simple function generator

A function generator is a versatile and extremely useful device, which provides the constructor with a simple and efficient means of testing his home-built projects. It should therefore be a virtually indispensable part of any hobbyist's basic equipment.

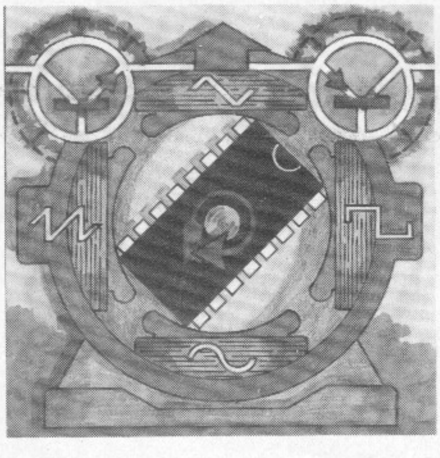
Most commercially available function generators suffer from the distinct disadvantage that they represent a pretty hefty investment for the amateur constructor, who, unlike a service workshop for example, is unlikely to ever make full use of the wide range of facilities offered by a professionally produced instrument. For this reason, the circuit described here, which incorporates a special function generator IC, type XR 2206, was designed to strike the right balance between cost and performance. Although lacking 'top-notch' specifications, it offers a wide range of waveforms, is both simple to build and calibrate, and is extremely easy to operate.

The function generator can switch between sine, square, triangle, sawtooth and rectangular pulse waveforms. It has a linearly calibrated frequency scale which covers a range of 9 Hz to 220 kHz. In addition to a special output stage which ensures a low output impedance, three calibrated output voltage ranges are provided: 0 ... 10 mV, 0 ... 100 mV and 0 ... 1 V (RMS). The circuit can be calibrated without the assistance of an oscilloscope, and the compact design means that it can be easily mounted in a neat case.

The XR 2206

The circuit utilises the purpose-built IC function generator, type XR 2206 (Exar), the pin configuration and internal block diagram of which are shown in figure 1. The heart of this IC is the VCO (which in fact is a current controlled oscillator, CCO, though the manufacturer's data calls it a VCO). The frequency of the oscillator is determined by the external capacitor and resistor, C_{ext} and R_{ext}. A control current, I_f, is switched via integrated current switches to one of the two current outputs (pin 7 or 8) of the IC, depending on the logic level of the selector input (pin 9), thus providing the possibility of frequency shift keying (FSK).

The VCO output is buffered by an integrated transistor, the collector of which is accessible at the synchronisation output, pin 11. This output provides a rectangular pulse waveform. In addition the VCO signal provides the basis for the signal generation carried out in the multiplier and sine converter section. Pins 13 . . . 16 allow adjustment of sine purity (distortion factor) and symmetry. The DC level at the signal output can be adjusted via pin 3.



The sine, triangle and sawtooth waveforms are buffered via a voltage follower, and are brought out at the low impedance output, pin 2.

The amplitude of the sine/triangle output can be varied linearly by a control voltage at AM input pin 1 of the IC. This makes amplitude modulation of the oscillator signal possible.

The voltage between the current connection pins 7 and 8 is stabilised to 3 V (typically) within the IC. As this reference voltage exhibits only a very small temperature coefficient (6×10^{-5} V/°C), the temperature stability of the oscillator frequency is also very good.

The control current I_f may vary between 1 μA and 3 mA; however, optimum temperature stability is obtained in the range between 15 μA and 750 μA. The frequency of the VCO is determined by this current I_f and the value of the external capacitor C_{ext}, the control current being adjusted by means of a resistance R_f between pins 7 or 8 and earth. The equation for the frequency is as follows:

$$f = \frac{I_f}{3\,C_{ext}} \quad (Hz, A, F)$$

$$f = \frac{1}{R_{ext}\,C_{ext}}$$

As a result of the above function the graph of frequency versus value of R_{ext} is not linear but hyperbolic (see figure 2, curve a). It would be possible to obtain an approximation to a linear curve by using an anti-logarithmic potentiometer. However, by means of a little ingenuity it is possible to vary the control current linearly, so that the resultant frequency scale will also be linear (see figure 2, curve b).

