Wide-range General Purpose Signal Generator

A transistor instrument covering 150 kHz–120 MHz in six bands

by L. Nelson-Jones, A.M.I.E.R.E.*

AN r.f. signal generator is a most useful if not essential piece of test equipment so far as the amateur radio or electronics enthusiast is concerned. It is, however, also one of the most expensive, if an instrument of reasonable accuracy, and performance is required. The author found that the available commercial instruments fell into two main categories: Those with a means of monitoring the r.f. level and those without level monitors. In the second class there was in general an uncertainty in the generated r.f. level of at least ±6 dB. One such unmonitored instrument which the author had the misfortune to meet some years ago, changed its output by nearly 10 dB over a frequency change of 10% (41-45 MHz) on the highest frequency band.

The accuracy of the majority of monitored instruments was ±2 dB overall though a few were good to only ±3 dB. The inaccuracies were in general spread about equally between the attenuators and the level monitoring circuit. The majority of the instruments studied had a maximum output of 100 mV into either 75, or 50Ω, and nearly all quoted a frequency setting accuracy of 1%.

From these various specifications, and the facilities available to the author, a specification was drawn up for the instrument to be described.

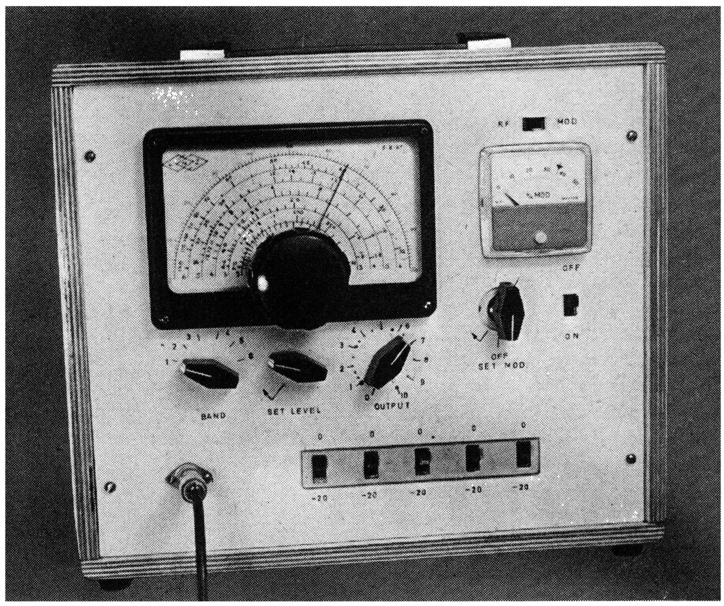
Accuracy of frequency setting	± 1%
Accuracy of level monitor	± 1 dB
Accuracy of step attenuator	± 0.5 dB per 20 dB step
Attenuation range of step attenuator	100 dB
Attenuation range of variable attenuator	0-20 dB calibrated
Accuracy of variable attenuator calibration	± 1 dB
Modulation level range	0-50%
Accuracy of modulation level setting	± 5% of indication from 10-50% modulation
Modulation frequency	400 Hz ± 50 Hz
Maximum unmodulated r.f. level	100 mV (terminated)
Output Impedance	75Ω constant

R.F. Oscillator

The circuit used is shown in Fig. 1 and is basically the familiar Hartley oscillator with the earth point moved to give a grounded collector configuration. The advantages found for this arrangement were that one side of the tuned circuit is grounded, greatly simplifying switching and layout; that only a single tapped winding is used on each range; and since the windings are grounded at one end it is a simple matter to arrange that unused windings are both grounded and shorted out. This prevents unused coils resonating with their stray capacitance and causing peaks or troughs in the output of the other ranges. The effect is similar to that found with the grid dip oscillator and is due to the coupling between coils resulting from their proximity to one another.

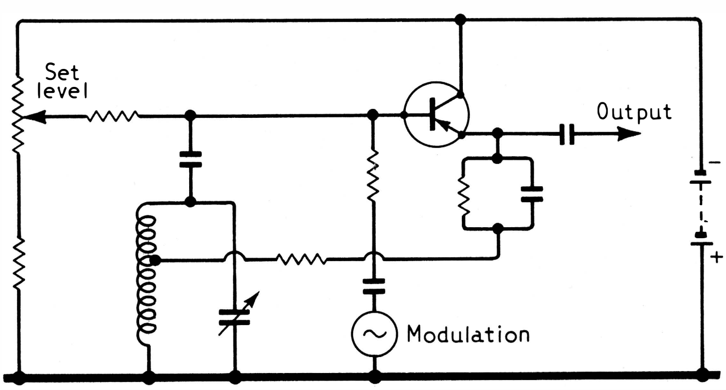
The level of oscillation is controlled by variation of the bias voltage applied to the oscillator. Further control of the level of oscillation, together with a reduction of harmonic content of the output, and some degree of equalization between ranges is provided by the degeneration produced by the unbypassed emitter resistor. Control of the oscillator by this means also saves changing the coil tapping point to find the correct degree of feedback for each range and makes it possible to use commercially available coils for the three lowest ranges. (For those with wave-winding facilities a tap at approximately 20-25% from the top of the winding is satisfactory.)

