12MHz Sweep Function Generator SFG 611

FEEDBACK

12MHz SWEEP FUNCTION GENERATOR SFG611

Contents

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Component replacement

Although this Feedback manual was believed to be correct at the time of printing, components supplied may differ slightly from those described.

We endeavour to improve our equipment continually by incorporating the latest developments and components, even up to the time of despatch. If it is practicable we include such new or revised information in the manual.

Whenever possible, replacement components should be similar to those originally supplied. These may be ordered direct from Feedback Instruments Limited or its agents by quoting the following information:

1. Equipment type
2. Equipment serial number
3. Component reference
4. Component value

Standard components can often be replaced by alternatives available locally.

The Health and Safety at Work Act 1974

We are required under the Health and Safety at Work Act 1974, to make available to users of this equipment certain information regarding its safe use.

The equipment, when used in normal or prescribed applications within the parameters set for its mechanical and electrical performance, should not cause any danger or hazard to health and safety if normal engineering practices are observed and they are used in accordance with the instructions supplied.

If, in specific cases, circumstances exist in which a potential hazard may be brought about by careless or improper use, these will be pointed out and the necessary precautions emphasized.

While we attempt to give the fullest possible user information in our handbooks, if there is any doubt whatsoever about any aspect relating to the proper use of this equipment the user should contact the Product Safety Officer at Feedback Instruments Limited, Crowborough.

DESCRIPTION AND SPECIFICATION

SECTION 1

Introduction

The 12MHz Sweep Function Generator SFG611 is a high-performance instrument offering versatile facilities which simplify many test measurements in the 0.01Hz to 12MHz frequency range.

The push-putton selected waveforms, sine, square or triangular, are available at levels up to 10V pk-pk open circuit from 50Ω. The continuous amplitude control, in conjunction with two fixed attenuators of x0.1 each, give a suitable range of output level control. The d.c offset facility gives a unipolar capability with all combinations of signal and offset free of clipping. Auxiliary outputs provide a triangular waveform and a TTL-compatible square waveform capable of driving two standard TTL loads.

The frequency range is selected by six push-buttons in decade ranges together with a (Hz/1000) switch, applicable to all ranges.

The mark/space ratio of all the waveforms can be varied by a continuous control in conjunction with three switch positions.

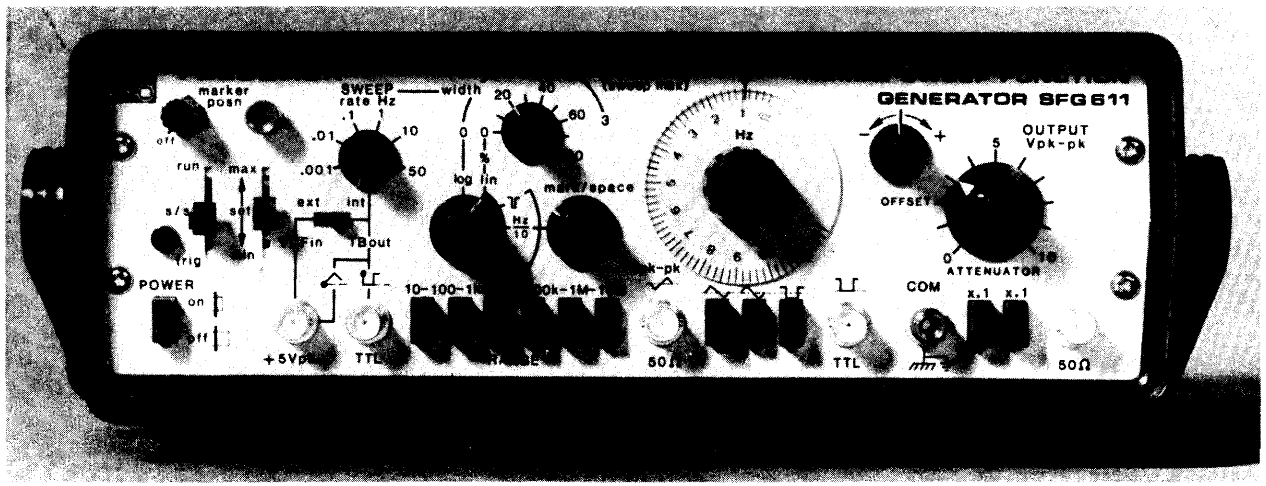


Fig 1.1

The comprehensive sweep facilities can be used in either logarithmic or linear mode, covering the need for overall frequency response or particular narrow-band measurements on 465kHz or 10.7MHz IF circuits, for example.

Internal or external sweep (VCF) can be selected by means of a slide switch. The internal sweep generator is continuously adjustable from 50Hz to 0.001Hz by means of a single logarithmic control. A triangular frequency sweep enables both directions of the sweep to be displayed, and an associated auxiliary output is provided for driving the oscilloscope timebase. Also incorporated is a 'single-shot' sweep facility, enabling the SFG611 to be used with X-Y recorders, a TTL square wave output then operates as a pen lift control.

An effective bright-trace marker gives high-resolution calibration of response features for use with an external frequency meter.

Mechanical

The SFG611 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 SFG611 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 SFG611 obviates the need for ventilation holes.

All controls are situated on the front panel, fig 1.1.

Specification

Frequency

Range

0.01Hz to 10MHz. Selected by six pushbuttons in decade ranges from 10 to 10M, plus (Hz/1000) switch position applicable to all ranges.

Range Overlap

Frequency dial calibrated nominally 1 to 10, with over-range from 0.2 to 12

Main Output

Waveforms

Sine, Square, Triangular, with pushbutton selection

Source Impedance

50Ω

Amplitude

10V pk-pk maximum open circuit

Amplitude Control

Single continuous control calibrated 0 to 10V pk-pk (at nominal 1V pk-pk intervals)

Stepped Attenuator

Two fixed attenuators selectable x0.1 each

Offset

Adjustable from –5V through 0 to +5V giving unipolar signal capability. All combinations of signal and offset are free of clipping. Offset not subject to continuous output amplitude control

Termination

BNC socket

Mark/Space

Control

Affects all waveforms from main and auxiliary outputs. Continuous control operational in three switch positions:

a) fixed mark, variable space, continuously variable from 1:1 to 1:19

b) Continuously adjustable mark space ratio from 19:1 to 1:19, at a fixed frequency of approximately x0.1 main frequency setting.

c) variable mark, fixed space, continuously variable from 1:1 to 19:1

Sweep Facility

Control
Slide switch enables internal or external sweep (VCF) to be selected

External
Gives normal unswept operation, but a voltage applied to the 'VCF' socket modifies the frequency of operation as follows:

Linear mode: Voltage applied to the VCF input increases frequency at the rate of about +0.3V per 1 major scale divison (negative voltages decrease frequency).

Logarithmic mode: Voltage applied to the VCF input decreases frequency at the rate of about 5V per factor of 10.

Internal
Provides a triangular waveform from the socket 'TB out ⁄\' and a corresponding square waveform from the 'TB out ⊔⊓ ' socket. Sweep frequency rate adjustable by single logarithmic control from 50Hz to 0.001Hz.

Triangle amplitude: 5V pk-pk (0V to +5V) from 1kΩ.

Square waveform TTL: (0V to +5V) to drive two standard loads available from 'TB out ⊔⊓ '.

Operating Modes
Lever switch 'run/S—S/trig' gives continuous operation in 'run' position. When moved from 'run' to 'S—S' (single shot) the triangle output goes to zero and then executes a half cycle (0V to +5V) when the switch is moved to the 'trig' position. When operated in the 'S—S' condition the 'TB out ⊔⊓ ' may be used as a 'pen lift' control for X—Y recorders. The 'set max—min' spring return lever switch over-rides the sweep triangle generator to hold the waveform at its maximum (5V) or minimum (0V) excursion. In the run condition this maximum or minimum is held only during the operation of the 'set max—min' switch. In 'single-shot' the conditon of maximum or minimum is held until some other condition is initiated.

Frequency Marker

An effective bright-up marker for use with oscilloscope displays of frequency responses is available as a hesitation in the sweep triangle voltage. The position of this is controlled by a 'marker' control. The triangular voltage and frequency at which this occurs can be held by an associated 'marker' pushbutton.

Sweep Width
This control gives the proportion of the sweep triangle voltage used to control the frequency of the internal sweep generator. The scale is calibrated from 0% to 80% for linear sweep, and from 0 to 3 decades for logarithmic sweep. In both conditions ('lin' and 'log') the maximum frequency is set by the main dial and occurs when the triangle output voltage from 'TB' is maximum (+5V). The calibration on the sweep width control indicates the sweep width as a proportion of the main frequency setting. e.g. linear mode, main dial 50kHz, sweep-width 80%, gives sweep from 10kHz to 50kHz, sweep-width two decades, gives sweep from 500Hz to 50kHz.

Auxiliary Outputs

TTL Square wave

Amplitude TTL compatible (nominal 0 to +5V)

Rise time <50ns unloaded
or (50+4.4C) ns with CpF added capacitance

Sink capacity Two standard TTL loads

Termination BNC

Triangular wave

Amplitude 1V pk-pk

Impedance 50Ω

Termination BNC

Power Requirements

Line voltage
110/220/240V, 50 or 60Hz, selected by external slide.

Consumption

25VA

Fuse

315mA slow blow (20mm x 5mm)

Dimensions and Weight

Width	300mm (12in)
Height (with feet)	115mm (4.5in)
Depth	226mm (9in)
Weight	2.7kg (6lb)

OPERATION

Installation of SFG611

The function generator 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 SFG611 should be withdrawn smoothly from the container. Take care that the inserts and SFG611 are held together during this time.

Inspect the SFG611 and if any damage is evident immediately notify the carriers.

Voltage selection

Ensure that the instrument is set for the appropriate supply voltage by inspecting the voltage selector on the back panel. Reset if necessary before connecting to the supply.

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 back panels of the SFG611 and to the terminal marked ⏚ on the front panel.

Preliminary settings

Users unfamiliar with the instrument are recommended to set the controls as follows before reading further, if they wish to try out the controls as they are described. This procedure may also be helpful at any time that a fresh activity is to be started. Set:

'marker position' off (anti-clockwise to operate switch)

'run-s/s-trig' switch to 'run'

sweep switch to ext

'log-lin' to 'lin'*

attenuator buttons out

'offset' to central position (zero offset)

'output volts' to a convenient value for observation

* Note

It is recommended that the SFG611 is always operated in the 'lin' mode, unless log sweeping is required, as this is the mode that gives minimum drift and the most accurate frequency calibration.

Frequency selection

If a frequency below 10Hz is required, move the 'log-lin' switch to the 'Hz/1000' position. For frequencies above 10Hz select 'lin' or 'log'. (Other possibilities will become apparent in later paragraphs).

Press the frequency range selector pushbutton whose adjacent markings span the desired frequency (in Hz or mHz as the case may be). Finally set the 'Frequency' dial to obtain that particular frequency in the range.

Note that each actual range extends somewhat above and below the nominal range indicated by the switch markings.

Thus for a frequency of 5Hz the 'log-lin' switch would be set to 'Hz/1000', the required range button would be '1K–10K' and the 'Frequency' dial would be set to 5.

Note that the frequency calibration is altered when the 'mark/space' facility is in use (bracketed positions of the log-lin switch; see 'Mark/Space ratio control'.

Outputs

Main output

One of the three waveform selector buttons should be depressed to select a triangle, sine or square wave as required. The selected waveform will then appear at the output socket with an amplitude which may be set by the 'output volts pk-pk' dial, whose calibration should be correct when neither of the attenuator buttons is depressed, and no load is connected to the output socket.

This output waveform may be raised or lowered 5V in d.c level by turning the 'offset' control. Thus if the amplitude is set to say 6V pk-pk (±3V pk), and +4V of offset are applied, the resulting signal will oscillate between +1V and +7V. It is always possible to set every part of a waveform to be of the same polarity in this way, and no combination of adjustments will cause clipping of the combined (alternating plus offset) output.

The combined waveform with offset is connected to the output socket effectively in series with a 50-ohm source impedance, either directly, or through either or both of the attenuators introduced when the 'X0.1' buttons are depressed. Each button introduces 20dB (X0.1 in voltage) attenuation, leaving the output impedance unchanged.

Auxiliary outputs

Two auxiliary outputs are provided which are synchronous with the main outputs. Their relative phases are indicated in fig 2.1. Their amplitudes and levels are unaffected by the main output controls.

