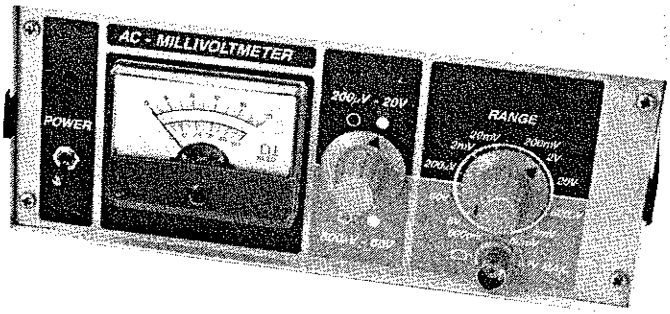
SIMPLE AC MILLIVOLTMETER



The third instrument in our series on budget test equipment is a wideband millivoltmeter with no fewer than twelve ranges, quite reasonable accuracy, a sensitivity of 200 μV and a frequency range from 20 Hz to over 2 MHz.

T. Giffard

A sensitive AC millivoltmeter is a useful instrument even if an oscilloscope is already available in your electronics workshop. This is mainly because signal levels are easier read from a meter scale than from an oscilloscope screen, which requires counting graticule divisions, multiplication by the set sensitivity, and conversion from the peak-to-peak value to the rms (root-mean-square) value. The AC millivoltmeter is also smaller and more sensitive than the average oscilloscope, and in addition may be powered by batteries. Compared to the digital multimeter, the AC millivoltmeter offers a much greater bandwidth. Although hard to beat for DC measurements, most DMMs have a frequency range of just 400 Hz which makes them really unsuitable even for signal tracing and frequency response measurements in AF amplifiers. By contrast, the AC millivoltmeter has a bandwidth of 20 Hz to 2 MHz.

The test instrument described here has no fewer than 12 measurement ranges from 0.2 mV to 60 V, and a high input impedance of 1 MΩ. The highest range, 60 V, allows output voltages of powerful AF amplifiers to be measured, while the most sensitive range, 0.2 mV, is suitable for direct signal level measurements on microphones and pick-up cartridges.

The choice of the enclosure and the design of the front-panel of the AC millivoltmeter are in line with the two earlier described instruments.

Circuit description

Since the instrument measures AC voltage only, off-set and drift are not normally problems in the amplifier stages. This means that integrated differential amplifiers in the form of operational amplifiers are not needed, and may be replaced by a circuit based on discrete transistors. The final version of this circuit was found to offer good stability at a reasonable bandwidth by virtue of the accurately compensated voltage divider at the input, and a PCB design that prevents problems with wiring capacitance by accommodating the range switch on the printed-circuit board.

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AV measurement ranges:
0.2 mV; 2 mV; 20 mV; 200 mV; 2 V; 20 V
0.6 mV; 6 mV; 60 mV; 600 mV; 6 V; 60 V

Accuracy:

- approx. 5% at 2 MHz with selected compensation capacitors in input attenuator; approx 3% at 100 kHz (depending on meter error).
- approx. 2% at 15 kHz; 10% above 15 kHz with non-selected standard MKT capacitors in input attenuator.

Bandwidth (0.5 dB):
17 Hz to 2 MHz

Input impedance:
1 MΩ//10 pF

Battery voltage:

nominal:	9 VDC
maximum:	10 VDC
minimum:	7.5 VDC

Current consumption:
7.5 mA typ. at 9 V.

Voltage divider

The circuit diagram in Fig. 1 shows frequency compensation capacitors fitted in parallel with every resistor in the input attenuator around rotary switch S_1. These capacitors linearize the frequency response above 500 kHz. Ceramic capacitors are connected in parallel with larger MKT (metallized multi-layer theraphtelate) types as a fine correction to the compensation at relatively high frequencies. If possible, the ceramic capacitors are selected to give a time constant of 11 μs for each of the *R*-*C* combinations in the voltage divider.

