thandar

TM 351 DIGITAL MULTIMETER

SERVICE MANUAL

"ADDENDUM

From March 1981: 47K (R43) is now fitted as standard across R3 (90Ω); this ensures that instruments which would otherwise only marginally meet specification on the 100Ω range are brought within it. The accuracy of all other ranges is unaffected."

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CONTENTS

GENERAL

Service Handling Precautions

Service work or recalibration should only be carried out by skilled engineers. Please note the following points before commencing work.

The tracks on the printed circuit board are very fine and may lift if subjected to excessive heat. Use only a miniature temperature controlled soldering iron and remove all solder with solder wick or suction before attempting to remove a component.

The integrated circuits IC2, IC3 and IC4 are CMOS devices and care should be taken when handling to avoid damage by static discharge.

The very high input impedance of the instrument can give rise to offset voltages caused by minute leakage currents. The PCB must be kept clean and dry to avoid this.

Dismantling the instrument

1. Invert the instrument and remove the 4 rubber feet.
2. Remove the 4 recessed and one surface screw.
3. Holding the case upper and lower together, turn the instrument the right way up and lift off the top. This permits access to the major calibration points; AC calibration should always be carried out with the instrument in the case lower, making sure that the pcb earth spring is making contact to the case lower earth plane, and with the top earth screen in place.
4. If further dismantling is required to replace components, proceed as follows:

   Remove the two top earth screen screws, unclip the plastic spacer, and lift off the screen.

   Remove the batteries and remove the two screws in the battery compartment; lift out the battery carrier.

   Remove the two countersunk screws that hold the battery carrier constraint and pcb to the case lower and remove the constraint. Remove the two other pcb retaining screws at the sides of the board.

   The complete pcb assembly can then be lifted out with the front panel still attached, though this can be removed if necessary by desoldering the socket connections.

Calibration Equipment

Ideally the sources being used for calibration should be at least a factor of 10 or more accurate than the TM351, or there should be another multimeter of 10 times the accuracy and resolution with which the source can be set. Thus, for example, the source instrument used for DC voltage calibration should have an accuracy of 0.01% or better.

SPECIFICATION

DC⎓VOLTAGE

Range	Resolution	Accuracy
200mV 2V 20V 200V 1000V	100µV 1mV 10mV 100mV 1V	± (0.1% of reading + 1 digit)

Maximum Allowable Input: 1100V DC or peak AC.

Input Impedance: 10MΩ

Normal Mode Rejection Ratio: > 60dB at 50Hz, 60Hz

Common Mode Rejection Ratio: >100dB at DC, 50Hz, 60Hz

AC~ VOLTAGE

Range	Resolution	Accuracy 50Hz-1kHz	Accuracy 1kHz-10kHz	Accuracy 10kHz-20kHz
200mV 2V 20V 200V	100µV 1mV 10mV 100mV	± (0.5% rdg +2 d)	± (1.5% rdg + 2 d)	± (5% rdg +5 d)
750V	1V	± (0.5% rdg +2d) at 50/60 Hz; ± (5% rdg +2 d) 60 Hz - 1kHz		

Maximum Allowable Input: 750V rms, 1100V peak, 10^6V.Hz, except 200mV range: 250V rms, 400V DC.

Input Impedance: 10MΩ in parallel with <100pF.

Response: Average responding, calibrated in rms of a sinewave.

Common Mode Noise Rejection: > 60dB at 50Hz, 60Hz.

DC⎓ CURRENT

Range	Resolution	Accuracy	Maximum Voltage Burden
200µ A 2mA 20mA	100nA 1µA 10µA	± (0.3% rdg +1 d)	200mV
200mA 2000mA	100µA 1mA	± (0.3% rdg +1 d)	1V
10A	10mA	± (2% rdg +2 d)	1V

Overload Protection: 2A (250V) fuse all ranges except 10A; maximum permissible input on 10A range: 10A, 20A for 10 secs.

AC~ CURRENT

Range	Resolution	Accuracy (50Hz - 1kHz)	Maximum Voltage Burden
200µA 2mA 20mA	100n A 1µA 10µA	± (1% rdg +2 d)	200mV
200mA 2000mA	100µA 1mA	± (1% rdg +2 d)	1V
10A	10mA	± (2.5% rdg +2 d)	1V

Overload Protection: 2A (250V) fuse all ranges except 10A; maximum permissible input on 10A range: 10A, 20A for 10 secs.

RESISTANCE AND DIODE CHECK

Range	Resolution	Accuracy	Full Scale Voltage
200Ω	100mΩ	± (0.2% rdg +1 d)	< 0.5V
2KΩ	1Ω	± (0.2% rdg +1 d)	< 0.5V
20KΩ	10Ω	± (0.2% rdg +1 d)	> 0.7V
200KΩ	100Ω	± (0.2% rdg +1 d)	> 0.7V
2000KΩ	1KΩ	± (0.2% rdg +1 d)	> 0.7V
20MΩ	10KΩ	± (1% rdg +1 d)	> 0.7V

Maximum Allowable Input: 250V DC or AC rms.

Diode Check: The 20KΩ range has sufficient full-scale voltage to to turn on a silicon diode at a current of approximately 100µA; the three higher ranges also have sufficient voltage but their excitation currents are much smaller and consequently their use for a diode check is not recommended.

The 200Ω and 2KΩ ranges will not turn on silicon diodes so in-circuit resistance measurements can be made.

GENERAL

Accuracy: The quoted accuracy specifications are for the temperature range 18°C - 28°C and are maintained for typically one year. For temperatures in the range 0° - 18°C and 28°C - 40°C the accuracy specification is typically degraded by <0·1 x the applicable accuracy specification per °C.

Display: 3½ digit 0·5" LCD with polarity, overrange and low battery indication.

Overrange Indication: '1' shows in M.S.D., with all other digits suppressed.

Maximum Common Mode Voltage: 1000V DC or AC peak

Power Requirements: Six alkaline or zinc carbon 'C' cells.

Battery Life: Typically > 4000 hours on DC and resistance measurements, > 1800 hours on AC measurements, from alkaline cells.

Low Battery Indicator: 'BAT' lights in display when typically 5% of battery life remains.

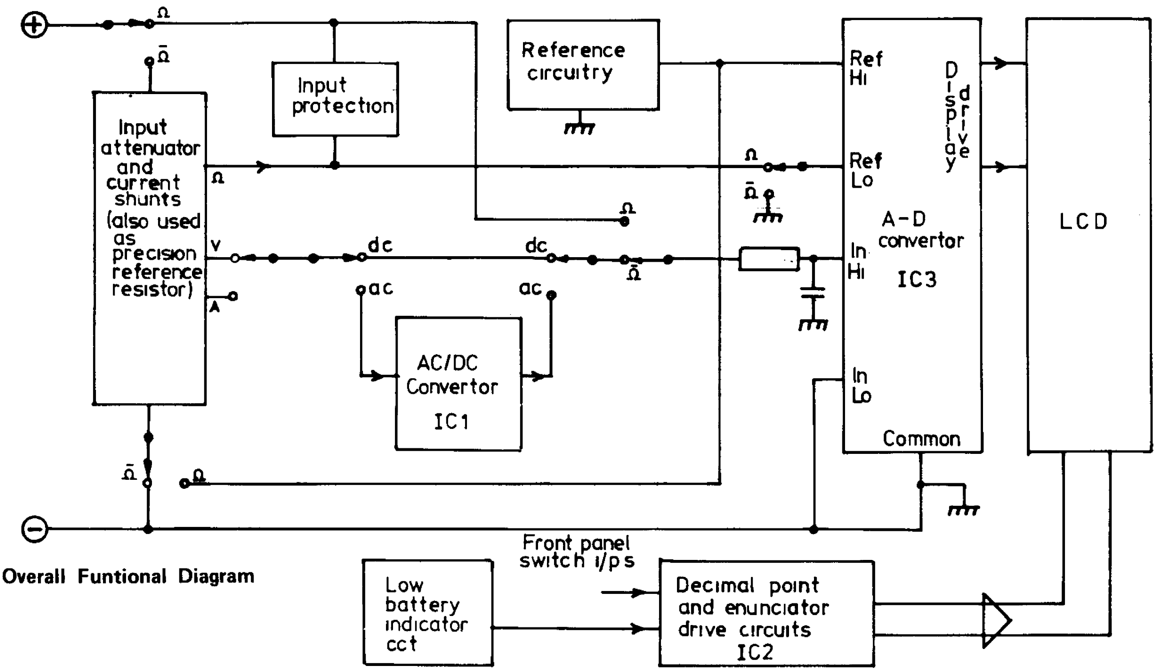
Environmental Operating Range: 5°C to 40°C, <80% RH.

