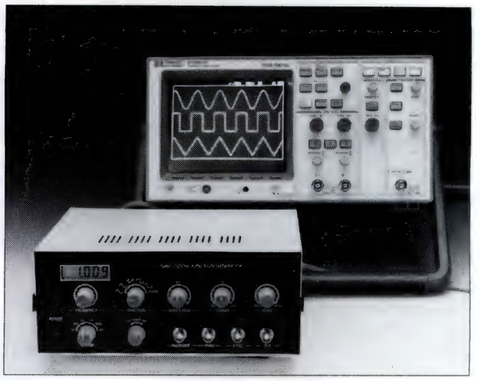
# FUNCTION GENERATOR

**Design by H. Bonekamp**




**A generator is described that, based on the MAX038, provides triangle, sawtooth, sine, rectangular and pulse waveforms.**

The MAX038, on which the present generator is based, is an integrated, high-frequency, precision function generator whose output frequency can be controlled over a frequency range of 0.1 Hz to 20 MHz by an internal 2.5 V bandgap voltage reference and an external resistor and capacitor. Its duty factor can be varied over a wide range by applying a ±2.3 V control signal, facilitating pulse-width modulation and the generation of sawtooth waveforms. Frequency modulation and frequency sweeping are achieved in the same way. The duty factor and frequency controls are independent.

## Circuit description

The circuit diagram of the generator proper is shown in **Fig. 1** and that of the liquid crystal display, LCD, in **Fig. 2**.

The frequency of the MAX038, $IC_1$, is determined by $C_1$–$C_7$ which are linked to pin 5 via $S_{1a}$. The highest frequency is governed by $C_5$–$C_7$, an arrangement that eliminates the effect of parasitic capacitances (about 20 pF). Switch section $S_{1b}$ sets the decimal point on the display.

The waveform is selected with $S_2$, one of whose sections (a) is linked to selection input pins 3 and 4 of $IC_1$. The second section (b) is used to set the duty factor and symmetry of relevant output signals (triangle, sine and rectangular).

The symmetry is set with an auxiliary voltage derived from the reference potential, $U_{ref}$ = 2.5 V, which is generated internally by $IC_1$. The duty factor must be adjusted with a symmetrical reference voltage, which is obtained by inverting $U_{ref}$ in $IC_{3a}$, that is, amplified by –1. The op amp is stabilized by an *RC* network. The control range of $P_1$ then extends from $-U_{ref}$ to $+U_{ref}$.

The signal at the wiper of $P_1$ is applied to duty factor adjust pin 7 of $IC_1$ via $IC_{2b}$ when $S_2$ is set to position sine, triangle or rectangular. In positions triangle and pulse, the potential at pin 7 is set with $P_2$. Although this potentiometer also has a control range of $-U_{ref}$ to $+U_{ref}$, this is reduced to about 40%. This diminution is required since all control inputs, with the exception of sweep, are normalized to a range based on a control voltage of ±1 V.

The signal frequency can be varied via voltage-controlled frequency adjust input pin 8 and via current-controlled frequency control current input pin 10 of $IC_1$.

A voltage is applied to pin 8 when an external signal is to provide frequency modulation. The control voltage, taken from $K_4$, is applied via $S_{3a}$ to $IC_{2a}$, in which it is raised ×2.4 to normalize it to ±1 V.

With switch $S_3$ in position 1, the input at pin 10 of $IC_1$ enables the frequency to be set manually so that the generator can be used in the traditional way. Pin 8 is then low (via $IC_{2a}$). The current sunk via pin 10 varies between 16 μA and 250 μA.

With $S_3$ in position 3, the central frequency can be set with $P_5$, whereupon the frequency sweep around this frequency is arranged by a voltage at $K_4$.

With $S_3$ in position 2, op amp $IC_{6b}$ raises the external sweep signal at $K_4$ ×7.5, whereupon the signal is passed to $IC_{6a}$ via $S_{3b}$. Op amp $IC_{6a}$ is connected as a voltage follower, whose output is converted into a current to pin 10 of $IC_1$ by $R_{30}$. Here again, pin 8 is made low.

The output signal is available at OUT (pin 19) of $IC_1$. Since this is not sufficient, it is applied to buffer amplifier $IC_4$. This op amp has a slew rate of 1000 V $\mu s^{-1}$ and a peak output current of 150 mA. It amplifies the output of $IC_1$ ×10 and, at the same time, ensures correct compensation of the offset voltage (in conjunction with $IC_{3b}$). The output voltage at $K_3$ can be preset between 0.5 $V_{pp}$ and 22 $V_{pp}$. Resistors $R_{22}$, $R_{23}$, $R_{24}$, and $R_{25}$ ensure an output impedance of 50 Ω, and at the same time that the output resistance can dissipate sufficient power.

The junction $R_{18}$-$R_{19}$-$R_{20}$ is at ground potential for a.c. via $C_{18}$, $C_{19}$ and $C_{20}$, but direct voltages at the output of $IC_{3b}$ are applied to $IC_4$. Since $IC_3$ does not work well with a capacitive load, a compensating network, $R_{18}$-$R_{19}$-$C_{17}$ is provided at its pin 7. In this way, the offset of the output signal can be adjusted by ±5 V.

The SYNC output (pin 14 of $IC_1$) is buffered by TTL gate $IC_{5e}$ and then applied to $K_1$. The signal is at TTL level. The impedance at $K_1$ is 50 Ω.

All op amps in the circuit, in which signals at frequencies up to 100 MHz can occur, are decoupled extensively.

The power supply is straightforward and traditional. The rectified symmetrical voltage is regulated by $IC_7$ and $IC_8$ to ±15 V and by $IC_9$ and $IC_{10}$ to ±5 V.