Input amplifier

Depending on the position of S_2 in the measurement amplifier, the AC voltage at the gate of FET T_1 that results in full-scale deflection of the meter is either 0.2 mV or 0.6 mV. The gate of the FET forms a very high impedance so that the voltage divider is hardly loaded. Components D_1-D_2 and R_8 protect the gate against overvoltage. Diodes D_1 and D_2 conduct at gate voltages of about +9.6 V and −0.6 V respectively and afford protection to about 50 V in the 0.2 mV range. Capacitor C_{13} prevents R_8 and its associated stray capacitance (the FET, the diodes and the relevant PCB tracks) forming a low-pass filter that would limit the bandwidth of the millivoltmeter. It should be noted, however, that the reactance of C_{13} drops with increasing frequency, which reduces the protective effect of the diodes at frequencies above 40 kHz or so. The values of R_8 and C_{13} are, therefore, a compromise between bandwidth and protection over a reasonable frequency range.

FET T_1 is not included in the feedback circuit of the measurement amplifier that follows it. It has its own feedback resistor, R_{11}, to give an amplification of about 1.5 times. R_9 functions as a drain resistor for direct voltage only. For alternating voltages, it is decoupled by C_{15} and C_{16}. These parts decouple the supply voltage and so help to stabilize the sensitive input stage. The DC setting of the FET is determined by the source resistor: since the gate is effectively grounded by the resistor ladder network, the voltage drop across the source resistor creates a negative gate voltage (U_{GS}), which determines the current through the drain- and the source resistors. The resultant bias setting can be deduced from the curves in Fig. 2. For a drain voltage of about +5.5 V, R_{11} = 680Ω to set a drain current of about 1.5 mA at U_{GS} = 1 V. It should be noted, however, that FETs in the same I_{DSS}-U_P group (here, the A-type of the BF256 is used) are subject to a certain production tolerance. Fortunately, this is of little consequence in this case because of the low drive level (below 1 mV).

Measurement amplifier

This consists of a differential amplifier, T_2-T_3, followed by a class-A output amplifier. The emitter current of the differential amplifier is sunk by current source T_4, which uses a LED, D_3, to supply a reference voltage of 1.8 V. A normal red LED has a typical voltage drop of about 1.5 V and can not be used in this application. The LED required is either a high-efficiency or an amber type which drops typically 1.8 V.

With R_{13} = 1 kΩ, T_4 sinks a constant current of 1.2 mA. The output stage also uses a constant current source, T_6. This current source forms a high AC resistance at the collector of T_5. Compared to a single collector resistor, the current source allows a much higher gain to be achieved. The previously mentioned reference voltage source, D_3, is also used for this second current source to give a constant current of about 2.5 mA (1.2 V/R_{19}).

The input FET is DC-coupled to the measurement amplifier and thus determines the bias setting by means of its drain voltage of between 4 V and 5 V. The inverting input of the 'discrete opamp', T_2–T_6, is formed by the base of T_3. This is DC-coupled to the output of the measurement amplifier by feedback resistor R_{15}, so that the differential amplifier regulates the direct voltage at the output (collectors of T_5-T_6) to the value that exists at the non-inverting opamp input, the base of T_2.

The overall gain for alternating voltages is either 83 times or 26 times as determined by switch S_2, which selects feedback resistors R_{15}-R_{16} or R_{15}-R_{17} in series with a parallel combination of capacitors, C_{17}-C_{18}. This simple switch arrangement results in two sets of measurement ranges.

