Alternatively, it is the square-root of the sum of the squares of Watts and VARs.

Distortion of the electric current by loads is measured in several ways. Power factor is the ratio of reactive to volt-amps. A negative value is a capacitive load, a positive is inductive. Current harmonics measure distortion of the wave form. For example, electronic loads often "cut off the peak" of the voltage to fill their power supplies. This flattening causes odd harmonics. Harmonics are often caused by tampering with meters.

CIRCUIT COMPONENTS DESCRIPTION

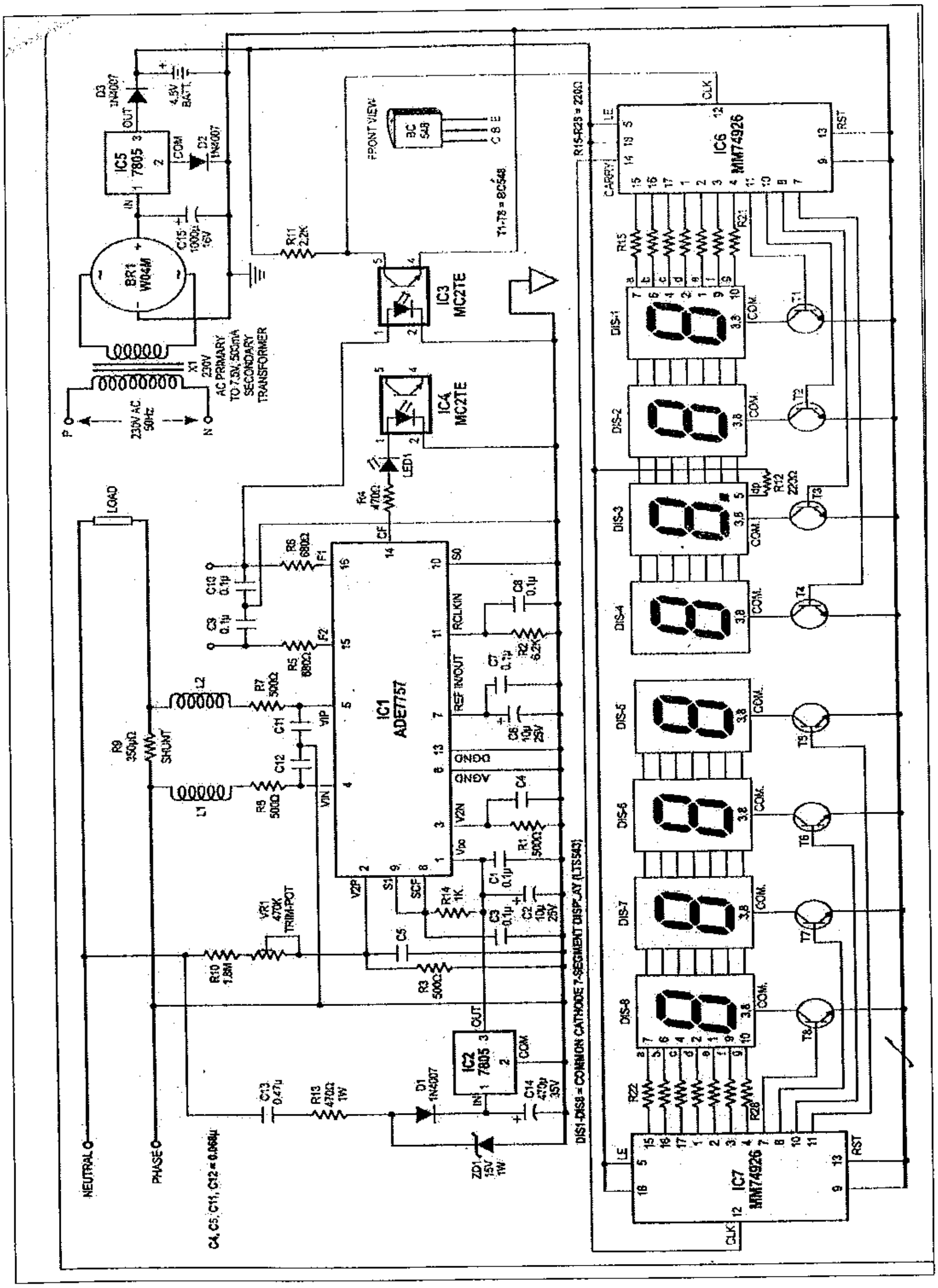

Fig. 2.1 Main circuit diagram

IC ADE7757

IC ADE7757 is a 16-lead SOIC narrow-body package constructed by Analog Devices. In the circuit, it is soldered on the conductor side of the PCB. The IC has an on-chip oscillator, so it requires no external crystal or resonator, thus reducing the overall cost of building a watt-hour meter. It operates off a 5V power supply..

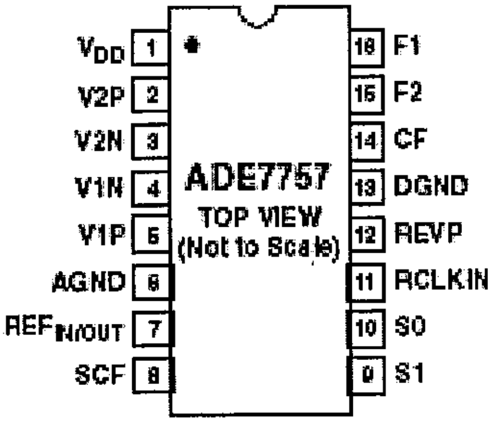

Fig2.2 (a) Pin Diagram of ADE7757

The following figure shows the functional block diagram of metering IC ADE7757.

FUNCTIONAL BLOCK DIAGRAM

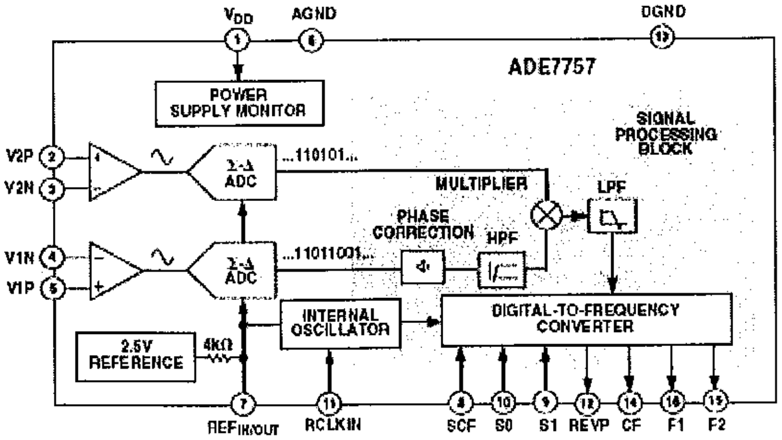

Fig.2.2 (b) Functional block diagram of IC ADE7757

In operation the chip directly interfaces with the shunt resistor (used as a current sensor) and AC analogue voltage sensing input. It has two analogue input channels designated as V1 and V2. Channel V1 (also called the current channel) is used for current sensing and channel V2 (also called 'voltage channel') is used for voltage sensing.

The differential output from the current sensing resistor is connected between V1P and V1N inputs, while the differential output signal proportional to the AC Line voltage, obtained through a resistor divider, is connected between pins V2P and V2N.

IC ADE7757 also has a reference circuit and a fixed DSP function for calculation of real power. A highly stable oscillator integrated into the chip provides the necessary clock for chip. IC ADE7757 supplies the average real power information on the F1 and F2 low-frequency outputs. These outputs maybe used to directly drive a stepper motor-based electromechanical counter or any other suitable counter.

