Variable-phase Oscillator VPO602

Contents

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DESCRIPTION

SECTION 1

1.1 Introduction

The Feedback VPO602 Variable-phase Oscillator is based on a novel RC oscillator that generates sine waves in quadrature. A block diagram of the main features of the circuit is shown in fig 1.1. The fine frequency controller is a dual-ganged air-spaced capacitor, giving effectively infinite resolution. The ranges are selected by switching in the requisite resistors. A simple potentiometer is energised from these quadrature signals in such a way as to provide a constant amplitude variable output phase that is adjustable from 0° to 180°.

An AGC system is used to control the amplitude of oscillation. Two output channels are provided, one reference phase (0°) and the other variable phase (ϕ). The ϕ-channel is switched to be either leading or lagging. Both channels have a maximum amplitude of 10 volts peak-to-peak with a calibrated output potentiometer and an X1.0, X0.1 and X.01 stepped attenuator to provide clean signals down to 10mV or less from either or both channels. There is also a facility so that an external signal within the frequency range of the instrument may be used to drive the Variable-phase Oscillator and so provide phase generation and measurement relative to an external source.

1.2 Mechanical

The VPO602 is housed in an ABS plastic case made in two halves each secured by two screws on each side. The case provides the main structural strength of the instrument. Removal of the case gives access to all components. Without the cover the VPO602 consists of a horizontal PWB fixed by small plastic brackets to the front and rear panels, providing a structure strong enough for normal handling and maintenance. The low power dissipation of the VPO602 obviates the need for ventilation holes.

The oscillator tuning capacitor and resistors are mounted in a diecast screening box fixed to the front panel. This provides complete electrostatic screening and protection from dust for the sensitive high impedance circuit.

All controls are situated on the front panel as in fig 1.2. They are:

Power	Red pushbutton power switch. Separate red power indicator.
Frequency	Rotary range switch. Fine frequency control with calibrated transparent dial that is approximately logarithmic.

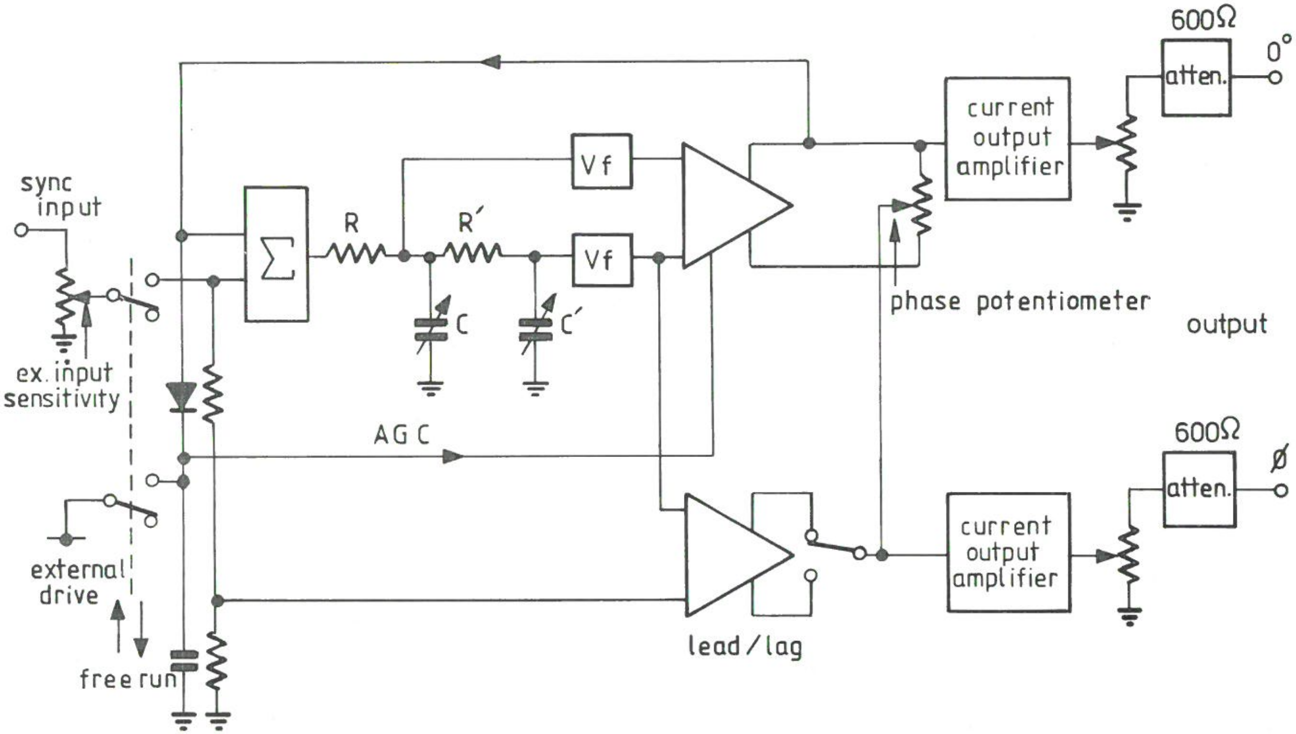


Fig 1.1 Block diagram of VPO602

Phase	Lever switch selecting 'lead' or 'lag'. Continuous 0° to 180° control calibrated transparent dial.
Amplitude	Two channels each having single rotary control and slide switch stepped attenuator.
External Drive	Rotary sensitive control coupled to anticlockwise switch position selecting normal oscillation.
Output Terminals	(0°) and (ϕ) outputs each from a pair of red and black 4mm binding posts.
External Drive	Input via 4mm socket

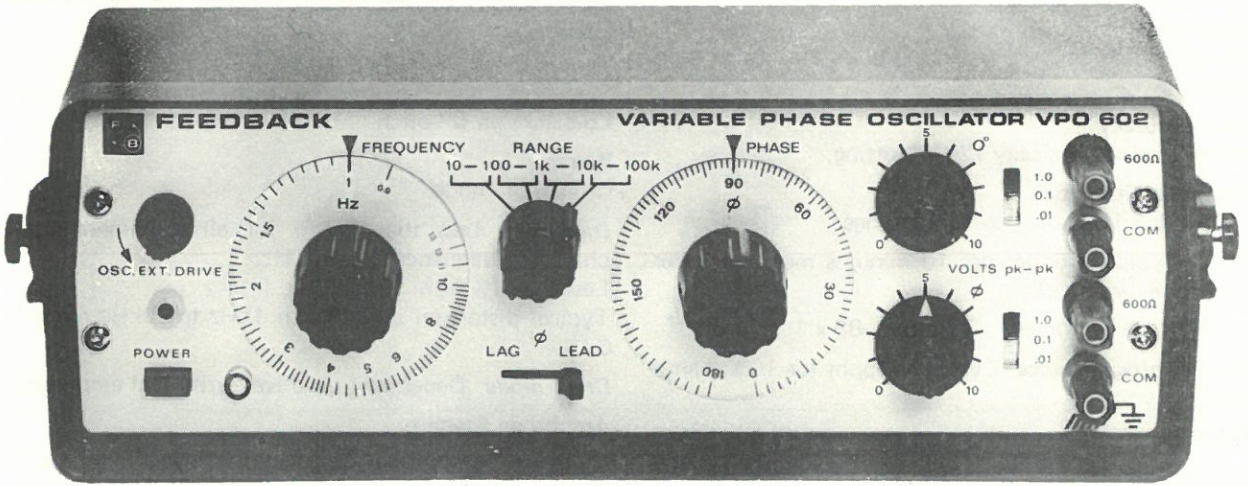


Fig 1.2

1.3 Specification of type VPO602

The VPO602 is a special-purpose, solid state sine-wave oscillator generating two signals of adjustable phase relationship, frequency and amplitude with external drive capability.