The display is coupled to $K_6$ on the generator via $K_1$. Pin 5 of this connector carries the SYNC signal (which has the same frequency as the output of the MAX038. Unfortunately, there is no possibility of the display showing whether the frequency is in Hz, kHz or MHz. However, a solution to this has been found: if the display shows only digits, the frequency is in Hz; if the digits are separated by a decimal point, the frequency is in kHz, and when the digits are separated by a decimal point and preceded by a colon, the frequency is in MHz.

The time base of the display circuit is provided by $IC_7$ (note that this must be the A version of the ICM7207). The IC also generates all control signals for the counter proper and display driver $IC_8$. The combination of these two ICs forms a frequency-independent counter. Depending on the level at pin 11 of $IC_7$, a measuring period of 0.1 s for the three highest frequency ranges or 1 s for the three lowest ranges is used. This gives measuring cycles of 0.2 s and 2 s respectively. This is too long for the highest frequencies, so that the times are scaled down by 100 and 10 respectively. This is done in $IC_6$. The final measuring result is displayed on $LCD_1$.

Power-up network $R_3$-$C_3$ arranges for

### Brief specification

Output waveform: sine, triangle, pulse, rectangular, sawtooth
Rectangular wave: $t_r$, $t_f$ << 15 ns
Duty factor: variable 15–85%
Sine wave: frequency range: 10 Hz–10 MHz; THD << 1%
Number of ranges: 6
Frequency stability: d*f*/*f* << 0.1%
Output level (sync): TTL
Output level (analogue): 20 V peak to peak
Offset compensation: ±5 V
Display: $4^1/_2$ digit
FM modulation: $f_0$ ±70%
FM sensitivity: ±1 V
FM bandwidth: 2 MHz ($R_{in}$ = 100 kΩ)
Sweep range: 25:1
Sweep sensitivity: 0–1 V
Sweep bandwidth: 10 kHz ($R_{in}$ = 100 kΩ)