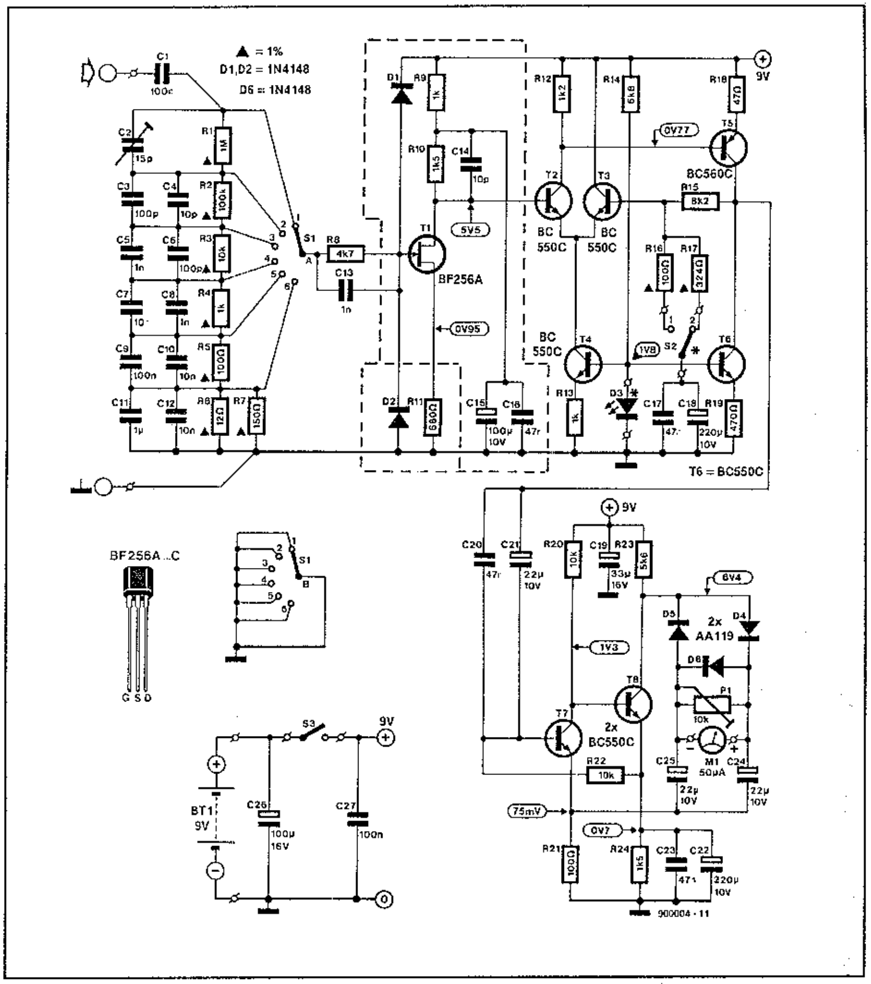


Fig. 1. Circuit diagram of the wideband millivoltmeter.

Fortunately, the transistors offer stable operation at relatively high frequencies, so that frequency compensation with a small ceramic capacitor is not needed in the AC feedback network. In practice, C_{14} alone does the job adequately.

Active rectifier

The signal rectifier is capacitively coupled to the measurement amplifier by C_{20} and C_{21}. The active part consists of a two-stage amplifier around T_7-T_8, which uses the rectifier and the moving-coil meter as part of its feedback network to achieve linear operation. The result is a high sensitivity of about 21 mV at the input of the rectifier for full-scale deflection (f.s.d.) of the moving-coil meter. The double meter scale is virtually linear, as shown on the front-panel layout in Fig. 3.

The high as well as stable amplification of the instrument results in a measure-

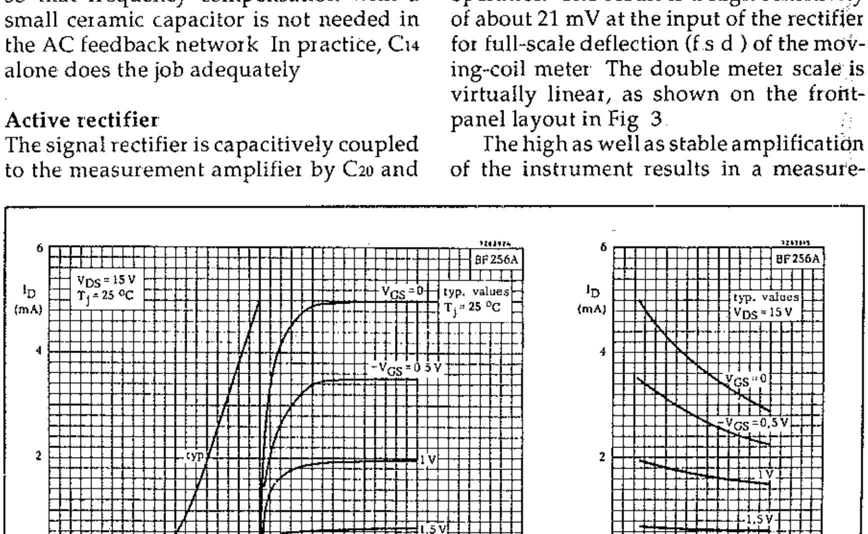


Fig. 2. BF256A FET design data.