To improve the overall stability of the oscillator further and



The author's protype signal generator. The front panel is overlaid with Perspex lettered on the reverse side.

Fig. 1. The basic circuit of the r.f. oscillator employed.



*Plessey Automation Ltd.

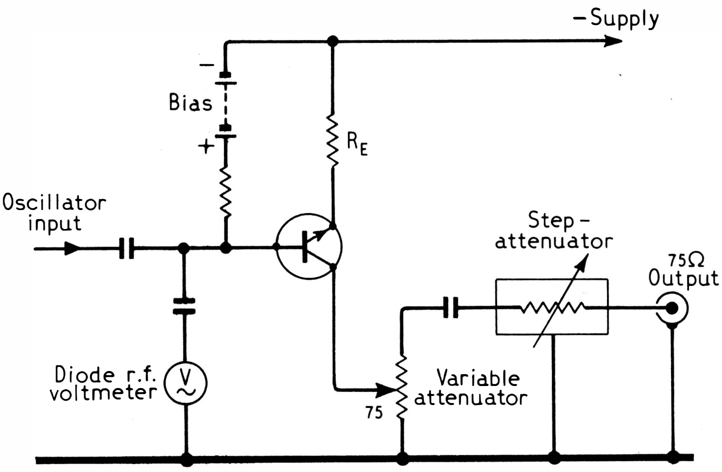


Fig. 2. Oscillator output amplifier and attenuator arrangement.

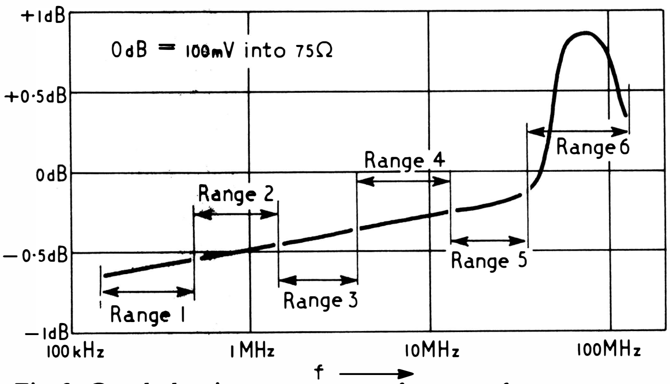


Fig. 3. Graph showing output versus frequency for a constant setting of the r.f. level indicator.

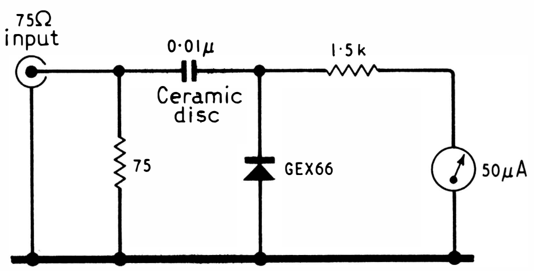


Fig. 4. Circuit used to obtain the graph of Fig. 3.

to help in reducing any tendency to squegging an additional emitter resistor is added, which is bypassed to r.f. The value of the unbypassed emitter resistor is chosen to be as high as possible while maintaining an adequate level of oscillation throughout the range at the minimum battery voltage (in this case 8 V).

Output Amplifier and Attenuator

The oscillator described above generates a good sinewave signal, but at a level and impedence unsuitable for general use. In many commercial generators a coupling winding is placed on the oscillator coil to obtain a suitable output level, this is then applied to a low inductance potentiometer followed by an attenuator pad in order to ensure a reasonably constant output impedance at the highest level settings. The use of such a coupling coil necessitates the use of another bank of contacts on the range selection switch.

It was felt that this method, though it works well enough, is a rather crude way of achieving the required end. A more fundamental method, made possible by the availability of good u.h.f. transistors, was therefore tried with considerable success. The method consists of feeding the variable attenuator, which is wired as a current-divider from a constant current generator. The result is a variable attenuator with a constant output impedance equal to the value of the potentiometer, providing that the output impedance of the current generator does not appreciably shunt the potentiometer.

The practical circuit used to achieve this is shown in Fig. 2. Level monitoring is achieved by the use of a diode voltmeter which measures the input to the current generator.

