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FRAME GRID VALVES FOR TELEVISION

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The frame grid valves for television tuners are the PCC89 and PCF86. The PCC89 is a variable-mu r.f. double triode for use as a cascode amplifier. It is the frame grid counterpart of the conventional PCC84, but it has twice the slope. The PCF86 is a combined triode and high-slope r.f. pentode for use in the mixer stage. Its conventional counterpart is the PCF80; but, again, the frame grid valve has about twice the slope of its predecessor, and the increase in conversion conductance is from 2.1mA/V to 4.5mA/V. With such substantial changes in characteristics, it is obvious that the frame grid types cannot be used as plug-in replacements for the earlier types. Tuners will necessarily have to be redesigned with different component values. In addition, the large increase in voltage gain will demand particular care with respect to stability, especially as tuners are progressively miniaturised and printed circuits are introduced.

The design of the r.f. amplifier round the PCC89 will be discussed in a later advertisement. Here we shall outline the special features of a frame grid mixer stage.

STABILITY

In the mixer, stability must be considered primarily at the frequency where the grid tuned circuit and the i.f. transformer most closely approach in frequency; that is to say, on channel 1. The stability of the stage is determined by the effective slope of the mixer valve, which is doubled when a frame grid valve is used. However, the impedances of the grid and anode circuits are likely to be substantially the same for the PCF80 and PCF86. The worst condition for stability is when the primary of the r.f. bandpass filter is detuned with respect to the secondary, feeding the mixer grid; and the impedance of the i.f. bandpass filter (which is usually built into the tuner itself) is at its highest.

In the 40Mc/s region the characteristics of the circuit are such that there is only a narrow margin of stability. In particular, there is very little allowance for stray capacitances. For maximum stability, especially during alignment, it is therefore advantageous to neutralise the anode-to-grid capacitance of the valve. This can be done with either a loop coupled transformer (Fig. 1) or with bottom capacitance coupling (Fig. 2). In either case, the equivalent bridge circuit is as shown in Fig. 3. The value of Cg2 is not particularly critical, since partial neutralisation should be sufficient. However, the normal precautions must be observed: the stage should be carefully wired, the placing of components near the valve-holder should be avoided as far as possible, and the i.f. transformer coil should be kept well away from the mixer grid circuit.

R.F. LOSSES

In the design of the PCF86, special attention has been given to the question of r.f. losses. The triode and pentode cathode pins are internally strapped to minimise cathode lead inductance. They should both be taken straight to ground. Accordingly, in the PCF86 the effective grid-cathode capacitance due to cathode lead inductance rises comparatively little with frequency. Thus at 200Mc/s its value is only 10% above its l.f. value; while in the PCF80 the increase is more like 25%, and the capacitance/frequency characteristic is steep.

The input impedance of the PCF86 pentode has been carefully controlled by a certain amount of screen regeneration which is built into the valve. The inductive component of the screen grid connection produces a negative damping effect in the grid-cathode circuit by virtue of Miller effect; and the total input conductance of the pentode, due to cathode lead and screen lead inductance, is held within narrow limits.

FIG. 1

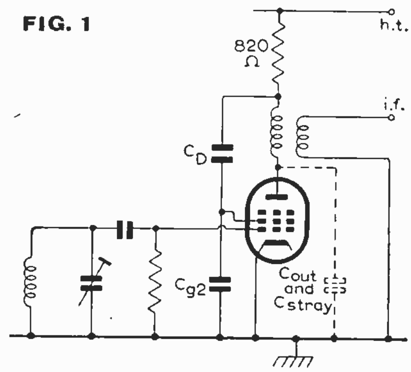


FIG. 2

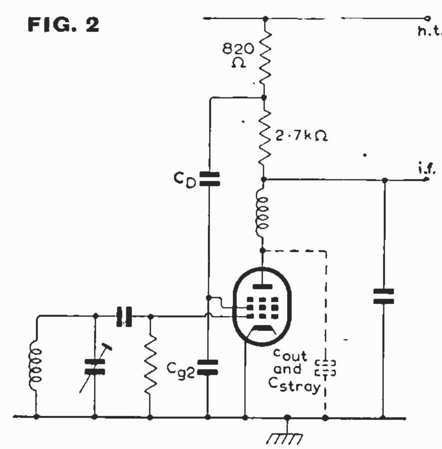
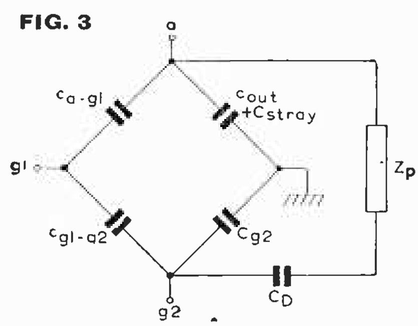


FIG. 3



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Wireless World

Broadcasting Parliament

WE in this journal are interested primarily in the technique of radio communications, and normally we leave it to others to decide for what ends they are used. Nevertheless, when some novel application or extension of function takes place, or is mooted, we are expected to have an opinion and when relevant to express it.

Thus, when broadcasting started we opened our pages to programme matters, both domestic and foreign, as a means of interesting new readers in the benefits and attractions of owning a wireless set, but as the service settled down and acquired a predictable pattern we were content to leave these things to others and to reserve comment for special occasions or any new turn of events.

A recent proposal by Mr. Aneurin Bevan that the Lords and Commons should be continuously televised as a means of increasing public interest in Parliamentary proceedings has again provoked discussion. We say "again" because the idea of broadcasting Parliament is not basically a new idea. As long ago as March 24th, 1926, the following comment appeared in this journal:

> "As we write, the question as to whether or not the Budget speech will be broadcast remains undecided, and very divergent views have been expressed on the subject. If we are asked what our opinion is as to the advisability or otherwise of broadcasting Parliamentary proceedings, we should most definitely state that, in general principle, we are opposed to such a course. In our opinion anything in the nature of regular or frequent broadcasting of Parliamentary debates would tend to convert the House into a stage, where members would always feel that they were being listened to by an audience not always in sympathy with their views and always critical of their powers of oratory. Popularity amongst the public would tend to depend more upon eloquence than upon substance in speeches, whereas it should be remembered that not always the best orators make the best statesmen, and, in fact, the reverse is not infrequently the case. Apart from these points, there are, of course, many other objections which might well be raised against the principle of broadcasting the proceedings of the House as a regular programme feature.
>
> "When, however a special occasion arises, as, for instance, in the case of the Budget speech, the matter might well be viewed somewhat differently. There are millions who may never have the opportunity of listening in the galleries on such an occasion, and from the point of view of national education such an exception might well be made without the creation of a precedent which would ultimately lead to regular or even frequent transmissions of the kind. We should, in fact, welcome Parliamentary broadcasting if carried out very occasionally and in special circumstances such as the present instance, where public interest is so great, in view of the novelty, as to outbalance objections."

As far as the main issues are concerned there is little that can be added to what was said nearly 34 years ago. Technically, it is now perhaps more difficult than it was in 1926 to provide a continuous broadcast from Westminster, for the simple reason, as Sir Ian Jacob has emphasized, that no channel is available. But Sir Ian does not rule out the possibility of televising the best debates as they occur during the course of the year. These would be dealt with as outside broadcasts and would take their place as part of the normal programmes. No doubt Mr. Bevan would object on the grounds that this implies selection, and therefore editing by, to use his own words, "the bureaucrats of Broadcasting House." It would certainly involve recording, for only the leisured few—and M.P.s—can afford the time to attend debates at, say, 11 o'clock in the morning. Unless Parliamentary broadcasts can be brought to the people at normal and, when sufficiently important, peak viewing hours they will fail to conform to the democratic principles which were the mainspring of Mr. Bevan's suggestion. Continuous live broadcasting of Parliament during normal working hours is likely to have an audience very little larger than the circulation of Hansard.

No official assessment of the feasibility of mounting cameras to command views of Members rising to speak in any part of the House has yet been published, but it is not technically impossible, though it is bound to present difficulties. It is much easier to place microphones than cameras, as has already been demonstrated by the sound reinforcement in the new House; but even here skilled supervision by an alert and experienced operator is necessary to switch in microphones adjacent to the appropriate Members during the cut and thrust of a heated debate. Control is simplified by the fact that sound quality is not seriously affected by directional effects. The same cannot be said of sight. Here the angle of viewing is all-important, as every film star and amateur photographer knows. If and when television cameras are installed we foresee a general reshuffling of seats by profile-conscious politicians adjacent to camera positions, though their plans may be brought to nought by telephoto lenses and the remote control devices which have already been developed for other purposes by the B.B.C. It is a thought to daunt even the most extrovert of British M.P.s who may not yet have had the experience of speaking, as have his Antipodean contemporaries, before "the 20 microphones which stand up like tall poppies all over the Chamber to provide the Australian Broadcasting Commission's pitiless non-stop coverage."*

* "Westminster with Differences," by the Canberra Correspondent of *The Times*, November 16th, 1959.

Transistor Switching Speed

REASONS FOR THE LIMITATIONS—AND SOME METHODS OF ACCELERATION

By ***P. M. THOMPSON**** *and* ***J. BATESON†***

THE early simplication of a phenomenon, necessary for forming a concept, must always be suspect. Such concepts are incomplete and if used in this form as a basis for further investigation will inevitably lead to erroneous ideas. Before further ideas are developed the original concept must be examined carefully. As an example, ideas based on the earlier classification of solids into conductors and non-conductors are now inadequate. Computer switching circuits have been divided into those which do or do not "saturate," and this has led to such erroneous ideas as that collector voltage saturation is the sole cause of carrier storage.

Switching a transistor on or off is governed by the existence of carriers in its base region. Fig. 1 shows a cross-section of a transistor in which the emitter and collector are similar. This is sometimes called a bilateral or, more correctly, a symmetrical transistor. The current it can pass when switched on is governed by the population of carriers in the base region which, in turn, is primarily determined by the rate of recombination and the base current. It is not affected significantly by the collector current, or by the collector voltage being saturated. It can be seen that if there is no base current, the emitter and collector currents must be equal, thus a carrier extracted at the collector must be replaced by one at the emitter immediately, and the only mechanism available for depopulating the base is recombination. When the collector voltage is saturated, not all the carriers which arrive at the collector are collected. Those carriers which are

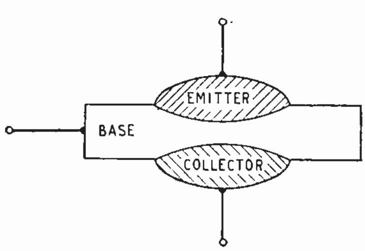


Fig. 1. Cross-section of a symmetrical transistor.

not collected are re-emitted from the collector junction, and those which *are* collected are replaced at the emitter junction. Thus the collector voltage being saturated does not affect the rate of depopulation.

Fig. 2 (a) shows a transistor being switched on and off by a current pulse at the base. The collector current waveform is shown at (b). Such a waveform would be obtained by placing a time constant in the base of a transistor having infinitely high switching speed, as in Fig. 2 (c). The time constant

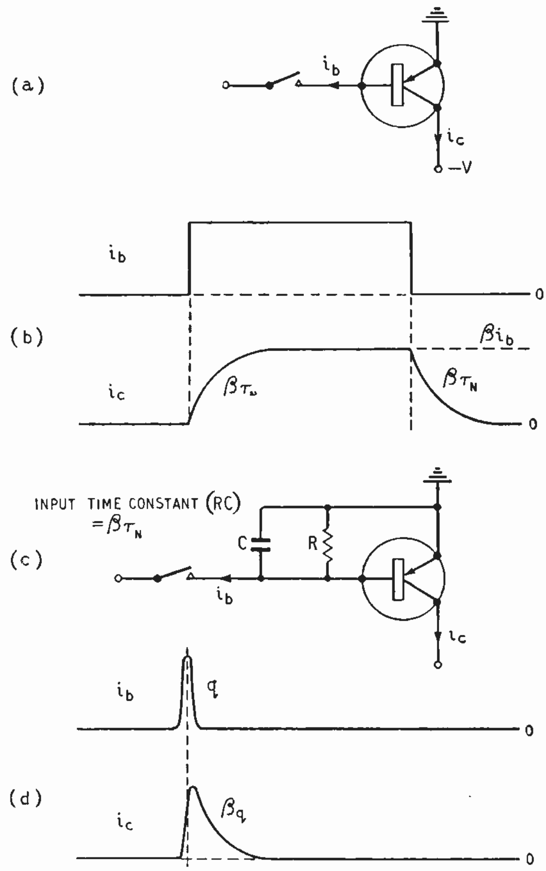


Fig. 2. Derivation of the charge concept in transistor switching: (a) transistor being switched by current pulse, (b) base and collector current waveforms, (c) equivalent circuit for producing the collector waveform, (d) base and collector current waveforms illustrating the charge concept.

would have a value of $\beta\tau_N$, where β is the d.c. current gain and τ_N the time it would take the collector current to rise to equality with the base current.

The presence of the time constant in this equivalent circuit introduces a concept which can be useful in the design of switching circuits. The equivalent capacitor must be charged when the transistor is turned on and discharged when it is turned off; in other words, the base can store a charge.‡ It follows that if we charge the base with a charge (q), β times that charge (βq) will be available at the collector. The current waveforms at the base and

* The Plessey Company, † The Eastern Ontario Institute of Technology, Canada. Both formerly of the Canadian Defence Research Telecommunications Establishment.

‡ The charge-control concept was previously mentioned in "International Transistor Convention and Exhibition," *Wireless World*, July/August, 1959.

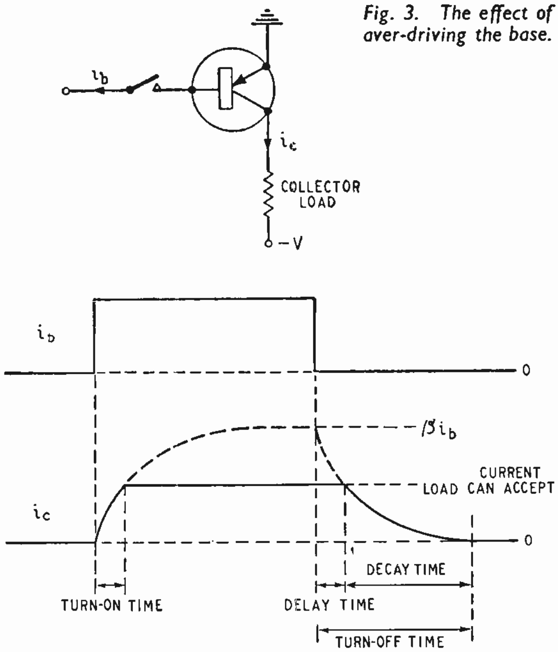


Fig. 3. The effect of over-driving the base.

collector might be very different, as shown in Fig. 2 (d), and it is the total output charge which is β times the total input charge. This is consistent with the d.c. β of the transistor, as can be seen by regarding the base current as the succession of a lot of separate charges, then the collector current is this succession multiplied by β.

In computers both the turn-on and turn-off times can be important. The transistor can be switched on more quickly by increasing the base current. The waveforms of Fig. 3 show a base current which is twice that needed to saturate the collector voltage. Here the base over-drive causes the transistor to turn on more quickly, but it also aggravates the problem of turning it off. The transistor turns off as if it were supplying βi_b, i.e., the current which could be collected; in this case twice that the collector load can accept.

The time lapse between turning off the base current and the start of the actual collector current decay is the time which would be taken for the collector current to decay from βi_b to the current which the collector load can accept. The time lapse, which is somewhat analogous to "lost motion" in relays, is shown in Fig. 3 as "delay time." A diode could be connected to draw the excess current, as in Fig. 4, but still this would not change the delay prior to the decay of i_c. A more profitable direction of investigation would be to consider the method by which the transistor was turned on quickly. The forward, base-current over-drive which turns the transistor on causes more carriers to be emitted into the base than are collected from it, resulting in storage in the base of excess carriers. This suggests a way of reducing the population of carriers in the base, which is to cause more of them to be collected than are emitted. It would follow from this that just as the population was increased by a forward base current it could likewise be reduced by a reverse base current.

The turn-off will be most rapid if no emission is allowed and both the emitter and collector are used as collectors. The maximum switching speed would be obtained from a transistor (see Fig. 5) by first applying a base over-drive to turn it on, then reducing the base drive to that just sufficient to maintain the collector current, and finally applying a large reverse base current to turn it off. This can be considered in terms of the equivalent circuit as follows. First apply a large current to charge the input capacitor, then maintain enough current to balance that flowing through the shunt resistance, and finally apply a reverse current to discharge the capacitor. It must be remembered, incidentally, that there is a limit to the reverse base current, and

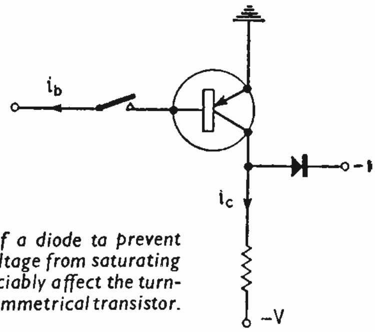


Fig. 4. Use of a diode to prevent the collector voltage from saturating does not appreciably affect the turn-off delay of a symmetrical transistor.

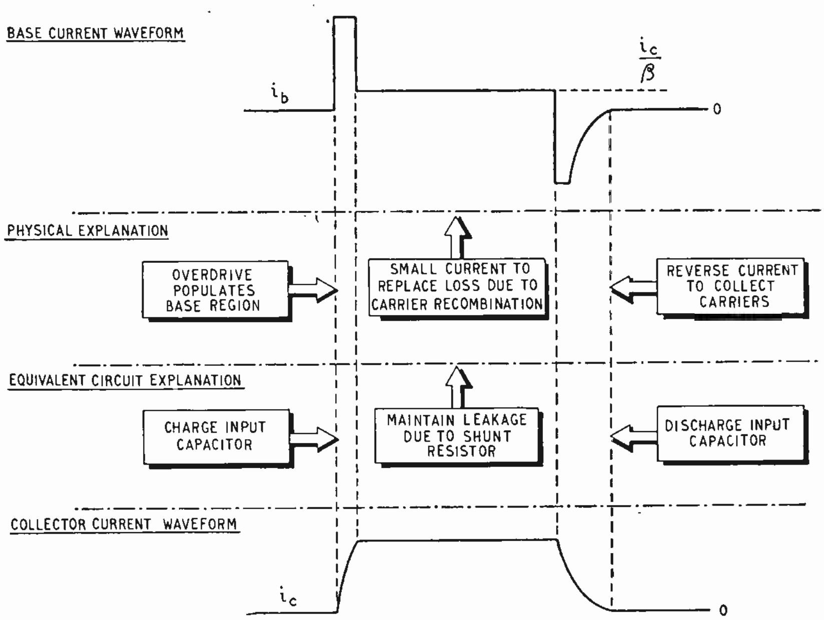


Fig. 5. Diagram to illustrate the accelerated switching of a transistor.

this is set by the rate at which carriers can diffuse to the junctions to be collected.

Up to this point we have considered only the ideal case of a symmetrical transistor. Many transistors used in switching circuits are constructed with their collectors larger than their emitters in order to improve their β and switching speed, and this unsymmetrical geometry modifies the turn-off delay when the collector circuit has been saturated. The advantages of making the emitter smaller than the collector can be seen from considering the fate of carriers emitted from various points of the emitter of the transistor shown in Fig. 1. Carriers emitted at the centre of the emitter will reach the collector much more quickly, on the average, than those emitted at the edge. If the emitter is made small and placed near the centre of the collector, as in Fig. 6, the average transit time will be shorter than in a symmetrical transistor and the number of carriers lost through recombination therefore fewer. When the collector voltage is allowed to saturate, emission will take place at the collector, and since emission takes place over the whole of the collector, carriers from the edges will have long path lengths and the average reverse transit time will be longer.

The asymmetry of construction thus leads to an asymmetry of switching time and the transistor will take longer to turn off. However, this does not detract from the method shown in Fig. 5 of accelerating the switching of a transistor. This switching waveform is approached fairly closely in the first of our two practical examples. The method was developed by R. H. Baker††; the circuit is shown in Fig. 7. Here, the current peak required to switch on the transistor is the difference between the currents through R_1 and R_2. When the transistor is switched on the collector voltage goes positive, and the base current is limited to i_c/β by the combination of silicon and germanium diodes. The collector can go positive until the voltage remaining between the collector and base terminals is the difference between the forward voltages of the silicon and germanium diodes; then the germanium diode conducts and allows the collector, instead of the base, to pass the excess input

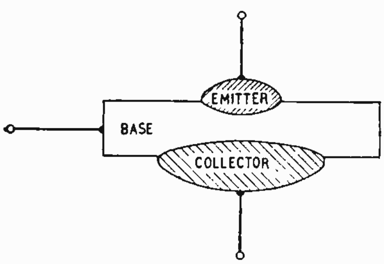


Fig. 6. Cross-section of a high-speed transistor.

current. The transistor is switched off by returning the input voltage to zero and allowing the current through R_2 to depopulate the base.

If, during switching, the change in voltage across the load is appreciable, the collector capacitance assumes some importance. Because it can be considered as being capacitance between collector and base it is sometimes called Miller capacitance and, as such, by applying negative feedback to the base, slows the rise of collector current. This has led to "low level logic," a type of computer-logic circuit

†† "The Design of Transistor Circuits for Digital Computers," by A. I. Pressman. John Rider (1959).

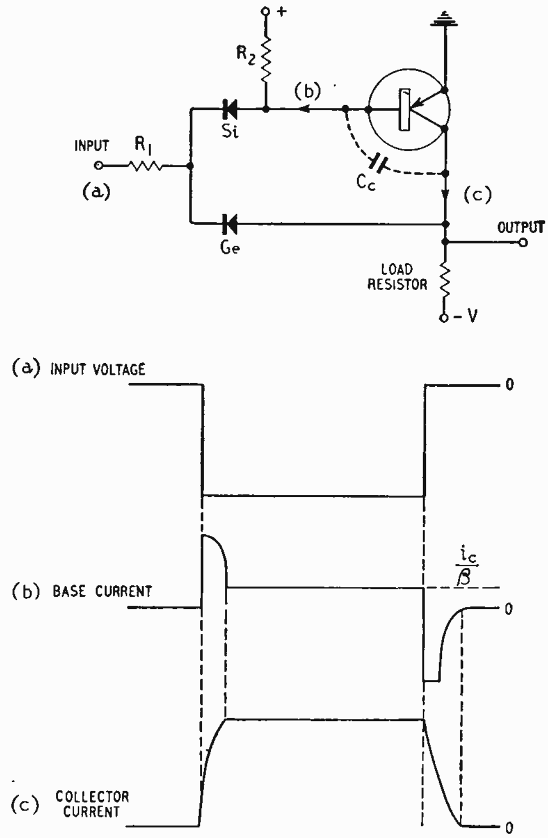


Fig. 7. Circuit for the rapid switching of transistors developed by R. H. Baker.

in which the changes of collector voltage are held to a minimum.

An example of low level logic is shown in Fig. 8, where the input voltage excursion is made just sufficient to switch the diodes between their conducting and non-conducting states. Here, there is no attempt to prevent base over-drive, the transistor being switched from the saturated to the non-saturated condition by the appropriate base currents. The transistor is regarded as being "on" when the base is overpopulated (i.e. when there is an excess of carriers over those required to supply the load current) and "off" when the transistor cannot supply the current the load can absorb.

Consider that the input terminals are all open circuit. Then, since R_3 is small, the currents flowing are determined principally by the values of R_1 and R_2. These are so arranged that i_1 is half the value of i_2, the other half of i_2 being supplied from the base as a forward current. Since the emitter diode is conducting, point X is clamped to earth potential, and the point Y is slightly negative. The base is now overpopulated and the collector effectively connected to earth.