Frequency

Range
10Hz to 100kHz in four switched ranges.
Resolution – infinite.

Range Overlap
30% at top of each range and 10% at bottom of each range.

Scale Accuracy
±5% of setting. Typically ±2% of setting.

Frequency Stability
Measured at 1kHz on 1 to 10kHz range.

Drift Typically 6ppm per 10 minutes measured after 10 minutes warm up.

Temperature coefficient Typically -80 x 10^{-6} deg C^{-1}.

Supply voltage change Typically 1ppm for 10% change in supply voltage.

Outputs

Two outputs are provided, one reference phase and one variable phase.

Each Output
Source impedance 600Ω

Amplitude Control
Single linear continuous control calibrated 0 to 10V pk-to-pk in 1V pk-to-pk intervals.
Three-position switched attenuator selecting X1.0, X0.1, and X.01.

Offset
The d.c component on each output is individually adjusted and is set typically to within 0.05V d.c of zero. This d.c component is reduced proportionally to the signal output by the output controls (or by resistive loading).

Terminations
Two 4mm binding posts for each output (Hi-red and Lo-black) on ¾" pitch.

Purity
Oscillation mode.

Distortion Less than 0.75% for all combinations of phase and frequency above 20Hz.
Less than 1% from 10 to 20Hz.
Typical distortion at 1kHz on 1kHz to 10kHz range is 0.1%.

Drive mode Dependent on drive purity and amplitude.

Amplitude Stability

Variation with frequency 10Hz to 100kHz less than ±1% from level at 1kHz on 1kHz to 10kHz range.

Variation with temperature Less than -0.15% deg C^{-1} at 1kHz on the 1kHz to 10kHz range.

Variation with phase setting Less than ±2% measured at 1kHz.

Phase Accuracy
Output phase angle is within ±2° of the indicated angle at all frequencies.

External Drive

Satisfactory operation is obtained for input signals of 1.0 to 200V pk-to-pk in the frequency range 10Hz to 100kHz.

Input impedance
5kΩ to 10kΩ depending on setting.

Termination 4mm socket.

Power Requirements

Line Voltage
200/250V or 100/125V rms 50 or 60Hz range selected by internal slide switch.

Consumption
7VA

Fuse
315mA slow blow (20mm x 5mm)
Littel fuse style 213
Beswick TDC123
Buss GMA

Dimensions & Weight

Width	300mm (12in)
Height (with feet)	115mm (4.5in)
Depth	225mm (9in)
Weight	2.35kg (5.2lb)

OPERATION

SECTION 2

2.1 Installation of VPO602

The oscillator is packed in inserts of expanded polystyrene to prevent damage in transit. On opening the end of the corrugated cardboard container, the inserts together with the VPO602 should be smoothly withdrawn from the container. Take care that the inserts and the VPO602 are held together during this time.

Inspect the VPO602 and if any damage is evident immediately notify the carriers.

2.2 Voltage Selection

Ensure that the instrument is set to the appropriate voltage supply either by inspecting the tag (if fitted) on the power cable or by removing the top cover of the instrument.

The voltage selection is accomplished by a slide switch on the printed circuit board and has positions marked '115' and '230'.

Set the switch to '115' for operation from 100 to 125V and to '230' for 200 to 250 volts.

Wire connections. The colour code of the power supply cable is:

Brown	Live
Blue	Neutral
Green/Yellow	Ground

The ground wire is connected to the front and rear panels of the VPO602 and to the common terminals on the front panel.

2.3 Oscillate/External Drive

The 'Osc/Ext. Drive' control is on the left-hand side of the VPO602 front panel. When the VPO602 is to be used as an oscillator the Osc/Ext. Drive control should be turned so as to operate the switch at the extreme anti-clockwise end of the control. When the VPO602 is to be used as a slave phase-shifter the instructions under 'External Drive' should be followed.

2.4 Frequency Selection

Any value of frequency in the range 10Hz to 100kHz may be obtained by use of the range switch and fine frequency control. The rotary range switch provides the following frequency decades:

10Hz to 100Hz
100Hz to 1.0kHz
1.0kHz to 10kHz
10kHz to 100kHz

The required frequency is set by the variable control, graduated 1 to 10 (.9 to 13 with overlap). For example to set 3.6kHz turn the range switch to the 1.0kHz to 10kHz range and turn the variable control to 3.6.

2.5 Outputs

The amplitude of each output sinewave is set by the appropriate output control knob calibrated from 0 to 10V pk-to-pk and is the open-circuit or no-load voltage. The output impedance is 600Ω and any loading will cause the output voltage to drop. In particular if the load is 600Ω the terminal voltages will be half that indicated.

In addition to the continuous control there is a 600Ω switched attenuator on each channel giving output amplitudes of 1, 1/10 or 1/100th of the amplitude set by the respective continuous control.

2.6 Phase Selection

The phase relationship between the two outputs is set by the phase dial and the lead/lag switch. Any angle can be set.

Angles such as 270° leading are obtained by selecting 90° lagging.

Note that:

$(\theta)^\circ$ leading = $(360 - \theta)^\circ$ lagging

$(\theta)^\circ$ lagging = $(360 - \theta)^\circ$ leading

The transistion at 0° and at 180° from lagging to leading as shown in fig 2.1 and vice versa does not in practice constitute a discontinuity since 0° is the same angle both leading and lagging, as is 180°.

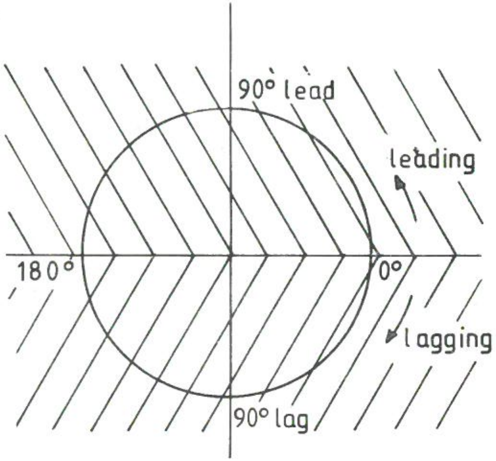


Fig 2.1

Should the variable-phase output be used as the reference the 0° output will vary with respect to the ϕ output. This may be convenient when the indicated phase angle bears a direct relationship to some useful feature of the external circuit. If this is done, remember that:

When properly tuned in as a slave phase-shifter the VPO602 shows zero phase angle between the synchronising signal and the 0° output.

The frequency of the variable-phase output deviates as the phase setting is changed. This is due to the rate of change of angle being added on to the existing rate of change of angle of the selected frequencies. At low frequencies this effect can be significant when examining narrow band circuits. The effect is completely avoided by using the 0° output as the driving source in preference to the $\phi°$ output.