This is done as follows. A constant voltage of 3 V is present at pin 7 of the IC. The current which flows from this pin to earth is directly proportional to the

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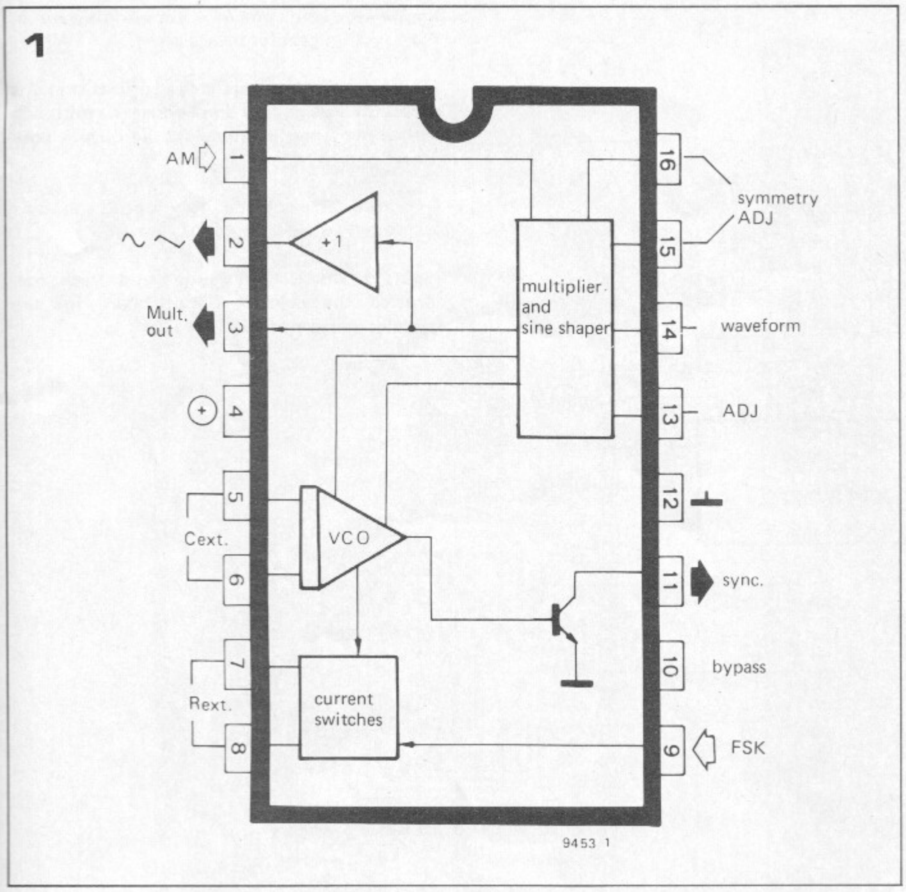

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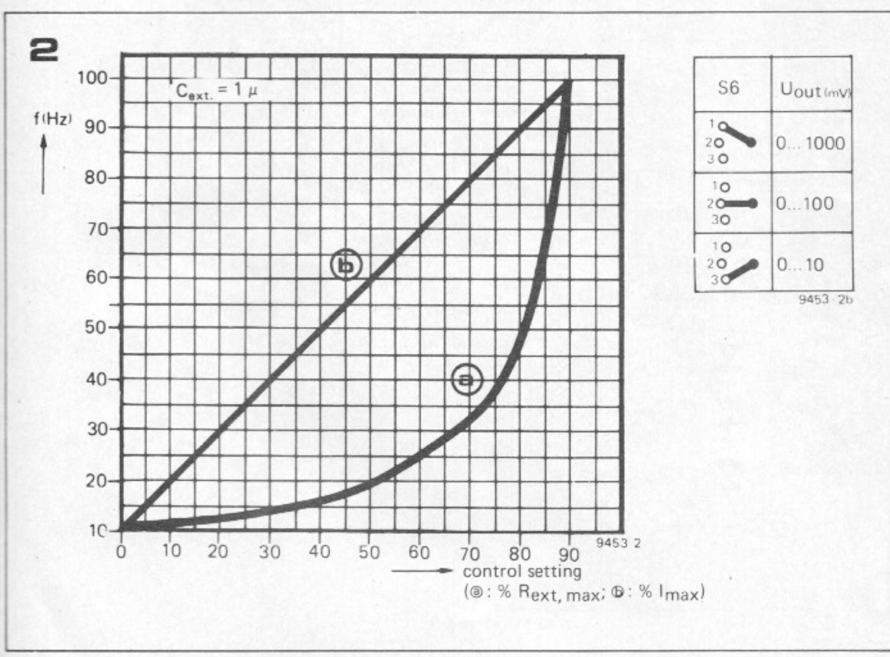

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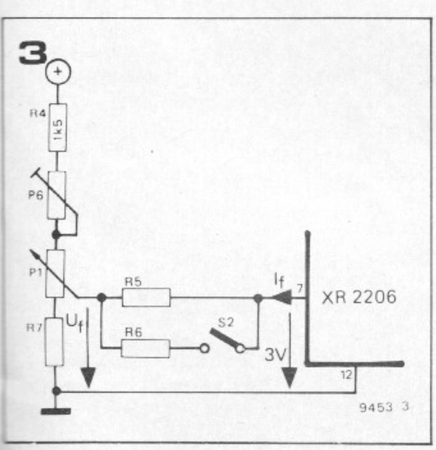


Figure 1. Internal block diagram of the function generator IC, XR 2206.

Figure 2. The principal feature of this function generator is the linear frequency scale, which considerably improves ease of operation.