Suppose that one of the input terminals is now connected to earth (this would be done by a circuit similar to that under discussion). Then point Y will be clamped close to earth potential and i_2 will be diverted, its new path being through the input diode from earth. Now i_1 proceeds to depopulate the base and disconnect the collector from earth. When the

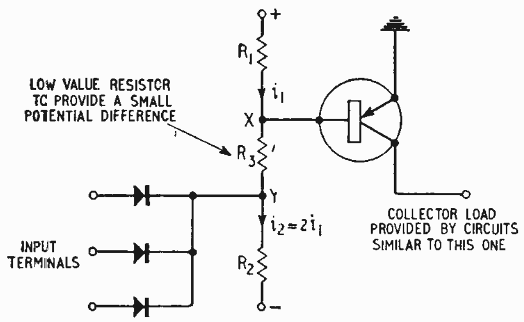


Fig. 8. Example of "low level logic" switching circuit.

base is cleared, all of i_1 flows through R_3 and point X becomes slightly positive. When $i_2 = 2i_1$ the turn-off current is approximately equal to the turn-on current, and the input capacitance is discharged in about the same time as that needed to charge it. Thus the turn-off and turn-on times also are approximately equal.

We should stress that this circuit is not the only way of performing low level logic; for example, Baker's technique may be applied. Also the method of turning the transistor on and off, which we have applied to the low level circuit, may be applied to circuits which are not necessarily low level. The two circuits which have been used here to exemplify the switching principles have been kept simple; however, the techniques may be found in many more complex circuits, a good example being the complementary pair circuits of N. F. Moody§. Furthermore, there are many other circuits which have been developed for fast switching of transistors, but in considering these circuits, an understanding of the true causes of carrier storage can assist the engineer in finding that which is most appropriate for his application.

Finally, the authors would like to thank R. S. Cobbold of the Canadian Defence Research Telecommunications Establishment, for review and criticism of the article.

§ "Controlled Saturation in Transistors and its Application in Trigger Circuit Design," by N. F. Moody, *Electronic Engineering*, 30, March and April, 1958.

New Acoustic Measurement Station

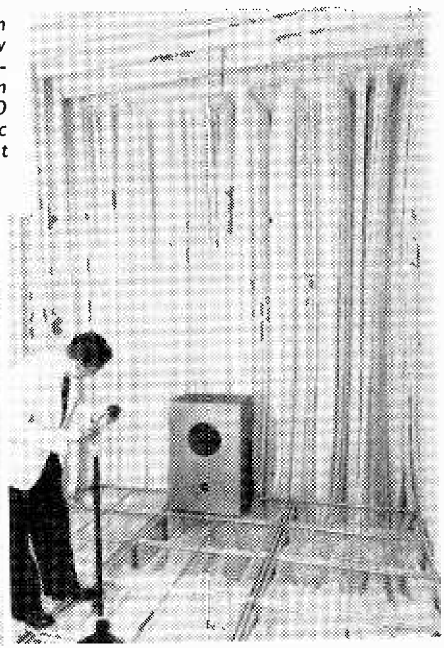
ACOUSTICAL Investigation and Research Organisation (AIRO) Ltd. recently opened in Hemel Hempstead a building in which various acoustic characteristics of materials, machines and electro-acoustic transducers can be measured.

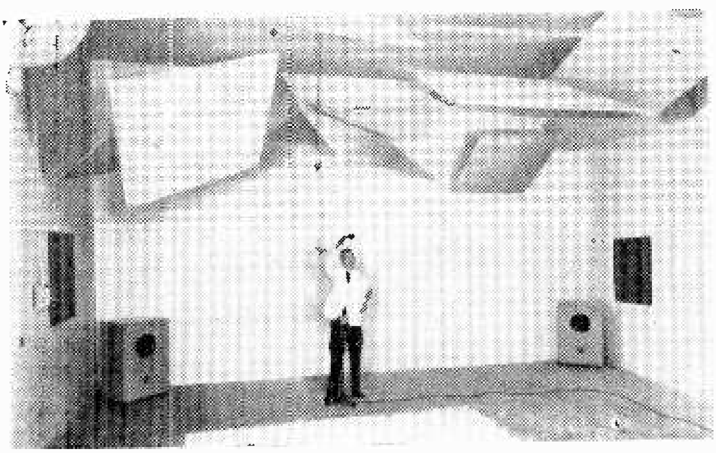
The building contains five rooms—an echo-free (anechoic) chamber, a reverberation chamber, two sound source rooms and a control room. There is also a 40ft long, 3ft square underground duct containing a 20ft long anechoic wedge for simulated field-free measurements from 100c/s down to 20c/s. Alternatively, for standing wave absorption measurements, a reflecting surface may be placed in front of the wedge in the duct.

The walls of the anechoic chamber (see photograph on right) are different from the usual "dragons teeth" construction and consist of "Bondacoust" fibrous absorbent material in strips of various widths between about 1½ and 3ft arranged to form a number of long wedge-like shapes. Five slightly different shapes are used to avoid any resonance effects.

Possible resonance effects are also carefully avoided in the source and reverberation rooms (see photograph of reverberation room below) by breaking up any regularities in reflection by means of rectangular and square reflecting panels hung at various distances and angles from the ceiling, as well as by making the walls slightly out of parallel by about half an inch per foot. Changes in the reverberation time caused by placing a sample of a material in the 10ft square floor space provided enable the absorption of the material to be measured. Alternatively, sound transmission can be measured by placing a sample in an aperture between the reverberation room and one of the source chambers.

Ventilation ducts to the reverberation room are surrounded by Helmholtz resonators tuned to various frequencies so as to provide at least 35dB sound isolation.





Reverberation room (below left) and echo-free room (right) in AIRO acoustic measurement station.

Crystal Calibrator

Battery-operated Spot-frequency Signal Generator

By G. de VISME

THE usefulness of a crystal calibrator to the short-wave enthusiast was pointed out by a colleague, and having seen the one built by him, the writer was inspired to construct one for himself and this article describes its construction, performance and use.

There is nothing in the least original about it, but for anyone interested in constructing an entirely

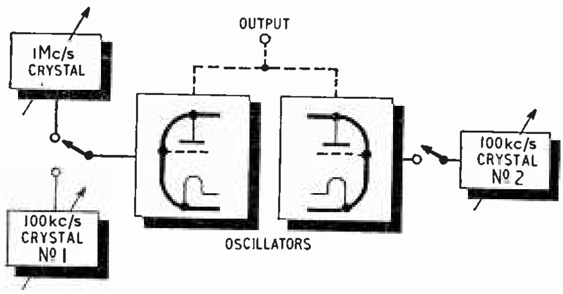


Fig. 1. One of two possible circuit arrangements for the frequency calibrator.

portable source of spot radio frequencies, constant in amplitude, phenomenally accurate in frequency and at low cost, this article may save him the job of working out component values, etc., for himself.

Requirements and Possible Arrangements.—The specifications set were as follows, in order of priority:—

(*i*) Low cost.
(*ii*) Easily detectable spot frequencies up to 30Mc/s.
(*iii*) Portability, i.e., battery-operated and compact.
(*iv*) Low battery consumption.

The first question was whether or not to use transistors. Requirements (*iii*) and (*iv*) certainly favour their use, whilst requirements (*i*) and to a lesser extent (*ii*) suggest miniature double-triodes. The latter alternative was chosen.

Specification (*ii*) implies the ability to amplitude-modulate every spot frequency effectively, and two possible arrangements suggested themselves:—

(*a*) Two 100-kc/s crystals and one 1-Mc/s crystal and one double-triode, used as shown in Fig. 1. The idea here is as follows:

Tune any receiver to the long-wave Light programme, the carrier frequency of which is 200kc/s to a very high degree of accuracy. Switch on the oscillator using crystal 2 (Fig. 1) and tune it to give zero beat with the Light programme. "Modulated" spot frequencies every 100kc/s can then be obtained by switching on the oscillator using crystal 1, and very slightly mistuning it.

For the benefit of readers not familiar with the use of quartz crystals as frequency standards, the following digression explains what is meant by "tuning" and "mistuning" a crystal.

A suitably-cut quartz crystal behaves, by virtue of the piezoelectric effect, as a series-tuned circuit of extremely high "Q," and resonating at a definite frequency. However, the values of the equivalent inductance and capacity of the circuit are altogether outside our experience of normal radio-frequency tuned circuits—for instance, the equivalent inductance might be 3H, whilst the equivalent capacity might be as little as 1/100pF.

Placed in an oscillatory circuit, the crystal will oscillate at a frequency making it either slightly inductive or slightly capacitive, depending on the circuit. In view of the enormous equivalent inductive and capacitive reactances of the crystal—which at resonance exactly balance, of course—the small reactive component required to make the circuit oscillate is attained at a frequency only minutely differing from the resonant frequency of the crystal.

Reactive elements added to the circuit, therefore, only very slightly affect the oscillatory frequency; thus a variable capacitor across the crystal acts as a very fine control of frequency in the immediate vicinity of the crystal's quoted frequency. This is what is meant by "crystal tuning." The crystal is

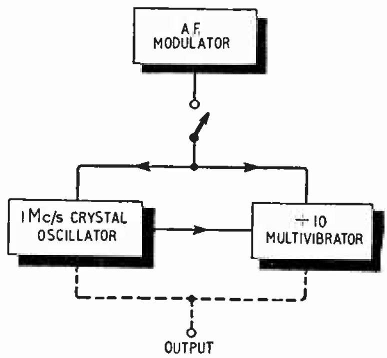


Fig. 2. The alternative circuit arrangement discussed in the text.

said to be "mistuned" when the added reactances in the circuit cause it to oscillate at a frequency differing from its quoted frequency; the greatest degree of mistuning possible, however, is of the order of the crystal frequency divided by the crystal "Q" (upwards of 20,000).

To resume, "modulated" spot frequencies every Mc/s are obtained by substituting the 1-Mc/s crystal for crystal 1. The word "modulated" is in inverted commas because a mere addition of two signals differing in frequency does not give actual a.m., but only beats.

This method worked quite satisfactorily when using the 1-Mc/s crystal, only of course the pitch of the "modulation" varied with the harmonic selected. The harmonics of crystal 1, however, tailed off in intensity above 4.5Mc/s, so multiples of 100kc/s could only be obtained up to this frequency. Since only one valve is used, the consumption is quite small. However, the idea might be worth further investigation, perhaps using transistors in place of the valve.

(*b*) The standard calibrator arrangement, which was finally adopted, and which is shown in Fig. 2.

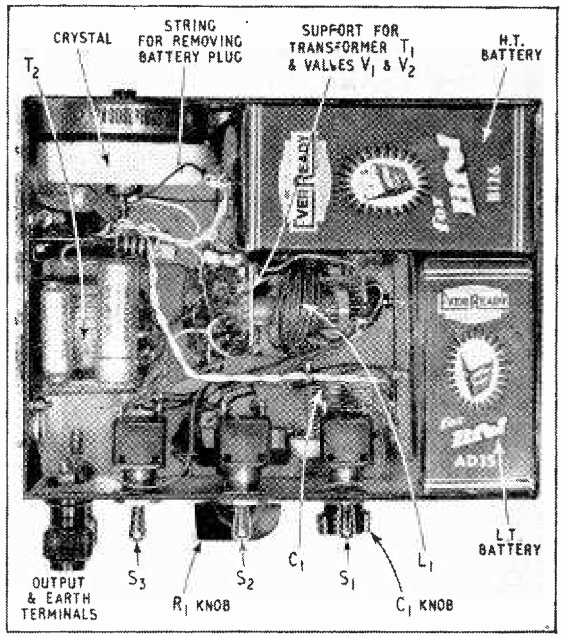
Circuit.—The circuit of arrangement (*b*), shown in Fig. 3, gives very powerfully modulated harmonics of both 1Mc/s and 100kc/s all the way up to 30Mc/s. In fact, harmonics of 1Mc/s could be detected even on a v.h.f. tuner.

The first section of V_1, together with the associated circuitry, comprises the crystal oscillator. The crystal is tuned by means of variable condenser C_1. The h.t. to this stage is drawn through half of the primary winding of transformer T_2, as also is the h.t. to the multivibrator (valve V_2 and associated circuitry).

The second section of V_1, with T_2, R_2, C_3, C_4 and C_5, forms an audio frequency Hartley oscillator. When switch S_1 is closed, this stage becomes operative and bursts into oscillation, and a.f. voltage oscillations appear across the windings of T_2. Thus the h.t. supply to both crystal oscillator and multivibrator is modulated at a.f. when S_1 is closed.

Since both these latter circuits operate non-linearly, variation of their h.t. supply amplitude-modulates their output.

Condenser C_2 and the secondary winding of transformer T_1 couple a very minute portion of the output of the crystal oscillator into the multivibrator, enabling the multivibrator frequency to lock itself to a sub-multiple of the crystal oscillator frequency.



Plan view (with lid removed) of the crystal calibrator. Circuit identifications relate to Fig. 3.

The only features worth drawing attention to are:—

(*i*) Anode modulation of both crystal oscillator and multivibrator is used.

(*ii*) The 1-MΩ variable resistance R_7 across one of the multivibrator grid leaks provides a very fine

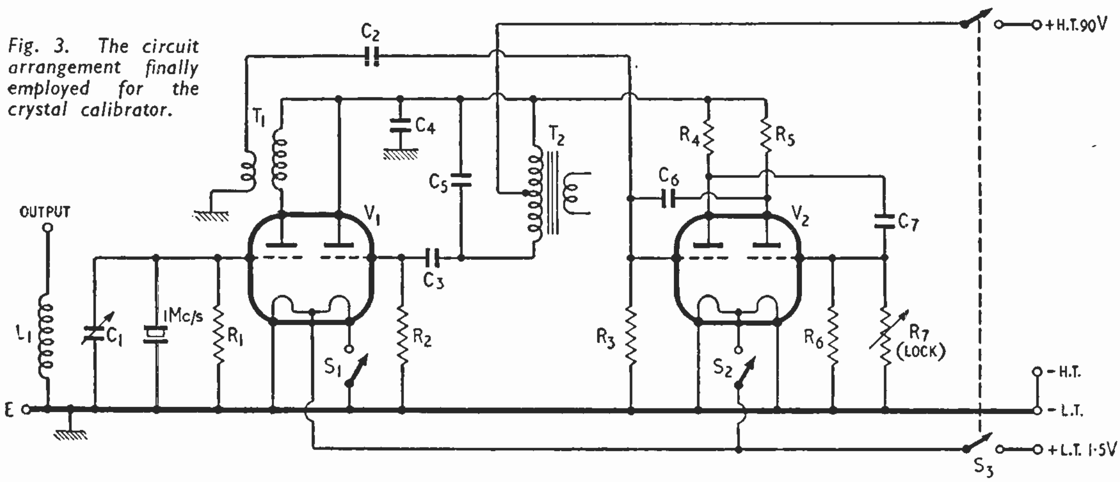


Fig. 3. The circuit arrangement finally employed for the crystal calibrator.

LIST OF PARTS

Capacitors
C_1 = 10-100pF air-spaced variable
C_2 = 3.5pF
C_3, C_5 = 0.01μF
C_4 = 0.05μF
C_6, C_7 = 33pF

Resistors
R_1 = 1MΩ
R_2 = 18kΩ
R_3, R_6 = 62kΩ
R_4, R_5 = 47kΩ
R_7 = 1MΩ variable

Miscellaneous
V_1 and V_2 = Type 3A5 or DCC90 (double triodes).
T_1 = Denco "Maxi-Q" Range 2 coil, Wearite PHF2, or similar type.
T_2 = Small output transformer, centre-tapped primary (R.M. Electric).
Crystal = Surplus P.O. Type PATT 2381A, 1Mc/s, see text.
L_1 = A few turns p.v.c. covered wire wound round T_1, V_1 and V_2
H.T. battery = Ever-Ready Type B126 (90V)
L.T. battery = Ever-Ready Type AD35 (1.5V)
S_1, S_2 = Single-pole on-off switches
S_3 = Double-pole on-off switch.

control of multivibrator frequency in the region of 100kc/s.

(*iii*) Filament consumption is reduced to a minimum by providing filament rather than h.t. switches in the audio oscillator and multivibrator sections, so that the filaments of these sections may be switched off when not in use.

(*iv*) The coil L_1 presents such a small reactance across the calibrator output terminals that there is very little extraneous pick-up by the wires connecting the receiver to the calibrator.

Layout and Construction.—The whole circuit and both batteries conveniently fit inside an "Oxo" tin, as shown in the illustrations.

Earth wires are all soldered directly to the tin, for convenience.

Screwing down the lid presented a slight problem; the metal was too thin to permit the use of self-tapping screws, so 6-BA nuts were soldered at suitable intervals inside the rim of the box. To prevent solder from running into the thread of the nut while soldering it into position, it was held on a 6-BA tap, the steel of which effectively resisted the flow of solder. (A match stick might serve equally well.)

Operation.—The instrument is tuned with the aid of the long-wave Light programme (200kc/s) by switching on both the crystal oscillator and multivibrator and making the necessary adjustments, first to the multivibrator lock control (R_7), and then to the crystal tuning control (C_1) so that, from a receiver tuned to the Light programme and at the same time picking up radiations from the calibrator, the signal amplitude remains quite steady.

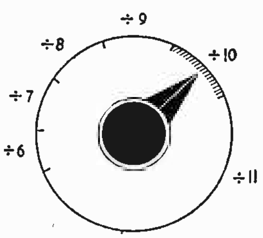


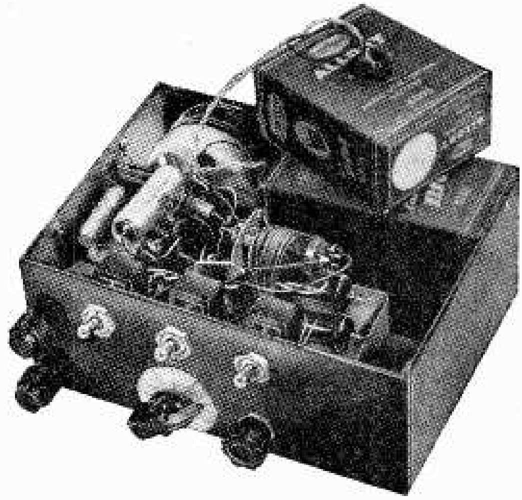
Fig. 4. Calibration of the multivibrator lock control, R_7.

A certain amount of "fiddling" with the coupling between the calibrator and the receiver aerial is needed to bring out the beats between the calibrator output and signal. In fact, it may not even be necessary to connect the calibrator output terminal to the receiver aerial at all—the metal of the calibrator box is thin enough to allow a certain amount of stray radiation. To limit direct radiation from the box the principle of the "common earth point" should be followed when wiring the circuit.

On switching on the audio oscillator, it may be found that the lock is slightly disturbed, for the depth of modulation of the h.t. to the multivibrator is very considerable; however, a small adjustment to the lock control is all that is required. When the multivibrator is locked to a sub-multiple of the crystal frequency (in this case, 1/10 of it)—the audio note in the receiver suddenly purifies itself.

The instrument is now radiating, m.c.w. or c.w. as desired with spot frequencies spaced at 100kc/s all the way up to 30Mc/s and further, and on m.c.w. there is no mistaking the characteristically baleful tone associated with each harmonic!

It will be noticed too that, very conveniently, the one-megacycle harmonics are much more pronounced than the intervening 100kc/s harmonics, so there is no confusion as to which spot frequency the receiver to be calibrated is actually tuned. It is somewhat unlikely that the receiver calibration will be so far out as to leave doubt as to which megacycle harmonic is which.


Another view of the calibrator with the l.t. battery withdrawn and showing position of the valves below L_1.

Other Spot Frequencies.—In addition to its use as a calibrator the instrument, insofar as it is a source of constant amplitude at any one frequency, may be used to line up i.f. stages, etc.

With the object of providing a very much wider range of spot frequencies, the multivibrator lock control (pre-set, and adjustable by means of a screwdriver on the normal instrument) is brought out to a knob. The locking is so effective that there is literally no position of this control in which the multivibrator is not locked to one or other sub-harmonic of the crystal frequency. The lock control can therefore be calibrated as shown in Fig. 4.

TABLE

÷6	÷7	÷8	÷9	÷10	÷11
167	143	125	111	100	91
(333)	286	250	222	200	182
(500)	428	375	333	300	273
(667)	572	(500)	444	400	364
833	714	625	556	500	455
	857	750	667	600	546
		875	778	700	637
			889	800	728
				900	818
					909

The table indicates the subdivisions of a megacycle obtainable in this way. They are expressed in kc/s.

Once again, since the crystal harmonics stand out so well above the multivibrator harmonics, it is immediately possible, by simply counting the multivibrator harmonics, to know exactly to which multivibrator harmonic the receiver is tuned.

With the resistance values given in Fig. 3, the nearest frequencies to the standard i.f. obtainable are 455kc/s (÷11) or 500kc/s (÷10).

It is perhaps worth noting that, supposing the 41 sub-divisions are uniformly distributed (which of course they are not exactly), the calibrator would give spot frequencies separated by about 25kc/s and no signal would be removed by more than 0.5×25kc/s from one of the calibrator frequencies. This interval is just within the audio range and so, by judicious adjustment of the lock control, an audio beat can be produced with any signal to which the receiver is tuned, and hence, by roughly estimating its pitch, pin down the signal frequency to within, say, 1 or 2 kc/s.

Battery Consumption and the effect of Battery Ageing.—The h.t. consumption, even with all circuits working, is quite small (about 4.5mA.). The l.t. consumption per filament section is 0.11A (at 1.4V), so the drain on the l.t. battery depends very much on which circuits are in use. However, a calibrator is not the kind of instrument which is left on for long periods, and it will normally be months before the l.t. battery requires replacement, and even longer before the h.t. battery is worn out.

Decline in the supply voltage does not affect the frequency accuracy of the instrument at all (naturally enough), but it does alter slightly the calibration shown in Fig. 4. When the supply is greatly reduced, it is difficult to obtain a lock on m.c.w., though on c.w. the multivibrator stops working before it stops locking. These effects give all the indication needed that it is time to replace one or both of the batteries.

How Many M.U.F.s?

By T. W. BENNINGTON*

FIVE DIFFERENT INTERPRETATIONS RECOMMENDED BY C.C.I.R.

A WELL-KNOWN adage which seems to be particularly applicable in radio technology is that "things are not always what they seem to be". Or should we render it "so simple as they seem to be", for that seems to be the case with the quantity known as the maximum usable frequency (m.u.f.), which is in common use in connection with high-frequency, long-distance transmission by way of the ionosphere.

The m.u.f. for a given distance along the ground is the frequency which corresponds to the critical frequency at vertical incidence, which is the highest frequency which will be reflected by a given layer, and above which the wave will penetrate the layer. Thus the m.u.f. for a given distance and layer may be loosely defined as the highest frequency which will be reflected from that layer at oblique incidence, so as to return to earth at that distance. But this is all very well, except that in practice there seem to be several different conceptions of what *is* the highest frequency to be effectively returned at a given distance, and, consequently, several different ideas as to what constitutes the m.u.f. The matter has become, in fact, so muddled and ambiguous that the C.C.I.R., in their recent assembly at Los Angeles, thought it well to attempt to clarify the situation by a recommendation on the "meaning of m.u.f.", in which they found it necessary to deal with no fewer than five different terms which have been, or might be, used, namely the "classical M.U.F.", the "standard M.U.F.", the "operational M.U.F.", the "theoretical M.U.F." and the "experimental M.U.F.".

In order to clarify our own minds we can, following the lead of the C.C.I.R., concentrate on the differences between the first three of these and dismiss the last two as being applicable only to the cases of particular calculations or experiments. Let us consider the situation for a particular ionospheric layer, for example, the F_2 layer, and for the "ordinary" component of the wave only.

With a given distribution of the ionisation with height in this layer we shall, by the vertical pulse-sounding technique, obtain a curve of virtual height with frequency (an h'-f curve) of a particular shape, as, for example, in Fig. 1(a). In this f_1 is the critical frequency, at which the wave penetrates the layer. The equivalent frequency/height parameters for any oblique angle are obtained by the use of what is known as the modified secant law, which governs radio-wave refraction in a curved medium where the refractive index decreases continuously with height. If we apply this to Fig. 1(a) for a distance of, say, 2,000km, then we obtain a curve of the form shown in Fig. 1(b). We notice that, for any frequency higher than f_2 there are not one, but two, virtual heights shown. Though f_2 has, in fact, been arbitrarily chosen, it is indicated in order to show that, with decreasing frequency, the upper of the two rays becomes, in practice, unobservable owing to absorption. But the two virtual heights shown for frequencies above f_2 do correspond to two separate rays, which will traverse different trajectories in covering the ground distance of 2,000km. The one which returns from the lower virtual height is the "low-

*Research Department, British Broadcasting Corporation.