The current generator transistor operates in class A and a bias source is used rather than a potentiometer across the supply. The bias potentiometer, if used, would have to be chosen to give sufficient collector current at minimum battery voltage and would result in a very high collector current at maximum battery voltage, with consequently reduced battery life. The current in this stage must exceed:

$$[(E_{OUT}\sqrt{2})/R_{LOAD}]10^3 \text{ mA},$$

for class A operation. For 75 Ω output impedance and 100 mV r.m.s., this gives:

$$(0.1 \times 1.414 \times 10^3)/37.5 = 3.77 \text{ mA}$$

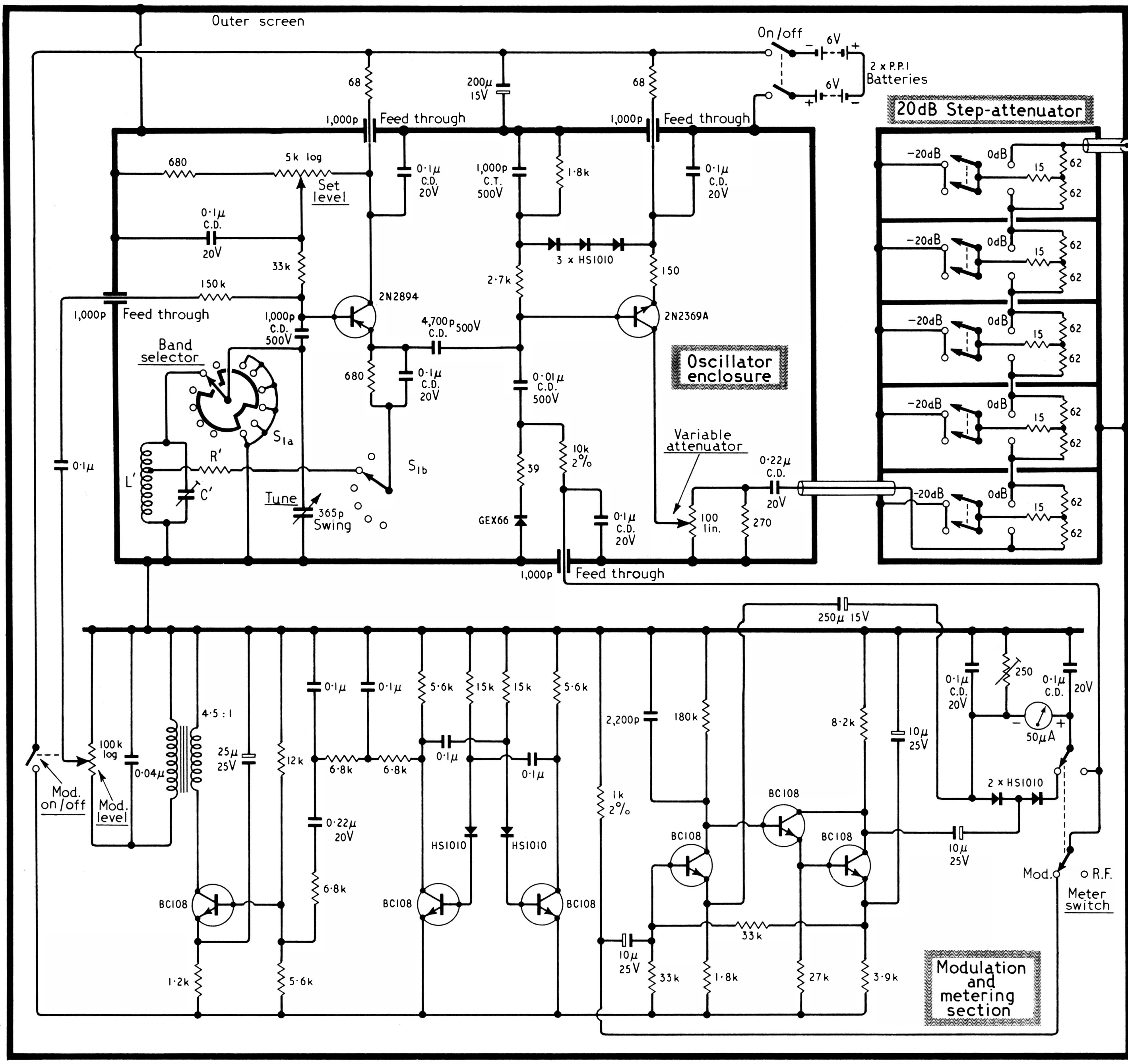
$R_{LOAD} = 37.5\ \Omega$ since so far as the current generator is concerned the current divider, and load (both 75 Ω are in parallel. A current of 5 mA is, therefore, adequate. In the circuit used (Fig. 5) the bias source is three forward biased silicon diodes, which provide approximately 2 V that is reasonably independent of supply voltage. This potential does, of course, vary with temperature, but for normal operating temperatures this is of little consequence providing that the collector current of the current generator is approximately 150% of the minimum as indicated above. The value of R_E depends on the voltage available from the oscillator and on the voltage required by the diode r.f. voltmeter for a reasonable value of d.c. output current for a level indicator. A value of 150 Ω was found to be a reasonable compromise, giving a d.c. current to the indicator of 36 μA. The meter semsitivity should not be lowered too much however or both the r.f. oscillator and the modulation measuring transistor will be unable to provide enough drive.

