Assembly Manual for the

1 GHZ Frequency Counter
K-3437

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Research & Development Division

These days, a digital frequency counter would rate as an essential item in any service workshop, amateur shack or electronics hobbyist's test instrument inventory. This economical project has been designed to simplify assembly and provide good performance. It features readout to 1000 MHz in three ranges and good sensitivity right across the range for ease of measurement on even low level signals.

IN ELECTRONICS MEASUREMENT, after volts, amps and ohms, the next most required quantity one needs to measure would undoubtedly be *frequency*. The nature of frequency measurement demands knowing a numerical quantity to some order of accuracy, and hence the most convenient method is via a digital display.

The *frequency* of any repetitive signal can be defined as the number of cycles that occur per unit of time. It is expressed in *Hertz* (after Heinrich Hertz, who demonstrated physical proof of James Clerk Maxwell's theory of electromagnetic radiation), this being the fundamental expression of *cycles per second*. The usual metric multipliers are applied — 1000 Hz = 1 kiloherz (kHz), 1 000 000 Hz (1000 kHz) = 1 megaherz (MHz), 1000 MHz = 1 gigaherz (GHz), etc.

The principle of digital frequency measurement is relatively simple. Imagine a flock of Farmer Smith's sheep galloping across a paddock. Now, we all know that sheep tend to play 'follow the leader', so they all run more or less in line. To count how many go past per second, Farmer Smith has his dog herd them towards a little contraption at the end of the paddock. This contraption is a funnel-shaped fence that forces them to go down a runway single file. Partway down the runway Farmer Smith stands by a gate which diverts the line of sheep into a side paddock where stands his deaf-mute offsider who counts the sheep that enter the paddock. Farmer Smith opens the gate for a pre-arranged fixed period, timed by his wristwatch. There are a lot of sheep and they're running fast, so he opens the gate for 10 seconds. His offsider counts the sheep and, knowing Farmer Smith opened the gate for 10 seconds, divides the number of sheep by 10 to get the number of sheep per second. As he can't call out the result, he writes it on a blackboard for Farmer Smith to see. It so happens that 112 sheep entered the paddock while the gate was open. The offsider, knowing the gate was open for 10

The completed instrument is smart, simple and functional. The front panel is a piece of translucent red perspex which provides a filter to improve visibility of the 7-segment LED displays.
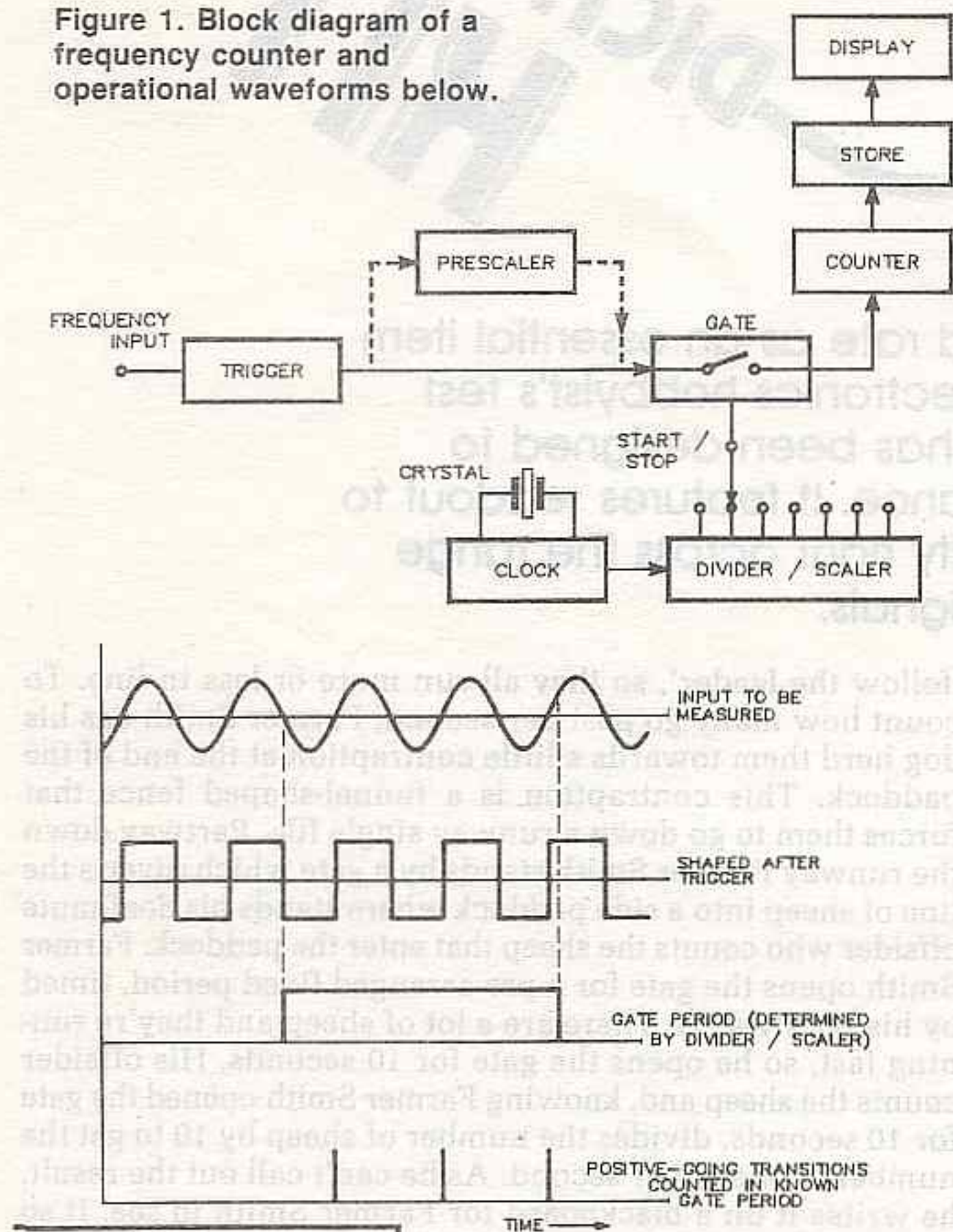
seconds, divides 112 by 10, giving 11.2, so Farmer Smith sees his offsider write '11.2' on the blackboard. Thus, he knows his flock was galloping by at 11.2 sheep per second.

Figure 1 shows a block diagram of a digital frequency counter. Note the similarities to Farmer Smith's contraption. There's a clock (Farmer Smith's wristwatch), a gate, the opening of which is timed by the clock, a counter (the deaf-mute offsider) and a display (the blackboard). Now in the 'real world' the input signal may be sinusoidal, or some other waveshape, so it is generally 'conditioned' before passing to the counter via the gate as digital circuitry requires on/off signals. The *trigger* performs this function. The period for which the gate allows the signal to pass to the counter is determined by the output from the *divider/scaler*, which has selectable output periods. The number of pulses per gate period are counted, stored and displayed. The counter output is stored in order to provide a steady display which would otherwise turn off between gate periods. In practice, gate periods generally ranging from 1 μs to one second are employed. It is the gate period which determines the fundamental display resolution.