Figure 3. This partial circuit configuration, with the XR 2206, produces an almost linearly calibrated frequency scale.

output frequency, so that a linear change in this current will, of course, cause a linear change in the frequency. In figure 3 this current change is effected by means of the voltage divider R4, P1, P6 and R7. The component values of this divider are so chosen that the voltage U_f at the wiper of P1 may vary between 0.3 and 2.8 V. This voltage determines the voltage drop across R5 (= 3 V – U_f) and, by virtue of Ohm's law, the frequency-determining current I_f which flows through this resistor. Since there is a linear relationship between voltage drop and current, a linearly calibrated scale for the adjustment of frequency can be obtained using a linear potentiometer:

$$I_f = \frac{3\text{ V} - U_f}{R_5}\text{, so}$$

$$f = \frac{3\text{ V} - U_f}{3 \times R_5 \times C_{ext}}\ (\text{Hz, V, }\Omega\text{, F})$$

When switch S2 is closed, and assuming that R5 = R6, then the control current is doubled, thereby doubling the frequency of the VCO. The adjustment range of P1 enables the frequency to be varied over slightly more than a decade, i.e. from 9 Hz . . . 110 Hz for example. Fine adjustment is achieved by means of P6.

The generator

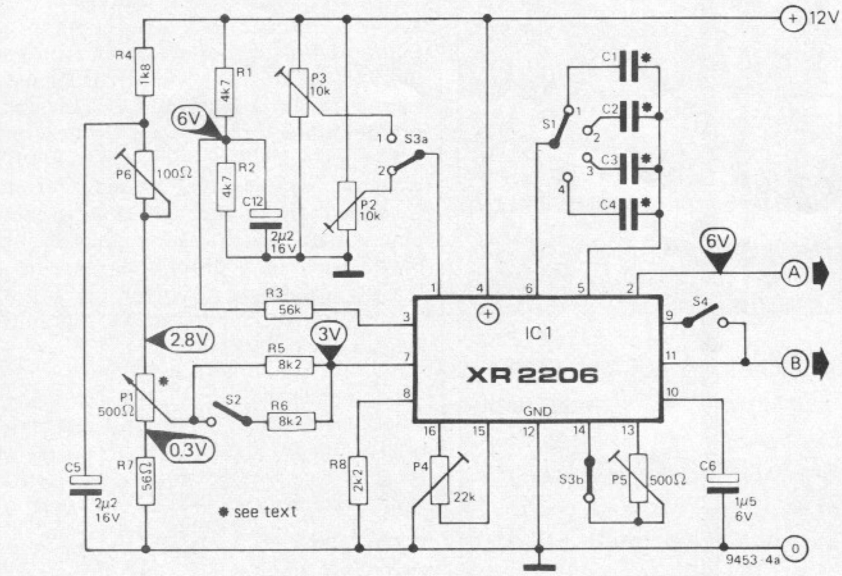
The complete circuit diagram of the generator is shown in figure 4. Pin 2 is the output for sine, triangle and sawtooth waveforms, whilst squarewave and rectangular pulse waveforms are available at pin 11. C1 to C4 are the frequency determining external capacitors (C_{ext}). Switching between frequency ranges is effected by means of S1. C5, C6 and C12 are decoupling capacitors.

The voltage divider R1/R2 halves the supply voltage, and via pin 3 sets the DC voltage level of the IC. As a result the DC voltage at pin 2 is also $\frac{U_b}{2}$ = 6 V.

The amplitude of the output signal may be varied by means of P2 and P3. The adjustment is carried out separately for sinewave (P2) and triangle/sawtooth (P3) in order that the peak-peak value of all three voltages be the same; S3a allows for switching between P2 and P3. The symmetry of the triangle and sine waveforms can be adjusted by means of potentiometer P4, whilst the distortion factor of the sine signal can be varied by means of P5. Switching between sine and triangle waveforms is achieved by S3b.

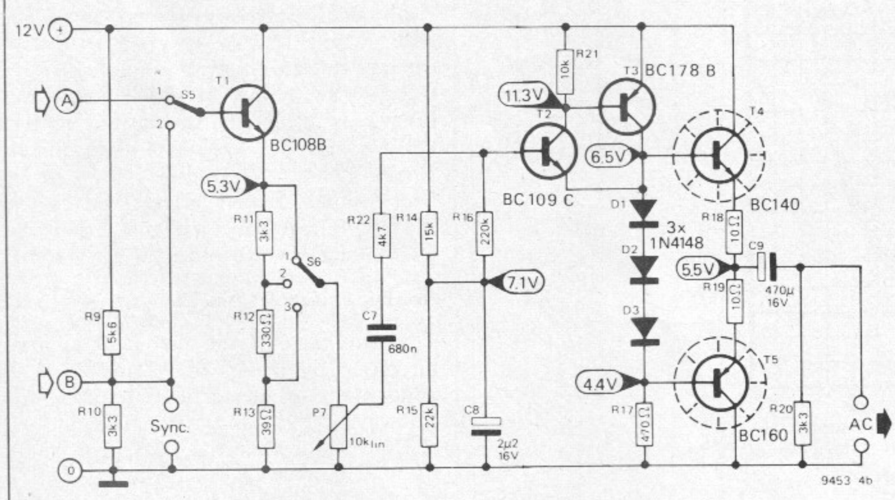
When switch S4 is closed a sawtooth signal is present at output A. The integrated current source will then switch between pin 7 and 8 at a rate equal to the frequency of the rectangular pulse signal at output B, thus providing an 'automatic' frequency shift keying. The slope of the trailing edge is determined by the value of R8, which should be not lower than 1 k.