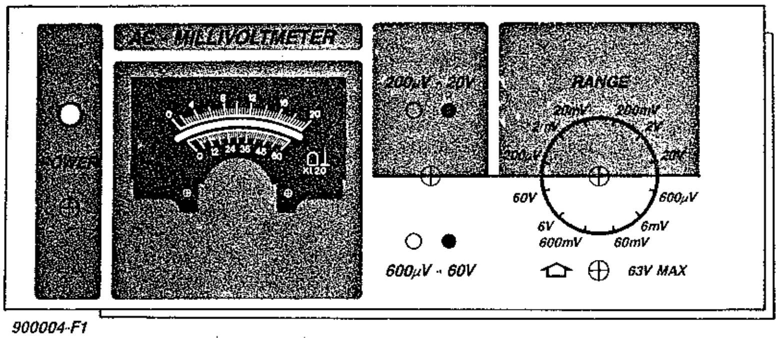


Fig. 3. Front-panel lay-out (shown at approx. 60% of true size).

ment range of 200 µV f.s.d., in which the lowest signal level that can be measured reliably is determined by the noise levels that exist in the discrete opamp and, of course, in the power supply. Consequently, the meter will not normally indicate '0' in the 200 µV range. Capacitors C_{26} and C_{27} reduce the noise on the supply voltage lines and compensate the negative effect of the rising internal resistance of the battery as this is slowly discharged.

Preset P_1 determines the form factor, i.e., it allows the meter indication to be reduced from the peak-to-peak value to the corresponding rms value. Note, however, that the set form factor is only valid for sine-wave voltages: the AC millivoltmeter does not contain a true-rms converter.

The signal rectifier consists of germanium diodes D_4-D_5. Silicon diode D_6 protects the coil in the meter against overloading.

Construction and alignment

As with the previous two instruments in this series, the construction depends entirely on the combination of the printed-circuit board (Fig. 4), the metal enclosure and the front-panel layout (Fig. 3). Together, these give a compact instrument that is simple to build because the wiring is kept to a minimum.

The two rotary switches are 6-way types with a special ring to set the number of positions. Set the ring to two positions on S_2. The same ring may be omitted or set to six positions in the case of the range selector, S_1. Select two suitable collet knobs for the switches and provide them with an additional pointer arrow opposite the one already printed on the plastic collar.

The population of the single-sided printed-circuit board should not present problems. Be sure to fit all components as close as possible to the board, i.e., keep all component terminals as short as possible. Check your work every now and then to prevent a long fault-finding session later.

Fit solder pins at the locations shown between the rotary switches. Next, bend a 20-mm high piece of tin plate to form the screening as shown on the photographs of the prototype board.

Cut and drill a suitable aluminium support plate that can be bolted on to the side panels of the LC-850 enclosure. The completed PCB is fitted on to this support plate with the aid of four 10-mm high threaded PCB spacers.

Use the front-panel foil as a template to cut and drill the aluminium front panel of the enclosure. Fit the power LED, the on/off switch, the moving-coil meter and the BNC socket. Connect wires to the LED, the switch and the meter, and a short length of screened cable to the BNC socket.

Remove the rear panel of the enclosure and insert the support plate with the PCB on it vertically between the side brackets of the enclosure. Move the assembly towards the front of the enclosure until the PCB is at about 50 mm from the front panel. This position allows enough room for the body of the moving-coil meter. Mark the holes in the side brackets to be used for securing the support panel. Cut the rotary switch spindles at the required distance from the front panel. Check if the two collet knobs fit, and remove them again.

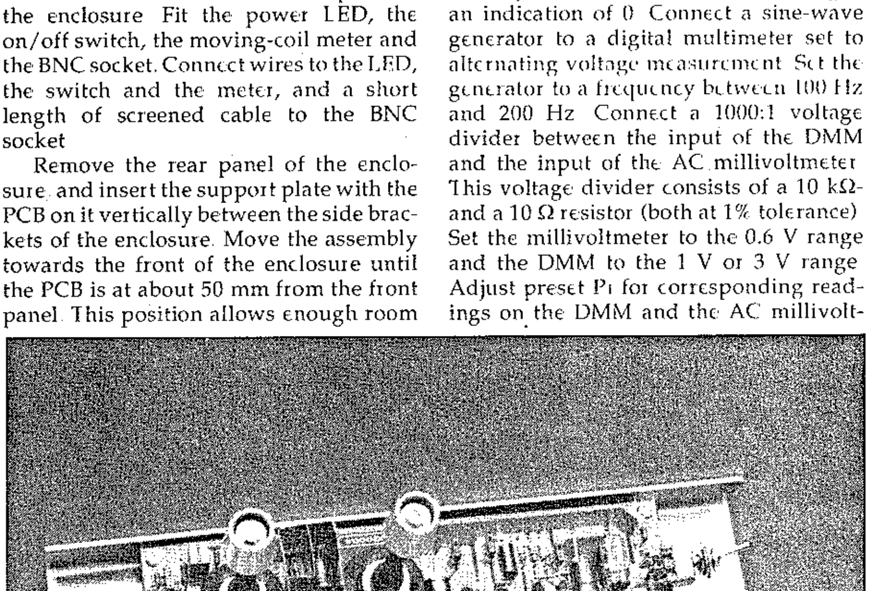
The enclosure has ample room behind the vertically fitted support plate for a 9-V battery or a battery pack made up of six penlight types. Rechargeable batteries may also be used, in which case it is necessary to fit a charge socket on the rear panel of the enclosure. The AC millivoltmeter must never be powered by a mains adapter without an internal 9 V regulator.

