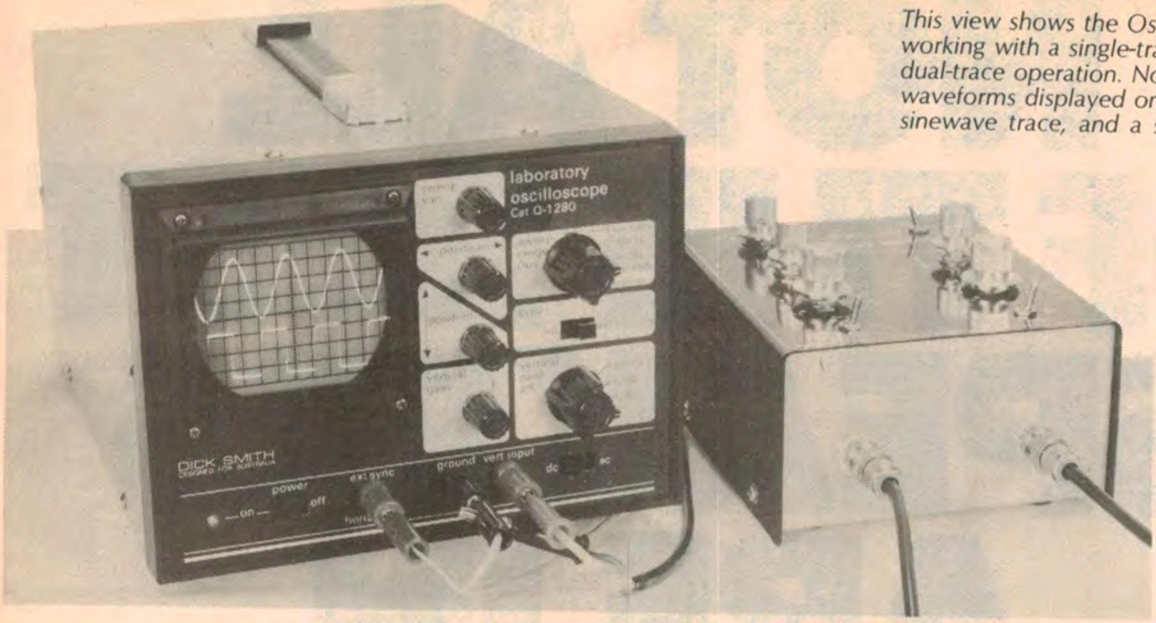
This view shows the Oscilloscope Switch working with a single-trace CRO to provide dual-trace operation. Note the two waveforms displayed on the CRT: an upper sinewave trace, and a squarewave.



Add dual-trace facilties to your CRO with this

Oscilloscope Switch

Dubbed the Oscilloscope Switch, this easy-to-build instrument will increase the versatility of your single-trace oscilloscope by providing dual-trace operation. It features switched attenuators, sync selection, AC or DC coupling and selectable chop rates.

by IAN POGSON

The oscilloscope is without doubt the most useful and versatile instrument we have for observing, measuring and analysing electrical signals. However, if an oscilloscope has only single trace capability, this limits its usefulness to a considerable degree.

Where two signals must be monitored simultaneously the single trace instrument can still be used in some cases but the operator needs more skill in interpreting the resultant display. For example, phase and frequency differences between two signals may be measured using the technique known as Lissajous figures. This involves feeding the two signals to the horizontal and vertical amplifiers of the oscilliscope, and is described in many textbooks.

There are other methods whereby a single trace oscilliscope can be used to compare different signals but they too require extra skill on the part of the operator.

By far the easiest way to monitor two signals simultaneously is to observe them on a dual trace oscilloscope.

Note the term "dual trace" rather than "dual beam". There are very few true double beam oscilloscopes these days, and even the more expensive ones usually use the dual trace system. In the dual trace oscilliscope, a single gun CRT is employed and the beam is switched rapidly between the two signals to give two traces which sweep across the tube face at the same speed.

Essentially, what our Oscilloscope Switch does is convert a normal single trace oscilloscope to dual trace operation, thereby greatly extending its versatility.

As an example, when testing an amplifier one can compare input and output signals and note any phase shifts or distortion. When testing a stereo amplifier, comparisons can be made of signals in both channels and crosstalk may also be observed directly.