The performance of the output stage is illustrated in Fig. 3 which shows the variation of actual output for a constant reading of the level indicator (that is a constant input to the current generator stage). The circuit of the voltmeter used to measure this and terminate the output of the signal generator is shown in Fig 4.

The current divider potentiometer used is a solid moulded carbon type (Plessey type E), which is stable and has a long operating life. Deposited track carbon types are not suitable because of wear problems. The lowest value available is 100 Ω but this can be reduced to 75 Ω by connecting a 270 Ω resistor across the potentiometer.

Attenuator

The majority of commercial generators use a ladder attenuator having either four, or five steps of 20 dB each. Owing to the difficulty of making a suitable screened enclosure and switch for such an attenuator it was decided to make a set of five separately switched attenuators. A suitable screened enclosure can then easily be made covering the complete attenuator and the output socket (see Fig. 7). The screen has intersection screening plates, each having a small slot to allow the coupling wire to pass through. The switches themselves are standard two-pole slide switches with a change-over action. Tinned steel sheet was used for the fabrication of the attenuator screen and all internal joints are soldered (in order to stop rusting the cut edges may be filed smooth and tinned also). The screen is made a close fit on to the aluminium front panel and secured with screws at frequent intervals.



All resistors — ¼W ±10% carbon composition
Capacitors — polyester tubular
} Unless otherwise marked

C.D. = Ceramic disc
C.T. = Ceramic tubular (or disc)

For details of attenuator resistors see text

Fig. 5. Overall circuit diagram of the generator. Some reduction in cost may be realized by using the transistors marked with an asterisk in the components comments section.

Very good screening of each section of the attenuator from the others; of the output socket from the rest of the generator; and the generator from the outside world is essential if the attenuator is to have any sort of accuracy at high degrees of attenuation, especially at the highest frequencies covered.

It was at first thought that obtaining suitable resistors for the attenuator was going to be a major stumbling block, fortunately experiments showed that the commonly available solid carbon moulded resistors were surprisingly good for this application. Such resistors are usually available only in 10% tolerance, which means buying two or three times the quantity required, and selecting resistors. This is still a cheap way of obtaining attenuator resistors. Since the resistors will be required to dissipate only a small amount of power, stability should not prove a problem, but care should be taken in soldering them into position to minimize heat transfer to the resistors. A pair of pliers gripping the lead between the resistor and the soldered joint, during soldering should suffice.

High stability cracked carbon, metal oxide, and other film resistors must not be used, since these will all have spiral tracks and will cause serious errors at the higher frequencies due to the inductive component of the resistor's impedance. Commercial attenuators do, in fact, use film resistors, but these are specially manufactured and do not have spiral tracks. Such resistors are expensive and not readily available, but if any reader is lucky enough to have such a source of non-spiral 15 and 62 Ω resistors he should certainly use them. (Calculated values 15.15 and 61.35 Ω).

A "T" configuration was chosen for the step attenuator sections since at high frequency stray capacitance is the most serious cause of attenuator error and as the value of the resistors used in the "T" are lower than in a "Π" arrangement the stray