Figure 1. Block diagram of a frequency counter and operational waveforms below.

SPECIFICATION

For the sake of accuracy, the clock almost always employs a quartz crystal oscillator. Inevitably, it is the accuracy and stability of this oscillator that determines the ultimate accuracy of the instrument. To provide a number of different frequency ranges, either the clock frequency can be changed or the input can be divided-down by a *pre-scaler*, or both.

In practice, frequency counters employ some amplification before the trigger circuitry to provide adequate sensitivity for measuring low-level signals.

Design details

Not so long ago, an 8-digit frequency counter capable of measuring up to 1 GHz would have been constructed of around 30 or more discrete ICs requiring a substantial power supply and housed in a case some 350 mm wide and 200 mm or more deep. Thanks to the wonders of large-scale integration, the circuitry these days is largely "swallowed up" in a single chip which provides the clock, divider, gate, counter and display driver functions.

The 'heart' of this project is just such a device, made by Intersil, the ICM7216C. This is a basic 10 MHz, 8-digit counter that will drive 7-segment LED displays. Some peripheral logic has been added to provide three measurement ranges of 10 MHz, 80 MHz and 1 GHz, along with two input stages. One covers the 10/80 MHz ranges, providing signal amplification and conditioning, the other providing amplification and pre-scaling for the 1 GHz input. The accompanying table gives the overall specification of the instrument.

Controls and functions have been kept to a minimum in order that the instrument be both low in cost and simple to use, without sacrificing the main requirements in frequency measurement.

Construction

The pc boards and front panel have been designed as an integrated unit to fit the H-2505 plastic instrument case, resulting in an easily assembled unit that both functions well and looks good. The relatively simple circuitry enabled a clean board layout and the elimination of point-to-point internal wiring, except for the mains cable. A 'motherboard', bolted to the case bottom, carries most of the electronics and the power supply. A vertical board, carrying the 7-segment displays, mounts behind the front panel, butted to the motherboard and secured by grooves in the case sides. Only simple links are required between the two boards, virtually eliminating the chance of wiring errors. The front panel is a piece of translucent red perspex, enabling the 8-digit display to be seen through it. The instrument annotation is silk-screen printed on it. Ventilation holes for the pcb-mounted mains transformer are drilled in the motherboard and the area of the case beneath it. The rear panel has slots top and bottom for general case ventilation.

The construction is best tackled in a logical order, and we suggest you follow the progression laid down here.

Frequency ranges	20 Hz to 10 MHz	Input impedance	
	20 Hz to 80 MHz	10-80 MHz input:	1M//50 pF
	30 MHz to 1 GH z	1 GHz input:	50 ohms
			5 V RMS
Gate time	1s, 10 MHz & 80 MHz ranges	Maximum input	(a) 5 Vp-p without R20, D3-D4.
	1.28s, 1 GHz range	10-80 MHz input:	(b) 10 Vp-p with optional components.
		1 GHz input:	
Resolution	1 Hz on 10 MHz range		
	10 Hz on 80 MHz range		
	100 Hz on 1 GHz range	Input sensitivity	
		10-80 MHz input	
Readout accuracy	+/- least significant digit,	20 Hz — 10 MHz:	40 mV RMS (typically <20 mV RMS)
	+/- timebase accuracy	10 MHz — 50 MHz:	40 mV RMS (typically <30 mV RMS)
		50 MHz — 80 MHz:	200 mV RMS max. (40 mV RMS min.)
Timebase accuracy	+/- 1 part per million		
	for Tamb. 0-40 deg. Celsius	*1 GHz input*	
	(both ranges).	30 MHz — 50 MHz:	40 mV RMS max. (typically <20 mV RMS)
		50 MHz — 1 GHz:	20 mV RMS max. (typically <15 mV RMS)
Input coupling	ac, dc blocking: 50 V max.		

First, the motherboard

All the low profile components can be loaded, trimmed and soldered into the board. The only critical point to note is that all the component leads around the input stages should be *kept as short as possible*. The body of these components should be flush with the board. If necessary, scrape the ceramic insulation off the legs of the capacitors to get them to sit down correctly. Long leads may introduce an inductive component into the active circuits and cause instability in the amplifiers.

The coil L1 is tightly wound with enamelled wire on a 5 mm mandrel. This diameter is not critical, but keep it somewhere near this size. Clean off the enamel at each end and tin the leads before inserting it into the board.

The mains switch should be installed flush to the board. Before insertion, place three lengths of spaghetti over the legs. The 7805 regulator (IC7), along with the heatsink, can now be fitted. Make sure that the mounting screw hole aligns with the heatsink before soldering the regulator into the final position.

Mount the power transformer flush to the board. Two mounting holes are provided if you wish to secure with M2.6 × 5 mm PK screws.

Next, the display board

The 7-segment displays are mounted up off the board so that they reach as close to the front panel as possible. Load them all on the board on a flat spacer-guide between the body and the board as illustrated in the diagram here. The standoff space should be enough to allow the pins to just penetrate the board enough for soldering. Don't solder them in place until you have them all in line and level. Resistor R28 can be inserted and soldered next. Mount the slider switch flush to the board but only solder one leg at this stage. At the final