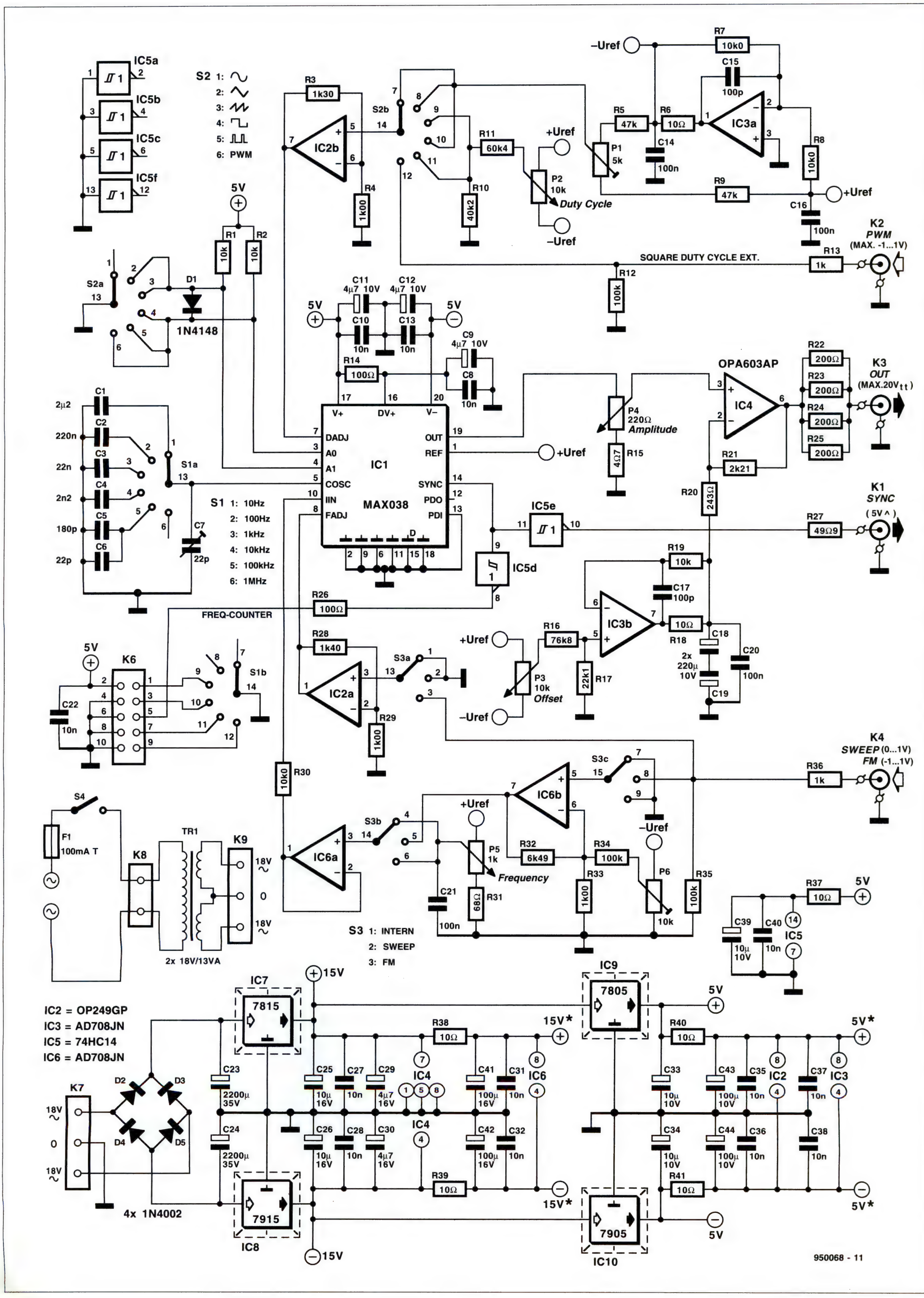



**Fig. 1**. Circuit diagram of the waveform generator.

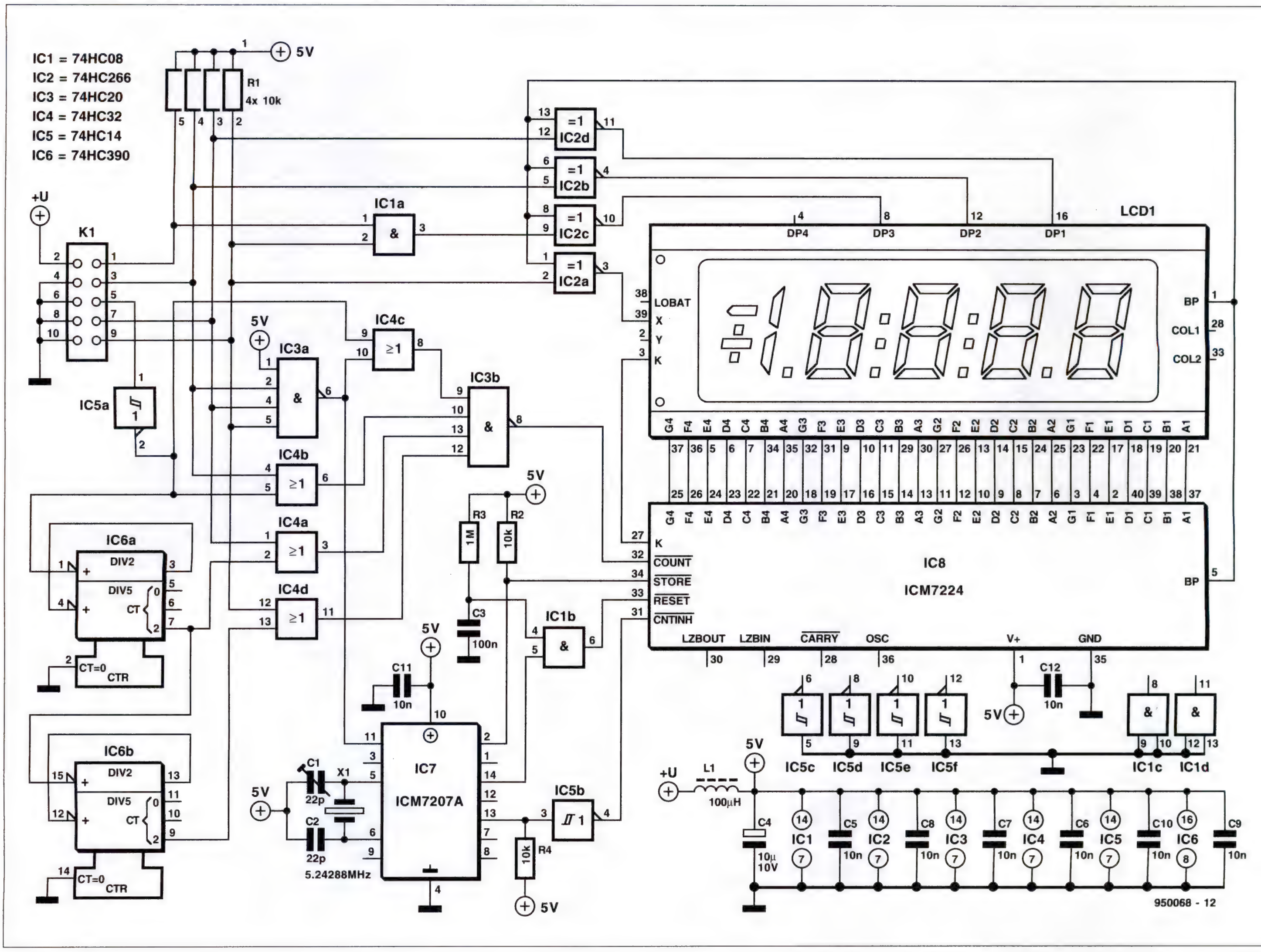



**Fig. 2**. Circuit diagram of the display unit.

the display to be set to a defined readout after the supply has been switched on. This prevents the appearance of undefined characters on the screen on power up.

The signal at pin 1 (BP) of the LCD ensures that the display is always driven by a.c. Driving it with d.c. would cause irreparable damage.

## Construction

The function generator is intended to be built on the double-side, through-plated printed-circuit board shown in **Fig. 4**. This board consists of three parts, mother board, display board and transformer board, which should be separated from each other before any other work is done.

It is best to start with the mother board: fit four spacers in the fixing holes near the corners—see **Fig. 3**. Use sockets for all ICs, except $IC_1$ and $IC_4$, which should be soldered directly to the board. (Sockets create too much spurious inductance). Note that $IC_4$ uses the copper pad on the board as heat sink, for which three special pins are provided on the device. Use adequate solder to ensure good thermal coupling with the copper. When the board has been completed, fix a small heat sink on