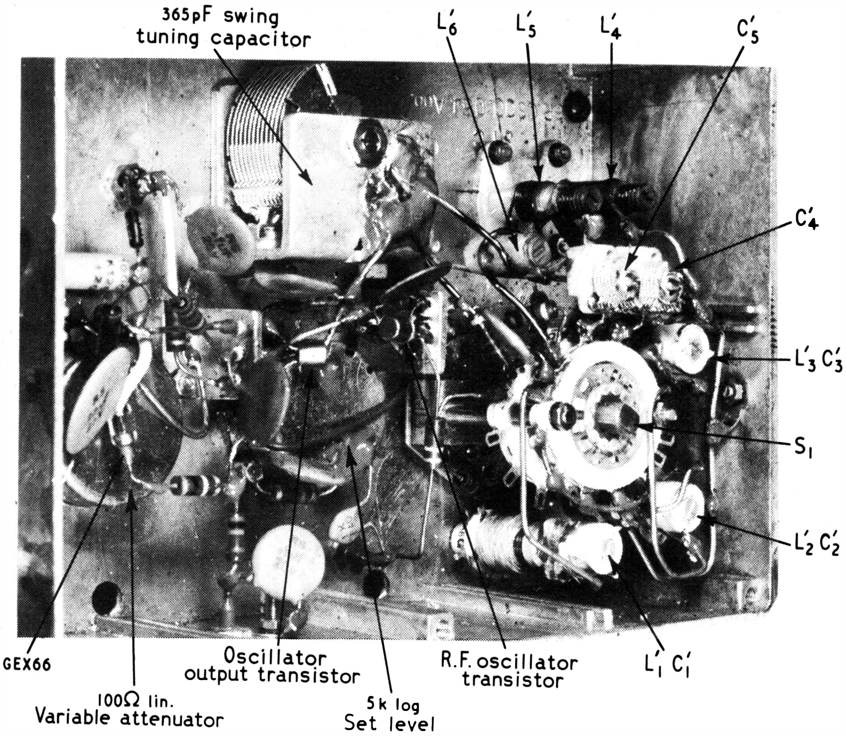


Fig. 6. Internal view of the r.f. oscillator enclosure.

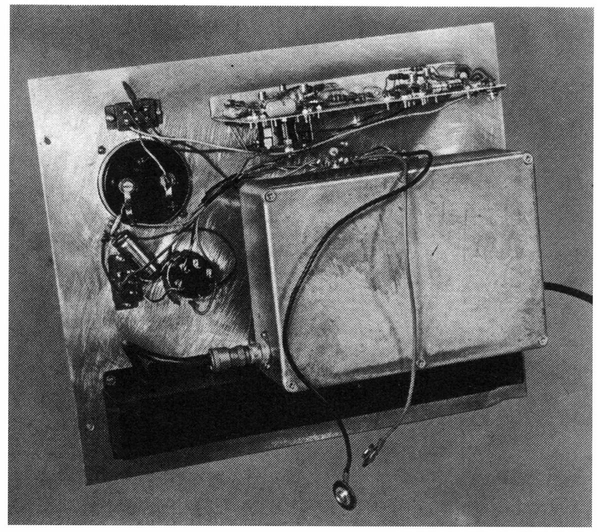


Fig. 7. Rear view of the instrument. The step attenuator is behind the metal case below the r.f. oscillator enclosure.

capacitances produce less shunting action. The values for the arms are 62Ω for the series elements and 15Ω for the parallel element. 15Ω is a standard value in the 10% range and suitable resistors may therefore be selected on a bridge. For the 62Ω resistors (a standard value in 5% resistors), 68Ω resistors (unselected) were each shunted with a resistor ranging from 470 to 1,000Ω to obtain a value, as measured on a bridge, which was as close to 62Ω as possible (±1%). This method increases the shunt capacity of the series arms, but does not appear to have produced any serious error even at 100 MHz, with the "T" configuration. The resistors are soldered directly to the switches and all leads kept as short as possible. Earth tags are put under the fixing screws of each switch and the leads to them are kept as short as possible.

Modulation

The modulating voltage is applied to the base of the oscillator transistor (Fig. 1) through a high value resistor to avoid shunting the r.f. voltages, a d.c. blocking capacitor is placed in series with this resistor to avoid shunting the oscillator transistor bias circuit. The modulating voltage required to produce a given level of modulation is not constant but depends on the collector current in the oscillator transistor and this in turn depends on the operating frequency. At the higher frequencies the oscillator transistor has to pass a larger collector current because of the higher losses of the tuned circuits, the lower dynamic impedance of the high frequency tuned circuits (both factors requiring a higher loop gain to maintain oscillation) and reduction of the *f* with current in the oscillator transistor.

Logarithmic potentiometers are used for both the r.f. and modulation level setting controls to enable easier setting despite the wide variations in the requirements with frequency. Since the modulation depth cannot be measured by measuring the modulating voltage, it was decided to measure the audio component of the r.f. level detector output. To achieve this a resistor is substituted for the meter in the level detector and a transistor millivoltmeter measures the audio component across it with the level meter connected to the output of the audio millivoltmeter. The frequency response of the millivoltmeter is limited to a few thousand cycles so that r.f. voltages cause no errors.

In the prototype instrument the 0-50 scale of the basic 50 μA meter indicates percentage modulation, as the degree of feedback is sufficient to linearize the scale of the millivoltmeter. With the circuit shown in Fig. 5, 50% modulation corresponds to 15 mV at the input to the millivoltmeter.

The modulation depth was set (using an oscilloscope) to 33%, and the r.f. level carefully monitored also (this must, as is customary, be set correctly before setting the modulation depth). The sensitivity (feedback value) of the millivoltmeter was then set to give a reading on the meter of 33 μA. 33% was chosen as being close to the commonly used figure of 30% modulation, but being easier to set up on the oscilloscope. The carrier is first set to 6 cm on the oscilloscope (peak-to-peak) and the modulation is increased until the trough of the modulation reduces the carrier to 4 cm, and the peak modulation increases the carrier to 8 cm, the modulation index is then 33%.