Environmental Storage Range: –40°C to 60°C (with alkaline batteries), <75%RH.

Dimensions: 255 x 150 x 50mm (excluding handle).

Weight: 800gms excluding batteries; 1200 gms including alkaline batteries.

FUNCTIONAL DESCRIPTION



Overall Funtional Diagram

The block diagram shows the overall functional and switching arrangement of the TM351. There is little difference in operation between voltage and current measurements, most of the switching being associated with the resistance mode.

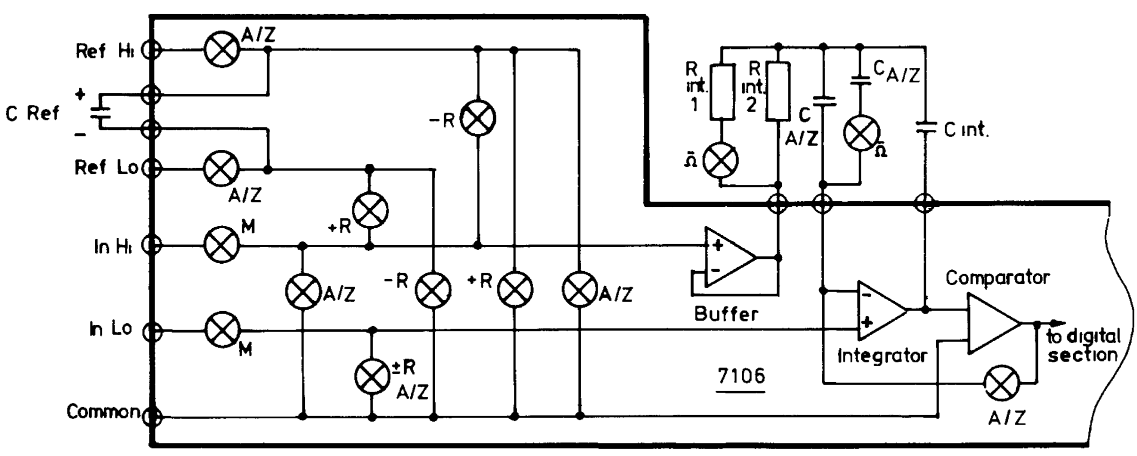
Analogue to Digital Converter

The analogue to digital converter is the most important part of the instrument since it is used in all measurements. It accepts for conversion only DC voltages in the range 0-200mV (0-2V on some resistance measurements); all other quantities to be measured must first be converted to a DC voltage in one of these ranges.

The A-D converter is contained on a single I.C. and consists essentially of three amplifiers, a clock generator, control switching for the three measurement phases and the digital logic to directly drive a seven segment 3½-digit liquid crystal display. The converter uses the dual slope integration technique and the conversion process can be considered in three phases, occupying a total of 4,000 internally generated clock pulses derived from the on-chip oscillator.

The notation beside each analogue gate in the diagram indicates which gates are closed during each phase.

1. Auto-zero (A/Z). During auto-zero two things happen. Firstly the instrument reference voltage is connected to the reference capacitor so that the capacitor stores the reference voltage when the A/Z gates are opened at the end of this phase; during the third phase of measurement the reference capacitor will be connected to the integrator to provide a positive or negative reference source as required.



ANALOGUE SECTION OF A/D CONVERTOR

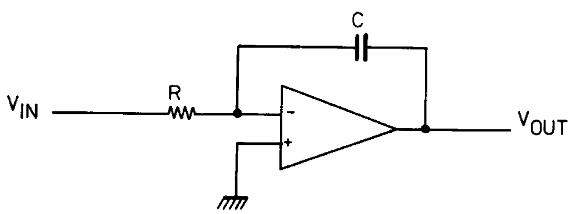
Secondly, the integrator is automatically zeroed causing the output of the integrator to sit exactly at the threshold of the comparator. This is achieved by means of an "auto-zero" capacitor on the input of the integrator; by closing the loop from comparator output to integrator input via an internal gate whilst clamping buffer and integrator non-inverting inputs to ground, any voltage offsets in the buffer, integrator or comparator are stored on the auto-zero capacitor which then provides offset voltage correction during the measurement and reference phases. The length of the auto zero phase depends upon the previous measurement, occupying a minimum of 1000 clock periods and up to 3000 if the previous input signal was zero.

2. Measure (M). The second phase occupies exactly 1000 clock periods and during this time the input signal (0-200mV say) is applied via the internal gating and buffer to the input of the integrator. The output of the integrator ramps away from its auto-zero level at a rate (slope) directly proportional to the magnitude of the input voltage; the larger the input the faster the integrator ramps. At the end of the 1000 periods the input signal is disconnected and the integrator output is at a voltage directly proportional to the input signal.

3. Reference phase (R). The reference voltage (100mV) is now applied to the integrator by connecting the reference capacitor. The reference polarity is automatically selected by the control logic to be opposite to that of the input so that the reference voltage always returns the integrator output to zero i.e. gates +R are closed if the input was positive, gates −R closed if the input was negative. Since the reference voltage is fixed the slope of the integrator output is constant, and the time taken to return it to the original (auto-zero) voltage is therefore proportional to the magnitude of the input signal. The comparator detects when the integrator output reaches its autozero voltage, disconnects the reference capacitor and stops the counter which has recorded the time to ramp down. The total count is decoded by further logic and output to the LCD.

The charging resistor on the integrator input can be switched by an external analogue gate to allow both 0-200mV and 0-2V (used on some resistance ranges) inputs to be accommodated without the integrator output limiting on the higher range.

The equations which define the operation are as follows:



i) V_{IN} is applied for a known time T (=1000 counts)

$$\text{Therefore } I_{IN} = \frac{C\,V_{OUT}}{T}$$

$$\text{But } I_{IN} = \frac{V_{IN}}{R}$$

$$\text{Therefore } V_{IN} = \frac{C\,V_{OUT}}{T} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

ii) V_{REF} is applied for a time t sufficient to ramp the integrator output back from V_{OUT} to zero.

$$\text{Therefore } I_{REF} = \frac{C\,V_{OUT}}{t}$$

$$\text{But } I_{REF} = \frac{V_{REF}}{R}$$

$$\text{Therefore } \frac{V_{REF}}{R} = \frac{C\,V_{OUT}}{t} \quad \ldots\ldots\ldots\ldots (2)$$

Dividing 1 by 2 gives

$$\frac{V_{IN}}{V_{REF}} = \frac{t}{T}$$

which for V_{REF} = 100mV and T = 1000

$$\text{means } V_{IN} = t\,\frac{mV}{10}$$

i.e. the count at the end of the reference phase is equivalent to V_{IN} in $\frac{mV}{10}$

Since T and t are derived from the same master clock, the accuracy of conversion is independent of long term clock frequency stability since only ratios are involved.

The accuracy of the conversion then becomes primarily that of the reference voltage V_{REF}.

Finally the new count is updated into the display latches and the cycle is repeated.

Typical A-D waveforms are shown overleaf

Measurement of DC Voltage

A 100mV reference is used for all voltage measurements. On the 200mV full scale range the input is applied direct to the A-D converter. To obtain the higher voltage ranges (2V, 20V, 200V, and 1000V) a precision resistor attenuating network is used to divide the input voltage by 10, 100, 1000, or 10000 to always give an input to the A-D converter in the range 0-200mV.

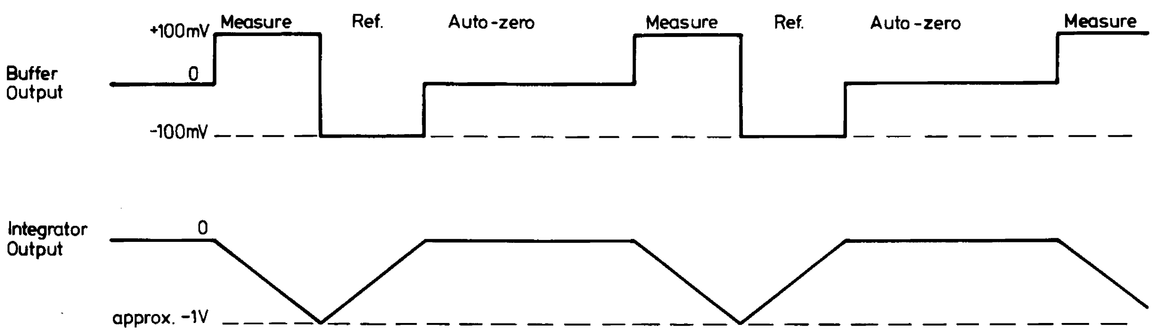
The attenuator network has a total impedance of 10MΩ which defines the input impedance of the instrument on all ranges including the 200mV range.