assembly into the case, it may be necessary to slightly adjust the position to fit the front panel.
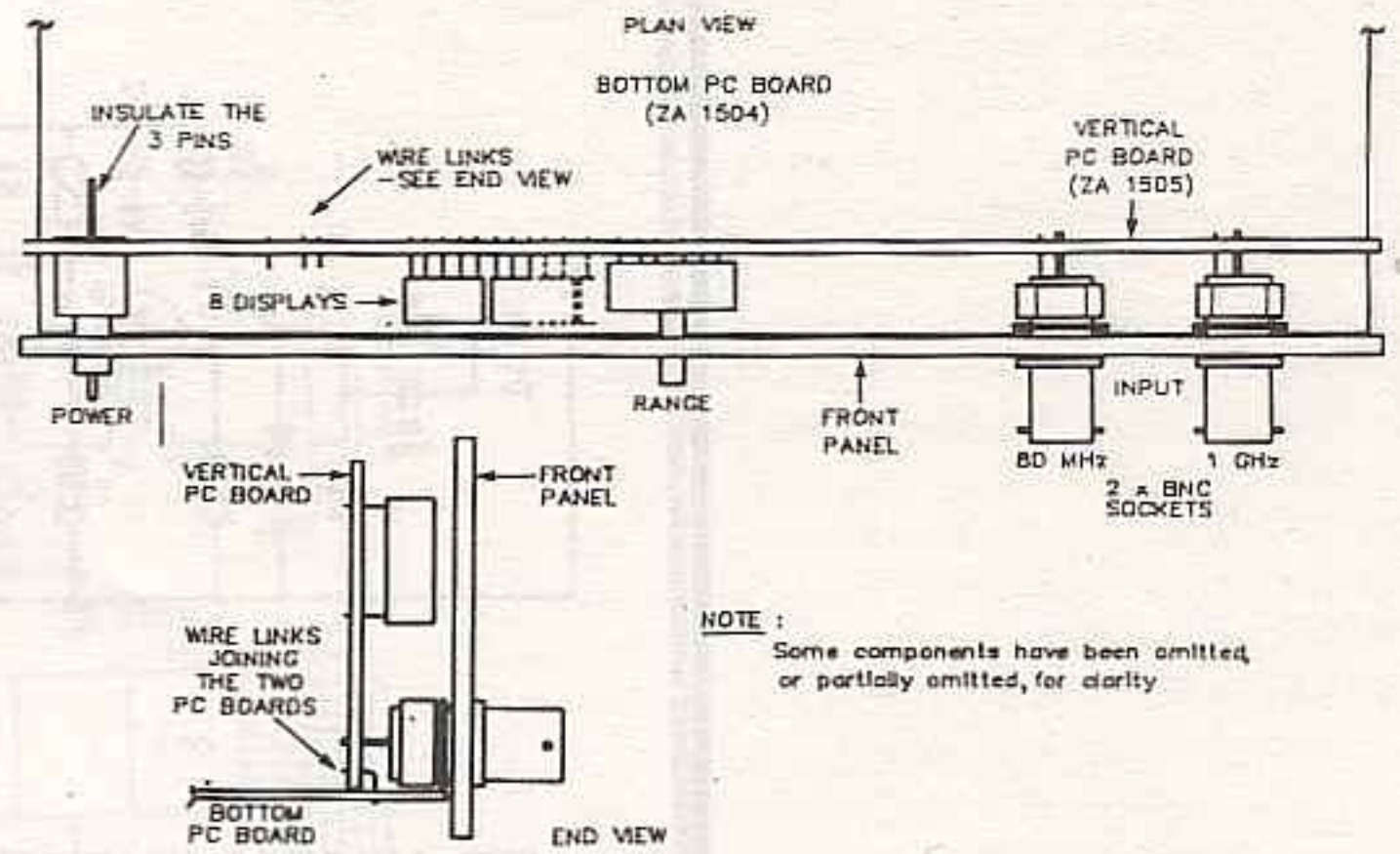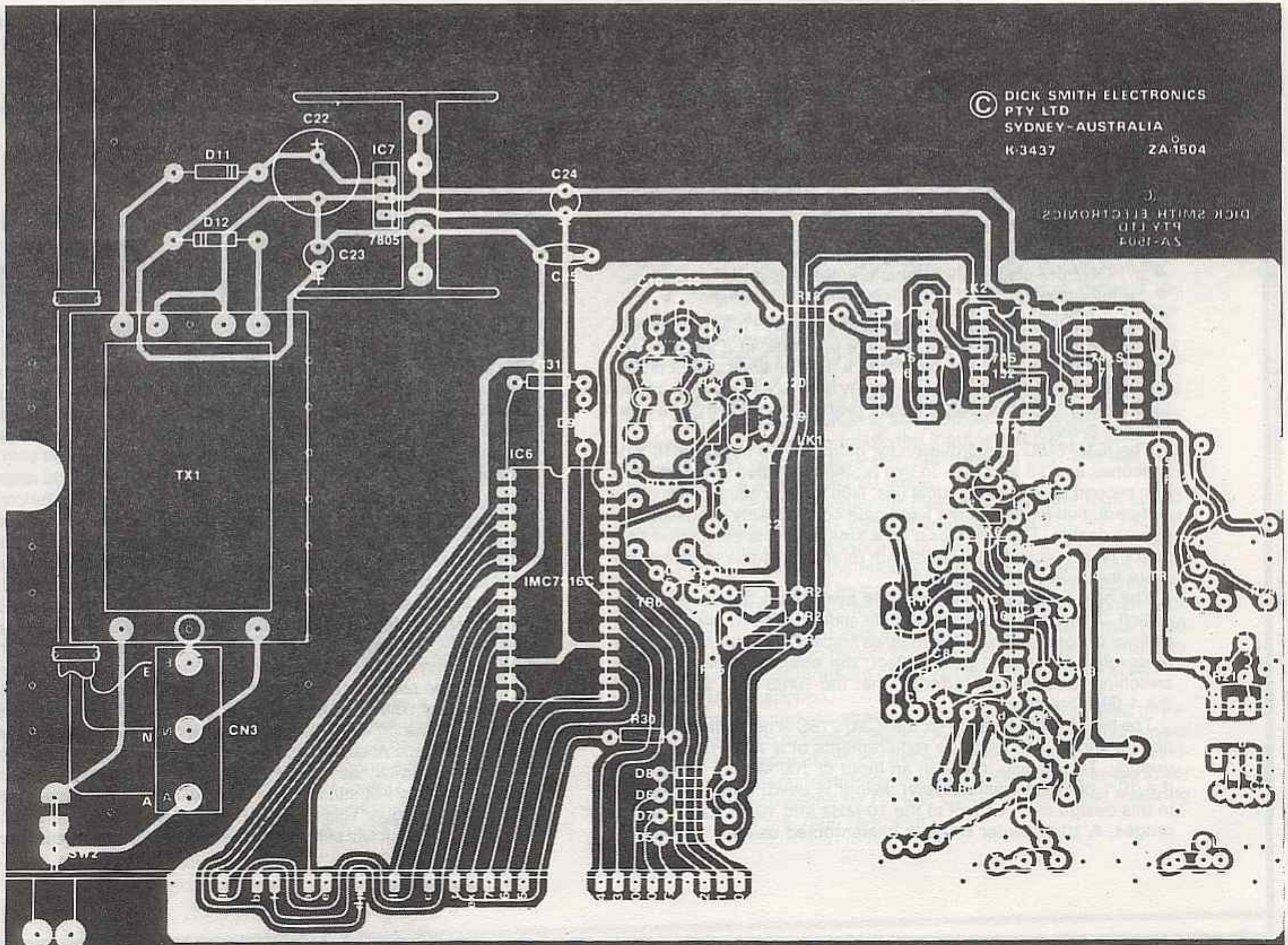
NOTE: Some components have been omitted or partially omitted, for clarity