IC ADE7757 also provides a high frequency output at the calibration frequency (CF) pin for a selected meter constant (presently: 3200 impulses/kWh). This high-frequency output provides instantaneous real-power information, which is used to speed up the calibration process. It also provides a means for quickly verifying the meter's functionality and accuracy in a production environment.

Theory of Operation

The two analog-to-digital converters (ADCs) used in the chip digitize the output of current and voltage sensors. The ADCs are 16-bit, sigma-delta type with an oversampling rate of 450 Khz. These work with oversampling so that the bandwidth of the input signal is much less than f_S /2, where 'f_S' is the sampling frequency. The sigma-delta converter contains a one-bit ADC and DAC. It produces a higher-resolution digital word output by averaging several one-bit samples.

The real power is derived from the instantaneous power signal. The instantaneous power signal is achieved by the direct multiplication of current and voltage signals. In order to extract the real power component (referred to as the DC Component), the instantaneous power is low-pass filtered. This scheme correctly calculates the real power for sinusoidal current and voltage waveforms at all power factors. All the signal processing is carried out in the digital domain, for superior stability over temperature and time.

The following figure shows the black diagram for signal processing along with waveforms at the output of the multiplier and after the low-pass filter.

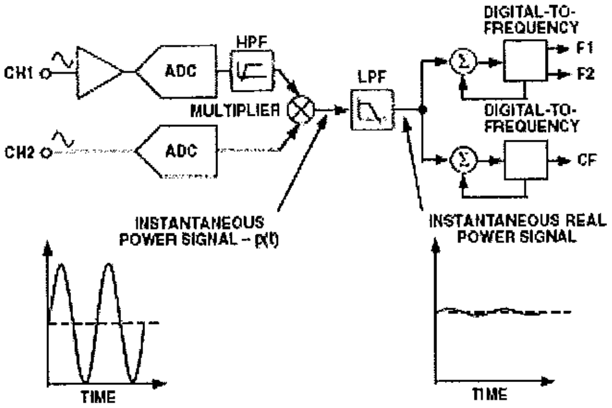

Fig.2.3 Block diagram of signal processing with the waveforms at the output for the multiplier and LPF.

It is observed that this method of extracting the real power information holds good even when the current is not in phase with the voltage. The real power component (DC Component) of the instantaneous power of sinusoidal voltage/current waveforms with a power factor of 0.5(current lagging the voltage by 60°).

$$\begin{array}{c}\text{Real Power}\\ \text{Component}\end{array} = \frac{V \times I \times \text{Cos } 60}{2}$$

Main Current Sampling (channel V1)

The voltage output of the current sensor (proportional to the load) is connected to channel V1 of IC ADE7757, which is a fully differential voltage input. The V1P is positive w.r.t V1N. The maximum peak differential signal on channel V1 should be less than +-30mV with reference to analog ground (AGND) for the specified operation. Typical Sampling connections are shown below.

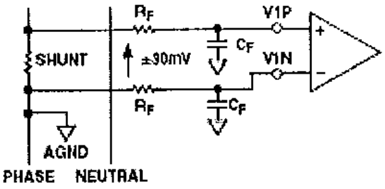

Fig.2.4. Typical mains current sampling.

Mains Voltage Sampling (channel V1)

The output of the line voltage sensor is connected to IC ADE7757 at this analog input. Channel V2,like channel V1,is a fully differential –voltage input channel with a maximum peak differential signal of +-165mV referenced to analog ground (AGND).It is easy to change the ratios of R_a and V_r to adjust the gain of the meter. Typical connections for mains voltage sampling are shown in fig.2.5.

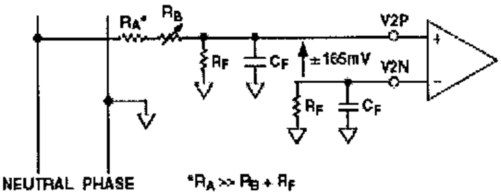

Fig.2.5. Typical Mains Voltage Sampling.

Power Supply Monitor

The on-chip power supply monitor of IC ADE7757 continuously monitors the power supply V_{DD}. If the Supply is less than 4V, IC is reset. This ensures the proper device operation at power-up and power-down. The power supply has a high degree of immunity to false triggering due to noisy supply.

Transfer Function

The Transfer Function refers to the relation between the true power into the load and its representation in terms of equivalent frequencies at F1 and F2 output points. The Transfer Function of IC ADE7757 is quiet linear.

The output frequency or pulse rate is related to the input voltage signals as follows:

$$\mathrm{Freq} = \frac{515.84 \times V1_{rms} \times V2_{rms} \times F_{1\text{-}4}}{V_{ref}^{2}}$$

Where, Freq is the output frequency on F1 and F2 (Hz), $V1_{rms}$ is the differential rms voltage signal on channel V1 (volts), $V12_{ms}$ is the differential rms voltage signal on channel V2 (volts), V_{ref} is the reference voltage and F1-4 is one of the four possible frequencies selected by using the S0 and S1 logic inputs.

S1	**S0**	**F1-4 (Hz)**
0	0	0.85
0	1	1.7
1	0	3.4
1	1	6.8

Tab.2.5 (a). F1-4 frequency selection

Shunt Selection

We must select the size/power dissipating rating of the shunt for developing V1rms (proportional to the line current).We have chosen the maximum current as 30 Amps and the shunt size as given in note as 35oU-ohms. The power dissipated (at 30 amps, would be

$30^{2} \times 350 \times 10^{-6} = 315mW$), which is reasonable low. The chosen shunt must:

1. Provide necessary dynamic range.
2. Dissipate less power.
3. Be small size.
4. Have low temperature coefficient.

Voltage Regulator IC 7805

The IC LM7805 is three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The IC LM7805 series is available in an aluminum TO-3 package which will allow over 1.0A load current if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Considerable effort was expanded to make the LM7805 series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

Features

- Output current in excess of 1A
- Internal thermal overload protection
- External components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in the aluminum TO-3 package

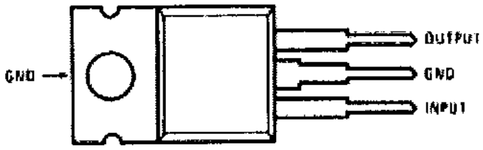

fig.2.6 package diagram of IC 7805

Power Supply

This design uses a simple low cost power supply based on a capacitor divider network, i.e., C17 and C18. Most of the line voltage is dropped across C17, a 0.47 uF, 630 V metalized polyester film capacitor. The impedance of C17 dictates the effective VA rating of the supply. However, the size of C17 is constrained by the power consumption specification in IEC 61036. The nominal VA rating of the supply in this design is 8 VA. The total power dissipation is approximately 0.5 W. Together with the power dissipated in the shunt at 30 A load, the total power consumption of the meter is 1 W.

IC MC2TE – Opto Coupler

An opto-coupler (or optical isolator) is a device that uses a short optical transmission path to transfer a signal between elements of a circuit, typically a transmitter and a receiver, while keeping them electrically isolated — since the signal goes from an electrical signal to an optical signal back to an electrical signal, electrical contact along the path is broken.