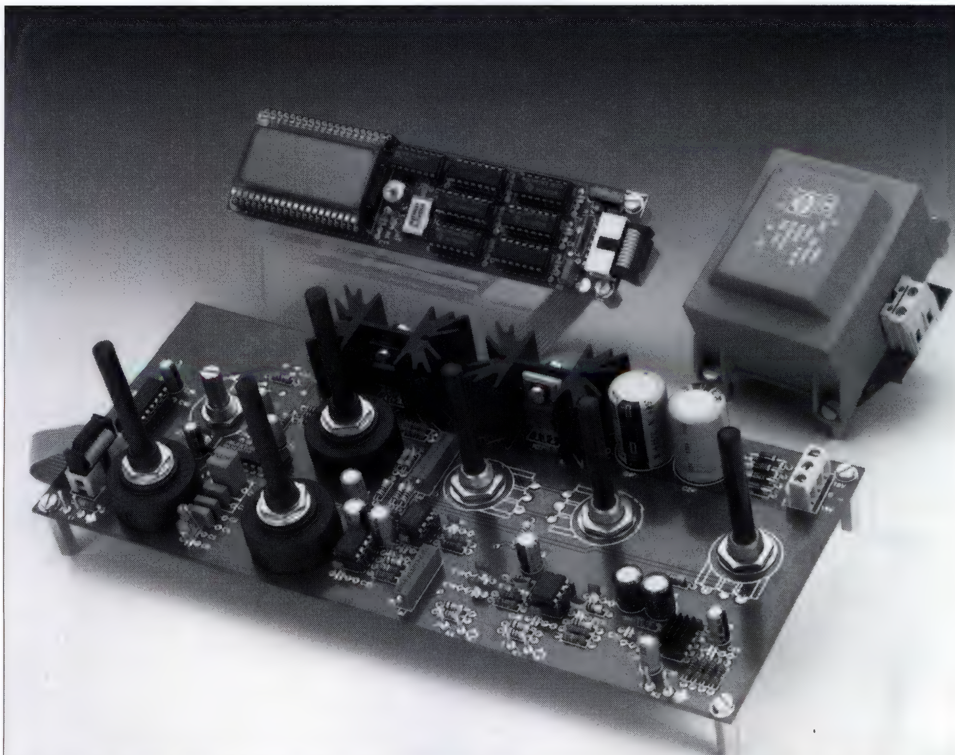


**Fig. 3.** The three boards that constitute the function generator.

to $IC_4$ as shown in **Fig. 5**: use a small drop of superglue for this.

A few points to note in the construction of this board: trimmer capacitor $C_7$ is fitted at the track side as are the four presets—see **Fig. 6**. The heat sinks for $IC_7$-$IC_8$ and $IC_9$-$IC_{10}$ are fitted at the component side. Make sure that the regulators mounted on a common heat sink are well insulated from one another: use ceramic washers and plastic tubing in each of the screw holes.

The mains transformer is mounted on a dedicated, small board, which has, however, no mechanical function: it merely provides the necessary connection points and makes the required link between the two secondary windings. The assembly is fitted in the enclosure by the eyelets in the transformer housing.

The display board is, of course, not essential, but it is very useful. An external frequency meter may also be used: if so, it must be connected to the SYNC output.

In the prototype, all ICs are fitted in sockets; the LCD in two single-row 20-pin sockets. Note that other than the specified LCD may be used.

The flatcable should be laid well away from $IC_1$, since the high-frequency digital signals carried by it may adversely affect the operation of the IC.

Finally, note that capacitor $C_4$ is a radial type that must be fitted axially.

## Setting up

Link the display board to the mother board via a short length of flatcable. Connect the mains transformer to $K_7$ on the mother board and switch on the mains. Take car not to touch anything at the primary side of the transformer.

To adjust the symmetry of the signal, set $S_2$ to position 4: rectangular wave. Select a frequency of about 10 kHz and turn $P_4$ fully anticlockwise. Connect a multimeter, set to direct voltage to the output, whose level should be minimal. Vary $P_3$ (offset) until the multimeter reads 0 V.

Place an *RC* network, consisting of a 10 kΩ resistor in series with a 1 μF polypropylene capacitor, in series with one of the multimeter leads and the output. Turn $P_4$ fully clockwise and vary $P_1$ until the d.c. component is 0 V.

Users fortunate enough to have access to a spectrum analyser can do the following. On the function generator, select a sine wave output and adjust the level of the second harmonic to a minimum with $P_1$.

To set the lower limit of the sweep range, note that the IC works optimally when the lower limit is set to one tenth of the value of the lower limit indicated by the range selector. Set $S_3$ to position 1, $S_1$ to position 3 or 4, and vary $P_5$ until the display shows a series of numbers. Set $S_3$ to position 2 and adjust $P_6$ until the value read on the display is one