4a



S1	C	f [Hz]	S2 fx2 [Hz]
1	1 μF	9. . .110	18. . . 220
2	100nF	90. . . 1100	180 . . . 2200
3	10 nF	0,9 . . . 11 kHz	1,8 . . . 22 kHz
4	1 nF	9 . . . 110 kHz	18 . . . 220 kHz

4b



4c

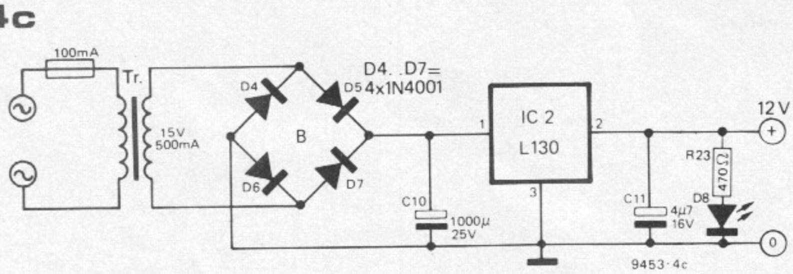


Figure 4a. The complete circuit diagram of the function generator section.

Figure 4b. The output stage ensures that the generator has a low impedance output and allows precise adjustment of the output voltage.

Figure 4c. The power supply is built round an integrated voltage regulator.

Figure 5. Component layout and track pattern of the printed circuit board for the function generator (EPS 9453).

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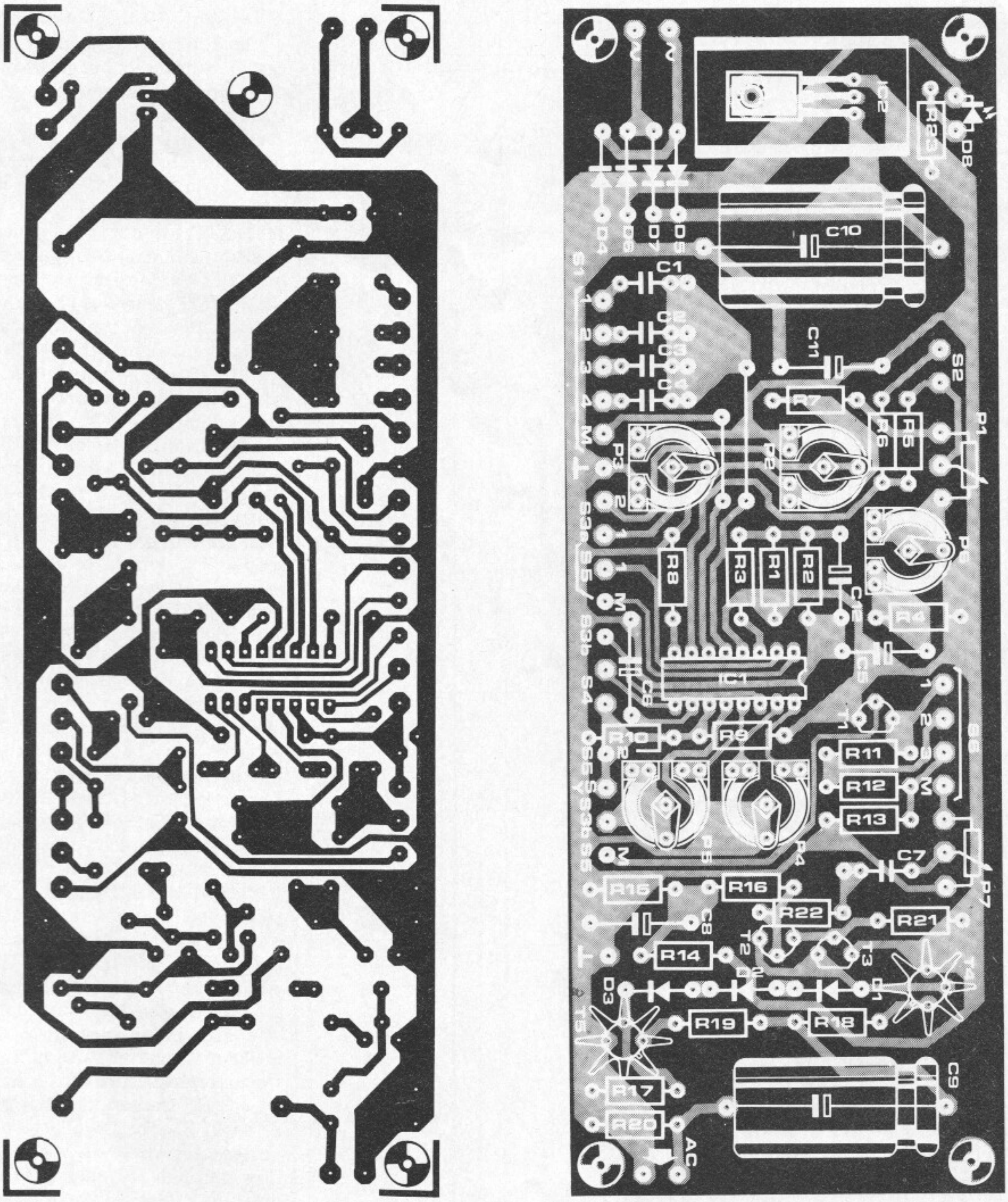