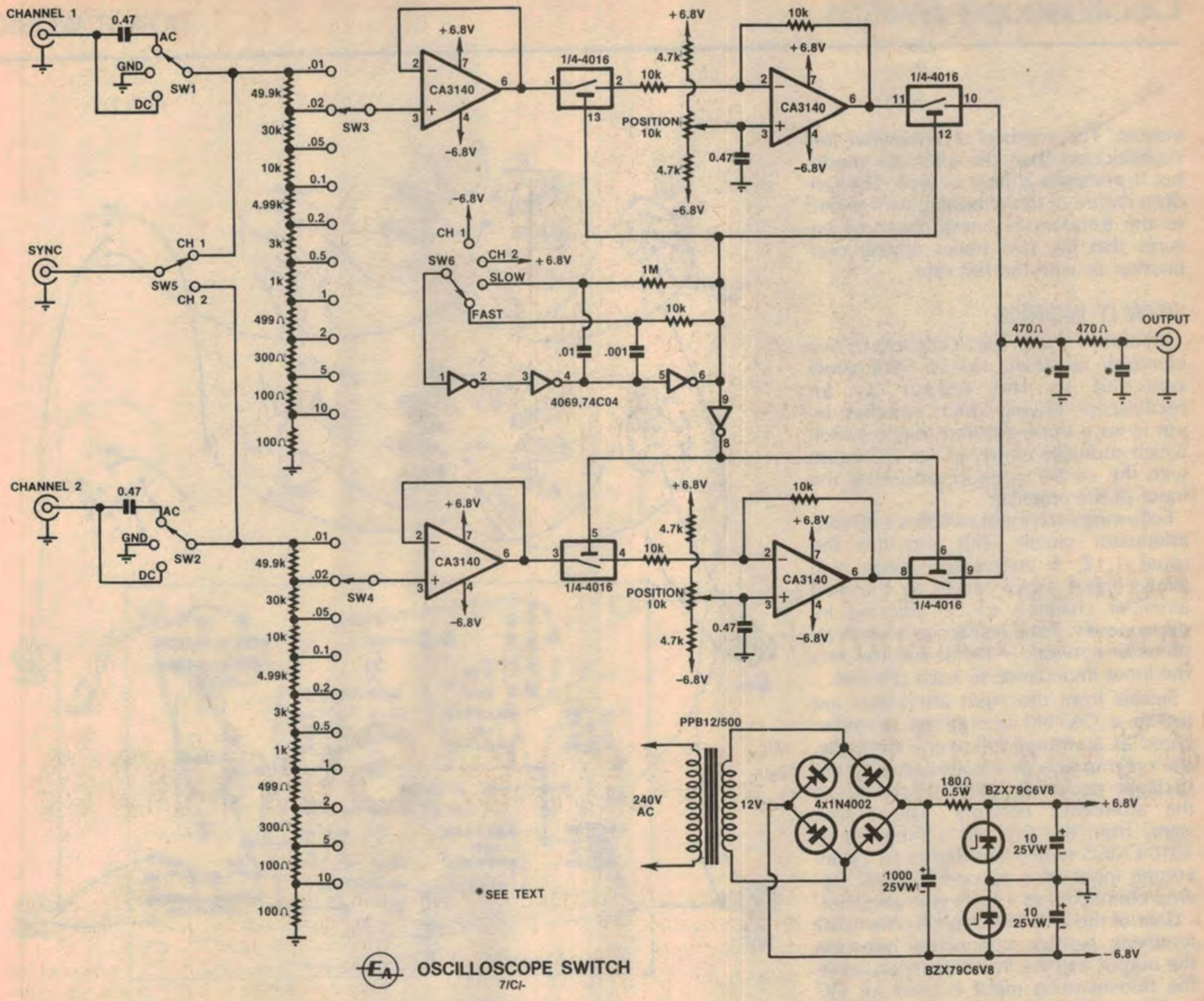
One might also use a dual trace oscilloscope for checking a transmitter – comparing the modulation envelope with the modulating signal. At the other end of the line, one can observe detection or demodulation in a radio receiver.

In digital circuitry, the dual trace oscilloscope really becomes indispensable for observing timing relationships between different pulse trains and seeing logic at work!

There are actually two modes of operation by which a dual trace display can be produced on a single trace oscilloscope. One is the "chopped" mode, the other is the "alternate" mode. In the chopped mode, the electron beam is switched rapidly between the two signals at a rate considerably higher than the frequency of the signals being observed.

In effect, what happens is that a square wave is applied to the vertical amplifier of the oscilloscope. At the same time, the signals to be displayed are superimposed on the square wave – one signal on the upper part of the waveform and the other signal on the lower part of the waveform. The vertical sections of the waveform become invisible, provided the rise and fall times of the square wave are fast enough.

The "chopped up" nature of the two apparent traces seems to disappear for two reasons. One is that each waveform develops visual continuity due to its "row of little dashes" nature. The other is that the switching frequency of the square wave is deliberately arranged not to be harmonically related to the signals being displayed. For this reason, the



The circuit consists of two identical amplifier channels alternately switched to the output by an oscillator.

dashes effectively "move" along the traces rather than remain stationary.