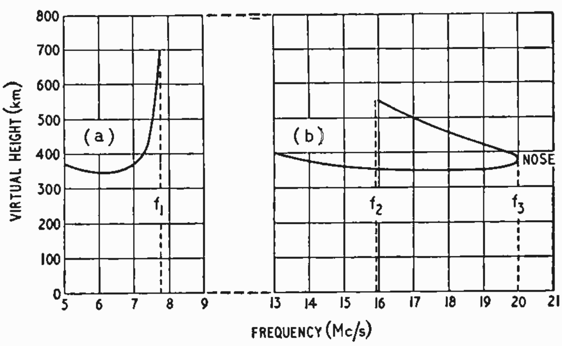


Fig. 1. Variation of virtual height with frequency (h'-f), F_2-layer, ordinary wave only; (a) for vertical incidence; (b) for transmission over a distance of 2,000km.

angle ray" and the other the "high-angle ray", and the situation is shown diagrammatically by the dashed lines in Fig. 2. But, with increasing frequency above f_2 the virtual height corresponding to the high angle ray gets nearer and nearer to that for the low angle ray, until at f_3 the two rays become one, and the situation is as shown by the full-line curve in Fig. 2. At f_3 then, on the "nose" of the curve, a single ray is returned, and on frequencies higher than this, no energy should be returned at all; f_3 is, therefore, the "classical M.U.F.".

All this, however, is something of a diversion (though perhaps a necessary one) from our main theme, which is to explain the reason for the existence of other m.u.f.'s than the classical one. In short-wave propagation work it is impracticable actually to calculate the oblique-incidence parameters from the observed vertical-incidence curves, for a large number of stations and for a mass of observations from each. A graphical method for determining the m.u.f. for any distance from the vertical incidence h'-f curves was long ago developed, but even more convenient in dealing with a large amount of data is that of using the standardised characteristics of the layers for any time and place in conjunction with a set of empirical "distance factors" which permit of calculation of the oblique-incidence m.u.f.'s for any distance from the vertical-incidence critical frequency. Both these methods give an approximation to the "classical M.U.F." of Fig. 1, and this practically determined value of m.u.f. is defined by the C.C.I.R. as the "standard M.U.F.".

Operational M.U.F.

But now we come to the real crux of the whole matter. It has long been found that, in practical communication, it is possible, particularly at certain seasons of year, times of day and in certain directions, to provide good service on frequencies considerably higher than the "classical M.U.F.". In other words the "operational M.U.F." (to use the C.C.I.R. definition) is often considerably higher than the "classical M.U.F.". Furthermore, unlike the "classical M.U.F.", which because it is determined by ionospheric refraction alone, does not vary with transmitted power, the "operational M.U.F." is power-dependent, increasing, within limits, with increasing power. The reasons for this increase in the operational above the "classical M.U.F." are not fully understood, but experiments indicate that usable signals are produced on these higher frequencies by scattering of the energy both

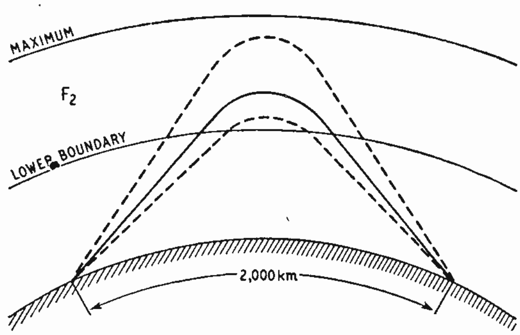


Fig. 2. Dashed-line curve shows high- and low-angle rays at 17Mc/s; full-line curve a single ray at 20Mc/s (see (b) Fig. 1).

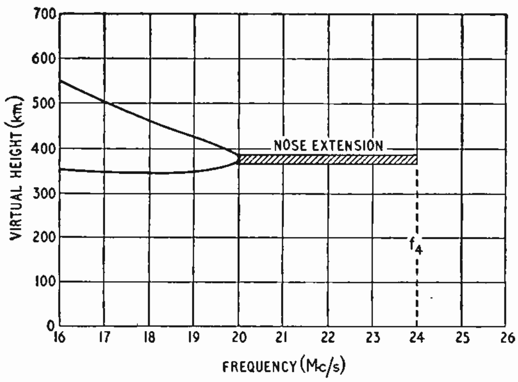


Fig. 3. Part of curve (b), Fig. 1, re-drawn and with a "nose extension" due to scattering and other processes, added for a 2,000-km transmission.

in the ionosphere and on the ground, by lateral deviation of the waves from the great-circle path, and possibly by some "bending" of the trajectories in the troposphere and lower ionosphere. The effect is to extend the nose of the oblique h'-f curve of Fig. 1(b) so that it becomes somewhat like Fig. 3, where f_4 is the "operational M.U.F.". The nose extension can extend to frequencies up to 25% above the "classical M.U.F.", but this extension varies, as has been said, for different seasons, times of day and circuits. It also varies, critically, for different types of service, for as the signals on frequencies above the "classical M.U.F." are due largely to scattering processes, they are unsuitable for services, like some types of high-speed telegraphy, which demand a highly coherent signal for their operation. It is interesting to note that sound broadcasting, which requires a higher signal-to-noise and signal-to-signal ratio than most other services, is less demanding in the matter of coherence of the signal than are the services just mentioned, and so has an "operational M.U.F." which is often well above the "classical M.U.F.".

Specifying M.U.F.

We see therefore that, whilst the classical and standard m.u.f.'s are capable of direct evaluation, the "operational M.U.F." is a more ambiguous quantity, and difficult to specify exactly. The C.C.I.R. has, in fact, left the matter of its specification fairly open, by recommending that "the ratio of the classical M.U.F. to the operational M.U.F. . . . should be determined by a combination of experience and theoretical studies".

There is one further point to bear in mind, so that we may be quite clear of what we are speaking. When we specify an m.u.f.—whether the classical, standard or operational—do we mean the instantaneous value observed at some time at the ionospheric point to which we are referring? If so we should state this fact, but if, as is the more usual case, we mean to specify a median value for some point we should use a clear expression like "the monthly median classical m.u.f." for a given month, time and place, or "the monthly median operational m.u.f. for the London/Johannesburg broadcast circuit" for a given month and time of day. In so doing we shall avoid ambiguity, and prevent the possibility of our specification being misconstrued.

Autumn Audio Fair

SELECTED NEW EQUIPMENT OF INTEREST

THE emphasis on tape recording in new developments was even greater at the Autumn Audio Fair than at other recent exhibitions of sound reproducing equipment.

The American Steelman transistor tape recorder is now being manufactured under licence in this country by Redifon. This recorder retains the capstan drive normal to a mains recorder, though d.c. bias and erase are used. Speeds of $1\frac{7}{8}$ and $3\frac{3}{4}$in/sec are provided, the response at the latter speed being given as from 150 to 7,500c/s. The output is 100mW. Thirteen Mallory RM-12R mercury cells are normally used.

A transistorized version (the L2/TA) of the well-known E.M.I. portable L2 tape recorder was also on show. An equalized playback stage with an output power of 70mW has been incorporated. The tape transport mechanism has also been improved: the wow and flutter is now less than 0.25% at $7\frac{1}{2}$in/sec. Since this instrument is designed for outside recording using new tape, no erase facilities are provided.

E.M.I. also showed their first domestic tape recorder (H.M.V. Type DSR1), a feature of which is the use of separate record and replay heads and amplifiers.

A new Simon recorder, the Minstrelle, incorporates the new Garrard deck and magazine. This recorder is very unusual in that it incorporates a built-in microphone. This is intended for speech recording and is mounted on foam rubber to reduce the effect of vibrations of the tape transport mechanism.

A four-track recorder has already been shown in this country by the Harting-Tandberg groups: two new models were shown at the Autumn Audio Fair by Telefunken and Recording Devices. The Telefunken 76K features a transistorized replay head amplifier and is for single-channel recording. On the other hand, the model shown by Recording Devices is for stereo and is essentially a 4-track version of the Stuzzi Tricorder (briefly described on p. 225 of our May, 1959, issue) with the amplifying equipment for the second stereo channel fitted in a separate cabinet. A stereo microphone comprising two moving-coil elements mounted at right angles to each other is available for use with this recorder.

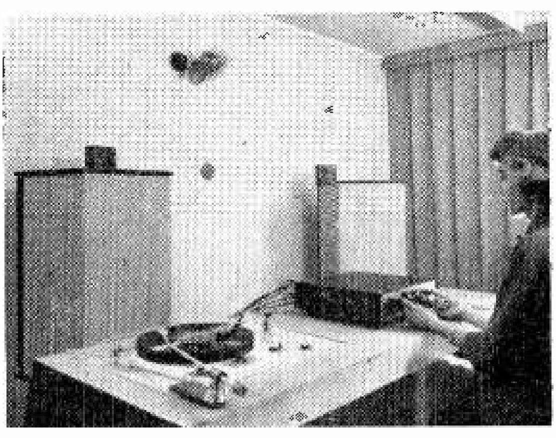
A recorder which can both record and replay stereophonically using the normal twin-track system was shown by Grundig (Model TK60).

Three-channel stereo tape recordings were demonstrated by Rank Cintel using the Ampex 300-3 recorder. Even when the final commercial stereo recording has only two channels, making the original master recording on three rather than two channels offers a number of advantages. The most important of these is that, when widely spaced microphones are used for recording, the "hole in the middle" fault can be readily avoided by using a third microphone in the middle to feed the third channel. Another advantage is that it is easier to adjust the balance between the soloist and orchestra after the recording has been made. This latter advantage also makes it easier to convert stereo to single-channel recordings, since these latter often require a different optimum balance between soloist and orchestra.

Tape suitable for the Ampex video recording system was shown by M.M.M. (Scotch Boy) and E.M.I. Since the direction of travel of the head gap relative to the tape is across its width in the Ampex system, rather than along its length, the magnetic particles in such video tape are oriented across its width rather than along its length. Because of the high relative speed between the head and gap, wear and heating problems are important in the design of video tape. It must also be more free from drop outs than ordinary tape.

An inexpensive two-speed ($33\frac{1}{3}$ and 45 r.p.m.) transcription gramophone turntable was introduced by Connoisseur. The wow and flutter are stated to be 0.15% and 0.1% respectively, and the rumble −50dB referred to 7cm/sec at 1kc/s using the R.I.A.A. record playback characteristic. The turntable is driven at the outer, rather than the usual inner, edge.

The sandwich method of loudspeaker cone construction in which the two skins are made of heavier and stiffer material than the filling so as to give a considerable overall increase in the stiffness-to-weight ratio, and which was discussed by D. A. Barlow in our December, 1958, issue (p. 564), was adopted for an experimental bass loudspeaker demonstrated by Leak. A system of magnet design to be described by A. E. Falkus in *Wireless World* was used in two new loudspeakers shown by Fane Acoustics. One of these was a 15-in bass unit with a 3-in-diameter voice coil, a fundamental resonance between 20 and 25c/s, and a 310,000-line magnet field. The other was a 5-in unit which forms the first of a range of speakers to be marketed by this company for set manufacturers.



Over 50% of the production time of Beam-Echo (Avantic) equipment is devoted to testing. The photograph shows the final listening test on an SPA21 stereophonic combined pre-amplifier and 2 x 12-watt amplifier being performed in a near acoustically dead room.

WORLD OF WIRELESS

B.(?)R.E.M.A.

SPEAKING at the annual dinner of the Radio and Electronics Industry (R.I.C. and E.E.A.) on November 18th, E. E. Rosen, chairman of the R.I.C., disclosed that the Registrar of the special court charged with the enforcement of the Restrictive Practices Act had notified the British Radio Equipment Manufacturers' Association that the British Content clause in the conditions of membership of the Association was considered to be an infringement of the Act.

Mr. Rosen pointed out that the purpose of the clause, which, since 1926, has been basic to the constitution of the Association, was to limit by specification the amount of foreign content of labour and material, because there is no mandatory definition which describes what is meant by British Content. He concluded, "Each one of our associations is proud of its British heritage, and B.R.E.M.A. has unanimously decided to contest the Registrar's contention. . . . I am sure it was never the intention that merely being British would be an infringement."

Servicing Exams.

THE highest failure rate since the examination was introduced in 1944 is recorded by the Radio Trades Examination Board in announcing the results of the 1959 servicing examinations. Of the 1,869 entrants for the sound radio examination 1,009 failed, 547 passed and 291 have to retake the practical test.

For the first time the practical test was carried out on the "Trainer-Tester" system and, in the opinion of the Board, proved to be a very satisfactory form of testing fault diagnosis. This system employs a pictorial layout of a receiver, a circuit diagram with component values and a series of fault sheets. Possibly the greatest advantage of the scheme is the uniformity of testing.

A soldering test has always been regarded as an important part of the practical examination for a servicing certificate; in fact, candidates failing in the soldering test have in the past been failed in the whole practical examination. As the new "practical test" is entirely paper work a more elaborate soldering and wiring test has been introduced.

Of the 485 entrants for the Television Servicing Certificate, 209 qualified, 94 have to retake the practical test and 106 failed. The "Trainer-Tester" scheme was not used for the TV exam.

Entries for the 1960 examinations, which will be held in May and June, must be received by the Board, 9 Bedford Square, London, W.C.1, not later than January 15th (television) or February 1st (sound radio).

Next year's examinations will probably be the last in which sound and television are separated. If present plans of the R.T.E.B. materialize future exams. will be taken in two stages. An intermediate examination will be taken at the end of a three years' course which will include television servicing at 3rd-year level, and success in this will be necessary before a candidate can take the final examination and secure the Board's certificate.

Conference on Computers

AT the second "Open Day" held on November 11th at the premises of I.C.T. Ltd., and organized by the Electronic Forum for Industry (E.F.F.I.) to bring together representatives of the suppliers and users of electronic equipment, most of the discussion centred on the applications of computers. C. Metcalfe, C.B.E. (E.M.I.), in opening the proceedings, emphasized the vital necessity of speed in adopting new ideas and methods if the alliance between electronics and industry was to be effective in meeting foreign competition. Early contact between suppliers and potential users was essential so that they could come to a working agreement to think in parallel during the development stage.

Following the showing of three documentary films on computer applications a panel consisting of E. R. Davies (English Electric); S. Gill (Ferranti); J. C. Gladman (A.E.I.); N. D. Hill (E.M.I.); R. L. Michaelson (Elliott Bros.) and L. Lightstone (I.C.T.) ably dealt with searching questions put by representatives of organizations interested in such diverse products as chemicals, footware, food, motor cars, cement and bright steel bars.

The third "Open Day" has been arranged at Olympia during the I.E.A. Exhibition in May and will take as its theme "The Satisfied User".

Servicemen's Pay

INCREASES in the basic rates of pay for servicemen come into operation on January 4th, as a result of an agreement between the R.T.R.A. and the Association of Radio and Electronic Engineers. The increases vary from 5s per week for a 17-year-old apprentice to £1 8s 8d per week for a London holder of the R.T.E.B. Television Servicing Certificate. Similar agreements have already been signed between the A.R.E.E. and the Scottish and Northern Ireland radio retailers' associations.

The figures quoted below are the minimum rates of pay for a 44-hour week (reduced from 46 hours) for servicemen over 21 years old, with the London rate in brackets.

	£	s	d	£	s	d
Servicemen who have served a 5-years' apprenticeship	11	7	4	(11	16	6)
Holders of R.T.E.B. radio servicing certificate with 5 years' apprenticeship ..	12	7	6	(12	16	8)
Holders of R.T.E.B. television servicing certificate with 5 years' apprenticeship	13	7	8	(13	18	8)
Semi-skilled persons doing general installation and maintenance	9	7	0	(9	14	4)

The rates of pay for apprentices range from £3 per week at 16 to £7 10s at 20. In addition, those entitled to the R.T.E.B. Radio Service Certificate will receive an additional 10s a week and those entitled to the Television Servicing Certificate a further £1. The secretary of the Association of Radio and Electronic Engineers is W. Criddle, 17 Tottenham Court Road, London, W.1.

V.A.S.C.A.

A NEW U.K. valve manufacturers' association has been formed under the title Electronic Valve and Semi-Conductor Manufacturers' Association

(V.A.S.C.A. for short). It is taking over from the British Radio Valve Manufacturers' Association (B.V.A.) its responsibilities for semiconductors and industrial valves and tubes. The B.V.A. will continue its separate interest in domestic valves and television tubes. The five founder-member firms of the Association are English Electric Valve Co., M.O. Valve Co./G.E.C., Mullard, Siemens Ediswan/B.T.H., and S.T.C.

The chairman of V.A.S.C.A. is G. A. Marriott (G.E.C.) and the secretary *pro tem* is W. R. West (secretary of B.V.A., 16, Jermyn Street, London, S.W.1).

Freeing Imports.—The recently announced removal of most of the controls on imports from the dollar area, Western Europe and many other countries—excluding Japan and the Soviet bloc—is of special interest to the radio and electronics industry. It would appear from the "negative list" included in the Board of Trade's Notice to Importers No. 920 that all radio and electronic apparatus (excluding transistors and parts thereof) and scientific instruments can now be imported from these areas without restriction. This removal of import controls does not affect the import tariffs.

Receiver Sales.—Figures for the despatch by manufacturers to the home trade of sound receivers in September were the highest on record, and those for television receivers the highest for any September. Sound receivers (including car sets) totalled 179,000 and television sets 345,000, bringing the respective totals for the nine months to 1.099M and 1.775M. These totals show increases of 20% and 64% respectively on the corresponding period last year. Radiogramophone despatches totalling 116,000 for the nine months were 3% down on the same period last year.

Radio Show 1960.—The 27th National Radio and Television Exhibition is to be held at Earls Court, London, from August 24th to September 3rd with a pre-view on the 23rd for overseas visitors and invited guests. It is being organized by Radio Industry Exhibitions Ltd., 49 Russell Square, London, W.C.1.

A.P.A.E. Exhibition.—The Association of Public Address Engineers is re-introducing its exhibition next year. It will be held at the King's Head Hotel, Harrow-on-the-Hill, Middx., on March 9th and will be open from 11.30 to 1.0 for members and the Press, 2.0 to 5.0 the trade, and 5.0 to 7.30 the public. Details are available from Alex J. Walker, honorary secretary, 394 Northolt Road, South Harrow, Middx.

P.M.G.'s Presentation.—Rarely, if ever before, has a recipient of the P.M.G.'s Certificate of Proficiency received his "ticket" at the hand of the Postmaster-General. At a ceremony at the Baltic Exchange, London, on November 4th to mark the 50th anniversary of the opening of the Post Office Coast Radio Service, the most recently qualified radio officer, P. N. Baker, received his second-class certificate from Mr. Bevins. Philip Baker is an eighteen-year-old student from Norwood Technical College who operates an amateur station under the call G3NPQ.

Printed Circuits.—A course of six lectures will be given on successive Tuesday evenings by P. G. L. Vivian, head of the chemistry department of Ultra Electric, at the Norwood Technical College, Knight's Hill, London, S.E.27, from January 12th. Fee 10s.

Transistor circuit techniques will be covered in a course of ten lectures to be given at the Medway College of Technology, Chatham, Kent, on Tuesday evenings, beginning January 19th.

"Words, Words, Words"—a correction. In lines 8 and 14 of the right-hand column of page 485 of the November issue, "transistor" should read "thermistor." It is regretted that this aberration passed unnoticed.

Vacuum Science.—The Joint British Committee for Vacuum Science and Technology consisting of representatives of ten societies and institutions has been formed as a result of last April's conference on high vacua sponsored by the Institute of Physics. Its objects are to co-ordinate and help to initiate meetings in the whole field of vacuum science and technology and to act in the collective interest of the constituent bodies by maintaining liaison with the International Organization for Vacuum Science and Technology and with vacuum societies of other countries. The Institute of Physics, 47 Belgrave Square, London, S.W.1, is providing the secretariat.

Relay Services Association.—The number of subscribers to television relay services in this country is increasing by about 100,000 a year. The figure at the end of December, 1958, quoted in the annual report of the Relay Services Association was 196,165, compared with 108,019 for the year before, but at the Association's annual luncheon on November 10th it was announced that the number is now approaching 300,000. The Association represents 95% of the relay services in this country, to which the total number of subscribers—both sound and TV—is over a million.

Brit.I.R.E. Council.—Professor E. E. Zepler, who occupies the chair in electronics at University College, Southampton, has been re-elected president of the British Institution of Radio Engineers. It is his second term of office. The following members have been elected to the council: Air Marshal Sir Raymund Hart (chairman of the Radio Industry Council), Ieuan Maddock (Atomic Weapons Research Establishment), E. K. Cole (Ekco), D. L. Leete (Manchester University) and Sqn. Ldr. W. L. Price (R.A.F., Technical College, Henlow). Dr. A. D. Booth (Birkbeck College, Computational Laboratory) and A. H. Whiteley (Whiteley Electrical) have been re-elected to the Council.

R.S.G.B.—An increase in membership for the third successive year is recorded in the annual report of the Radio Society of Great Britain. The year's increase of 445 brought the total to 9,540 on June 30th. The number of licensed transmitting members increased by 451, making a total of 6,349. The report records that 66% of the 8,463 holders of U.K. Amateur (Sound) Licences in force on June 30th were members of the Society. The number of amateur television transmitting licences in force at that date was 93. A total of 142 societies are affiliated with the R.S.G.B.

Colour Television will be the subject of this year's Christmas Holiday Lecture for secondary school children to be given by G. G. Gouriet. It will be delivered in the Institution's Lecture Theatre, Savoy Place, London, W.C.2, at 3.0 on December 30th and repeated on the following day at the same time. Admission is free but tickets must be obtained from the Institution.

For E. & R.E. read E.T.—With its January issue our sister journal *Electronic & Radio Engineer* changes its title to *Electronic Technology*.

Publication Dates

We apologize to our readers for the inconvenience they may have suffered as a result of our recent delays in publication. These have been due entirely to difficulties arising in the aftermath of the dispute in the printing industry. We are sorry for the irritation this may have caused, and are hoping to produce the next issue of "WIRELESS WORLD" within only a few days of our normal publication date, and to be back to normal by the appearance of the February issue.

If, for any reason, any recent issues have not been obtainable through the normal Trade channels, we would remind our readers that copies to complete their files are available by post from the Publishers.

Personalities

R. Ferguson, O.B.E., general manager since 1947 of the Marconi International Marine Communication Company, which he joined in 1910, has been elected to the board and becomes managing director. In 1919, after service in the Royal Flying Corps, he joined the newly formed Radio Communication Company, and was general manager of that company when, in 1928, the British Wireless Marine Service was formed as the joint service organization of the Marconi Marine and Radio Communication Companies. Mr. Ferguson then became manager of the new organization, and was appointed joint general manager of the Marconi International Marine Communication Company and its subsidiaries in 1929. For ten years from 1934 he was seconded to the Egyptian State Broadcasting as general manager. Mr. Ferguson began his career as a sea-going radio officer and in January, 1911, was granted the P.M.G.'s certificate for wireless proficiency. This he lost when the *Empress of Ireland,* of which he was chief wireless operator, sank in the St. Lawrence in May, 1914. At a ceremony on November 4th to mark the 50th anniversary of the Post Office Coast Radio Service, the Postmaster-General presented Mr. Ferguson with a framed copy of his original certificate.

R. FERGUSON

D. P. FURNEAUX

D. P. Furneaux, M.A., B.Sc., who joined the Marconi organization in 1953 and for the past four years has been a management executive of the company, succeeds Mr. Ferguson as general manager. After taking an honours degree in natural science at Trinity College, Cambridge, he served in the Royal Air Force Technical Branch during World War II. Demobilized in 1946 with the rank of Wing Commander, he held commercial appointments in South Africa before returning to England in 1950 to join the staff at Sheffield University.