The auxiliary square wave output can be used to drive two TTL loads. Alternatively, if it is loaded with 50 ohms, it produces a fast square wave, 0V to 0.6V approximately.

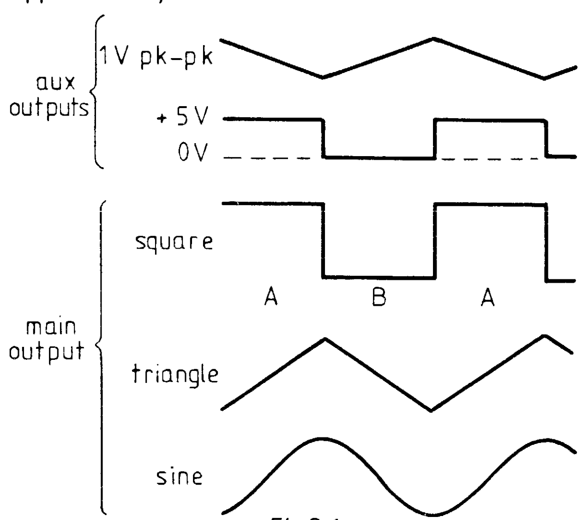


Fig 2.1

Mark/space ratio control

This control is brought into operation when the 'log-lin' switch is in any of the three bracketed positions adjacent to the control.

With the switch turned to ⊔⊓, i.e clockwise one step from 'lin', the mark/space control affects only the half-cycle indicated by A in fig 2.1, slowing it down by a factor which may be adjusted between 1 and 19 times compared with the other half-cycle, whose duration is unaffected.

Similarly with the switch two positions further on at ⊓⊔, the control affects half-cycle B.

With the switch in the intermediate position, marked Hz/10, both half-cycles are slowed down. The relative durations can be adjusted by the rotary control, and the time of the whole cycle is increased to approximately ten times that indicated by the frequency calibration (i.e frequency is reduced tenfold).

The frequency of the main output waveforms can be altered from the calibrated value by the application of a control voltage. This voltage may be derived from an external source or from an internal sweep oscillator, selected by the 'ext-int' switch (below the sweep rate control).

If 'ext' is selected, the sweep width, sweep rate and marker controls will have no effect. A signal voltage applied to the VCF socket alters the frequency as follows:

In all linear modes (lin, ⊓⊔, Hz/10, ⊔⊓, Hz/1000) a positive signal increases the frequency, and negative signal decreases it, at a rate of about one major scale division (one-tenth the nominal frequency range) per 0.3V.

In logarithmic mode a positive VCF signal *decreases* the frequency and a negative signal *increases* it by about one decade (i.e factor of 10) per 5V.

In neither case should the VCF signal take a value which would drive the frequency outside the limits zero and 20% above the nominal range set by the frequency selector switch.

Swept-frequency operation

In order to use the internal sweep oscillator, set:

'log-lin' to either 'log' or 'lin' as desired
'ext-int' to 'int'
'run-S/S-trig' to 'run'

With these settings the sweep oscillator produces at the VCF/TB socket a triangular waveform which always sweeps between 0V (for minimum frequency) and +5V (maximum and nominal frequency), irrespective of the sweep width control setting. The rates of rise and fall are equal, and the sweep frequency is adjustable over a wide range by the 'sweep rate' control. For oscilloscope displays of frequency response it is recommended that an X–Y oscilloscope use this voltage for X-deflection, fig 2.2.

The 'sweep width' control selects a portion of that waveform for VCF, thus altering the extent of the decrease in frequency. Meanwhile the adjacent socket provides a square wave suitable for pen lift control of a recorder, or for triggering an oscilloscope if it has no X–Y facility.

The 'run-S/S-trig' control stops and starts the sweep oscillator as follows.

In the 'run' condition the sweep oscillator runs continuously.

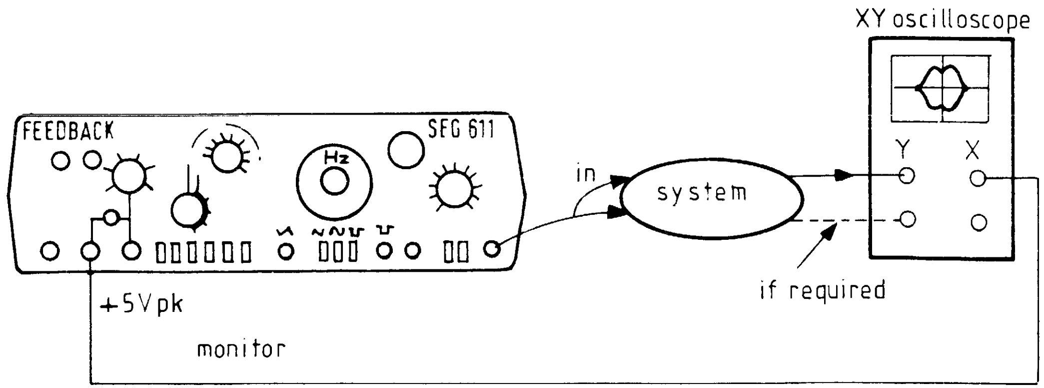


Fig 2.2 Signal connections for swept-frequency operation (⏚ not shown)

In the 'S/S' condition the sweep signal goes to zero and will remain there until a new sweep is started by moving the switch against the spring bias to 'trig'. Each time a sweep is triggered its TTL output goes low while the frequency increases; during the return half-cycle of the sweep oscillator (frequency decreasing) the TTL output goes high. The TTL output can therefore be used as a 'pen lift' control when recording frequency responses.

Frequency setting for internally-swept operation using the calibrations of the SFG611.

The maximum frequency of a sweep should be set first. It is simply that which is set on the normal frequency controls.

The minimum frequency is that frequency multiplied by a factor (less than one) which is determined by the sweep width control. This may be shown by simple examples.

Example 1. It is required to sweep from 300kHz to 600kHz to examine the response of a 465kHz IF transformer.

First the highest frequency is set by pressing the range selector between 100k and 1M and setting the frequency dial to 6. Assuming a linear sweep is required, the lowest frequency is 50% of the highest. So 'lin' is selected, and the sweep width is set to 50% (the inner scale).

In this case the maximum sweep rate might be usable, but note the later paragraph on distortion.

Example 2. An audio circuit is to be tested between 20Hz and 20kHz. A logarithmic display of response is required.

'Log' condition is selected. The high-end frequency is set by selecting range 10k–100k and setting 2 on the frequency dial. The lowest frequency is 3 decades lower than the highest; sweep width is therefore set to 3. (More generally the number of decades is the common logarithm of frequency ratio).

In this example a much lower sweep rate will be required, certainly well below the 20Hz bottom frequency of the sweep range.

In setting up this display the oscilloscope's horizontal sensitivity may conveniently be adjusted so that the trace is just 9cm long. The display scale is then 3cm per decade, the graticule lines corresponding to frequencies of 20, 43, 93, 200, 400Hz etc. For many practical purposes these can be taken as 20, 40, 100, 200, 400Hz etc, see fig 2.3.

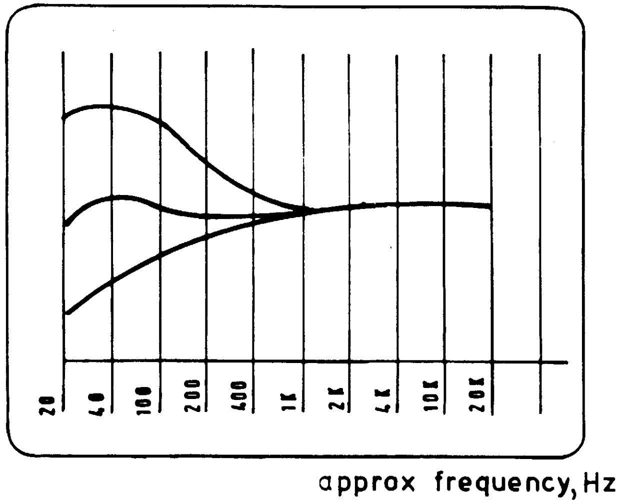


Fig 2.3

Frequency checking

It will be found when a swept-frequency characteristic is being displayed that the main frequency control acts in a manner similar to an 'X shift': that is to say the display can be moved laterally. If for example it is required to find out the centre frequency of a resonant circuit – fig 2.4(a) – all that need be done is to turn the

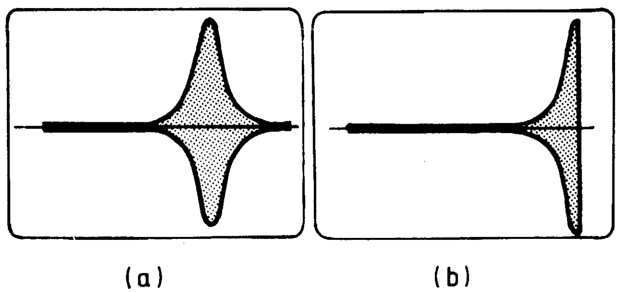


Fig 2.4

main frequency control until the point to be measured is at the right-hand end of the trace – fig 2.4(b) – and then to read off the frequency from the frequency dial.

If alternatively it is desired to leave the controls undisturbed the frequency of interest can be scaled directly if the sweep is linear. When logarithmic sweep is in use and the frequency ratio is at all large the desired frequency f may be calculated in terms of the end frequencies f_1, f_2 by applying the following formula to the lengths l and m measured from the oscilloscope face (fig 2.5).

$$f = f_1 \, e^{\frac{m}{l} \ln (f_2/f_1)}$$

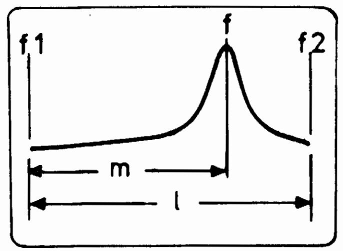


Fig 2.5

Using external frequency meter

Several controls are provided which greatly facilitate frequency-response work when used in conjunction with an external frequency meter. The latter may conveniently be driven from the auxiliary TTL output near the main output socket.

The end-frequencies of the sweep may be accurately set using the 'set' control.

If the 'set' control is moved to 'max' the sweep oscillator is held in the condition giving maximum frequency; similarly 'min' gives the minimum frequency reached during a sweep. To adjust the end frequencies of a sweep, first switch to 'max' and set the main frequency controls; then switch to 'min' and adjust the sweep width until the desired minimum frequency is obtained.

While swept operation is in progress the frequency meter may be expected to read the average frequency. Note that this will be half the sum of the end frequencies only if the sweep is linear. During logarithmic swept operation the average frequency is

$$f\,(av) = \frac{f_{max} - f_{min}}{\ln \left(\frac{f_{max}}{f_{min}} \right)}$$

Frequency marker

A marker is provided for use with the arrangement of fig 2.2. The marker controls are inoperative if the rotary marker control is set to 'off'. However as this control is rotated away from the off position the marker appears as a brightening of the oscilloscope trace. It may be positioned anywhere across the screen. (It is produced by causing the sweep process to pause momentarily, and therefore alters the sweep period slightly).

If a feature (e.g a resonance) is to have its frequency measured, the marker should be set to mark the feature on the display. Pressing the marker pushbutton will then hold the frequency of the oscillator at the value marked; the marked frequency can then be read directly on the frequency meter.

Display Distortion

When a swept frequency is used to examine the characteristic of a circuit it is important that the circuit under test is given long enough to respond properly to each frequency. This means that the frequency must be swept sufficiently slowly. This is especially true of resonant circuits where there is an exponential build up of amplitude in response to the sudden application of a resonant signal as shown in fig 2.6.

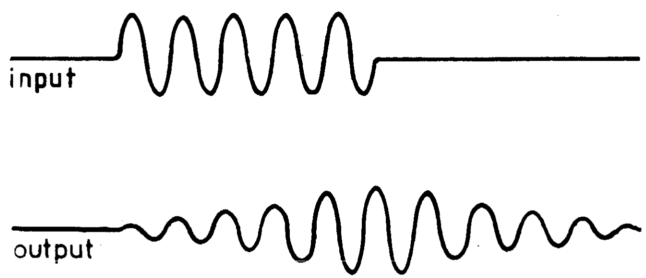
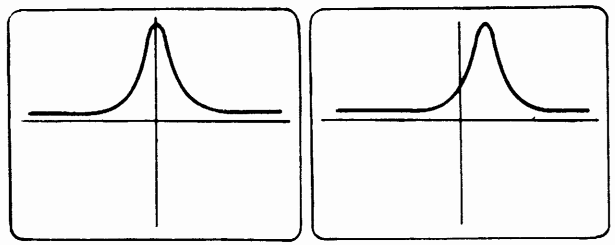


Fig 2.6

From this familiar response it can be seen that the average response of the resonant circuit is effectively delayed in time with respect to the stimulus. This sort of effect occurs when the stimulus is a swept-frequency signal; the main response of the circuit tends to occur after the stimulus is past so that the response is displaced (fig 2.7).



