Project 170

PRECISION CRO CALIBRATOR

Anyone who has used a CRO will know what an incredibly useful instrument it can be — providing you can be sure of its calibrations. This handy low-cost calibrator will let you check and adjust all main settings easily and efficiently. Designed by the Electrical Engineering staff at Sydney University, it is easily built and can also be used to check out a CRO you're considering buying.

WHEN OSCILLOSCOPES or 'CROs' first started to be used in electronics, they were simply used to 'look at' what was going on in a circuit. Just being able to 'see' what was happening to the voltages and currents was a big step forward from what had been possible before, and for a while that was enough.

But nowadays people expect to be able to use a CRO in a much more quantitative fashion, to measure instantaneous voltages, voltage changes and timing details. In order to be used in this more serious way, a CRO naturally needs to be properly calibrated.

The small low-cost calibrator described here has been designed to make calibration of almost any reasonably modern CRO a fairly simple and straightforward job. It produces pulses of known accurate amplitude and timing, whose peak-to-peak voltage and repetition rate can be varied over a wide range to allow most of a CRO's normal ranges to be checked.

While the calibrator can be used to check and adjust both gain and linearity for both the vertical and horizontal channels of an instrument, in practice most CROs do not provide a means of adjusting the linearity of the vertical amplifier(s) — only the gain. Similarly although you can use the calibrator to check horizontal linearity, most instruments only allow you to adjust the horizontal gain and average timebase sweep speed.

A CRO which was made more than ten years ago (fairly rare in the commercial world, but still common in hobby workplaces) can easily drift a few percent in a period of months. Hence the need for a handy reference like this calibrator.

In addition to its main intended use in keeping your existing CRO or CROs calibrated, it is probably also worth taking along when you are looking at new CROs with an eye to purchase. It has surprised the authors to see how badly some otherwise impressive units fared, even brand new.

We will now discuss how the calibrator is used, for those who may not have been exposed to such procedures before. In addition to checking vertical gain accuracy and sweep speed, we will also explain how to check overshoot, timebase non-linearity, the presence of a satisfactory vertical delay line for viewing non-repetitive triggering events, and vertical non-linearity.

Note that we must assume you have access to the operating manual of your CRO, for details regarding the manufacturer's recommended procedures in adjusting the instrument. This varies from instrument to instrument, and it is often important to adjust things like the vertical attenuator and timebase ranges in a particular order.

Vertical calibration

This is initially fairly simple. Referring to the first CRO screen photograph (represented in Figure 1), the instrument's appropriate present potentiometer is adjusted to obtain precisely the correct deflection. The photograph was taken on a brand new CRO on a medium voltage deflection scale, and so the trace is narrow and sharp. The adjustment should be done on the range(s) specified by the manufacturer, but the checking of calibration should be done on several of the available ranges.

Figure 2 shows the same (brand new) CRO on its most sensitive range. There are two points to note. The first is that the trace was fuzzy, primarily on account of CRO amplifier noise. This requires that the operator effect some estimate of the difference between trace centres. It is best to take one edge (in Figure 2 the lower) and adjust the vertical position so as to set the reference edge precisely on a graticule line. Then the same edge of the trace on the other part of the squarewave cycle gives the deflection.

In Figure 2 the deflection is clearly about 5.2 divisions. The second point to note is that the CRO (correct to the limit of measurement on the 50 mV/div range) is 4 per cent high on the 1 mV/div range. Thus the need to check performance against specifications on *all* ranges is very clearly demonstrated.

Horizontal calibration

Initial sweep calibration should similarly be carried out at the sweep speed specified for the particular CRO, but a check is recommended over a wider range. Figure 3 is of a set of 10 timing pulses arrayed over a CRO screen. With the fine vertical edge of the first pulse set on the first vertical graticule line, the same part of the last pulse should align with the final graticule vertical. Even on the screen of the high quality and fast writing speed CRO used for this the intensity must be set quite high to clearly show the fast vertical edges.

Timebase Linearity

Regrettably for readers, but fortunately for ETI, we were unable to locate a CRO with bad linearity. Referring still to Figure 3, had there been a non-linearity in the sweep, it would have been evident as one or more vertical pulses not being aligned with their respective graticule lines after the horizontal calibration had set the end pulses on their respective markers. We have observed such problems even on new CROs. The calibrator prevented a poor purchase in that case!