F. N. Sutherland, C.B.E., M.A., M.I.E.E., managing director of Marconi's Wireless Telegraph Co., has been elected to the board of Marconi Marine.

John Keir, who joined Marconi's sea-going staff in 1915, is appointed personal assistant to the managing director of Marconi Marine. For some years he was managing director of the associated company, Companhia Marconi Brasileira.

JOHN KEIR

O. W. Humphreys, C.B.E., B.Sc., M.I.E.E., F.Inst.P., director of the Research Laboratories of the General Electric Co. since 1951, and a member of the board of the G.E.C. since 1953, has been appointed Director for Research and Technical Development. He graduated with honours in physics at University College, London, in 1925 and joined the staff of the Laboratories in 1927. He was appointed manager of the Laboratories ten years ago. Mr. Humphreys is chairman of the D.S.I.R. Radio Research Board; chairman of the International Special Committee on Radio Interference (C.I.S.P.R.); chairman of the Postmaster-General's Advisory Committees on the control of radio interference from industrial, scientific and medical equipment and from ignition systems; and chairman of the Guided Weapons Committee of the Society of British Aircraft Constructors.

O. W. HUMPHREYS

L. G. A. Sims, D.Sc., Ph.D., M.I.E.E., who has become professor of electrical engineering at the University of Southampton, had been senior lecturer in the Electrical Engineering Department since 1952. He graduated with first class honours and a Bowen Research Scholarship at the University of Birmingham in 1924. After a period at the G.E.C. Research Laboratories he joined the staff of Birmingham University and founded the electronics laboratory. Professor Sims was head of the Electrical Engineering Department of the Northampton Polytechnic, London, from 1936 to 1939 and has also held senior teaching appointments at the Royal Naval College, Greenwich, and the Royal Aircraft Establishment, Farnborough.

J. C. Simmonds, M.Sc.(Eng.), Ph.D., M.I.E.E., managing director of Airmec, Ltd., has been appointed managing director of British Communications Corporation Ltd., and of Radio & Television Trust Ltd., of which Airmec is a subsidiary. Dr. Simmonds, who is 46, joined Airmec in 1946. For the previous nine years he was a development engineer in the Radio Branch of the Post Office Engineering Department.

P. M. Thompson, co-author of the article on page 530 emigrated to Canada in 1950 at the age of 24 and until recently was in the transistor section of the Electronics Laboratory of the Canadian Defence Research Telecommunications Establishment, where the work he describes was carried out. He has recently joined the Plessey organization. Mr. Thompson took the natural science tripos at Cambridge and after a short while at A.T. & E., Liverpool, returned to the Cavendish Laboratory. For a few years before going to Canada he was with Salford Electrical Instruments.

J. Bateson, who, with P. M. Thompson, writes on the switching speed of transistors in this issue, went to Canada in 1948 after leaving the Signals Branch of the R.A.F. He was until recently in the Radio Propagation Laboratory of the Canadian Defence Research Telecommunications Establishment and is now teaching at the Eastern Ontario Institute of Technology, Ottawa. He is 39.

Sqn. Ldr. G. de Visme, B.Sc., contributor of the article on page 534 on a battery-fed crystal calibrator, graduated in 1942 and ten years later received the diploma in electronics from Southampton University. He was for two years in the G.E.C. Research Laboratories and since 1950 has been in the Education Branch of the R.A.F.

J. F. Coales, O.B.E., M.A., M.I.E.E., F.Inst.P., reader in control engineering at Cambridge University, has been elected a member of the executive council of the International Federation of Automatic Control. He is the only U.K. member. After graduating at Cambridge he joined the Admiralty scientific service in 1929 and from 1940 to 1946 was in charge of the development of naval gunnery radar. In 1946 he joined Elliott Brothers as research director. Six years later he returned to Cambridge University to take charge of post-graduate studies in control engineering.

Wing Cdr. E. W. Anderson, O.B.E., D.F.C., A.F.C., has succeeded **Capt. F. J. Wylie** as president of the Institute of Navigation. He was a schoolmaster for some time before joining the R.A.F. in 1940. For his navigation of the *Aries* on her pioneer polar flights he received the A.F.C. He left the R.A.F. in 1954 as its senior navigator and went to Elliott Brothers but is now with the Sperry Gyroscope Company at their new factory at Bracknell.

Dr. J. C. SIMMONDS (See opposite page)

Wing. Cdr. E. W. ANDERSON

P. J. Farmer, A.F.R.Ae.S., has been appointed editor of our associate journal *Data Processing* of which he has been acting editor since its introduction at the beginning of the year. He joined our publishers, Iliffe and Sons, in 1954 and in 1957 was appointed assistant editor of *Aircraft Production*. Before joining Iliffe he was engaged in structural design of guided missiles and was associated with the design of the Seaslug and the Firestreak anti-aircraft weapons.

D. E. D. Hickman, who discusses Wien bridge oscillators in this issue, served for five years as an air wireless fitter in the R.A.F. and on demobilization went to the Decca Navigator Co. Since August, 1958, he has been with Solartron Research and Development Laboratories where he is at present engaged on the design of electronic equipment for a digital tape recording machine.

K. R. Simmonds, B.Sc.(Eng.), A.M.I.E.E., has been appointed general manager of the International Rectifier Co. (Gt. Britain) Ltd., of Oxted, Surrey. For the past two years he has been general manager (marketing) of Texas Instruments Ltd., and was previously with Elliott Bros. (London) Ltd., whom he joined in 1948, and was for some time manager of their radar division at Rochester.

K. R. SIMMONDS

G. W. A. Dummer, M.B.E., M.I.E.E., who writes on the miniaturization of components on page 545, joined the Telecommunications Research Establishment (now the Royal Radar Establishment) in 1939 and was associated with the design of the first p.p.i. used in radar. He was at one time in charge of a group designing synthetic radar trainers and later became responsible for component development and panclimatic testing. More recently he has been doing fundamental work on printed and potted circuit techniques and is now in charge of a component development division.

W. H. Clarke, manager of the Studio Recording Division of RCA Great Britain Ltd., has been elected a director of the company with which he has been associated for over 27 years.

OBITUARY

H. W. Allen, who joined the Marconi Company as its first secretary on its formation in July 1897 as the Wireless Telegraph and Signal Company, died on October 7th at the age of 89. He claimed the unique distinction of being the first person to enter the wireless industry. Mr. Allen held various positions in the Marconi group and on the formation of the Imperial and International Communications Co. (now Cable and Wireless) was appointed general manager. He retired in 1930 and resided in Cape Town from 1947 until July this year when he returned to this country.

Dr. J. Zenneck, the German physicist who propounded the theory of groundwave (sometimes called the Zenneck wave) propagation and the effects of the ground on polarization and absorption, died recently at the age of 88. He began his career as a physicist when in 1895 he became assistant to his former teacher, Professor F. Braun, the cathode-ray tube pioneer. Dr. Zenneck, who was at one time editor of *Hochfrequenztechnik und Elektroakustik*, initiated ionospheric research in Germany and set up its first ionospheric research station in Kochel, Bavaria.

News from the Industry

Redifon are supplying a series of single-sideband h.f. transmitters (Type G423) and associated receivers (Type R403) for four Post Office coast radio stations—Land's End, Niton, North Foreland and Anglesey. Redifon are also supplying f.m./a.m. radio-telephone equipment for the Peninsular and Orient S.N. Co.'s fleet of passenger and passenger-cargo liners, the company's London terminal and at Tilbury Docks—a total of 31 installations.

Decca are supplying two high-power radars (TM909 and D808) for the recently launched Orient liner, *Oriana*. The two radars will be installed in the wheelhouse with a slave display in the chart room. The total number of ships for which orders for radar have been received by Decca now exceeds 9,000. Decca state that they have equipped approximately half the world's radar-fitted ships.

The B.B.C. has ordered from Marconi's two 100-kW short-wave transmitters to replace two at Daventry used for its External Services. To facilitate a changeover from one frequency to another each transmitter has two independent r.f. amplifiers with a common modulator. By tuning the standby amplifier to the new frequency the changeover can be carried out in a matter of seconds.

Ampex Electronics Ltd., which earlier this year established a factory in Reading, Berks., to produce Ampex equipment in this country, is now making the FR-100 series tape handler—a multi-channel analogue recorder for laboratory and industrial use. The marketing in this country of this British-made equipment and also certain Ampex products manufactured in the U.S.A. is being undertaken by a recently established associate company, Redwood City Engineering Ltd., also at Reading.

Sony Corporation, the Japanese radio receiver manufacturers, have announced that they are setting up an Irish company—Sony Ltd.—to assemble transistor sets in a factory at Shannon airport.

Marconi's have concluded an agreement with the Government of India for the manufacture under licence in India of Marconi v.h.f. multi-channel radio terminals and repeaters, and ancillary equipment. Marconi's are to supply all necessary technical assistance for indigenous manufacture.

Continental Distributors Ltd., of 121 Earls Court Road, London, S.W.5, have been appointed agents for the Nuclear Chicago Corporation, of the U.S.A. They will handle the Corporation's nucleonic measuring equipment and laboratory counting systems and in the New Year will be able to offer servicing facilities.

"Designing for Diecasting" is the title of a 32-page booklet issued by Fry's Diecastings Ltd., of Merton Works, Prince George's Road, London, S.W.19, for the benefit of designers and manufacturers of equipment. It is one of a series of technical booklets issued by Fry's and covers the basic principles of the diecasting process.

R.E.E. Telecommunications Ltd., of Crewkerne, Somerset, manufacturers of "Telecomm" v.h.f. radio-telephones, have made arrangements for installing and servicing facilities at fourteen centres throughout the country.

Marconi Marine.—Among recent installations of communication and navigational equipment undertaken by Marconi Marine are those in the new cargo liners *Indian Industry* and *Cheshire* and the Grimsby trawler *Ogano*.

Nash & Thompson Ltd., of Chessington, Surrey, have appointed A. R. Bolton & Co., 3a St. Vincent Street, Edinburgh 3 (Tel.: Caledonia 2065) as their sole agents for Scotland.

Philips Electrical Ltd. have opened new and enlarged headquarters for their south-western region at 51 Victoria Street, Bristol (Tel.: 93311). The four-storey building houses offices, stores, showroom and a hearing-aid centre.

Hazeltine Research Corporation, a research subsidiary of Hazeltine Corporation, of New York, is opening a new research and development centre in Plainview, Long Island.

Scope Laboratories, of Australia, manufacturers of the Superspeed soldering irons marketed in the U.K. by Enthoven Solders, and of electronic welding timers, etc., have moved to a new factory at Bulla Road, Airport West, Melbourne.

EXPORT NEWS

Belgium.—An IBM 610 automatic decimal point computer has been installed for the Faculty of Science at Ghent University. It will be used for scientific and engineering work, and in particular for solving problems connected with nuclear physics, astronomy and astrophysics.

West Africa.—Domestic sound and television equipment manufactured by Pye, Ekco, Garrard and Grampian is included in the selection of over 300 consumer goods for the display sponsored by the Design Centre which has been shown in Accra, Ghana, during November, and will be seen in Lagos, Nigeria, from January 11th to 23rd.

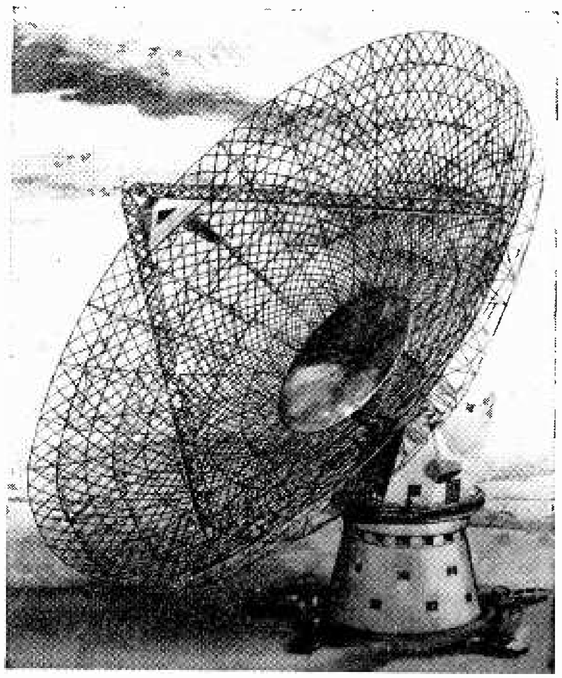
U.S.S.R.—A three-man delegation from the Scientific Instrument Manufacturers' Association visited the Soviet Union in the middle of November to explore the possibilities for an exhibition of British scientific instruments (with lectures and demonstrations) in Moscow in the second half of next year. The delegation consisted of H. D. Binyon (Solartron), F. Hamill (Hilger and Watts) and K. A. Macdonald (Unicam Instruments).

U.S.A.—The Audio Manufacturers' Group of B.R.E.M.A. is organizing a composite exhibit of audio equipment for the British Exhibition to be held in New York next June. The chairman of the group is Major J. F. E. Clarke (Clarke and Smith Manufacturing Co.), the vice-chairman D. A. Lyons (Trix) and the secretary S. E. Allchurch, 49 Russell Square, London, W.C.1.

Middle East.—The Advisory Council on Middle East Trade set up by the President of the Board of Trade in February last year to advise the Government on problems concerning trade in that area, has issued a booklet "Exporting to the Middle East." It outlines the importance of the Middle East markets, the past achievements of British industry there and what the region offers today.

Bulgaria's first television station, which opened in Sofia on November 7th, was designed and built by Pye, Ltd. Equipment supplied includes transmitters, aerial, studio and control equipment, film scanning equipment and an outside broadcast unit.

Switzerland.—Equipment manufactured by Electronic Instruments Ltd. has been included in the special survey trolley designed by the Health Physics Group of C.E.R.N., for use at the Nuclear Research Centre, Geneva.



A.E.I. Electronic Apparatus Division has developed the servo system for the control of the 210-foot radio-telescope to be erected in Australia. We reproduce an artist's conception of the telescope, which is to be built by a German firm for the Commonwealth Scientific and Industrial Research Organization at Parkes, N.S.W. In addition to the servo control equipment, A.E.I. is also supplying the inter-communication system between the master station and its eleven out-stations and some of the electrical gear.

By

G. W. A. DUMMER*

M.B.E., M.I.E.E., M.I.R.E.

Miniaturization and Micro-Miniaturization

NEW TECHNIQUES OFFERING INCREASED RELIABILITY

EXTREME miniaturization (micro-miniaturization) has been made possible by the changeover from valve to transistor circuits and is being increasingly emphasized by new developments in solid-state physics. The two main reasons for developing these techniques are (1) a significant reduction in size and weight, and (2) the possibility of increased reliability. It is this second point which may contain the real value of micro-miniaturization techniques, particularly from the military point of view. The present average failure rate for normal components under laboratory conditions is about five failures per thousand per year. Failure rates are many times higher in Service equipment, depending greatly on environmental conditions.

The effective packaging efficiency of components in sub-miniature equipments is still quite low, mainly because of cooling requirements and the necessity for providing withdrawal space for units or accessibility space for repair. Even in an i.f. "strip" the ratio is about three parts air to one part electronics, i.e., component packaging efficiency is about 25%. The fundamental point is, however, that with present shapes of sub-miniature components it is not possible to pack more components into a given space because of difficulties in soldering them in (even with miniature soldering irons) whilst providing adequate accessibility for repair. The limit of miniaturization has, therefore, been reached. The next logical step in development is to use components in which the actual working element only is used.

In any typical tubular component most of the available volume is taken up by material which plays no part in its electrical performance. In a cracked-carbon resistor the active carbon-film element has a volume of approximately 1/500th of the total component volume. Similarly, in a ceramic capacitor about 1/250th of the volume is effective, the remainder consisting of ceramic tube, case and connections. The heat dissipation of the cylindrical shape component is inefficient because of the low surface-area/volume ratio and an increase in power loading (or a reduction in effective size) could be made by opening out the cylinder and its leads into flat strips, provided that sound connections to the films are made. The comparatively large end connections on tubular components could thus be obviated and to a certain extent individual component-protection techniques may be reduced and the unit protected as a whole.

The miniaturization problem is, of course, aided by the low voltage-rating requirements of transistor

* Royal Radar Establishment.

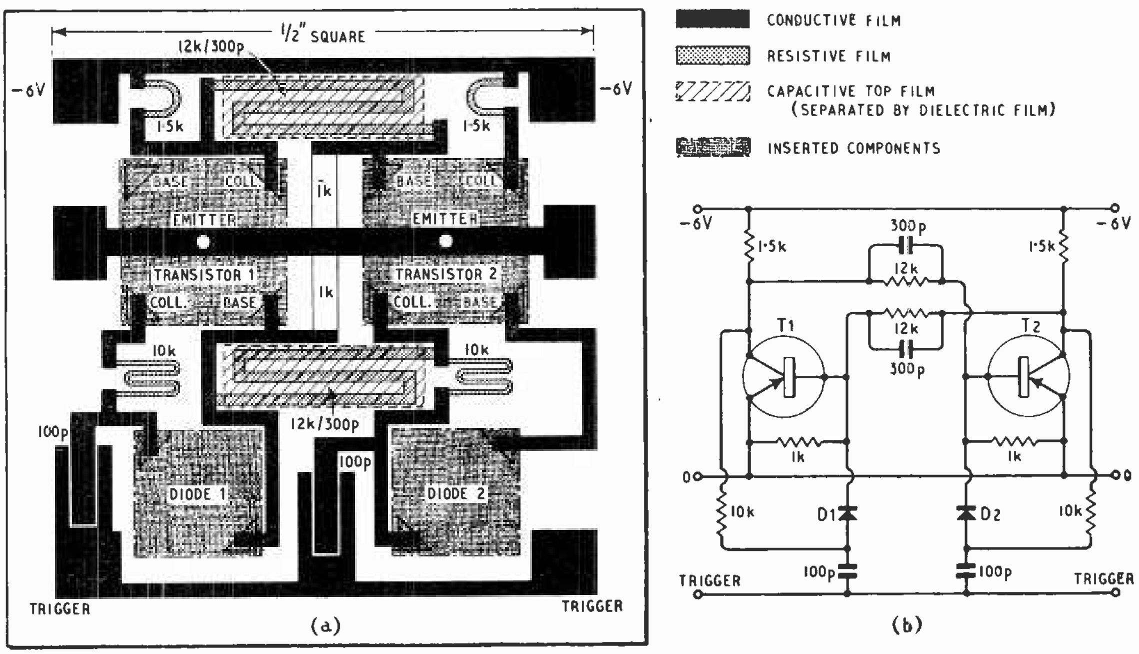


Fig. 1. Proposed layout (a) and (b) theoretical circuit diagram of binary-counter stage of flat-film form.

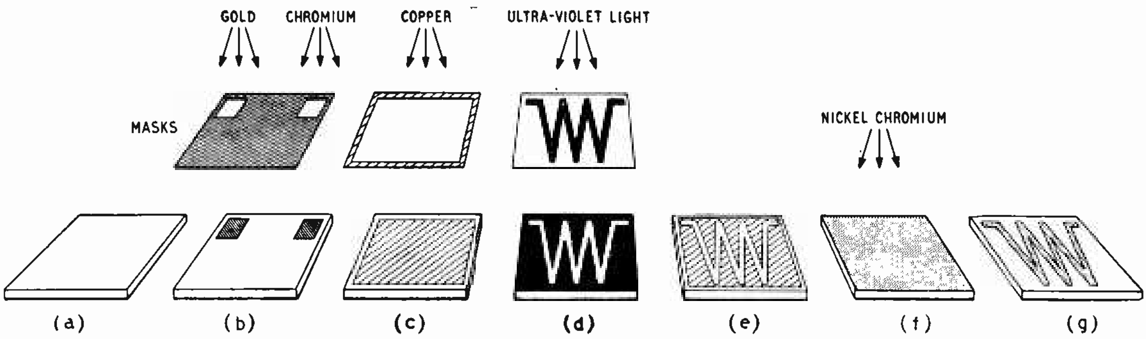


Fig. 2. Stages in production of high-definition film-type resistors with terminals. (a) Substrate is cleaned. (b) Gold/chromium laminated terminals are deposited by evaporation through mask. (c) Temporary copper coating is vaporized onto plate. (d) Plate coated with light-sensitive resist is exposed to ultra-violet light through a mask to render exposed resist insoluble. (e) Unexposed resist is washed away and exposed copper removed by etching. (f) Overall Nichrome coating is deposited by evaporation process and component is annealed at 350°C. (g) Remaining copper is removed by selective etching, leaving only desirec meandered nickel-chromium resistor pattern. Steps (b) (e) and (f) are carried out at pressure equivalent to 10^{-4}mm of mercury.

components. Because of these low operating voltages and the low power ratings, it now becomes possible to design components using extremely thin films of resistive, dielectric, magnetic, conductive or semiconducting materials. For instance, resistors can be made by

(1) evaporation of metal alloys such as Nichrome, with end connections of evaporated nickel,
(2) platinum-gold alloy, chemically deposited and subsequently fired, with soldered end connections, or
(3) in tin-antimony oxide with evaporated metal end connections.

All of these show remarkably high potential reliability but some will need more evaluation. In the majority of transistor circuits high values of resistance are not required and 100 kΩ is regarded as a reasonable maximum for most circuit applications. For low-voltage, high-value capacitors, four possibilities exist, namely,

(1) thin plates of high-permittivity ceramic—possibly multilayer,
(2) thin plastics films such as polystyrene, etc.,
(3) anodic films such as tantalum or aluminium oxide, and
(4) evaporated metal-oxide films of many types—e.g., silicon monoxide, alumina, etc.

Magnetic materials are also available as

(1) thin films rolled from powder alloys,
(2) films electro-deposited from alloys, and
(3) films evaporated from alloys.

The three circuit elements of resistance, inductance and capacitance are, therefore, available in film form and the problem is how to use them in conjunction with the transistor itself. An important point is that careful process control during evaporation plays an essential part in forming these films. As with the transistor where very pure materials are essential, the use of accurate process control means higher reliability.

TABLE

Construction	Packing Density (Components per cu. ft.)	Estimated Reliability (Failures/1000hrs)
Pre-war ..	1,000	1.0%
Miniature ..	5,000	0.5%
Subminiature	50,000	0.1%
Micro-module	600,000	0.01%
Circuit plate ..	2,500,000	0.01%
Solid circuit ..	50-100 million	Negligible

It has become common to quote packing densities per cubic foot, and although these figures become somewhat meaningless at the higher packing rates, they are nevertheless used as a method of comparison, and the table shows the comparison rates between packing density and estimated reliability. It should be stressed that this is *estimated* reliability only, as a considerable time will have to elapse before these reliability estimates can be proved.

Assembly Techniques

There are four possible methods of assembly for micro-circuits; these are summarized below:—

1. *Component-assembly or Micro-module System*—single or multiple components on plates, stacked and connected by riser wires.
2. *Circuit Assemblies*—single complete circuit function on a plate.
3. *Solid Assemblies*—true solid circuits consisting of single crystals with controlled resistivity areas, etc.
4. *Sealed Assemblies*—Micro-miniature components sealed in subminiature valve cases.

Micro-module System.—This system is now reasonably well known in Great Britain. Its main advantage is that components can be tested individually before final assembly. The concept hinges around a module 0.31 in square. This is very similar, in principle, to the well known "Tinker Toy" construction. It consists of ceramic plates on which are deposited the various flat circuit elements, including transistors and diodes, mounted one above the other and connected together by riser wires terminating in oversize end plates. The complete assembly is encapsulated in the usual way to produce a non-repairable, rigid assembly capable of withstanding vibration, shock, climatic conditions, etc. At present, some of the components in this assembly are of a tentative nature—that is, carbon-resin resistors and transistors utilizing ceramic wafers cemented together with synthetic adhesive—but it is finally intended to produce all these items in high-stability materials, preferably of an inorganic nature.

e.g., Nichrome resistors, tantalum-oxide capacitors and completely sealed semiconductor elements.

