function generator

A function generator is without doubt an essential part of any serious electronics hobbyist's laboratory. It is indispensible wherever sinewaves, triangle waves or square waves are needed. In the January 1978 issue of Elektor we published a design for a function generator and since then it has remained a very popular project. The new design we present here uses the same function generator IC as its predecessor: the XR2206 from Exar. We have, of course, taken note of the advances that the last seven years have brought so this new function generator is a great improvement over the old, being more sophisticated and more capable in many areas.

made-to-measure waveforms

Technical specifications

- **Frequency range:** 1 Hz . . . 110 kHz, divided into five decades
- **External-voltage controlled:** 0.1 . . . 10 V on the VCO input gives a frequency range of 1 . . . 100, input impedance is 1 MΩ
- **Waveforms:** sine, triangle, square
- **Harmonic distortion on the sinewave:** 0.5%
- **DC OUT:** all waveforms, amplitude 100 mV . . . 10 V_{pp}, d.c. level adjustable from −5 V to +5 V, output impedance is 50 Ω, short-circuit protected
- **AC OUT:** all waveforms, amplitude 10 mV . . . 1 V_{pp}, frequency range 0.1 Hz . . . 110 kHz (−3 dB), output impedance is 600 Ω, short circuit protected
- **SYNC OUTPUT:** square wave, amplitude 500 mV_{pp}, no d.c. voltage component present, output impedance is 1 kΩ, short circuit protected, shut-off impedance ≥ 10 kΩ

Although the 'simple function generator' described in January 1978 was (and is) a popular project, the time has come for it to be replaced. Over the years many things change and technology, in particular, has taken big steps forward. A new function generator would therefore seem to be in order. Furthermore, it will not have escaped our readers' attention that Elektor has been publishing a series of test instruments. Actually, it is not really a series, but as we had quite a few lab instruments on our planning sheets we felt it would be worth while to put them all in the same cases to form a 'family'. It all started with the pulse generator and capacitance meter, now we add a function generator and next month it will be a frequency counter. What comes after that you will just have to wait and see.

A new function generator could be expected to have a completely new concept and be made with the latest ICs. That is what we thought as well but after searching for a replacement for the XR2206 we decided to remain faithful to this old IC. There are a number of reasons for this. First of all, the function generator must retain a fairly simple layout. The circuit must not become too expensive and it must not contain exotic ICs that are not freely available. A completely discrete circuit seemed too complicated to guarantee that every one built would work properly. A digital solution (with the waveform stored in an EPROM followed by a digital to analog converter) would be very up to date but would require expensive, difficult to find components. What it all comes down to is this: although ten years old, the XR2206 still seems the best IC to use as the heart of a new function generator.

Deciding to use the XR2206 in a new function generator does not mean falling back on an old design. We have used a number of clever (we are modest today, aren't we) solutions to overcome the well-known (infamous even) drawbacks of the 2206. How this is done is described elsewhere in this issue by the article 'the XR2206 in the function generator'.

What can it do?

The aim was clear: to develop a small, efficient function generator. Nobody wants a huge case covered in knobs and switches if they can have a good-quality basic instrument that is not completely shadowed by the (rather expensive) ready-made units that are available. As the technical specifications in the table here show, we think we have succeeded in this and even the front panel (figure 5) is quite attractive. The standard waveforms are available: sine, triangle and square. Price considerations mean that digital frequency setting and read-out have not been included. This is taken care of by a single knob, which, once calibrated, is accurate enough. It is always possible to connect a frequency meter to the generator to see exactly what frequency is selected. For normal use it is important to have a large output-voltage range with a variable offset level. The DC OUTput has a maximum amplitude of 10 $V_{peak\text{-}peak}$ at an output impedance of 50 Ω. The offset can be varied between —5 V and +5 V, which is of particular use where a square wave at TTL or CMOS level is needed. A separate output for audio use (AC OUT) is fitted with an output capacitor; its signal level can be set between 10 mV and 1 V (again peak-peak) and the output impedance is 600 Ω.