This, combined with the visual persistence of the tube phosphor and the human eye, makes the two traces appear continuous.

In situations where high frequencies are to be measured however, the chopped trace mode cannot be used. The main reason is that the chopping rate is limited by the bandwidth of the oscilloscope, so that the "chopped" nature of the traces tends to become more apparent when viewing high frequency signals. In these situations, the "alternate" mode of dual trace operation is used.

In this mode, a square wave of lower frequency than those being displayed is applied to the oscilloscope vertical amplifier. The square wave is locked to half the timebase frequency and again has the signals to be displayed superimposed on the upper and lower sections of the waveform. However, in this case the beam traces the upper half of the square wave (and one signal) in one complete sweep and the lower half of the square wave (with the other signal) on the successive sweep. Hence the "alternate" operation.

Thus, in the alternate mode, the two traces are produced successively and persistence effects in the tube phosphor and the human eyes make it seem as though there are two separate and simultaneous traces.

Most dual trace oscilloscopes have both chopped and alternate trace operation, with the mode automatically selected by the timebase switch (chopped for low speeds and alternate for high). On the more flexible instruments the user has the option of selecting the mode of operation himself.

Our new Oscilloscope Switch has a fast chop rate of 65kHz, but to provide the alternate mode would involve gaining access to the timebase circuitry of the oscilloscope to be used with the switch. As an alternative (no pun intended!) we have provided a slow chop rate (74Hz)

SPECIFICATION

Bandwidth (−3dB):
DC coupled — DC to 1MHz
AC coupled — Approx 10Hz to 1MHz

Input impedance:
100kΩ shunted by ≤30pF

Trigger source:
Channel 1 triggered by Channel 1 signal; Channel 2 triggered by Channel 2 signal

Maximum input voltages (attenuator set to .01):
DC — ±4V; AC — 3V RMS

DC blocking on AC input:
±250V (DC + peak AC)

Output DC level shift: ±2V

Chop frequencies:
Slow — 74Hz; Fast — 65kHz

---

instead. This method is somewhat less sophisticated than the alternate mode, but it performs almost as well. The random nature of the chopping with regard to the frequencies being observed ensures that the two traces appear continuous, as with the fast rate.

HOW IT WORKS

Refer now the circuit. It consists of two identical amplifier circuits alternately switched to the output by an oscilloscope driving CMOS switches. Input is via a three-position toggle switch which provides either AC or DC input, with the centre position grounding the input of the amplifier.

Following each input switch is a 10-step attenuator circuit. This provides the usual 1, 2, 5 attenuation steps, and allows input signal levels to the two amplifier channels to be adjusted independently. Total resistance of each attenuator network is 100kΩ and this sets the input impedance to each channel.

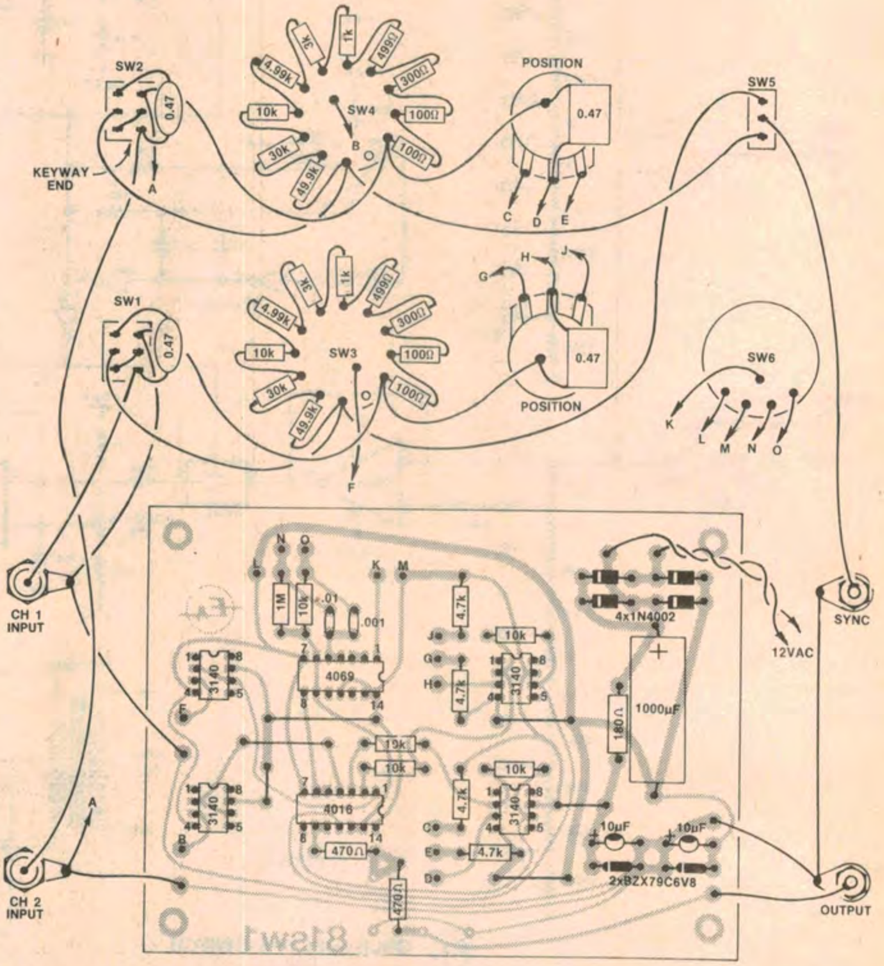
Signals from the input attenuator are fed to a CA3140 operational amplifier wired as a voltage follower. Essentially, the op-amp acts as a buffer, its high impedance providing minimal loading on the attenuator network. The output signal from the CA3140 is then fed to 4016 CMOS switch and thence to the inverting input of a second CA3140 op-amp connected as a unity gain amplifier.