The selection of the 0.31in × 0.31in dimensions for the module was based on a review of component performance, manufacturing capabilities and voltage and power levels. Power dissipations of one to two watts per micro-module, working frequencies up to 100 Mc/s, 75 V maximum levels, and the application to general circuitry (i.f., r.f., a.f., filter, oscillator and computer-logic circuits) were the influencing parameters in the selection of this geometry. The 0.31-in square was the smallest size in which the desired ranges of many components could be accommodated, including glass, electrolytic and high-permittivity capacitors, diodes, ceramic resonators, metal-film resistors and even some electromechanical parts such as potentiometers and trimmer capacitors. This system was sponsored by the U.S. Army Signal Corps Research and Development Laboratory. Whilst R.C.A. act as the main contractor, there are some 170 firms engaged in making the individual component micro-elements. The whole programme is timed to be complete by late 1961 and it should be emphasized that this is a production contract rather than a research and development contract. It will be interesting to see how the reliability of the system proves in practice.

Circuit Assemblies.—The flat plate or substrate is processed to produce conductors, resistors, capacitors, and transistors and diodes are inserted to form a complete circuit function. The construction is almost entirely two-dimensional, using film-type components (which are described later). The technique lends itself to evaporation processes with very closely controlled parameters. The advantage of this system is that only a few connections have to be made between units; but the reject rate of each individual component must be made very low indeed.

Work at the Royal Radar Establishment has been carried out on this system in preference to the component-assembly system, and small, complete circuit functions have been the target. A ½in × ½in module has been chosen and this can be extended in two planes to become ½in × 1in, 1in × 1in, ½in × 2½in, etc. A simple multivibrator circuit is being constructed initially. This consists of eight resistors, two capacitors, two transistors, and two diodes, and the layout of the ½in-square plate is shown in Fig. 1(a) together with the theoretical circuit (Fig. 1(b)).

The work on resistors, capacitors, etc., will now be described.

Fixed Resistors.—Film resistors have been made for many years as evaporated Nichrome resistors for waveguide loads, and fired platinum-gold solutions as flat-plate resistors. Alternatively, tin-antimony-oxide films have been made which have excellent stability.

It has been decided that for micro-miniaturization work, carbon mix and similar types of resistors should not be used and all the work is aimed at employing inorganic resistive materials. A considerable basic study of the processes and substrates is being made, e.g., special studies of binding energies between films and substrates are being made, particularly for nickel-chromium on glass.

Nickel-chromium work is divided into two processes, one for resistors with line widths above 0.015in, and one for resistors composed of narrower lines. Resistors with "wide" lines are made by evaporating nickel-chromium directly on to a heated subtrate, the final thickness of the Nichrome being approximately 6×10^{-6} mm. Simple pattern meandering is made by mechanical masking and the resistance elements are annealed at 350°C for at least half an hour. Resistors with line widths down to 0.004in are made by deposition of an intermediate layer of copper which is photo-mechanically processed. Deposition of the nickel-chromium on to the heated substrate follows in the usual way and the copper mask is etched away subsequently, lifting the superfluous nickel-chromium with it and leaving the correct pattern. Annealing follows in the usual way. The stages in the development of the high-definition films are shown in Fig. 2.

Capacitors and Dielectrics.—Although thin plastics films have been developed in thicknesses as small as 0.0001in and below, and can be used as also can high-permittivity plates down to 0.001in in thickness, most of the work for this programme has been done on evaporation techniques. Both silicon-monoxide and magnesium-fluoride capacitors have been made experimentally at R.R.E. for low-voltage operation; but again a thorough understanding of the mechanism of adhesion is the prime object of the work, and many research contracts have been arranged to implement this programme.

Glass microscope slides have been employed as substrates, although surface imperfections make these far from ideal. Masks were arranged to allow evaporation of four capacitor specimens on one slide, each specimen having an area of 0.6 cm^2. Aluminium, chromium, gold, copper and silver have all been tried as electrode materials. The most consistent results were obtained with aluminium and this has been used for all later work. Initial experiments were made using magnesium fluoride and zinc sulphide as dielectrics since these were known to be easy to evaporate. It was found that capacitors made with magnesium-fluoride films thicker than 5×10^{-4} mm had a tendency to craze; but this was

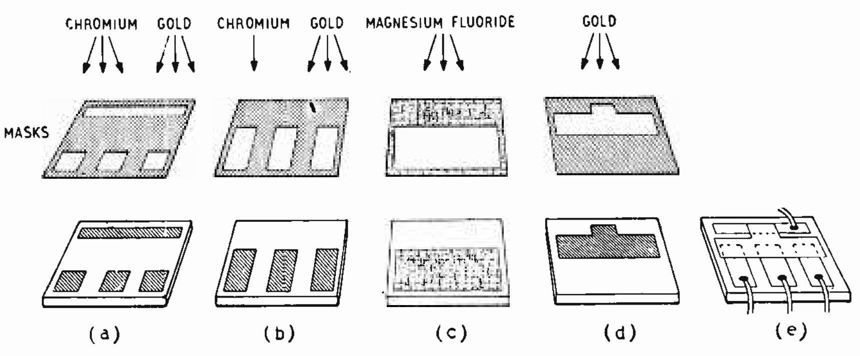


Fig. 3. Stages in production of gold-electrode, magnesium-fluoride-dielectric capacitors. (a) Chromium and gold terminals are applied by evaporation. (b) Gold electrodes are applied over chromium layer to give adhesion to substrate. (c) Magnesium-fluoride dielectric is applied and annealed at 300°C for 30 minutes. (d) Common electrode is applied to form (e) three-capacitor block.

avoided by heating the substrate during deposition. Fig. 3 shows the stages in the process. Zinc sulphide gave surprisingly good results and thick films were easy to obtain: atmospheric moisture, however, caused deterioration over a period of weeks.

Most of the work has been on silicon monoxide. Initially pure, resublimed lump silicon monoxide was used but spitting from the containing boat during evaporation occurred. Mixtures of silicon and silicon dioxide gave improved results. For the best

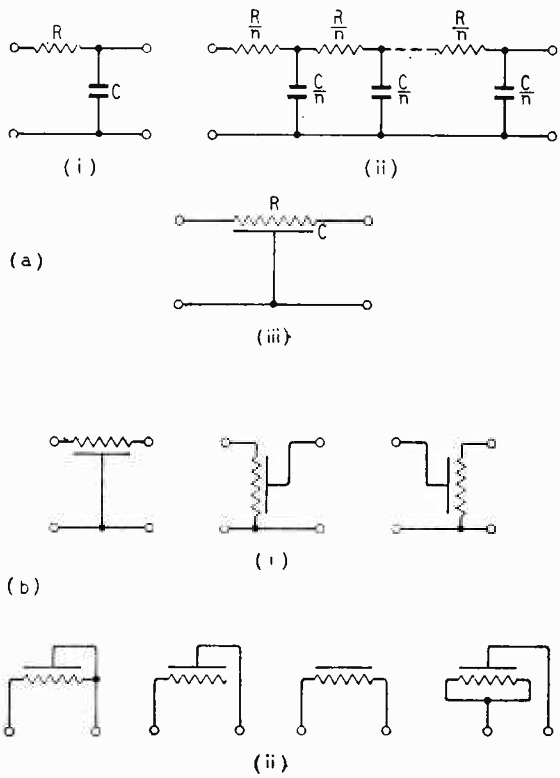


Fig. 4. (a) Evolution from (i) single R-C low-pass four terminal filter through (ii) multi-stage filter ("lumped constants") to (iii) distributed-constant type of low-pass filter. (b) Possible (i) four terminal and (ii) two terminal distributed R-C networks of the simplest type.

electrical properties, slow evaporation rates (10 to 15×10^{-7} mm/sec, heated substrates and a small residual air pressure (1 to 3×10^{-5} cm mercury) were all required. The addition of calcium borate to the mixture in the boat resulted in the disappearance of the straw colour of the film. The substitution of a phosphate gave a deep orange film. This may provide useful information concerning the leakage mechanism by a study of the effects of addition of materials of different valencies.

Mechanical crazing of the film has also been studied. Silicon monoxide shows crazing typical of a compressively stressed film. Crazing is greatly accelerated by storage in a moist atmosphere; but it is very much delayed in a desiccator.

The permittivity of evaporated silicon monoxide films was found to be approximately 5, whilst the leakage measured on films in air showed an exponential relation between current and voltage.

Breakdown voltages of the order of 100 volts/micron can be achieved. Initial breakdowns at weak points in the film can self-heal in air; but not in a vacuum.

Future work will be directed towards the controlled evaporation of mixtures with a view eventually to the exploitation of materials with much higher permittivities such as titania and barium titanate. It is hoped that fundamental studies of breakdown and leakage mechanism will also be continued.

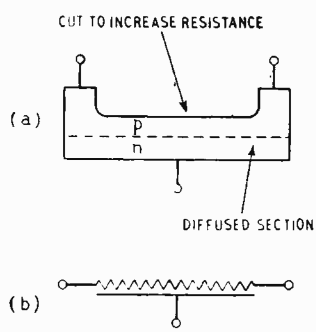
Conductors.—The conductors now used consist of layers of evaporated chromium and evaporated gold, starting with chromium, which adheres to the base. The resistivity is below 0.5 ohms per square. The conductors are evaporated on to the cold substrate using mechanical masking techniques. Lines produced by masking techniques can be as narrow as 0.01in, and the mask apertures are made by etching through copper suitably protected by a light-sensitive temporary coating ("photo resist").

Substrates.—Most of the work has been done to date on microscope slides of glass with a high soda content, because the expansion coefficient of this glass most nearly matches that of the evaporated Nichrome resistors. It is essential to have a flawless surface for high resolution pattern resistors: ceramic substrates have been investigated but do not possess a sufficiently smooth surface. Ion migration in glass should not be a problem as the operating temperature of the substrate is not expected to be above about 80°C when germanium is used and, even for silicon transistors, the temperature will not be above 150°C.

Transistors and Diodes.—The first stage in all micro-miniaturization work is the development of a suitably protected flat-shaped transistor. Many attempts have been made to protect the surface of both germanium and silicon active elements, and although some photo-sensitive solutions and silane (silicon hydride) treatments can be used, the long-term effects have not yet been fully evaluated. A range of small flat-cased transistors (fully sealed) is to be developed which are capable of being let into recesses in ceramic or glass substrates. The size of the sealed transistor is not to exceed 0.125-in square or 0.125-in dia. ×0.040-in thick, with flush electrode contacts. It is emphasized that fully-sealed cases of inorganic materials are required and both glass and ceramic cases are to be investigated. Diode construction would be similar to, and fit the same size specification as, the transistor.

Distributed Component Techniques.—Distributed resistor-capacitor networks can consist basically of sandwiched layers of conducting, dielectric and resistive films, with various connections brought out. Fig. 4(a) shows the extension of a single R-C filter

Fig. 5. (a) Appearance and (b) equivalent theoretical circuit of distributed-type element made by diffusion processes for solid-circuit techniques.



through a cascaded filter of the lumped-constant type to the distributed component. By changing round the terminals of the distributed component, different types of four-terminal networks may be achieved, and by open- or short-circuiting the terminals, two-terminal components are possible. Fig. 4(b) shows three possible types of four-pole connections and four possible two-pole connections.

Solid Assemblies.—Experimental work in doping techniques in silicon and germanium crystals has shown that it is possible to control resistivity in parts of the crystal and capacitance can be produced by using p-n junctions. This holds out the possibility of incorporating both active and passive circuit elements in a single block. Provided control conditions are adequate, the intrinsic reliability of such a device should be very high indeed.

In America, Texas Instruments Inc. have made working models of a simple multivibrator and a phase-shift oscillator which they call single-crystal circuits. By diffusion, evaporation, electrolytic and chemical forming, ultrasonic cutting of the crystal and similar processes, a semiconductor wafer is made to perform the function of the complete circuit. External leads are required only for the input and output signals and the power source. The individual components lose their identity because the device as a whole is performing the circuit function.

Doping techniques in silicon are being fully investigated both in the U.S.A. and in this country: a distributed component network has been made in the U.K. by diffusing into a p-type crystal n-type impurities and cutting it to shape as shown in Fig. 5. This shaped crystal formed the basis for a phase-shift oscillator; but as a power gain of 27dB was required for oscillation, a pentode was used as an interim measure in place of a transistor. The amplitude and frequency of oscillation could be altered by changing the bias across the junction. 180° phase change was obtained at 0.5Mc/s.

Oxide masking processes are being investigated for the diffusion techniques. The thickness of the silicon oxide determines the depth of the junction when both p- and n-type impurities are diffused into the silicon block, whilst the shape determines the area of diffusion. These techniques, however, are in the early experimental stages.

Sealed Assemblies.—In this technique individual assemblies of film type components with suitable interconnections are arranged in three-dimensional form in a subminiature-valve envelope, such as that shown in Fig. 6. These use hermetic seals in the case to provide complete protection to the miniature components inside. Using these component assemblies in conjunction with the miniature tubes specially developed for high reliability, complete circuits can be made which take up very little space.

Conclusions.—Micro-miniaturization techniques will undoubtedly have an influence on low-voltage circuitry where high packing densities are required, and it is possible that through this technique the reliability of electronic equipment may be improved. Ideally the aim is to reduce the size of existing subminiature transistorized equipment by a factor of ten, and to improve the reliability by a factor of ten.

It should be remembered that high reliability is a very difficult goal to achieve, and not until production assemblies have finally passed the acid test of operational use can their real reliability be estimated.

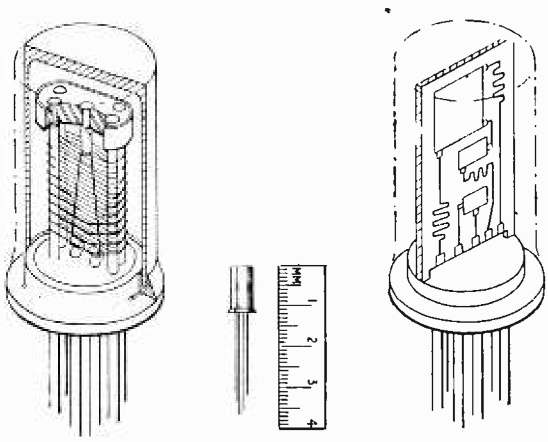


Fig. 6. Comparison of (a) micro-miniature thermionic valve with (b) component-assembly hermetically sealed in similar envelope; also shown (c) is size of envelope relative to scale calibrated in mm.

Nevertheless, there is no doubt that in these techniques lies the only possibility of achieving higher orders of reliability as compared with conventional subminiature components.

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Wien Bridge Oscillators

Both the basic equations and normalized expressions for the phase/frequency and amplitude/frequency characteristics of the Wien bridge network are derived. The various sources of frequency drift and errors caused by the parameters of the associated amplifier within the regenerative loop are discussed. Various methods of amplitude stabilization are discussed and their limitations pointed out. Finally a design procedure is presented for a low-frequency Wien bridge oscillator employing thermistor stabilization, and the procedure illustrated by a practical example.

THEORETICAL ANALYSIS AND PRACTICAL DESIGN

By D. E. D. HICKMAN*

WHERE accurate and stable frequency generation over a wide range of frequencies with low distortion is required, the Wien bridge oscillator has much to recommend it. It is these attributes, together with the inherent simplicity of this type of circuit, which have led to its widespread use in the majority of low-frequency signal generators that are currently available. The Wien bridge oscillator is particularly appropriate for use in decade oscillators since range multiplication may easily be achieved by switching capacitors while fine control of frequency may be covered by switched or variable resistors[1].

Over most of the audio-frequency range and up to several hundred kilocycles per second, the thermistor is the generally favoured method of amplitude stabilization; its advantages being (a) that the power developed in the thermistor is not a function of frequency (since its own temperature time constant is long compared with the period of oscillation) and (b) that no distortion is introduced by the thermistor which is sensitive only to the r.m.s. value of the voltage developed across it.

The author was recently faced with the task of designing a suitable oscillator to run at a constant frequency of 50 c/s at an amplitude of some twenty volts r.m.s. which was to be an inexpensive but reasonably accurate frequency standard for a synchronous hysteresis-type capstan motor of a general-purpose instrumentation tape recorder/reproducer. Consequently a comprehensive analysis was carried out for the Wien bridge circuit and this is given.

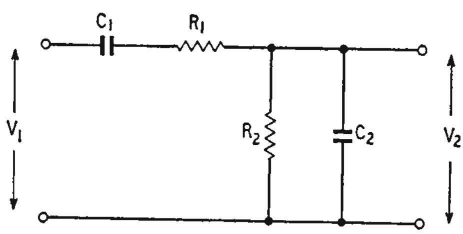

Fig. 1. Reactive section of Wien bridge.

It is felt that, although the particular application for which the design was intended was a specialized one, the analysis and information presented by this paper may be of sufficient general interest to warrant its publication.

Circuit Analysis of the Reactive Section of the Wien Bridge.—Fig. 1 illustrates the frequency determining part of the conventional Wien bridge.

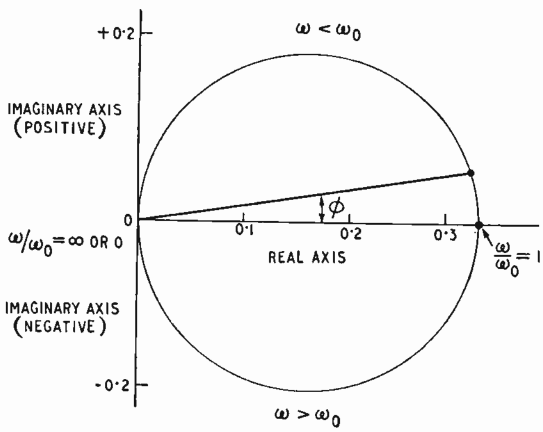

Fig. 2. Transmission of a symmetrical Wien network.

The transmission $T = V_2/V_1$ at any angular frequency ω is obtained from

$$T = \frac{\dfrac{R_2}{1 + j\omega C_2 R_2}}{R_1 + \dfrac{1}{j\omega C_1} + \dfrac{R_2}{1 + j\omega C_2 R_2}}$$

Which simplifies to

$$T = [j\omega C_1 R_2] \div [1 - \omega^2 C_1 C_2 R_1 R_2 + j\{\omega C_1 R_1 + \omega C_2 R_2 + \omega C_1 R_2\}] \quad \ldots \quad (1)$$

Rationalising this expression we have

$$T = [\omega C_1 R_2 (\omega C_1 R_1 + \omega C_2 R_2 + \omega C_1 R_2) + j\omega C_1 R_2 (1 - \omega^2 C_1 C_2 R_1 R_2)] \div [(1 - 2\omega^2 C_1 C_2 R_1 R_2 + \omega^4 C_1^2 C_2^2 R_1^2 R_2^2) + (\omega C_1 R_1 + \omega C_2 R_2 + \omega C_1 R_2)^2]$$

At any given frequency ω rads/sec, the phase shift ϕ of V_2 with respect to V_1 is given by

$$\phi = \tan^{-1} \frac{1 - \omega^2 C_1 C_2 R_1 R_2}{\omega C_1 R_1 + \omega C_2 R_2 + \omega C_1 R_2} \quad \ldots \quad (2)$$

For zero phase shift $\phi = 0$, i.e., $1 - \omega^2 C_1 C_2 R_1 R_2 = 0$. Thus the frequency f_0 at which $\phi = 0$ is given by

$$f_0 = \frac{1}{2\pi\sqrt{C_1 C_2 R_1 R_2}} \quad \ldots \quad (3)$$

It is customary practice to make the resistor

* Solartron Research and Development Ltd

values equal, and also the condenser values equal. Thus, putting $R_1 = R_2 = R$ and $C_1 = C_2 = C$ in equations (1) (2) and (3) we obtain equations for transmission, phase shift and frequency at which the phase shift is zero, respectively as follows

$$T = \frac{j\omega CR}{1 - \omega^2 C^2 R^2 + 3j\,\omega CR} \quad \ldots \ldots \ldots \quad (4)$$

$$\phi = \tan^{-1}\left(\frac{1 - \omega^2 C^2 R^2}{3\omega CR}\right) \quad \ldots \ldots \ldots \quad (5)$$

$$f_o = \frac{1}{2\pi CR} \quad \ldots \ldots \ldots \quad (6)$$

In order to examine the characteristics of the network where $C_1 = C_2 = C$ and $R_1 = R_2 = R$ at frequencies other than f_o it is convenient to derive normalized equations for transmission and phase shift. Thus using equation (6), and replacing CR by $1/\omega_o$ in equation (4), we obtain the following expression

$$T = \frac{j(\omega/\omega_o)}{1 - (\omega/\omega_o)^2 + 3j(\omega/\omega_o)}$$

Let $\omega/\omega_o = \rho$, then

$$T = \frac{j\rho(1 - \rho^2 - 3j\rho)}{(1 - \rho^2 + 3j\rho)(1 - \rho^2 - 3j\rho)}$$

$$= \frac{3\rho^2}{(1 - \rho^2)^2 + 9\rho^2} + j\frac{\rho - \rho^3}{(1 - \rho^2)^2 + 9\rho^2}$$

Replacing ρ by ω/ω_o, the normalized transmission equation becomes

$$T = \frac{3(\omega/\omega_o)^2}{[1-(\omega/\omega_o)^2]^2+9(\omega/\omega_o)^2} + j\frac{(\omega/\omega_o) - (\omega/\omega_o)^3}{[1 - (\omega/\omega_o)^2]^2 + 9(\omega/\omega_o)^2} \quad \ldots \quad (7)$$

From this equation we can deduce the phase shift at any fractional frequency deviation.

$$\tan\phi_{\,\omega/\omega_o} = [1 - (\omega/\omega_o)^2]/3(\omega/\omega_o) \quad \ldots \ldots \quad (8)$$

Fig. (2) shows the theoretical transmission factor of a symmetrical Wien bridge given by equation (7), plotted in the complex plane for values of ω/ω_o from 0 to ∞. It may be shown that the effect of changing the ratios R_1/R_2 and C_1/C_2 from unity is that of increasing or reducing the diameter of the circle diagram for transmission.

From Fig. 2 the modulus of the normalized

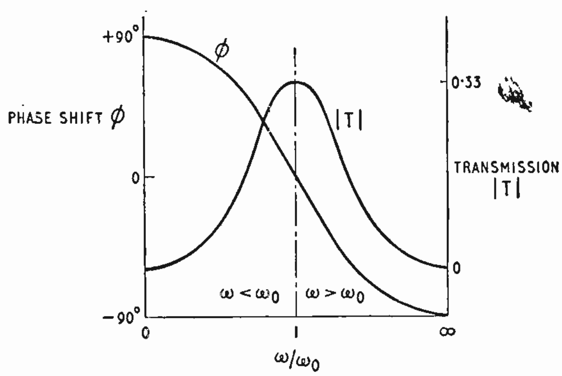

Fig. 3. Normalized transmission modulus and phase shift of a symmetrical Wien network plotted against ω/ω_o.

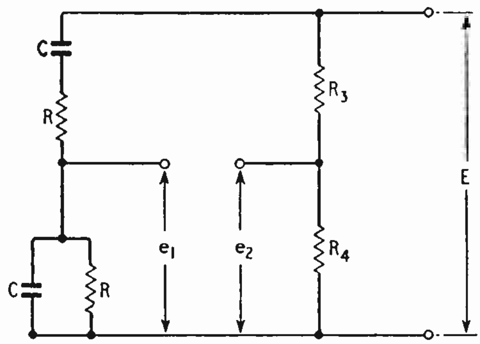

Fig. 4. Complete Wien bridge network.

transmission and phase shift may be plotted with respect to ω/ω_o as the horizontal axis. Fig. 3 shows the result of doing this.

For the Wien bridge oscillator it is desirable for the rate of phase change with frequency to be a maximum at $\omega/\omega_o = 1$, since in this case phase changes due to component variations or any other cause produce a minimum change in oscillator frequency. The curve of ϕ against ω/ω_o verifies that maximum rate of phase change occurs when $\omega/\omega_o = 1$, since this is a point of inflexion on the phase curve.