A series of short tinned copper links can now be soldered to the series of holes along the bottom edge of the board. Cut these to about 15 mm long and bend them at right angles, pointing away from the board, so that they will align with the holes in the motherboard. The two boards can now be brought together so that all the wire links thread through the holes in the motherboard. The edge of the display board should butt up to the surface of the other. With the boards held at right angles, solder all the links.
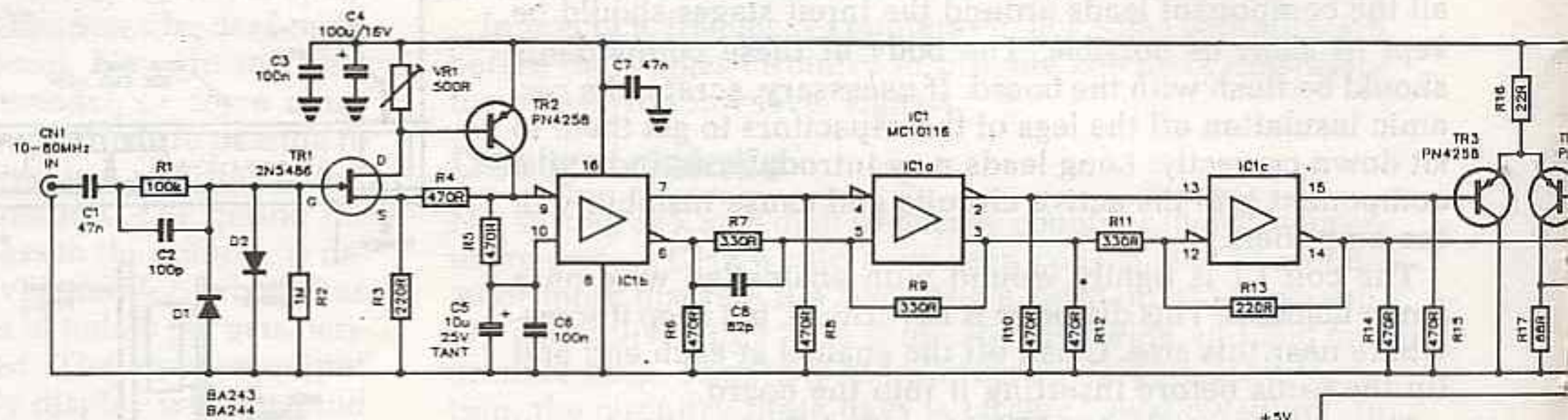
Mounting in the case

At this stage, try fitting the assembly into the case. The display panel should slide down in the rear slot of the three near the front edge. The four mounting holes in the motherboard should align over the appropriate posts. Adjust to fit if necessary.
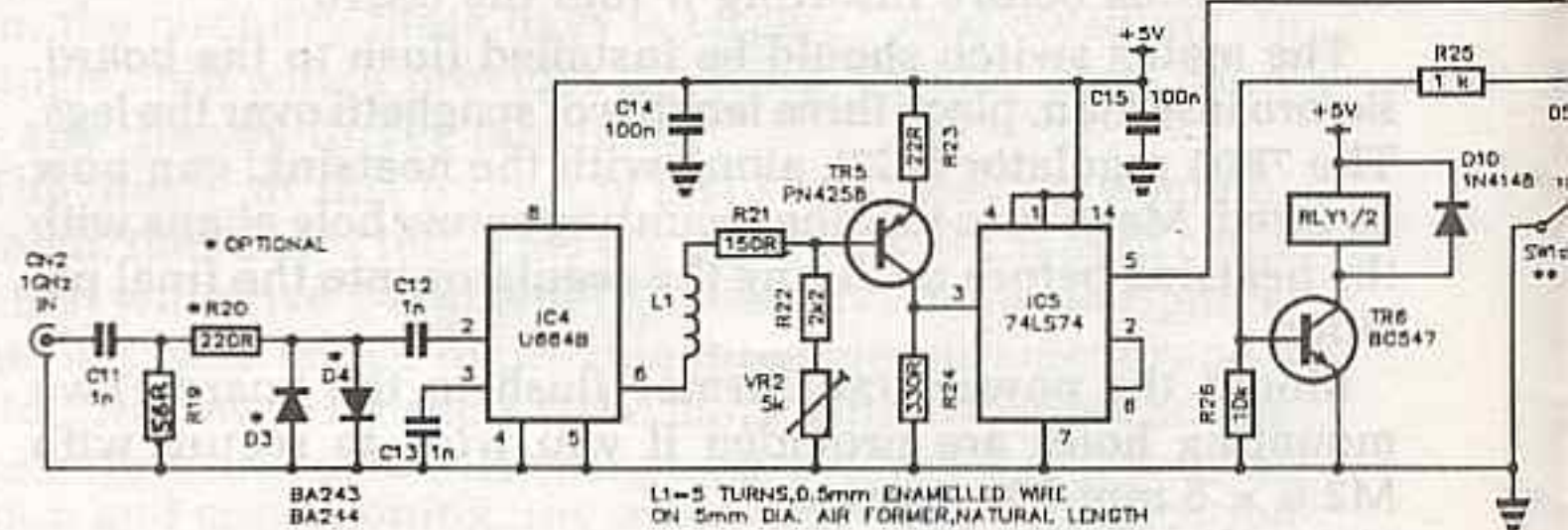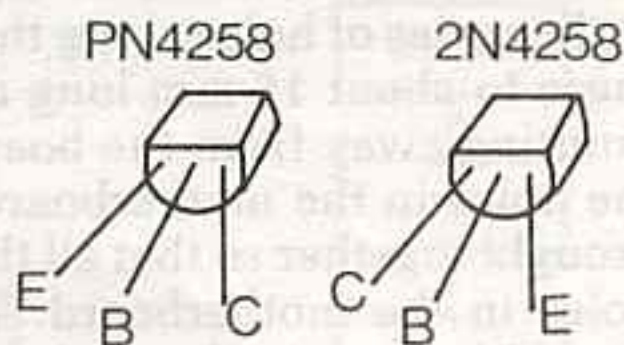
(TRANSISTOR PINOUT)

PN4258   2N4258

E B C   C B E

*If R20 NOT USED, substitute link.

L1=5 TURNS,0.5mm ENAMELLED WIRE ON 5mm DIA. AIR FORMER, NATURAL LENGTH

Constructors please note: If supplied with the crystal type HI-Q7.8125MHz GE03c, leave C18 OUT of the circuit. With other types of crystals, insert C18 in the circuit.
If supplied with crystal type DMK 10.00MHz, C21 has to be IN the circuit. With other types of crystals, leave C21 out of the circuit.
If supplied with a 2N4258 instead of a PN4258 (as shown on Parts List and circuit diagram) please refer to the above transistor pinout diagram for correct orientation.

CIRCUIT OPERATION

The circuit comprises three basic blocks:

- a wideband amplifier covering from near dc to 80 MHz
- a 1 GHz pre-scaler with signal conditioner, and
- an integrated 10 MHz 8-digit counter/display driver.

The heart of the counter is built around an Intersil ICM7216 series 8-digit counter-display driver IC. This provides, in a single chip, a high frequency timebase oscillator, a decade timebase counter, multiplexed 7-segment decoder/display drivers for common-anode LED displays and the logic circuitry required to implement a total counter system.

The ICM7216C has provision for gating times between 10 milliseconds and 10 seconds. In this project, we have only used the one second period. In practical use, little is to be gained with other accumulation times and the fixed gate considerably simplifies the overall design. The need for a gate time switch is eliminated and so too is the decimal point shift with reference to this time and the input frequency range scaling.