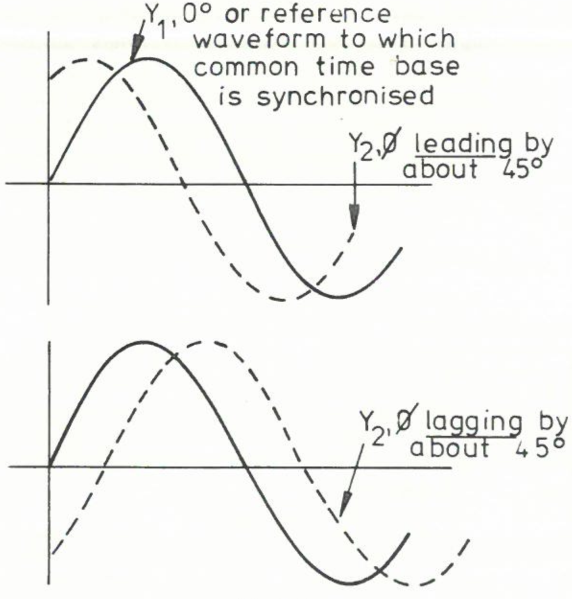


Fig 2.2

When observing the two outputs on an oscilloscope note that:

1. Using a Time Base where the CRT spot moves in the conventional manner from left to right, the two outputs will be displayed as in fig 2.2.

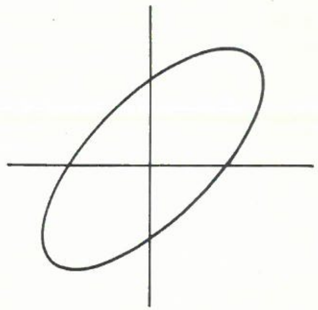


Fig 2.3

2. Using an X-Y display a 45° angle is shown as in fig 2.3. It does not matter if the signal is leading *or* lagging. The difference between the leading and lagging display being in the direction in which the spot traces out the ellipse. Above 10Hz this is difficult to see.

N.B. In this display mode the shape (not position) of the ellipse can vary as the lead/lag switch is operated, this shows that there is a phase change between the X and Y inputs of the oscilloscope, – due perhaps to 'AC' coupling or differing band widths of the X and Y channels.

2.7 External Drive

In order to generate phase angles or make phase measurements relative to some external frequency (e.g the mains supply) it is necessary to 'synchronise' the VPO602 output to the required frequency. This is done by disabling the normal internal oscillatory loop of the generator and then driving the circuit from the external source. In this condition the VPO602 acts as a resonant circuit ($Q \approx 10$) and thus has to be 'tuned in' to the external source. Fig 2.4 is a suggested circuit for phase measurement of a system powered by an external source.

To carry out this phase measurement:

Initially connect the external signal to the external drive socket at C. The frequency is set (see Frequency Selection Section 2.4) to the approximate external frequency.

The 'Osc/Ext Drive' knob is turned a little clockwise, the 'Phase' Dial is set to 0° and the output used as an X-input signal to the oscilloscope.

Then with the Y-input connected to the external signal at A, the frequency is finely adjusted to produce a straight line display as shown. To avoid distortion caused by overdriving during this tuning process, the drive sensitivity control D should be adjusted to maintain an output amplitude approximately equal to the self-oscillation amplitude.

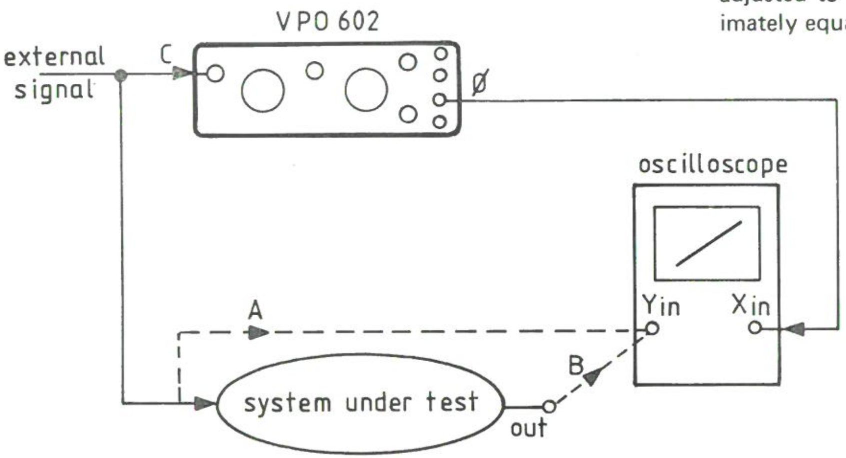


Fig 2.4

Once this setting-up procedure of tuning and amplitude adjustment is completed it is possible to measure the phase and gain of the variable-phase output in the normal manner. In this case the oscilloscope Y-input is first transferred to point B. Then adjust the phase and amplitude controls of the VPO602 to once more obtain the original straight-line display, thereby measuring the phase and gain of the externally powered system.

If a series of such measurements is made it is good practice to check the original tuning from time to time by returning the oscilloscope Y-input to point A. This will prevent any drift occuring in the external frequency or the VPO602 tuning causing a phase error. It is possible to tune the VPO602 to some setting other than the optimum zero phase input to the output condition. An accurate measurement can still be made by subtracting the phase angle measured with the oscilloscope Y-input connected to point A from the angle measured when the input is connected to point B.

Many circuit configurations are possible to suit particular needs.

CIRCUIT DESCRIPTION

SECTION 3

For convenience the circuits in this section are simplified or in the form of block diagrams. The full circuit is shown in fig 4.4.

3.1 RC Frequency Network

The oscillator is based on the circuit shown in fig 3.1.

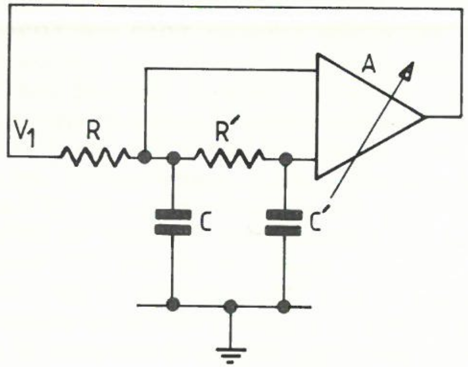


Fig 3.1 Basic oscillator

The circuit was used in preference to other RC circuits because it enables the frame of the double-gang variable capacitor C, C' to be grounded. Also because the current flowing through R and C is the same, the voltages across R and C are in quadrature. At resonance the amplifier A amplifies VR', shown in the phasor diagram fig 3.2, by X3 to provide the feedback voltage V_1 to maintain oscillation. The phase and gain relationship of the network RCR'C' is very similar to that of the active side of the well known Wien Bridge.

The resonant frequency is given by $f_o = \frac{1}{2\pi RC}$ where $R = R'$ and $C = C'$.

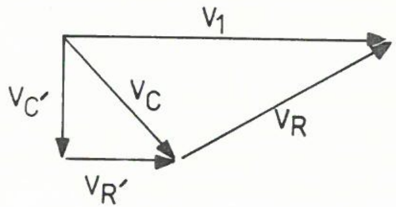


Fig 3.2 Phasor diagram

The amplitude of oscillation is maintained by controlling the gain of the amplifier A in response to the amplitude measured by a peak diode detector.