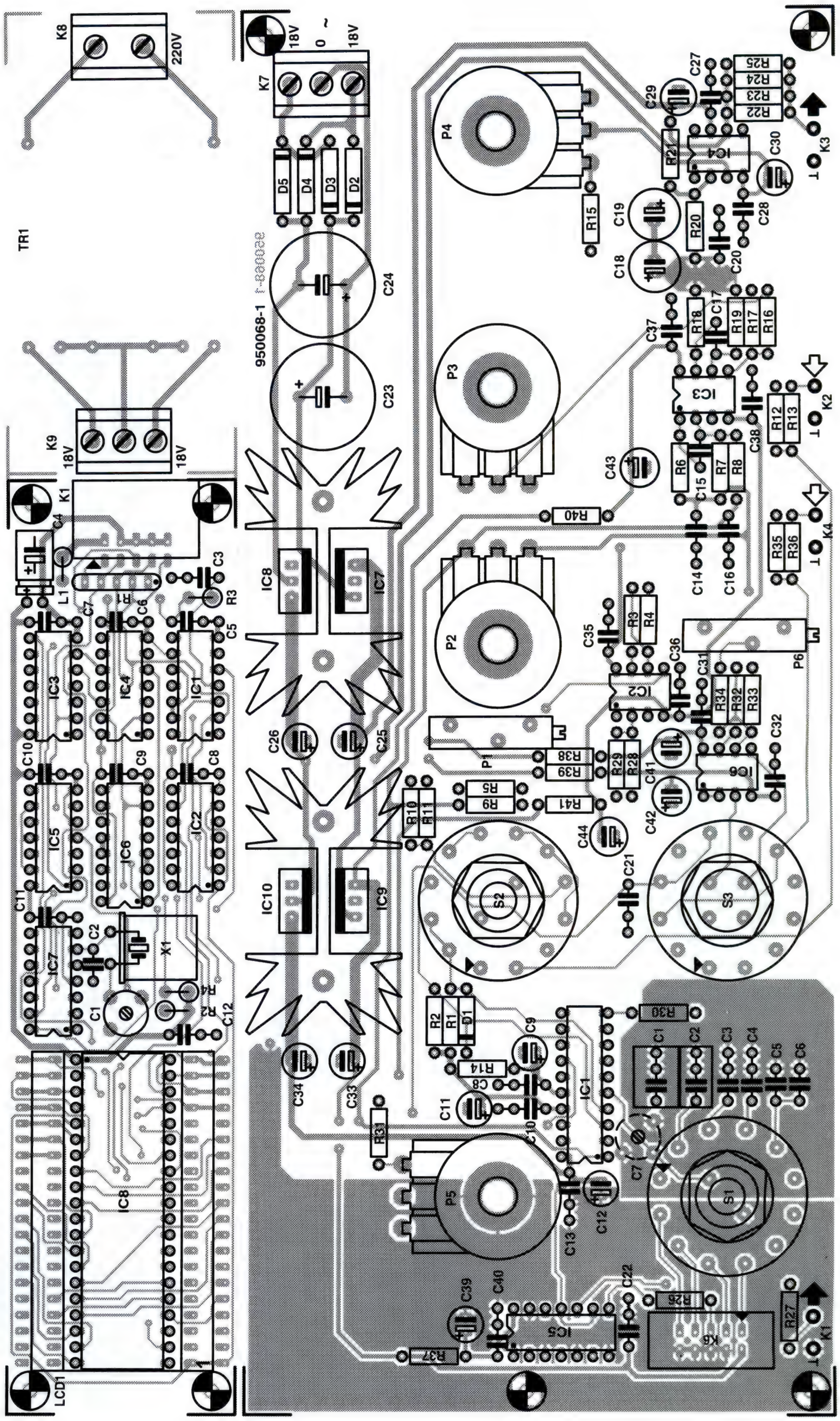



**Fig. 4**. Component side of the double-sided, through-plated PCB.

tenth of that when $S_3$ was in position 1.

To set the upper limit of the sweep range, set $S_1$ to position 6, turn $P_5$ fully clockwise and vary $C_7$ until th display reads 10 MHz.

To set up the display board, retain switch $S_1$ in position 6 and place the function generator in the vicinity of a medium wave radio receiver. Connect a short length of bare circuit wire to the output of the function generator and tune the receiver to a station whose frequency is known, but which should be near the top end of the band above 1 MHz. Vary $P_5$ until the station is wholly suppressed and adjust $C_1$ (display board) until the display reads the frequency of the radio station.

The display module is, of course, best calibrated with a standard frequency meter.

## Assembling the generator

When the generator has been set up and works correctly, it should be assembled in a suitable enclosure, for instance, as shown in **Fig. 7**. The enclosure should be sturdy and be screened to minimize electromagnetic radiation.

Mount the transformer at the right of the rear panel and the other two boards close behind the front panel. A possible front panel layout is given in **Fig. 8**: note that a ready-made foil for this is available. A photocopy of Fig. 8 can be used as a drilling template for the front panel.

Wiring from the mains entry (with integrated fuse holder) at the rear panel to the mains transformer should be as short as possible and be kept well away from $C_1$–$C_7$.