Complete Bridge.—We have shown that at a frequency given by $f = 1/2\pi\sqrt{C_1 C_2 R_1 R_2}$ the output of the reactive network is in phase with the input. From this point on, we shall only consider the case where $C_1 = C_2 = C$ and $R_1 = R_2 = R$ which are the conditions for what is called a "symmetrical" network. Equation (7) gives the transmission as

$$T = \frac{3(\omega/\omega_o)^2}{[1-(\omega/\omega_o)^2]^2+9(\omega/\omega_o)^2} + j\frac{(\omega/\omega_o) - (\omega/\omega_o)^3}{[1-(\omega/\omega_o)^2]^2+9(\omega/\omega_o)^2}$$

At the frequency at which ω/ω_o is unity, the imaginary term reduces to zero and the transmission is 1/3. Thus we see that for the bridge of Fig. 4 to be in balance, $e_1 = e_2$, R_3 must equal $2R_4$.

The phase and amplitude discriminating properties of the balanced Wien bridge network may be applied to the measurement of capacity in terms of resistance and frequency. Such measurements can be made with considerable precision since resistance and frequency standards are known to great accuracy[2, 3].

Complete Oscillator.—It is theoretically possible to construct an oscillator using only the reactive branch of the Wien bridge. The output of the network is used as the input of a linear amplifier whose output is connected to the input terminals of the network, and the amplifier gain is adjusted critically to equal +3. However, with this arrangement, it is found that many factors external to the Wien network affect the frequency and it is difficult to achieve a satisfactory waveform. It is common practice therefore to use an amplifier with a gain considerably greater than 3, and to reduce the gain to 3 by a large amount of negative feedback, applied in series with the input. (It is of course necessary to ensure that the amplifier phase shift is zero or an integral multiple of 360 degrees so as to produce oscillation.)

The effect of the application of heavy negative feedback by R_3 and R_4 in Fig. 5 is to complete the bridge circuit and it is convenient to consider the action in terms of bridge and amplifier parameters. The procedure for achieving undamped oscillations is to apply a small amount of unbalance to the bridge by making R_3 in Fig. 5 slightly greater than $2R_4$, the unbalance voltage then forming the input signal to the amplifier. The gain of the amplifier is then adjusted so that the output is $3e_1$, and oscillation at the frequency $f_o = 1/2\pi CR$ will then ensure.

The negative feedback produced by R_3 and R_4 is very effective in improving the general performance of the amplifier by reducing distortion and improving the bandwidth, and also in making the frequency practically independent of valve and circuit component changes.

In the previous calculations that were made on the Wien bridge network the source impedance driving the network was assumed to be zero. If this is not the case in practice, the frequency at which the bridge offers zero phase shift is modified as is also the transmission of the network.

A cathode follower is therefore often used to drive the bridge from the output of the amplifier. Where more than two a.c. coupled stages are used in the loop, however, difficulty may be experienced due to a component of the feedback becoming positive at some low frequency and thus causing the well-known "hunting" effect. If the anode of the second valve is set to a voltage somewhat less than the h.t. voltage, the cathode follower may be directly coupled to the output of the second valve and hunting should then not occur due to this cause.

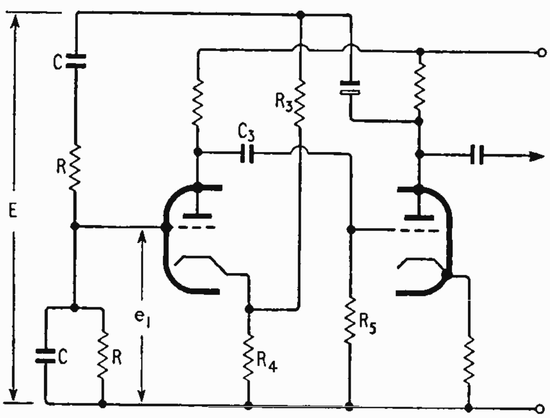

Fig. 5. Basic Wien bridge oscillator circuit.

An alternative, and simpler, approach is to use a low value of anode load for the second valve and operate this stage at a fairly large anode current. This is the approach chosen by the author in the final design of the oscillator described later in this paper. Under these conditions the majority of the gain is supplied by the first valve which can conveniently be a high slope r.f. pentode.

Effect of the Coupling Time Constant.—It has been mentioned that one of the uses of the negative feedback is to reduce the effect of valve and circuit parameters upon the generated frequency f_o. At low frequencies it is necessary to consider the effect of the coupling circuit $C_3\,R_5$ upon the generated frequency. D. L. A. Smith has derived[4] an expression for the generated angular frequency of a Wien bridge oscillator without negative feedback in which the amplifier phase shift is not negligible. By equating the loop phase shift to zero and solving for ω he obtains

$$\omega = \frac{1}{CR}\left(1 + 2\,\frac{CR}{C_3R_5}\right)^{1/2} \quad \ldots \ldots \ldots \ldots \quad (9)$$

where C R is the time constant of the bridge and $C_3\,R_5$ is the time constant of the coupling circuit between the two valves. Assuming $C_3\,R_5 > 2C\,R$, equation (9) may be expanded to

$$\omega = \frac{1}{CR}\left(1 + \frac{CR}{C_3R_5} - \frac{1}{2}\left(\frac{CR}{C_3R_5}\right)^2 + \ldots\right)$$

Thus, to a first approximation

$$\omega \simeq \frac{1}{CR} + \frac{1}{C_3R_5} \quad \ldots \ldots \ldots \quad (10)$$

He then goes on to use this effect as a means of adjusting the frequency of oscillation over a narrow range, thus providing a simple and effective method of incremental frequency control.

It is normally desirable, however, that the effect of the coupling circuit upon the generated frequency shall be negligible. Consequently it is obviously essential that the coupling circuit time constant should be large in comparison to the period of the generated frequency.

With no negative feedback, the fractional frequency deviation due to the circuit would be $\delta\omega/\omega = CR/C_3R_5$. The error with negative feedback however is reduced in the ratio $1 : (1 + A\beta)$ and for a typical circuit with $\beta = 1/3$ and $A = 90$, the error would be reduced by a factor of $1 : 31$. Of course, the greater is A, the more the reduction of the effect of $C_3\,R_5$ upon the frequency of oscillation. For frequencies of the order of a few cycles per second upwards, component values of 0.25 μF and 1MΩ respectively for C_3 and R_5 are quite sufficient for most purposes.

Amplitude Stabilization.—It is well known that if an oscillator output contains harmonics, considerable frequency error may be introduced which makes the generated frequency differ from the predicted frequency[5]. It is therefore desirable that the output waveform should contain little or no distortion. It is also desirable that the output level of the oscillator should remain constant over a wide frequency range, so that some means of automatic amplitude stabilization becomes necessary. It is possible to have a fixed amount of gain and a small adjustment of the negative feedback which will just allow the system to oscillate, but the adjustment is necessarily extremely critical and difficulty is experienced in obtaining just the right conditions of equilibrium where the loop gain is unity. The methods of stabilizing Wien bridge oscillators may be divided into two main groups: (a) Thermal Methods and (b) A.G.C. Methods.

Thermal Methods.—Of these methods (a) is usually the simplest although it tends to suffer from the obvious disadvantage that the amplitude of stabilization is to some extent dependent upon the ambient temperature; although careful choice of component values considerably reduces this limitation. Some years ago, before the invention of the thermistor, it was common practice to use a lamp as the temperature sensitive element[6]. This had the advantage that its operating temperature was normally rather greater than the ambient temperature, though

(*Continued on page* 553)

it suffered from the attendant disadvantage that a fair amount of power was required from the oscillator in order that the lamp should be operating on a suitable part of its resistance/temperature characteristic.

Both lamp and thermistor methods however are extremely useful since they do not introduce distortion, resistance not being a function of frequency (to a first order approximation).

One method of compensating for the drop in output voltage that occurs with rise of temperature is to follow the oscillator with an amplifier whose gain is a function of temperature such that the reduction in output from the oscillator is precisely compensated by an increase in gain of the correcting amplifier. By this means it is possible to achieve a reasonably flat amplitude/temperature characteristic but, in the interests of frequency stability, hum, and noise level, it is desirable that the oscillator itself should run at a nearly constant amplitude.

By operating the stabilizing thermistor in an uncompensated Wien bridge oscillator at a reasonable power level of the order of 40 to 50 milliwatts, the power dissipated in the thermistor due to the current in it is an appreciable fraction of the total dissipation caused by the sum of the electrical power and ambient heating. The latter will then have negligible effect.

A.G.C. Methods.—Briefly, the principle involved in a.g.c. methods of stabilization is to rectify the output waveform and apply the resulting d.c. to the grid of the first stage as a bias voltage which is proportional to the peak value of the output voltage. By choosing a valve with variable mu characteristics, the gain of the first stage is considerably altered by the bias, and stabilization can thus be achieved. If the fraction of input signal excursion to the grid base is small, as it normally is, very good shape and frequency stability can be achieved, although care is necessary in the design to see that the rectifying circuit does not impose a non-linear and complex load on the amplifier, and thus give rise to unwanted phase shifts within the regenerative loop. Even better amplitude stability may be achieved by the use of amplified, delayed a.g.c.

An alternative method of applying a.g.c. has been suggested. Fig. 6 is a diagram of a Wien bridge oscillator with the suggested method of stabilization incorporated. The operation of the circuit is as follows:—

The output voltage appearing across the anode load resistor R_6 is rectified by the diode V3 and the resulting waveform, smoothed by C_5, appears across R_8. R_8 acts as the d.c. load for V3, while the d.c. return path is formed by R_9 via E_B to earth. E_B may conveniently be obtained from a potentiometer connected between h.t. positive and earth, and serves as a fixed delay for V3. V2 is a cathode follower whose grid bias voltage is determined by the rectified d.c. component of the oscillator output voltage. The anode current in V2 determines the mutual conductance of that valve. Over a fairly small range of anode current variation the relationship between mutual conductance and grid voltage is linear, provided that the optimum d.c. operating conditions are chosen for the particular type of valve. However, any non-linearity in the relation between g_m and v_g is of little consequence in this application since V2 is only being used as a regulating device.

The output impedance of the cathode follower is effectively shunted across the lower part of the resistive section of the Wien bridge. The orientation of V3 is such that if the oscillation amplitude tends to increase, the negative bias voltage due to V3 is increased, the anode current of V2 is thereby reduced, the consequent reduction in the g_m of V2 increases the effective shunting impedance as seen from the cathode of V1, and this gives rise to an increase in the feedback fraction. In order to prevent any changes in the d.c. operating conditions of V1 by virtue of the current changes in V2, the cathode of V2 is isolated for d.c. from the cathode of V1 by means of a large capacitor C_4. The large value of capacity is necessary so that its reactance at the frequency of operation is small in comparison to R_7. If this capacity is too small, the effective total impedance of the lower section of the divider chain would have an imaginary component, the frequency of oscillation would alter to bring the output from

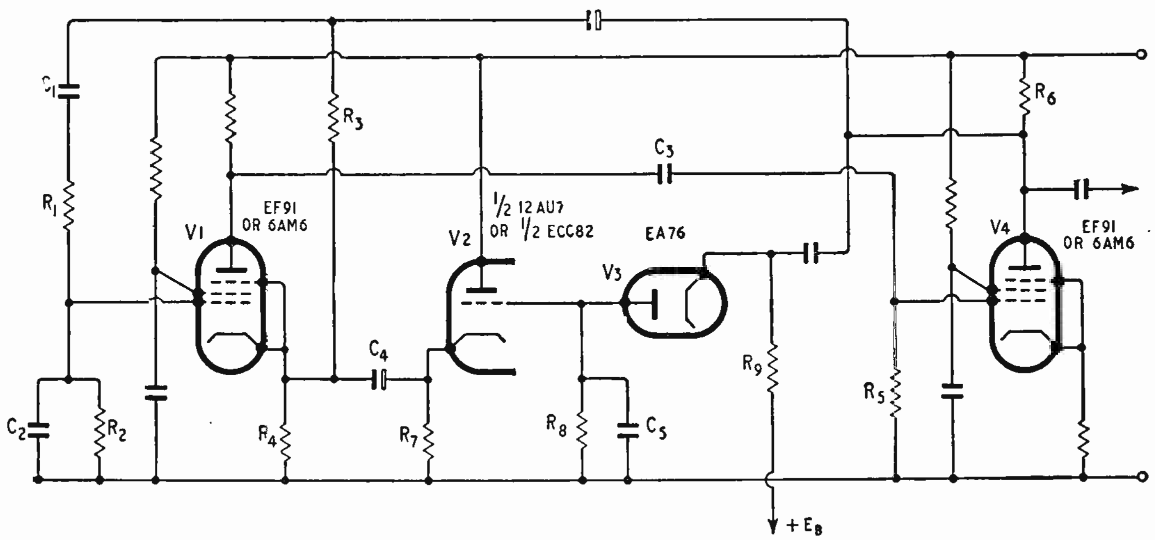

Fig. 6. Possible method of stabilizing the amplitude of a Wien bridge oscillator.

the bridge back into phase with the bridge input, and a frequency error would be obtained.

With very careful design, such methods of stabilizing the output voltage of Wien bridge oscillators by means of amplified a.g.c. can be very effective, but the control circuitry has a tendency to become very complicated if good frequency stability is required.

The most important difficulty involved in the design of a.g.c. controlled oscillators is the choice of optimum filter time constants to give effective smoothing of the control voltage over the working frequency range without introducing the phenomenon of "hunting"—an effect caused by the response time lag of the correcting system allowing the amplitude to grow and then be over-corrected by the controlling voltage.

Various aspects relating to the theory of Wien bridge oscillators have now been discussed with particular reference to the available methods of amplitude stabilization. Using the results of the foregoing discussion a general procedure is now given for the design of a simple thermistor stabilized oscillator.

Design of a Practical Oscillator: Procedure.—Referring to Fig. 7, the first stage in the design is

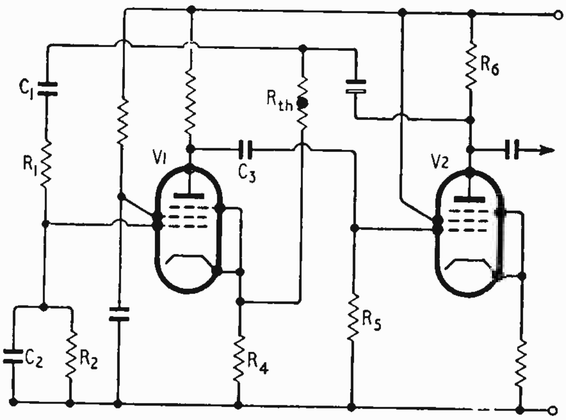

Fig. 7. Theoretical circuit diagram of Wien bridge oscillator used as basis for design procedure.

to work out required values for the frequency determining part of the Wien bridge itself, for the various frequencies involved.

Such values are obtained from equation (3): $f_o = 1/2\pi\sqrt{C_1 C_2 R_1 R_2}$.

Determine from the valve curves the value of cathode resistance R_4 for the first stage that gives satisfactory operation at an anode current of the order of 1 to 2 mA.

The operating value of resistance, R_{th}, of the thermistor must therefore be approximately $2R_4$.

Work out, from the output voltage V_o required, the voltage across the thermistor, V_{th}. This is of course $2V_o/3$. The power dissipated by the thermistor is thus $P_{th} = V^2_{th}/R_{th}$. For satisfactory operation it is desirable that this should be between about 40 and 50 mW. If this is not the case, make small adjustments to the value of the cathode resistor and re-calculate the power developed in the thermistor for the same output voltage and ratio R_{th}/R_4.

From the manufacturer's curves of thermistor resistance plotted against power, select a suitable thermistor that gives the required resistance for the given power dissipation.

Determine the input impedance of the bridge and the current demanded by the bridge. For medium to low frequencies this impedance is sensibly 3 R_4 since $R_4 + R_{th} << $ the impedance of C_1, R_1 and C_2, R_2. The current is given by $V_o/3R_4$ where V_o is the output voltage of the oscillator.

Adjust the operating conditions of V2 so as to make the d.c. component of its anode current at least $1\frac{1}{2}$ to 2 times $V_o/3R_4$. This is done by operating V2 with a low value of anode load R_6.

Calculate the open loop amplifier gain of the two stages (A). Determine the amplifier input voltage by dividing the output voltage by the open loop amplifier gain A. The gain should not be so great that the input for the required output voltage is less than say 1 to 10mV as the amplifier would then be more liable to pickup of extraneous hum, etc.

Calculate the feedback factor $1 + A\beta$. In this case take $\beta = 1/3$. From the largest value of CR in the bridge circuit, i.e., that for the lowest frequency, evaluate the smallest permissible time constant for the inter-stage coupling circuit C_3 R_5 that would produce say no more than 0.1% frequency error. $C_3 R_5 > 10^3 C_1 R_1/(1 + A\beta)$. It is usual to make R_5 of the order of 470kΩ to 1MΩ.

This completes the design. If small adjustments of output voltage are required, they can be obtained by inserting a small potentiometer (about 1kΩ) in series with the thermistor.

Design of a Practical Oscillator: Example.—In the practical example shown in Fig. 8, a frequency of 50 c/s was required, at an output of 22V r.m.s.

The first stage is to work out the bridge component values. Using $C_1 = C_2 = C = 8{,}200$pF, $R = 1/2\pi Cf = 10^{12}/2\pi \times 8{,}200 \times 50 = 388$ kΩ. Since this is a non-standard value, the nearest preferred values of 330kΩ and 56kΩ were used in series.

A cathode resistor R_4 of 2.7kΩ was chosen for the first valve to operate this valve at a quiescent anode current of 1.5mA.

The operating resistance of the thermistor must therefore be $2 \times 2.7 = 5.4$kΩ.

The voltage across this is $2/3 \times 22 = 14.7$V. The power developed in the thermistor is then $14.7^2/5.4 = 40$mW. This was considered to be a satisfactory level of power dissipation.

From the appropriate resistance/power curves, a suitable thermistor was selected. In this case the S.T.C. type A5513/100 gives a resistance of about 5.4kΩ when the power dissipation is about 40mW at an ambient temperature of about 35°C.

The bridge input impedance is approximately $3 \times 2.7 = 8.1$kΩ. The bridge current is thus 22V/8.1kΩ = 2.7mA.

The output stage is therefore operated at about 10mA which is of the order of 3 times as great.

Using a 100kΩ anode load for the first stage and 10kΩ for the anode load of the second stage, the overall gain using an EF86 and EF91 for V_1 and V_2 is obtained from the product of the gains of V_1 and V_2. For the first stage (EF86), taking μ as 1,000, the gain

$$A_1 = \frac{1000 \times 100}{1000 + 100 + 2.7(1001)} = 26$$

For the second stage (EF91) the load impedance is effectively the anode load R_6 shunted by the input

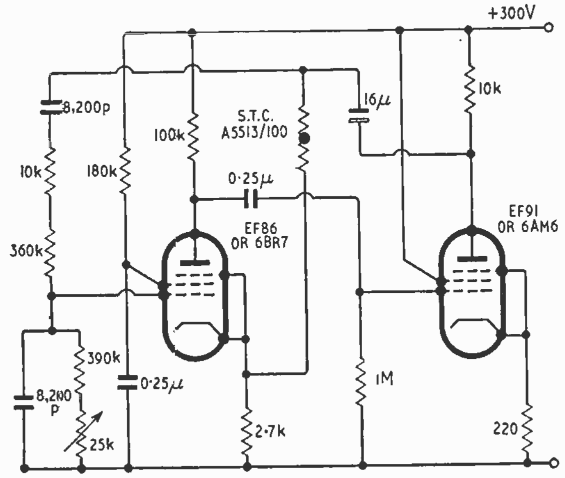

Fig. 8. Practical circuit of a thermister-stabilized Wien bridge oscillator.

impedance of the bridge which in this case is 8.1kΩ. The effective anode load is thus $10 \times 8.1/(10 + 8.1) = 4.5\text{k}\Omega$. The gain of this stage is then

$$A_2 = \frac{7500 \times 4.5}{1000 + 4.5 + 0.22(7501)} = 12.7$$

Therefore the total loop gain (open) $= A_1A_2 = 26 \times 12.7 = 330$. Therefore the input voltage to the bridge $= V_o/A_1A_2 = 22/330 = 67\text{mV}$. This is appreciably above the hum level expected at this point.

For the coupling circuit C_3 R_5 to introduce less than 0.1% frequency change at 50 c/s the following relation must be satisfied:—

$$C_3R_5 > 10^3 . \frac{C_1R_1}{1 - A\beta} = \frac{10^3 \times 386 \times 8200 \times 10^{-9}}{1 + (330 \times 1/3)}$$
$$= 0.03 \text{ sec.}$$

The actual values chosen for the coupling circuit were $C_3 = 0.25\mu\text{F}$; $R_5 = 1\text{M}\Omega$. These give a time constant of 0.25 sec, thus giving an improvement in the reduction of the effect of the coupling circuit time constant upon the generated frequency nearly 10 times better than that stipulated.

A measurement of total harmonic distortion was made on the prototype oscillator using a wave analyser and this was found to be of the order of or less than 0.02%.

The circuit diagram of the practical oscillator to which the design refers appears in Fig. 8. It is seen that in this case the bridge has been made slightly asymmetrical in that R_1 and R_2 are not quite equal. This was to facilitate small changes in the operating frequency so that a number of oscillator units could be set up against a sub-standard frequency during production testing.

Although no new methods have been employed in the design of the practical Wien bridge oscillator it is felt that a satisfactory design procedure has been established and experiments have confirmed that the use of this procedure is satisfactory.

Acknowledgement.—The author wishes to thank Mr. L. V. Mayhead, Assoc. Brit. I.R.E., who gave much valuable assistance and advice during the experimental work carried out in connection with the subject of this paper.

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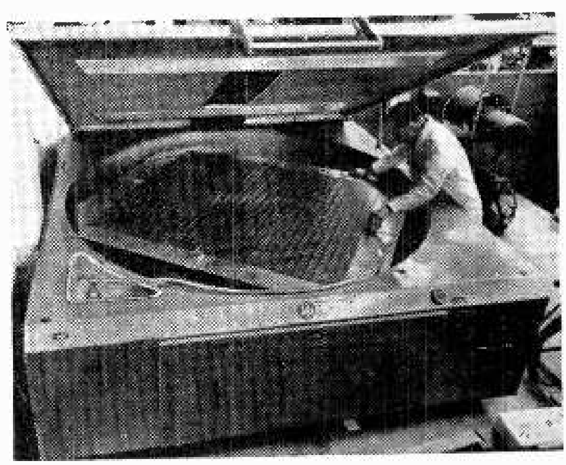
25 sq ft of Printed Circuit

HOW large is it possible to make a printed circuit? Theoretically perhaps there is no limit, but it might be of interest to learn that Printed Circuits Ltd. (a company within A.E.I. group) is producing what are said to be the largest printed circuits so far made, at least in this country.

The photograph shows part of the latest automatic equipment employed in their Borehamwood factory and in this instance 1,100 separate circuits are being processed on a single board measuring 5ft × 5ft.

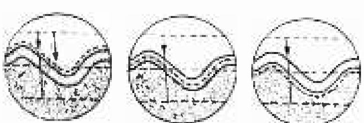
This new process should open up new fields of application for printed circuits and it also considerably accelerates the rate of production of smaller units.



Right: Automatic equipment processing 25 sq ft of printed circuits (Printed Circuits Ltd.).