Overshoot

This phenomenon is becoming rarer on CROs these days. The only CRO we could locate with significant overshoot proved to have neither graticule illumination for clear illustrations nor the ability to give a good look for single edge blow up.

We settled for using a 10 year old CRO — also with no graticule illumination. Figure 4 shows overshoot on the edges of the inverted timing waveforms, rather than the voltage waveforms. These were easier to trigger on than the relatively infrequent edges of the voltage calibration squarewave. The overshoot is the 'wiggle' seen at the beginning of the clear horizontal parts of the trace.

Delay Line

Figure 5 shows the rising edge of the voltage calibration waveform on a high quality oscilloscope. The trace was rather dim, because the sweep occurs only at 1 kHz, despite the sweep speed of 10 ns/div. The same edge that triggered the timebase can be seen, because the CRO contains a delay line, so that the signal is delayed for long enough (some tens of nanoseconds usually) to allow the sweep to commence before the signal is applied to the vertical deflection plates. A view such as this is impossible otherwise.

The edge is not perfect. The salient feature is a minor step-like appearance at the top of the edge. This is in fact not CRO

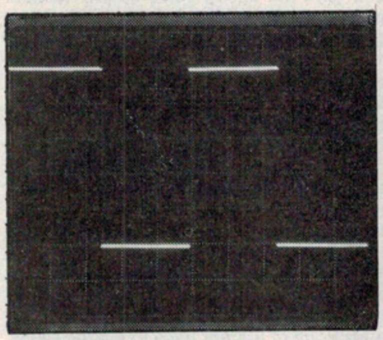


Figure 1. Vertical calibration. New Trio CS-1022 set to 0.2 ms/div, 50 mV/div.

induced overshoot, but the result of mismatch in the connection from the calibrator via a 50 ohms cable to the 1 m/50 pF input impedance of the CRO. Such is the typical situation which will be encountered.

Construction & setting up

The construction is basically a case of duplicating the prototype shown here. Initially drill the appropriate holes in the panel of the case being used. All the electronics is attached to the panel along with the switches and connectors, so the shape of the rear of the container is not important.

Once drilled, the various holes on the front label can be lined up with the holes in the panel and the label attached. After adhering the label, fit the components and their knobs where applicable. Next assemble the pc board, exercising the usual care to ensure that all the polarised components are orientated correctly. Also take care to leave the solder joints clean and free of blobs which might short tracks together. Remember that only resistors and capacitors without polarity markings can be put in either way around, because everything else is polarised in some way!

Next attach all the components which are mounted to the rear of the panel controls. These components are fixed to the panel controls to reduce the number of flying leads. Be careful to get all of them in their correct circuit locations, as reversal of components here can lead to 'satisfactory' but uncalibrated operation.

Finally connect the pc board to the panel with short lengths of hookup wire. The leads should be as short as is practicable while leaving the board accessible for alignment, servicing, etc. Long leads can give rise to unwanted coupling between the circuit sections, and may also permit the radiation of unwanted EMI (Electro-Magnetic Interference), even up to VHF frequencies, because of the sharp edges generated by the driver circuits.

With a battery connected the unit should now function. It remains only to adjust the supply to its correct voltage. This of course

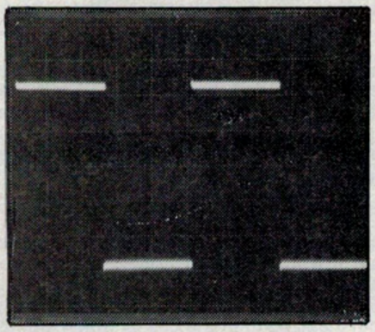


Figure 2. The same CRO as in Figure 1, at 1 mV/ div.

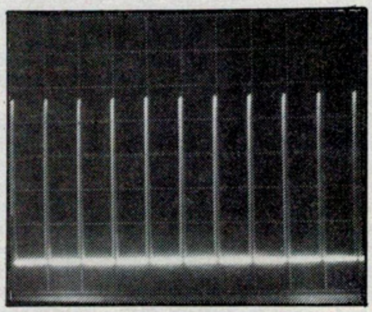


Figure 3. A seven year old Tektronix 465 is shown at 1 ms/div. Its last calibration date was not recorded, if it happened at all!