Parts list

Resistors:
R1,R2,R22 = 4k7
R3 = 56 k
R4 = 1k8
R5,R6 = 8k2
R7 = 56 Ω
R8 = 2k2
R9 = 5k6
R10,R11,R20 = 3k3
R12 = 330 Ω
R13 = 39 Ω
R14 = 15 k
R15 = 22 k
R16 = 220 k
R17,R23 = 470 Ω
R18,R19 = 10 Ω
R21 = 10 k

Potentiometers:
P1 = 500 Ω wirewound
P2,P3 = 10 k preset
P4 = 22 k preset
P5 = 500 Ω preset
P6 = 100 Ω preset
P7 = 10 k lin

Capacitors:
C1 = 1 μ
C2 = 100 n
C3 = 10 n
C4 = 1 n
C5,C8,C12 = 2μ2/16 V tantalum
C6 = 1μ5/6 V tantalum
C7 = 680 n
C9 = 470 μ/16 V
C10 = 1000 μ/25 V
C11 = 4μ7/16 V

Semiconductors:
IC1 = XR 2206
IC2 = L 130
T1 = BC 108 (107, 109, 546, 547, 548)B
T2 = BC 109 (107, 108, 546, 547, 548, 549)C
T3 = BC 178 (177, 179, 556, 557, 558)B
T4 = BC 140
T5 = BC 160
D1 . . . D3 = 1N4148
D4 . . . D7 = 1N4001
D8 = LED

Switches:
S1 = multiposition; 1 pole 4 way
S2 = SPST
D3a,S3b,S4,S5 = multiposition; 4 pole 5 way, or 3 switches; DPDT, SPDT, SPST
S6 = multiposition; single pole 3 way

Miscellaneous:
Tr = transformer 15 V/500 mA
100 mA fuse with holder
2 heat sinks, type TO 5 (for T4/T5)
4 sockets, 4 mm diameter

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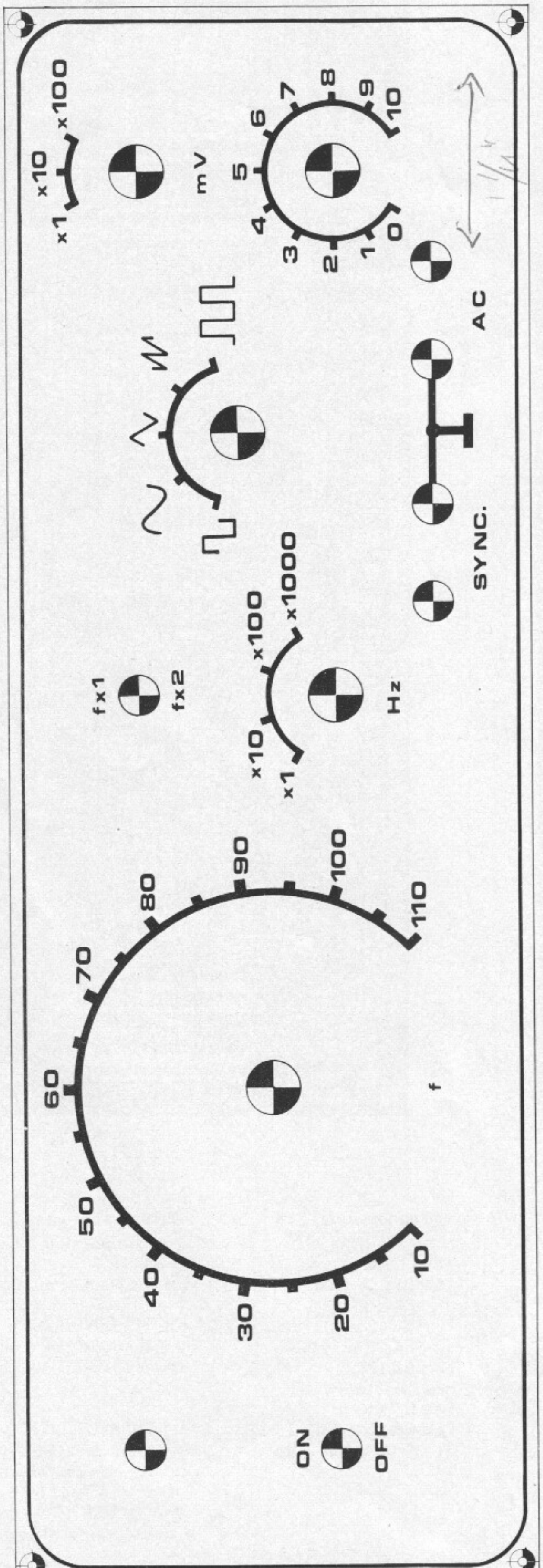