Gain of the amplifier is set by the 10kΩ feedback resistor connected between the output and the inverting input, while the non-inverting input is used for DC position adjustment. A voltage divider consisting of a 10kΩ potentiometer and two 4.7kΩ resistors is connected across the positive supply rails. By adjusting the pot, the user can set the reference voltage on the non-inverting input (pin 3) according to requirements.

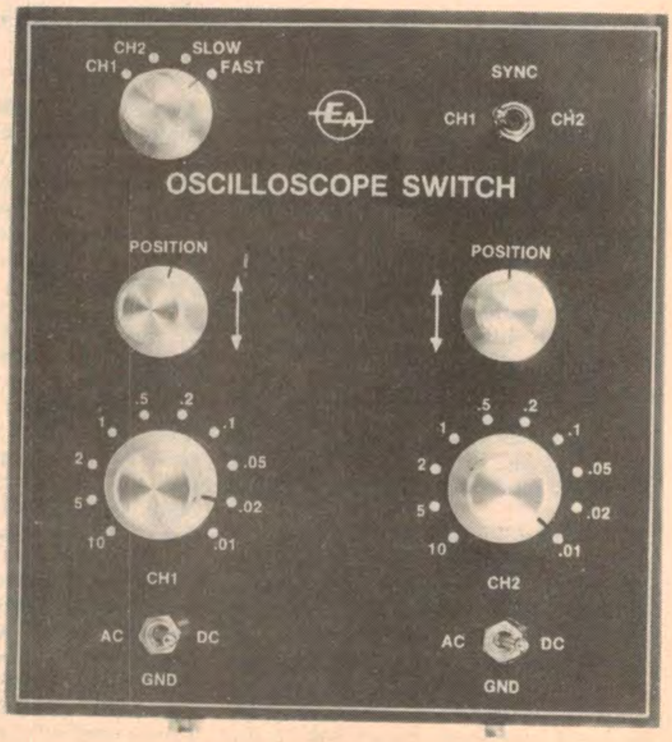
Output signals from the unity gain amplifier are fed to a second CMOS switch whose control electrode is wired in parallel with the first. (Some readers may be wondering why we have included CMOS switches on the inputs to the unity gain amplifiers. Why switch the inputs as well as the outputs? We tried the circuitry both with and without the first set of CMOS switches and found that the circuit depicted worked best and minimised output transients.)

Switching transients are further reduced by a two section RC filter wired between the output switches and the output socket. This circuit is something of a compromise between bandwidth and transient suppression, and is open to experimentation by individual constructors. More about this later on.

