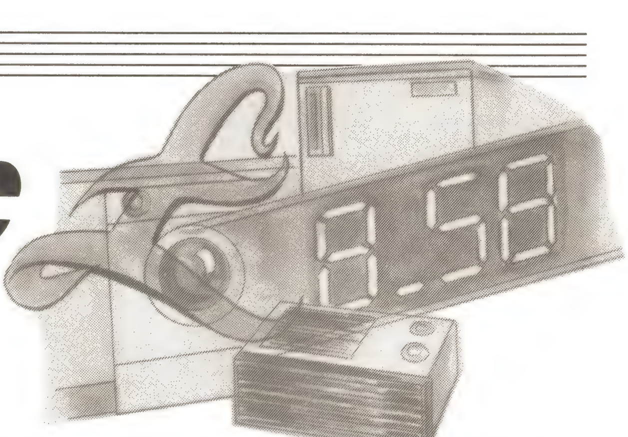
Constructional Project



PIC-ELECTRIC METER

JOHN BECKER

Part One

Know just how much each electrical appliance in your home is adding to your electricity bill.

Learn more about the EEPROM version of the PIC family of microcontrollers.

THIS microcontrolled PIC-Electric Meter monitors domestic electricity consumption and gives a digital readout of cost. Any 230V to 240V a.c. mains powered electrical appliance, such as a Fridge; Washing Machine; Tumble Dryer; Room Heater; Kettle; Computer and so forth, can be plugged into the meter.

Loads from about 60W to 3500W can be monitored. Data acquired using the meter has obvious benefits in terms of evaluating the economical use of most household electrical equipment, so helping to keep electricity bills down.

Since PIC-Electric carries potentially lethal mains voltages at high currents, its construction should only be undertaken by an *experienced* constructor. It should NOT be attempted by the *beginner,* unless carefully supervised by a qualified person.

Be aware that while PIC-Electric is plugged into the mains supply, potentially lethal voltages will be present within its case. Always *unplug* the unit from the mains *before* making any assembly changes.

WHAT IT DOES

Current sampling takes place 100 times a second, detecting the amperage being drawn by the monitored appliance at the positive and negative peaks of each mains a.c. sinewave. The total number of electrical units (one unit = one kilowatt/hour) and the cumulative cost since monitoring commenced is updated at each sampling.

A four-digit l.e.d. module displays the results, automatically alternating between the two totals. Elapsed time since monitoring started can be displayed by pressing a pushbutton switch. Instantaneous load values can also be displayed.

The cost per unit of electricity, to two decimal places, is programmed into PIC-Electric by two pushbutton switches. The value is stored in the microcontroller's non-volatile memory which retains the data even when it is unpowered.

Stored information can be updated at any time. The cumulative totals of the units used and their cost are reset each time PIC-Electric is switched on, and can also be reset at any time during monitoring.

The advantage of taking samples synchronously with the mains cycles is that with appliances whose consumption varies irregularly, such as a washing machine working through its programmed cycle, for example, the operational costs over a given period can be calculated with an excellent degree of accuracy. Estimating the running costs of such equipment from its quoted maximum wattage specification is highly unreliable.

Cumulative units and cost are displayed in a repeating cycle of four display formats: pounds, pence to two decimal places, hundreds of units, tens of units to two decimal places, each being displayed for about five seconds.

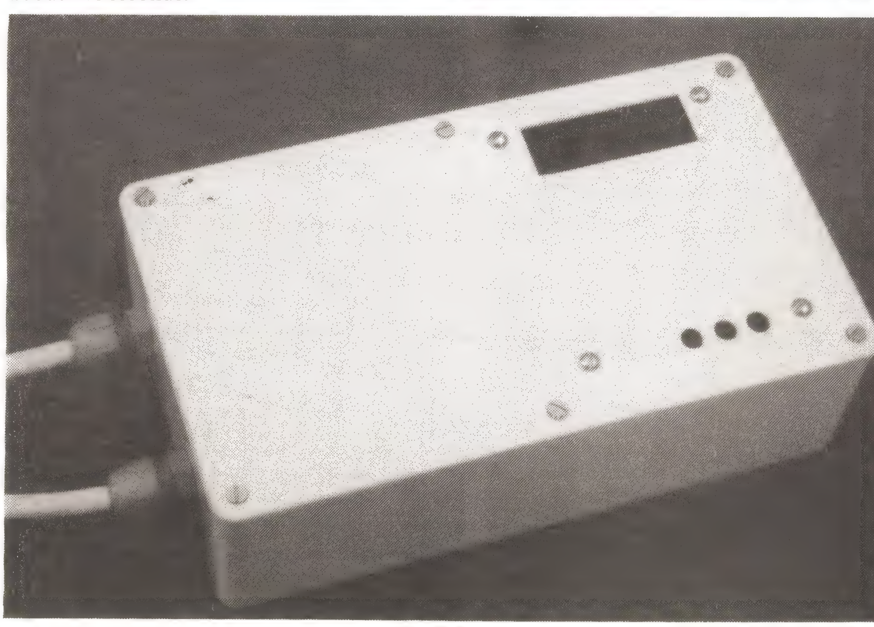
IN CONTROL

The microcontroller used in the PIC-Electric is the PIC16C84 device manufactured by Microchip Technology. This is a high performance, low cost, CMOS device having 1K × 14-bits of EEPROM (Electrically Erasable Programmable Read-Only Memory) program memory, 64 bytes of 8-bit EEPROM data memory and 36 × 8-bit general purpose SRAM (Static Random Access Memory) registers.

SPECIFICATION . . .