The output stage

A prerequisite of a good signal generator is a low output impedance and a precise, easily adjustable output voltage. Both these conditions are met by the output stage shown in figure 4b.

The sine, triangle and sawtooth signals from output A of the generator stage are fed via switch S5 to the base of T1. The squarewave and pulse signals are present at output B of the generator, this output being the collector terminal of a buffer transistor contained within the IC (see figure 1). R9 is the collector resistor of this transistor, and at the same time, together with R10, forms a voltage divider which limits the amplitude of the squarewave signals to approximately 4.5 V. This ensures that the sync. output is both TTL compatible and short-circuit proof and may therefore be used to drive TTL circuitry, as well as to provide synchronisation and trigger signals for an oscilloscope. T1, which is connected as an emitter follower, buffers the relatively high impedance outputs of the generator (600 Ω and 2000 Ω). The division ratio of the voltage divider R11 . . . R13 are 1, 10 and 100, thus dividing the output amplitude into three switchable (by means of S6) decade ranges. The output voltage can be varied continuously within these ranges by means of P7.

The actual output stage itself consists of transistors T2 to T5, which together form a DC coupled voltage follower. T2 and T3 form an emitter-follower consisting of a complementary Darlington pair, which ensures that the output stage has a high input impedance and that the output transistors T4 and T5, which are also a complementary pair, are driven from a low impedance source. The high input impedance reduces the load on P7 and allows a non-electrolytic capacitor to be used for C7. Via diodes D1 . . . D3 transistors T4 and T5 receive a base bias voltage which causes a quiescent current of approx. 30 mA to flow through the emitter resistors. This measure effectively reduces the distortion of the output stage. C9 AC couples the output signal. The impedance of the AC output is approximately 5 Ω, which means that it can be connected direct to a loudspeaker. The AC output is also short-circuit proof.

The power supply

The supply (see figure 4c) is quite straightforward, being built round an IC regulator which produces a stable 12 V output. Since the supply, generator and output stage are all mounted on the same board, the only external connection required is the mains transformer (approx. 15 V/0.5 A). LED D8 provides on/off indication.

Printed circuit board and front panel

The entire generator is mounted on a single printed circuit board (see fig-

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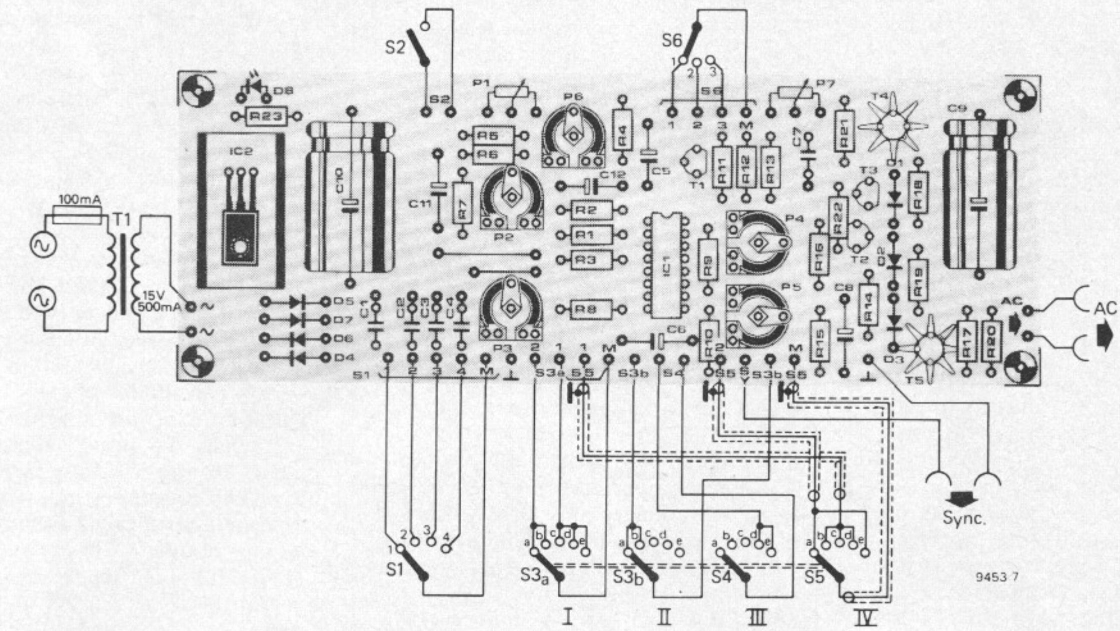