The signal is kept as clean as possible at higher frequencies by the use of a wide-band d.c.-coupled output amplifier. To be honest we must admit that the sine waveform is not completely free of distortion but this is an evil shared by almost all function generators. Distortion measurements on hi-fi equipment should be made with an actual sinewave generator (such as a Wien bridge oscillator). We have none the less done our best to make the sinewave as pure as possible. The result of our labour is shown in figure 1; the upper trace shows the waveform from the Elektor function generator while underneath this is the equivalent from a ready-made generator that is also based on the 2206. Clearly, 'our's' is the better waveform, with less than 0.5% harmonic distortion.

Another important detail is the VCO input. This is used to provide a linear frequency control in a range of 1. . . 100 based on a d.c. voltage of 0.1. . . 10 V

The circuit will only work optimally if the tracks on the printed circuit board and the wiring in general are kept short. For this reason the board we have designed is double-sided. This not only improves the quality of the waveform, it also makes construction easier.

The circuit

We will start with the simplest part of the circuit: the power supply. This has the usual configuration with centre-tapped mains transformer, bridge rectifier and a pair of voltage regulators (IC4 and IC5) to provide the symmetrical + and —15 V. The purpose of LED D9 is to indicate that the generator is switched on. The maximum supply voltage to the XR2206 is only 26 V, however, so + and —8 V are fed to pins 4 and 12 of IC1 respectively via zener diodes D7 and D8. Within the IC is a very stable voltage reference giving 3 V d.c. (relative to the negative supply line). This voltage, which is available at pin 10 of the IC, is decoupled by capacitor C1 and is used in this circuit as a reference for the frequency setting by means of P2. The reference is buffered by IC2 in order to reduce the load on it. This same reference voltage is also present at pin 7 of IC1. The frequency of the 2206 is directly proportional to the current flowing from this pin, which is determined by the voltage at the wiper of potentiometer P2. When the voltage here is high, 3 V for example, very little current flows so the frequency is at its minimum (f_{min}). The frequency is highest (f_{max}) if the voltage at the wiper is low (when the wiper is turned completely to the negative supply side). Note that all the voltages quoted here are relative to the negative supply line. The lower and upper limits of the frequency scale can be changed with presets P1 and P3.

The FSK input, pin 9, of the IC is used to switch the frequency setting of the 2206 from pin 7 to pin 8. When S2 is switched to EXT potentiometer P2 no longer has any effect and it is the current from pin 8 that determines the frequency. This current depends on the control voltage across resistor R9, which is provided by the VCO input via IC3. The 3140 inverts the VCO voltage so that when it increases the frequency also increases. At the same time IC3 serves to ensure that the VCO voltage range corresponds to the range to which IC1 reacts. To do this the non-inverting input of IC3 is linked to the 3 V reference via voltage divider R6/R7. If the VCO input is not required this whole section can be omitted. This includes IC3, R5. . . R9 and S2. The connection for the common pole of S2 must then be

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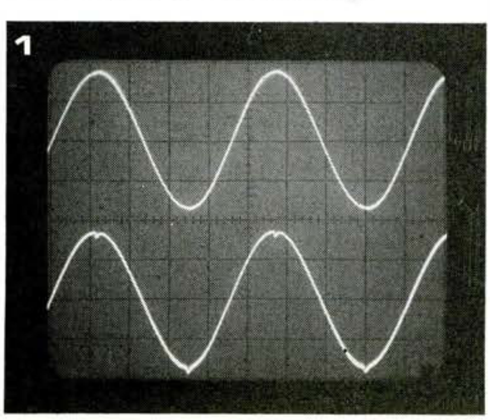

Figure 1. The sinewaves generated by the Elektor function generator (above) and a ready-made equivalent (below).