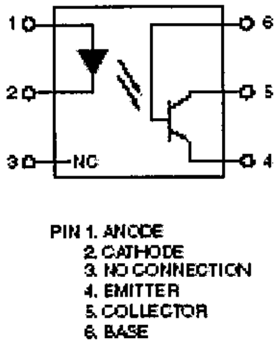

Fig.2.7 Schematic of an Opto Coupler

A common implementation involves an LED and a light sensor, separated so that light may travel across a barrier but electrical current may not. When an electrical signal is applied to the input of the opto-isolator, its LED lights, its light sensor then activates, and a corresponding electrical signal is generated at the output. Unlike a transformer, the opto-isolator allows for DC coupling and generally provides significant protection from serious over voltage conditions in one circuit affecting the other.

IC MM74926

The MM74926 CMOS counter consist of a 4-digit counter, an internal output latch, NPN output sourcing drivers for a 7-segment display and an internal multiplexing circuitry with four multiplexing outputs. The multiplexing circuit has its own free-running oscillator and requires no external clock. The counters advance on the negative edge of the clock. A HIGH signal on the Reset input will reset the counter to zero and reset the carry out low. A LOW signal on the latch Enable input will latch the numbers in the counter into the internal output latches. A HIGH signal on the display select input will select the number in the counter to be displayed; a LOW signal on the display select input will select the number in the output latch to be displayed.

The MM74926 is a 4-decade counter and has a latch enable, clock, reset inputs and also has a display select and a carry out used for cascading counters.

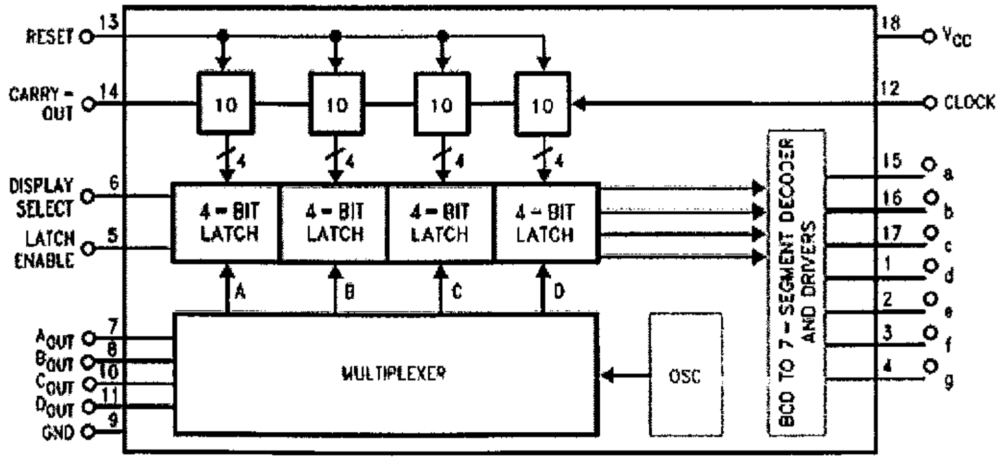

Fig. 2.8(a) Logic Diagram for IC MM74926

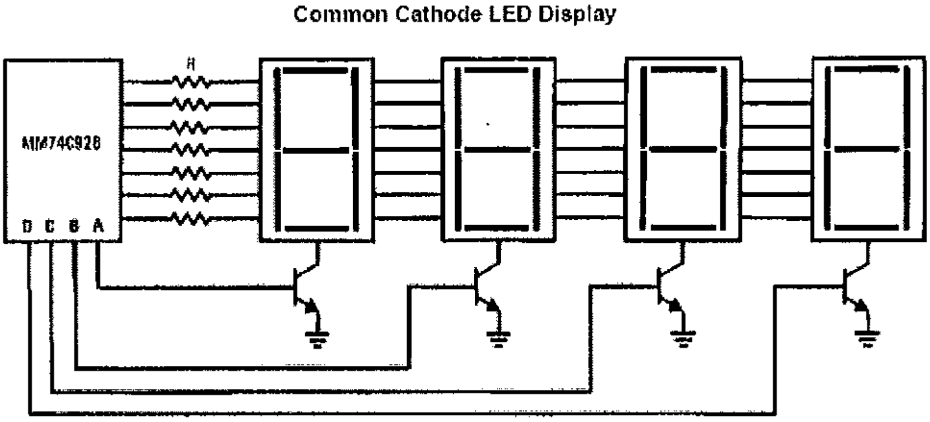

Fig.2.8 (b) Common Cathode LED display

Seven-segment display

A seven segment display, as its name indicates, is composed of seven elements. Individually on or off, they can be combined to produce idealized representations of the Hindu-Arabic numerals. Each of the numbers 0, 6, 7 and 9 may be represented by two or more different glyphs on seven-segment displays.

The seven segments are arranged as a rectangle of two vertical segments on each side with one horizontal segment on the top and bottom. Additionally, the seventh segment bisects the rectangle horizontally. There are also fourteen-segment displays and sixteen-segment displays (for full alphanumerics); however, these have mostly been replaced by dot-matrix displays.

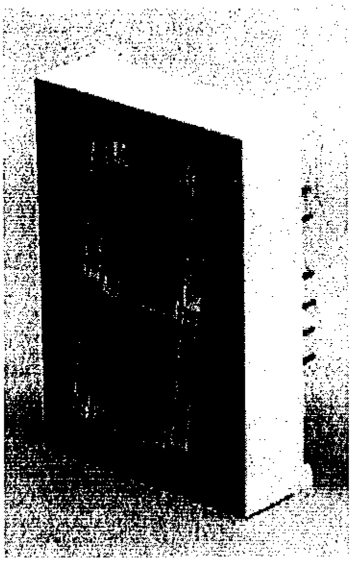

Fig.2.9 Seven-segment Display

The segments of a 7-segment display are referred to by the letters A to G, as follows:

```
 AAAAAA
F      B
F      B
F      B
 GGGGGG
E      C
E      C
E      C
 DDDDDD    DP
```

where the optional DP decimal point (an "eighth segment") is used for the display of non-integer numbers.

ANTIALIAS FILTERS

The antialias filters on Channel 1 and Channel 2 are one possible source of external phase errors. The antialias filters are low-pass filters that are placed before the analog inputs of any ADC. They are required to prevent a possible distortion due to sampling called aliasing. Figure 2.10 illustrates the effects of aliasing.

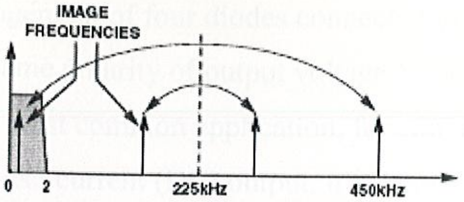

Fig. 2.10 Effects of Aliasing

Figure 2.10 shows how frequency components (arrows shown in black) above half the sampling frequency (also know as the Nyquist frequency), i.e., 450 kHz, are imaged or folded back down below 225 kHz (arrows labeled as Image Frequencies). 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., 450 kHz, will move into the band of interest for metering, i.e., 0 kHz to 2 kHz. This fact will allow users to use a very simple low-pass filter (LPF) to attenuate these high frequencies (near 450 kHz) and 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 20 dB/dec.

W04M- Bridge Rectifier

A diode bridge is an arrangement of four diodes connected in a bridge circuit as shown below, that provides the same polarity of output voltage for any polarity of the input voltage. When used in its most common application, for conversion of alternating current (AC) input into direct current (DC) output, it is known as a bridge rectifier. The diagram describes a diode-bridge design known as a full-wave rectifier or Graetz circuit. This design can be used to rectify single phase AC when no transformer center tap is available.