(a) (b)

Fig 2.7

With a sweep generator employing a 'blanked' and/or rapid return it is not easy to tell when this sort of distortion is occurring. With the SFG611 where sweeping occurs in both directions, the response when sweeping too fast appears as in fig 2.8.
On reducing the sweep speed the two traces come together to give a true display.

The SFG611, by always providing sweep up and sweep down of frequency, gives a continual check on the suitability of the sweep speed chosen and also gives optimum display brilliance through the absence of trace blanking. Further, the continuously adjustable sweep rate control allows optimum repetitive rate consistent with minimal distortion.

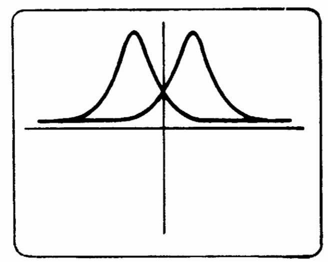


Fig 2.8

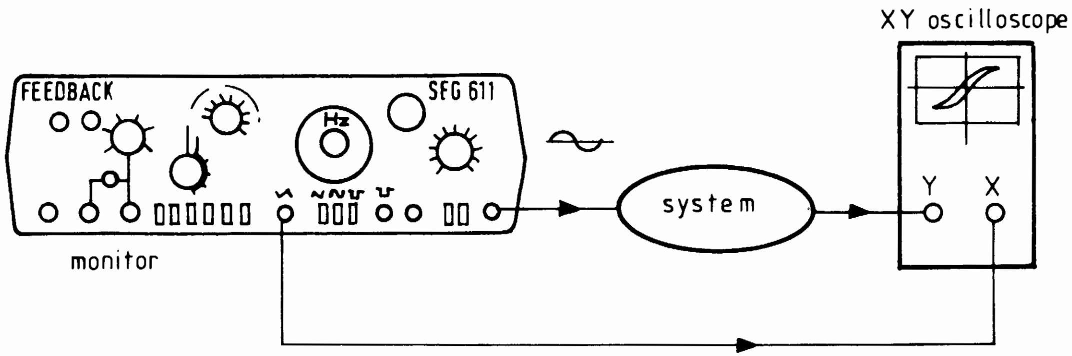


Fig 2.9

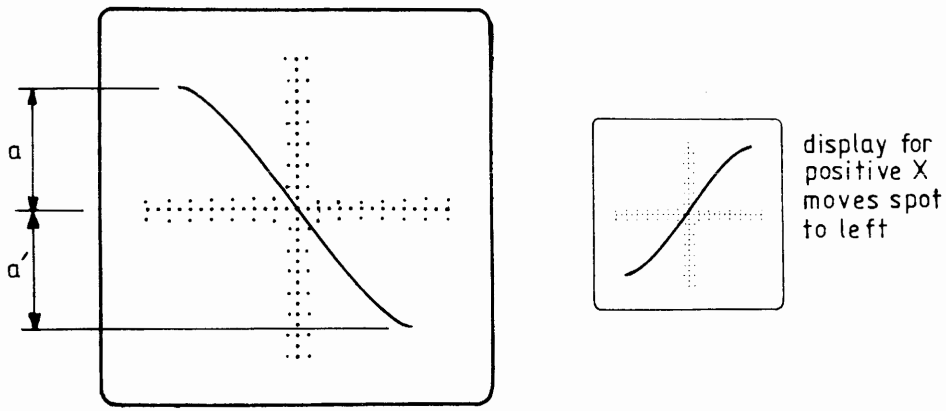


Fig 2.10

2.10 Phase Measurement

Measurement of the phase shift of a signal in a system under test may be made as in fig 2.9. Usually a +ve voltage on the Y and X inputs of the oscilloscope moves the spot upwards and to the right respectively. This may be verified by short-circuiting the system to obtain zero phase shift. The display can be arranged symmetrically about the X axis as in fig 2.10, i.e a=a'.

To simplify calculations it is convenient to adjust the X deflection to be nine scale divisions as in fig 2.11.

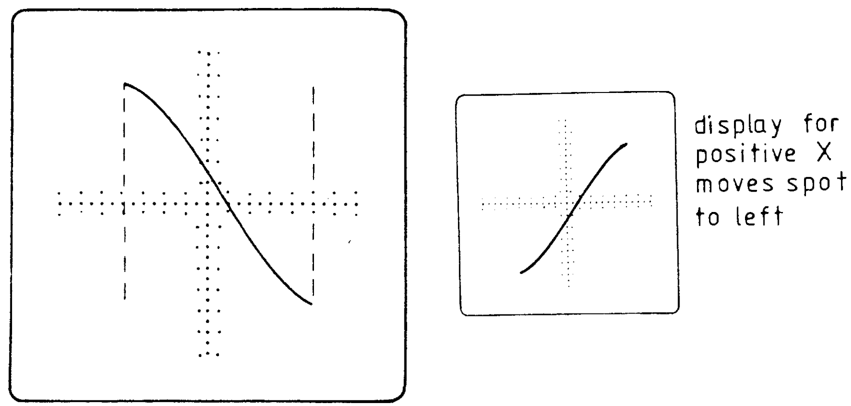


Fig 2.11

The phase angle in fig 2.12 is then given by $90^\circ \times \frac{p}{q}$ but since q was adjusted to equal nine divisions the phase angle becomes simply $(10p)^\circ$.

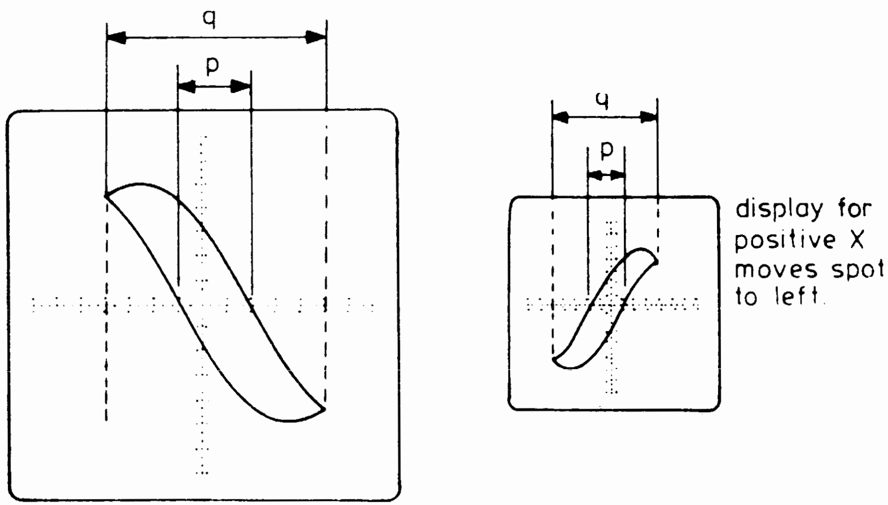


Fig 2.12

When the angle is greater than 90° then the display will be in the form of fig 2.13.

In this case the angle is $180^\circ - (90^\circ \times \frac{p}{q})$

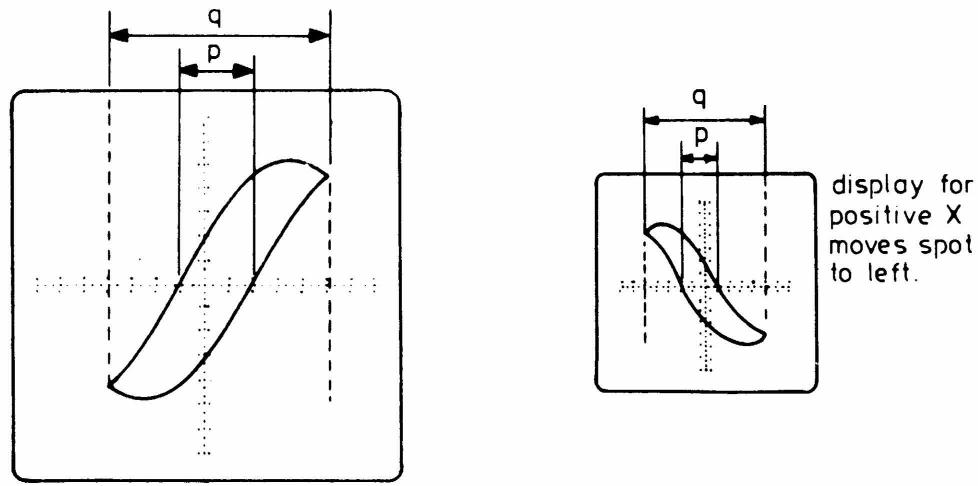
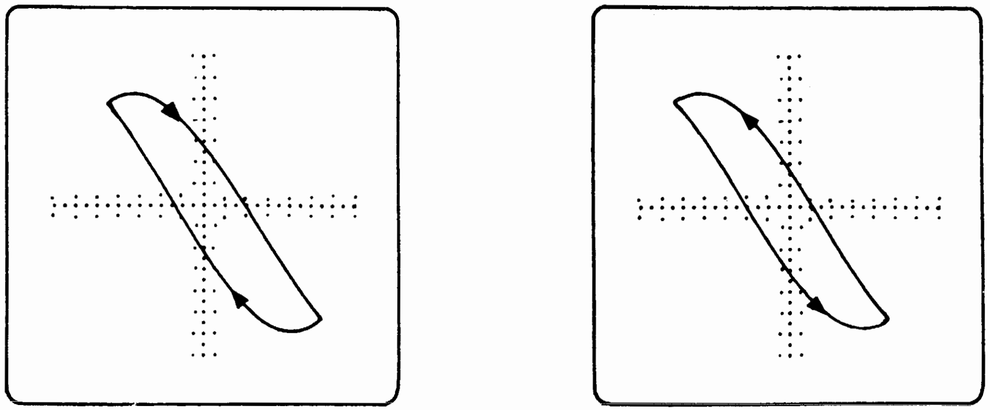


Fig 2.13

It is sometimes not known if the angle is leading or lagging. At low frequencies (as will often be the case in servo systems) this can be found by noting the direction in which the spot traces the loop as in fig 2.14.



clockwise —— lagging
[leading for positive X moves spot to left]

anticlockwise —— leading
[lagging for positive X moves spot to left]

Fig 2.14

At higher frequencies it may be necessary to use the TTL output of the SFG611 on the 'Z modulation' of the oscilloscope; this will brighten one half of the trace. Assuming that a +ve voltage brightens the trace then the phase is identified as in fig 2.15.

If a +ve input voltage to the Z modulation dims the trace, the two conditions are reversed.

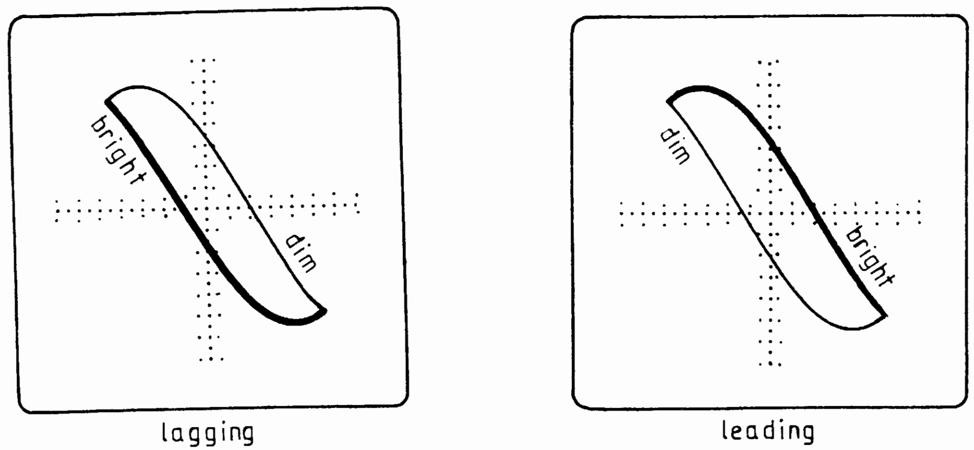


Fig 2.15

Transient Response Measurement

Use the test circuit of fig 2.17. The monitor triangular output then acts as a time base.