A simple *LC* oscillator was rejected for this application, although at first it might seem the most obvious choice. The main reason was the difficulty of maintaining a reasonable waveform and an adequate level of oscillation with varying battery voltage at all battery voltages. Stabilization of the supply voltage would cure this problem, of course, but this was felt to be too wasteful of battery power.

The circuit used consists of a multivibrator feeding a shaping filter which in turn drives a tuned output stage. This tuned output stage provides the necessary drive to the modulation input of the r.f. oscillator via the modulation level setting potentiometer. The main problem is to obtain an accurate inductance for the secondary of the tuned output transformer which has a value of 3 henries, in the prototype an ungapped 25 mm ferrite pot core was used. Two courses are open in order to get accurate tuning. (a) If a bridge is available, the secondary can be wound on first with excess turns, which are then removed until the correct value is obtained, and the correct number of primary turns calculated by dividing the secondary turns by 4.5; or (b) The transformer can be wound using the nominal turns given later and the tuning capacitor varied by trial. In either case the tuning is not critical as the *Q* is low. The effect of severe mistuning is a loss of output and increased waveform distortion. The values given for the multivibrator in Fig. 5 result in a modulation frequency of a little over 400 Hz (the prototype gave 430 Hz). The base resistors of this multivibrator can, of course, also be varied to bring the multivibrator to resonance with the tuned output transformer, providing that the tuned transformer is not too far from its correct frequency.

Calibration

The dial for the r.f. section of this instrument can be calibrated in two ways:

The output of the generator can be mixed in a diode mixer with the output of another signal generator with known errors. An audio amplifier and loudspeaker are connected to the diode mixer and the dial is calibrated by beating the fundamentals together and noting the dial reading for zero beat, using the 0-100 scale printed on the Eddystone dial. The dial readings are then plotted on graph paper against the known frequency and a smooth curve drawn, from which to read off the exact readings for any desired frequency marking. This information is then transferred to the dial.

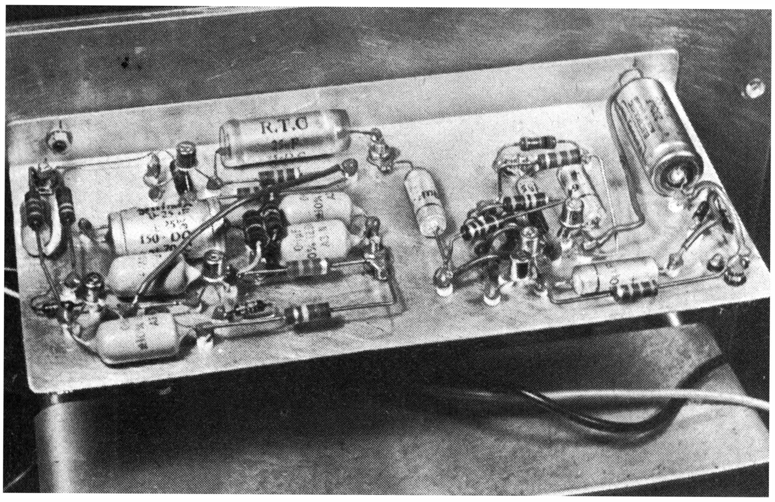
In the second method the output of the generator is fed into a receiver. The difficulty with this method is the gaps left, for instance, a receiver using a 460-470 kHz i.f. will not cover this frequency. The range above 30 MHz is also rather a problem.

In both these cases checks of the calibration of the reference standard, whether it be another signal generator, or a receiver, can be made against a crystal oscillator or other frequency standard. The author used the 1 MHz standard described in the January 1968 edition of *Wireless World* to check the calibration of a borrowed signal generator. The borrowed generator only covered up to 80 MHz so that harmonics were used above this, with a check using an f.m. receiver on the 88-108 MHz band. No doubt the ingenuity of readers will find other ways of achieving an accurate calibration, and the lucky few may even have access to a high-frequency digital counter for a short while.

It may be found impossible to maintain oscillation at the low frequency end of bands 5 and 6 due to the very unfavourable *L.C.* ratio. This is of no consequence as there is considerable overlap between these bands. The phenomena is present on at least one commercial signal generator and need cause no concern.

In the initial stages of calibration the extremes of each range are first set by means of the dust cores of the coils, and the trimmer capacitors so as to obtain a small overlap of the lowest three ranges, and with the lowest range starting at about 145 kHz. A greater overlap will be found possible on the upper ranges.