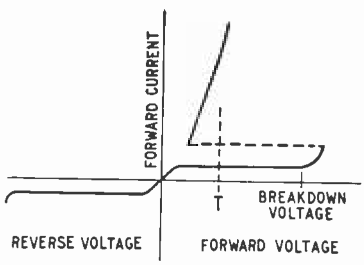
Technical Notebook

Automatic Dimensional Check of mass-produced parts in factories is given by an electronic device based on a counting system described in the Russian journal *Priborostroienie*, No. 7, 1959. The parts to be checked are placed between the c.r.t. and a photocell, which feeds an electronic counter via a waveform shaping circuit. A coarse raster is traced out on the c.r.t. screen with a horizontal deflection frequency of 1c/s and a vertical deflection frequency of 50c/s. Two thin curved lines are drawn on a transparent material fixed to the screen, one of them representing the upper limit of the contour of the parts to be checked and the other representing the lower limit. Normally, with no parts interposed between the tube and photocell, the light to the cell is interrupted twice by the two drawn lines for each vertical deflection of the scanning spot. As a result two impulses from the photocell are, after shaping, counted by the electronic counter. When a part is being checked, if its contour falls between the two lines, as shown in the centre diagram, the scanning light spot is interrupted twice, as before, and the count of 2 registered by the counter is used as a signal for an automatic control system to accept the part. If the part is too big, as shown in the left-hand diagram, there is only one light-spot interruption and one impulse counted, and this is used to reject the part. If the part is too small, as shown on the right, three impulses are counted,



and again this is used to reject the part. The contour lines on the screen of the c.r.t. are somewhat larger than the actual parts being checked, and an optical focusing system, between the screen and the parts, reduces the image of the lines to the required dimensions.

Silicon Controlled Rectifier, a switching device which can be considered as a semiconductor equivalent of the thyratron (see July/August, 1959, issue, p. 348), is now being manufactured in Great Britain. It is a p-n-p-n structure with three terminals, and can be regarded as two transistors coupled by a common collector junction. It



offers a high impedance (several megohms) in each direction between two of the terminals, but can be triggered into a low-impedance condition in one direction by application of a small signal to the third (control electrode) terminal. The volt-amp characteristic is shown in the diagram. In the reverse direction it is almost identical with that of a simple silicon rectifier. The forward direction is a mirror image of the reverse characteristic up to the breakdown voltage. If a small current (10-100mA) is applied to the control electrode when the forward voltage is below breakdown (e.g., at T in the diagram), the rectifier will remain conducting until the voltage across it falls to almost zero. A common technique used for controlling the output of the rectifier is to change the phase of the trigger current in relation to the a.c. voltage applied to the device. In a range of silicon controlled rectifiers introduced by A.E.I. Electronic Apparatus Division, loads up to 10A at peak inverse voltages between 25V and 300V can be handled. A typical triggering current is 50mA at 2 volts.

Television Frame Interlace Errors due to the difference in the integrated sync pulse waveform on odd and even frames can be reduced by adding a line-timebase waveform component to the integrated sync pulses; also a substantial improvement in regularity of synchronisation in the presence of noise can be achieved, according to a paper by H. W. Proudfoot in *I.R.E. Transactions on Broadcast and Television Receivers* for May, 1959. The practice of adding a differentiated and inverted sync component to the integrated waveform is well-known; however, in the presence of noise, this can result in frame timebase stability worse than that achieved by the simple integrator. Proudfoot's scheme employs a train of twice line frequency "spikes" which are derived from the line timebase by a ringing coil, amplifier, clipper and differentiator. These pulses perform the same function as does the differentiated and inverted sync waveform. The frame oscillator is "primed," so to speak, by the rise in the integrated waveform due to the frame-sync pulse train, then the flyback is actually initiated by one of the spikes. Provided that a reasonable balance between spike and integrated-pulse amplitude is struck, and the spikes have sufficiently sharp leading edges, correct interlace is achieved. In addition, as the locally-generated spikes are free of noise, the performance under noisy-signal conditions is improved—an increase of 15dB, compared with the simpler integrator, in noise rejection was achieved in tests on a typical American monitor unit operating on the 525-line, 60-frame negative modulation system. The circuit given uses a double triode and two semiconductor diodes; but the author suggests that it could be simplified considerably by deriving the spike waveform at high level (i.e. line output stage rather than line-oscillator).

170° Television Tube, with a flat 17-inch screen and a depth of only 5 inches, is reported by *Electronic News* for October 13th, 1959, as a development from Multi-Tron Laboratory in the U.S.A. It is said to weigh only six pounds and to require very low scanning power, thus being suitable for transistorized portable receivers. The extremely wide deflection angle is achieved by what is called "electron optical projection." Another similar tube, with a 160° deflection angle and a length of 6½ inches, has been developed by the firm. This, according to the report, requires a scanning power of only 3½-4 watts, and, since the tube can be used with standard 110° deflector coils, there is thought to be a possibility of incorporating it into existing receiver designs. The 170° tube, on the other hand, apparently needs an entirely new design of deflector coil assembly.

Standard Solar Cells have been introduced by the International Rectifier Co. (Great Britain) for checking the efficiencies of production silicon solar cells. They are intended for calibrating artificial light sources in terms of solar radiation. Accompanying curves show conversion efficiences at different radiation intensities.

Elements of Electronic Circuits

8.—TWO-STATE CIRCUITS

By J. M. PETERS, B.Sc. (Eng.), A.M.I.E.E., A.M.Brit.I.R.E.

CIRCUITS producing abrupt transitions between two electrical states (usually high voltage and low voltage) take many different forms and have many different applications in the field of electronic switching, pulse generation and digital computing. The circuits may be free-running in operation, providing a source of square (or near square) waves, or may have to be triggered from one state to the other by an external voltage, giving an action rather analogous to that of an electromechanical relay. They may have two stable states, or one stable and one unstable state. Some types of circuits use one valve and others use two.

Probably the best-known two-state circuit is the multivibrator. This month it will be considered simply as a waveform generator; next month as a triggered circuit. The multivibrator consists basically of a two-stage RC coupled amplifier which has its output coupled back to its input. Voltage changes within the amplifier, due primarily to the charging or discharging of capacitors, cause the amplifier to change suddenly from a stable state to an unstable state, at regular intervals. Because of this the term "flip-flop" is sometimes applied to this class of circuit. The name "multivibrator" derives from the waveforms produced at the anodes of the two valves, which are approximately rectangular and hence rich in harmonics.

Fig. 1 illustrates the fundamental circuit which,

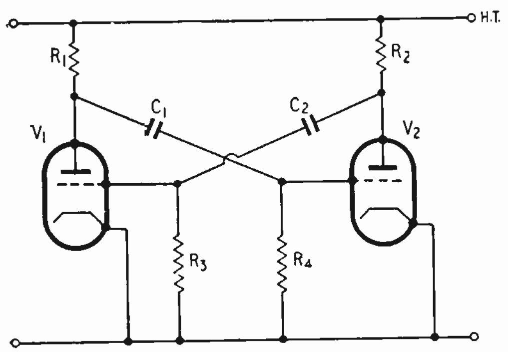


Fig. 1

for simplicity, is shown as consisting of two RC coupled triodes. Advantages can, however, be gained by using pentodes in that (a) cleaner anode waveform pulses can be obtained, and (b) as anode circuits are "electron-coupled" to the remainder of the valve (screen and control grids are shielded from the anode by the suppressor grid) any variation in load does not significantly affect the frequency of oscillation of the circuit.

Now let us consider the action in detail. When the circuit is switched on, both valves conduct and oscillations commence, as shown in the waveform diagram Fig. 2. The sequence of operation is as follows: At stage A the grid voltage of V_1 is assumed

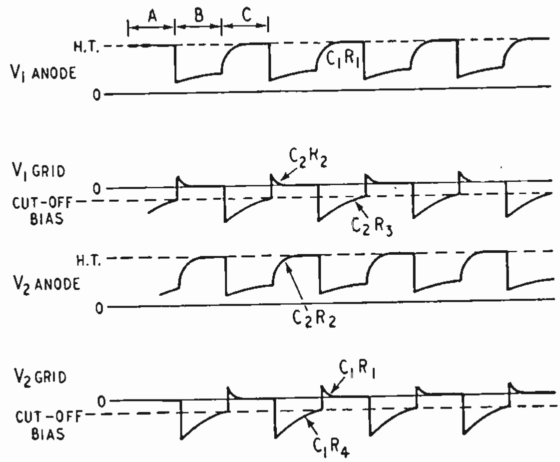


Fig. 2

to be rising towards zero volts. As the grid of V_1 rises through cut-off, V_1 starts to conduct, causing the anode voltage of the valve to drop. This drop in voltage is applied to V_2 grid via the coupling capacitor C_1 and results in a rise in voltage at V_2 anode. The rise is passed back to the grid of V_1 via the coupling capacitor C_2, so causing a further increase in current in V_1. A cumulative action develops, causing V_1 grid to rise to a positive value and V_2 grid to drop to a large negative value (well beyond the V_2 cut-off point).

Note: V_1 grid does not rise as much as V_2 grid falls, because the flow of grid current in V_1 makes the grid/cathode resistance small and hence the voltage developed across R_3 is limited.

The "amplification" stage is now over and the circuit is said to "relax" during stage B (hence the term "relaxation oscillator"). During this lull C_2 *charges* via R_2 and the low-resistance grid/cathode path of V_1, causing V_1 grid voltage to drop to zero with time constant C_2R_2 and V_2 anode voltage to rise to h.t. with the same time constant. Also during stage B, C_1 *discharges* through R_4 and V_2 grid voltage rises to zero through cut-off with time constant C_1R_4. As soon as V_2 starts to conduct the sudden amplifying action takes place all over again and the circuit "flops" into the unstable state once more. Amplification ceases when V_1 is cut-off.

Stage C sees a further quiet or "relaxed" period, during which C_1 *charges* via R_1 and the low resistance grid/cathode path of V_2, causing V_2 grid voltage to drop to zero with time constant C_1R_1 and V_1 anode voltage to rise to h.t. with the same time constant. Also during stage C, C_2 *discharges* through R_3 and V_1 grid voltage rises to zero through cut-off with time constant C_2R_3. When V_1 re-conducts, sudden amplification again takes place and the circuit "flips" into the unstable state once more and the cycle repeats itself.

In order that the rise in anode voltages to h.t should be rapid, i.e., that the time constants C_1R_1 and C_2R_2 should be short, it is usual to make the anode load resistors R_1 and R_2 fairly low values. Very often, to make the start of each negative-going anode voltage pulse more clearly defined, the grid voltages are caused to rise more sharply through cut-off. This is done by connecting R_3 and R_4 to h.t. instead of to earth, as shown in Fig. 3.

The frequency at which the free-running multivibrator will oscillate is largely dependent on the time constants C_1R_4 and C_2R_3, as well as on the minimum values of grid voltage together with the values of cut-off bias for the chosen valves. For high-frequency circuits account has to be taken of inter-electrode and stray capacitance effects when deriving the formula for frequency of oscillation.

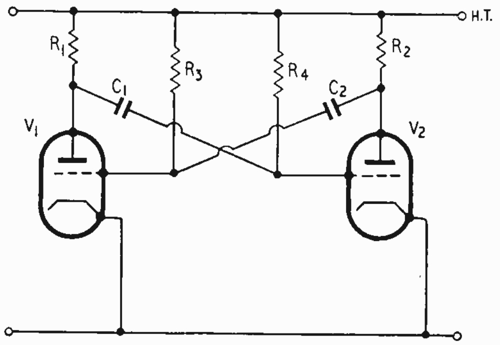


Fig. 3

It can be shown that the period of oscillation is expressed approximately by the following formula:

$$T_{seconds} \approx C_1R_4 \log_e K_1 + C_2R_3 \log_e K_2$$

where K_1 is the ratio of minimum grid voltage to cut-off voltage for V_1, and K_2 is the ratio of minimum

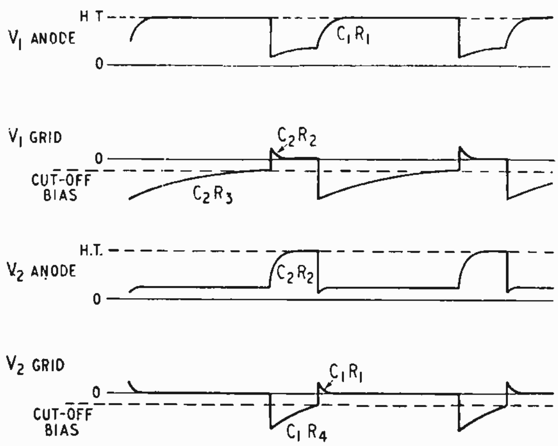


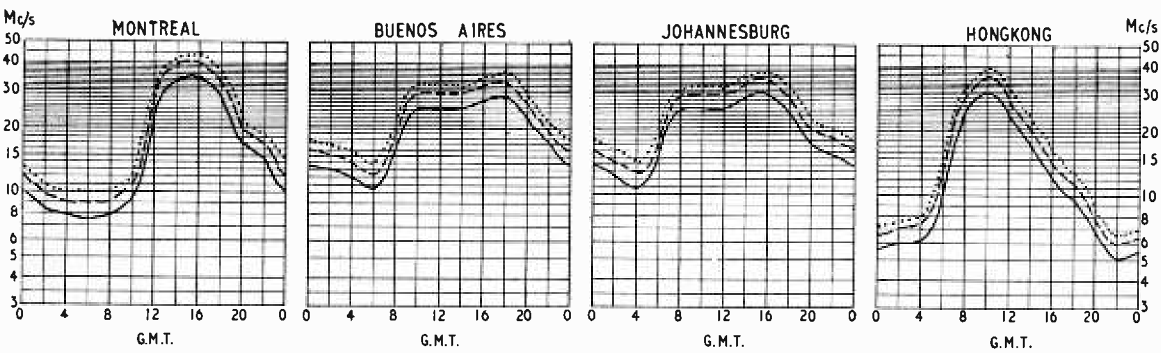
Fig. 4

grid voltage to cut-off voltage for V_2. It should be noted that this relationship will only apply at low frequencies of oscillation where stray and inter-electrode capacitances have negligible effect.

An important point about the circuit action described above is that the duration of the positive and negative going portions of each anode voltage waveform is equal. For this reason the circuit is known as a "symmetrical" multivibrator. It is possible, however, to make the two portions of unequal duration if the time constants C_1R_4 and C_2R_3 are made unequal. This is illustrated in Fig. 4 where, by making $R_3 = 3R_4$, the positive V_1 anode pulse is lengthened to approximately three times the duration of the V_2 anode pulse. Under these conditions the circuit is known as an "asymmetrical" multivibrator. By making R_3 or R_4 variable, pulses of varying width can be produced, i.e., a variable mark-to-space ratio can be obtained.

SHORT-WAVE CONDITIONS

Prediction for December



THE full-line curves indicate the highest frequencies likely to be usable at any time of the day or night for reliable communications over four long-distance paths from this country during December.

Broken-line curves give the highest frequencies that will sustain a partial service throughout the same period.

•••••••••• FREQUENCY BELOW WHICH COMMUNICATION SHOULD BE POSSIBLE FOR 25% OF THE TOTAL TIME

— — — PREDICTED MEDIAN STANDARD MAXIMUM USABLE FREQUENCY

——— FREQUENCY BELOW WHICH COMMUNICATION SHOULD BE POSSIBLE ON ALL UNDISTURBED DAYS

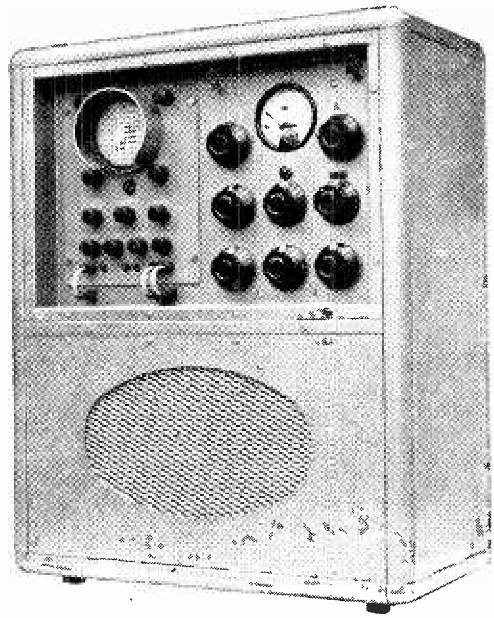
V.H.F./F.M. Multipath-Propagation Test-Set

SIMPLE APPARATUS GIVING VISUAL DISPLAY

IN a practical radio-communication system the signal at the receiving site will generally consist of a direct signal from the transmitter and one or more delayed signals which have been reflected from near or distant objects. In the case of a frequency-modulated transmission this multipath propagation causes unwanted phase and amplitude modulation of the carrier, giving rise to perceptible distortion of the reproduced programme if the time delays and relative amplitudes of the reflected signals are sufficiently large. The audible effect produced varies from a noise similar to that of an overloaded a.f. amplifier (when the difference in length of path travelled is small) to a hiss like co-channel interference (large path-length difference). At intermediate path-length differences the distortion closely resembles the effect of something loose in the loudspeaker.

The mathematical analysis of the way in which the delayed signals cause distortion has been recorded.* To ensure satisfactory results from an f.m. receiver, it is clearly essential to reduce to a minimum the distortion caused by multipath propagation. A receiver with good amplitude limiting can remove the a.m. component of this distortion and thus effect a considerable improvement. However the phase-modulation component can only be reduced by careful siting of the aerial to discriminate against the more harmful of the reflected signals. In the case of a receiver with inadequate limiting, where the unwanted amplitude modulation makes an additional contribution to the audible distortion, attention to the aerial is even more important. This is easier said than done because the nuisance value of multipath distortion varies widely with programme material. Distortion which is hardly detectable by listening to, say, speech may be completely intolerable on piano music. What is needed, then, is a relatively simple equipment for obtaining a clear visual display of the characteristics of the received signal to aid the correct installation of aerials: this test-set should also be accurate and consistent enough to allow measurement to be made of the severity of interference at the installation site.

An apparatus complying with these requirements has been developed at the B.B.C. Research Department, Kingswood Warren; it consists of a tuner unit, oscilloscope, a.f. amplifier, loudspeaker and power supply.



Appearance of multipath-propagation test-set developed by the B.B.C. Loudspeaker and a.f. amplifier are fitted to enable use as high-grade demonstration receiver.

Deriving the Display.—As the transmitter frequency deviates, due to modulation, the number of wavelengths travelled by the reflected signal relative to the number of wavelengths travelled by the direct signal also varies. This changes the phase of the reflected signal relative to that of the direct signal, resulting in a variation of instantaneous amplitude (amplitude modulation) of the received signal. Also the number of phase reversals which occur for a given deviation of the transmitter frequency depend on the excess path length travelled by the reflected signal.

Thus the amplitude-modulated component of the f.m. carrier can be used to derive a display indicating the presence of multipath distortion. A simple measurement of the amount of amplitude modulation present is not alone sufficient, because the extra distance travelled by the delayed signal also has an effect on its "nuisance value." For instance, it has been found by listening tests that the amount of audible distortion caused by the presence of a reflected signal of 35 per cent of the main signal in amplitude and excess path length 8km; is the same as that caused by a signal of only 6 per cent of the main signal, but which has travelled over a path 29km longer than that followed by the main signal. Some means, therefore, is required for the evaluation of excess path length travelled by the reflected signal. The test-set is therefore arranged to give a kind of "wobbulator" display with the amplitude of the incoming signal plotted against its frequency deviation. Fluctuations due to phase changes of the reflected signal are thus displayed in such a way that both the depth of amplitude modulation of the signal and the number of reversals of phase for a given change in frequency can be seen.

A block schematic diagram (Fig. 1) shows the way in which the equipment is arranged. The X-deflection voltage for the oscilloscope is obtained from the discriminator output of the tuner, and the Y-deflection voltage from the control-grid potential of the

* See, for instance: "F.M. Multipath Distortion," by M. G. Scroggie, B.Sc., M.I.E.E., *Wireless World*, Dec., 1956, p. 578.

saturated-pentode limiter valve. Both of these circuits are direct-coupled so that l.f. phase distortion is avoided.

Interpretation of the Display.—The vertical deflection from the zero base line of the oscilloscope display represents the instantaneous signal level. The horizontal deflection of the spot indicates the instantaneous frequency of the carrier wave. In the absence of delayed signals the instantaneous amplitude remains constant as the carrier frequency varies and the oscilloscope trace is a horizontal straight line whose length is proportional to the peak deviation. If a reflected signal is received in addition to the direct signal, the phase difference between them, and hence the amplitude of their resultant, varies with the instantaneous frequency, and a trace of the type shown in Fig. 2 is obtained. This is a photograph of the oscilloscope display with an input including one delayed signal of amplitude 20 per cent of that of the direct signal, with a path difference of 8km; the carrier deviation is ±75kc/s at a modulation frequency of 120c/s. The ratio of the amplitudes of the two signals is a/b and the path difference in km

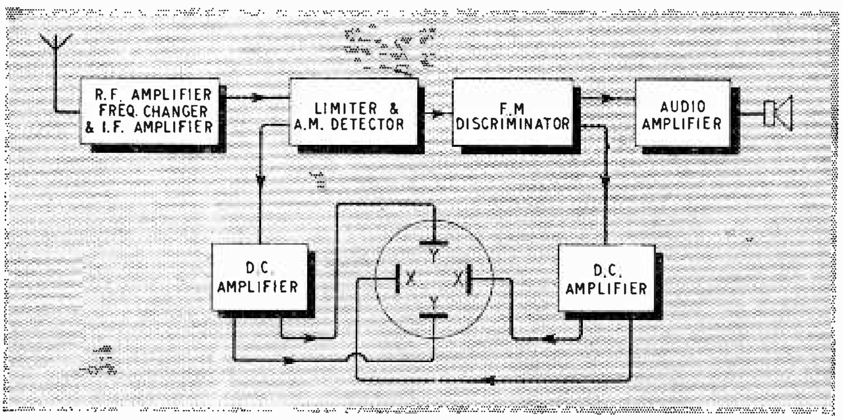


Fig. 1. Block-schematic diagram of equipment for test-set as arranged by B.B.C.

turns out to be equal to 2N, where N is the number of complete cycles of amplitude variation in the total bandwidth of ±75kc/s. In general, several reflected signals are received simultaneously and the shape of the trace is more complicated. Fig. 3, for example, shows the trace resulting from a complex signal containing three delayed signals with path differences of 8km, 16km and 24km. Signals containing even more components and producing more complicated displays may be encountered at sites which are unfavourably situated for v.h.f. reception.

A source of difficulty in interpreting the display is doubling of the trace due to phase shift of the amplitude modulation. The display shown in Fig. 2 represents a low modulation frequency and a comparatively small path difference so that the forward and return traces are almost exactly superimposed. If either the modulation frequency or the path difference is increased, the reflected signal delay becomes a significant fraction of the frequency modulation period, resulting in appreciable de-phasing of the amplitude modulation and a doubling of the trace in the oscilloscope display. An additional cause of differential displacement of the forward and return traces is the inevitable, but small, distortion of the discriminator output which arises from the unwanted phase modulation of the signal due to reflection.

Both of these effects are inherent in multipath propagation and contribute more to the blurring of the display when receiving programme than do small deficiencies in the phase characteristics of the equipment. Despite these limitations it has been found in practice that the display can be interpreted with reasonable accuracy on programme material.

An example of the type of display obtained with programme modulation is shown in Fig. 4 (a). In this case the programme was a news reading and the signal contained five delayed components with the following path differences and relative amplitudes:—1,000 ft, 25%; 2 miles, 10%; 5 miles, 10%; 10 miles, 5% and 15 miles, 5%. Fig. 4 (b) shows the display given by the same complex signal but with the transmission modulated ±75kc/s with 120c/s tone. The complex signals represented in Figs. 2, 3 and 4 were produced with a laboratory multipath simulator which generates the reflected signals artificially using a magnetostriction delay line. One type of reflection which operation on programme may conceal or make difficult to measure is that from a near object. This type of reflection gives rise to a more gradual change of amplitude with a variation of frequency than does a long path-difference reflection, so that only a fraction of a cycle appears on the display, resulting in either a broad maximum or minimum or a tilt of the trace. Fortunately, although this type of reflection may be quite large in amplitude when compared with longer distance signals, it is of little importance from the distortion viewpoint.