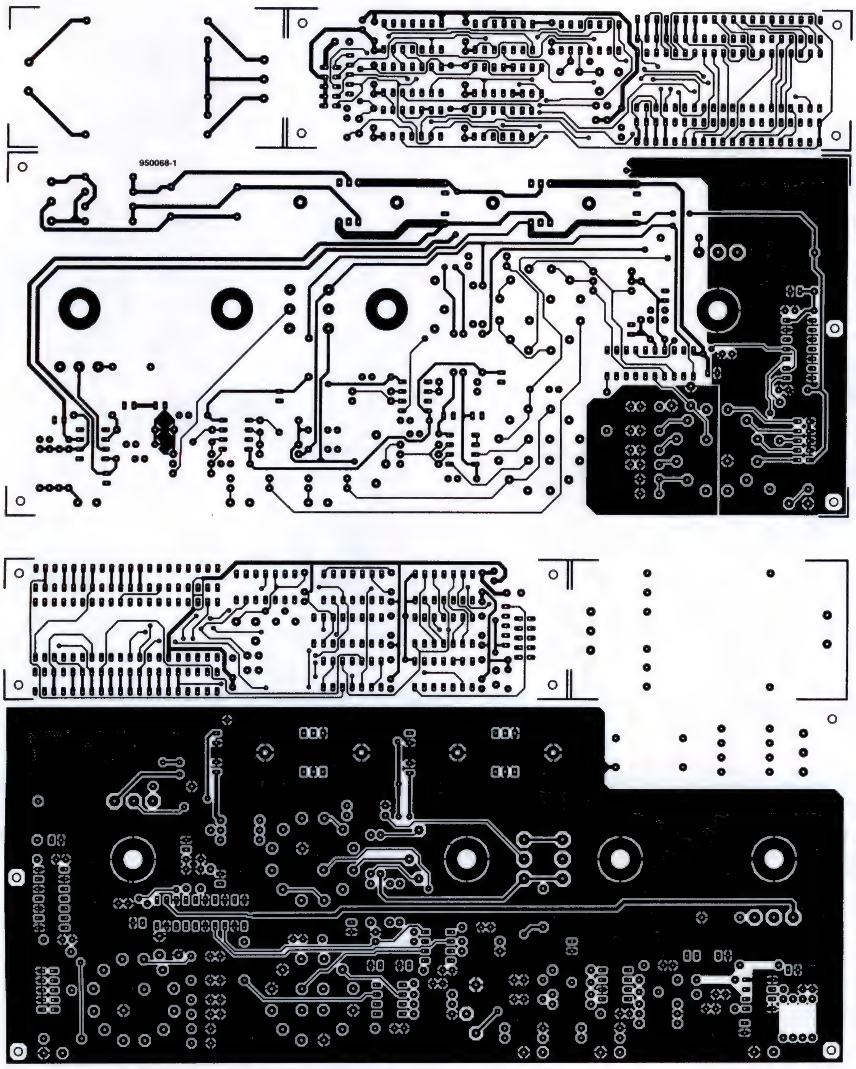



**Fig. 4b**. Track side and third foil f the PCB (scale 1:2).

## Parts list

MOTHER BOARD

**Resistors**:

$R_1$, $R_2$, $R_{19}$ = 10 kΩ
$R_3$ = 1.30 kΩ*
$R_4$, $R_{29}$, $R_{33}$ = 1.0 kΩ*
$R_5$, $R_9$ = 47 kΩ
$R_6$, $R_{18}$, $R_{37}$–$R_{41}$ = 10 Ω
$R_7$, $R_8$, $R_{30}$ = 10.0 kΩ*
$R_{10}$ = 40.2 kΩ*
$R_{11}$ = 60.4 kΩ*
$R_{12}$, $R_{34}$, $R_{35}$ = 100 kΩ
$R_{13}$, $R_{36}$ = 1 kΩ
$R_{14}$, $R_{26}$ = 100 Ω
$R_{15}$ = 4.7 Ω
$R_{16}$ = 76.8 kΩ*
$R_{17}$ = 22.1 kΩ*
$R_{20}$ = 243 Ω*
$R_{21}$ = 2.21 kΩ*
$R_{22}$–$R_{25}$ = 200 Ω*
$R_{27}$ = 49.9 Ω*
$R_{28}$ = 1.40 kΩ*
$R_{31}$ = 68 Ω
$R_{32}$ = 6.49 kΩ*
* = 1%

**Potentiometers**

$P_1$ = 5 kΩ (4.7 kΩ) multiturn preset
$P_2$, $P_3$ = 10 kΩ linear
$P_4$ = 220 Ω (250 Ω) linear
$P_5$ = 1 kΩ multiturn, linear (e.g. Bourns Type 3590S-002-102)
$P_6$ = 10 kΩ multiturn preset