Measurement of DC Current

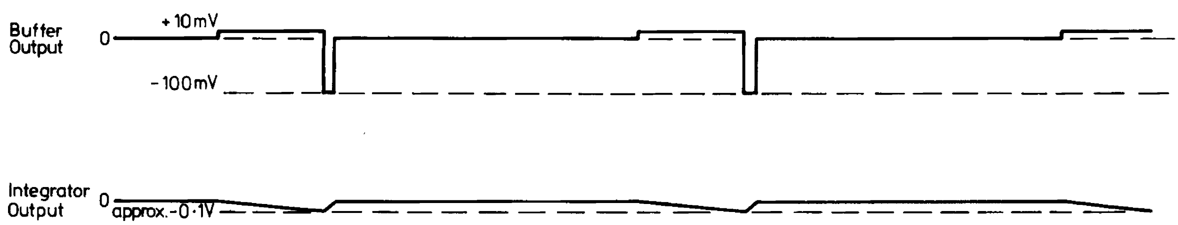
A 100mV reference is used for all current measurements and the current to be measured is forced through a precision resistor to generate a voltage in the range 0-200mV, i.e. 1kΩ for 200μA full scale, 100Ω for 2mA, 10Ω for 20mA, 1Ω for 200mA, 0.1Ω for 2000mA and 0.01Ω for 10A.

TYPICAL A-D CONVERTOR WAVEFORMS

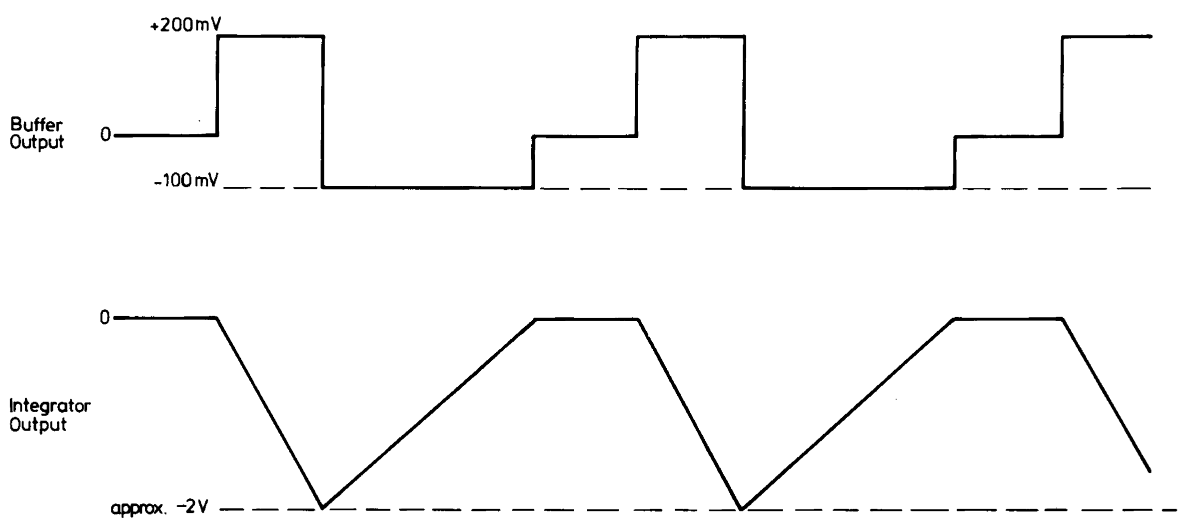
1. Vin =100mV



2. Vin = 10mV



3. Vin = 200mV



Measurement of AC Voltage and Current

In principle AC measurement consists of a precision half-wave rectification of the AC signal to provide the DC input required by the A-D Converter. Again 200mV range inputs are applied direct and a 100mV reference is used.

On the higher voltage ranges the precision resistor attenuator is used, with compensation capacitors across the resistors to give correct AC attenuation over the specified frequency range.

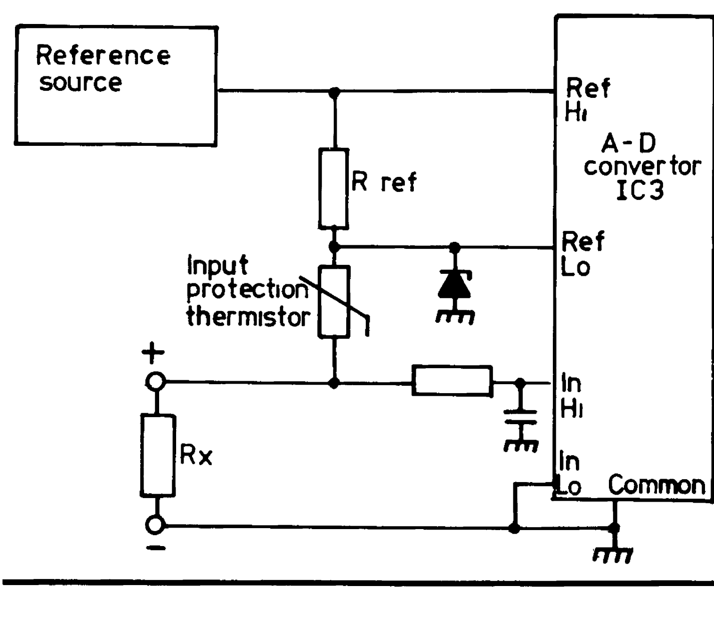
Resistance Measurements

The overall block diagram can be reduced to that shown below where R_{REF} is an appropriate part of the precision resistor attenuator and R_X is the unknown resistance being measured.

In this mode the reference voltage for the A-D converter is derived from the current flowing in R_{REF}, which is in series with R_x so that the same current flows in each. The voltage across R_x is now measured by the A-D converter and displayed relative to the reference voltage. Thus, since the same current flows in R_{REF} and R_X, if their values are equal the reference voltage equals the measured voltage and the display output will read 1.000. For instance, by making R_{REF} 100Ω and switching the decimal point, the display will read 100.0 when R_X = 100Ω and 200.0 when R_X = 200Ω.

This simple scheme is made possible by the very low input bias currents required by the A-D converter, which ensure that the currents in R_{REF} and R_X are essentially the same, even when measuring very large resistances. The reference source voltage is theoretically irrelevant although practical considerations, such as the current drawn by R_x and available integrator swing in the converter limit the maximum voltage, and noise in the A-D limits minimum voltages. Hence the TM351 produces an approximate 0-200mV across R_X on the 200Ω and 2kΩ ranges and 0-2V on the higher resistance ranges where the current drawn from R_{REF} and R_X is less; the higher ranges thus become suitable for functional diode checks with up to 100μA bias current supplied. To limit the integrator output swing on these ranges with a 0-2V input, the integrator current is reduced by switching out R_{INT1}. At the same time the size of the auto-zero capacitor is reduced to improve settling time.

Protection of the ohms ranges is two fold. Assuming no more than line voltages are accidentally applied to the input terminals IN HI is protected by clamping diodes inside the I.C., the current being limited by the input filter resistor. The remainder of the circuitry is protected by a positive temperature coefficient thermistor and clamping transistor with a high surge current capability configured as a diode. During measurements any voltage dropped across the thermistor has no effect on the reference and measured voltages, which are measured differentially by the A-D converter.