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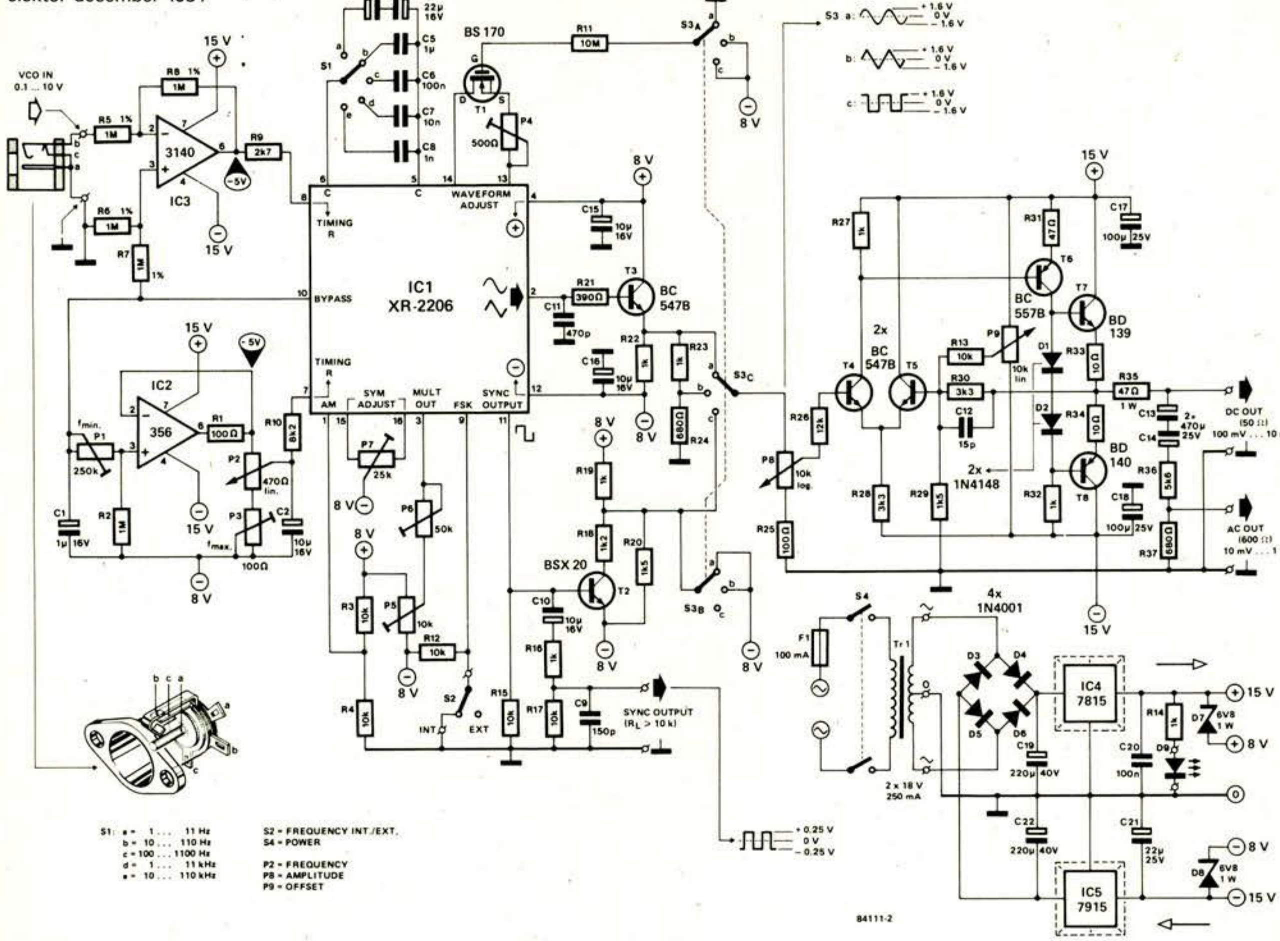

Figure 2. The circuit of the function generator consists of three basic sections: the generator based on IC1, the d.c.-coupled output amplifier (T4...T8) and the symmetrical supply (IC4 and IC5).