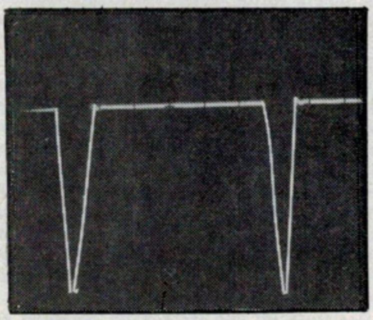


Figure 4. A BWD 511 of unguessable age. CRO calibrator set to 1µs timing pulses, CRO at 1 V/div and 0.2 µs/div. No graticule illumination available.

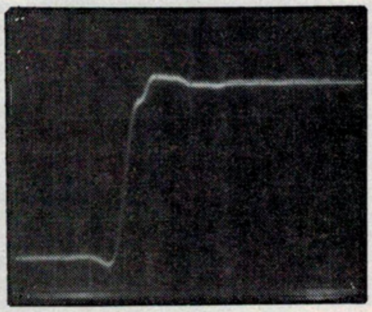


Figure 5. Tek 465 again, 20 mV/div and 10 ns/div, with the calibrator on 100 mV range. ▶

The CRO calibrator circuit divides into six parts. These are a power supply section, a 1 MHz clock, a 10 MHz clock, a divider chain, a voltage output section and a timing pulse output section. Each will be discussed in its turn.

Power supply

The power supply consists of ICs 1, 2 and part of IC3, with their surrounding components. Q1 is used as a saturating pass element, to connect and disconnect the battery from those parts of the device which are not continuously powered. IC1 is the only IC connected all the time to the supply. Initially consider that C1 is discharged. IC1(b) and (c) have their inputs held low, so that their outputs are high. These gates are connected in parallel to increase the current delivering capacity. Because the outputs are high, Q1 is held off.

In this condition the current drain from the battery is so small that it will last its shelf life, and it may be considered unconnected.

When PB1 is depressed to turn on the instrument, C1 is charged up rapidly via R1. The inputs of IC1(b) and (c) and taken high and the outputs are thus driven low, turning on Q1. This applies almost the full battery potential to IC2, a precision supply regulator IC, via the external supply jack. Capacitors C3 and C4 decouple the rail to prevent instability problems arising from the source impedance of the battery. RV1 is used to trim the regulated supply voltage to 5.05 volts, while C5, C6 and C7 provide further decoupling and compensation.

C1 will slowly discharge via R3. When it reaches about half rail potential, IC1(b) and (c) will once again turn Q1 off, returning the instrument to the quiescent (off) condition. Thus automatic turnoff is effected. Should PB2 be fitted, it may be used to manually turn off the supply.

If the unregulated supply falls below a level where good regulation of the 5.05 volt supply by IC2 is not possible (when the battery goes flat, for example), IC3(a) and IC1(a) and (d) are wired to immediately turn the supply off. Note that IC3 is powered from the 5.05 volt rail. When the input of IC3(a) falls to below about half its supply rail, which is about 5.05 volts, it charges C2 via R5. This causes IC1(a) and (d) to discharge C1 via D1 and R2, which shuts off the supply.

Resistors R6 and R7 set the potential on the collector of Q1 which is required to initiate this automatic shutdown. This mechanism prevents any attempt to use the device when it is potentially operating incorrectly due to a low battery condition.

1 MHz Clock

The 1 MHz clock is crystal controlled and provides the timing reference for all (but the 10 MHz) timing signals and the voltage calibration squarewave. The oscillator consists of IC4(b) and surrounding components. It runs off the 5.05 volt supply, and operates continuously when the unit is in the on state.

Divider Chain

The divider chain consists of six decade counters. These provide signals divided by 10, 100, etc, up to 1 million, giving 10 per cent duty-cycle pulses of from 100 kHz to 1 Hz, all derived from the 1 MHz reference. The 'on' indicator is driven from one of these dividers, giving fast flashes with low duty cycle to give indication without wasting power.

Timing Pulse Output

IC3(b/d) and IC11 with surrounding components form the timing pulse output section. This section, when enabled, shapes the timing pulse train and delivers it to the output with 50 ohm impedance. With SW1(a) in the 'time' position, IC3(d) is enabled. The disabling system prevents the gates consuming power when not required. SW2(a) selects the timing train with the required frequency.

SW2(b) selects the capacitor which defines the shape of the output pulse. This mechanism is incorporated to provide pulses whose edges are conveniently visible on all frequency ranges.