There are six basic display functions available:

- ★ **Cost per unit of electricity to 99·99 pence**
- ★ **Units of electricity used to 9999·99**
- ★ **Cumulative cost to £99 99·99 pence**
- ★ **Elapsed time to 159 hours 59 minutes and 59 seconds**
- ★ **Instantaneous current flow up to 15A**
- ★ **Initial setting-up (very simple)**



PIC-Electric has been designed so that the PIC16C84 can be programmed in situ on the assembled printed circuit board. Data is transferred to the microcontroller via the serial port of a PC-compatible computer.

Other than a connector and cable, no additional hardware is needed, although a suitable software program is required. This facility makes it possible to use the PIC-Electric assembly for other applications, using different analogue sensors and controlling software. Both software and pre-programmed PIC16C84s are available – see *Shoptalk* page.

HOW IT WORKS

A block diagram for the PIC-Electric Meter is shown in Fig. 1. The meter comprises a current sensor, analogue-to-digital converter (ADC), sync pulse generator, microcontroller, display module and a power supply (PSU).

The sensor is connected in series with the load (appliance) being monitored, producing an output voltage which increases linearly with the amount of current flowing. The resulting voltage is fed to a serial ADC which is sampled by the microcontroller each time a sync pulse derived from the mains power supply is received.

Software programmed, the microcontroller processes the sampled data, stores it and displays the appropriate results according to the stage of the processing cycle and in response to the "mode" pushbutton switch commands.

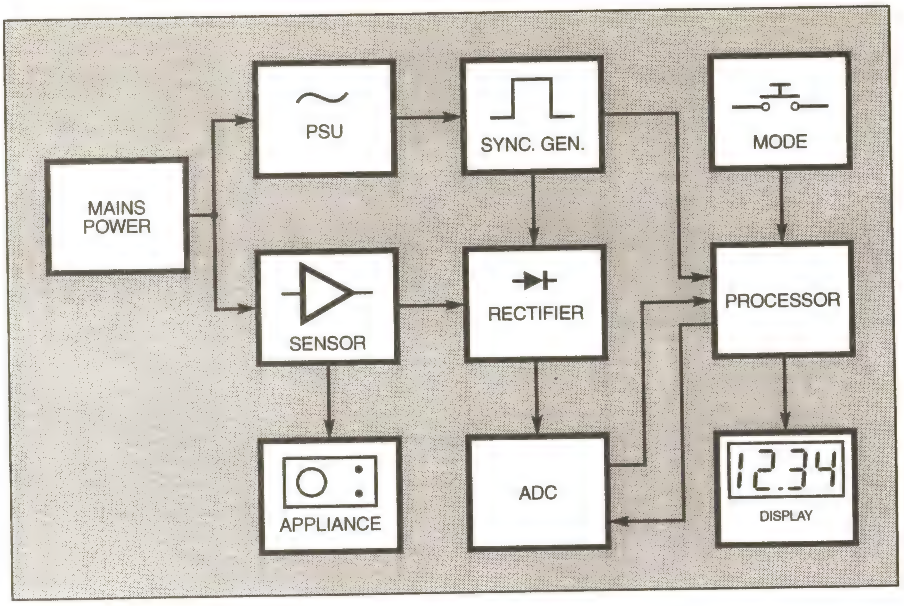


Fig. 1. Block diagram for the PIC-Electric Meter.

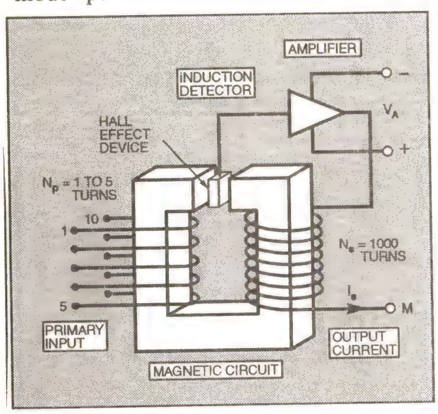


Fig. 2. Hall-effect current sensor and transducer functional diagram.

CURRENT SENSOR

The current sensor is a dedicated transducer which uses Hall-effect technology, whereby current measurement is carried out by measuring the magnetic field that is generated by a current carrying conductor. The schematic drawing of the Hall-effect Transducer is shown in Fig. 2.

Basically, the device consists of a ferromagnetic former around which are wound two coils. The primary coil is tapped and the number of turns through which the current flows can be selected according to the maximum current to be monitored. In the PIC-Electric, the primary winding is connected so that only one coil turn is used, allowing a theoretical maximum of 25A to be drawn through the sensor.

Within the gap between the legs of the magnetic former is a Hall-effect semiconductor device. This is placed at right angles to the magnetic field generated by current passing through the primary coil. The resulting voltage generated across the semiconductor is linearly proportional to the magnetic field, and hence to the current flowing in the circuit.

The device can be used to measure alternating or direct currents (a.c. or d.c.). Its output does not depend on a changing magnetic field, only on the instantaneous strength of the field. The bandwidth of the device is from d.c. to 150kHz.

The voltage generated across the semiconductor is processed by an internal amplifier and fed through the secondary winding of the transducer, generating an output current. An output current of 25mA is generated by a 25A primary current flowing through the sensor, to within ±0·6 per cent. By feeding the current through a known value resistor, typically 100Ω to 190Ω, the current can be converted to an equivalent output voltage.

When connected for 25A maximum current, the resistance of the primary coil is only 0·3 milliohms, and so imposes very little insertion loss between the mains power source and the appliance being monitored. The isolation between the primary coil and the sensor's output is 2·5kV r.m.s. at 50Hz for one minute.

The sensor also requires a dual d.c. supply voltage of ±15V, consuming about 10mA, plus the output current.

SENSOR CIRCUIT AND PSU

The circuit diagram for the Sensor connections and the Main Power Supply for the PIC-Electric is shown in Fig. 3. Mains power input to the circuit is via plug PL1.