Setting up

The instrument is aligned before it is re-assembled and fitted into the enclosure. Connect the meter, the on/off switch, the LED, the BNC socket and a 9-V battery. Fit the knobs provisionally on the switch spindles.

Switch on and check that the current consumption is 7–8 mA. Use a digital multimeter to measure the voltage at the anode of D_3 (+1.8 V) and the positive terminal of C_{21} (between +5 V and +6 V). The latter voltage must be virtually equal to that at the drain of T_1. If this is not the case, replace the FET, or adapt R_{11}. Check that the collector of T_8 is at about +6.4 V.

Set the instrument to the 60 V range and adjust the mechanical meter setting to an indication of 0. Connect a sine-wave generator to a digital multimeter set to alternating voltage measurement. Set the generator to a frequency between 100 Hz and 200 Hz. Connect a 1000:1 voltage divider between the input of the DMM and the input of the AC millivoltmeter. This voltage divider consists of a 10 kΩ and a 10 Ω resistor (both at 1% tolerance). Set the millivoltmeter to the 0.6 V range and the DMM to the 1 V or 3 V range. Adjust preset P_1 for corresponding readings on the DMM and the AC millivolt-



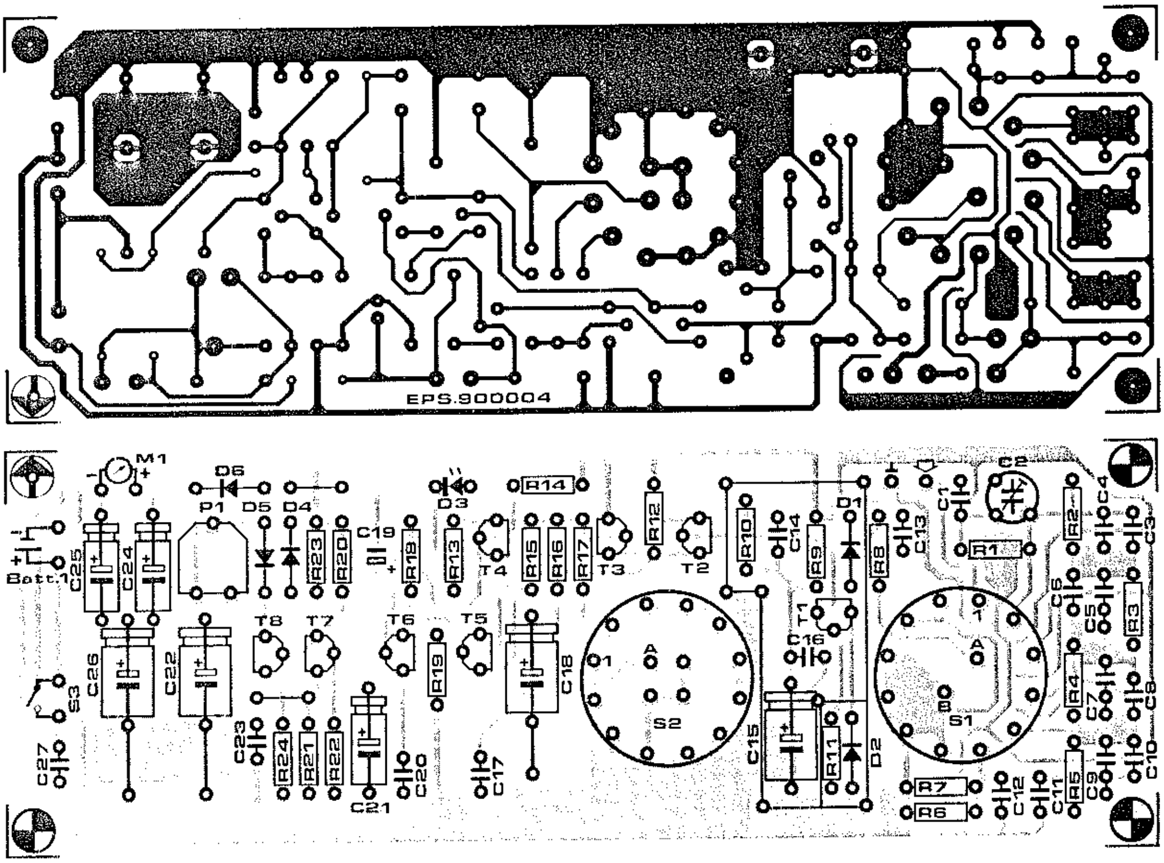


Fig. 4. Track layout and component mounting plan of the single-sided printed-circuit board for the millivoltmeter.

meter — i.e., disregard the multipliers 1 (V) and 0.001 (mV) — and check the adjustment for a couple of amplitude settings on the generator.

Check the indications on the millivoltmeter against those on the DMM. If the meter scale deviates considerably, try fitting another pair of diodes in positions D_4 and D_5 (Types BAT85 may be used if the stated germanium diodes are hard to obtain).

Since 1%-tolerance resistors are used in the input attenuator, the indications in the other ranges follow the results of the above alignment to within 1%.