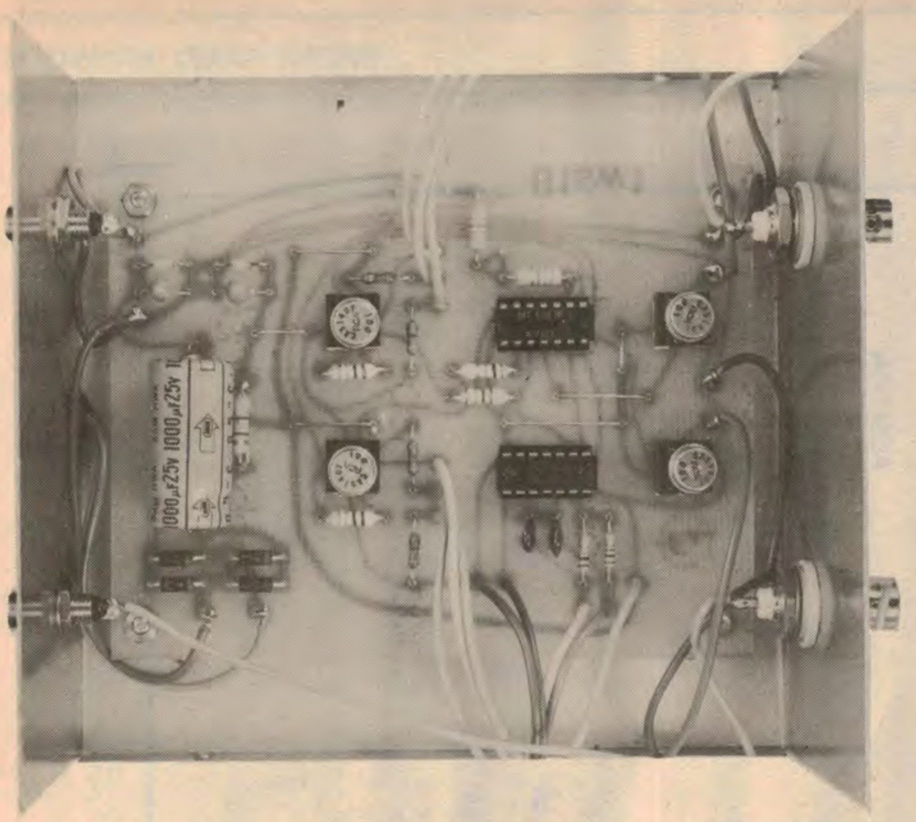
The switching oscillator consists of three sections of a 4069 (74C04) hex in-



ABOVE: the wiring diagram for the Oscilloscope Switch. Note that the resistors on the attenuator switches must be 2% types.



RIGHT: the completed prototype. As well as providing dual-trace operation, it also provides a calibrated attenuator for a CRO which doesn't already have this feature.



View inside the prototype showing the assembled PCB. Observe the precautions listed in the text regarding the CMOS ICs, and don't forget the wire links.

PARTS LIST

1 metal case, 150 x 76 x 134mm
1 Scotchcal front panel, 134 x 150mm
1 printed circuit board, 81sw1, 124 x 93mm
1 single-pole 4-position rotary switch (see text)
2 single-pole 12-position rotary switches (see text)
2 2-pole 3-position miniature toggle switches
1 SPDT miniature toggle switch
2 10kΩ linear potentiometers
5 knobs to suit front panel
1 12VAC plugpack transformer
4 8-pin DIL sockets (optional)
2 14-pin DIL sockets (optional)
2 single hole mounting RCA sockets
1 rubber grommet
2 insulated BNC sockets (see text)

SEMICONDUCTORS
4 1N4002 or similar power diodes
2 BZX796C6V8 zener diodes
4 CA3140 op-amps
1 4069 or 74C04 hex inverter
1 4016 or 4066 quad bilateral switch

RESISTORS (½W, 5% unless stated)
1 x 1MΩ, 5 x 10kΩ, 4 x 4.7kΩ, 2 x 470Ω, 1 x 180Ω ½W
RESISTORS(¼W, 2%)
2 x 49.9kΩ, 2 x 30kΩ, 2 x 10kΩ, 2 x 4.99kΩ, 2 x 3kΩ, 2 x 1kΩ, 2 x 499Ω, 2 x 300Ω, 4 x 100Ω

CAPACITORS
1 1000µF 25W axial lead electrolytic
2 10µF 25VW tantalum
4 0.47µF 250V metallised polyester (greencap)
1 .01µF greencap
1 .001µF greencap
1 47pF ceramic (see text)

MISCELLANEOUS
Screws, nuts, hookup wire, PC stakes, solder etc.

NOTE: Ratings are those used on the prototype. Components with higher ratings may generally be used providing they are physically compatible. Components with lower ratings may also be used in some cases, provided the ratings are not exceeded.

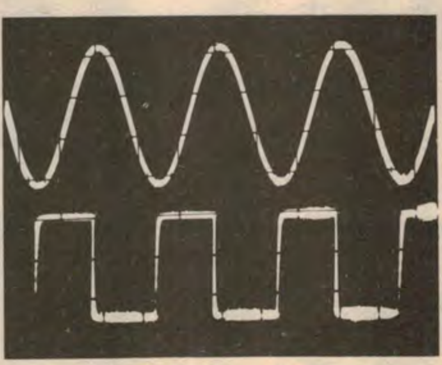
verter arranged in standard three-gate configuration. It has two switched output frequencies selected by switch SW6 to provide the fast and slow chop rates (65kHz and 74Hz). A fourth section of the hex inverter is used to give a second output (at pin 8) which is 180° out of phase with pin 6.