The Hall-effect sensor, X1, has its primary winding inserted in series with the Live connection between PL1 and the output socket SK1. The mains Neutral and Earth lines are taken direct to SK1.

From PL1, mains power is also supplied to the primary winding of transformer T1. This has two 12V secondary windings connected in series, with the junction, or centre tap, of the two windings providing the 0V line. The output of the sensor is connected to the 0V line via resistor R1, into which the output current flows, creating an equivalent voltage which is destined for the ADC (IC7 in Fig. 6, later).

The secondary voltage from transformer T1 is bridge rectified by REC1, whose posi-

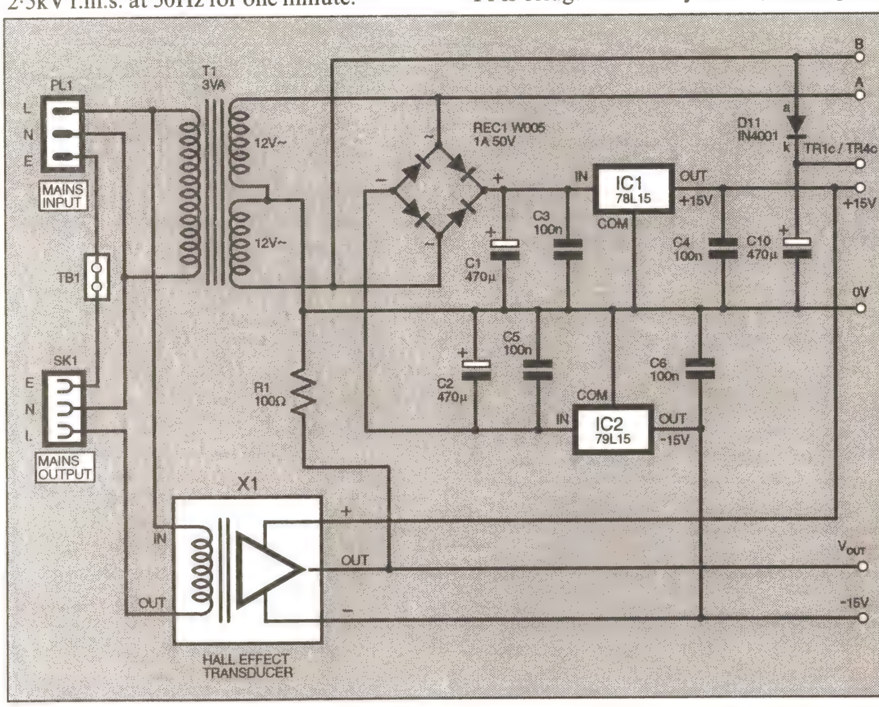


Fig. 3. Circuit diagram for Sensor and Power Supply.

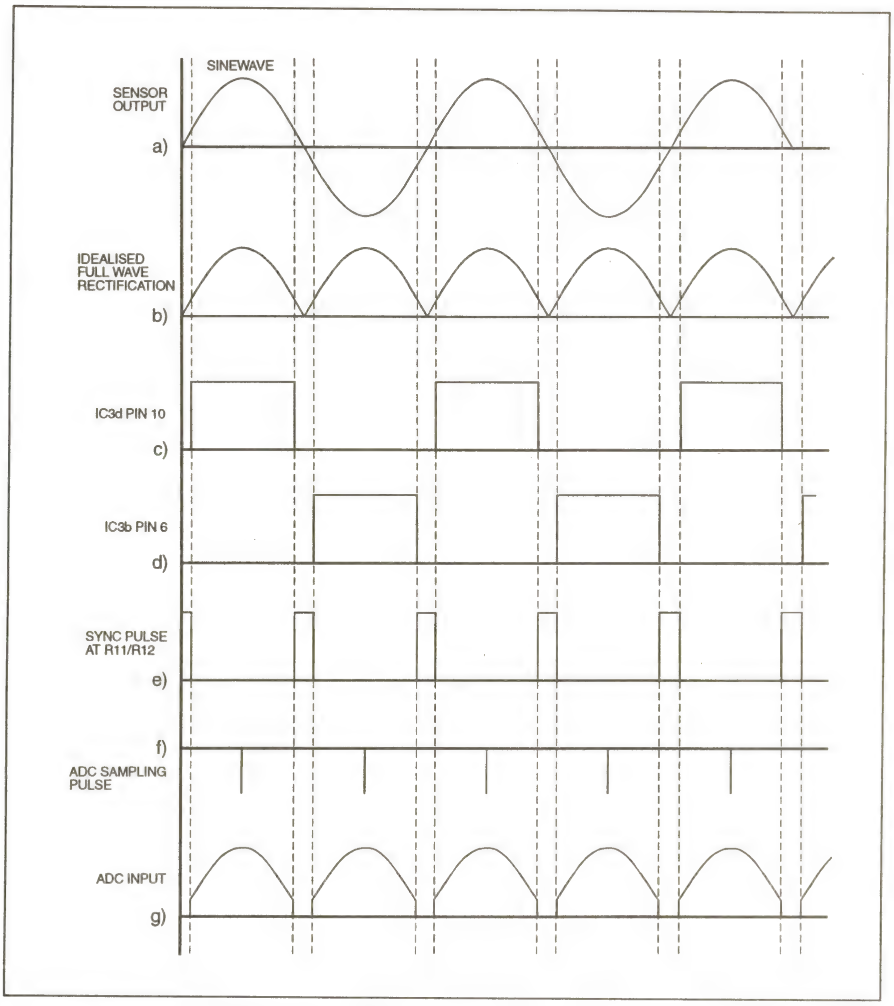


Fig. 4. Significant waveforms associated with the PIC-Electric.

tive output is smoothed by capacitors C1 and C3, and regulated down to +15V d.c. by IC1. The negative output from REC1 is smoothed by capacitors C2 and C5, and regulated down to −15V by IC2. This dual voltage (+/−) 15V supply powers the d.c. aspect of the sensor X1.