On the 1μs range, the pulses are not modified by a capacitive load on IC11(c/d/e), but are shaped by the driving network formed by the sections of IC4 not used in the oscillator. Not only does this provide neat, visible pulses at this frequency, but it makes use of the gates in the package already handling 1 MHz signals. This reduces the chances of crosstalk between these signals, with components in very high frequency ranges, and the slower timing signals. Such crosstalk can upset triggering and interfere with the waveform being displayed.

10 MHz Clock

The 10 MHz clock circuit is built around IC12. It differs somewhat from the 1 MHz clock in order to allow clean operation at this high frequency. R39 and C18 with IC12(c/d) form the output wave of the oscillator into a pulse string for easy alignment against graticule timing marks. Note that the circuit is separately decoupled by C19, and is only powered by completing the earth return when required, as selected by the range switch SW2(b).

This circuit consumes considerable power in relation to the other parts of the calibrator, and so is not activated when not required. Its output is fed to a different connector. If it is not required, this whole section can be deleted, removing the 10 MHz 100 ns range with commensurate cost saving. If no fast CROs are likely to be encountered, this would not be a problem.

Output Section

The voltage output section, when enabled by SW1(a), produces calibrated output squarewaves at 1 kHz. The voltage level is selected by SW3. When not enabled Q2 remains off. When enabled it is switched into and out of saturation by IC11(b). Capacitor C16 is selected to precisely pull Q2 out of saturation as quickly as possible.

When fully saturated, Q2 has approximately 0.05 volts drop across it — hence the 5.05 volt supply. R16 through R36 provide a precise 1-2-5 sequence attenuator using only E12 series preferred resistor values. Signals of 1 mV p-p to 5 V p-p are developed. The output impedance is at most a few hundred ohms. Because no buffer is provided, the CRO input must not be terminated in 50 ohms.

WHILE WE'RE TALKING ABOUT CROs . . .

While we're thinking about CROs and their performance, let's consider for a moment a few general aspects of oscilloscope or 'CRO' performance which are often taken for granted.

Nowadays there are quite a few CROs available for around the same price as a humble (humble?) audio amplifier. But we expect rather different things from the two types of equipment. For example we only expect amplifiers to have a bandwidth of from 20 Hz to 20 kHz — yet for the same money we expect a CRO to have a bandwidth of dc to 20 MHz! This is a very big difference, yet some of the better CROs go a great deal further, to 200 MHz or even 500 MHz.

Astute readers will guess at once that something is traded for this wide range. But perhaps few of you may have realised just what it is that is missing from the CRO's performance.

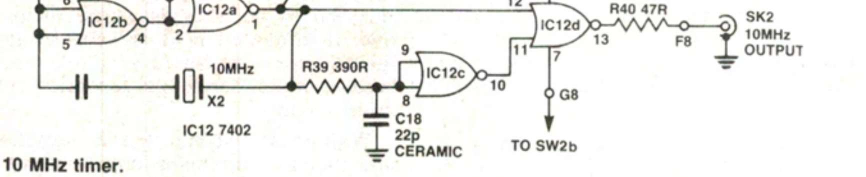
One of the things usually noted in the 'fine print' of CRO specifications is linearity. A vertical deflection linearity error of one or two per cent is typical, probably specified for a deflection of say six or seven major divisions.

In an audio amplifier this would be called distortion, and if it rose much above say .01%, today's audio enthusiast would be most unhappy. By paying more money, you can get an amplifier with ten times lower distortion again. In addition, the audio amp is expected to maintain this low level of distortion even at power output levels of 100 watts or so — a far cry from the few tens of volts, at low currents, expected from the CRO deflection amps.