Put the output waveform on to the Y plates, adjust the SFG611 until the transient occupies the oscilloscope screen as shown in fig 2.16.

The time $T = \frac{1}{2F}$ where F is the frequency setting.

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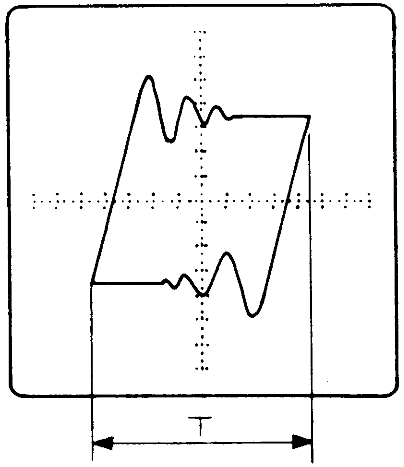


Fig 2.16

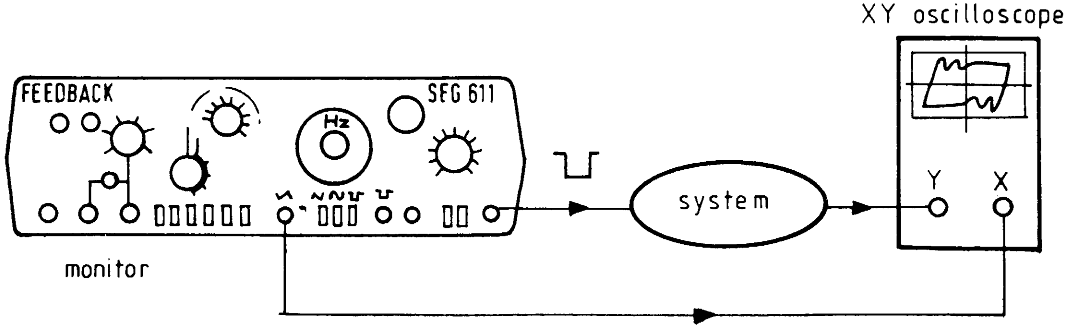


Fig 2.17

Measurement of following error

When a servo mechanism or voltage follower is excited by a linear ramp of R volt/second, after an initial transient the output follows the input but with a 'following error' E_f.

The method illustrated in fig 2.18 displays this error as a gap between the forward and return traces. For servos a 'velocity constant' K_v is defined.

$$K_v = \frac{R}{E_f} \text{ where } R = \frac{\text{pk to pk amplitude of drive}}{\text{time for one half cycle}}$$

$$E_f = \frac{\text{vertical gap in volts V}}{2}$$

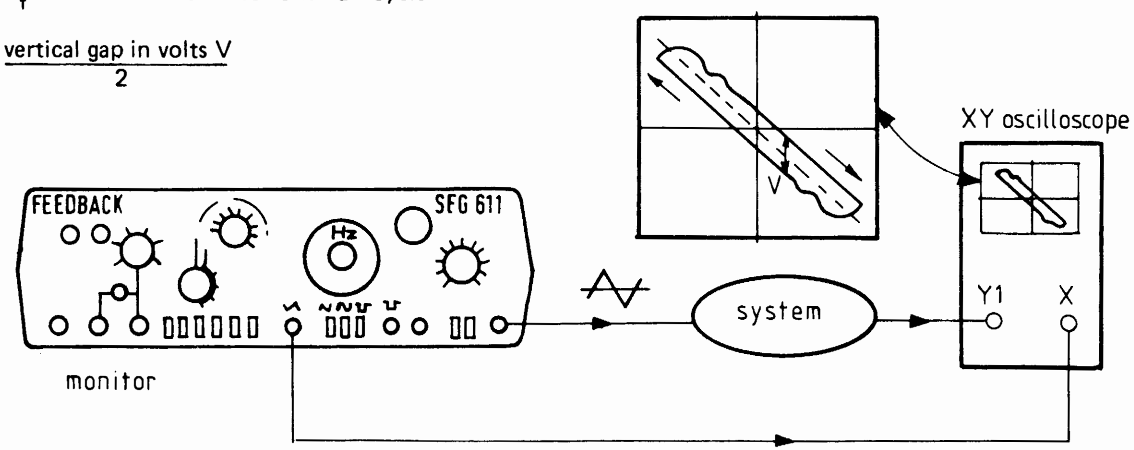


Fig 2.18

CIRCUIT DESCRIPTION

SECTION 3

Synopsis

An integrate-and-switch type oscillator drives the output stage either directly or through shapers, enabling triangle, sine or square waveforms to be produced. A sweep oscillator, also of integrate-and-switch type, modifies the current which is integrated in the main oscillator to change the latter's frequency. This modification is accomplished by extensive use of current mirrors, and for logarithmic sweep uses the exponential $i_e - V_{be}$ characteristic of a transistor. Logic is provided for controlling the sweep action, and provides an auxiliary output for pen lift control.

While several simplified circuit diagrams are provided in this section, references in the text are occasionally made to components which will be found only on the main circuit diagram, fig 4.4.

The basic oscillator

The principle of operation is indicated by the much simplified fig 3.1. Current i or i' is switched into the capacitor to produce a voltage which rises or falls respectively. Variation of i, i' alters the rate of change of voltage, and is used to effect the fine frequency control of the oscillator. The voltage on the capacitor is reproduced by a voltage-follower amplifier Tr22, 23. When it rises sufficiently the output of comparator AR goes negative, cutting off Tr24. The current i_o ceases to flow in the right-hand resistor R, so that positive feedback is applied to give a decisive switching action. Diversion of i_o into Tr23 causes a negative-going voltage step which, applied by the voltage follower Tr18 to the diode switch, diverts i into the voltage follower, and allows i' to flow into the capacitor, reversing the direction of current in the capacitor. The voltage on the capacitor will then fall steadily until a similar process takes place in the reverse direction. The d.c level at point B of fig 3.1 is in practice adjusted by the network R89, 90, 91 so that the same magnitude of bias between points B and C is obtained for each direction of switching.

Since the voltage at point B follows that at point C apart from the switching voltage (approximately $i_oR/2$), the latter can be kept quite small, just sufficient to divert the current from one diode pair to the other. A small switching voltage cuts down the spurious charge fed to the capacitor by self-capacitance of the diodes.

i_o is nominally 10mA and R is 150 ohms, so that the switching voltage and the peak-to-peak output are both 1.5V.

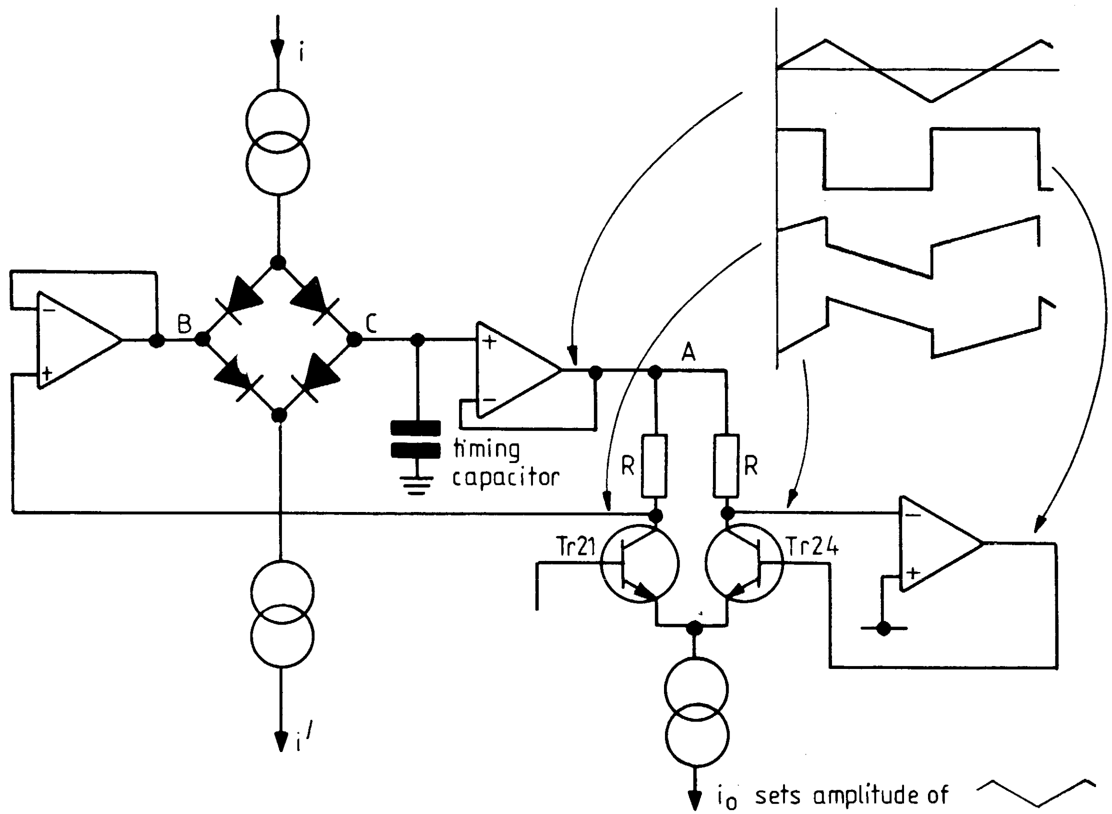


Fig 3.1

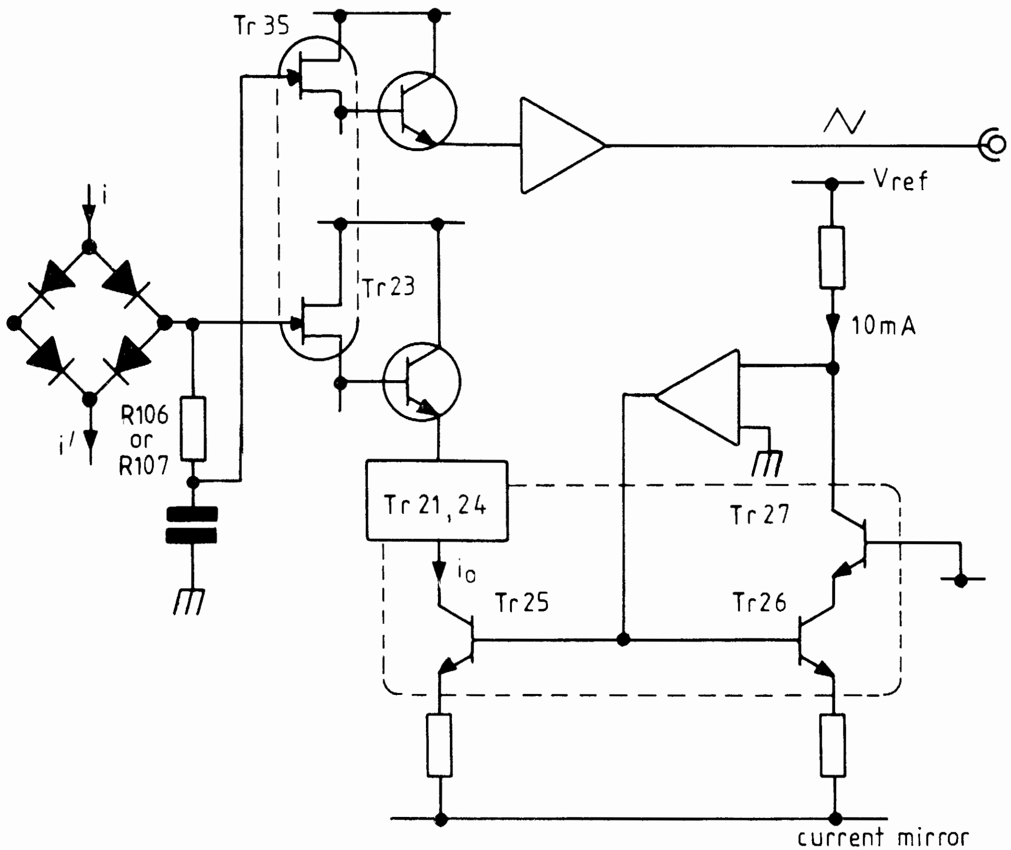

Tr 35
Tr23
i
i'
R106
or
R107
Vref
10mA
Tr 21, 24
Tr 27
io
Tr25
Tr26
current mirror

Fig 3.2

Fig 3.2 shows some of the circuits immediately surrounding those of fig 3.1. The voltage follower FET Tr35 passes the voltage across the timing capacitor to an amplifier which provides the triangle waveform at low impedance to other circuits. The voltage follower Tr23 is a matched FET on the same chip. Its input is modified on the two highest frequency ranges by R106 or R107. The purpose is to compensate for delays in the switching action (which though small are not negligible compared with e.g the 50ns half-period of a 10MHz signal).