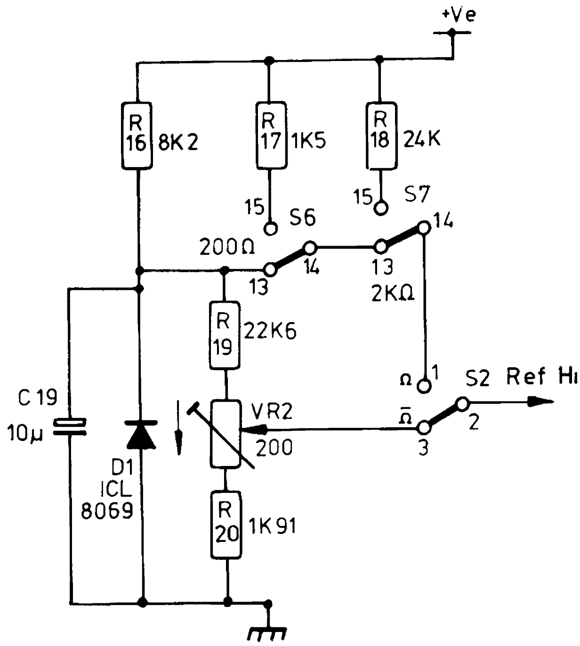


Resistance Measurement Functional Diagram

CIRCUIT DESCRIPTIONS

(Also see full circuit diagram at back of manual)

Reference Voltage circuit



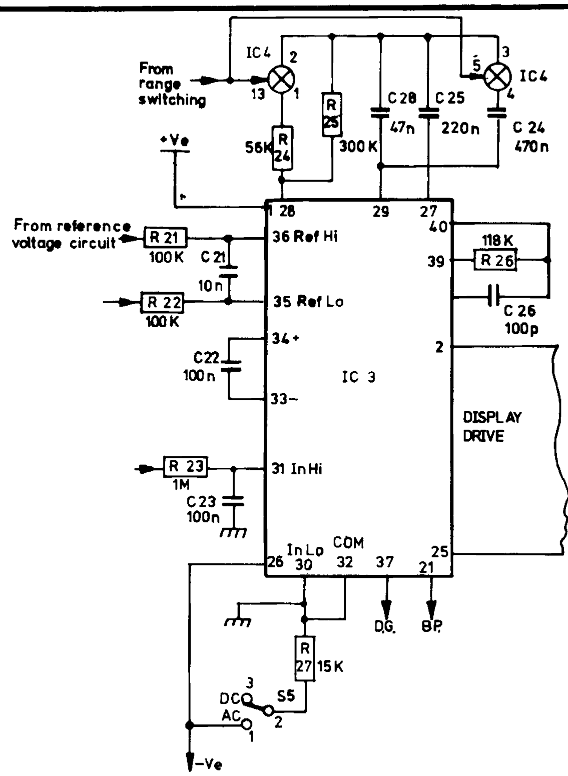
The 100mV reference voltage is derived from the 'Widlar' reference diode D1 which gives a stable source of approximately 1.2V with a low output impedance and low temperature coefficient. R16 provides bias current for D1, and R19, VR2 and R20 form a potential divider to provide 100mV at REF HI input via S2-2 for all voltage and current measurements.

During resistance measurements the REF HI input is switched by S2-2 to the top of the reference diode except for the 200 Ω and 2kΩ ranges when the positive rail is used as the reference source via R17 and R18 respectively.

A-D Converter

The TM351 uses a single chip CMOS A-D converter (IC3) containing all the amplifiers, measurement phase control, clock generator and digital display logic required to make up an A-D converter operating on the principles described previously. Both the reference and measurement inputs are fully differential.

The reference voltage is applied between pins 36 and 35, pin 35 normally being connected to the common rail except for resistance measurements. During the auto-zero phase the reference inputs are internally connected to the reference capacitor, C22. During the reference phase, other gates connect this capacitor to the A-D input to give $+V_{REF}$ or $-V_{REF}$ as required to drive the integrator output back to zero. The reference capacitor must be a low leakage type and is chosen large enough in comparison to the stray capacitances on its nodes so as to prevent these introducing any "roll-over" error between readings for positive and negative inputs of the same magnitude.



Measurement input, pin 31, is fed via the input filter, R23 and C23. During voltage or current measurements this filter is connected to either the output of the AC/DC converter or the input attenuator/current shunts by S4-5 or S3-11 and S5-11. When the measurement is of resistance, the measurement input filter is connected directly to the positive input terminal. The negative measurement input is connected to the common rail normally generated internally by IC3 except for AC measurements where R27 is switched in, overriding the internal regulator and making the common rail sit at least 3V below the positive rail, depending on battery voltage. The reason for this is to allow for common mode voltage limitations of IC1.

Digital ground (D.G.) is internally generated by IC3 and is regulated to 4–6V below +VE. IC3 also generates the backplane drive waveform (B.P.) consisting of a 50Hz square wave. The display drive waveforms consist of square waves in antiphase to the B.P. signal when the segment is required to be visible and in phase when it is not. The drive lines are directly connected to each segment, there being a line for each one.

R26 and C26 are external timing components of the internal clock oscillator, which oscillates at 40kHz, the optimum frequency for maximum rejection of 50 and 60Hz interference.

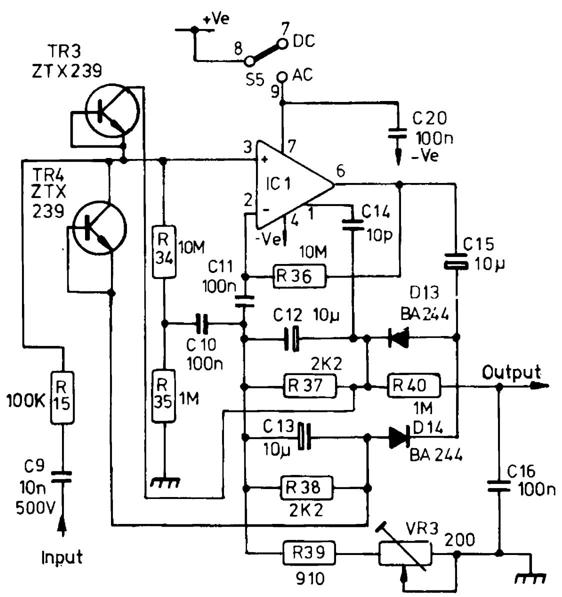
C25 is the integrator capacitor connected to the integrator output, pin 27, and the integrator input, pin 29, via the auto-zero capacitors C24 and C28. For all measurements except the higher ohms ranges (20kΩ to 20MΩ) C24 is switched in parallel with C28; to minimise "settling" time on the higher ohms ranges C28 alone is used. C24 and C28 must be low leakage types. C25 must have low leakage and also a low dielectric absorption to prevent roll-over errors; for this reason polypropylene is used.

The integrator resistor for all measurements except the higher resistance ranges is R24 in parallel with R25. When the reference is nominally 1V on the higher resistance ranges, R24 is switched out and R25 alone is the integrator resistor; this limits the charge current and ensures that the integrator does not saturate.

The analogue gates which switch out the auto-zero capacitor and the integrator resistor are contained in IC4 and controlled by the range and function switching logic.

Note: IC3 is housed in a reversed package which means that the legs have been physically inverted from the standard package. Consequently, pin 1, viewed relative to the package indentation (now on the underside), is where pin 40 would be, and vice-versa.

AC-DC Converter



The AC-DC converter consists of IC1 and associated components. AC voltages from the input attenuator, or developed across the current shunts are coupled to the input of IC1 by the D.C. isolating capacitor C9. R15 with TR3 and TR4 connected as diodes give input protection to line voltages. R34 and R35 refer the non-inverting input to the common rail with C10 bootstrap capacitor providing the necessary high input impedance. R36 provides DC feedback around IC1 to stabilise its quiescent output, which is AC coupled via C15 into the two rectifying diodes D13 and D14. Rectified charge is stored on C12 and C13, the output being taken from C12. C13, R38 and D14 are included to maintain constant charge in C15 to reduce recovery time from overload. C14 provides high frequency compensation, being switched in only when D13 or D14 turn on, when the amplifier has near unity gain. This maximises amplifier slew rate whilst switching the diodes. C11 couples the AC feedback to the negative input.

Conversion gain is set by R37, R39 and VR3. The output from C12 consists of a DC level equal to the signal mean riding on an AC signal. The AC component is removed by the filter R40, C16 and the DC level fed to the A-D converter via S5-11.

The AC-DC converter is only powered up (via S5-8) during AC measurements to minimise overall current consumption.

DC and AC Voltage Measurement

For all ranges the input is routed via S2 and S4 to the top of the 10MΩ attenuator chain consisting of RP1, R3, R4, R5 and R6. The attenuator output is taken from S10-11 via S4-8 and S5-5 to either the AC-DC converter, IC1, or directly to the input of the A-D converter IC3 via S5-11, S3-11, and R23. When the 2V range is selected, AC compensation is effected by C1, C2, VC1, C17 and C4. On the 20V ranges, C5, VC6 and C7 are switched in parallel with VC1, C17 and C4 and they all compensate this range. On the 200V range all the previous compensation is removed, and compensation is provided by C8 and VC3 across the 90kΩ, together with C18 and C29 to ground.