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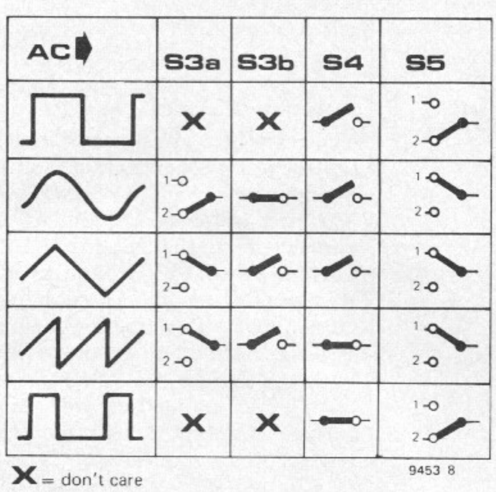

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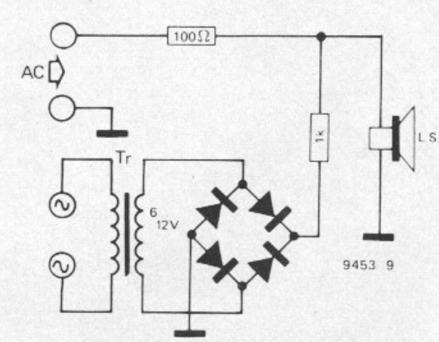


ure 5), thus considerably facilitating construction. Figure 6 shows a suggested design for the front panel.
The individual controls and sockets are arranged in functional groups for ease of operation. The power indicator LED, D8, is mounted above the on/off switch. To the right of them is potentiometer P1 which controls the signal frequency. The large easily-read scale allows fine frequency adjustment. The desired frequency range can be selected using the 'Hz' switch (x 1, x 10, x 100, x 1000); i.e. 10 . . . 110 Hz, 100 Hz . . . 1.1 kHz, 1 kHz . . . 11 kHz, 10 kHz . . . 110 kHz. Each of these frequencies can be doubled using the f x 2 switch, so that eight frequency ranges are available in

Figure 6. The ergonomically designed front panel facilitates operation of the function generator.

Figure 7. Wiring diagram for the sockets, switches and potentiometers situated on the front panel.

Figure 8. The single multiposition switch used to select the desired waveform can be replaced by three separate switches (S3a, S3b, S4 and S5).

Figure 9. Accurate frequency calibration can be achieved by using this simple supplementary circuit.

all. The selector switch for the various waveforms is situated to the right of the frequency controls.

The output voltage is continuously variable between 0 ... 10 mV, 0 ... 100 mV, and 0 ... 1000 mV, the appropriate range being selected by means of the 'mV' switch (x 1, x 10 and x 100). The output signal is taken from the 'AC' terminals, and the synchronisation signal from the 'sync' terminals.

Wiring and construction

To further facilitate construction of the function generator a wiring diagram (see figure 7) is provided. In particular, the wiring of the selector switch for the various waveforms seems fairly complicated at first sight. A 4-pole, 5-way switch is required, which must first be wired 'internally' and then soldered to the appropriate connections on the printed circuit board (see figure 7). It is recommended that screened wire be used for switch S5, since this will prevent crosstalk from the squarewave signal on these leads. The wiring for switches S1, S2 and S6, as well as that for the AC and sync outputs, should present no special problems.

Components

A wirewound potentiometer is recommended for P1, since this type generally has a superior linearity to that of carbon potentiometers. Of course the use of a 10 turn potentiometer with slow motion drive, which would provide extremely accurate adjustment of frequency, is also possible; however this would naturally involve somewhat more expense. Only close tolerance capacitors (MKM) should be used for C1 . . . C4.

It is also worth mentioning that it is, of course, possible to replace the multiposition switch used to select the desired waveform by three separate switches (see figure 8). This solution does complicate the operating procedure slightly, and whether it proves cheaper or not will depend on the type of switch which is used.