grounded. The actual frequency range of the generator is decided by capacitors C3...C8 and is switched by means of switch S1. Two electrolytics in series are used for the lowest range, giving the equivalent of a bipolar 11 μF capacitor.
A rather complex procedure is used for selecting the different waveforms, based on three-pole switch S3. A sinewave is produced when S3 is in position a. Part A of the switch then electronically inserts preset P4 between pins 13 and 14 (waveform adjust) via VMOSFET T1. Part B shorts the output of T2 by connecting it to −8 V so that the square wave cannot distort the sinewave. Part C feeds the signal from IC1, after buffering by T3, to the output amplifier.
Position b selects the triangular waveform. Section A now deselects the forming of a sinewave via the BS170, section B still disables the square wave and section C again feeds the signal to the output amplifier. One small change noted in this position is that the signal from IC1 (pin 2) travels via a voltage divider after T3. This is needed to keep the amplitudes of the sine and triangle the same at the output as the XR2206 gives the triangle a much greater amplitude than the sine.
The square wave is selected when S3 is in position c. Again T1 is kept 'off' by means of part A. Section B allows the square wave, which is amplified by T2, to pass on via section C to the output amplifier.
The square wave is always available at the SYNC OUTPUT of IC1 (pin 11). Its amplitude is only 0.5 V_{pp} but it is a pure waveform. All d.c. components are blocked by capacitor C10. The symmetry of the waveform can be changed by means of preset P7 connected between pins 15 and 16. The amplitude of the signal output at pin 2 is set with preset P6 and its d.c. value is changed by means of preset P5. The AM input of the 2206 (pin 1) is fixed at +4 V d.c. by voltage divider R3/R4.
The output amplifier is completely discrete, consisting of a differential amplifier (T4 and T5), a driver (T6) and two power transistors (T7 and T8). The gain of this whole section is determined by the ratio R30 : R29, which works out at a little more than three times. A 15 pF capacitor, C12, is included to ensure frequency stability without effecting the amplifier's slew rate too much. The quiescent current of the output stage is set by diodes D1 and D2. The output current is limited by resistor R35, which also defines the impedance of the DC OUTput. The d.c. offset can be set with potentiometer P9. Output 'volume' is controlled by means of P8. A bipolar electrolytic, consisting of capacitors C13 and C14, is used for d.c. suppression. The output voltage is lowered by voltage divider R36/R37, whose values are chosen to give an impedance of 600 Ω.