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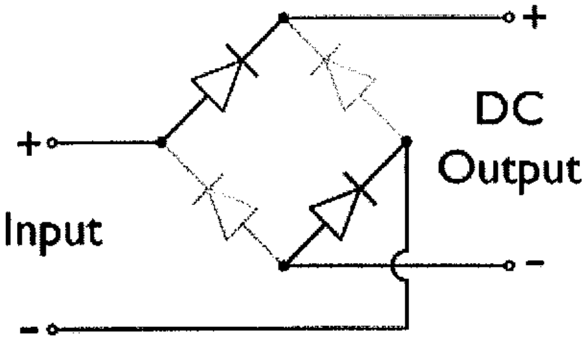

Fig.2.11 Bridge rectifier circuit

When the right hand corner is positive relative to the left hand corner, current flows along the upper path and returns to the supply via the lower path.

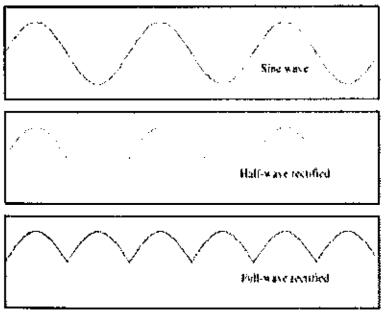

Fig.2.12 AC, half-wave and full wave rectified signals

CIRCUIT DESIGN

Taking the following assumptions,

Line Voltage = 220V (terminal)

I_{MAX} = 30 A (lb = 5A)

Meter Calibration at lb (5 A)

Current ranges for the specified accuracy are expressed in terms of basic current (lb) which is defined as the value of the current in accordance with which the relevant performance of a direct connection meter is fixed. Imax is the maximum current at which the accuracy is maintained.

(i) Shunt Selection

This is the most critical part of the design as in order to arrive at the values of $V1_{rms}$ and $V2_{rms}$, we must select the size and the power dissipation rating of the shunt for developing V1rms proportional to the line current.

I_{MAX} = 30 Amps

Therefore, choosing shunt of 350 u-ohms,

$$\text{Power dissipation} = 30 \times 30 \times 350 \times 10^{-6} = 315 \text{ mW}$$

An important consideration in choosing the shunt is that it should be small size so that it can be installed within them meter to avoid tampering.

(ii) $V1_{rms}$ at constant basic current of 5 A

$$= 5 \times 350 \times 10^{-6} \text{ ohms} = 1.75 \text{ mV(rms)}$$

(iii) with lb = 5 A and mains voltage of 230 AC rms,

Energy consumed in 1 hr = 230 x 5 = 1150 kWh = 1.150 kWh

We selected 100 impulses / kwh, i.e. 100 impulses will be required to register 1kWh.

Therefore, for 1.15 kWh, we require = 115 impulses.

Therefore, freq = 115/3600 = 0.0319 Hz

Power dissipated at lb (5A) = 230 x 5 = 1.150 kWh

Now,

$$\text{Freq} = \frac{515.84 \times V1_{rms} \times V2_{rms} \times F_{1\text{-}4}}{V_{ref}^{2}}$$

$$0.0319 = \frac{515.84 \times 1.75 \times 10^{-3} \times V2_{rms} \times 3.4}{(2.5)^{2}}$$

Therefore, $V2_{rms} = 64.9$ mV.

S1	S0	OSC Relation[1]	$F_{1\text{-}4}$ at Nominal OSC (Hz)[2]
0	0	$OSC/2_{19}$	0.86
0	1	$OSC/2_{18}$	1.72
1	0	$OSC/2_{17}$	3.44
1	1	$OSC/2_{16}$	6.86

Tab.3.1 $F_{1\text{-}4}$ Frequency Selection

Now selecting the calibration frequency to logic 1,

Output pulses at CF = 32 x Pulse rate at either f1,f2

=> Meter constant = 3200 impulses / kWh

SCF	S1	S0	CF Max for AC Signals (Hz)*
1	0	0	128 × F1, F2 = 22.4
0	0	0	64 × F1, F2 = 11.2
1	0	1	64 × F1, F2 = 22.4
0	0	1	32 × F1, F2 = 11.2
1	1	0	32 × F1, F2 = 22.4
0	1	0	16 × F1, F2 = 11.2
1	1	1	16 × F1, F2 = 22.4
0	1	1	2048 × F1, F2 = 2.867 kHz

Tab.3.2 Maximum output frequency on CF.

- ⇨ Current range for accuracy = 2% of Ib to the I_{MAX} (i.e 75 ma to 30 A)
- ⇨ Dynamic Range is 400.

Calibrating the Meter

We calibrate the meter by attenuating the line voltage down to 61.5mV. This is carried out by a resistor trim pot.

IMAX = 30 A

$V = IR \leq 30m\ V$

Therefore, $R \leq 1.8$ m-ohms.

Resolution of important measurement improves as R increases.

V2 < 165 mV lists the maximum at the voltage input terminal to be 165 mV.

Choosing the Filter –3 dB Cutoff Frequency

Along with the magnitude response, all filters also have a phase response. The magnitude and phase response of a simple RC filter (R = 500 ohms, C = 0.068 μF) are shown in figures 3.1 & 3.2. It is seen that the attenuation at 450 kHz for this simple LPF is approximately 40 dB.

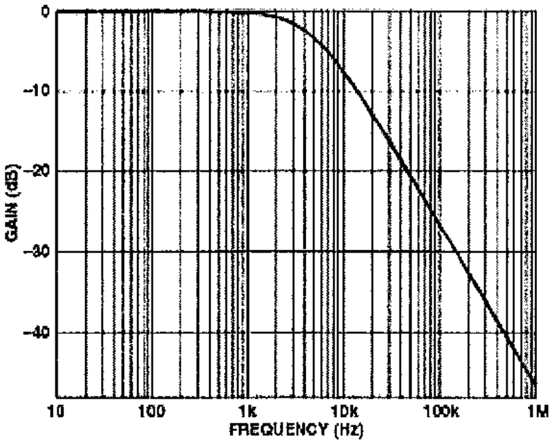

Fig 3.1 Magnitude Response

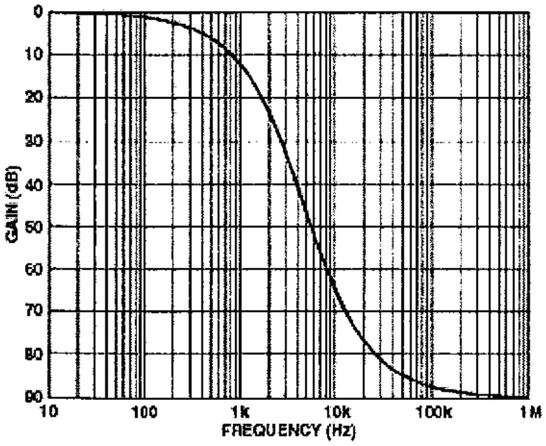

Fig. 3.2 Phase response.

This is enough attenuation to ensure no ill effects due to aliasing. The phase response can introduce significant errors if the phase response of the LPFs on Channel 1 and Channel 2 is not matched. Phase mismatch can easily occur due to poor component tolerances in the LPF. The lower the cutoff frequency in the LPF (anti-alias filter), the more pronounced these errors will be. Even with the corner frequency set at 4.7 kHz (w_C = 1/ RC ; R = 500 ohms, C = 0.068 μF), the phase errors due to poor component tolerances can be significant.