An additional unregulated *positive* d.c. voltage is required to power the 7-segment display (X3) l.e.d.s. This is generated from only one of the transformer's secondary windings. Diode D11 half-wave rectifies the voltage and capacitor C10 provides the necessary smoothing.

SIGNAL FORMAT

The output from the Hall-effect sensor X1 is a sinewave whose amplitude increases with the current sensed, peaking above and below the 0V power line, as shown in Fig. 4a. To suit the ADC, the signal needs to be rectified so that the negative portion of the waveform is inverted to make both its aspects positive, as shown idealised in Fig. 4b.

Normally, rectification requires the use of diodes in series with the voltage path. Silicon diodes, though, cause an insertion loss of about 0·7V, which is undesirable when dealing with low level signals.

There are several ways in which this problem can be overcome. The technique chosen here is shown in the Signal Formatting and Sync circuit diagram of Fig. 5. Also shown is the circuit which generates the 100Hz synchronisation signal.

The Hall-effect sensor output signal is first fed to the non-inverting buffer op.amp IC5a pin 3, whose output is fed to analogue gate "switch" IC4a pin 4, via resistor R7. The output from IC5a is also inverted by IC5b and fed through resistor R8 to a second analogue gate, IC4b pin 1. Diodes D3 and D4 prevent IC4a and IC4b from being adversely affected by the negative aspects of the signals.

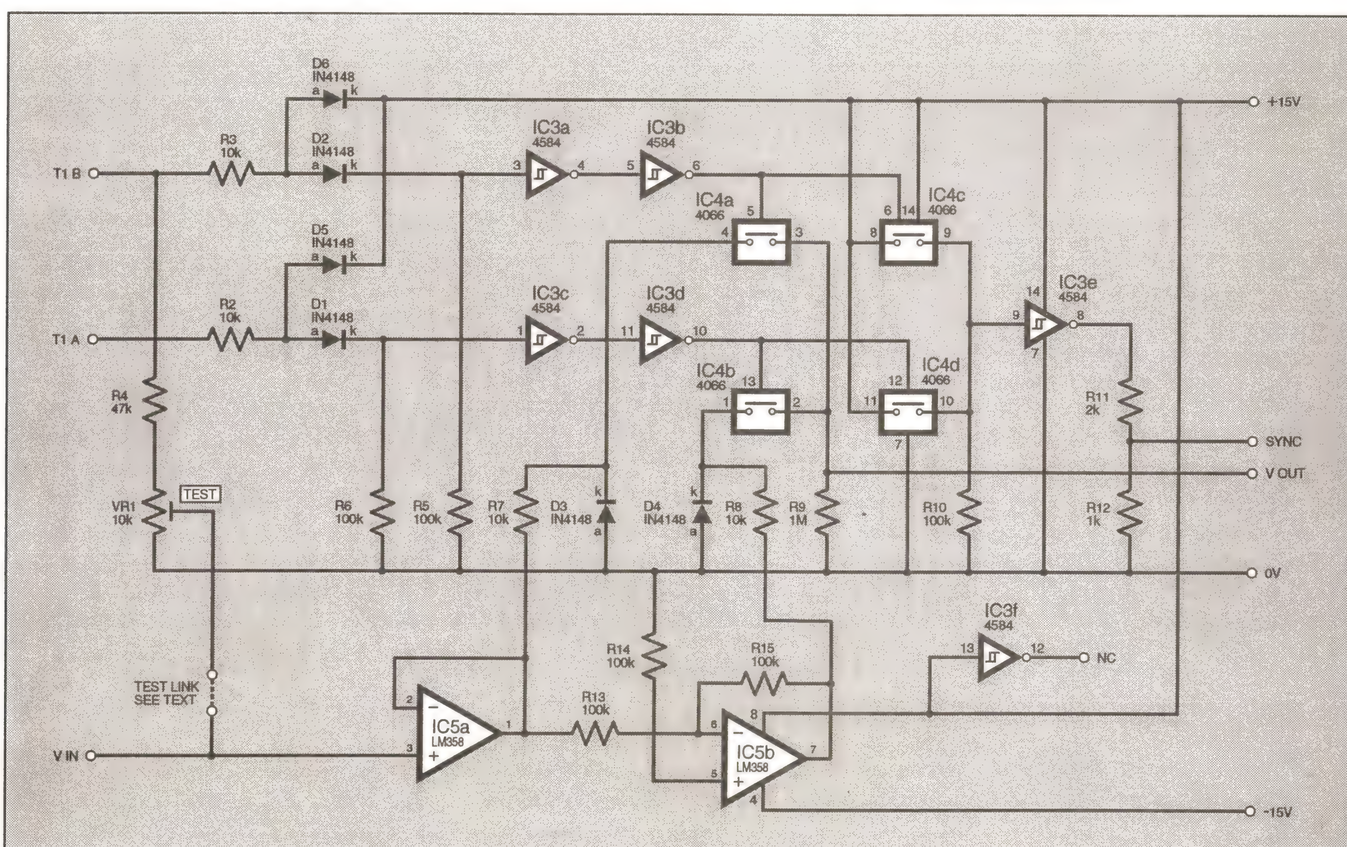


Fig. 5. Sync and Signal Formatting circuit diagram.

CONTROL SIGNALS

Controlling signals for IC4a and IC4b are derived from the secondary windings of transformer T1. Transformer line *B* in Fig. 3 is fed, via resistor R3 and diode D2, to Schmitt trigger inverters IC3a and IC3b.