The only front panel control made available is the range-select switch. This three position, two pole slider caters to the input frequency range of up to 1 GHz in three steps. One pole of the switch is devoted to decimal point select, the other controls the logic switching required to interface either the 10/80 MHz amplifier or the 1 GHz pre-scaler.
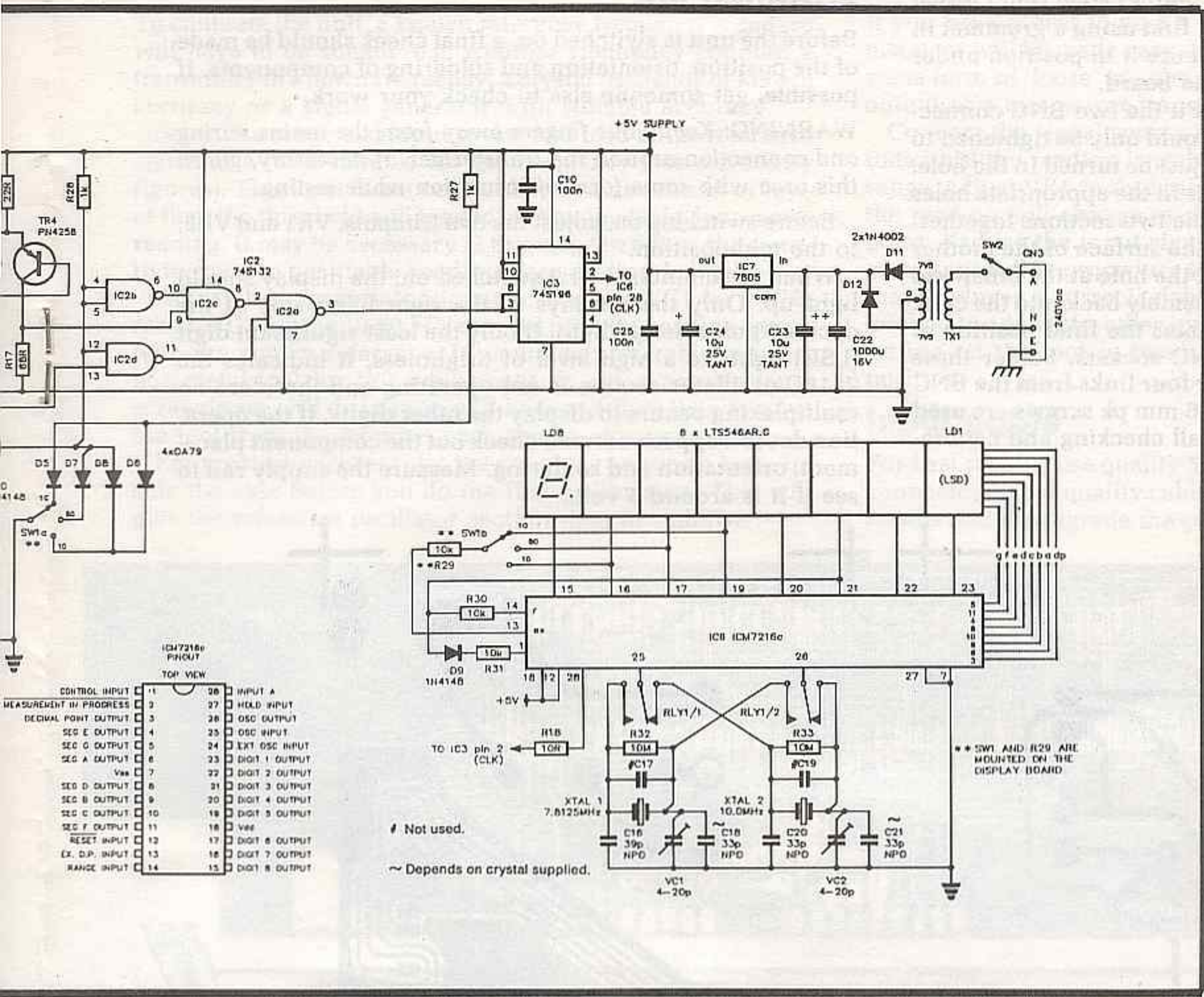
The time base reference for the ICM7216C is normally a 10 MHz crystal and this satisfys the requirements of a 10 MHz input frequency. This is also true with an input of 100 MHz or 1000 MHz if a 10:1 or 100:1 (respectively) divider is used. This is the case in this design with respect to the 10 MHz and 100 MHz (80 MHz) ranges. A 10:1 divider stage is implemented using a 74S196. A

10 MHz crystal and the surrounding components provide the reference via the contacts of the RLY1 relay.

On the 1 GHZ range, the division ratio is not a factor of 10. The U664b pre-scaler divides the input frequency by 64. A further divide-by-two stage is provided by a 74LS74. The input frequency therefore has been pre-scaled by a factor of 128. In order that the final readout is 10 MHz, the intermediate reference has to be a factor of the input frequency divided by the pre-scaler division ratio. This makes the crystal required 7.8125 MHz. The changeover to this crystal and its surrounding components is provided by the relay. The necessary gating and switching is provided by the simple diode network connected to SW1 and the transistor TR6.

Some readers may be quick to question why this second reference is necessary when the normal 10 MHz crystal would be correct if the pre-scaling ratio suited the 64 division of the input stage. This could be arranged by using two 5:4 stages. A 74167 synchronous decade rate multiplier could be used to do this job nicely. The total ratio would then be 64:1 × 5:4 × 5:4 resulting in 100:1. This certainly meets the requirements of a 10 MHz reference and the 10 MHz counter. The factor that is not obvious at face value is the input waveform to the 7216. The minimum period of any part of the incoming waveform cannot be less than 50 ns for proper operation. It can be seen that after the first divide-by-64 stage, the resultant frequency (with 1 GHz input) will be 15.625 MHz. This sets the half cycle period at 32 ns. Because the division function of the following 5:4 stage does not result in a 50% duty cycle (even though the frequency division is correct), some of the shortest periods in this division train will still only be 32 ns wide. The same applies to the following stage. This means that the final pulse train presented to the 7216 input will still contain periods of 32 ns, far less than

+5V SUPPLY

TR4 PN4258
R26 1k
R27 1k
C10 100n
IC2b IC2c IC2a
IC2 74S132
IC3 74S196
TO IC6 pin 2B (CLK)
IC2d
D5 D7 D8 D6
4x0A79
1N4148
SW1d
R17

IC7 7805
out in
com
C25 100n
C24 10u 25V TANT
C23 10u 25V TANT
C22 1000u 16V
D11
D12
2x1N4002
7V
6V
TX1
SW2 CN3
240Vac
A N E

8 x LTS546AR.G
LD8

SW1b 10k R29
R30 10k
R31 10k
D9 1N4148
IC6 ICM7216c
LD1 (LSD)
gfedcbadp
15 16 17 19 20 21 22 23
25 26
27
+5V
R18 10R
TO IC3 pin 2 (CLK)
RLY1/1 RLY1/2
R32 10M
C17
R33 10M
C19
XTAL 1 7.8125MHz
XTAL 2 10.0MHz
C16 39p NPO
C18 33p NPO
C20 33p NPO
C21 33p NPO
VC1 4-20p
VC2 4-20p

** SW1 AND R29 ARE MOUNTED ON THE DISPLAY BOARD

~ Depends on crystal supplied.