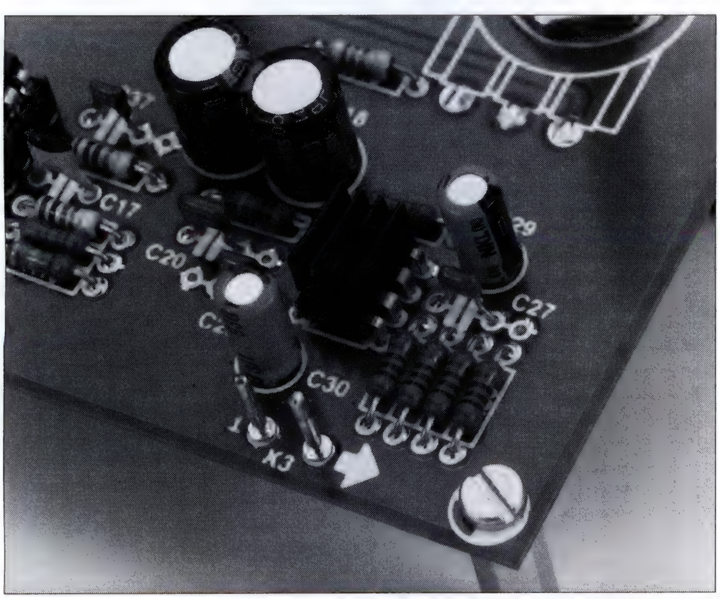


**Fig. 5**. Detail of how to fix a small heat sink on to $IC_4$ with a drop of superglue.

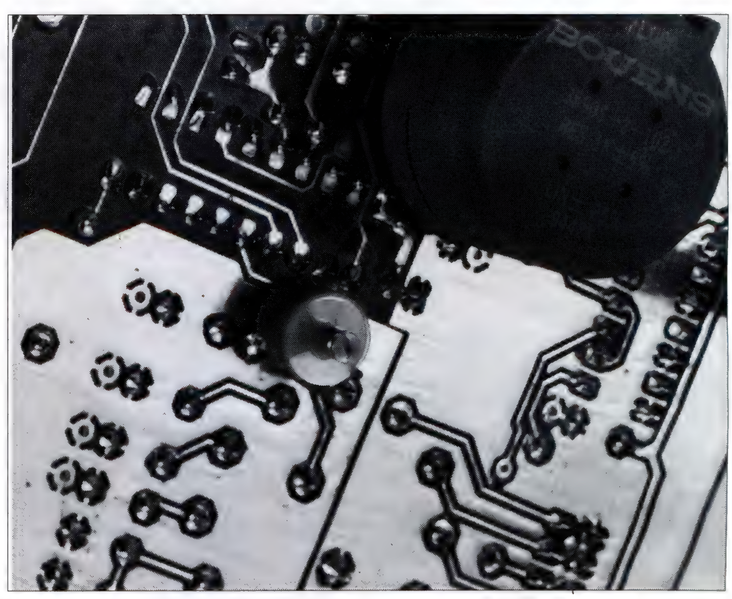
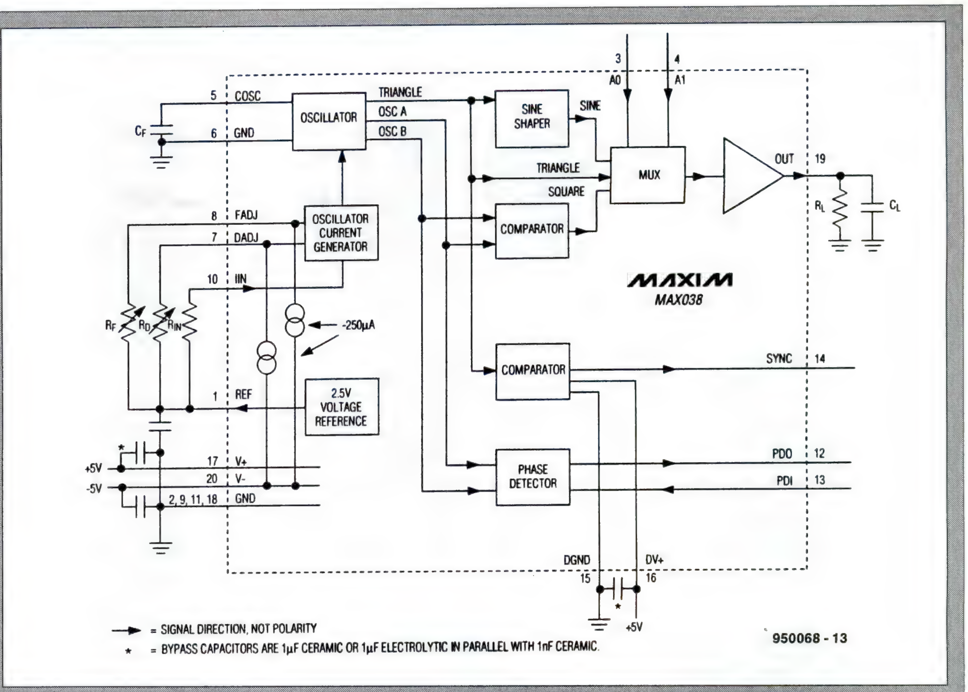


**Fig. 6**. Detail showing how trimmer $C_7$ is fitted at the trackside of the mother board.

## High-frequency waveform generator MAX038




The MAX038 is a high-frequency function generator that produces low-distortion sine, triangle, sawtooth or rectangular (pulse) waveforms at frequencies from less than 1 Hz to 20 MHz or more, using a minimum of external components. Frequency and duty factor can be independently controlled by programming the current, voltage or resistance. The desired output waveform is selected under logic control by setting the appropriate code at the $A_0$ and $A_1$ inputs. A SYNC output and phase detector are included to simplify designs requiring tracking to an external signal source.

The MAX038 operates with ±5 V ±5% power supplies. The basic oscillator is a relaxation type that operates by alternately charging and discharging a capacitor, $C_F$, with constant currents, simultaneously producing a triangle wave and a rectangular wave. The charging and discharge currents are controlled by the current flowing into IIN, and are modulated by the voltages applied to FADJ and DADJ. The current into IIN can be varied from 2 µA to 750 µA, producing more than two decades of frequency for any value of $C_F$. Applying ±2.4 V to FADJ changes the nominal frequency (with $U_{FADJ}$ = 0 V) by ±70%; this procedure can be used for fine control.

The duty factor (the percentage of time that the output waveform is positive) can be controlled from 10% to 90% by applying ±2.3 V to DADJ. This voltage changes the $C_F$ charging and discharge current ratio while nearly constant frequency is maintained.

A stable 2.5 V reference voltage, REF, allows simple determination of IIN, FADJ, or DADJ with fixed resistors, and permits adjustable operation when potentiometers are connected from each of these inputs to REF. FADJ and/or DADJ can be grounded, producing the nominal frequency with a 50% duty factor.

The output frequency is inversely proportional to $C_F$: values can be selected for this capacitor to produce frequencies above 20 MHz.

A sine-shaping circuit converts the oscillator triangle wave into a low-distortion sine wave with constant amplitude. The triangle, rectangular and sine waves are input to a multiplexer. Two address lines, $A_0$ and $A_1$, control which of the three waveforms is selected. The output amplifier produces a constant 2 $V_{pp}$ amplitude (±1 V), regardless of wave shape or frequency.

The triangle is also sent to a comparator that produces a high-speed rectangular-wave SYNC waveform that can be used to synchronize other oscillators. The SYNC circuit has separate power-supply leads and can be disabled.

Two other phase-quadrature rectangular waves are generated in the basic oscillator and sent to one side of an XOR phase detector The other side of the phase detector input, PDI, can be connected to an external oscillator. The phase detector output, PDO, is a current source that can be connected directly to FADJ to synchronize the MAX038 with the external oscillator.