Tr21, 24, 26, 27 are all part of a matched transistor array. Tr25, 26, 27 in conjunction with amplifier AN form a current mirror by which the current in R121 is reproduced as the i_o of fig 3.1. This current can be adjusted by R119, which, acting through AN, Tr26, Tr27, alters the voltage across R121.

Triangle-wave amplifier

The triangle waveform across the timing capacitor provides the input to the FET input stage Tr35 of an amplifier comprising also emitter follower Tr34, and a voltage follower comprising long-tailed pair Tr33, 32 with 100% negative feedback derived from output emitter follower Tr31. R147, C38 stabilise the feedback. The amplifier drives the auxiliary triangle-output socket via resistors providing a 50-ohm output impedance, it also provides the input waveform for the output amplifier, directly when triangle output is required, or after conversion by the sine shaper.

Waveform shapers

Square-wave shaper

The switch stage of the basic oscillator AR, drives the long-tailed pair Tr29, Tr30 which switches the current in R138, R139 to give two square-wave outputs. One obtained from Tr30 collector directly feeds the output amplifier; its amplitude is adjusted by varying R128, and its level by R139. The other drives the emitter of Tr28, whose collector drives the auxiliary TTL output socket.

Sine shaper

The sine shaper is driven by the amplified triangle wave. It comprises the monolithic array of transistors 37 to 41, with Tr36. Fig 3.3 shows a simplified version of part of the circuit, which may be thought of as having two non-linear stages. The first, Tr41 and Tr38, is a pair of emitter followers which impresses the input triangle voltage across R162, R160 in series. The circuit is designed so that as each extremity of the triangle is reached, one of the emitter followers tends to cut off, clipping the peak of the triangle into a rounded shape, fig 3.4. The signal voltage is then reduced by the potentiometer R162, R160, so that the signal and the working range of base-emitter voltage are more nearly equal. A second stage of limiting is then introduced by Tr39 Tr40, which form a long-tailed pair in which the adjust-

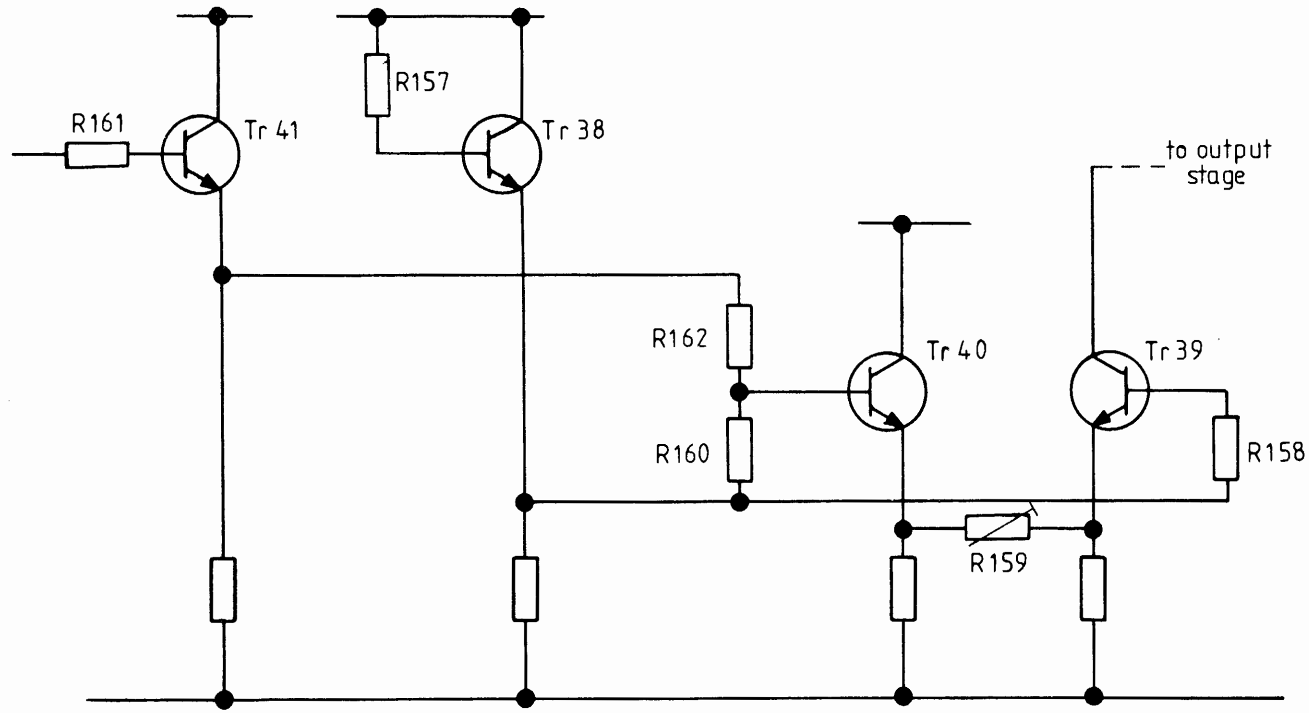

R161
Tr 41
R157
Tr 38
to output stage
R162
Tr 40
Tr 39
R160
R158
R159

Fig 3.3

able resistance of R159 is used to compensate for tolerances, and controls the rapidity with which Tr39, Tr40 limit. This second stage of the circuit is so adjusted that if it were fed with a triangle input, the output current at the collector of Tr39 would be somewhat as fig 3.5. However when fed with the clipped wave of fig 3.4 quite an accurate sine wave of output current is obtained.

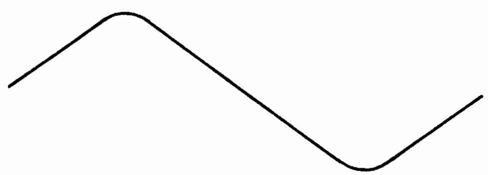


Fig 3.4

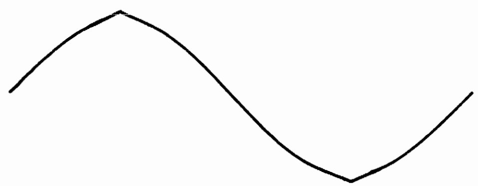


Fig 3.5

The remainder of the sine shaper accepts this current and simply derives an output sine wave of voltage whose level and amplitude are adjustable by R152 and R153 respectively.

Resistors 157, 158 and 161 are 'stoppers' to prevent parasitic oscillations. Their values are chosen to maintain approximate symmetry of the impedances seen by the bases of both stages.

Output Amplifier

A simplified form of this is shown in fig 3.6. A signal, selected by the triangle/sine/square switches, is adjusted in amplitude by the 'volts' control R37. From its slider there are two paths to the output stage. Fig 3.6a outlines the path taken by low-frequency components of the signal, and fig 3.6b that taken by high frequencies.

AK is a transconductance amplifier having a differential voltage input and a current output at high impedance. It drives the common-emitter stage Tr9 which, through cascaded emitter followers, drives the output stage. This will be seen in the full circuit to comprise three paralleled cascodes. Feedback from the emitter resistance in the output stage is taken in a balanced feedback network back to the input of the amplifier, ensuring a stabilised gain approximating to unity. The feedback loop is stabilised by C13 which provides its dominant lag. The d.c level at all points up to the output stage current is set by R42.

The gain of the cascode output stage is very nearly equal to the ratio of load and emitter resistances, i.e 50/6.6 = 7.6.

The output stage has a 50Ω load whose supply is variable in voltage by the 'offset' control. This is connected either directly or through 50Ω attenuators to the output socket.

From the amplifier input, high frequencies are fed via emitter follower Tr8 and a transmission line to the emitter of Tr9, whose base is grounded by C13. The collector of Tr9 drives the output stage as before. The resistors in series with the emitters of Tr8, Tr9 provide some degenerative feedback, stabilising the gain of these stages. The high-frequency gain of the whole amplifier can be adjusted by R49 to match the low-frequency gain. C12 is adjusted to correct errors in phase of the signal at the input to AK, caused by stray capacitance.

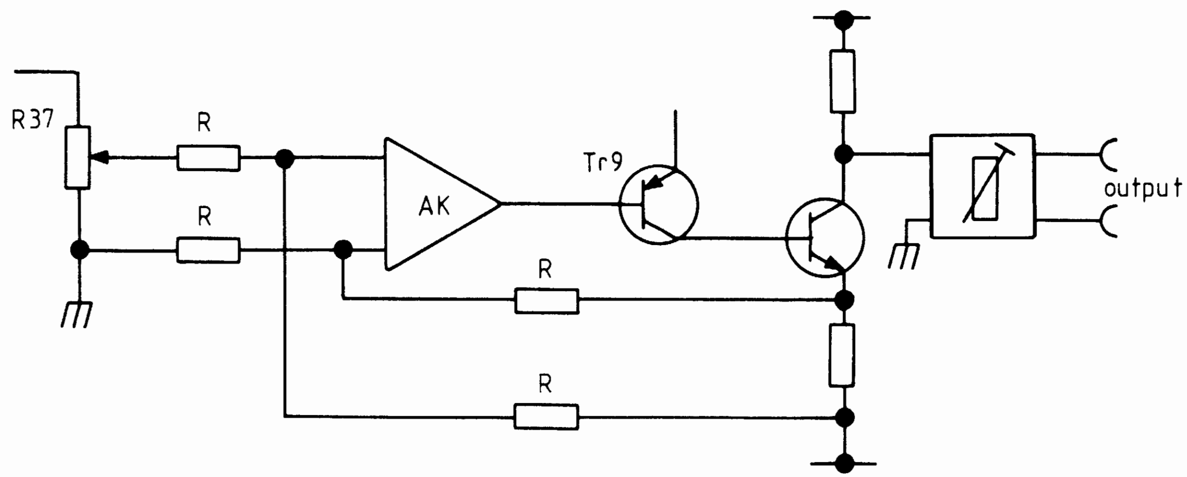


Fig 3.6a

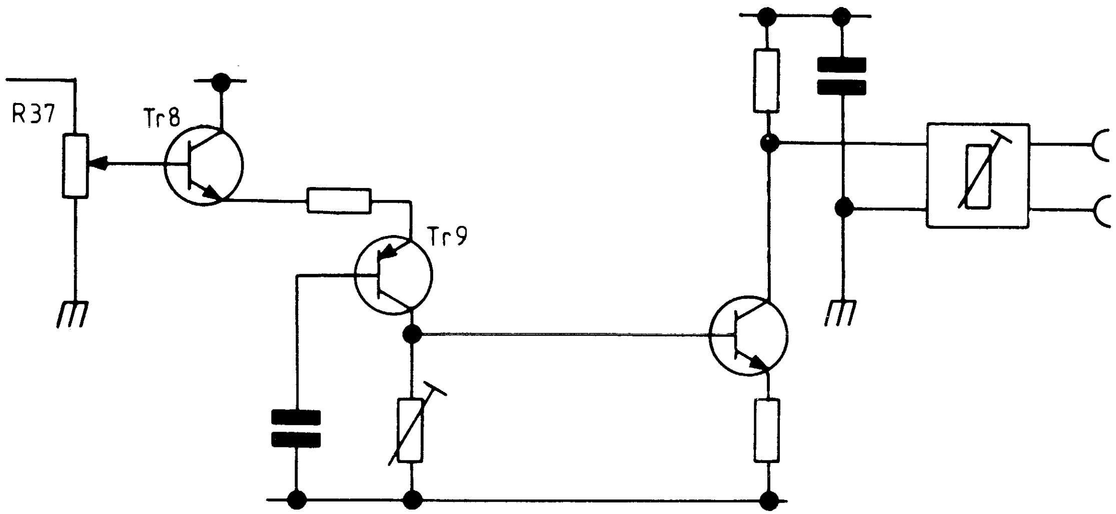


Fig 3.6b

Setting the frequency

The frequency is determined by the capacitance of the timing capacitor and by the current fed into it. The capacitance is represented by capacitors C23 to C28, switched by the frequency range-setting buttons. The current is variable by one or more of:

the frequency dial knob

the mark/space ratio control function

the internal sweep oscillator

an external signal for voltage control of frequency (VCF).