⌀ Not used.

ICM7216c PINOUT TOP VIEW

Pin	Name
CONTROL INPUT	1
MEASUREMENT IN PROGRESS	2
DECIMAL POINT OUTPUT	3
SEG C OUTPUT	4
SEG G OUTPUT	5
SEG A OUTPUT	6
Vss	7
SEG D OUTPUT	8
SEG B OUTPUT	9
SEG E OUTPUT	10
SEG F OUTPUT	11
RESET INPUT	12
EX. D.P. INPUT	13
RANGE INPUT	14

Pin	Name
28	INPUT A
27	HOLD INPUT
26	OSC OUTPUT
25	OSC INPUT
24	EXT OSC INPUT
23	DIGIT 1 OUTPUT
22	DIGIT 2 OUTPUT
21	DIGIT 3 OUTPUT
20	DIGIT 4 OUTPUT
19	DIGIT 5 OUTPUT
18	Vdd
17	DIGIT 6 OUTPUT
16	DIGIT 7 OUTPUT
15	DIGIT 8 OUTPUT

the 50 ns minimum requirement.

1 GHz pre-scaler

The U664b pre-scaler was originally designed for use in frequency synthesizers in CATV tuners. Not only is it capable of operating up to 1 GHz but also has considerably high sensitivity in the frequency range between 30 MHz and 1 GHz. The IC operates from a 5 V rail. This makes the power supply requirements simple as other stages in the counter also run from this same potential.

The input stage is kept very simple. The circuit shows components R20, D3 and D4 as optional. These are only included if there is a likelihood that in use, the input may be above 5 Vp-p. A problem may arise if the counter is to be used around high power transmitters or if the input is to be placed on a test point with a high dc potential.

Following the pre-scaler is an output buffer and a dc level-shift stage. A bias adjust pot (VR2) is provided to set the threshold point for the following divider stage. The 74LS74 D-type flip-flop is configured to operate in a divide-by-two toggle mode. The other half of the chip is not used.

10 MHz/80 MHz input stage

This section uses the tried and proven MC10116 ECL triple line receiver. the second and third stages of this chip are configured to operate as Schmitt triggers.

The input stage uses a FET/transistor pair as a low gain, wideband amplifier. VR1 provides an adjustment range to cater to parameter spreads in active components. The pot in reality becomes the sensitivity set point. The following differential amplifier is dc-coupled throughout. The transistor output pair TR3/TR4 provide the interface between the ECL differential output of the MC10116 and the input of the following 74S132 Schmitt trigger.

Logic control switch

To avoid running signal lines to the range switch, relatively simple control is achieved by the use of the 72S132 NAND two-input gate. In this system, the output from the 10/80 MHz stage is gated via section c. The output from the 1 GHz pre-scaler is gated via section d. Only the steady dc logic value of the control gates is required to make the changeover. Pins 4, 5 and 12 carry the state from the remote range switch. This dc switching confines the high frequency signal lines to the short runs of the pc board tracks around the critical areas.

The 74S196 also plays a role in the dc switching system. If either the 10 MHz or 1 GHz range is selected, this pre-settable decade counter is configured to follow the input when pin 1 is held low. If the 80 MHz range is selected, pin 1 will be high and this sets the counter in a divide-by-10 mode.

IC2 and IC3 are Schottky devices to achieve the high speed switching rates from the 10/80 MHz stage. It is IC3, the 74S196 that limits the input frequency to 80 MHz. This is not because of any ability to clock at any frequency above this figure but again because of the internal frequency division mode. The configuration uses a divide-by-two followed by a divide-by-five function. It is this latter divider that sets a 4:5 duty cycle in the output pulse train that is the limiting factor. The shortest period is less than the 50 ns minimum requirement of the 7216c if frequencies in excess of 80 MHz are applied.

The power supply is straightforward and uses a 7805 three-terminal regulator to provide the 5 V for the system. Ceramic bypass capacitors are spread around the supply rail on the board, providing distributed high frequency bypassing. Bypassing at the lower frequencies is provided by C4 and C24, the latter also ensuring the stability of the 7805 regulator.

Remove the assembly and fit the mains cable. Don't forget to thread it through the back panel first using a grommet in the panel. Use two cable ties to secure it in position under the transformer core and along the board.

Now comes the final tricky bit! Fit the two BNC connectors to the front panel. The nuts should only be tightened to the point where the connector can just be turned in the hole. Orientate the sockets so that the pins fit the appropriate holes in the display board as you bring the two sections together. The flat of the nuts should lay on the surface of the mother board. The mains switch should fit the hole at the other end of the panel. Now slide the total assembly back into the case. The front panel position now dictates the final position of the slider switch and the two BNC sockets. Solder these points. All that remains is to solder four links from the BNC pins to the motherboard. Four 4 × 6 mm pk screws are used to secure the board in place after all checking and calibration has been carried out.

Powering up

Before the unit is switched on, a final check should be made of the position, orientation and soldering of components. If possible, get someone else to check your work.

WARNING: Keep your fingers away from the mains wiring and connection around the transformer. If necessary, guard this area with some form of insulation while testing.

Before switching on, adjust the two trimpots, VR1 and VR2, to the mid-position.