The common rail, generated by IC3, is connected to the common terminal via S3-8 and to the bottom of the attenuator via S11-8, all measurement being made with respect to this rail.

On all DC ranges R23 provides inherent protection to IC3 measurement input to 1100V DC or peak AC. On the AC ranges, R15 with TR3 and TR4 provide input protection to the AC-DC converter to line voltages on the 200mV range, when the input is applied direct, and to 750V rms on all other ranges, when the input is attenuated.

DC and AC Current Measurements

Currents to be measured are routed via S2-11, and FS1 to the range selection switches, which feed the current into the appropriate current shunts from .1Ω to a total of 1000Ω. The derived voltage is sensed via the 900Ω shunt and routed via S11-8 and S4-8 and treated as for attenuated voltage inputs. R41 and R42 are S.O.T. resistors trimming R4 and R5 respectively. R6 is used in four terminal mode, being fed directly from the common terminal.

R1 forms a ten amp current shunt, accessed via the 10A socket and the common socket. On all current measurements the common terminal is connected directly to the power lead of R6 with the sense lead of R6 connected to the common rail.

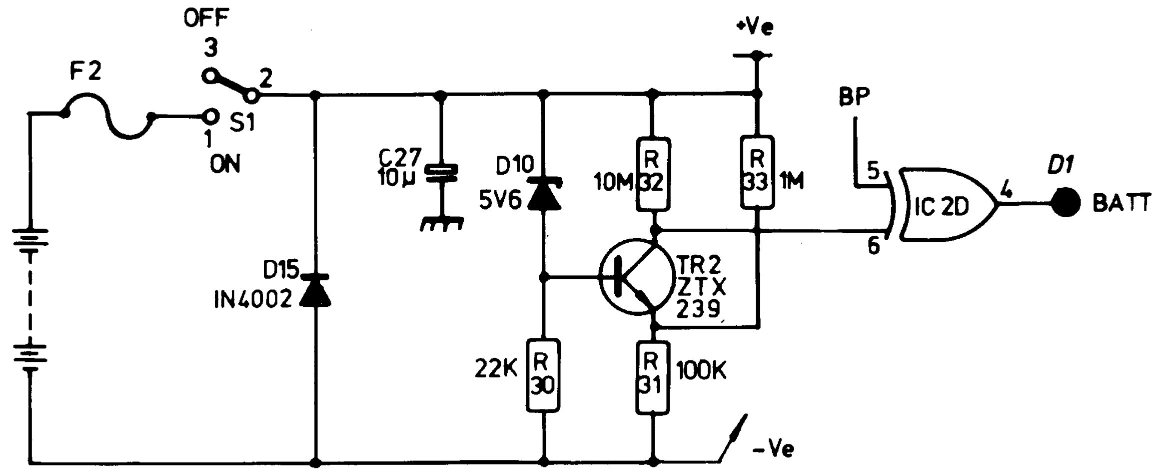
Input protection to line voltages when switched for current measurement is provided by FS1, D4 and D5.

Resistance Measurements

For the basic theory of operation refer to the relevant section of the Functional Description. To provide the reference resistor, the bottom of the input attenuator, R6, is switched from the common rail to the positive reference line by S2-8. The other end of the reference resistor is selected by the kΩ range switches to give a total value of 100Ω to 10MΩ. Switch S2-5 now connects this end of the reference resistor to the negative reference input of IC3, at the same time disconnecting this input from the common rail. Thermistor, TH1, couples the reference resistor current into the external unknown resistor via S2-11 and the positive input terminal. The positive measurement input of the A-D converter is also connected to the positive terminal via S4-5 and S3-11. The common input terminal is connected to the common rail via S3-8.

TR1 (which is normally shorted to the common rail) in conjunction with TH1 provide input protection to line voltages for the IC3 reference inputs. Inherent protection for the IC3 measurement inputs is provided by R23.

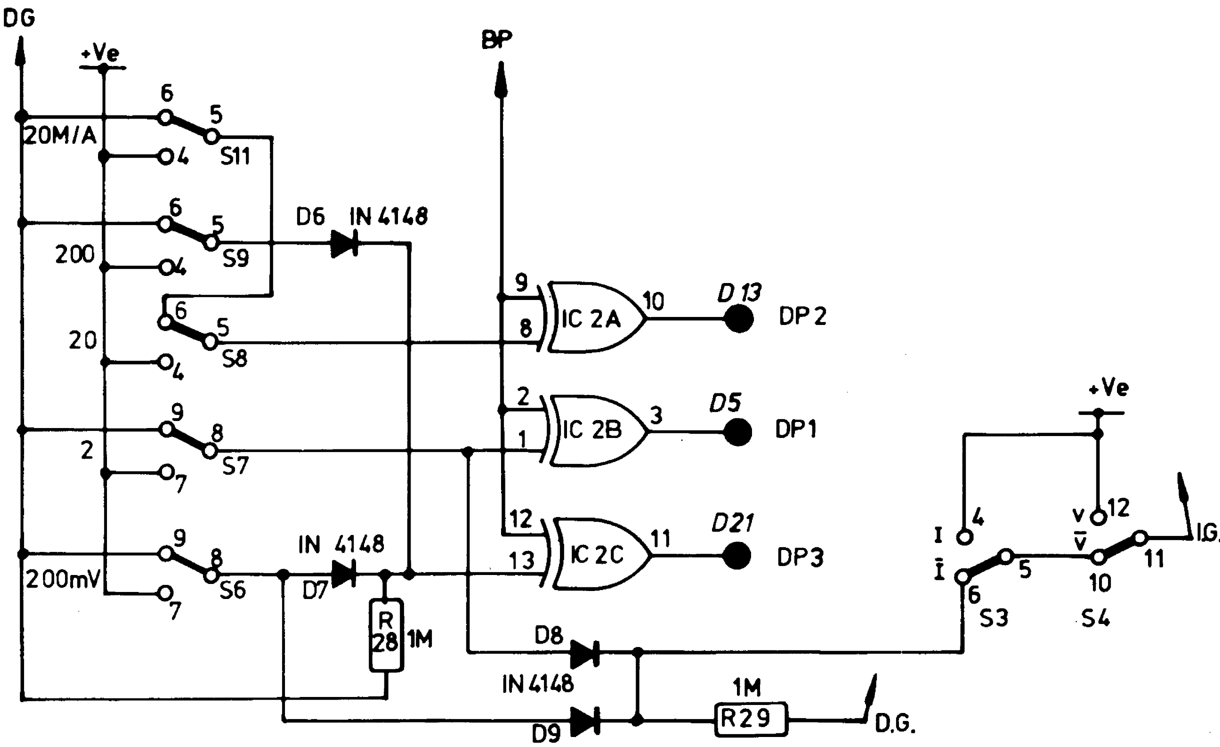
Low Battery Indicator and Decimal Point Switching