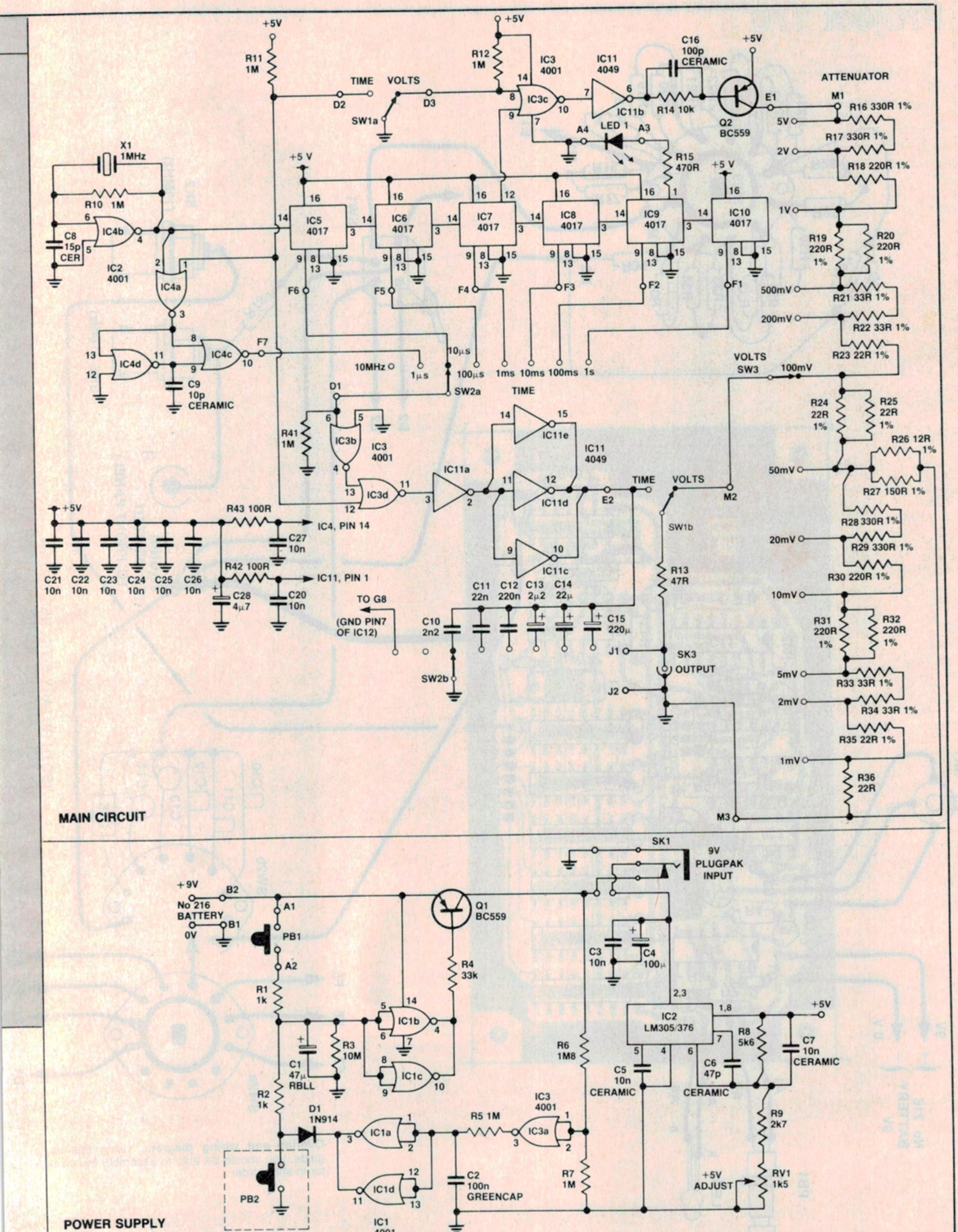
The CRO can of course get away with this relatively poor linearity because the human eye can't perceive less than about one per cent distortion, whereas our ears most certainly can — particularly on the right kind of programme material. Round two to the audio amplifier.