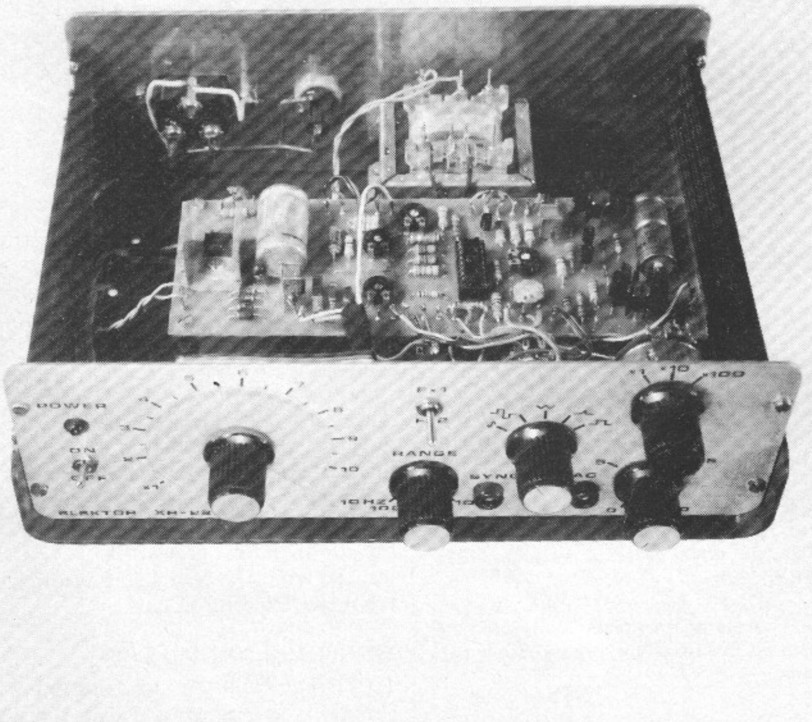
Calibration

After the components have been soldered onto the circuit board and the external switches and potentiometers have been wired up, the entire construction should be carefully checked. Once this has been done power can be applied and the on load supply voltage measured. This should not vary more than 10% from 12 V.

Amplitude calibration

- First of all switch S6 should be set to position 1 (x 100) and potentiometer P7 turned fully clockwise (maximum amplitude).
- Select a sinewave signal with a frequency of approx. 1 kHz.
- Set P2 for minimum amplitude, i.e. turn the wiper to earth.
- Set P4 and P5 to their mid-position.
- Connect a universal multimeter with an AC voltage range of 2 V RMS to the AC output of the generator, and adjust P2 for an output of either 1 V or 2 V RMS.

The above step requires a little clarification. The advantage of selecting the higher output voltage of 2 V RMS is offset by a resultant deterioration in the quality of the waveform at high frequencies (above roughly 50 kHz). Thus, in order to obtain a reasonably pure waveform for frequencies up to approx. 200 kHz, it is recommended that the output voltage be set to 1 V.



To achieve the low distortion factor of typ. 0.5% specified in the IC's data sheet, further calibration using a distortion factor meter is required. In this respect it should be mentioned that, in spite of the carefully designed board layout and the use of screened leads to and from switch S5, there is the likelihood of crosstalk (largely within the IC itself) between the squarewave- and sinewave outputs. At increased frequencies this results in pulse spikes being superimposed upon the sinewave signal. For applications which require a minimal distortion factor the simplest solution to this problem is to short out the squarewave output, thereby removing the source of the distortion.

- Coarse adjustment of the output signal for distortion is achieved using P5, whilst P4 provides fine adjustment. If no distortion factor meter is available, then setting P4 and P5 to their mid-position should give satisfactory results.
- The amplitude of the triangle and sawtooth signals can be adjusted by means of P3. Switch to the triangle waveform, and adjust P3 until the multimeter reads approx. 0.8 V.

Of course the adjustment procedure can also be carried out using an oscilloscope:

sine: by means of P2 set the amplitude to 2.82 V_{pp} (the equivalent of 1 V RMS) or 5.65 V_{pp} (2 V RMS).

triangle: by means of P3 set to 2.82 V_{pp} or 5.65 V_{pp}.

Frequency calibration

There are basically two methods of calibrating the function generator frequency scale.

The first is to use a frequency counter connected to the synchronisation output, set P1 to 100 Hz, and by means of P6 the frequency can be adjusted to correspond with the scale reading.

The second method is to use the circuit of figure 9. The AC voltage of roughly 6 . . . 12 V supplied by the bell transformer is rectified and fed via a 1 k resistor to a loudspeaker. This results in a pulsed DC voltage which has a frequency of 100 Hz, and which is clearly audible, being applied to the loudspeaker. In addition the loudspeaker is fed via a 100 ohm resistor with a 100 Hz sinewave signal taken from the function generator (AC output). Since these two signals add, a beat note is produced as they drift in and out of phase. By means of P6 the frequency of the function generator can then be adjusted until zero beat occurs. In only a very few cases will an absolute zero beat be produced, since both the mains- and the generator frequency are subject to periodic fluctuations. For this reason it is sufficient to reach a low beat frequency of under 5 Hz. ◼