Fig. 8. Modulation oscillator and modulation voltmeter chassis. The modulation output transformer is under the left hand of chassis and the voltmeter sensitivity adjustment potentiometer is under the right-hand edge of the chassis.



The coils specified for ranges one, two and three have their cores accessible only from outside the screened enclosure at a point lying behind the front panel, but as the normal adjuster is flexible no trouble was found in adjusting these cores. There is a space of some two inches between the panel and the oscillator enclosure to allow for the flexible coupling between the dial assembly and the tuning capacitor shaft.

Two Ever-Ready PP1 batteries or equivalent, are used in series to provide a 12-volt supply which should give 300 hours life with average use. As has been said, no stabilization of their output has been used since no advantage was found, in accuracy, or in any other way from doing so.

Constructional Details

The prototype generator is housed in a plywood case finished in polyurethane varnish. The inside of the case is lined with tinned steel, the joints being soldered. The front panel is fixed to brackets soldered to this lining and additional spring contacts provide extra connection points with the front panel so as to form a second complete screen round the oscillator which is mounted in a metal case, in order to reduce stray radiation.

The use of batteries for power is of great assistance in reducing stray radiation since there is no need for elaborate filtering of mains leads where they pass through the outer casing. In the author's experience the mains lead of many signal generators is a major cause of such stray radiation. Another cause is the meter used for the level indicator, since this is connected to the diode r.f. voltmeter circuit. The body of the meter is in most cases of a plastic construction, and there is, as a result, a "hole" in the screen where the meter passes through the front panel. If this is found to be a source of an unacceptable level of stray radiation it will be necessary to fit a complete metal screen over the rear of the meter with feed-through capacitors for the connections. This is done in many commercial generators.

The front panel of the prototype is of $\frac{1}{8}$in. Dural, but this is overlaid with a $\frac{3}{32}$in. Perspex panel. This overlay has all the dial markings in Indian ink (in reverse) on the rear of the panel. A lettering stencil was used to letter the panel with a stylus pen, the stencil being reversed. After lettering, the rear of the Perspex overlay was painted with two coats of white cellulose paint. The result of the use of this overlay is a front panel of neat appearance which is easily cleaned, and from which the lettering will not rub off. The overlay is held in position by the dial assembly, the meter, the output socket, and the front panel screws. A further advantage of this overlay, is that it has enabled the various other component fixing screws to be hidden, the front panel being thick enough to take countersunk screws. In marking the Perspex with Indian ink it may be found hard to get clear lines due to lack of "wetting", but if the area to be lettered is first rubbed over well with a hard typing eraser and then cleaned well, the slight roughening will enable the lettering to adhere. The slight roughening will not show once the panel is painted white, provided it has been well cleaned after using the eraser.

The instrument described provides a standard of performance equal to many of the commercially available instruments costing many times the outlay required for its construction. It is hoped that this article will encourage others to construct their own instruments, and that it has shown the guiding principles which led to the successful conclusion of the author's design.

Coil details

Band 1; Electroniques MZT.8.
Connections, green to chassis, yellow to R', black to S_{1A}.

Band 2; Electroniques MZT.9.
Connections, brown to earth, yellow to *R'*, black to S_{1A} Link blue to green.

The coupling winding, which is not used on Bands 1 & 3, is connected in series with the main winding on Band 2 to enable coverage of the 460-470 kHz region.

Band 3; Electroniques MZT.10.
Connections as Band 1.

Band 4; 30 turns of 28 s.w.g. enamelled copper wire, tapped 6 turns from the top, close wound. Bottom of winding to earth, tap to *R'*, top to S_{1A}.

Band 5; 8 turns of 24 s.w.g. enamelled copper wire, tapped 2 turns from the top, connections as Band 4. Close wound.

Band 6; one turn of 18 s.w.g. enamelled copper wire wound with a pitch of 0.2 inches. There is no tap on this coil as the lead inductance of the oscillator circuit provides a large part of the required inductance. The resistor *R'* connects direct between S_{1A} and S_{1B}. The lead from S_{1A} wiper to the tuning capacitor stator is also very much part of the tuning inductance on this range and should be as short and straight as possible. The former is cemented to the single turn coil.

Bands 4, 5 & 6 coils are wound on formers which are of 6 mm internal diameter, and of 0.3 inches outside diameter such as Aladdin 8A-6044-21/6E moulded in bakelite with a square base. Suitable cores are Aladdin 9R-1044-81 which have a similar adjustment slot to the cores of the coils for bands 1, 2 & 3. Both these items are also supplied by Electroniques. A suitable trimming tool type TT.1 is also available from this source. Finish with a thin coat of the same polyurethane varnish as used on the case. The coil for former band 6 has the square base removed and the core may be cut in half if adjustment is difficult.