THE OPERATION OF THE CIRCUIT

IC ADE 7757 (IC1) is at the heart of the energy meter. It directly interfaces with the shunt resistor and operates off the AC input. The only analog circuitry used in the IC ADE7757 is the sigma delta ADCs and reference circuit. All other signals are carried out in digital domain.

The power supply for IC ADE7757 is derived directly from mains using the capacitor divider network comprising of C13 and C14.Most of the voltage is dropped across C13(0.47μF polyester capacitor), while resistor R13(470-ohm) is used as a current limiter. The output across C14 is limited to 15V DC, which serves as an input to the regulator 7805(IC2).The regulated 5V is fed to IC1 as its VDD pin 1.In this application, the phase line is connected to AGND(pin 6) and DGND(pin 13) and hence to the common terminal of the regulator IC2.

Two MM74926 ICs (IC 6 & IC7) are cascaded to act as an 8-digit ripple counter, in conjunction with eight 7-segment displays (DIS1 to DIS-8) which require additional 5V regulated and isolated supply. A conventional 5V regulator circuit incorporating a bridge rectifier (BR1), a smooth capacitor (C15) and a regulator IC 7805(IC5) has been used for the purpose.

A 4.5Vrechargeable battery is used to provide back up so that the counter doesn't reset when the mains fail. Diode D3 prevents battery discharge through the regulator during mains interruption. The voltage drop across diode D3 is compensated by using diode D2 in series with the common terminal of regulator 7805 (IC5).

The F1 output of IC1 is coupled to 8-digit ripple counter IC MM74926 via opto-coupler IC3, while LED1 indicates that's IC1 is working. CMOS IC MM74926 consists of a 4 digit counter, internal output latch, n-p-n output source drivers for the 7-segment display and internal multiplexing circuitry with four multiplexed outputs. As multiplexing circuit has its own free running oscillator, it doesn't require external clock. The counter advances on the negative edge of the clock pulse. The high output of the latch enable pin displays counter outputs.

IC6 drives the first four 7-segment displays (DIS-1 to DIS-4), while IC7 drives the remaining four displays (DIS-5 to DIS-8).IC6 is cascaded to IC7 by connecting the "carry" output of IC6 to the clock input of IC7.

Transistors T1 to T8 drive the respective digit displays DIS-1 through DIS-8.Since F1 output comprises 100 pulses for each energy unit(kWh),a decimal point is placed between DIS-2 and DIS3.Thus the display can now show up to 999999.99 units and restart from 000000.00.

The meter and the PCB layout must be designed such that the conducted and radiated electromagnetic disturbances and the electrostatic discharge do not damage the meter or disturb its working.

All the precautionary components and the design techniques (ferrite beads, capacitor line filter etc.) contribute to protect the meter circuitry from all forms of electromagnetic disturbances.

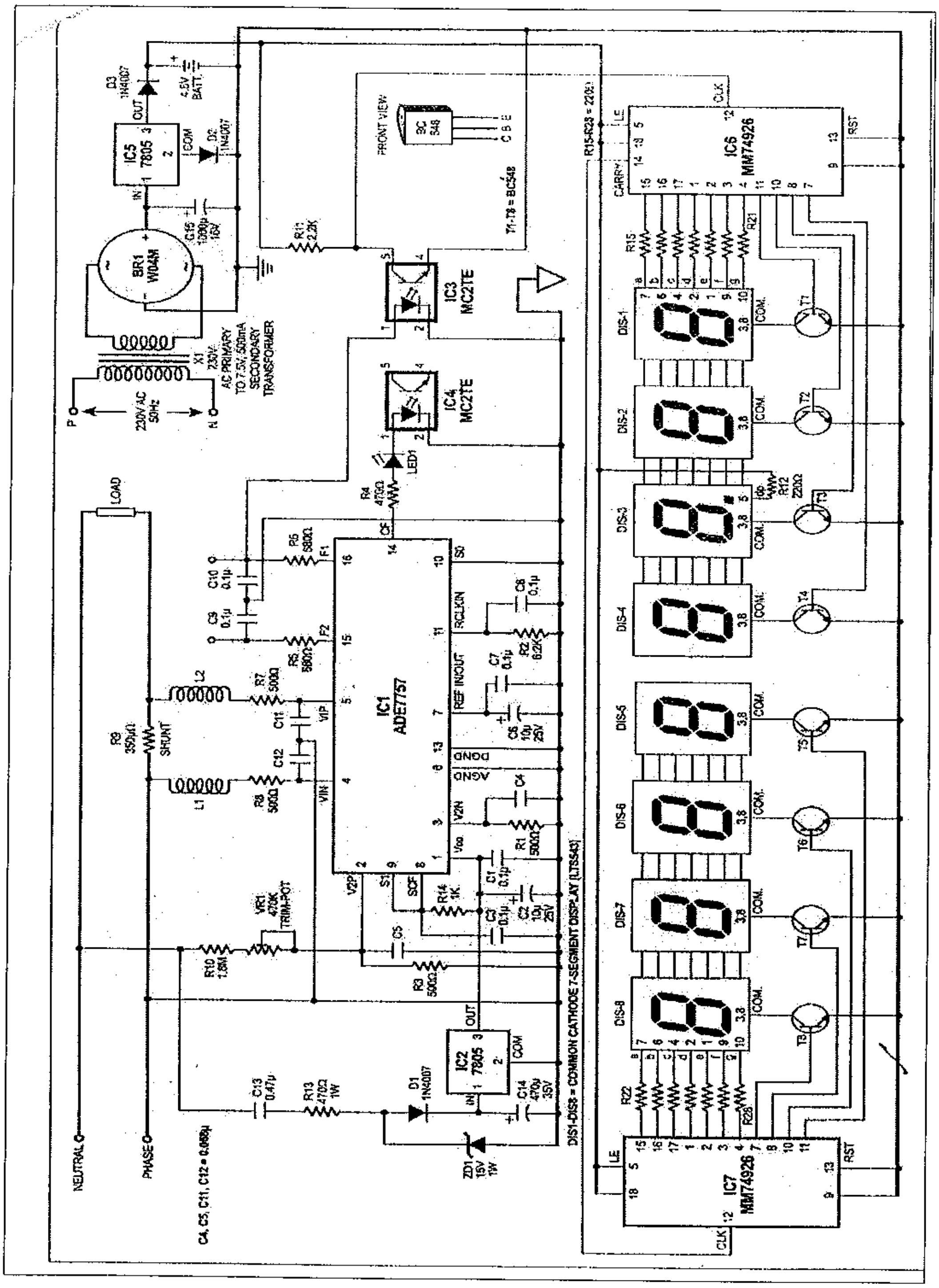

Fig. 4.1 Main Circuit Diagram

CONCLUSION

As part of testing the circuit, a 100W bulb was used as load to the energy meter.
The energy consumed by the bulb in one hour, as displayed by the meter= 106.5 Wh.
True energy of the bulb = 100 W.

$$\textbf{Percentage Error} = \frac{\text{Energy registered by the meter} - \text{True energy}}{\text{True energy}} \times 100$$

$$= \frac{106.5 - 100}{100} \times 100 = \mathbf{6.5\ \%}$$

Thus, we observed that the circuit was designed satisfactorily and produced expected results.

This being a non-commercial educational project, all the laid down design principles have not been adhered to.

Further Work

To further extend the scope of our design we can interface our meter with a microprocessor.

The meter readings can be converted into signals that can be processed by a microcontroller. This data will then be sent to the user's computer via a wireless network. A software program will then monitor and track the total energy consumption, notifying the user if the usage is approaching a preset limit.