It will be convenient to work backwards from the basic oscillator to the various sources of frequency control.

Voltage-to-current transducer

In both linear and logarithmic modes the timing current is controlled by a manually-set voltage and by a sweep voltage (if any). It is convenient to consider linear and logarithmic modes separately.

Linear operation

In this mode frequency control derives from the voltage at the output of amplifier AP, pin 7. The current in the timing capacitor is proportional to that voltage. Several controls affect the constant of proportionality.

Fig 3.7 shows a simplified version of the circuit immediately following this amplifier, when switched into the linear mode. Amplifier AY and Tr42 form a voltage follower so that the lower end of R77 is at $-V_o$. AX, Tr5, R77, R78 form an inverting amplifier causing the emitter of Tr6 to be at $+V_o$. These potentials are applied to a resistor network which can be adjusted to provide a wide range of currents.

Its simplest form is obtained with the 'lin-log' switch set to 'Hz/1000'. The 1MΩ resistors R77 and R78, in conjunction with V_o, determine the current flowing into Tr6 and Tr42. The collector currents of these transistors are each fed into a current mirror based on an operational amplifier (AL, AM), whose output (Tr20, Tr19) supplies the timing current to the basic oscillator. In this condition the mark/space controls are inoperative.

With other settings of the 'log/lin' switch R77 and R78 are shunted by other resistors. For instance in the normal 'lin' position the shunt is R81, whose resistance is 1000 times less than that of R77 and R78, thus raising the timing current (and hence the frequency) one thousandfold.

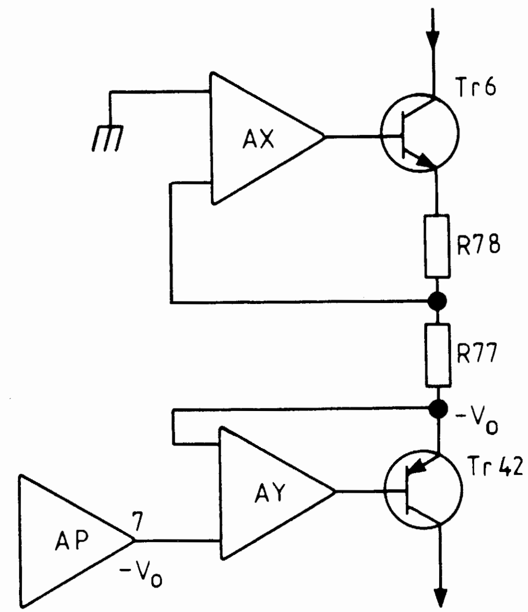


Fig 3.7

In any of the mark/space ratio control group of positions the circuit is further modified so that the emitters of Tr6, Tr42 are grounded by separate resistors. In the ⊔⌐ and ⌐⊓ positions one of these is R86 and the other is half of the variable mark/space ratio control R88. In the Hz/10 position both halves of R88 are used. Thus the current to one or both of Tr6, Tr42 is reduced by a controllable amount, increasing the duration of the corresponding half-period. The Hz/10 setting gives rise to a frequency fixed at approximately one-tenth the scale value, with a mark/space ratio continuously variable between 19:1 and 1:19.

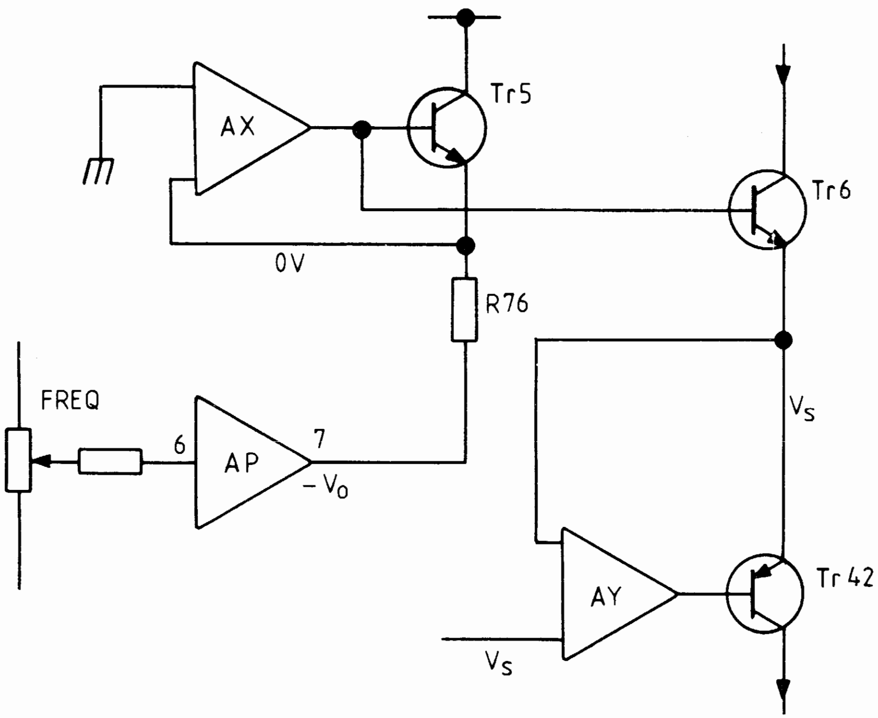


Fig 3.8

V_o is determined by the two inputs to input AP pin 6. One is derived from the frequency control potentiometer R30 via a voltage follower AP pin 8. In external mode the input to AP pin 3, and hence also the supply to this potentiometer, is constant; the external control voltage comes directly to AP pin 6 via R26 from the panel socket. In internal mode the input to AP pin 6 is modified by superimposition of a portion of the sweep oscillator output, adjustable by R24.

Logarithmic operation

In logarithmic mode the manually-set control voltage only is applied as an input to amplifier AP pin 6 to determine its output, V_o; the sweep control takes a different path. Internal sweep current from the collector of Tr3, or external sweep from R26, enters the network R31 to R34 of which R33 is a thermistor, to produce a sweep control voltage V_s shown in the simplified diagram fig 3.8.

Amplifier AY and Tr42 form a voltage follower to establish the voltage V_s at the emitters of Tr42, Tr6. AX and Tr5 likewise hold the emitter of Tr5 at ground potential. The potentials of the bases of Tr5, Tr6 must be such as to satisfy in Tr5 the relationship

$$V_{be} = V_t \ln ki$$

which applies to all the transistors, where V_{be} is the voltage of the base with respect to the emitter, i is the emitter current, and for the moment it may be assumed that all the transistors have the same constants.

Tr5's base potential is therefore $V_t \ln kV_o/R76$. For Tr6 therefore

$$V_{be} = (V_t \ln kV_o/R76) - V_s$$

and this must equal $V_t \ln ki$ where i now denotes the emitter current of Tr6, from which it follows that

$$i = \frac{V_o}{R76} e^{-V_s/V_t}$$

This current (ignoring the comparatively small base currents) flows, as in the linear case, in the collectors of Tr5, Tr42 and into the current mirrors which establish the timing current.

The timing current, and therefore the frequency, are therefore proportional both to the frequency control voltage V_o and to the exponential of the sweep voltage V_s, as is required.

The assumption that V_t is the same for all the transistors is well justified, since V_t is a physical constant of the semiconductor junction of which they are made. However geometrical variations can vary k. This variation is easily compensated for by applying a small offset in V_{be}, for which provision exists in the offset adjustments associated with several of the operational amplifiers.

Sweep oscillator

A considerably simplified circuit of the sweep oscillator is shown in fig 3.9. AG is a type 3080 transconductance-type operational amplifier. It has a very high output impedance and both current and voltage input terminals. As used in the SFG611 the differential pair of voltage terminals (pins 2 and 3) receives signals which in general saturate the device and therefore determine only the direction of the output current; the magnitude of the output current is then determined by the 'bias' current into pin 5. This current is set by the 'sweep rate' control potentiometer, acting through a logarithmic amplifier. The current in R15 flows mainly into Tr2, establishing a volt drop across it which is little varied by circuit conditions, but provides compensation for temperature variations in Tr1. Tr1 diverts into the bias terminal of AG a small portion of this current, which is logarithmically related to the setting voltage, due to the transistor characteristic.

The output current of AG passes into a capacitor, whose potential therefore rises or falls according to the current direction. This voltage is passed by cascaded voltage followers (ignoring for a moment the pair of diodes, discussed later under 'marker') to a further 3080, AH, serving as a comparator, which drives some logic. Clamp diodes at the comparator output limit the voltage there to levels suitable for the logic.

Two outputs from the logic are connected to AG's pair of voltage input terminals. When the instrument is set to 'run', one output is derived from the AH comparator after three logic inversions, and the other after two inversions, and the latter output is fed back to the comparator to provide positive feedback around comparator and logic. The resulting action is as follows.

Suppose that the signal at B in fig 3.9 is positive, that A is at ground potential, and that a current bias signal is being supplied to AG. Current from AG will charge the capacitor so that the potentials of the outputs of AF and AP pin 14 will rise until, when the latter's output exceeds the positive logic potential at B, comparator AH switches. At this point the logic outputs reverse, the change to ground potential at B locks the comparator in the reverse condition and the capacitor is now discharged. The process reverses again when AP pin 14 goes negative, again switching the comparator AH.

The sweep output from AP pin 14 is available externally from the 'TB out/VCF in' socket whenever internal sweep is selected.

Outline of the logic

The logic may be conveniently thought of in three sections. Each is fairly straightforward, although it is tedious to follow signals all the way through it.

The first section is combinational logic formed by the switches and gates connected to them. Next comes the pair of cross-connected gates AC, output pins 10 and 11, which has both outputs forced to 1 in 'run' mode, but in other modes becomes a set-reset flip-flop. Finally there are separate clusters of combinational logic determining respectively (AJ) the outputs which control the analogue circuits and (AB) the 'trig' socket output.