With this arrangement, the oscillator output at pin 6 controls the CMOS switches in Channel 1 while the inverted output from pin 8 controls the switches in Channel 2.

The remaining two switch positions on SW6 switch the oscillator off so that the user can select either channel for display. For example, in the CH 1 position, pin 1 of the 4069 is pulled low, thus forcing pin 6 high and activating the CMOS switches in Channel 1. In the CH 2 position, pins 1 and 8 of the 4069 go high and the Channel 2 trace is displayed.

When viewing the signal traces, the oscilloscope timebase frequency must be synchronised directly from one of the two input signals – the one desired to be kept stationary. In our circuit, sync signals are derived directly from the wipers of the input switches (SW1 and SW2) and are selected by switch SW5.

In practice, this means that the oscilloscope should be set for external synchronisation of the timebase (Ext Sync) and the external sync terminal connected to the sync terminal on the Oscilloscope Switch. SW5 then allows the user to synchronise to either Channel 1 or Channel 2.



A typical display produced by the Oscilloscope Switch. The small breaks in the traces are the graticule lines.

The power supply is derived from a nominal 12V AC which may be obtained from a plugpack or any other suitable transformer. The 12V AC is fed to a bridge rectifier using four 1N4002 (or similar) power diodes, and the rectified output filtered by a 1000µF 25VW electrolytic capacitor. The filtered DC output is then split and regulated by two BZX79/C6V8 zener diodes to give the plus and minus 6.8V supply rails.