The final design is based on a concept of a plug-in device where electricity used by the appliance runs through it and then measured and processed to be sent to the home-owner's computer. The block diagram of the appliance monitoring module is illustrated in Figure 5.1, where it clearly shows the interaction between the electricity from the power outlet and electricity to the appliance, creating a wireless signal to the computer with the aid of the microcontroller.

The monitoring device then sends a wireless signal to the home-owner's computer, where it is further processed to reveal trends and information regarding energy consumption.

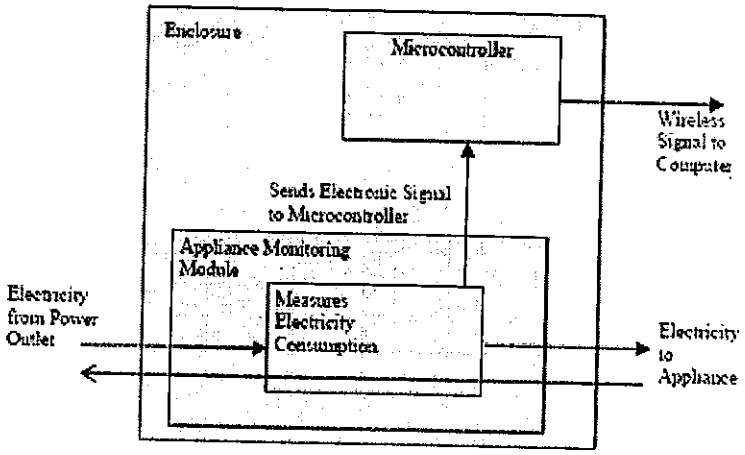

fig. 5.1 Block diagram for energy meter-computer interface

The Smart House

The Circuit of the energy meter when modified and extended could also find use in a "Smart House" application. "Smart house" could use the information coming from the meter to power down appliances that are connected to connected controller modules. All a module inside the home needs to look for is the flag, since the microcontroller calculates projected and total cost, and sends out a flag whether or not the electricity usage has gone over the homeowner-defined budget. In one scenario: A smart thermostat is set to a range of acceptable and preferred temperatures. Once the thermostat detects that the electricity (or gas) budget has been exceeded, it lowers the temp in the house to the lowest setting the homeowner set.

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APPENDIX A

ADE7757–SPECIFICATIONS (V_{DD} = 5 V ± 5%, AGND = DGND = 0 V, On-Chip Reference, RCLKIN = 6.2 kΩ, 0.5% ± 50 ppm/°C, T_{MIN} to T_{MAX} = −40°C to +85°C, unless otherwise noted.)

TRANSFER FUNCTION

Frequency Outputs F1 and F2

The ADE7757 calculates the product of two voltage signals (on Channel V1 and Channel V2) and then low-pass filters this product to extract real power information. This real power information is then converted to a frequency. The frequency information is output on F1 and F2 in the form of active low pulses. The pulse rate at these outputs is relatively low, e.g., 0.175 Hz maximum for ac signals with S0 = S1 = 0. This means that the frequency at these outputs is generated from real power information accumulated over a relatively long period of time. The result is an output frequency that is proportional to the average real power. The averaging of the real power signal is implicit to the digital-to-frequency conversion. The output frequency or pulse rate is related to the input voltage signals by the following equation:

$$Freq = \frac{515.84 \times V1_{rms} \times V2_{rms} \times F_{1-4}}{{V_{REF}}^2}$$

where

Freq = Output frequency on F1 and F2 (Hz).

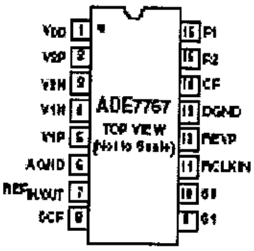
$V1_{rms}$ = Differential rms voltage signal on Channel V1 (V).

$V2_{rms}$ = Differential rms voltage signal on Channel V2 (V).

V_{REF} = The reference voltage (2.5 V).

F_{1-4} = One of four possible frequencies selected by using the logic inputs S0 and S1.

Parameter	Value	Unit	Test Conditions/Comments
ACCURACY[1,2]			
Measurement Error[1] on Channel V1	0.1	% Reading typ	Channel V2 with Full-Scale Signal (±165 mV), 25°C Over a Dynamic Range 500 to 1 Line Frequency = 45 Hz to 65 Hz
Phase Error[1] between Channels			
V1 Phase Lead 37° (PF = 0.8 Capacitive)	±0.1	Degrees (°) max	
V1 Phase Lag 60° (PF = 0.5 Inductive)	±0.1	Degrees (°) max	
AC Power Supply Rejection[1]			S0 = S1 = 1,
Output Frequency Variation (CF)	0.2	% Reading typ	V1 = 21.2 mV rms, V2 = 116.7 mV rms @ 50 Hz Ripple on V_{DD} of 200 mV rms @ 100 Hz
DC Power Supply Rejection[1]			S0 = S1 = 1,
Output Frequency Variation (CF)	±0.3	% Reading typ	V1 = 21.2 mV rms, V2 = 116.7 mV rms, V_{DD} = 5 V ± 250 mV
ANALOG INPUTS			See Analog Inputs section
Channel V1 Maximum Signal Level	±30	mV max	V1P and V1N to AGND
Channel V2 Maximum Signal Level	±165	mV max	V2P and V2N to AGND
Input Impedance (DC)	320	kΩ min	OSC = 450 kHz, RCLKIN = 6.2 kΩ, 0.5% ± 50 ppm/°C
Bandwidth (–3 dB)	7	kHz nominal	OSC = 450 kHz, RCLKIN = 6.2 kΩ, 0.5% ± 50 ppm/°C
ADC Offset Error[1,2]	±18	mV max	See Terminology Section and Typical Performance Characteristics
Gain Error[1]	±4	% Ideal typ	External 2.5 V Reference V1 = 21.2 mV rms, V2 = 116.7 mV rms
OSCILLATOR FREQUENCY (OSC)	450	kHz nominal	RCLKIN = 6.2 kΩ, 0.5% ± 50 ppm/°C
Oscillator Frequency Tolerance[1]	±12	% Reading typ	
Oscillator Frequency Stability[1]	±30	ppm/°C typ	
REFERENCE INPUT			
$REF_{IN/OUT}$ Input Voltage Range	2.7	V max	2.5 V + 8%
	2.3	V min	2.5 V – 8%
Input Capacitance	10	pF max	
ON-CHIP REFERENCE			Nominal 2.5 V
Reference Error	±200	mV max	
Temperature Coefficient	±20	ppm/°C typ	
LOGIC INPUTS[4]			
SCF, S0, S1,			
Input High Voltage, V_{INH}	2.4	V min	V_{DD} = 5 V ± 5%
Input Low Voltage, V_{INL}	0.8	V max	V_{DD} = 5 V ± 5%
Input Current, I_{IN}	±1	µA max	Typically 10 nA, V_{IN} = 0 V to V_{DD}
Input Capacitance, C_{IN}	10	pF max	
LOGIC OUTPUTS[4]			
F1 and F2			
Output High Voltage, V_{OH}	4.5	V min	I_{SOURCE} = 10 mA V_{DD} = 5 V
Output Low Voltage, V_{OL}	0.5	V max	I_{SINK} = 10 mA V_{DD} = 5 V
CF			
Output High Voltage, V_{OH}	4	V min	I_{SOURCE} = 5 mA V_{DD} = 5 V
Output Low Voltage, VOL	0.5	V max	I_{SINK} = 5 mA V_{DD} = 5 V
Frequency Output Error[1,2] (CF)	±10	% Ideal typ	External 2.5 V Reference, V1 = 21.2 mV rms, V2 = 116.7 mV rms
POWER SUPPLY			For Specified Performance
V_{DD}	4.75	V min	5 V – 5%
	5.25	V max	5 V + 5%
I_{DD}	5	mA max	Typically 4 mA