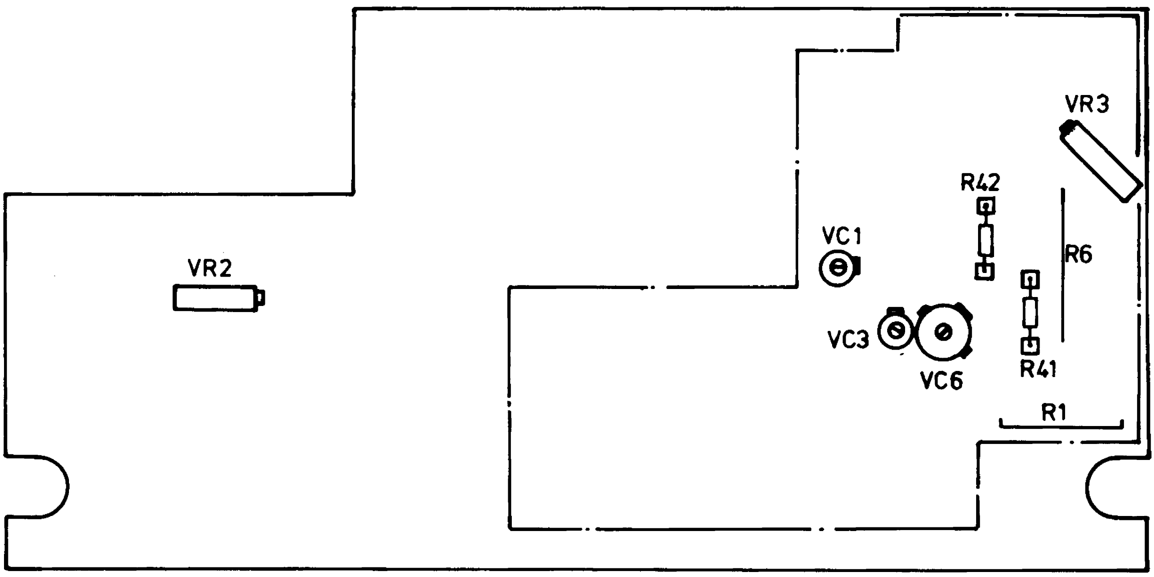
The low battery indicator consists of TR2 and associated components. Under high battery conditions TR2 is turned on, which causes IC2D pin 6 to be low. The exclusive -OR function of IC2 means that if either gate input is low the output will follow the other input i.e. the drive to the low battery indicator on the L.C.D. is in phase with the back plane signal so the indicator is not seen. As the battery volts reduce the current available in R31 is reduced until it can only supply the current in R33 at which point TR2 turns off. The zener diode D10 determines the voltage at which this happens. As TR2 turns off, so the input to IC2D goes high and the output of the exclusive -OR gate now becomes the inverse of the backplane signal, causing the low battery indicator to become visible.

The decimal point switching uses the remaining three exclusive -OR gates in IC2. Once again a high on any gate input causes the output to become in antiphase to the B.P. signal so that the relevant decimal point becomes visible. Diode D6 and D7 cause DP3 to become visible if either the 200mV or 200V buttons are pushed, R28 pulling the gate input low if neither is pushed.

The same switch poles are used to control the analogue gates of IC4, via the I.G. (integrator gate) signal. Switches S3-5 and S4-11 maintain I.G. permanently high in voltage and current modes, thus keeping the gates in IC4 closed. For the resistance mode ($\bar{I}$ and $\bar{V}$) R29 pulls I.G. low to open the gates except for the 200Ω and 2kΩ ranges when D8 and D9 pull I.G. high.



CALIBRATION

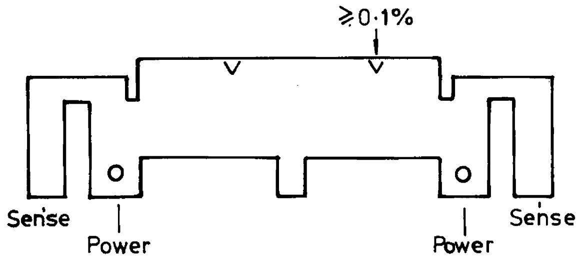


The diagram shows the position of the calibration points, viewed with the case upper removed. AC Calibration should only be carried out with the instrument in the case lower, making sure that the pcb earth spring is in contact with the lower earth plane, and with the top earth screen in place.
Procedure is as follows:

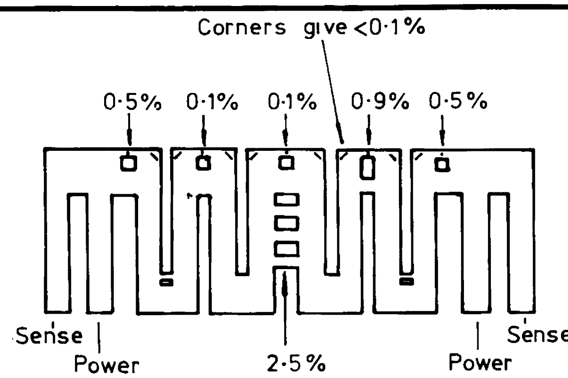
Function / Range	Input	Adjustment	Display Limits
DC/200mV	OV (S/C)	NONE. Zero check	± 0.000
DC/200mV	100mV DC	VR2; 100mV V_{REF}	100.00
DC/200mV	−100mV DC	NONE. Rollover check	−99.9 to −100.1
AC/200mV	100mV AC 60Hz	VR3; AC/DC converter gain	100.0
AC/2v	1V AC 4kHz	VC1; 2V range high frequency compensation	1.000
AC/20V	10V AC 4kHz	VC6; 20V range high frequency compensation	10.00
AC/200V	100V AC 4kHz	VC3; 200V range high frequency compensation	99.8 (note 1)
DC/ 2000mA	1000mA DC	Trim R6 (note 2)	997 to 1003
DC/ 200mA	100mA DC	Shunt R5 with R42 S.O.T. (note 3)	99.7 to 100.3
DC/20mA	10mA DC	Shunt R4 with R41 S.O.T. (note 3)	9.97 to 10.03
DC/10A	10A DC	Trim R1 (note 2)	9.81 to 10.19

Notes

1. The 100V AC 4kHz adjustment is deliberately offset to ensure the instrument meets specification at 20kHz.
2. R6 and R1 are etched ferry-alloy 4-terminal resistors which are nominally below their 0.1Ω and 0.01Ω values and are trimmed in circuit by removing parts of the resistor with side-cutters. The diagrams (see over) indicate the approximate change in resistance as the unit is trimmed. On R6 the bridges indicated should be completely removed by making a cut at both ends, finer trimming if required can be achieved by carefully cutting the corners as shown. On R1, make the smallest possible notches at first to gauge how much material to remove and space the notches as evenly as possible to minimise current density and local heating. **Take care to ensure no trimmings are left inside the instrument.**
3. The table overleaf can be used to speed the selection of S.O.T. resistors.



10A SHUNT (R1)



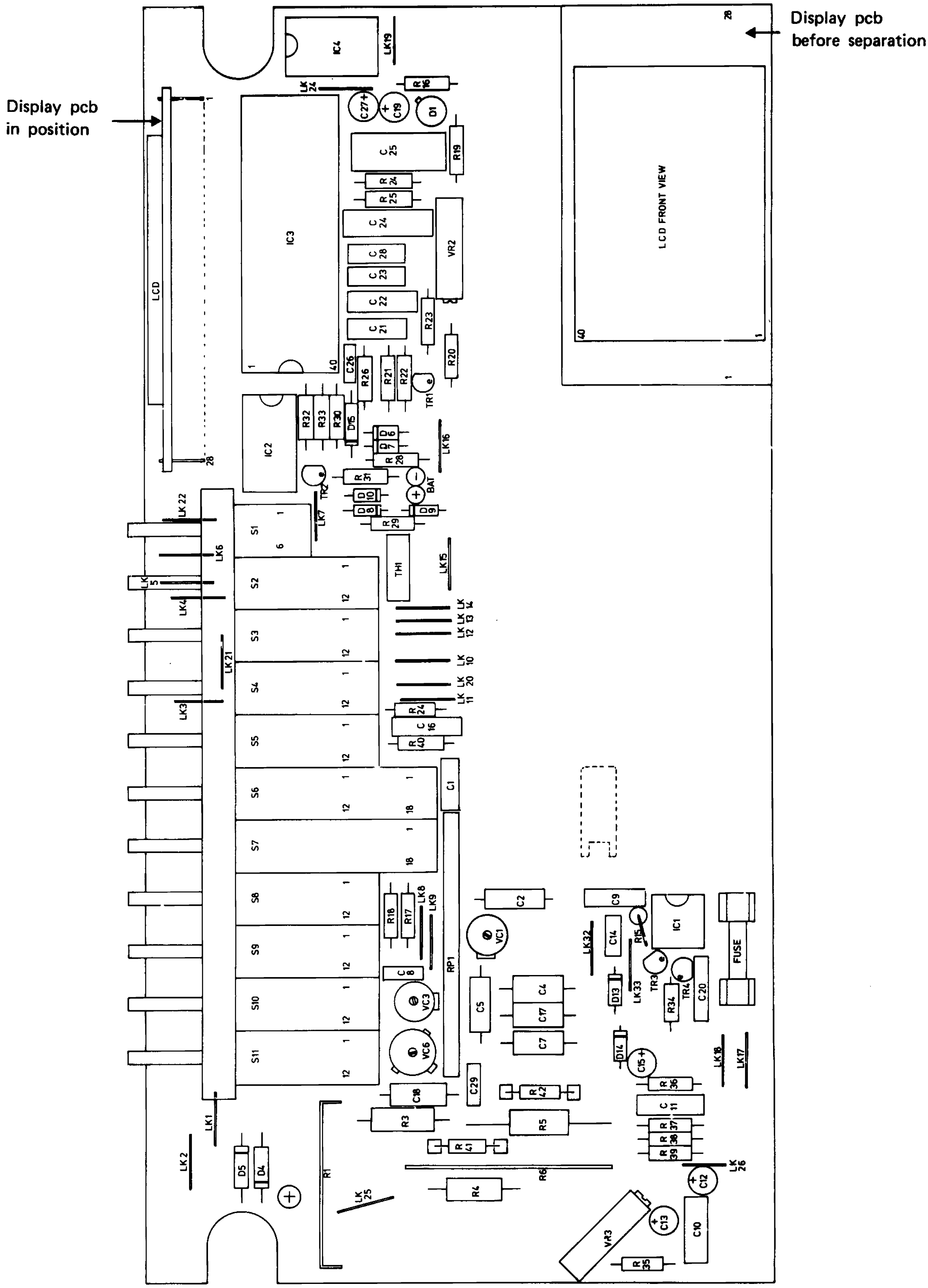
2A SHUNT (R6)