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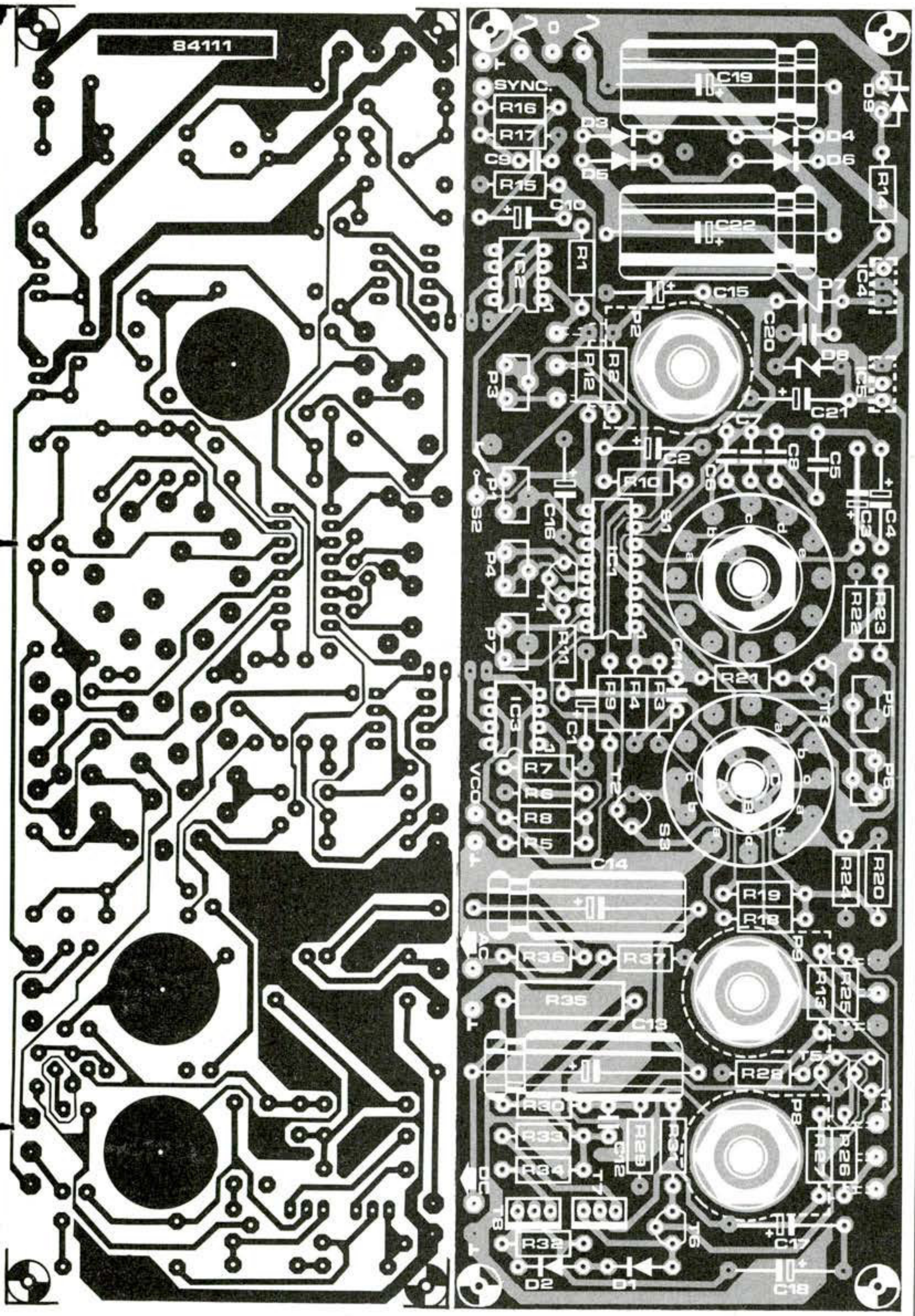

Figure 3. The printed circuit board for the function generator is double-sided, thus keeping wiring to a minimum and the connections to the board short. Both sides of this board are shown on the printed circuit board pages near the centre of this issue.

Parts list

Resistors:
R1, R25 = 100 Ω
R2 = 1 M
R3, R4, R12, R13, R15, R17 = 10 k
R5, R6, R7, R8 = 1 M, 1% metal film
R9 = 2k7
R10 = 8k2
R11 = 10 M
R14, R16, R19, R22, R23, R27, R32 = 1 k
R18 = 1k2
R20, R29 = 1k5
R21 = 390 Ω
R24, R37 = 680 Ω
R26 = 12 k
R28, R30 = 3k3
R31 = 47 Ω
R33, R34 = 10 Ω
R35 = 47 Ω/1 W
R36 = 5k6
P1 = 250 k preset (vertical type)
P2 = 470 Ω wire-wound pot (with long spindle)
P3 = 100 Ω preset (vertical type)
P4 = 500 Ω preset (vertical type)
P5 = 10 k preset (vertical type)
P6 = 50 k preset (vertical type)
P7 = 25 k preset (vertical type)
P8 = 10 k log. pot. (long spindle)
P9 = 10 k lin. pot. (long spindle)