PIN FUNCTION DESCRIPTIONS

Pin No.	Mnemonic	Description
1	V_{DD}	Power Supply. This pin provides the supply voltage for the circuitry in the ADE7757. The supply voltage should be maintained at 5 V ± 5% for specified operation. This pin should be decoupled with a 10 µF capacitor in parallel with a ceramic 100 nF capacitor.
2, 3	V2P, V2N	Analog Inputs for Channel V2 (voltage channel). These inputs provide a fully differential input pair. The maximum differential input voltage is ±165 mV for specified operation. Both inputs have internal ESD protection circuitry; an overvoltage of ±6 V can be sustained on these inputs without risk of permanent damage.
4, 5	V1N, V1P	Analog Inputs for Channel V1 (current channel). These inputs are fully differential voltage inputs with a maximum signal level of ±30 mV with respect to the V1N pin for specified operation. Both inputs have internal ESD protection circuitry and, in addition, an overvoltage of ±6 V can be sustained on these inputs without risk of permanent damage.
6	AGND	This provides the ground reference for the analog circuitry in the ADE7757, i.e., ADCs and reference. This pin should be tied to the analog ground plane of the PCB. The analog ground plane is the ground reference for all analog circuitry, e.g., antialiasing filters, current and voltage sensors, and so forth. For accurate noise suppression, the analog ground plane should be connected to the digital ground plane at only one point. A star ground configuration will help to keep noisy digital currents away from the analog circuits.
7	$REF_{IN/OUT}$	This pin provides access to the on-chip voltage reference. The on-chip reference has a nominal value of 2.5 V and a typical temperature coefficient of 20 ppm/°C. An external reference source may also be connected at this pin. In either case, this pin should be decoupled to AGND with a 1 µF tantalum capacitor and a 100 nF ceramic capacitor. The internal reference cannot be used to drive an external load.
8	SCF	Select Calibration Frequency. This logic input is used to select the frequency on the calibration output CF. Table III shows calibration frequencies selection.
9, 10	S1, S0	These logic inputs are used to select one of four possible frequencies for the digital-to-frequency conversion. With this logic input, designers have greater flexibility when designing an energy meter. See the Selecting a Frequency for an Energy Meter Application section.
11	RCLKIN	To enable the internal oscillator as a clock source to the chip, a precise low temperature drift resistor at a nominal value of 6.2 kΩ must be connected from this pin to DGND.
12	REVP	This logic output will go high when negative power is detected, i.e., when the phase angle between the voltage and current signals is greater than 90°. This output is not latched and will be reset when positive power is once again detected. The output will go high or low at the same time that a pulse is issued on CF.
13	DGND	This provides the ground reference for the digital circuitry in the ADE7757, i.e., multiplier, filters, and digital-to-frequency converter. This pin should be tied to the digital ground plane of the PCB. The digital ground plane is the ground reference for all digital circuitry, e.g., counters (mechanical and digital), MCUs, and indicator LEDs. For accurate noise suppression, the analog ground plane should be connected to the digital ground plane at one point only, i.e., a star ground.
14	CF	Calibration Frequency Logic Output. The CF logic output provides instantaneous real power information. This output is intended for calibration purposes. Also see SCF pin description.
15, 16	F2, F1	Low Frequency Logic Outputs. F1 and F2 supply *average real power* information. The logic outputs can be used to directly drive electromechanical counters and 2-phase stepper motors. See the Transfer Function section.

APPENDIX B

PHOTOTRANSISTOR OPTOCOUPLER

MCT2E

ABSOLUTE MAXIMUM RATINGS

Parameter	Symbol	Device	Value	Units
TOTAL DEVICE Storage Temperature	T_{STG}	ALL	-55 to +150	°C
Operating Temperature	T_{OPR}	ALL	-55 to +100	°C
Lead Solder Temperature	T_{SOL}	ALL	260 for 10 sec	°C
Total Device Power Dissipation @ $T_A = 25°C$	P_D	-M	250	mW
		Non-M	260	
Derate above 25°C		-M	2.94	mW/°C
		Non-M	3.3	
EMITTER DC/Average Forward Input Current	I_F	-M	60	mA
		Non-M	100	
Reverse Input Voltage	V_R	ALL	3	V
Forward Current - Peak (800µs, 2% Duty Cycle)	I_F(pk)	ALL	3	A
LED Power Dissipation @ $T_A = 25°C$	P_D	-M	120	mW
		Non-M	150	
Derate above 25°C		-M	1.41	mW/°C
		Non-M	2.0	
DETECTOR Collector Current	I_C	ALL	50	mA
Collector-Emitter Voltage	V_{CEO}	ALL	30	V
Detector Power Dissipation @ $T_A = 25°C$	P_D	ALL	150	mW
Derate above 25°C		-M	1.76	mW/°C
		Non-M	2.0	

ELECTRICAL CHARACTERISTICS (T_A = 25°C Unless otherwise specified.)

INDIVIDUAL COMPONENT CHARACTERISTICS

Parameter	Test Conditions	Symbol	Device	Min	Typ**	Max	Unit
EMITTER							
Input Forward Voltage	(I_F = 20 mA)	V_F	MCT2/-M MCT2E/-M MCT271 MCT2200 MCT2201 MCT2202		1.25	1.50	V
	(T_A = 0-70°C, I_F = 40 mA)		MCT210		1.33		
Reverse Leakage Current	(V_R = 3.0 V)	I_R	MCT2/-M MCT2E/-M MCT271 MCT2200 MCT2201 MCT2202		0.001	10	µA
	(T_A = 0-70°C, V_R = 6.0 V)		MCT210				
DETECTOR							
Collector-Emitter Breakdown Voltage	(I_C = 1.0 mA, I_F = 0)	BV_{CEO}	ALL	30	100		V
	(T_A = 0-70°C)		MCT210				
Collector-Base Breakdown Voltage	(I_C = 10 µA, I_F = 0)	BV_{CBO}	MCT2/-M MCT2E/-M MCT271 MCT2200 MCT2201 MCT2202	70	120		V
	(T_A = 0-70°C)		MCT210	30			
Emitter-Collector Breakdown Voltage	(I_E = 100 µA, I_F = 0)	BV_{ECO}	MCT2/-M MCT2E/-M MCT271 MCT2200 MCT2201 MCT2202	7	10		V
	(T_A = 0-70°C)		MCT210	6	10		
Collector-Emitter Dark Current	(V_{CE} = 10 V, I_F = 0)	I_{CEO}	ALL		1	50	nA
	(V_{CE} = 5 V, T_A = 0-70°C)					30	µA
Collector-Base Dark Current	(V_{CB} = 10 V, I_F = 0)	I_{CBO}	ALL			20	nA
Capacitance	(V_{CE} = 0 V, f = 1 MHz)	C_{CE}	ALL		8		pF

** Typical values at T_A = 25°C

APPENDIX C

MM74C926

DC Electrical Characteristics Min/Max limits apply at $-40°C \le T_j \le +85°C$, unless otherwise noted