TRIM POSITIONS TO GIVE % CHANGE OF READINGS SHOWN

DISPLAY ERROR %	S.O.T. RESISTOR VALUE	
	100mA (R42)	10mA (R41)
0.2	390	3K9
0.3	270	2K7
0.4	240	2K4
0.5	150	1K5
0.6	120	1K2
0.7	120	1K2
0.8	100	1K0
0.9	91	910
1.0	82	820
1.1	75	750
1.2	68	680
1.3	62	620
1.4	62	620
1.5	56	560
1.6	51	510
1.7	47	470
1.8	47	470
1.9	43	430
2.0	43	430
2.1	39	390
2.2	39	390
2.3	36	360
2.4	36	360
2.5	33	330
2.6	33	330
2.7	30	300
2.8	30	300
2.9	30	300
3.0	27	270

Selection of Shunting Resistors

COMPONENT LAYOUT



PARTS LIST

Resistors

Ref	Description			Part No
R1	R01	Ferryalloy		23320-0004
R2	Not used			
R3	90RB	MF	50ppm	23215-0413
R4	9RC	MF	100ppm	23215-0606
R5	R90	.04% 3W WW		23295-0005
R6	R10	Ferryalloy		23320-0003
R7 to R14 Not used				
R15	100KJ	W5	CF	23179-4100
R16	8K2J	W25	CF	23185-2820
R17	1K5J	W25	CF	23185-2150
R18	24KJ	W25	CF	23187-3240
R19	22K6F	W25	MF 50ppm	23202-3226
R20	1K91F	W25	MF 50ppm	23202-2191
R21	100KJ	W25	CF	23185-4100
R22	100KJ	W25	CF	23185-4100
R23	1M0J	W25	CF	23185-5100
R24	56KJ	W25	CF	23185-3560
R25	300KJ	W25	CF	23187-4300
R26	118KF	W25	MF 50ppm	23202-4118
R27	15KJ	W25	CF	23185-3150
R28	1M0J	W25	CF	23185-5100
R29	1M0J	W25	CF	23185-5100
R30	22KJ	W25	CF	23185-3220
R31	100KJ	W25	CF	23185-4100
R32	10MJ	W25	CF	23185-6100
R33	1M0J	W25	CF	23185-5100
R34	10MJ	W25	CF	23185-6100
R35	1M0J	W25	CF	23185-5100
R36	10MJ	W25	CF	23185-6100
R37	2K2J	W25	CF	23185-2220
R38	2K2J	W25	CF	23185-2220
R39	910RJ	W25	CF	23187-1910
R40	1M0J	W25	CF	23185-5100

Ref	Description	Part No
R41	Select on Test	See separate list
R42	Select on Test	See separate list
VR1	Deleted	
VR2	PS20 Turn 200R	23371-0006
VR3	PS 20 Turn 200R	23371-0006
RP1	Precision Voltage Divider	23310-0003
TH1	HV Current Limiter	23386-0002

Select on Test Resistors

Ref	Select from			Part No	Ref	Select from			Part No
					R42	390RJ	W25	CF	23185-1390
R41	3K9J	W25	CF	23185-2390		300RJ	W25	CF	23187-1300
	2K7J	W25	CF	23185-2270		270RJ	W25	CF	23185-1270
	2K4J	W25	CF	23187-2240		240RJ	W25	CF	23187-1240
	1K5J	W25	CF	23185-2150		150RJ	W25	CF	23185-1150
	1K2J	W25	CF	23185-2120		120RJ	W25	CF	23185-1120
	1K0J	W25	CF	23185-2100		100RJ	W25	CF	23185-1100
	910RJ	W25	CF	23187-1910		91RJ	W25	CF	23187-0910
	820RJ	W25	CF	23185-1820		82RJ	W25	CF	23185-0820
	750RJ	W25	CF	23187-1750		75RJ	W25	CF	23187-0750
	680RJ	W25	CF	23185-1680		68RJ	W25	CF	23185-0680
	620RJ	W25	CF	23187-1620		62RJ	W25	CF	23187-0620
	560RJ	W25	CF	23185-1560		56RJ	W25	CF	23185-0560
	510RJ	W25	CF	23187-1510		51RJ	W25	CF	23187-0510
	470RJ	W25	CF	23185-1470		47RJ	W25	CF	23185-0470
	430RJ	W25	CF	23187-1430		43RJ	W25	CF	23187-0430
	390RJ	W25	CF	23185-1390		39RJ	W25	CF	23185-0390
	360RJ	W25	CF	23187-1360		36RJ	W25	CF	23187-0360
	330RJ	W25	CF	23185-1330		33RJ	W25	CF	23185-0330
	300RJ	W25	CF	23187-1300		30RJ	W25	CF	23187-0300
	270RJ	W25	CF	23185-1270		27RJ	W25	CF	23185-0270

Capacitors

Ref	Description			Part No
C1	10PJ	1KV	Cer	23450-0048
C2	1N0J	63V	Poly/S	23646-0005
C3	Not used			
C4	150PJ	160V	Poly/S	23647-0510
C5	680PJ	160V	Poly/S	23647-0512
C6	Not used			
C7	220PJ	160V	Poly/S	23647-0514
C8	22PG	63V	Cer	23427-0323
C9	10NS	500V	Cer	23424-0435
C10	100NJ	100V	Poly/E	23620-0207
C11	100NJ	100V	Poly/E	23620-0207
C12	10UF	16V	Elec	23557-0621
C13	10UF	16V	Elec	23557-0621
C14	10PC	63V	Cer	23427-0328
C15	10UF	16V	Elec	23557-0621
C16	100NJ	100V	Poly/E	23620-0207
C17	47PG	63V	Cer	23427-0329
C18	470PJ	160V	Poly/S	23647-0513
C19	10UF	16V	Elec	23557-0621
C20	100NJ	100V	Poly/E	23620-0207
C21	10NK	100V	Poly/E	23620-0213
C22	100NJ	100V	Poly/E	23620-0207
C23	100NJ	100V	Poly/E	23620-0207
C24	470NJ	100V	Poly/E	23620-0214
C25	220NK	250V	Poly/P	23684-0002
C26	100PG	63V	Cer	23427-0322
C27	10UF	16V	Elec	23557-0621
C28	47NJ	100V	Poly/E	23620-0217
C29	100PG	63V	Cer	23427-0322

VC1	Trimcap 2-18pF	23984-0004
VC3	Trimcap 2-18pF	23984-0004
VC6	Trimcap 10-200pF	23984-0006