3.2 RC Oscillator Amplifier

Fig 3.3 shows the controlled gain amplifier A of fig 3.1, used to maintain oscillation in the RC network. The FET TR7a and TR7b provide suitable high impedance inputs for connection from the RC network. The long-tailed pair TR15 and TR16 form a differential voltage to current stage which feeds the transistors in the gain control circuit TR17 to 20. The current gain of this stage is controlled at some value less than X1 by the gain control voltage. The unity gain output amplifier stage TR1 to 6 provides a differential input with a single-ended output suitable for driving the RC network. Provision is also made for injecting an external drive signal into the base of TR2.

3.3 Amplitude control circuit

The amplitude of oscillation is controlled by automatically adjusting the loop gain of the oscillator. The amplitude is detected at the emitter of TR1 in fig 3.3 by the peak-to-peak detector in fig 3.4.

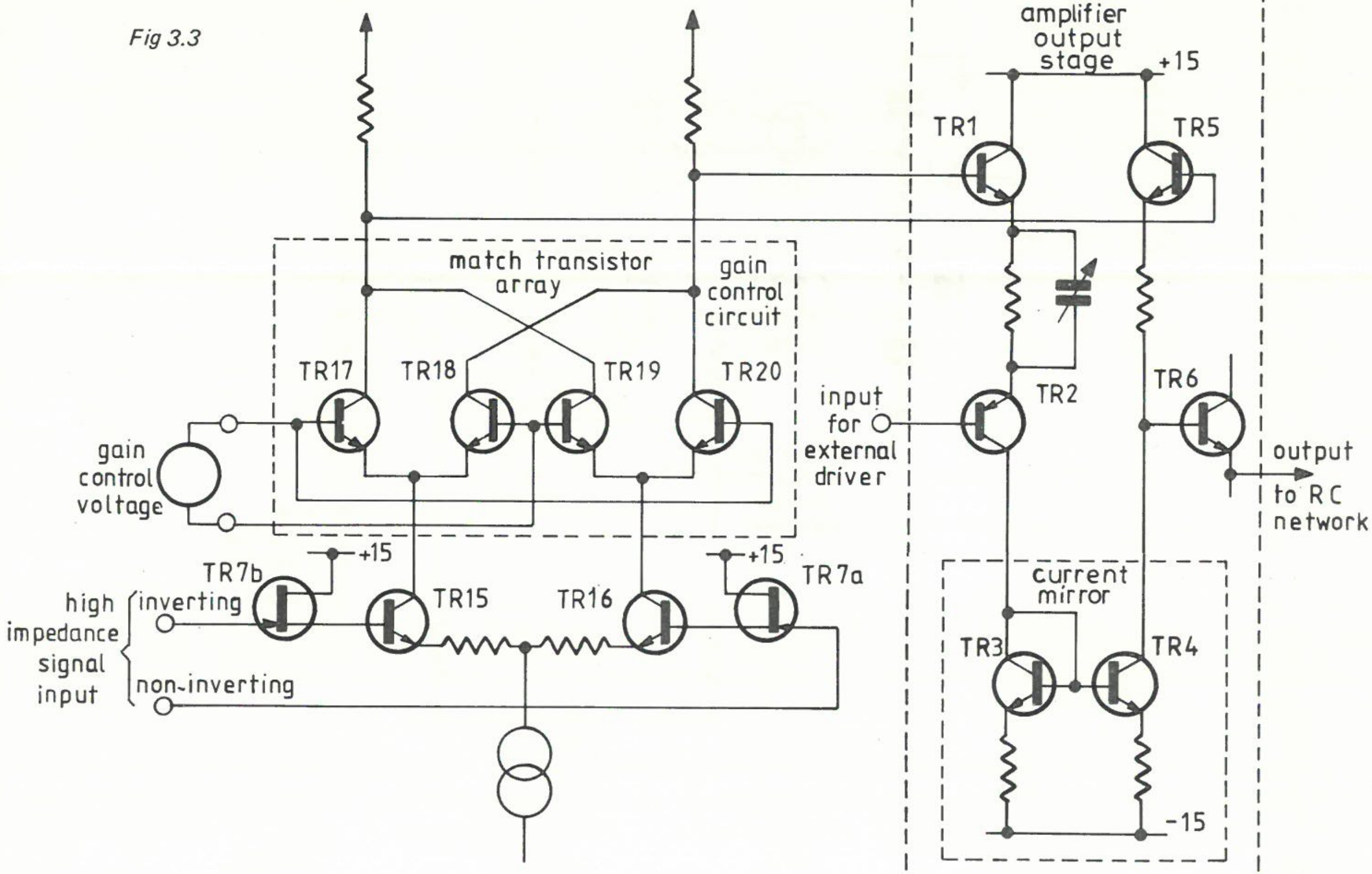
The gain-controlled amplifier is very sensitive to the control voltage so the circuit associated with the peak-to-peak detection in fact attenuates the peak-to-peak signal and is arranged to shift the d.c level to control the oscillation. R26 presets the amplitude of oscillation and R30 provides a preset control voltage to the oscillator amplifier when the VPO602 is being driven from an external source.

3.4 Variable-phase circuit

Fig 3.5 is a block diagram showing the principle of operation of the variable-phase generating circuit.

Such a circuit produces a constant amplitude output for changes in phasor setting. Using this diagram together with the main circuit diagram fig 4.4, the voltages $V\sin\omega t$ and $-V\sin\omega t$ are generated across R39 and R40 through which the oscillator amplifier current flows. This voltage is fed to the phase potentiometer R50 via the emitter followers TR23 and TR24. The output slider of the phase potentiometer is connected to the circuit containing TR26-29, TR31-36 and TR40 which combines the function of leading or lagging current source and negative resistance. The actual value of negative resistance is approximately equal to, and set by R59 and R60. The in-quadrature current $\pm V\cos\omega t$ is generated by TR40 and TR36 connected via TR7a FET voltage follower, across C4 of the RC frequency determining network. The magnitude of the current is adjusted by R64. Transistors TR31-34 are arranged as a changeover switch S4. The use of transistors to effect the switching in place of a mechanical switch avoids problems of switch contact shorting or open circuitry on switching.