Trimmer C_2 is adjusted for optimum compensation at an input frequency of 200 kHz. An oscilloscope and a sine-wave oscillator are required for this calibration to compare the indicated levels in the 200 mV ranges. If these instruments are not available, set C_2 to about two-thirds of its range to give a capacitance of 10–12 pF.

The prototype shown in the photographs has a 1-dB bandwidth of over 4 MHz, and an indication error smaller than 5% at 2 MHz.

Previously featured test equipment in this series:

RF inductance meter *Elektor Electronics* October 1989

LF/HF signal tracer *Elektor Electronics* December 1989

Parts list

Resistors:

R_1 = 1M0; 1%
R_2 = 100k; 1%
R_3 = 10k; 1%
R_4 = 1k0; 1%
R_5;R_{16} = 100Ω; 1%
R_6 = 12Ω; 1%
R_7 = 150Ω; 1%
R_8 = 4k7
R_9;R_{13} = 1k0
R_{10};R_{24} = 1k5
R_{11} = 680Ω
R_{12} = 1k2
R_{14} = 6k8
R_{15} = 8k2
R_{17} = 342Ω; 1%
R_{18} = 47Ω
R_{19} = 470Ω
R_{20};R_{22} = 10k
R_{21} = 100Ω
R_{23} = 5k6
P_1 = 10k preset H

Capacitors:

C_1;C_{27} = 100n ceramic
C_2 = 15p trimmer
C_3 = 100p polystyrene (styroflex)
C_4;C_{14} = 10p
C_5 = 1n0
C_7 = 10n
C_6 = 100p
C_8;C_{13} = 1n0 ceramic
C_9 = 100n
C_{10};C_{12} = 10n ceramic
C_{11} = 1µ0
C_{15} = 100µ; 10 V
C_{16};C_{17};C_{20};C_{23} = 47n ceramic
C_{18};C_{22} = 220µ; 10 V
C_{19} = 33µ; 16 V tantalum bead
C_{21};C_{24};C_{25} = 22µ; 10 V
C_{26} = 100µ; 16 V

Semiconductors:

D_1;D_2;D_6 = 1N4148
D_3 = amber or high-intensity LED (U_f = 1.8 V; see text)
D_4;D_5 = AA119
T_1 = BF256A
T_2;T_3;T_4;T_6;T_7;T_8 = BC550C
T_5 = BC560C

Miscellaneous:

S_1;S_2 = 2-pole 6-way rotary switch for PCB mounting.
S_3 = miniature SPDT switch.
BT_1 = 9-V battery with clip.
M_1 = 50 µA moving-coil meter e.g., Monador Type PM2.
Metal enclosure: H=80 mm; W=200 mm; D=180 mm. E.g., Telet LC-850 (C-I Electronics, P.O. Box 22089, 6360 AB Nuth, Holland).
PCB Type 900004 (see Readers Services page).
Front-panel foil 900004-F (see Readers Services page).