This sequence of components rectifies the positive-going signals from the transformer, reshaping them to square wave pulses at positive supply line amplitude. Only voltages above the positive-going Schmitt trigger threshold of about 8V trigger IC3a (with +15V supply); the equivalent negative-going threshold is typically about 6·9V. Diode D6 limits the maximum voltage which can be presented to the input of IC3a.

The output from IC3b controls analogue gate IC4a via its pin 5 which, when high, allows signals from IC5a to pass through the gate from pin 4 to pin 3.

Signals from transformer line *A*, which are of opposite phase to those from line *B*, are similarly processed by inverters IC3c, IC3d and their associated components, controlling analogue gate IC4b and the signals fed to it from IC5b.

The outputs of IC4a and IC4b are connected together, feeding into resistor R9 from where they are routed to the ADC (IC7). Since the controlling signals are of opposite phase, the gates open or "switch" alternately, passing through only the positive aspects of the analogue voltages from the op.amps. Because the Schmitt threshold voltages for IC3a and IC3c are several volts above 0V, the analogue voltage presented to the ADC appears similar to the waveform in Fig. 4g.

Note that an oscilloscope may show slight differences in the relative amplitudes of alternate peaks of the actual waveform fed to the ADC. This is due to the inherent and uncorrected offset voltages of the op.amp circuits. The differences are balanced out in the software summing routines.

Synchronisation pulses at 100Hz are generated by gates IC4c and IC4d, which are controlled respectively by the outputs from IC3b and IC3d. Both inputs (pins 8, 11) to IC4c and IC4d are tied to the positive supply line.

COMPONENTS

Approx cost guidance only **£55**
excluding case, mains socket and cable

Resistors

R1, R24 to R32	100Ω (10 off)
R2, R3, R7, R8, R33	10k (5 off)
R4	47k
R5, R6, R10, R13 to R17	100k (8 off)
R9	1M
R11, R34	2k (2 off)
R12, R18 to R23, R35 to R37	1k (10 off)

All 0·25W 5% carbon film or better.

Potentiometers

VR1, VR2	10k enclosed carbon preset (2 off)

Capacitors

C1, C2, C10	470µ radial elect., 35V (3 off)
C3 to C7, C11, C12	100n polyester (7 off)
C8, C9	15p polystyrene (2 off)

Semiconductors

D1 to D8	1N4148 signal diode (8 off)
D9	red l.e.d., sub-min
D10	BZY88C12 12V 400mW Zener diode
D11	1N4001 1A 50V rect. diode
REC1	WO05 50V 1A bridge rect.
TR1 to TR4	BC337 *npn* transistor
IC1	78L15 +15V 100mA regulator
IC2	79L15 −15V 100mA regulator
IC3	4584 Hex Schmitt inverter
IC4	4066 quad bilateral analogue switch
IC5	LM358 dual op.amp
IC6	78L05 +5V 100mA regulator
IC7	TLC549IP 8-bit serial ADC
IC8	74HC4078 8-input OR/NOR gate
IC9	PIC16C84 programmed EEPROM microcontroller (see text)

See SHOP TALK Page

Miscellaneous

X1	current transducer, Hall-effect
X2	4MHz crystal
X3	4 × 7-segment display module, common anode
S1	d.p.s.t. min. slide switch, p.c.b. mounting (see text)
S2 to S4	pushbutton p.c.b. mounting switch, push-to-make (see text) (3 off)
T1	3VA mains, p.c.b. mounting, transformer with twin 12V secondaries

Printed circuit boards for Sensor/PSU and Controller/Display, available from the *EPE PCB Service*, codes 977 (Sen/PSU) and 978 (Cont./Disp.) respectively; 8-pin d.i.l. socket (2 off); 14-pin d.i.l. socket (3 off); 18-pin d.i.l. socket; plastic case, 188mm × 108mm × 160mm; mains cable gland (2 off); 2-way 15A mains terminal block; mains plug and socket; p.c.b. mounting supports, screw base (4 off); nuts and bolts; connecting wire; mains cable; cable ties (3 off); terminal pins; solder, etc.

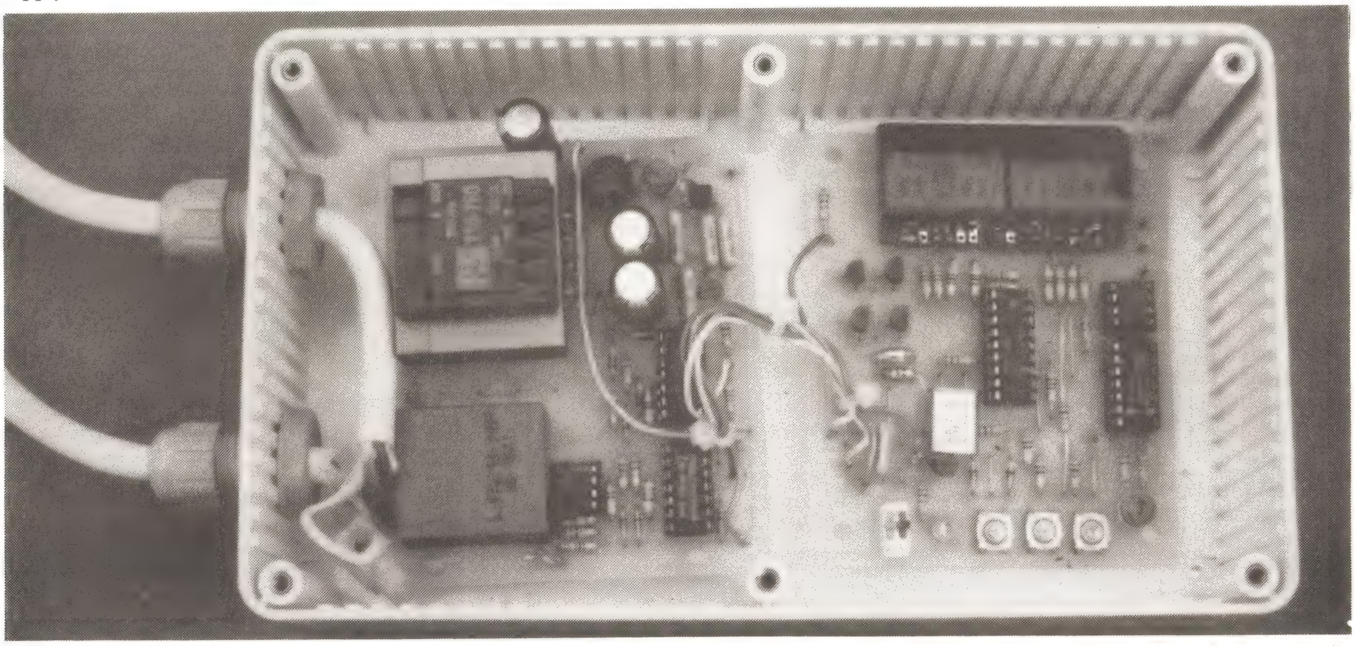
Their outputs (pins 9, 10) are connected together and fed into resistor R10 and Schmitt inverter IC3e. The potential divider formed by resistors R11 and R12 across the output of IC3e limits the resultant sync pulse amplitude to a maximum of +5V, to suit the PIC microcontroller IC9.