Fig 3.3


match transistor array
gain control circuit
TR17
TR18
TR19
TR20
gain control voltage
+15
TR7b
high impedance signal input
inverting
non-inverting
TR15
TR16
+15
TR7a
amplifier output stage
+15
TR1
TR5
TR2
TR6
input for external driver
output
to R C network
current mirror
TR3
TR4
−15

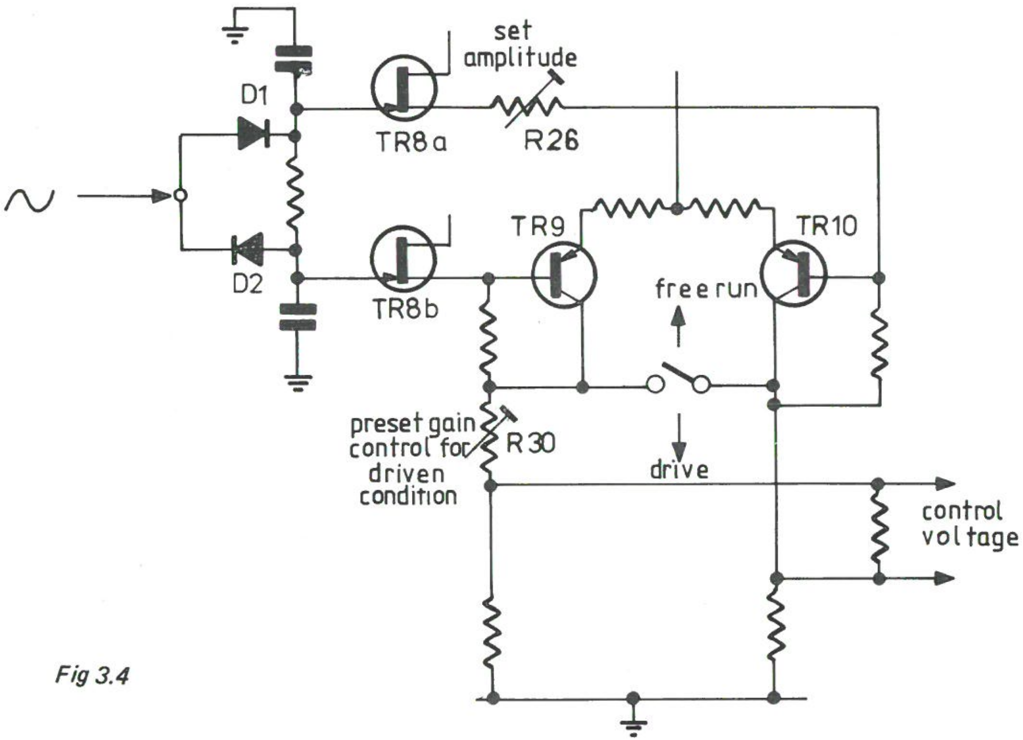

set
amplitude
D1
TR8a
R26
TR9
TR10
D2
TR8b
free run
preset gain
control for
driven
condition
R30
drive
control
voltage

Fig 3.4

3.5 Output Amplifiers

The output amplifiers are arranged to have a current (high impedance) output. These outputs are connected to the sliders on the output amplitude controls which are shunted with the resistors of the switched output attenuators. This provides for each channel a constant 600-ohm output impedance with a linear amplitude scale. The output transistors are TR30 and TR39 with constant current loads provided by TR37 and TR38.

3.6 Power Supply

The VPO602 circuits operate on a regulated ±15-volt supply with regulation by an IC dual regulator AA. Resistors R78 and 79 provide a current limit at about 80mA in the event of power line short-circuit.

The mains transformer has a double primary winding connected in series for 200-250-volt operation and in parallel for 100 to 125-volt a.c supplies. Voltage selection is conveniently effected by a slide switch positioned on the main PWB.

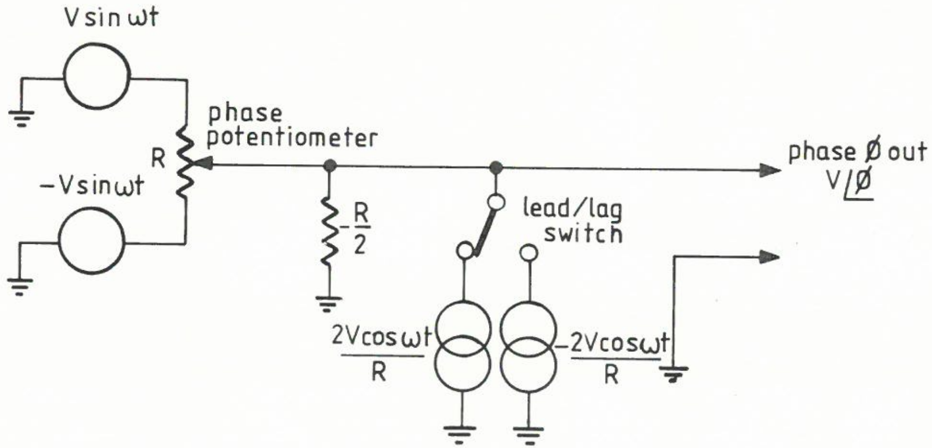


Fig 3.5

MAINTENANCE

SECTION 4

4.1 Fault location

Faults will appear as abnormal outputs from the oscillator or as calibration inaccuracies. The nature of the abnormality allows narrowing of the area in which the fault is located.

There is access to most of the components by removal of the case.

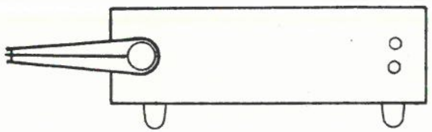


Fig 4.1

First remove the handle by pulling it outwards at each end in turn, thereby releasing each centre cap. This needs firm pressure. Then remove, with a Posidriv No 2 screwdriver, the four screws on each side of the case (two of which are in the handle boss).

The top and bottom halves of the cover can then be lifted off. The chassis formed by the PWB and front and rear panels is strong enough for normal handling during maintenance.

On replacing the handle, press home the centre caps and then rotate them until they click into position.

The handle also acts as a stand and can be re-positioned by easing outwards the two ends simultaneously.

Positions of components and test points referred to in the following tables can be found by reference to the component diagram fig 4.3 and the complete circuit diagram fig 4.4.

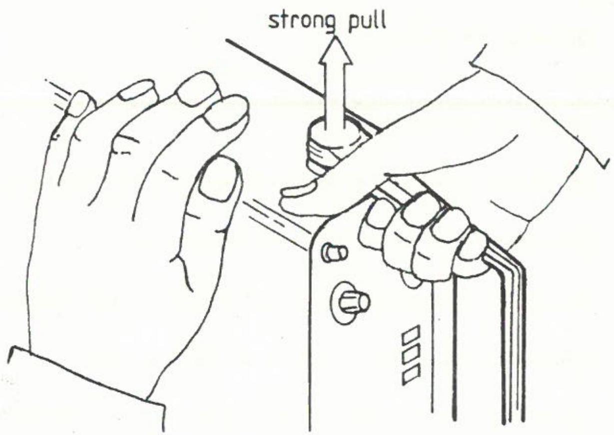


Fig 4.2

4.2 Preset Controls

Before assuming a fault condition, check that the preset controls are not in need of adjustment. The table overleaf sets out a list of the controls and the malfunctions that can occur if the controls are improperly set.