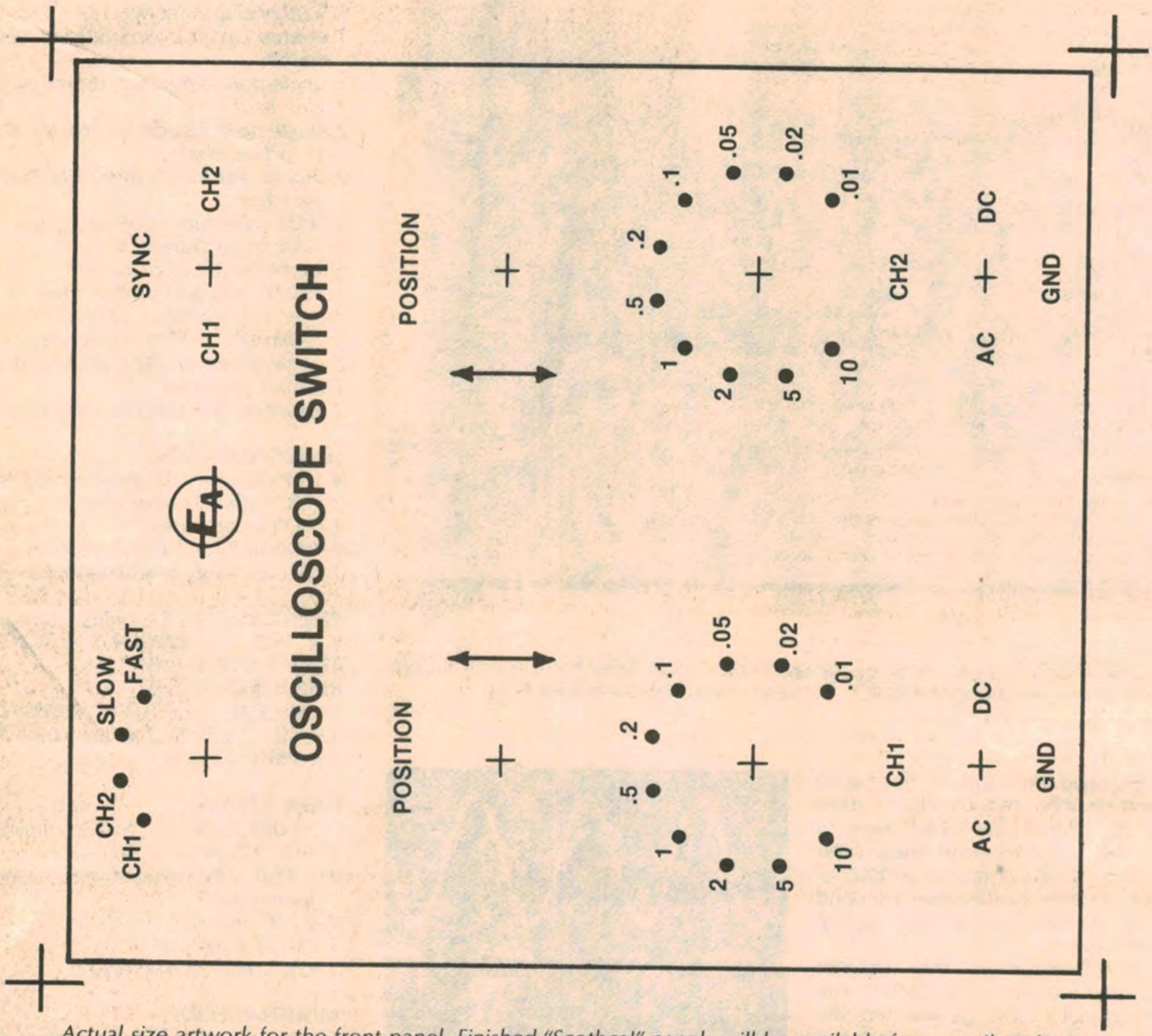
CONSTRUCTION

We built our Oscilloscope Switch into a standard metal case measuring 150 x 76 x 134mm. Construction is straightforward, with most components mounted on a small printed circuit board (PCB) measuring 124 x 93mm and coded 81sw1. A Scotchcal label provides an attractive finish to the completed instrument.

Both the PCB and the Scotchcal label should be available through the usual retail outlets by the time this article appears in print. A list of potential suppliers is published on the last page of the magazine.

Commence construction by assembling the PC board. Follow the accompanying wiring diagram carefully and make

FRONT PANEL ARTWORK



Actual size artwork for the front panel. Finished "Scothcal" panels will be available from retail outlets.

sure that all polarised components are correctly oriented. Don't forget to install the six wire links, and leave the CMOS ICs (4016, 4069) till last. We used IC sockets in the prototype and readers may care to do the same.

If you do elect to solder the ICs into circuit, then the following precautions should be observed for the CMOS devices: avoid handling the pins; earth the barrel of your soldering iron to the earth track on the PC board using a clip lead; and solder the supply pins (pins 7 and 14) first.

The use of PC stakes is recommended to facilitate external connections to the PCB.

Once the PCB assembly is complete, the case can be drilled to accept the two RCA sockets, the BNC input sockets, and the rubber grommet through which the power supply leads pass. This done, the PCB can be mounted in the case using machine nuts and screws and the wiring to the sockets completed.

The next step is to fix the Scotchcal label to the case lid and drill the holes for the various front panel controls. However, if you are using a case similar to that used for the prototype, you may find that the Scotchcal panel will not adhere properly due to the rough nature of the painted finish. The solution is to augment the adhesive on the panel with rubber cement such as Bostik or similar material.

Now mount the front panel controls and complete the wiring according to the diagram. Note that the two potentiometers should be oriented so that their lugs face each other, and that the resistors fitted to the attenuator switches must be 2% close tolerance types (or better).

Some readers may think that some of the resistor values specified for the attenuator network are a little strange, eg 49.9kΩ, 4.99kΩ and 499Ω. The explanation is quite simple — these are the close tolerance preferred values and are so close to the required values of 50kΩ, 5kΩ and 500Ω that it really doesn't matter! If you have difficulty in obtaining some values, then the 49.9kΩ resistor can be replaced by two parallel 100kΩ resistors, the 30kΩ resistor can be replaced by two series 15kΩ resistors, and so on.

A few other comments on components may also prove helpful. First, although a single-pole 4-position switch

We estimate that the current cost of parts for this project is approximately

$60.00

This includes sales tax but does not include a plugpack.

has been specified in the parts list, we actually used a 3-pole 4-position unit. The latter type is more readily available, and does not appear to be any more expensive. Also, 2-pole 3-position miniature toggle switches are specified in the parts list, but only one pole of each switch is used in the circuit. Again, the 2-pole types are more readily available.