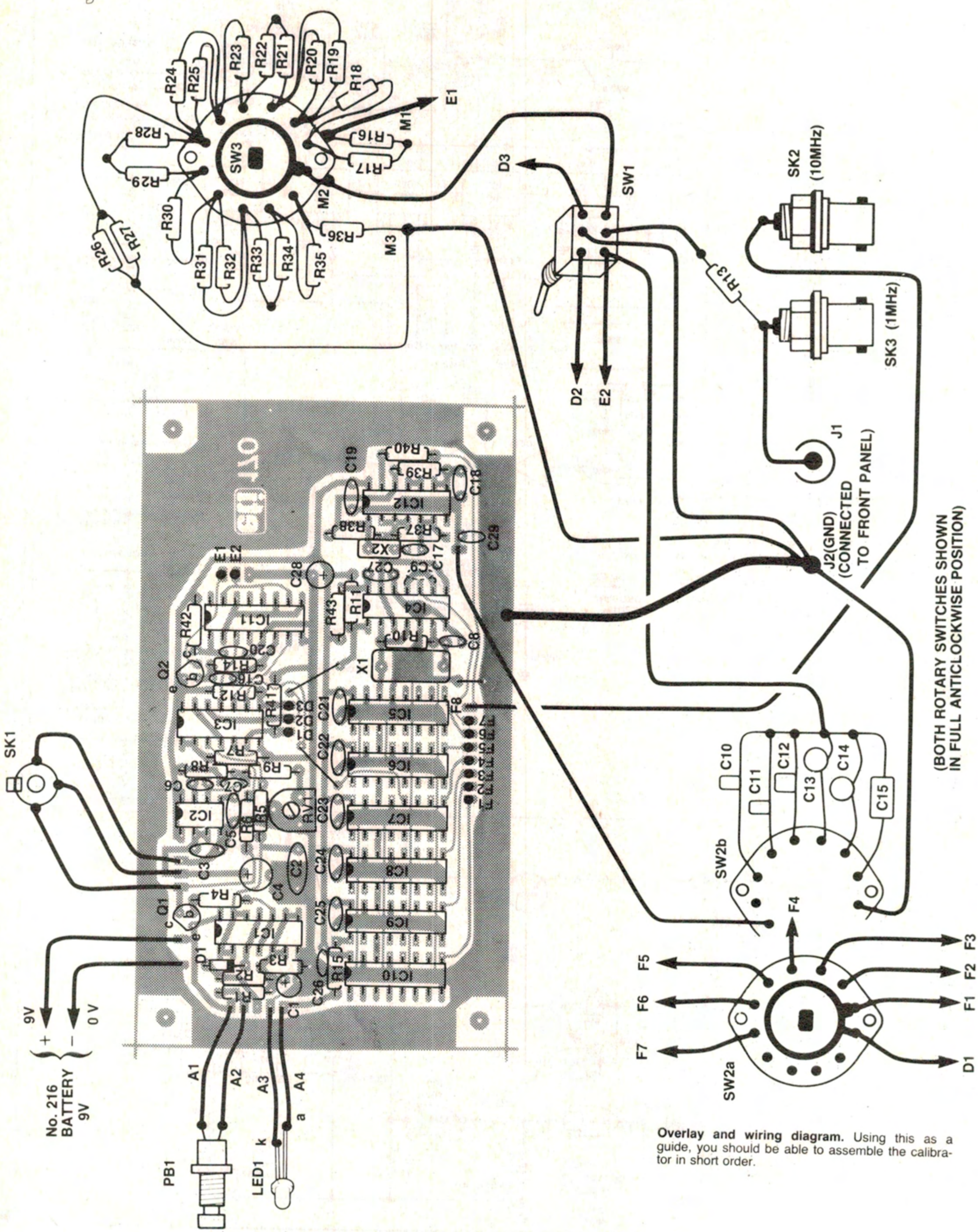
In most applications where a CRO is used, the user expects to be able to resolve the position of the trace to within 0.1 divisions, on a screen with eight vertical and 10 horizontal divisions. This represents a dynamic range of about 38 dB in the vertical direction. Compare this with the 50 dB or more you get from your cassette player, or the 96 dB from a compact disc.

The upshot of this is that the signal-to-noise ratio of a CRO can be relatively poor, and the spot position uncertainty fairly large. Round three to the audio amplifier.