Modulation transformer; Secondary, 667 turns, primary 149 turns, 40 s.w.g. enamelled single silk covered wire. Core, 1 pair of Mullard FX 2240 ungapped cores. Former, Mullard DT.2179 (mounting used in prototype, terminal board DT.2227; mounting clip DT.2228).

Component comments

Band switch; S_{1A} wafer TSW/2/S. S_{1B} wafer TSW6/2/—. Switch mechanism TSW/SH/2½/2. Studding 6 BA. TSW/ST/6/12 (12 inches). Spacers 0.5 inch TSW/SP/½L (4 off). Available from Electroniques.

Wafer S_{1B} is assembled nearest to the front panel.

Tuning capacitor; Jackson Bros., type JB/5250/1/365.

Trimmer capacitors; (bands 4 & 5 only) Jackson Bros., type JB/5440/8 or Mullard type E7850 or E7875. 2-8 pF concentric type available from Henry's Radio who can also supply a 10 pF capacitor similar to the Jackson type named.

Variable attenuator; Plessey type E, 100 Ω, linear. Available from Electroniques under part no. E/100/LIN.

Dial assembly and flexible coupling; Eddystone Radio type 598 with type 893 coupler or Jackson Bros., type JB/4693.

Resistors R'; Band 1—1kΩ; Band 2—820 Ω; Band 3—820 Ω; Band 4—680 Ω; Band 5—390 Ω; Band 6—68 Ω.

Attenuator resistors; Erie type 16, Morganite type S or Radiospares ½-watt (see text).

Transistors; r.f. oscillator output stage—2N2369, 2N2369A, TIS49*, types BSX20 and BSX44 should also function satisfactorily. For the r.f. oscillator—2N2894, V405A or TIS50*.

Diodes; silicon Emihus HS1010 (high conductance with V_f less than 1 V at $I_f = 50$ mA) most high conductance silicon diodes are suitable, e.e., 1S120*, OA200/202, CV7040. The germanium device in the level monitor circuit is Mullard GEX66 or 64. Most other germanium point contact diodes are unsuitable and give too large an error at the highest frequencies.

Semicinductors marked are likely to be cheaper and easier to obtain than the others specified.*

Feed-through capacitors; 1000 pF, Erie type 361.

Attenuator switches; (also used for ON/OFF and meter switch) Radiospares "slide switches".

Oscillator enclosure; S.T.C. die-cast case type 46R.C500.-064.A00 available as type 46R.064.A. from many suppliers.

P.C.M. Copes with Everything

The recent introduction of 24-channel pulse code modulation systems using 1.536 Mbits, carried by conventional telephone cables repeatered at 2000 yd intervals, is only the first step in an integrated system covering the whole country. This emerged from a colloquium at the I.E.E. at which the present state of p.c.m. was discussed by representatives of the Post Office and the communications industry. At present the larger capacity systems are only at the laboratory stage and some are little more than gleams in the eyes of the designers. The next step (according to A. C. Frost and K. W. Cattermole) will probably be 96-channel systems using 6-8 Mbits. These will make the viewphone a practical proposition, probably causing an increased demand for communication links. It is visualized also that bit rates will be increased to between 100 and 1000 Mbits to accommodate future needs including television links. Signals with these high bit rates will probably be transmitted by microwave links either in waveguides or freespace, intercontinental links using satellite relay stations.

The subject of distortion was discussed at some length, and a recording of music, presented by D. E. L. Shorter of the B.B.C., very effectively demonstrated the increase in background noise when the number of quantizing steps is reduced. The quantizing noise gets less "white" and an audible interference pattern is produced. While 2^7 levels are quite adequate for telephonic speech, 2^{11} or 2^{12} need to be used for high quality music. It is possible to accommodate 4 music channels in a 1.536 Mbit system normally used for carrying 24 speech channels. Television is more tolerant of quantization distortion than music and 2^7 or 2^8 levels provide a good quality picture. However, this results in a bit rate in excess of 100 Mbits.

The closing talk was given by A. H. Reeves, the inventor of p.c.m. Letting his imagination take over, he spoke of a world in the not too distant future where communication links will permit people to carry out many jobs from the comfort of their homes, conferences using closed-circuit television etc. For this, he said, reliable links capable of bit rates of the order of 10^9 or 10^{10} bits will be required. Light is the most probable answer. At present the loss in glass-fibre guides is about 200 dB/km. The theoretical loss is of the order of 6 dB/km so that fibres with losses of only 30 to 40 dB/km should be practical in the near future. With these, repeatered cables using 30 or more fibres are possible for both land and transoceanic links. The repeaters will probably make use of gallium arsenide i.c. lasers.

He went on to predict that an electro-optical revolution is in the offing and that the sooner this was recognized and a start made the better, as it would be cheaper in the long run. His closing words were "I'm prepared to take a large bet that I'm right!"