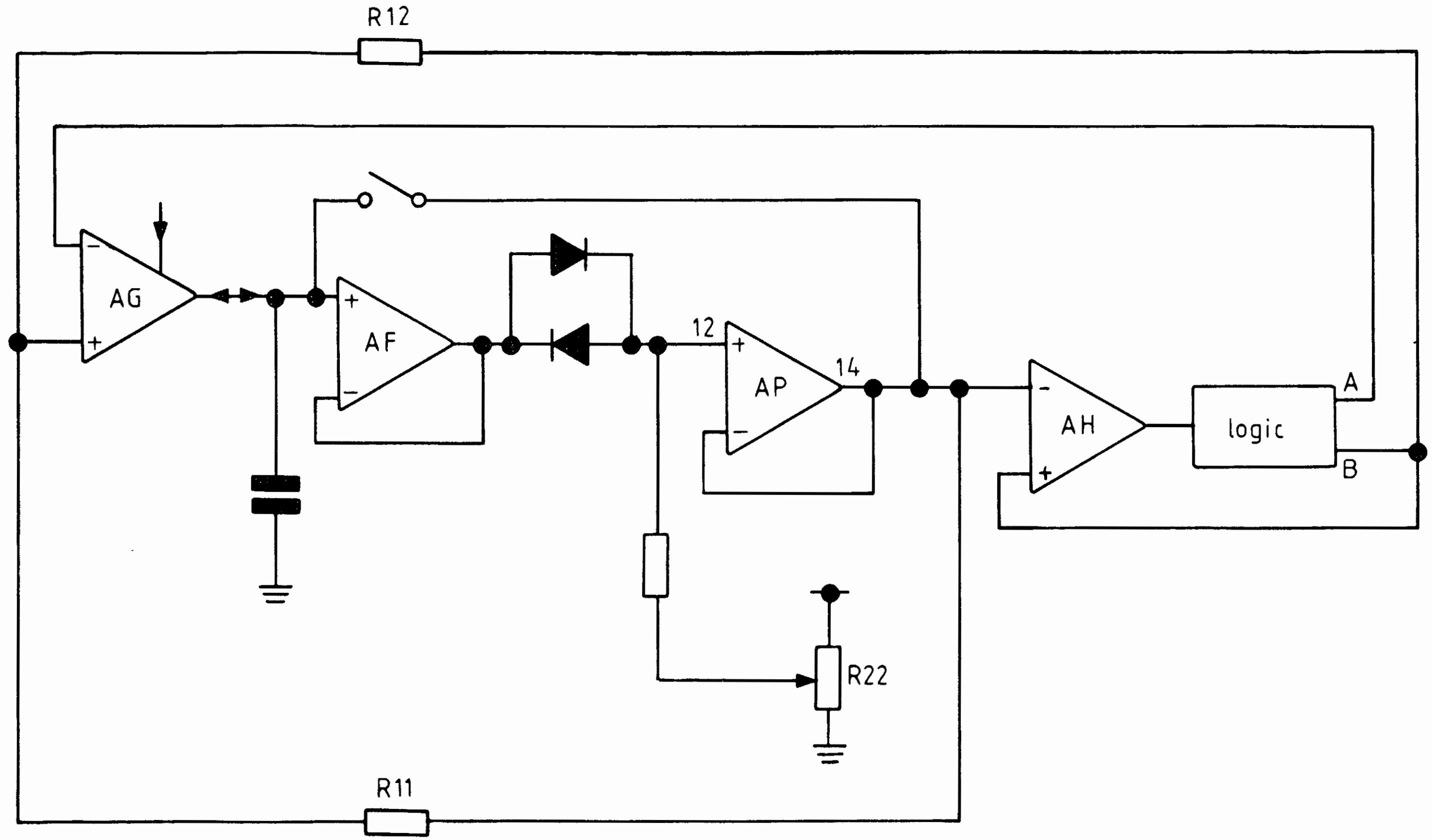


Fig 3.9

The flip-flop AC10, 11 controls the logic outputs to the analogue circuits as follows. 'Run' mode has already been described. Otherwise both outputs (A and B in fig 3.9) follow the upper output of the flip-flop. Although their effects on AG appear to conflict, resistors R12, R11 ensure that output B of the logic over-rides the other output (only a small difference between the voltages being necessary because of the comparator action of AG). Since a positive signal at B increases the positive sweep voltage and the frequency, we may therefore associate the pin 11 output of flip-flop AC10, 11 with raising the frequency.

Setting the sweep range

If the 'max/set/min' switch S15 is moved to either end position, the output of the NOR gate which normally supplies the sweep rate control potentiometer goes to zero, thus causing the sweep rate control amplifier Tr1 to deliver maximum bias current to AG. Acting through the following gates the switch also sets flip-flop AC10, 11 one way or the other (irrespective of the state of Sw14). The sweep oscillator ouput is thus rapidly driven to the maximum or minimum value according to the switch 'max' or 'min' setting.

Single-sweep operation

If the 'run/single-shot/trig' switch S14 is moved away from the 'run' position, the lag network R5, C1 delays the rise of the input to the following gate sufficiently to ensure that the flop-flop AC10, 11 is 'cleared', i.e set to the state which causes a decrease in frequency. The frequency thus runs down at the normal set rate to its minimum value. Setting the switch to 'trig' sets flip-flop AC10, 11, so that a normal half-cycle of rising-frequency sweep takes place. The flip-flop will remain set, so that separate action is needed to reset the flip-flop and the frequency, such as use of the 'set min' switch, which can also be used to hasten setting-up after 'run' if desired.

Trigger output

The flip-flop AJ3, 4 is set (G true) by operating the 'trig' switch and cleared by flip-flop AC10, 11 being cleared. It is therefore set for the duration of a single-shot sweep. This signal is combined with others in three gates which finally drive Tr4 whose collector drives the 'trig' socket on the panel. The 'trig' output goes low when the frequency is increasing during 'run', and for the duration of a single-shot sweep. It is thus suitable for use as an oscilloscope trigger on 'run' and as a pen-lift control when pen-recording a single sweep.

Marker

The back-to-back diodes D4, D5 provide a marker on the screen of an oscilloscope used to display the swept output. The diodes do not conduct significantly until a potential somewhat exceeding 0.6V is applied to them. If the marker control R22 has its slider set to a potential v, say, then fig 3.10 shows the resulting relation between the output of AF and pin 12 of AP. Consequently as the sweep voltage rises or falls through the value v, the input (and therefore output) of the latter hesitate at the

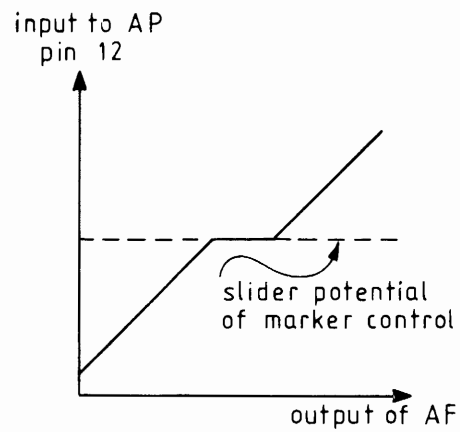


Fig 3.10

momentarily constant value v, causing a bright spot in the oscilloscope trace. By altering v, the point in the sweep at which the hesitation occurs can be moved.

In order to set the marker to indicate a particular frequency, the 'marker position' pushbutton connects the sweep oscillator output (AP pin 14) back to AF's input, thus bringing to zero the potential across the diodes. (The influence of AG is negligible in this configuration, because of its high output impedance). The sweep output is therefore now determined only by v, the marker potential. Sweep voltage and frequency of the main output corresponding to the marker can now be measured.

Power supplies

A conventional combination of transformer, rectifier and reservoir capacitors delivers power nominally at ±25V to five integrated-circuit regulators. One of these, BG, is part of the output amplifier and its output is adjustable by the output offset control R69. The others deliver fixed outputs. One of them, BE, delivers −15V for the output amplifier, while the others deliver +15V, +5V and −15V for the remaining circuits.

MAINTENANCE

SECTION 4

Access

WARNING

Before working on the instrument with the cover removed the following precautions must be observed.

Disconnect all external connections from the instrument before removing the cover. After removing the cover observe carefully where the components in the mains (line) supply circuit are located. They are all between a small vertical panel and the back panel, but note particularly that if the lower half of the cover is removed this exposes live connections to the power switch.

EVERY PART OF THE MAINS CIRCUIT CAN CARRY DANGEROUS VOLTAGE. WHILE THE POWER CABLE IS CONNECTED, AVOID ALL CONTACT.

There is access to all the components by removal of the cover. To remove it, grasp one end of the carrying handle firmly and pull it outwards, fig 4.1, thereby releasing the centre cap. Firm pressure is needed. Remove the other end of the handle similarly. Then remove with a Pozidriv 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 taken 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.

In normal use the handle acts also as a stand, and can be repositioned by easing the two ends outwards simultaneously.

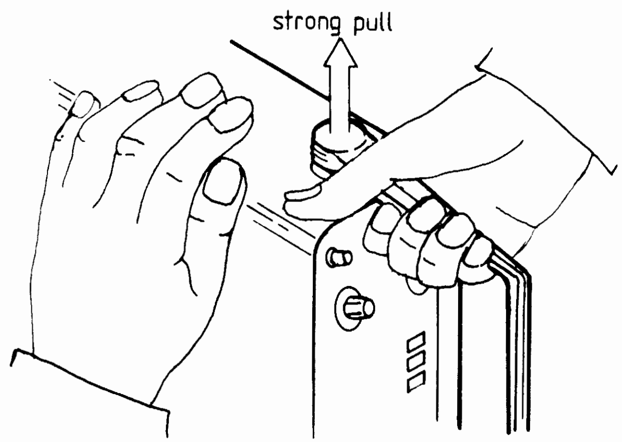


Fig 4.1

Internal adjustments

Quite severe malfunctions can occur, even in a sound instrument, if the internal adjustments are incorrectly set. Before assuming a fault, check whether the following procedure will provide proper operation. This is a systematic procedure for adjusting a correctly-working SFG611 to specification; it is not a fault-finding procedure.

An oscilloscope, an accurate voltmeter capable of reading 10V d.c, a distortion meter and a frequency meter or the equivalent are required. The SFG611 should be removed from its case.

Setting-up procedure.

Initially set the controls as follows:

control	*setting*
run—s/s—trig	run
sweep ext—int	ext
lin—log	lin
frequency range	10k—100k
frequency (Hz)	10 (for 100kHz)
waveform	triangle
offset	central
output	10 (maximum)
attenuators	out
power	on

1. Connect the oscilloscope to the monitor ∿ output and adjust R91 as necessary to obtain oscillation.
2. Set the monitor ∿ waveform to exactly 1.0V peak-to-peak by adjusting R119. Adjust R117 to make the waveform symmetrical about zero.
3. Connect the oscilloscope to the 'max' end of R37. Press the square waveform selector button. Adjust R139 so that the displayed square wave is about 1.5V peak-to-peak, adjust R128 until it is symmetrical about zero volts. These two adjustments will interact.
4. Connect the meter across the load of the output stage, which is the row of six paralleled resistors near the back of the component board. The positive ends are nearer the front. Adjust R42 to bring this voltage to 10 volts.
5. Temporarily transfer the +ve meter lead to 0V. The meter is now connected across the output. Adjust the offset control until it reads zero. Check the 10V reading again with the former meter connection restored, then disconnect the meter.
6. Connect the oscilloscope to the main output. Set the output control to maximum. Select square wave output. Adjust the output square wave for optimum top and bottom flatness using R49 and C12.
7. Select sine wave output. Adjust R159 and R117 for minimum distortion. Use the distortion meter for fine adjustment.

8. Adjust R153 to give an output of about 11V peak-to-peak. Adjust R152 to make it symmetrical about 0V.

   Check the distortion and re-do step 7 if necessary.

9. Set the sine and square wave output amplitudes and levels to match the triangle wave as follows:

   With triangle wave selected adjust the 'offset' control for zero d.c component in the output. Without disturbing the shaft, move the knob to the central mark. To do this, remove the cap of the knob, fig 4.2; holding the knob firmly, slacken the collet nut, freeing the knob. When the knob is placed as required, tighten the nut and replace the cap.

   Select square wave output. Adjust R139, R128 to give the same peak-to-peak amplitude as that of the triangle wave, with zero d.c component.

   Select sine wave output. Adjust R153, R152 to give the same peak-to-peak output and zero d.c component.

10. Connect the frequency meter to the output. (If not available, adjust the oscilloscope to display about 10 cycles on the screen). Adjust R75 so that on switching between 'log' and 'lin' the frequency change is minimised.

11. Set R84, R95 mid-way. Set the main frequency dial ('Hz') to give an output frequency of 10kHz, then move it on the shaft so that the '1' calibration mark is correct, figs 4.2, 4.3. Since re-adjustment may be needed, do not replace the cap immediately, and tighten the collet nut only lightly. Set the dial to the '10' calibration mark and adjust R71 to give a frequency of 100kHz. These adjustments should be checked and redone as necessary until both calibrations are correct. After this the collet may be tightened and the cap replaced on the knob.

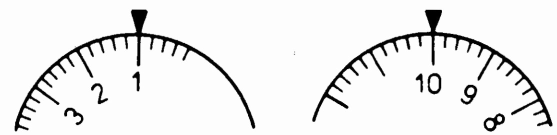


Fig 4.2

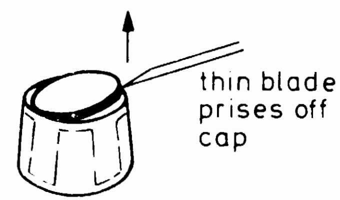


Fig 4.3

12. With the frequency dial at '10' switch the 'lin-log' switch to Hz/1000. Adjust R84 and R95 to bring the period of each half of the waveform respectively to 5ms, giving a 100Hz symmetrical waveform.
13. Select the 100Hz to 1kHz range. Set the frequency dial to '10' and bring the frequency to 1kHz by adjusting R73.
14. Select the 10Hz to 100Hz range. With the frequency dial at '10' bring the frequency to 100Hz by adjusting R74.
15. Switch to 'Hz/1000', press the 10k–100k range selector button and adjust the frequency to 100Hz. Then without moving the frequency dial again press the 1M–10M selector button and bring the frequency to 10kHz by adjusting C33.
16. While on this setting, observe the triangle waveform on the oscilloscope and adjust R91 to give equal-sized 'flats' at the top and bottom of the waveform.
17. Switch to 'lin', select 10kHz to 100kHz range and set the frequency to 100kHz. Then without further movement of the dial select the 100k–1M range. If the frequency is not 1MHz within, say, 2% then replace R107 (adjust-on-test, value nominally 10 ohms) with a different resistance. The frequency at the high end of the range is increased by about 0.4% for every additional 1 ohm. Keep leads short!
18. Still maintaining the position of the dial, select the 1M to 10M range. If the frequency is not sufficiently accurate at 10MHz, replace R106 (adjust-on-test, nominally 110 ohms) with a different resistance. Again the frequency at the high end of the range is increased by about 0.4% for every additional ohm. Keep leads short!