Symptom	*Control*
Amplitude of both outputs wrong at all frequencies	R26
DC offset on 0° output	R77
DC offset on ϕ output	R74
DC offset changes on ϕ output with lead/lag switch especially around 90°	R5
DC offset changes on ϕ output from 0° end to 180° end	R41
Frequency calibration out at all frequencies	Position of frequency knob and dial on shaft
Frequency calibration out at '10' end of dial (all ranges)	C6 (inside die-cast screening case)
Frequency calibration in region of 100kHz only	C2
Tendency to oscillate in driven mode at some or all frequencies	R30
Phase errors at *top of each* frequency range (lead ≠ -lag)	C7
Small changes in ϕ output amplitude with changes in ϕ setting	R60, R64

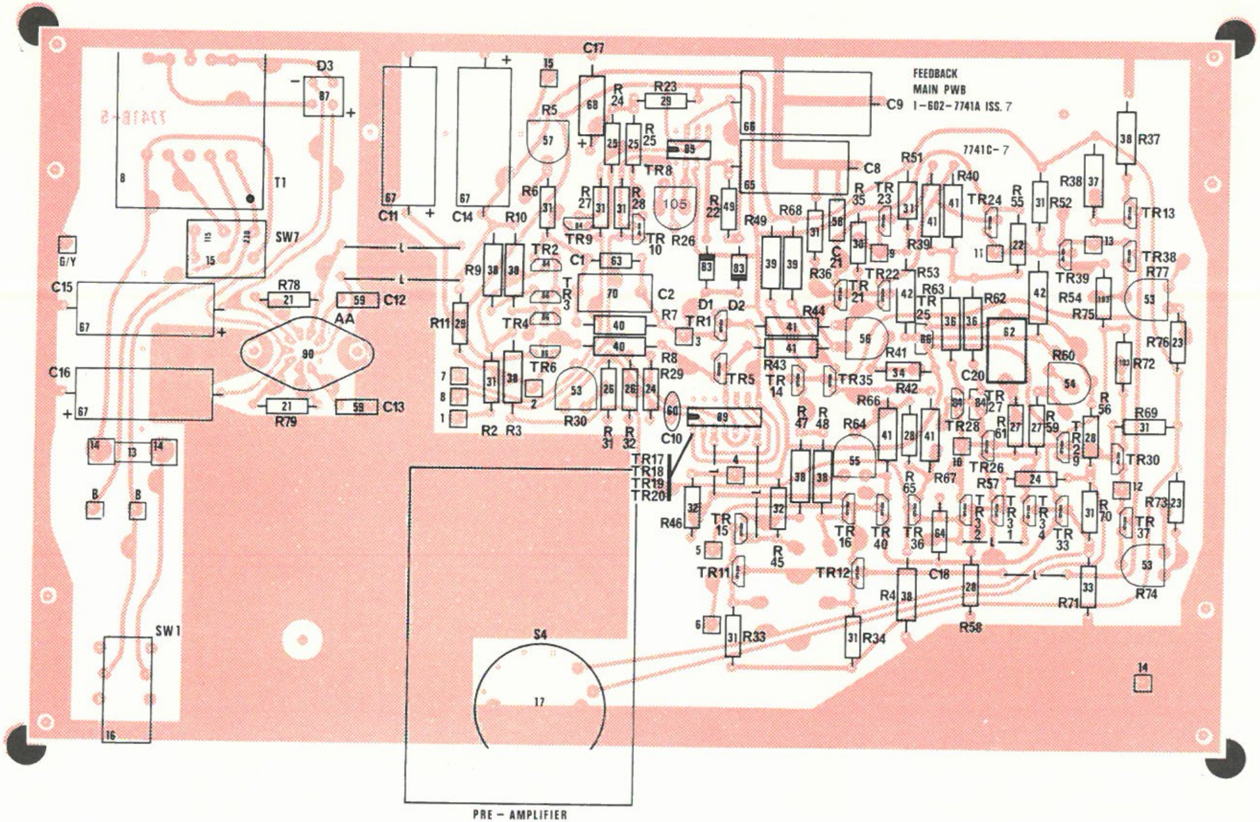


Fig 4.3 VPO602 Component diagram

4.3 VPO602 Setting-up Procedure

This is a procedure for bringing the VPO602 up to specification – it is not a fault-finding procedure, although failure to set-up will indicate a fault condition.

To set up use a good XY oscilloscope with a long persistence tube. For some tests, notably tests Nos 3 to 6 it is important that there should be zero phase shift between the X and Y channels. Check this by applying the same VPO602 signal to both the X and Y inputs and observing a straight-line display.

1. Connect the oscilloscope to the main 0°-output, turn the amplitude controls to maximum and set the frequency to 1kHz on the 1kHz to 10kHz range.
   Set potentiometer R77 to bring the d.c output level to 0V. Re-connect the oscilloscope to the variable-phase output, set the variable phase output to 0° and bring the d.c output level to zero by means of potentiometer R74.

2. a) Re-connect the oscilloscope to the 0° phase output. Adjust R26 to bring the peak-to-peak amplitude to 10V.

Use an oscilloscope with an XY display for the following tests.

b) Connect the 0°-output to the X-input of the oscilloscope and the variable-phase output to the Y-input of the oscilloscope.

Adjust the oscilloscope sensitivities to produce a straight line at about 45° across most of the oscilloscope face.

If the variable-phase control is now slowly turned from 0° to 180° (end to end of rotation), the display should change as shown in fig 4.5(a).

The display is made up of a series of ellipses with the outside envelope forming a rectangle as seen in the persistent afterglow.

This display should be an exact rectangle. Departures from this ideal are corrected by the following adjustments.

3. Fig 4.5(b) shows the effect of adjusting potentiometer R5 on the vertical movement of the display. This can also be verified by setting the phase dial to 90° and switching the lead/lag switch.

4. Adjusting potentiometer R64 varies the magnitude of the quadrature signal applied to the variable-phase circuit and so controls the amplitude of the variable-phase output, predominently at 90°. The effect is shown in fig 4.5(c).

5. Fig 4.5(d) shows the effect, by adjusting potentiometer R60, on the amplitude changes which occur near 0 to 180°.

6. Potentiometer R41 controls the trapezoidal distortion of the display as shown in fig 4.5(e).

Fig 4.5(a) The display is made up of a series of ellipses, with the outside forming a rectangle as seen in the persistent afterglow.

Fig 4.5(b) Any vertical movement of the display is corrected by adjusting R5.

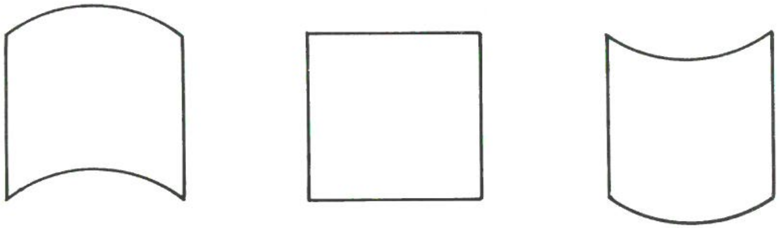
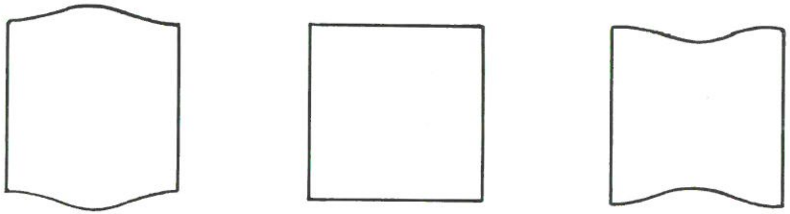


Fig 4.5(c) Adjusting R64 varies the magnitude of the in-quadrature signals applied to the variable-phase circuit. It controls the amplitude of variable-phase output predominantly at 90°.