10 MHz timer.


MAIN CIRCUIT
+5V
R11 1M
TIME
VOLTS
D2
D3
SW1a
R12 1M
IC3 4001
IC3c
IC11 4049
IC11b
C16 100p CERAMIC
R14 10k
Q2 BC559
E1
ATTENUATOR
M1
R16 330R 1%
5V
R17 330R 1%
2V
R18 220R 1%
1V
R19 220R 1%
R20 220R 1%
500mV
R21 33R 1%
200mV
R22 33R 1%
R23 22R 1%
A4
LED 1
A3
R15 470R
X1 1MHz
R10 1M
C8 15p CER
IC4b
IC2 4001
IC4a
IC4d
IC4c
F7
C9 10p CERAMIC
IC5 4017
IC6 4017
IC7 4017
IC8 4017
IC9 4017
IC10 4017
F6
F5
F4
F3
F2
F1
10MHz
1µs
10µs
100µs
1ms
10ms
100ms
1s
SW2a
D1
R41 1M
IC3b
IC3 4001
IC3d
IC11a
TIME
IC11e
IC11 4049
IC11d
IC11c
E2
TIME
VOLTS
M2
SW1b
VOLTS SW3
100mV
R24 22R 1%
R25 22R 1%
R26 12R 1%
50mV
R27 150R 1%
R28 330R 1%
20mV
R29 330R 1%
R30 220R 1%
10mV
R31 220R 1%
R32 220R 1%
5mV
R33 33R 1%
2mV
R34 33R 1%
R35 22R 1%
1mV
R36 22R
M3
R13 47R
J1
SK3 OUTPUT
J2
+5V
R43 100R
IC4, PIN 14
C27 10n
R42 100R
IC11, PIN 1
C28 4µ7
C20 10n
C21 10n
C22 10n
C23 10n
C24 10n
C25 10n
C26 10n
TO G8
(GND PIN7 OF IC12)
C10 2n2
C11 22n
C12 220n
C13 2µ2
C14 22µ
C15 220µ
SW2b
POWER SUPPLY
SK1
9V PLUGPAK INPUT
+9V
No 216 BATTERY
0V
B2
B1
A1
PB1
A2
Q1 BC559
R4 33k
R1 1k
IC1b
IC1c
C1 47µ RBLL
R3 10M
R2 1k
D1 1N914
IC1a
IC1d
IC1 4001
R5 1M
IC3a
IC3 4001
C2 100n GREENCAP
PB2
C3 10n
C4 100µ
IC2 LM305/376
R6 1M8
R7 1M
C5 10n CERAMIC
C6 47p CERAMIC
R8 5k6
C7 10n CERAMIC
R9 2k7
RV1 1k5
+5V ADJUST
+5V



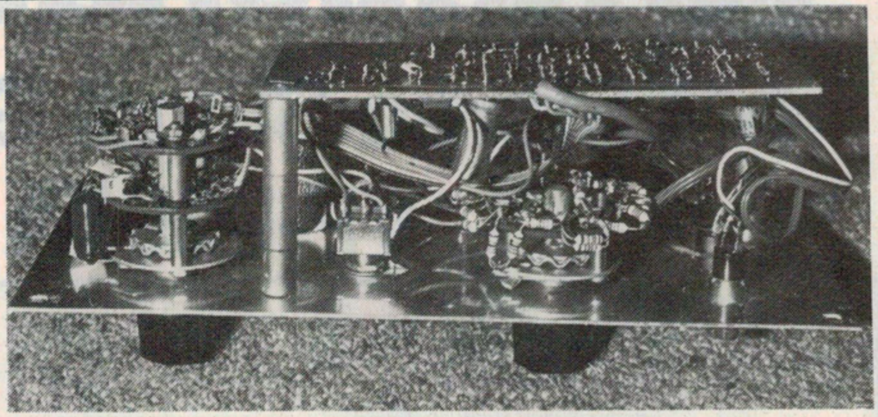
Overlay and wiring diagram. Using this as a guide, you should be able to assemble the calibrator in short order.