Component Replacement Table

The SFG611 is not critical with regard to most of the component types but proper performances can only be expected if component replacements are reasonably similar.

A brief general specification of suitable components is given in this table.

Type	*Rating*	*Tolerance*	*Fixing*	*Position*
Resistor carbon film	¼ W	5%	PWB hole centres 0.5" Resistor dia 0.1" or less	R1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 17, 18, 19, 20, 21, 25, 27, 28, 29, 31, 32, 34, 35, 45, 50, 51, 59, 60, 61, 79, 80, 90, 92, 106, 107, 108, 112, 116, 120, 123, 124, 125, 126, 129, 131, 132, 133, 134, 135, 136, 137, 138, 141, 142, 144, 145, 147, 148, 151, 154, 155, 156, 163, 164, 165, 166.
Resistor metal film		1%		R23, 26, 39. 40, 41, 43, 44, 46, 48, 52, 53, 55, 56, 57, 58, 68, 70, 72, 76, 77, 78, 81, 82, 83, 85, 86, 87, 93, 94, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 110, 111, 114, 115, 121, 122, 127, 149, 150, 160, 162.
Resistor carbon	⅛ W	10%	PWB hole centres 0.3" Dia. 0.1"	R36, 38, 47, 54, 89, 109, 113, 118, 140, 143, 146, 157, 158, 161, 167.

Type	*Rating*	*Tolerance*	*Fixing*	*Position*
Resistor metal film	1W	1%	PWB hole centres 0.8" Dia. 0.2"	R62, 63, 64, 65, 66, 67.
Preset cermet potentiometer			see fig 4.6	R42, 49, 71, 73, 74, 75, 84, 91, 95, 117, 119 128, 139, 152, 153.
Front panel controls				R13, 22, 24, 30, 37, 69, 88.
Capacitor aluminium electrolytic	25V	+50 −10%	rear panel	C34 & 35
Capacitor tantalum electrolytic bead	20V	±20%	PWB hole centres 0.2"	C8, 14, 15, 16, 17, 21, 22, 40
Capacitor ceramic disc	20V	+50 −25%	PCB 0.2"	C6, 7, 9, 11, 18, 19, 20, 29, 31, 32, 33, 36, 37, 39
Capacitor PEPT film	⩾ 63V	±10%	0.3%	C1, 3, 4, 5, 10, 13, 30
Capacitor PEPT film	⩾ 63V	±10%	0.4"	C2

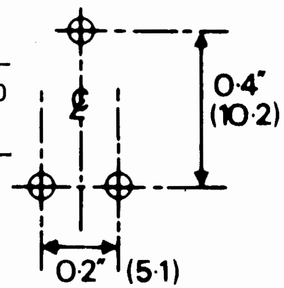


Fig 4.6

Type	*Rating*	*Tolerance*	*Fixing*	*Position*
Capacitor tubular ceramic	750V	±5%	0.3″	C38
Capacitor trimmer compression mica			0.6″	C12, 23
Capacitor polystyrene	100V	±1%	see PWB	C24, 25, 26
Capacitor polycarbonate	63V	±10%	see PWB	C27, 28

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*
ZTX108C	2N930	BC108C
ZTX213C	2N3251	BC178
ZTX313	2N2369	BSX20
ZTX450	No suitable alternative	
ZTX510	2N2894	BSX29

diodes BAX13 may be replaced by 1N914

Other components are listed below with the manufacturers' names.

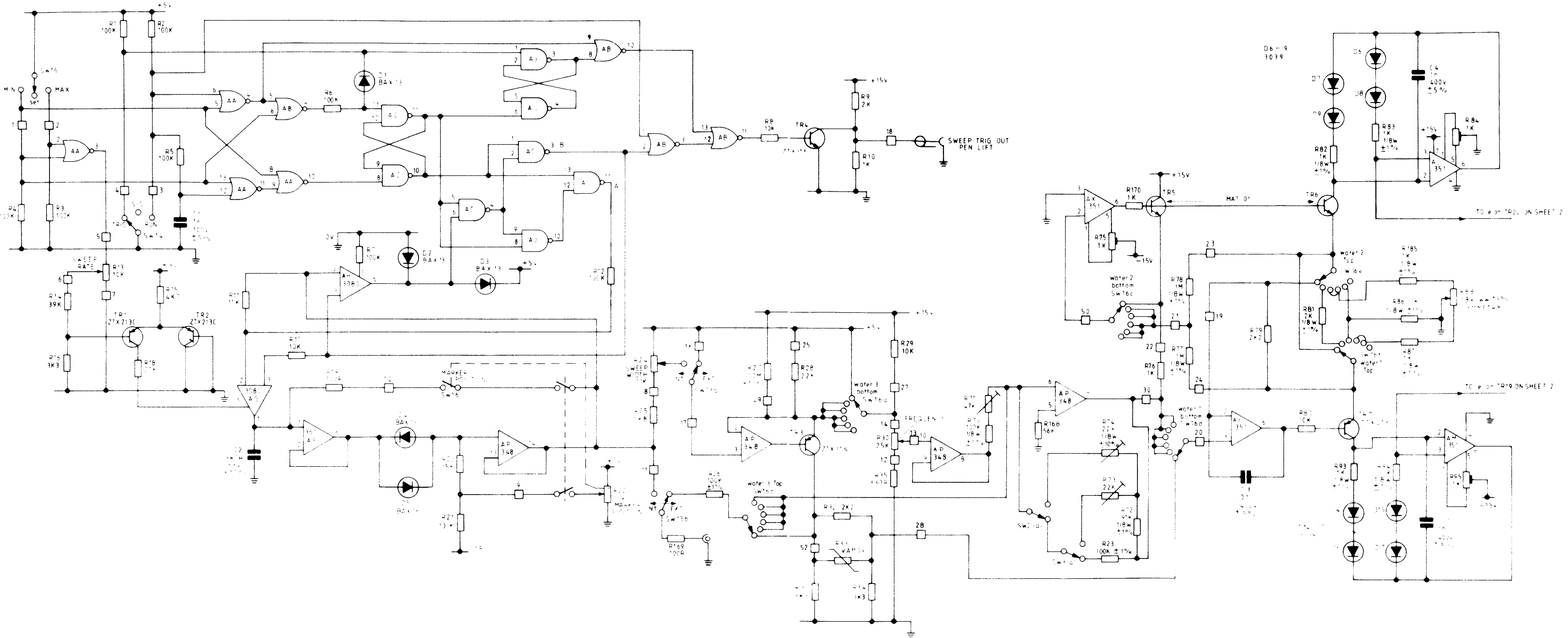
Type No	*Manufacturer*
2N5912	Siliconix
MAT01GH	Bourns
CA3039	RCA
CA3080	RCA
CD4001BE	RCA
CD4011BE	RCA
SP9680	Plessey
SL3127CDP	Plessey
LM348N	National
LF351N	National
μA78GCUI	Signetics
μA78L05CS	Signetics
μA78L15CS	Signetics
μA79L05CS	Signetics
μA78M15CU	Signetics
μA79M15CU	Signetics

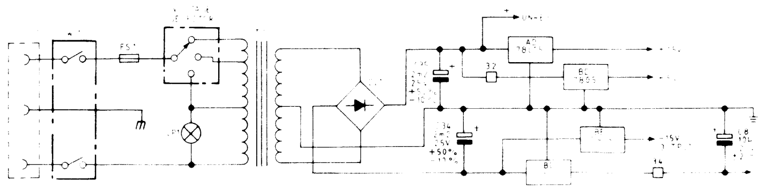
Other components including mains transformer and pushbutton switches are supplied to Feedback specifications and should be ordered through Feedback Instruments Limited, Crowborough, Sussex.

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.





NOTES:

1 ALL RESISTORS 1/8w ± 5% UNLESS STATED

2 351's pin 4 −15V pin 7 +15V UNLESS STATED
3080 pin 4 −15V pin 7 +15V UNLESS STATED
348 pin 4 +15V pin 11 −15V

Fig 4.4 Circuit diagram, drg. 1-611-9813 sht 1, iss 3.

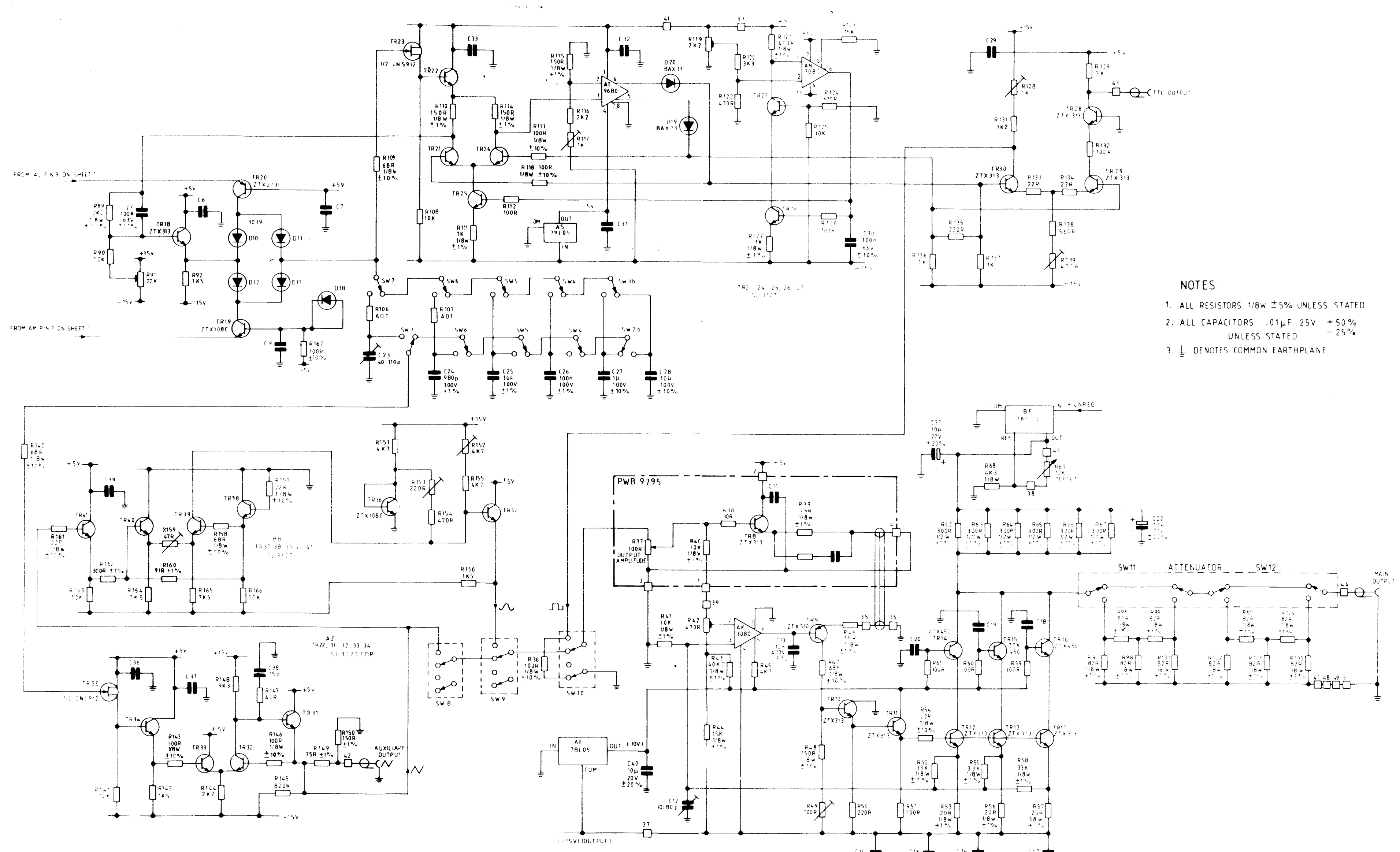


Fig 4.5 Circuit diagram, drg. 1-611-9813 sht 2, iss 2.