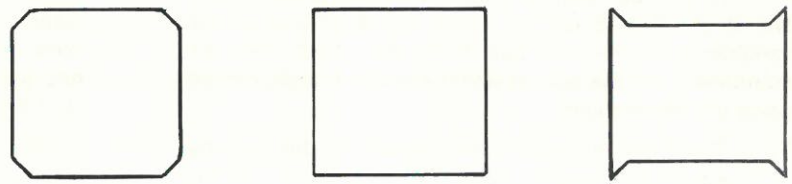


Fig 4.5(d) Adjusting R60 affects the amplitude changes which occur near 0° and 180°

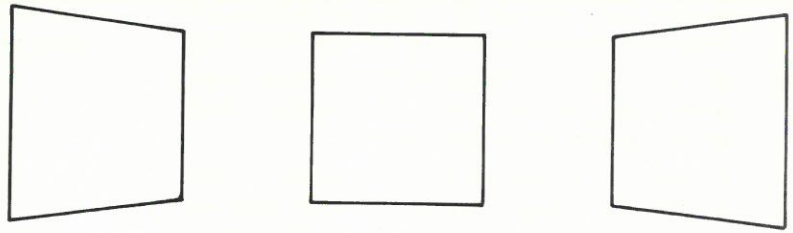


Fig 4.5(e) The trapezoidal distortion of the display can be controlled by adjusting R41.

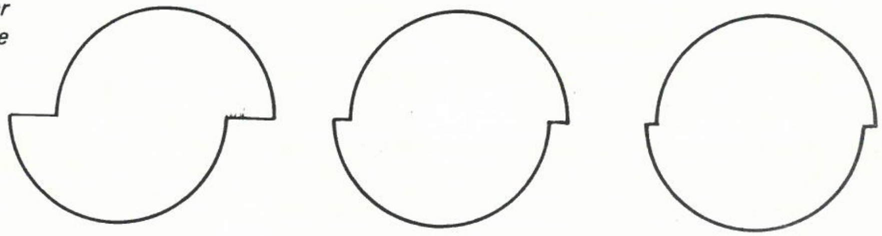


Fig 4.5(f) Adjust R30 to stop oscillation at any frequency. Over adjustment will cause flats on the circular trace.

It will be noticed that the adjustments in tests No. 3 and No. 6 do not affect the amplitude of the variable-phase output but they do affect the d.c component on the output waveform which is dependent upon the phase angle.

7. The frequency dial is positioned on the shaft by selecting frequency range 100 to 1kHz and setting the frequency to exactly 100Hz on a timer counter. The dial is then tightened on to the shaft at the 1 position. The dial is then turned to the 10 position and capacitor C6 is adjusted to bring the frequency to exactly 1kHz as in fig 4.6 and 4.7.

8. While still set at 1kHz on the 100 to 1kHz range, recheck that the oscilloscope used shows no phase change between the X and Y inputs.

   Connect the 0° output to the X input and the variable-phase output to the Y input. Unscrew capacitor C7 and set the phase dial to 90° lead (an approximately circular trace on the display will appear). Without touching the phase dial, switch to lag. Any small difference between the two displays (lead and lag) should be minimised by adjustment of capacitor C7.

   Recheck test No. 7 and trim capacitor C6 if necessary.

9. Check frequency dial calibration at 10kHz on the 10 to 100kHz range. Turn the dial to indicate 100kHz and adjust capacitor C2 to bring the frequency to 100kHz.

10. Switch the external drive control to external drive. Adjust potentiometer R30 so that the oscillator does not oscillate at any frequency setting. Do not over adjust as this unnecessarily reduces the Q of the VPO as a tuned circuit.

    Finally apply a 1kHz sine wave to the external input and observe satisfactory tuning. Check that potentiometer R30 has not been over adjusted by applying a square wave to the external input and displaying a circular trace on the oscilloscope — the display should be as in fig 4.5(f). Large flats show that potentiometer R30 is over adjusted.

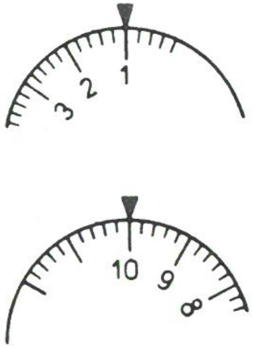


Fig 4.6

Fig 4.7

4.4 Diagnostic Table

Unless otherwise stated, set the controls on the instrument as follows

Frequency range	1kHz to 10kHz	ϕ-output amplitude	maximum
Frequency dial	1.0	ϕ-angle	90° leading
0°-output amplitude	maximum	Attenuators	x 1.0

Symptom	*Test point*	*Correct output at Test point*	*Probable location of fault if specified output not present*
Power indicator lamp not lighting	Check supply voltage Check fuse	Voltage in range 100-125 or 200-250	Power supply
Malfunction in general	Regulated lines +15V -15V ④	+15V ± 1V -15V ± 1V -10.4V ± 1V	Power supply regulator or S/C on lines
Neither output present	①	1kHz sine wave 5-6V pk-pk DC level between +1V and -6V	
	Voltage between ② and ③. When oscillating ③ is about 30mV+ve with respect to ②	③ more than 50mV +ve with respect to ②.	Amplitude control circuit around TR8 to 10.
		③ -ve with respect to ②.	Oscillator Amplifier loop
Variable-phase output grossly in error except at 0° and 180°	⑤	1kHz sine wave 3V pk-pk +11VDC independent of phase angle	Variable phase circuit TR26-29, TR31-36 and TR40

① etc. indicates a test point

4.5 Component Replacement Table

The VPO602 is not critical with regard to component types but proper performances can only be expected if component replacements are of reasonably similar type.

A brief general specification of suitable components is listed together with a look-up table.

Component	*Spec*	*Component*	*Spec*	*Component*	*Spec*	*Component*	*Spec*	*Component*	*Spec*
Resistors								Capacitors	
R1	F	R24	A	R47	D	R70	A	C1	K
R2	A	R25	A	R48	D	R71	A	C2	L
R3	D	R26	E	R49	D	R72	A	C3 }	M
R4	D	R27	A	R50	G	R73	A	C4 }	
R5	E	R28	A	R51	A	R74	E	C5	K
R6	A	R29	A	R52	A	R75	A	C6	L
R7	D	R30	E	R53	D	R76	A	C7	L
R8	D	R31	A	R54	D	R77	E	C8	N
R9	D	R32	A	R55	A	R78	A	C9	N
R10	D	R33	A	R56	A	R79	A	C10	P
R11	A	R34	A	R57	A	R80	H	C11	Q
R12	D	R35	A	R58	A	R81	B	C12	P
R13	D	R36	A	R59	A	R82	B	C13	P
R14	D	R37	D	R60	E	R83	B	C14	Q
R15	D	R38	D	R61	A	R84	B	C15	Q
R16	D	R39	D	R62	D	R85	B	C16	Q
R17	D	R40	D	R63	D	R86	H	C17	Q
R18	D	R41	E	R64	E	R87	B	C18	K
R19	D	R42	A	R65	A	R88	B	C19	—
R20	D	R43	D	R66	D	R89	B	C20	K
R21	D	R44	D	R67	D	R90	B	C21	P
R22	A	R45	A	R68	D	R91	B		
R23	A	R46	A	R69	A				