Symbol	Parameter	Conditions	Min	Typ	Max	Units
CMOS TO CMOS						
$V_{IN(1)}$	Logical "1" Input Voltage	$V_{CC} = 5V$	3.5			V
$V_{IN(0)}$	Logical "0" Input Voltage	$V_{CC} = 5V$			1.5	V
$V_{OUT(1)}$	Logical "1" Output Voltage (Carry-Out and Digit Output Only)	$V_{CC} = 5V, I_O = -10\ \mu A$	4.5			V
$V_{OUT(0)}$	Logical "0" Output Voltage	$V_{CC} = 5V, I_O = 10\ \mu A$			0.5	V
$I_{IN(1)}$	Logical "1" Input Current	$V_{CC} = 5V, V_{IN} = 15V$		0.005	1	μA
$I_{IN(0)}$	Logical "0" Input Current	$V_{CC} = 5V, V_{IN} = 0V$	−1	−0.005		μA
I_{CC}	Supply Current	$V_{CC} = 5V$, Outputs Open Circuit, $V_{IN} = 0V$ or $5V$		20	1000	μA
CMOS/LPTTL INTERFACE						
$V_{IN(1)}$	Logical "1" Input Voltage	$V_{CC} = 4.75V$	$V_{CC} - 2$			V
$V_{IN(0)}$	Logical "0" Input Voltage	$V_{CC} = 4.75V$			0.8	V
$V_{OUT(1)}$	Logical "1" Output Voltage (Carry-Out and Digit Output Only)	$V_{CC} = 4.75V$, $I_O = -360\ \mu A$	2.4			V
$V_{OUT(0)}$	Logical "0" Output Voltage	$V_{CC} = 4.75V, I_O = 360\ \mu A$			0.4	V
OUTPUT DRIVE						
V_{OUT}	Output Voltage (Segment Sourcing Output)	$I_{OUT} = -65$ mA, $V_{CC} = 5V$, $T_j = 25°C$ $I_{OUT} = -40$ mA, $V_{CC} = 5V$ $\left\{\begin{array}{l} T_j = 100°C \\ T_j = 150°C \end{array}\right.$	$V_{CC} - 2$ $V_{CC} - 1.6$ $V_{CC} - 2$	$V_{CC} - 1.3$ $V_{CC} - 1.2$ $V_{CC} - 1.4$		V V V
R_{ON}	Output Resistance (Segment Sourcing Output) Output Resistance (Segment Output) Temperature Coefficient	$I_{OUT} = -65$ mA, $V_{CC} = 5V$, $T_j = 25°C$ $I_{OUT} = -40$ mA, $V_{CC} = 5V$ $\left\{\begin{array}{l} T_j = 100°C \\ T_j = 150°C \end{array}\right.$		20 30 35 0.6	32 40 50 0.8	Ω Ω Ω %/°C
I_{SOURCE}	Output Source Current (Digit Output)	$V_{CC} = 4.75V, V_{OUT} = 1.75V, T_j = 150°C$	−1	−2		mA
I_{SOURCE}	Output Source Current (Carry-Out)	$V_{CC} = 5V, V_{OUT} = 0V, T_j = 25°C$	−1.75	−3.3		mA
I_{SINK}	Output Sink Current (All Outputs)	$V_{CC} = 5V, V_{OUT} = V_{CC}, T_j = 25°C$	1.75	3.6		mA
θ_{jA}	Thermal Resistance	MM74C925 (Note 4) MM74C926, MM74C927, MM74C928		75 70	100 90	°C/W °C/W

APPENDIX D

LM7805

Series Voltage Regulator

Electrical Characteristics LM78XXC (Note 2)

0°C ≤ T_J ≤ 125°C unless otherwise noted.

Output Voltage				5V			12V			15V			Units
Input Voltage (unless otherwise noted)				10V			19V			23V			
Symbol	Parameter	Conditions		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
V_O	Output Voltage	Tj = 25°C, 5 mA ≤ I_O ≤ 1A		4.8	5	5.2	11.5	12	12.5	14.4	15	15.6	V
		P_D ≤ 15W, 5 mA ≤ I_O ≤ 1A		4.75		5.25	11.4		12.6	14.25		15.75	V
		$V_{MIN} \le V_{IN} \le V_{MAX}$		$(7.5 \le V_{IN} \le 20)$			$(14.5 \le V_{IN} \le 27)$			$(17.5 \le V_{IN} \le 30)$			V
ΔV_O	Line Regulation	I_O = 500 mA	Tj = 25°C		3	50		4	120		4	150	mV
			ΔV_{IN}	$(7 \le V_{IN} \le 25)$			$14.5 \le V_{IN} \le 30)$			$(17.5 \le V_{IN} \le 30)$			V
			0°C ≤ Tj ≤ +125°C			50			120			150	mV
			ΔV_{IN}	$(8 \le V_{IN} \le 20)$			$(15 \le V_{IN} \le 27)$			$(18.5 \le V_{IN} \le 30)$			V
		I_O ≤ 1A	Tj = 25°C			50			120			150	mV
			ΔV_{IN}	$(7.5 \le V_{IN} \le 20)$			$(14.6 \le V_{IN} \le 27)$			$(17.7 \le V_{IN} \le 30)$			V
			0°C ≤ Tj ≤ +125°C			25			60			75	mV
			ΔV_{IN}	$(8 \le V_{IN} \le 12)$			$(16 \le V_{IN} \le 22)$			$(20 \le V_{IN} \le 26)$			V
ΔV_O	Load Regulation	Tj = 25°C	5 mA ≤ I_O ≤ 1.5A		10	50		12	120		12	150	mV
			250 mA ≤ I_O ≤ 750 mA			25			60			75	mV
		5 mA ≤ I_O ≤ 1A, 0°C ≤ Tj ≤ +125°C				50			120			150	mV
I_Q	Quiescent Current	I_O ≤ 1A	Tj = 25°C			8			8			8	mA
			0°C ≤ Tj ≤ +125°C			8.5			8.5			8.5	mA
ΔI_Q	Quiescent Current Change	5 mA ≤ I_O ≤ 1A				0.5			0.5			0.5	mA
		Tj = 25°C, I_O ≤ 1A				1.0			1.0			1.0	mA
		$V_{MIN} \le V_{IN} \le V_{MAX}$		$(7.5 \le V_{IN} \le 20)$			$(14.8 \le V_{IN} \le 27)$			$(17.9 \le V_{IN} \le 30)$			V
		I_O ≤ 500 mA, 0°C ≤ Tj ≤ +125°C				1.0			1.0			1.0	mA
		$V_{MIN} \le V_{IN} \le V_{MAX}$		$(7 \le V_{IN} \le 25)$			$(14.5 \le V_{IN} \le 30)$			$(17.5 \le V_{IN} \le 30)$			V
V_N	Output Noise Voltage	T_A =25°C, 10 Hz ≤ f ≤ 100 kHz			40			75			90		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	f = 120 Hz	I_O ≤ 1A, Tj = 25°C or	62	80		55	72		54	70		dB
			I_O ≤ 500 mA 0°C ≤ Tj ≤ +125°C	62			55			54			dB
		$V_{MIN} \le V_{IN} \le V_{MAX}$		$(8 \le V_{IN} \le 18)$			$(15 \le V_{IN} \le 25)$			$(18.5 \le V_{IN} \le 28.5)$			V
R_O	Dropout Voltage	Tj = 25°C, I_{OUT} = 1A			2.0			2.0			2.0		V
	Output Resistance	f = 1 kHz			8			18			19		mΩ