When the counter is first switched on, the display should light up. Only the displays to the right hand side of the decimal point should light. If only the least significant digit (LSD) lights to a high level of brightness, it indicates the 7216C oscillator section is not operating and therefore no multiplexing occurs to display the other digits. If the operation doesn't appear normal, check out the component placement, orientation and soldering. Measure the supply rail to see if it is around 5 volts.
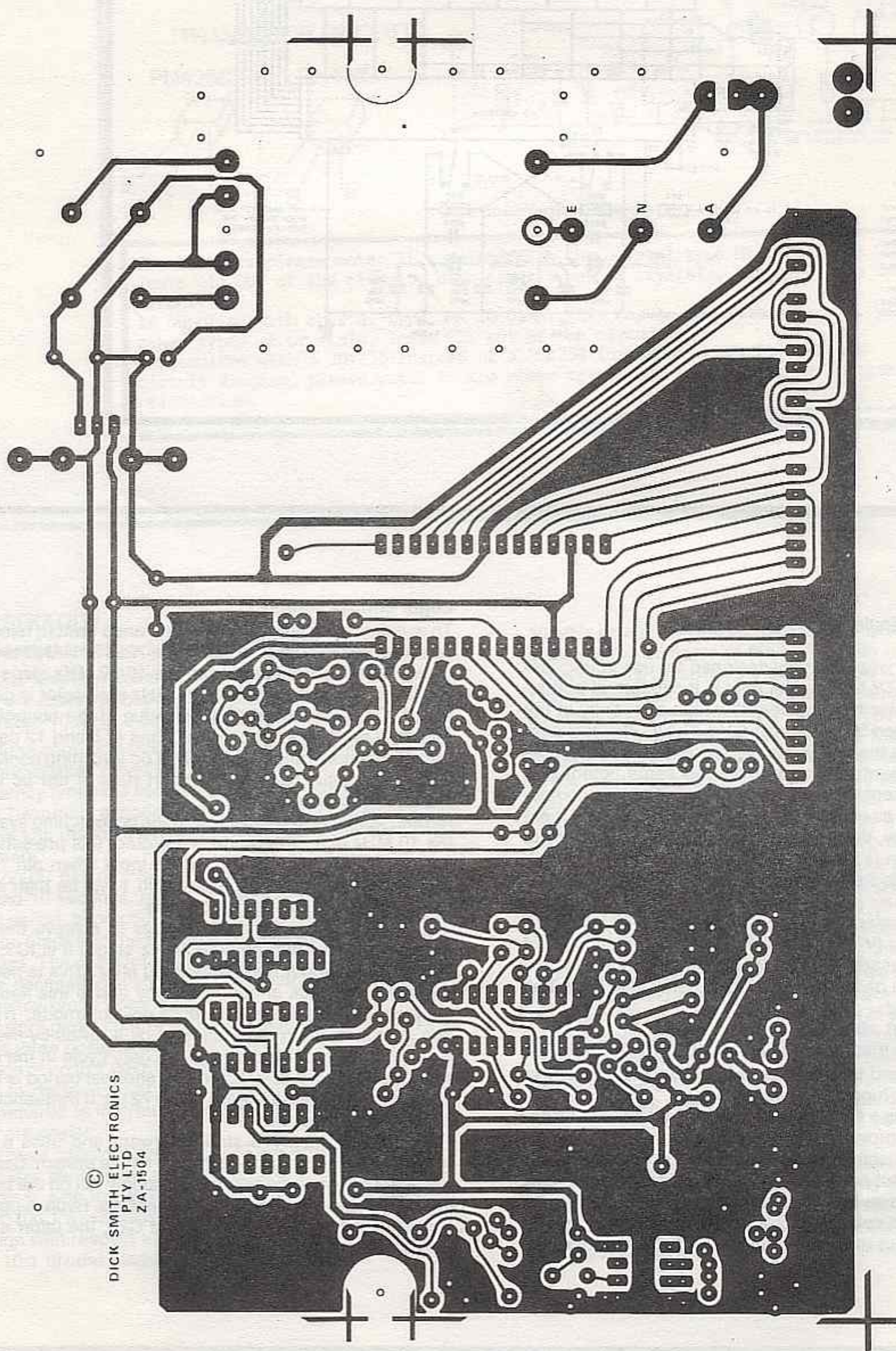
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Calibration

To calibrate the unit, a known reference frequency standard will have to be sought. e.g: Another frequency counter, a transmitter of known frequency, a crystal oscillator of known accuracy or a signal generator with suitable accuracy.

Select the range and input socket and feed in the reference signal at a level suitable for the frequency (see sensitivity figures). This level is not critical but a value around or lower than the threshold will tend to give an unstable, inaccurate reading. It may be necessary at this stage to adjust the sensitivity pots to get stable readings (see section below).

Adjust the appropriate trimmer capacitor (VC1 for 1 GHz range, VC2 for the 10-80 MHz range) until the reading agrees with the known reference. It would be preferable to use a non-metal tool for this adjustment. It not, a conventional screwdriver will do but you will have to adjust then remove the tool from the trimmer each time a change is made.

For greatest accuracy, let the counter run for an hour inside the case before you do the final calibration. This will give the reference oscillator section time to stabilise.

Sensitivity setting

If you have access to an RF signal generator, then this adjustment will be made easy. If not, you may have to arrange some form of 'loose' coupling. A 'sniffer coil' to receive the output of a low power transmitter will do fine.

Connect the signal source and increase the output amplitude until the reading is stable. On the 10 MHz or 80 MHz range, adjust VR1 to find mid-point position. You will find the reading will change or disappear either side of the set point. Reduce the input signal level and re-adjust the trimmer. Repeat this procedure to find the most sensitive point that produces a correct, stable reading. Carry out the same method to adjust the other input stage. You will find that the setting on this pot is reasonably wide. Set it to the mid-position.