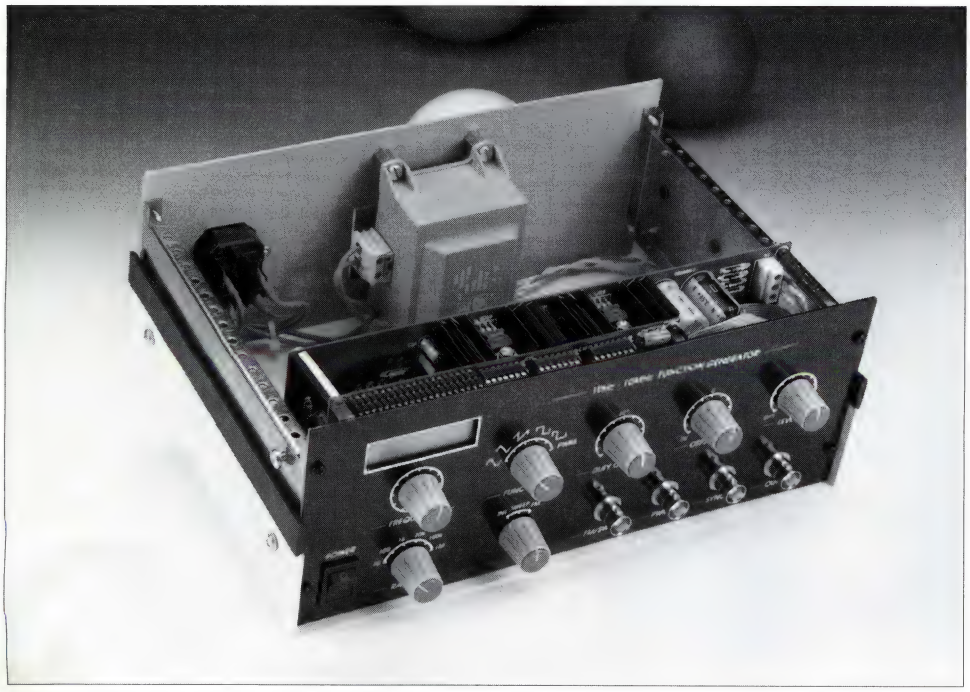


**Fig. 7**. The completed function generator with top of enclosure removed.

**Capacitors**:
$C_1$ = 2.2 µF, polypropylene*, 10%
$C_2$ = 220 nF, polypropylene*, 5%
$C_3$ = 22 nF, polypropylene*, 5%
$C_4$ = 2.2 nF, polypropylene*
$C_5$ = 180 pF, polyester, 2%
$C_6$ = 22 pF, polyester, 2%
$C_7$ = 22 pF foil trimmer
$C_8$, $C_{10}$, $C_{13}$, $C_{22}$, $C_{27}$, $C_{28}$, $C_{31}$, $C_{32}$, $C_{35}$–$C_{38}$, $C_{40}$ = 10 nF
$C_9$, $C_{11}$, $C_{12}$ = 4.7 µF, 10 V, radial
$C_{14}$, $C_{16}$, $C_{20}$, $C_{21}$ = 100 nF
$C_{15}$, $C_{17}$= 100 pF ceramic
$C_{18}$, $C_{19}$ = 220 µF, 10 V, radial
$C_{23}$, $C_{24}$ = 2200 µF, 35 V, radial
$C_{25}$, $C_{26}$ = 10 µF, 16 V, radial
$C_{29}$, $C_{30}$ = 4.7 µF, 16 V, radial
$C_{33}$, $C_{34}$, $C_{39}$ = 10 µF, 10 V, radial
$C_{41}$, $C_{42}$ = 100 µF, 16 V, radial
$C_{43}$, $C_{44}$ = 100 µF, 10 V, radial

**Semiconductors**:
$D_1$ = 1N4148
$D_2$–$D_5$ = 1N4002


**Fig. 8**. Suggested front panel layout for the function generator (scale 1:1). A self-adhesive foil is available – see p. 70

**Integrated circuits**:
$IC_1$ = MAX038CPP (Maxim)
$IC_2$ = OP249GP (Analog Devices)
$IC_3$, $IC_6$ = AD708JN (Analog Devices)
$IC_4$ = OPA603AP (Burr Brown)
$IC_5$ = 74HC14
$IC_7$ = 7815
$IC_8$ = 7915
$IC_9$ = 7805
$I_{10}$ = 7905

**Miscellaneous**:
$K_1$–$K_4$ = BNC socket (board fitting)
$K_6$ = 10-way box header
$K_7$, $K_9$ = 3-way terminal block, 5 mm pitch
$K_8$ = 2-way terminal block, 7.5 mm pitch
$S_1$, $S_2$ = 2-pole, 6-position rotary switch
$S_3$ = 4-pole, 3-position rotary switch
$S_4$ = double-pole on/off switch
$F_1$ = fuse, 100 mA, slow
$Tr_1$ = mains transformer, secondary 2×18 V, 13 VA
2 off heat sink, 6.5 $K W^{-1}$ (e.g. SK129/25*)
1 off heat sink, 83 $K W^{-1}$ (e.g. ICK6/8L) for DIP-8 case
4 off ceramic washers
Screened cable as required
Enclosure to individual requirements (prototype = LC960 from LTP)
PCB Ref. No. 950068 (see p. 70)
Front panel foil Ref. No. 950068-F (see p. 70)
* Dau (UK) Ltd, Phone (01243) 553031

DISPLAY BOARD

**Resistors**:
$R_1$ = array of 4 × 10 kΩ
$R_2$, $R_4$ = 10 kΩ
$R_3$ = 1 MΩ

**Capacitors**:
$C_1$ = 22 pF foil trimmer
$C_2$ = 22 pF ceramic
$C_3$ = 100 nF, polypropylene
$C_4$ = 10 µF, 10 V, radial
$C_5$–$C_{12}$ = 10 nF

**Inductors**:
$L_1$ = 100 µH

**Integrated circuits**:
$IC_1$ = 74HC08
$IC_2$ = 74HC266
$IC_3$ = 74HC20
$IC_4$ = 74HC32
$IC_5$ = 74HC14
$IC_6$ = 74HC390
$IC_7$ = ICM7207A
$IC_8$ = ICM7224

**Miscellaneous**:
$K_1$ = 10-way box header
$LCD_1$ = 4.5 digit liquid crystal display (prototype Seiko SP516P)
$X_1$ = crystal, 5.24288 MHz
2 off 10-way socket
10-core flatcable as required.

[950068]