The waveforms of the sync pulse and the signals which control IC4 are shown in Fig. 4c to Fig. 4e. The point at which the ADC samples the analogue signal is shown in Fig. 4f.

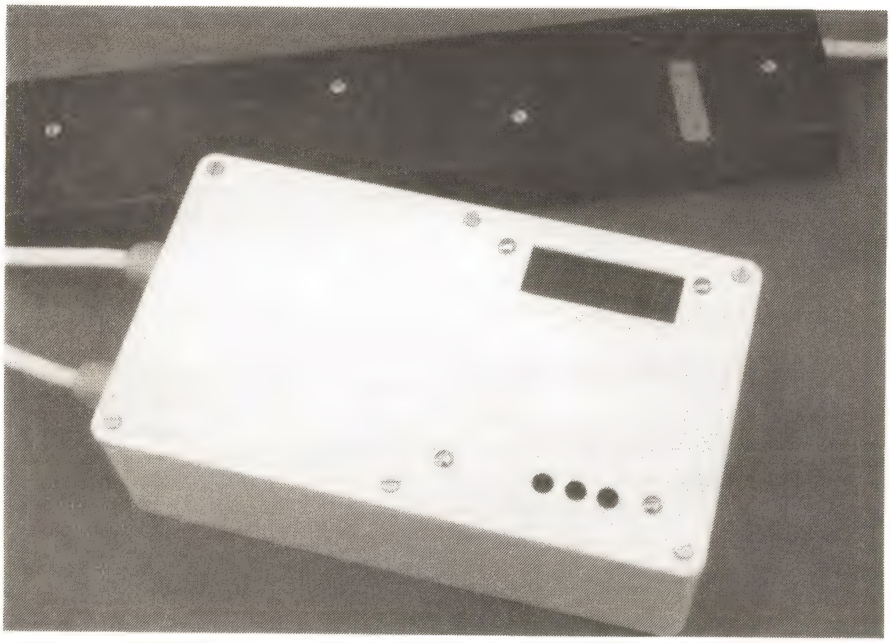
TEST CIRCUIT

Also shown in Fig. 5 are details of a simple test circuit formed by resistor R4 and preset VR1. R4 is connected to transformer line *B* which supplies a sinewave having the same phase as that from the sensor.

The wiper of VR1 can be linked to the analogue processing circuit at IC5a pin 3 to provide a test signal in place of that from the sensor. This allows tests to be made without plugging a mains appliance into PIC-Electric.



The completed PIC-Electric Meter with lid removed to show siting of circuit boards. Note that the Display p.c.b. is normally bolted to the rear of the case lid, behind the display window.



The completed PIC-Electric Meter showing the readout display window and three holes for access to the Reset and Function setting switches.

CONTROL AND DISPLAY

Details of the Control and Display circuit are shown in Fig. 6. Basically, the circuit comprises the PIC microcontroller IC9, the ADC IC7, and display module X3. The majority of the circuit is under control by the microcontroller and its software.

The power supply for most of this circuit has to be regulated at +5V, a function which is carried out by IC6.

ADC

Analogue-to-digital conversion of the processed signal is performed by IC7. This is an 8-bit serial ADC chip whose reference voltage is provided by the potential divider consisting of resistors R33, R34 and preset VR2.

Data conversion and output are controlled by the chip's internal clock system and external input/output (I/O) clock pulses. The maximum sampling rate the chip can handle is about 40kHz.

When IC7's $\overline{CS}$ pin 5 is high, the data output (D OUT) pin 6 is in a high impedance state and the I/O clock (CLK) pin 7 is disabled. Reading of the conversion result is initiated when $\overline{CS}$ is brought low.

On this action, the most significant bit (MSB) of the previous conversion appears on the data output. The falling edges of the next four I/O clock cycles shift out the next four MSB data bits.

The on-chip sample-and-hold begins sampling the analogue input after the fourth high-to-low transition of the I/O clock. The sampling operation basically involves the charging of internal capacitors to the level of the analogue input voltage.

Three more I/O clock cycles are then applied to the CLK pin and the final three conversion bits are shifted out. After the eighth I/O clock cycle, $\overline{CS}$ must go high or the I/O clock remain low for at least 36 internal system clock cycles to allow completion of the internal hold and conversion functions.