Capacitors:
C1 = 1 μ/16 V
C2, C10, C15, C16 = 10 μ/16 V
C3, C4, C21 = 22 μ/25 V
C5 = 1μ (MKT)
C6 = 100 n (MKT)
C7 = 10 n (MKT)
C8 = 1 n (MKT)
C9 = 150 p
C11 = 470 p
C12 = 15 p
C13, C14 = 470 μ/25 V
C17, C18 = 100 μ/25 V
C19, C22 = 220 μ/40 V
C20 = 100 n

Semiconductors:
D1, D2 = 1N4148
D3 . . . D6 = 1N4001
D7, D8 = 6V8/1 W zener
D9 = LED, red
T1 = BS170
T2 = BSX20, 2N2369
T3 . . . T5 = BC547B
T6 = BC557B
T7 = BD139
T8 = BD140
IC1 = XR2206
IC2 = LF356N
IC3 = CA3140E
IC4 = 7815
IC5 = 7915

Switches:
S1 = double-pole 6-way rotary wafer switch
S2 = miniature single-pole toggle switch
S3 = 4-pole 3-way rotary wafer switch
S4 = miniature double-pole mains switch

Miscellaneous:
F1 = fuse, 100 mA
Tr1 = mains transformer, 2 × 18 V/250 mA
3 off BNC sockets (screw mounting)
1 off d.c. power socket for VCO input (see figure 2) (*Cirkit/Ambit*)
Heatsink for IC4 and IC5

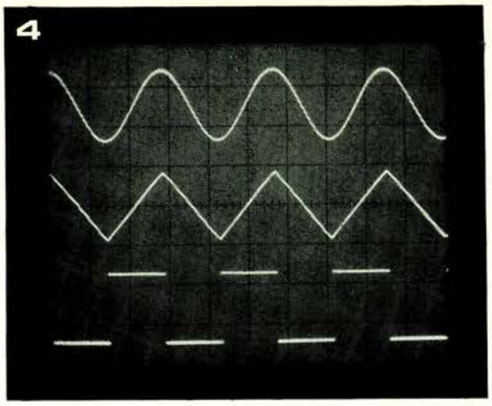

Figure 4. These are the output signals that the function generator can provide: a sine, triangle and square wave (200 μs/division horizontal, 1 V/division vertical).

Take care in construction

Any test equipment, especially if it is home-made, must be trustworthy. This is only possible if it is constructed and calibrated very carefully so read the rest of this article before plugging in your soldering iron.

The printed circuit board designed for this project is double-sided but does not have through-plated holes. For this reason a number of components must be soldered at both sides of the board. In these cases there is a copper pad at each side. The parts in question are listed below and we suggest that these should be mounted first.

- One connection each for P1 and P7.
- One side of R2, R3, R4, R6, R7, R12, R15, R17, R20, R22, R24, R25, R28, R29, R37, and C20.
- The negative side of C1, C2, C15 and C19.
- The positive side of C17 and C21.
- The collector of T3 and T5.
- The emitter of T2.
- Both sides of C16, C18 and D8.
- Two connections each of P5, P9 and IC4.
- One connection of IC5, S2 and the DC OUTput.
- Finally, there are two pairs of connections through the board near both IC2 and IC3. These consist of four wires inserted in the appropriate holes and soldered at both sides.

The connection points for the potentiometers (P2, P8 and P9), the sockets, the transformer and switch S2 can be fitted with soldering pins. Those for P2, P8, P9 and the transformer are fitted on the reverse side of the board, the others on the component side. Make sure that the 'collar' on the pins is not too wide or it may cause short circuits on the board.

The MKT capacitors are mounted slightly above the board to prevent shorts. The potentiometers must also be mounted carefully so that they do not foul any other components.

The voltage regulators, IC4 and IC5, are placed on the reverse side of the board, with the metal mounting base facing P2. Each of these ICs must be fitted with a heatsink, or they may both be mounted on a piece of aluminium of about 60 × 100 mm (and 1.5 mm thick) as we have done. In either case the ICs must be electrically isolated from the heatsink(s).

There are numerous different types of rotary wafer switches that could be used for this project. If the switches used have a movable detent so that only the number of ways needed can be switched it is advisable to use this.