VC2, VC4, VC5 Not used

Semi-conductors

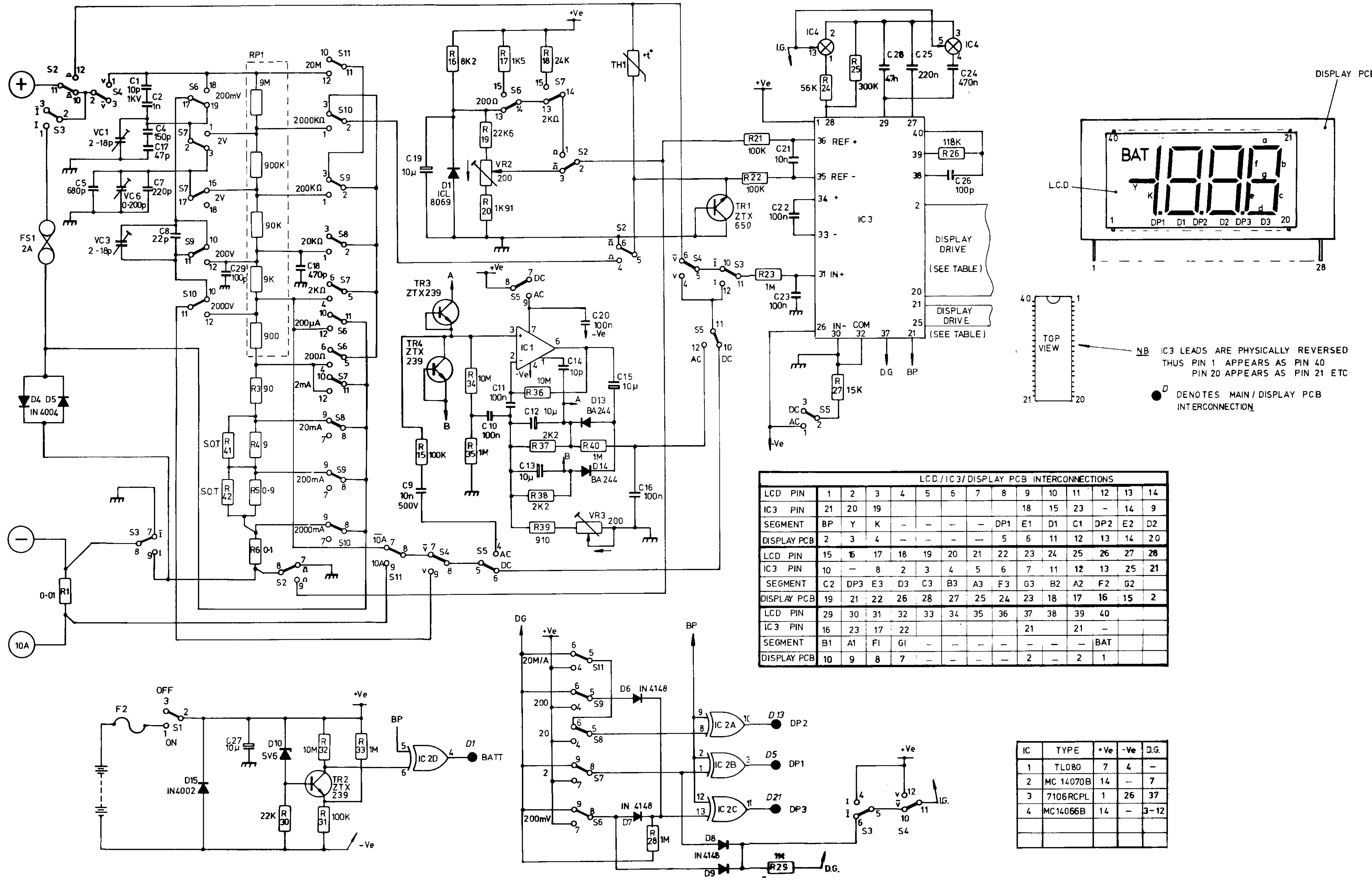
Ref	Description		Part No
D1	IC	MPS5010	27161-0002
D2, D3	Not used		
D4	Dio	1N4002	25115-0907
D5	Dio	1N4002	25115-0907
D6	Dio	1N4148	25021-0901
D7	Dio	1N4148	25021-0901
D8	Dio	1N4148	25021-0901
D9	Dio	1N4148	25021-0901
D10	Dio	Zen 5V6 Sel	25130-0806
D11	Not used		
D12	Not used		
D13	Dio	BA244	25030-0901
D14	Dio	BA244	25030-0901
D15	Dio	1N4002	25115-0907
TR1	Tran	NPN ZTX650	25388-0206
TR2	Tran	NPN ZTX239	25380-0229
TR3	Tran	NPN ZTX239	25380-0229
TR4	Tran	NPN ZTX239	25380-0229
IC1	IC	TLO80CP	27106-0603
IC2	IC	CD4070BE	27205-0001
IC3	IC	ICL7106RCPL	27153-0003
IC4	IC	CD4066B	27156-0001

Opto, Electro/Mechanical, Mechanical and Packaging Parts

Description		Part No
Fuse Clip	2 off	23312-0240
Wire post (for SOT resistors)	4 off	22466-0002
28 Way PCB Header		22573-0032
IC Holder 8 pin		22574-0118
IC Holder 14 pin	2 off	22574-0119
IC Holder 40 pin		22574-0125
Molex terminal	5 off	35311-0020
Threaded Stud 8MM L	2 off	20205-0600
Switchbank		22225-0518
Turret lug		22466-0001
Track pin		22469-0502
Earthing tag, switchbank		31511-0040
PCB Switchbank		35515-0500
PCB Main		35515-0510
Pushbutton, Red		37113-0120
Pushbutton, Black	6 off	37113-0130
Pushbutton, Grey	4 off	37113-0140
Washer M3 (Battery holder to constraint)	2 off	20030-0244
Washer Shake/pf M3 (AC Screen)	2 off	20037-0301
Screw 6BA x 3/16" Pn hd (PCB fixing and Case fixing)	6 off	20134-0501
Screw 6BA x 3/16" cs head (Constraint to case)	2 off	20118-0002
Fibre Washer (PCB)	2 off	20612-0010
Battery Holder		20656-0011
Support post		20661-0212
Spacer M3 x 20mm	2 off	20661-0213
Battery	6 off	22010-0405
Battery Compartment Constraint		33145-0310
Pad, Batt Restraint Case upper	cut from	10300-0316
Foam pad 2 off 50 x 20 x 4mm	cut from	10300-0301
Screw M3 x 5mm (s/tap) (Batt holder to Constraint & AC Screen)	4 off	20062-0600

Description		Part No
LCD		26100-0010
Side trim, front	2 off	31332-0490
Side trim, rear	2 off	31332-0500
AC Screen		31344-0010
Screen, Case lower		31346-0050
Insulator, Case lower		31346-0060
Case Lower		33537-0160
Earth Spring, Case lwr		35358-0480
Socket, Red	2 off	22571-0653
Socket, Black		22571-0654
Display Bezel		31711-0020
Front Panel		33331-0300
Case Upper		33537-0150
Screw 6BA x 1¼"L (Case)		20134-0503
Handle		31336-0200
Feet, Black	4 off	31748-0190
Rear Panel		33331-0340
Battery Cover		33335-0060
Logo label		37522-0010
Instruction label		37558-0120
Serial No label		37522-0020
Test leads, pair		22490-0030
Instruction Book		48581-0220
Guarantee Card		48581-0230
Fuse 2 Amp	2 off	22315-0210
Polybag (for fuse)		10615-0213
Polybag (for Test leads)		10615-0214
Carton		38113-0260
Protective packing piece		38161-0010
Printed sleeve		38181-0140
Aircap sheet,	cut from	10612-0202

GENERAL CIRCUIT DIAGRAM



LCD/IC3/DISPLAY PCB INTERCONNECTIONS														
LCD PIN	1	2	3	4	5	6	7	8	9	10	11	12	13	14
IC3 PIN	21	20	19						18	15	23	–	14	9
SEGMENT	BP	Y	K	–	–	–	–	DP1	E1	D1	C1	DP2	E2	D2
DISPLAY PCB	2	3	4	–	–	–	–	5	6	11	12	13	14	20
LCD PIN	15	16	17	18	19	20	21	22	23	24	25	26	27	28
IC3 PIN	10	–	8	2	3	4	5	6	7	11	12	13	25	21
SEGMENT	C2	DP3	E3	D3	C3	B3	A3	F3	G3	B2	A2	F2	G2	
DISPLAY PCB	19	21	22	26	28	27	25	24	23	18	17	16	15	2
LCD PIN	29	30	31	32	33	34	35	36	37	38	39	40		
IC3 PIN	16	23	17	22					21		21	–		
SEGMENT	B1	A1	F1	G1	–	–	–	–	–	–	–	BAT		
DISPLAY PCB	10	9	8	7	–	–	–	–	2	–	2	1		

IC	TYPE	+Ve	-Ve	D.G.
1	TL080	7	4	–
2	MC 14070B	14	–	7
3	7106RCPL	1	26	37
4	MC14066B	14	–	3-12