In Fig. 6, the $\overline{CS}$ pin is brought low only when microcontroller IC9 lines RA0 to RA3 are all low simultaneously, causing IC8's output pin 8 to also go low. Note that IC8 is a 74HC4078 8-input OR/NOR gate used in its OR mode and that the 4000 series near-equivalent *4078* ***cannot*** be substituted since the latter is purely a NOR gate without the extra OR inversion at pin 1.

DISPLAY MODULE

Each of the multiplexed four digits of the l.e.d. display module has seven segments and a decimal point which are controlled by microcontroller's data lines RB1 to RB7, plus RA4. The segments and decimal point are turned on when their respective data lines are low. Resistors R24 to R31 limit the current flowing through the segments.

Technical literature shows that PIC16C84 microcontrollers can supply (source) 20mA or sink 25mA per data line, though each port (RA or RB) is limited to the total amount of current which can be sunk or sourced: 80mA sunk by Port RA, 150mA sunk by Port RB, 50mA sourced by Port RA and 100mA sourced by Port RB.

With resistors R24 to R31 at the values shown, when each digit has all seven segments and a decimal point turned on, the source current required is about 120mA. Although Port RB can sink this amount of current, Port RA cannot source it. Increasing the resistor values to suit Port RA would not allow the l.e.d.s to glow with adequate brightness, consequently current boosting is required and is supplied by transistors TR1 to TR4.

The transistors are connected in series with the common-anode digits of the display and are controlled by IC9's data lines RA0 to RA3. Each data line when taken high allows the transistor to conduct voltage to the selected digit. Although the transistors' collectors are fed from a voltage greater than the +5V available from IC7, the maximum voltage which is fed from their emitters to each digit is about 0·7V below the voltage of the controlling RA data line connected to their bases, i.e. about 4·3V.

FUNCTION SWITCHES

Function switches S3 and S4 select which data is displayed on the l.e.d. module. Their use and effect is determined by which routine the software is running at the time of their pressing, as discussed next month.

In all routines, the status of the switches S3 and S4 can only be read when software sets data lines RA0 to RA3 low, so setting low IC8 pin 1. If either of the switches is pressed at that time, a logic 0 will be read from the respective data line RB2 or RB3.

Resistors R16 and R17 tie the outputs of the switches to the positive rail, consequently if a switch is unpressed or IC8 pin 8 is high, a logic 1 will be read. R36 and R37 ensure that no connection is made between the two data lines if both switches are pressed simultaneously.

MICRO-CONTROLLER

The PIC16C84 microcontroller is shown as IC9 in Fig. 6. As a device which has an EEPROM program memory, it can be repeatedly reprogrammed without the need for ultra-violet (UV) erasure, unlike the rest of the current PIC range of microcontrollers. The reprogrammability, of at least 1000 times and probably more, makes it ideal for situations where controlling software is being developed step by step.

An additional advantage over other PIC devices is that this chip also has a EEPROM data memory which can be written to and read from by the controlling software, with a maximum of about one million write cycles. This facility makes the processor eminently suitable for systems which require some data factors to be changed according to varying situations, such as the need to periodically update the PIC-Electric Meter with revised electricity unit prices.

PIC-Electric has been designed so that the microcontroller can be serially programmed from a PC-compatible computer, running suitable software, whilst plugged into the printed circuit board. All that is required is that the PC should provide data via resistor R22 to IC9 pin 13, the DIO/RB7 data line, and a clock signal via R23 to IC9 pin 12, the CLK/RB6 data line, plus the 0V common connection.

The PIC16C84 cannot be programmed by the *PIC-DATS System* published in *EPE* May '95 issue, but it can be programmed by the Simple PIC16C84 Programmer published in this issue. Proprietary software is also available from a variety of commercial sources. The chip's programming instruction codes are common to all current PIC devices, except for four additional commands.

The microcontroller IC9 is powered at +5V and in normal running mode its $\overline{MCLR}$ (master clear, or reset) pin 4 is held at about the same voltage, as supplied via diode D7 and resistors R20, R32. In programming mode, though, the pin needs to be held at between +12V and +14V.

For programming, S1 switches the +15V supply line through diode D8, overriding the voltage from D7. Zener diode D10 reduces the programming voltage to +12V.

To reset IC9, $\overline{MCLR}$ has to be taken to 0V, an action performed by pushswitch S2. Resistor R20 prevents the voltage at the D7/D8 junction from being shorted to 0V when S2 is pressed. R32 is included at the manufacturer's recommendation.

The microcontroller contains its own clock generating circuit whose frequency and mode of operation is determined by a choice of external component types, as detailed in the chip's data sheet. For this application, a clock frequency of 4MHz is set by crystal X2 in conjunction with capacitors C8, C9 and resistor R21.

Since the microcontroller effectively acts upon software instruction codes at one quarter of the clock frequency, an operational speed of 1MHz is achieved here. This is more than fast enough to process data acquired from the ADC at a 100Hz sampling rate, even though the software contains around 700 commands.