Input cable

For best results, use quality 50 ohm coaxial cable with BNC connectors. Low quality cable may give less than preferable results and downgrade the performance of the instrument.
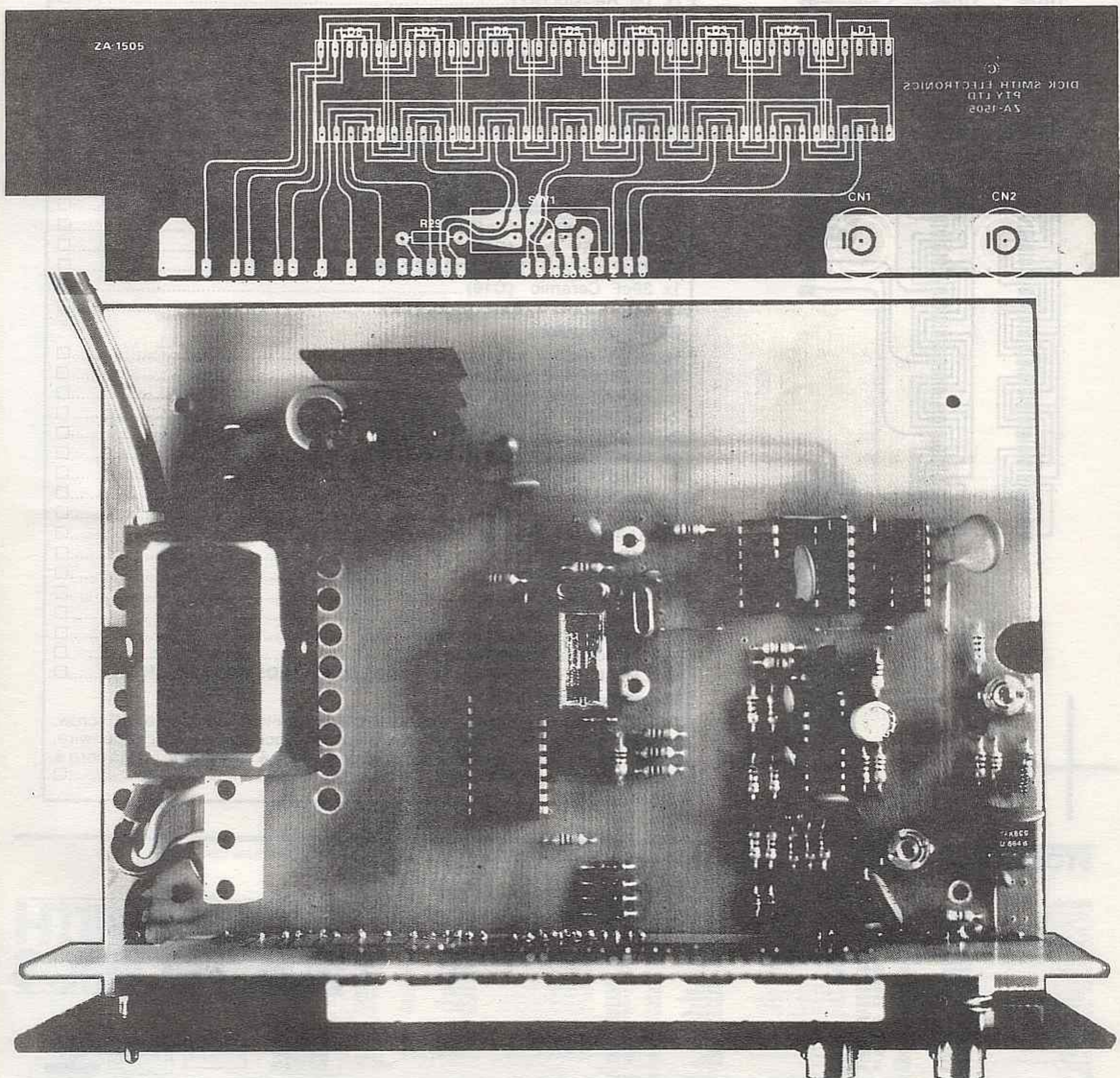
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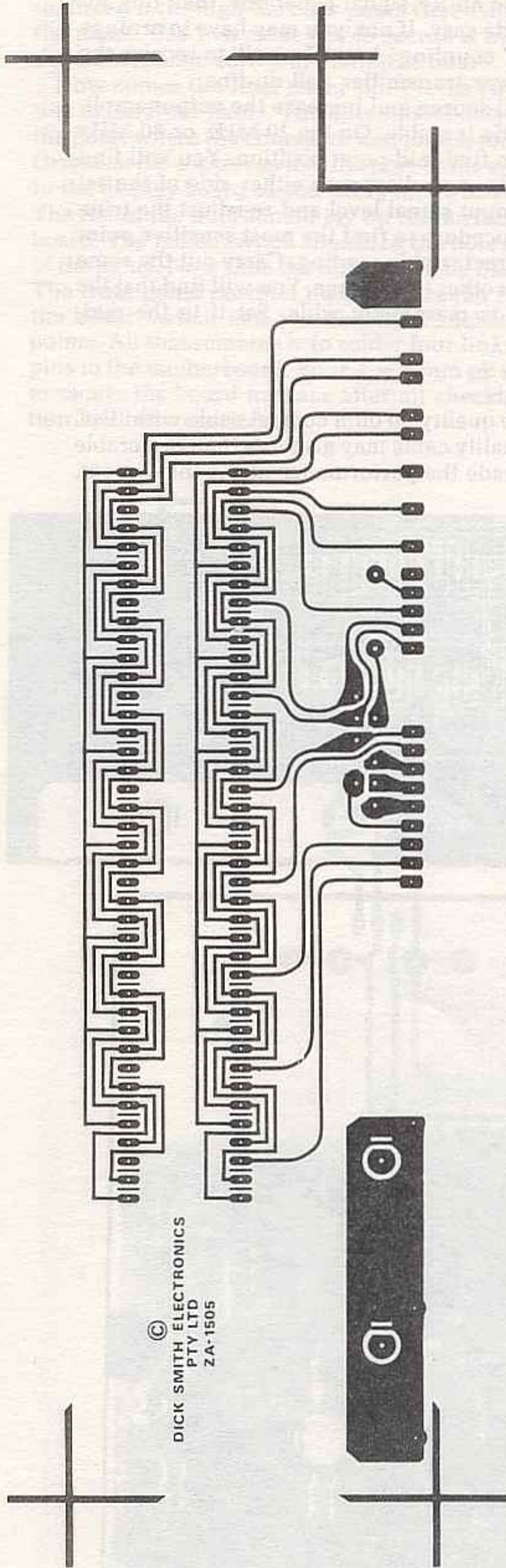
PARTS LIST

Resistors

All Resistors 1/4W unless specified

1x 10R Resistor (R18) ☐
2x 22R Resistor (R16,R23) ☐
1x 56R Resistor (R19) ☐
1x 68R Resistor (R17) ☐
1x 150R Resistor (R21) ☐
3x 220R Resistor (R3,R13,R20) ☐
4x 330R Resistor (R7,R9,R11,R24) ☐
8x 470R Resistor (R4,R5,R6,R8,R10,R12,R14,R15) ☐
3x 1K Resistor (R25,R27,R28) ☐
1x 2.2K Resistor(R22) ☐
4x 10K Resistor (R26,R29,R30,R31) ☐
1x 100K Resistor (R1) ☐
1x 1M Resistor (R2) ☐
2x 10M Resistor (R32,R33) ☐
1x 500R Trimpot (VR1) ☐
1x 5K Trimpot (VR2) ☐

Capacitors

1x 82pF Ceramic (C8) ☐
1x 100pF Ceramic (C2) ☐
3x .001uF Ceramic (C11,C12,C13) ☐
2x .047uF Ceramic (C1,C7) ☐
6x .1uF Ceramic (C3,C6,C10,C14,C15,C25) ☐
1x 100uF 16V Electro (C4) ☐
1x 1000uF 16V Electro(C22) ☐
3x 10uF 25V Tant (C5,C23,C24) ☐
3x 33pF Ceramic NPO (C18,C20,C21) ☐
1x 39pF Ceramic (C16) ☐
2x 4.2pF-20pF Trimcap (VC1,VC2) ☐

Semiconductors

1x .BC547/DS547 transistor (TR6) ☐
1x 2N5486/MPF105 Transistor(TR1) ☐
4x PN4258 Transistor(TR2,TR3,TR4,TR5) ☐
2x IN914/IN4148 Diode(D9,D10) ☐
2x IN4002 Diode(D11,D12) ☐
4x OA47 Diode(D5,D6,D7,D8) ☐
1x 74LS74 IC(IC5) ☐
1x MC10116P IC(IC1) ☐
1x 7805 Volt Reg(IC7) ☐
4x BA243/BA244/BA282 Diode(D1,D2,D3,D4) ☐
1x 74S132 IC(IC2) ☐
1x 74S196 IC(IC3) ☐
1x U664B IC (IC4) ☐
1x 7216C IC (IC6) ☐
1x 7.8125MHz Xtal(XTAL1) ☐
1x 10.000MHz Xtal(XTAL2) ☐
8x LTS546 AR/G Displays(LD1,LD2,LD3,LD4,LD5,LD6,LD7,LD8) ☐

Miscellaneous

PCB mains block, heatsink, slide switch, toggle switch, relay, cable ties, screw, spagetti tubing, tined coppper wire, grommet, sockets, enamel copper wire, solder, s/t screws, transformer, plastic case, front & rear panel, mains cord & plug, PCB main, PCB display. ☐

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