As in our other 'test equipment series' projects the printed circuit board is dimensioned to fit snugly in a Verobox (number 075-01411D, 205 × 140 × 75 mm). The corners of the board must be filed a bit to make it fit perfectly into the slots provided in the case. The project is given a very attractive appearance by the self-adhesive front panel foil that should be stuck onto the case. The appropriate holes should be drilled beforehand. The 'power' LED and the VCO socket are stuck onto the back of the front panel using two-component adhesive. The photographs clearly show how all the hardware fits together. The fact that all the electronics fits onto a single printed circuit board greatly simplifies matters.

Calibration

Not all the presets are accessible after the

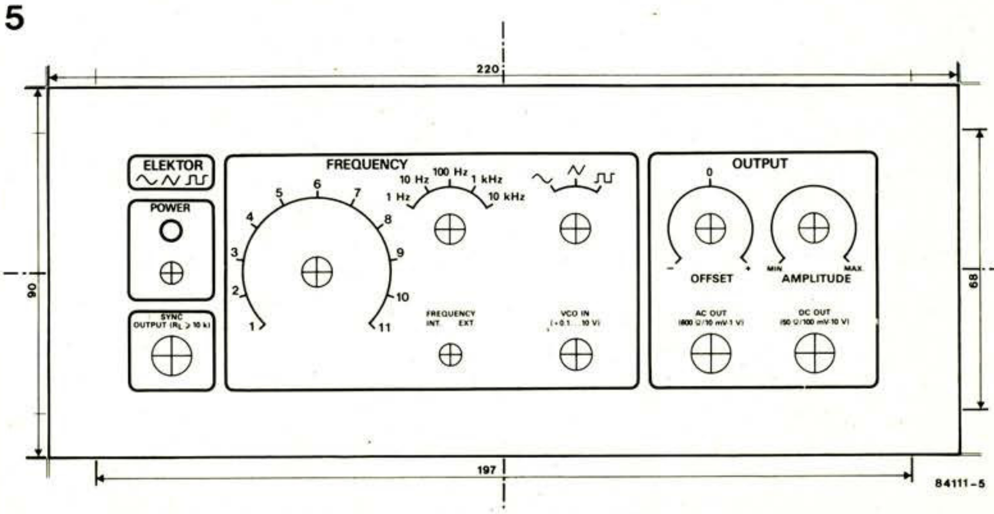

Figure 5. This front panel gives the project an attractive finished appearance. Before sticking the foil to the Verobox's aluminium panel all the holes must be drilled.

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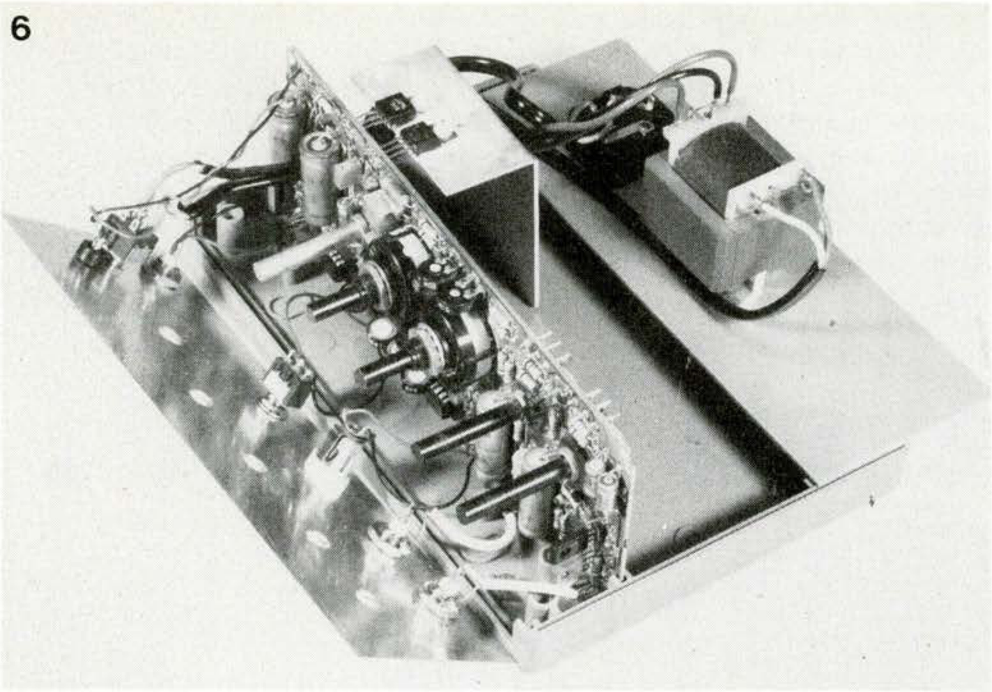