PARTS LIST — ETI-170 CRO CALIBRATOR

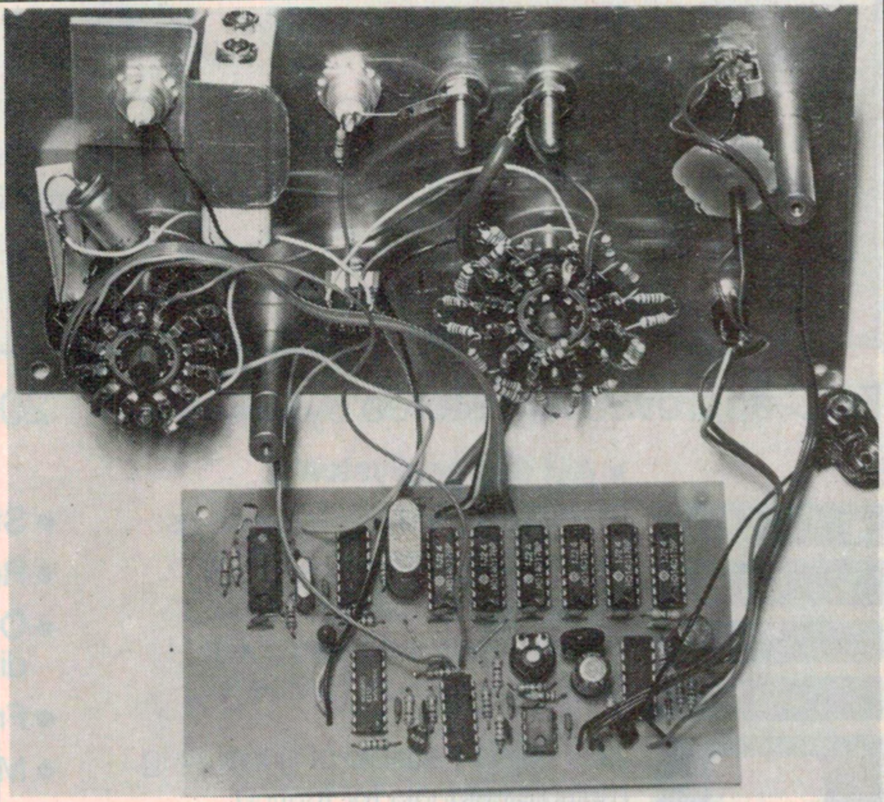
Resistors	all ¼W, 2% unless noted
R1, R2, R38	1k
R3	10M
R4	33k
R5, 7, 10, 11, 12, 41	1M
R6	1M8
R8	5k6
R9	2k7
R13, R40	47R
R14	10k
R15, R37	470R
R16, 17, 28, 29	330R 1%
R18, 19, 20, 30, 31, 32	220R 1%
R21, 22, 33, 34	33R 1%
R23, 24, 25, 35, 36	22R 1%
R26	12R 1%
R27	150R 1%
R37	470R
R39	390R
R42, R43	100R
Capacitors	
C1	47µ/16VW RB electro.
C2	100n/100V met. poly.
C3, 5, 7, 19-27, 29	10n ceramic monolithic
C4	100µ/25VW RB electro.
C6	47p ceramic
C8	15p NPO ceramic
C9	10p NPO ceramic
C10	2n2 ceramic monolithic
C11	22n ceramic monolithic
C12	220n met. poly.
C13	2µ2/35VW solid tant.
C14	22µ/6VW solid tant.
C15	220µ/16VW electro.
C16	100p ceramic
C17, C18	22p NPO ceramic
C28	4µ7/35VW solid tant.
Semiconductors	
D1	1N914 diode or similar
LED1	5 mm red LED with bezel
IC1, 3, 4	4001 CMOS quad NOR
IC2	LM305/376 regulator
IC5, 6, 7, 8, 9, 10	4017 CMOS decade divider
IC11	4049 CMOS hex inverter
IC12	7402 TTL quad NOR
Q1, Q2	BC559 or similar
Miscellaneous	
SW1	DPDT sub-min. toggle
SW2	2-pole 8-pos. rotary
SW3	1-pole 12-pos. rotary
PB1	Mom. contact sub-min. pushbutton
SK1	3.5 mm sub-min jack socket with sw.
SK2, SK3	Panel-type BNC socket
J1, J2	Tip jacks
X1	1 MHz crystal, par. res. with 30p
X2	10 MHz crystal, par. res. with 30p

ETI-270 pc board and Scotchcal label; 196 x 112 x 60 mm zippy box; 2 small knobs; 216-type 9 V battery; battery clip lead; 2 x 45 mm tapped spacers for pcb mounting; hookup wire, nuts, bolts, etc.

Estimated price: $60



Mounting the pc board to the panel. The leads should be as short as possible to avoid coupling between circuit sections and to prevent unwanted radiation.



Inside the case. Apart from the ICs and other components mounted on the PCB there are few other components required and these are mounted directly on the switches. Note the battery clamp bracket, attached to the front panel by the 10 MHz output socket.

requires a known accurate reference. We used a 3½-digit multimeter, which is adequate. It should be attached to the regulated supply rail, and RV1 adjusted to give the specified 5.05 volts. This gives 1% accuracy to the unit. As most CROs are good only to 2% or so, this is reasonable.

Further accuracy can be obtained if required by using the following alignment procedure. Switch the circuit to volts. Attach a 4½-digit meter to the volts output. Short IC3 pin 10 to rail momentarily, and set RV1 for 5 volts on the 5 V range. This gives accuracy limited only by the attenuator chain resistor tolerance.

Artwork: Front panel artwork and drilling diagram are available on request to ETI, PO Box 227, Waterloo, NSW 2017. ●