Spec.	*Type*	*Rating*	*Tolerance*	*Fixing*	*Position*
A	Resistor	1/8W or more	±5% or less	PWB hole ctrs 0.6″ Res. dia. less than 0.2″	R2, 6, 11, 22, 23, 24, 25, 27, 28, 29, 31, 32, 33, 34, 35, 36, 42, 45, 46, 51, 52, 55, 56, 57, 58, 59, 61, 65, 69, 70, 71, 72, 73, 75, 76, 78, 79
B		1/8W	±1%	mounted on slide switches	R81, 82, 83, 84, 85, 87, 88, 89, 90, 91
D		1/8W or more	±1%	PWB hole ctrs 0.8″ Resistor dia. 0.2″ or less	R3, 4, 7, 8, 9, 10, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 37, 38, 39, 40, 43, 44, 47, 48, 49, 53, 54, 62, 63, 66, 67, 68
E	Preset Cermet potentiometer	0.1W or more	±20% or less	see fig 4.8	R5, 26, 30, 41, 60, 64, 74, 77
F	Potentiometer 10kΩ Double-pole switch	Mains 8W	±20%	16mm dia 4mm shaft 10mm FMF	R1
G	Potentiometer 5kΩ Effective electrical angle 336° ± 2° linear		±5%	1 3/8″ body diam.	R50

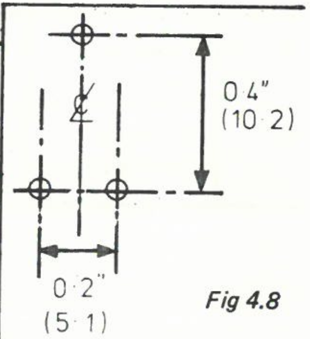


Fig 4.8

Spec	*Type*	*Rating*	*Tolerance*	*Fixing*	*Position*
H	Potentiometer Wire-wound 1kΩ	½W	±10%	15/16" dia. ¼" shaft 5/8" FMF	R80, 86
K	Capacitor	100V	±2½%	see PWB	C1, 5, 18, 20
L	Capacitor compression	100V	–	PWB centres 0.6" 0.4" wide	C2, 6, 7
M	Jackson Bros. Type P222 two-gang 510pF per section				C3, 4
N	Capacitor plastic film	63V	±10%	See PWB	C8, 9
P	Capacitor Ceramic			See PWB	C10, 12, 13, 21
Q	Capacitor Electrolytic	35V wkg	-20 +80%		C11, 14, 15, 16, 17

Transistors

If the Ferranti transistor types are not available the following types bearing EIA or Pro-Electron type numbers may be used. This table does not imply that the types listed are equivalents in any other situation.

Ferranti	EIA	Pro-Electron
ZTX108CK	2N930	BC108C
ZTX213CK	2N3251	BC213C

Other components are listed below with the Manufacturer's name.

Circuit ref	Type No	Manufacturer
TR7 and 8	J412	Siliconix
AD	MC1468R	Motorola
TR17 to 20	CA3046	RCA

Other components including mains transformer and switches are supplied to Feedback specifications and should be ordered through Feedback Instruments Limited, Crowborough, Sussex.

Returned instruments

Should the instrument be returned for repair and recalibration at any time, the mains plug should be removed, as no provision for the plug is included in the packing when we return the instrument to you. The address to which an instrument should be returned is:

Feedback Instruments Limited,
Servicing Department,
Park Road,
Crowborough, TN6 2QR,
Sussex, England.

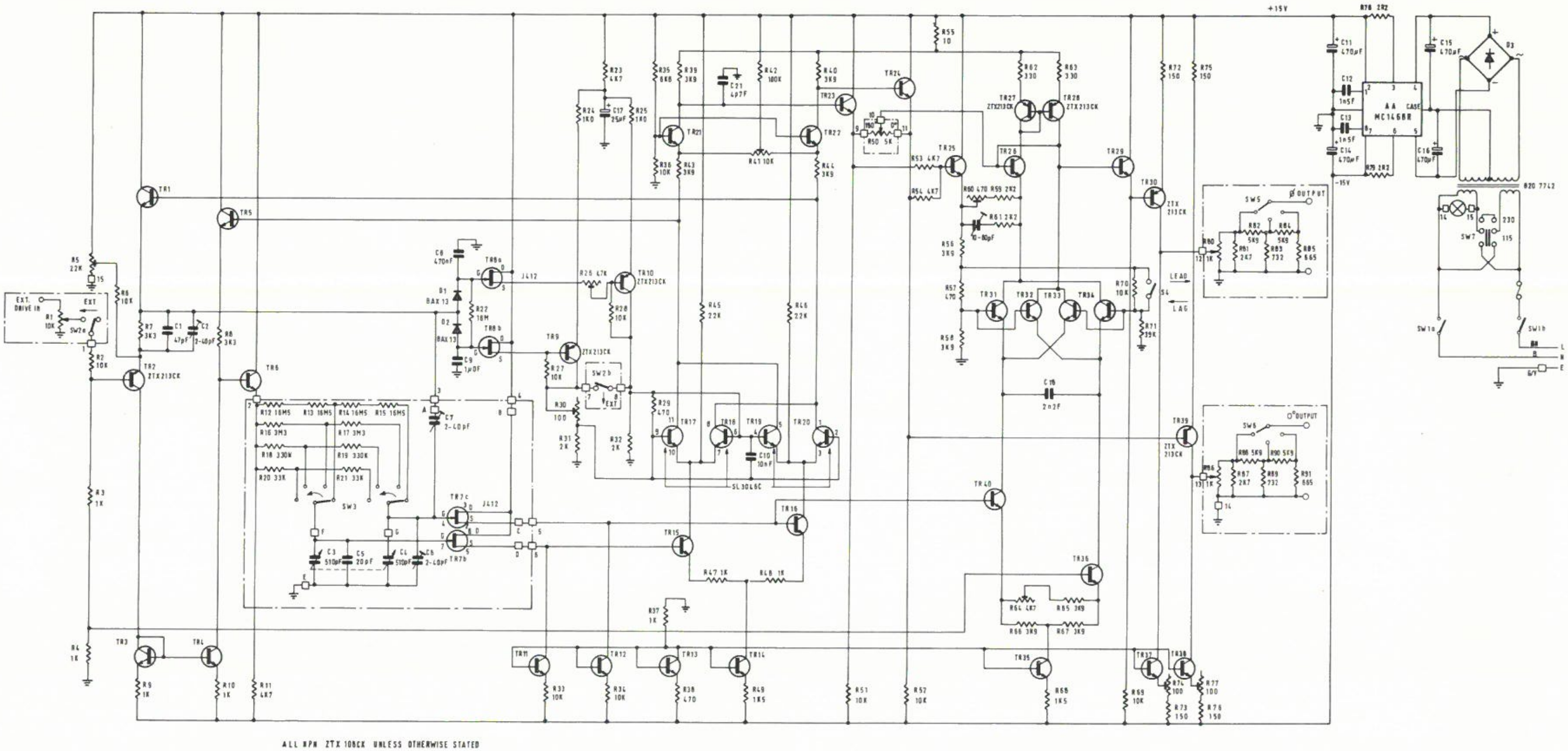


Fig 4.4 VPO602 Circuit diagram