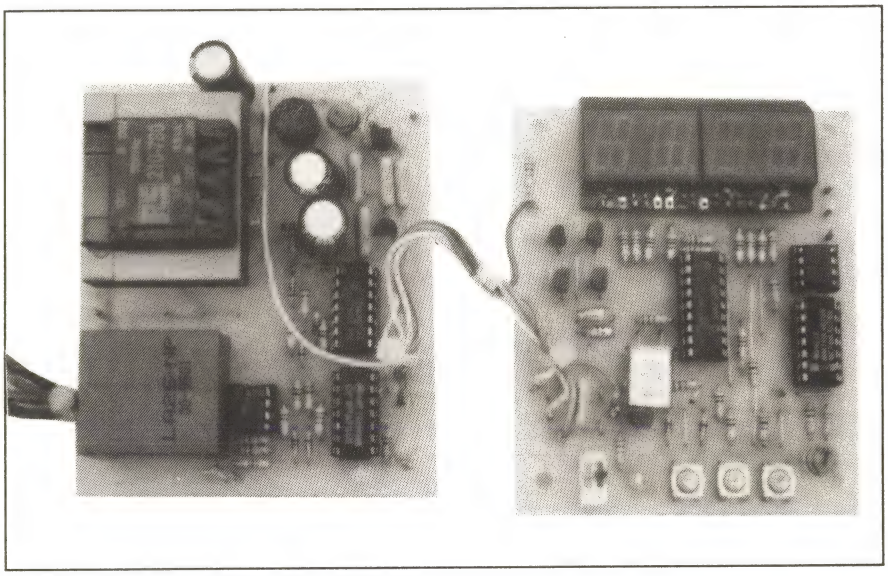
SOFTWARE

Software of the source-code listing for the PIC-Electric Meter (together with Simple PIC16C84 Programmer software) can be supplied from the Editorial Office as a 3.5in. disk (UK £2.50, overseas surface £3.10, airmail £4.10). A pre-programmed PIC16C84 chip (together with p.c.b.s) for PIC-Electric, ready to plug straight in, is obtainable from Magenta Electronics. See *Shoptalk* for details.

Detailed description of all the software for the PIC-Electric is beyond the scope of this article. A brief operational description follows the "First Tests" section (next month). The source code listing available has comments embodied into it which clarify further aspects of the program.

There are also four software routines in the listing which will be of general interest to PIC programming readers since they show practical examples of coding procedures which were found to be unclearly explained by the *Microchip Data Book*. The routines include EEPROM data storage and retrieval, multiplexed display look-up tabling, and indirect addressing.

Next Month: Constructional details, testing procedures and using the Meter.



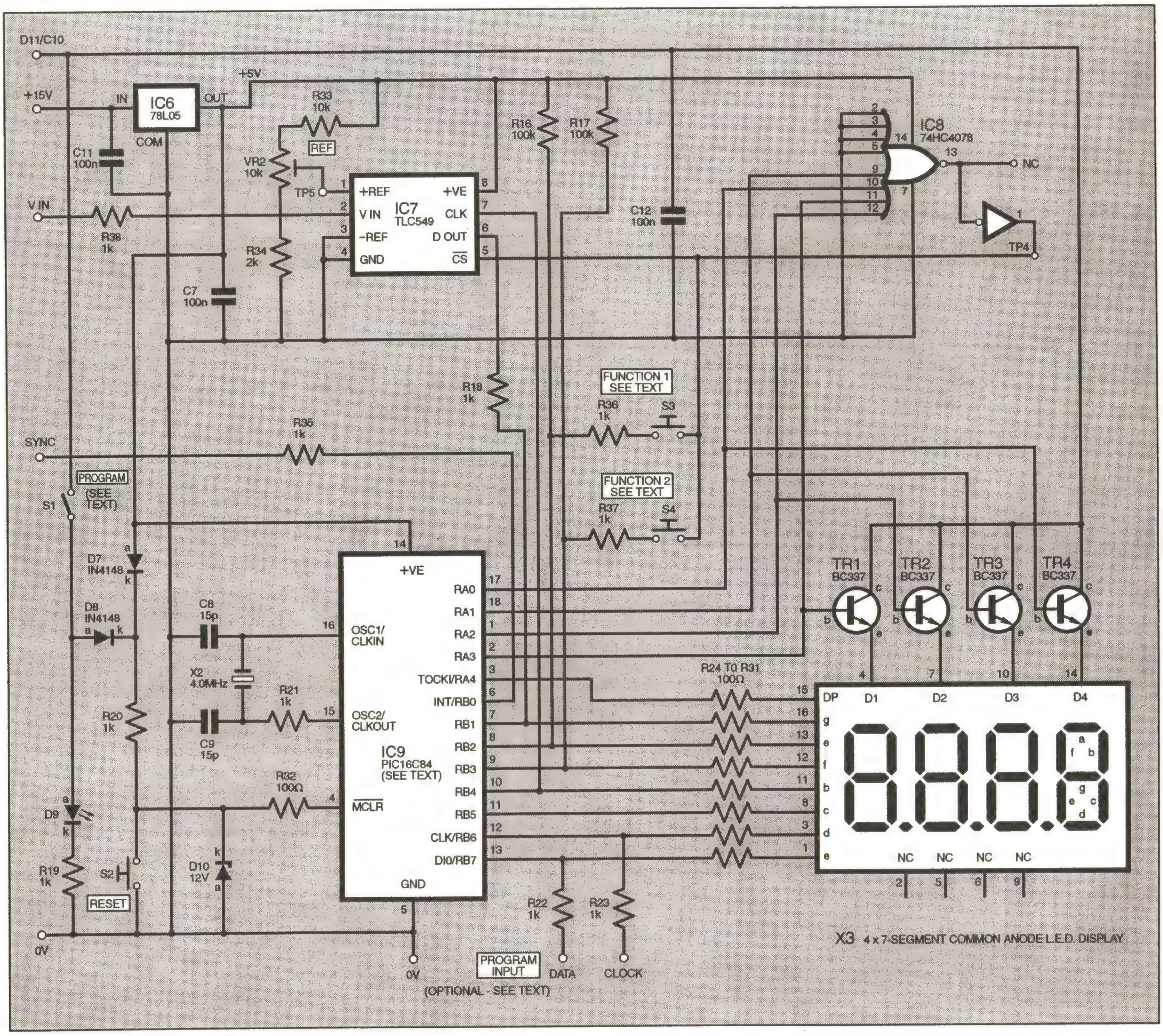


Fig. 6. PIC-Electric Controller and Display circuit.