Figure 6. This is how the function generator is put together. Front panel, printed circuit board and back panel simply slide into grooves in the case (if the right Verobox is used). The switches, potentiometers and sockets are fitted to the front panel. Transformer and a fuse holder, and possibly a socket for the power, are mounted on the back panel.
N.B.: It is very important to insulate the power switch well (and ideally the transformer connections also) as there is a danger of it touching C19 or C22.

circuit has been fitted into the case so it is easier to calibrate them first. Connect the power transformer temporarily and before switching on set the presets as follows: Turn P8 fully right (maximum amplitude), all other pots and presets to mid-position, S2 closed, S3 set to square wave (c) and S1 to the 1...11 kHz range (d).
The power may now be applied. Connect a multimeter (with the most sensitive d.c. range selected) to the DC OUTput and set P9 so that the meter reads zero volts. Measure and note the peak to peak voltage of the square wave at this output with an oscilloscope.
The triangle wave is then selected with S3 (position b) and the peak to peak voltage is again measured. This value is trimmed with P6 until it is the same as that just measured for the square wave. At the same time the d.c. voltage at the output (seen on the multimeter) is set to zero volts with P5. Repeat this adjustment of P5 and P6 a few times until both amplitude and d.c. voltage are correct.
The sinewave is now selected by means of S3 (position a) and presets P4 and P7 are then used to reduce the distortion as much as possible. A distortion meter could be used for this but it is also possible to set it up 'by eye'. Turn P4 and P7 and see how they effect the waveform on the oscilloscope.
The final calibration involves setting the scale division. The front panel should be placed on the printed circuit board, taking care not to cause any short circuits, and a suitable knob is fitted onto P2. The knob should be fitted onto the spindle in such a way that the whole range of the scale can be scanned. Turn P2 until it points exactly towards '1' on the scale and then set the frequency to exactly 1 kHz with P1, measured with an oscilloscope or frequency meter. The knob is then turned to '10' and the frequency is set to 10 kHz by means of P3.

The other ranges are then automatically calibrated, as far as the tolerances of C3...C8 allow. If 5% capacitors are used the ranges are accurate to within 5%. An exception to this is C3 plus C4. The nominal value of the resultant capacitor is already 10% too large (as it is 11 μF instead of 10 μF) and the electrolytics have a tolerance of −10/+50%. Experimenting with different electrolytics should enable this lowest range to be made accurate.
Perfectionists can also test the tolerance of the other capacitors (this is child's play using the Elektor capacitance meter). Furthermore cermet presets could be used for P1 and P3, and metal film resistors for R2, R9 and R10. A small frequency meter could also be made to give a direct readout of the function generator's output.
None of this is strictly necessary, however. The original intention was to make a straightforward test instrument and that is what this is without all the extras. ◄

Figure 7. In this photo the function generator is completely finished, except for the lid which still has to be put on the case. The mains cable travels via the printed circuit board to the power switch on the front panel. Both voltage regulators (on the reverse side of the board) are fixed onto a home-made heatsink. The wire-wound potentiometer for the frequency setting is located under the heatsink.

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