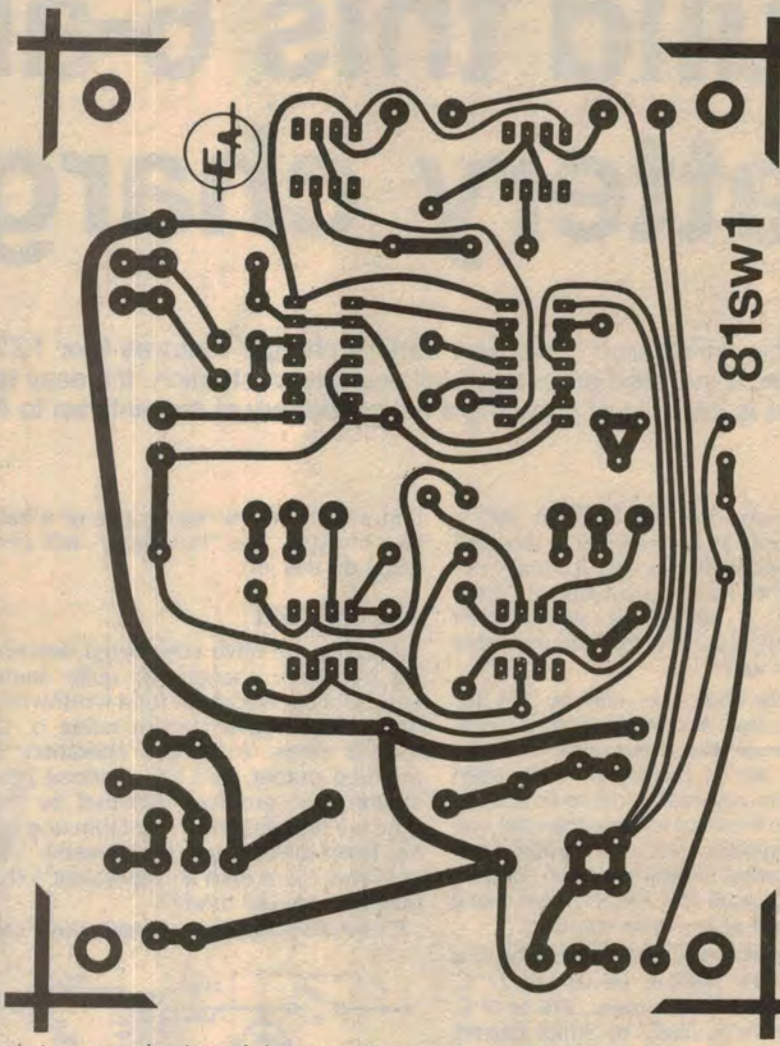
Insulated BNC sockets were fitted to the prototype since we wished to use probes with BNC plugs. Many constructors will no doubt prefer to do the same, although other types of sockets may be used if you so wish. Whatever type of input socket you do decide to use, it should be insulated from chassis to keep channel crosstalk to a minimum.

We used RCA sockets for the sync and output sockets.

With respect to ICs, it is worth noting that type 4069 is identical with type 74C04, while type 4016 may be replaced with type 4066. The CA3140 op-amps used were in the TO-5 style package, although standard 8-pin DIL packages may be used instead. Either type can be plugged into the 8-pin DIL socket.

We mentioned earlier that the RC filter on the output was open to some experimentation. We found that a 47pF capacitor fitted between the two resistors was sufficient, the capacitance of the output cable substituting for the second capacitor. Admittedly, this did reduce the bandwidth of the system somewhat, but it also significantly reduced the switching transients.

We also found on the prototype that we could dispense with the 47pF capacitor, provided the output cable capacitance was of the order of 80pF.



Actual size reproduction of the printed circuit board pattern.

FINAL TESTING

With the construction of the Oscilloscope Switch now complete we are in a position to test and set it up for use. We suggest that you go through the following procedure:

- Set SW1 and SW2 to "AC", SW3 and SW4 to ".01", and SW6 to "FAST";
- Set both "POSITION" potentiometers to mid-position;
- Connect the output cable to the input socket of the oscilloscope and the sync lead to the external sync input of the oscilloscope;
- Switch on the oscilloscope, set it to DC input, and adjust the trace to the centre of the screen.

Now switch on the Oscilloscope Switch. Two traces should now appear on the screen, and these should move vertically with adjustment of the two position controls. If the movement of the traces is restricted, the gain control of the oscilloscope is set too low. Advance the gain control until the trace can be moved over the full range of the screen.

From here on, it is simply a matter of getting used to the operation of the Oscilloscope Switch. In general, you will find that fast chop will be best for viewing low frequency signals, while slow chop will be best for high frequencies.

The way in which the input switches are used will soon become obvious. Selection of "AC" or "DC" depends on whether the DC component of the signal is to be taken into consideration, while the "GND" position grounds the input circuit without grounding the input signal. The latter facility is useful for setting the trace so that DC signal levels can be measured.

We settled for an input impedance of 100kΩ rather than 1MΩ. A 1MΩ attenuator would require some elaborate frequency compensation, whereas 100kΩ could be used without any compensation and with only a relatively small effect on the losses of high frequency components. However, there are some losses and to keep these to a minimum we suggest that wherever possible the attenuator should be set to ".01" when viewing frequencies above about 500kHz.

Finally, the Oscilloscope Switch provides the bonus of a calibrated attenuator for a CRO which doesn't already have this feature. Assuming that you have a CRO with a sensitivity of 10mV/div or better, the procedure is to set the attenuator switch on the Oscilloscope Switch to "1" and feed in a suitable AC reference voltage say 5V p-p. (An unabashed plug: the EA Voltage Reference, described in June 1976 and January 1977, is ideal for this purpose.)

Now all you have to do is adjust the sensitivity of your CRO to give a reading of 1V/div. The result – a calibrated attenuator capable of switching from 10mV/div sensitivity down to 10V/div sensitivity!