When using this apparatus to determine the best position for a receiving aerial the signal from each of the local transmitters should be examined to ensure that good performance on one programme is not obtained at the expense of another.

To aid in the estimation of acceptable levels of multipath propagation a table has been compiled, showing the result of a listening test made by the B.B.C. A high-grade loudspeaker and a receiver having good a.m. suppression (50dB) were used; the programme material—a piano recital—was of a type which is particularly susceptible to the form of distortion produced by multipath propagation. Whilst the reduction of secondary-signal relative amplitude to below the figures shown should result

TABLE

Path difference (miles)	2	5	10	15
(km)	3.2	8	16	24
Amplitude relative to main signal	57%	22%	6%	4%

Relative amplitude of a single secondary signal in multipath propagation giving "perceptible" distortion on a good receiver using critical programme material.

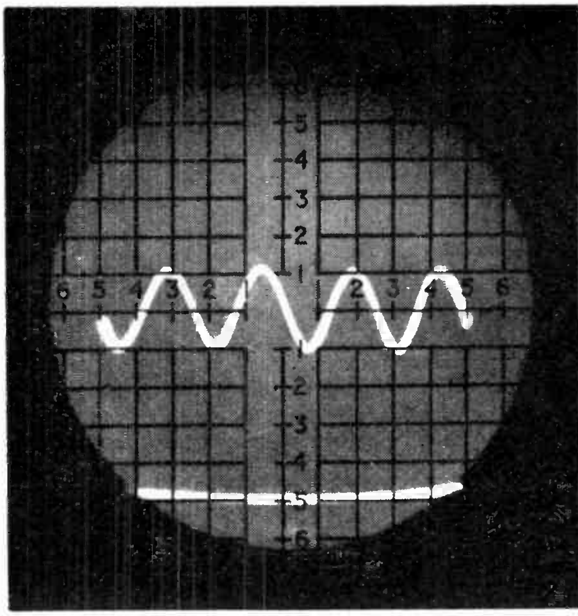


Fig. 2. Photograph of display showing one delayed signal of excess path length 8km, amplitude 20% of direct signal. The base line is recorded by a second exposure.

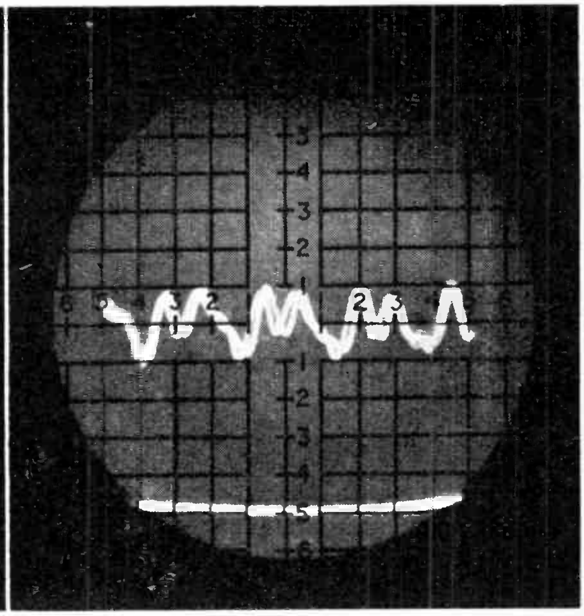


Fig. 3. Display given by complex signal with three delayed signals of path-length differences: 8km, 16km and 24km. Amplitude of each delayed signal is 10% of direct signal.

in satisfactory service when using a "good" receiver, these values may have to be halved if a receiver with poor a.m. suppression is used. For speech, on a good receiver, an interfering signal of amplitude twice—or even three to four times in the case of the larger path differences—that of the direct signal may be present before distortion is heard.

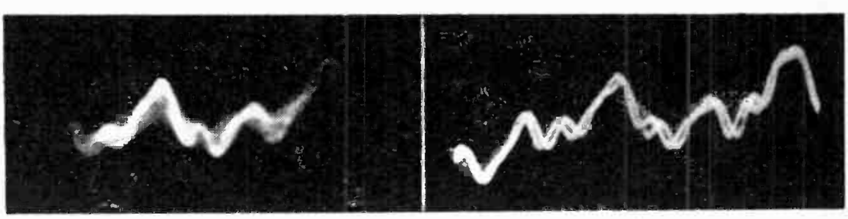
Circuit Details

A display of the type required can be produced quite simply with a f.m.-tuner unit which employs a saturated grid limiter and a balanced discriminator together with a small direct-coupled oscilloscope. Some slight modification to the tuner is required to extract the voltages (including the d.c. component) developed at the limiter grid and the discriminator output. However, for accuracy and ease of use, some refinements are desirable and some of those fitted to the B.B.C. apparatus are shown in the "skeleton" circuit of the i.f.-amplifier limiter and discriminator sections of the tuner (Fig. 5.)

The a.m. output to the oscilloscope Y-amplifier is taken from the limiter control grid (V3) through a 100-kΩ "filter" resistor: section (c) of S1 earths this line in the "set-zero" position so that the oscilloscope spot may be set at the bottom of the graticule. Another section (b) of S1 earths the X-input terminal for horizontal centring of the spot, in the "set-zero" position and connects this terminal to a preset potentiometer across the 6.3-V heater supply when set to "calibrate." This potentiometer is set up either with the aid of a signal generator giving an f.m. output of standard deviation, or by comparison with 440c/s continuous tone (deviation $\pm$18kc/s) radiated by the Network Three transmitters before programme transmission starts, to give an output equal to that given by the discriminator when demodulating a $\pm$75kc/s-deviated signal. Thus the X-gain control can be set in the absence of a signal generator. S1(a) earths this calibrating voltage to avoid hum being induced into other circuits in the "use" or "zero" positions. So that this calibration is reliable the tuner must have good static limiting, i.e., the discriminator output must not vary with changes of signal strength.

For the a.m. output from the limiter to be usable amplitude limiting must not occur in the tuner prior to the limiter control grid, i.e., the receiver must accept all input signal strengths which it is likely to encounter and amplify them in a linear manner. If limiting does occur the vertical deflection of the oscilloscope will be distorted, and, to avoid this an a.g.c. circuit is fitted, fed from the limiter grid: the limiter grid current also operates a signal-strength meter. Without the provision of gain-stabilising measures in the tuner this meter can be expected to have a short-term accuracy of about $\pm$6dB. Whilst the a.g.c. circuit is most helpful in obtaining

Fig. 4. Display of complex signal containing the following delayed signals:—1,000ft, 25% relative amplitude referred to main signal; 2 miles, 10%; 5 miles, 10%; 10 miles, 5% and 15 miles, 5%. (a) Programme (news reading). (b) Tone ($\pm$75kc/s at 120c/s).



(a) (b)

a linear display and in reducing the amount of "knob-twiddling" necessary during the setting up of an aerial, it can, under some conditions of propagation, cause the display to jitter in sympathy with the programme modulation. To avoid this a switch (S2) is provided by which the a.g.c. potential may be replaced by manual gain-control bias which is obtained from the 6.3-V heater supply, via a point-contact diode. When operating on manual gain control it is essential that the i.f.-gain-control potentiometer is not set at too high a level, as this may result in overloading of the i.f. amplifier. This can be avoided by first setting-up the receiver on a.g.c., then switching to manual control and adjusting the i.f.-gain control to give the same vertical deflection of the oscilloscope trace. To avoid detuning effects in the first i.f. amplifier when its bias is varied, a 41-Ω unbypassed cathode resistor is used to provide negative voltage feedback.

No firm figure can be set for the maximum gain required prior to the limiter grid, but the gain should be sufficient to ensure that the signal does not drop below about 1V (pk) at this point; because, below this level, detection is markedly non-linear.

Three more requirements for the tuner are a flat i.f. response over the ±75kc/s swept by the f.m. carrier, a highly stable local oscillator and good a.m. rejection. As the vertical deflection of the trace is dependent on the gain of the tuner, any humps in the i.f. response will be displayed on the oscilloscope—±½dB variations are not a nuisance.

Good local-oscillator stability is desirable because it avoids continuous retuning when the receiver is first switched on.

A.F.C. was fitted to the tuner used in the equipment; but it was found to be necessary to increase its time constant to a value of the order of 1 sec. to avoid phase distortion of the display. This makes tuning tedious as a result of the rather sluggish action of the a.f.c. in tending to compensate for tuning adjustments. A switch (S3) has, therefore, been added so that the a.f.c. can be disconnected when tuning. No tuning indicator is needed as the correct horizontal centring of the display indicates the correct tuning point.

The output from the discriminator must not contain a.m. products of sufficient amplitude to be seen in the display. Thus good a.m. rejection is required in the limiter, and this must remain good down to the lowest signal input at which the test-set is required to work. With the component values shown in the circuit diagram and an adequate amount of pre-limiter gain an a.m. rejection factor of 35dB was achieved for a signal input of 30μV, rising to 40dB over the range 100μV to 10mV. It should go without saying that the discriminator must be linear and equally balanced about earth.

One other limitation imposed upon the equipment is by the bandwidth of the Y-amplifier. The amplitude modulation resulting from multipath propagation contains components which are high harmonics of the original modulation frequency. If the bandwidth of the Y-deflection channel is restricted, these components can be severely attenuated when the fundamental modulating frequency is high, particularly if the path difference of the principal delay signals are also large; and this will reduce the apparent depth of amplitude modulation. In the original apparatus, the gain of the Y channel was 3dB down at 13kc/s.

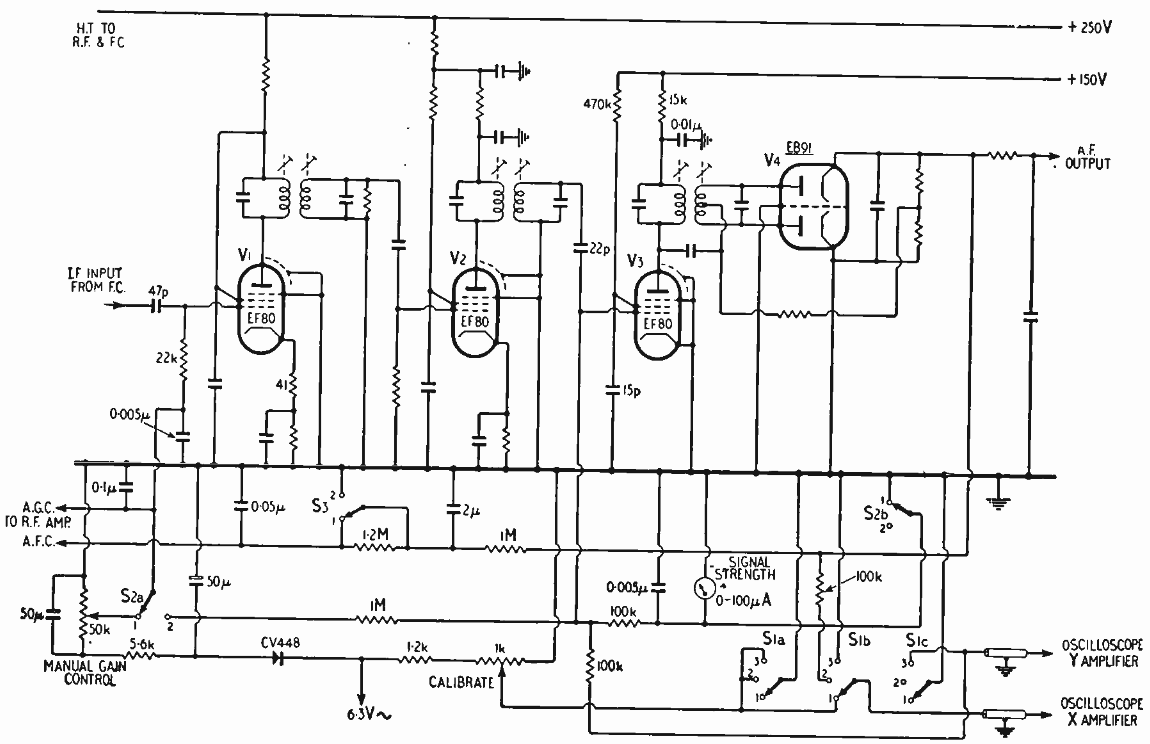


Fig. 5. Skeleton circuit diagram of modifications by B.B.C. to tuner to feed display-tube direct-coupled amplifiers. Switch functions and positions:—S1: position 1, "calibrate"; 2, "operate"; 3, "set zero"; S2: 1, "manual gain control"; 2, "a.g.c." S3: 1, "a.f.c. on"; 2, "a.f.c. off."

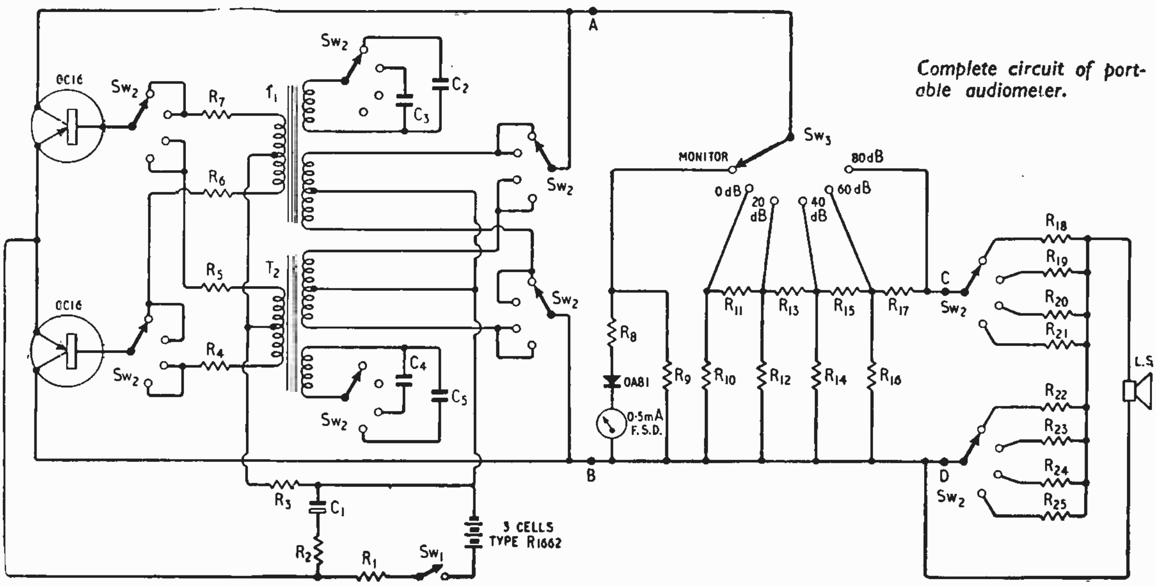
Transistorized Audiometer

Simple Portable Unit for Testing Children's Hearing

By H. J. F. CRABBE and P. DENES, M.Sc., A.M.I.E.E.

WHEN testing the hearing of small children, it is often useful to have an audiometer which is small enough to be carried around the room easily and which does not intimidate the child by its appearance. It must produce a high enough sound intensity at the subject's ear even when held several feet away, because putting the instrument too close to the child would distract it. In addition, it should be possible to operate the controls unobtrusively and to carry the instrument easily in one hand. Since such an instrument would not be used for detailed testing it is sufficient to have only a small number of output intensities and frequencies available. This article describes the construction of an audiometer which fulfils these mechanical requirements and produces sounds at four frequencies—500 c/s, 1 k/cs, 2 kc/s and 4 kc/s—and five intensities—0, 20, 40, 60, 80 dB above normal threshold.

Basic Description.—In essentials, the instrument comprises an oscillator, attenuator and loudspeaker, all mounted in one small box. Assuming the use of transistors in the generating circuit, the lower limits of size and weight are determined by the loudspeaker with its mounting, and the battery for the power supply. The capacity of the battery is in turn dependent on the consumption of the circuit and on the permissible frequency of battery replacement. It was decided to use a 3½-in speaker of standard design, and the unit chosen had the best efficiency and smoothest frequency response compatible with a moderate size of magnet. Using a totally enclosed box, it was found that only 1/10 W was required to produce the 80 dB level at 1000 c/s, and less than this at higher frequencies. At 500 c/s, the efficiency can be maintained by using the restricted air volume behind the cone to raise the resonant frequency of the speaker to approximately 400 c/s. The unit used in the prototype had a free air resonance of



Complete circuit of portable audiometer.

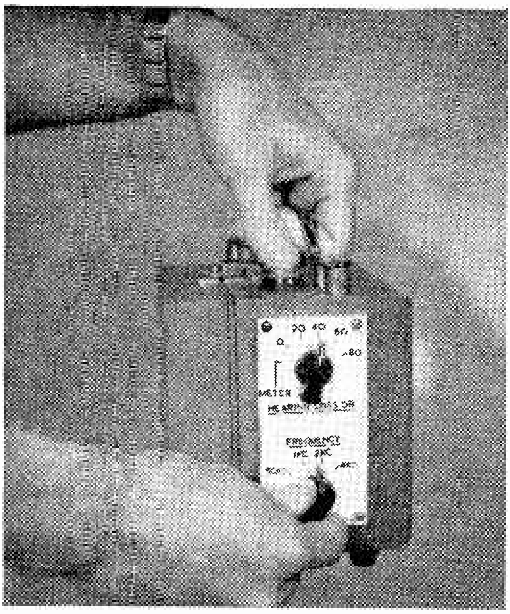
TABLE OF COMPONENTS

	R_1	10Ω	1W
	R_2	10Ω	¼W
	R_3	330Ω	¼W
See text	R_4	132Ω	¼W
See text	R_5	132Ω	¼W
See text	R_6	170Ω	¼W
See text	R_7	170Ω	¼W
See text	R_8	1.3kΩ	¼W
	R_9	20Ω	½W
	R_{10}	22Ω	½W
	R_{11}	200Ω	¼W
	R_{12}	24Ω	½W
	R_{13}	200Ω	¼W
	R_{14}	24Ω	½W
	R_{15}	200Ω	¼W
	R_{16}	24Ω	½W
	R_{17}	200Ω	¼W
See text	R_{18}	5Ω	¼W
See text	R_{19}	10Ω	¼W
See text	R_{20}	15Ω	¼W
See text	R_{21}	15Ω	¼W
See text	R_{22}	∞	
See text	R_{23}	51Ω	¼W
See text	R_{24}	10Ω	¼W
See text	R_{25}	10Ω	¼W
	C_1	500μF, 6V wkg	
See text	C_2	0.188μF	
See text	C_3	0.044μF	
See text	C_4	0.156μF	
See text	C_5	0.037μF	
	L.S.	Elac 3D/10	

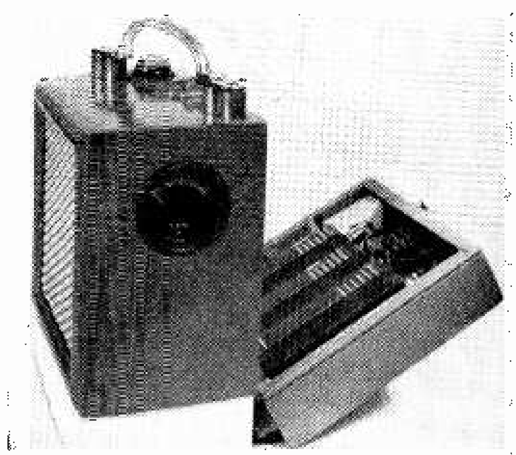
T_1 and T_2 are wound on Ferroxcube LA7 pot core assemblies.

T_1 Tuned winding: 900 turns of 40 s.w.g. enamelled (0.55H).
Both c.t. windings: 44 turns of 28 s.w.g. enamelled.

T_2 Tuned winding: 250 turns of 34 s.w.g. enamelled (0.04H).
Both c.t. windings: 16 turns of 24 s.w.g. enamelled.



Two views of the completed audiometer.



230 c/s, and the air volume in the box after the insertion of components was 26 cu in, which brought the peak up to 390 c/s. Allowing for losses in an attenuator and in the components which correct for variations of loudspeaker impedance with frequency, a maximum power of ¼ W is needed from the transistor circuit.

Oscillator.—This moderate requirement of ¼ W can be met with ease by the simplest of tuned-transformer oscillators, using a push-pull arrangement for a good waveform. The circuit is shown in the diagram, where it will be seen that a pair of OC 16s are used. These are power transistors capable of delivering several watts, but they are employed here to achieve complete reliability and safety, for with continuous oscillation their maximum dissipation is never reached, even at high ambient temperatures. In addition, no heat sink is required, which is a great asset with the rather tight packing of components in the finished unit.

The output of the oscillator appears between the transistor collectors and is fed into the attenuator at points A and B in the circuit. This voltage is also coupled back to the transistor bases by means of the centre-tapped transformer windings, and resistors R_{4-7} are chosen to produce the maximum output consistent with a pure waveform. The frequency of oscillation is determined by the tuned winding on each transformer, and condensers C_{2-5} are adjusted to give 500 c/s, 1 kc/s, 2 kc/s and 4 kc/s respectively. It is not possible to cover the whole range with one transformer, because an inductance which provides a sufficiently high dynamic impedance to avoid shunting the resistive load at low frequencies will be too heavily damped to prevent distortion at high frequencies, and vice versa. The base circuits are returned to the negative line via R_3, and this, in conjunction with the common emitter resistor R_1, provides a high degree of d.c. stability. R_2 and C_1 prevent very rapid changes of the supply voltage as the on/off switch is operated; this ensures a smooth rise and fall for the oscillatory envelope, thus preventing audible " clicks " in the output. This is in conformity with the British Standards Institute specification for audiometers.*

Attenuator and Loudspeaker Circuit.—The attenuator is of the simple ladder variety, with four 20 dB steps, and offers a load of 20 Ω to the oscillator. At this low impedance stray capacity is of no consequence and the whole assembly is mounted on a small Yaxley type switch (Sw 3). An additional switch position connects the oscillator to a monitoring meter, and R_8 is adjusted to provide full scale deflection at 1 kc/s. The meter may be calibrated in dB and is useful for checking the state of the battery as reflected in amplitude of oscillation. The output of the attenuator is fed to the loudspeaker circuit, and the resistors R_{18-25} are arranged to produce the correct level at the loudspeaker terminals at each frequency. As this will vary from one speaker to another, individual adjustment is necessary.

The best procedure here is to mount the speaker and components in the box in their final positions, bringing out a separate pair of wires from the loudspeaker coil. First measure the loudspeaker impedance at the four frequencies. Then at each frequency in turn connect a resistor in series with the speaker which, in combination with the measured loudspeaker impedance, will produce an attenuation of exactly 80 dB. Place the instrument in an anechoic chamber and adjust the input voltage so that the tone is just perceptible at a distance of three feet. If this is repeated with a number of subjects, the mean values of input voltage will approximate to those required at the speaker terminals to produce a signal 80 dB above normal threshold level.

With the attenuator set to 80 dB hearing loss (zero attenuation) and a 22 Ω resistor connected between C and D in place of the loudspeaker network, the output of the oscillator can be measured at each frequency. The difference between these voltages and those ascertained as above represents the attenuation to be introduced by R_{18-25}. It simply remains to choose values producing this attenuation and to ensure that in combination with the loudspeaker impedance they always offer a load of 22 Ω to the attenuator between points C and D. The various figures relevant to this setting up procedure as measured on the prototype are shown in the table,

*B.S. 2980: 1958, " Pure Tone Audiometers."

Frequency (c/s)	Loudspeaker impedance in Ω as finally mounted in sealed box	R.M.S. volts at loudspeaker with 80dB hearing loss	R.M.S. volts between points C and D into 22Ω load with zero attenuation (80dB hearing loss)
500	17.5	1.51	2.00
1000	15.5	1.27	2.32
2000	19.0	0.57	2.00
4000	23.0	0.69	2.14

Table showing, at the four frequencies used, the loudspeaker impedance, the voltage needed at the loudspeaker, and the output obtained from the oscillator, all as measured on the prototype.

and the values of R_{18-25} given are for this particular loudspeaker and pair of transistors.

Construction.—The whole circuit is contained in a wooden instrument case which is approximately a 5-in cube. The loudspeaker is fixed in the side remote from the lid, and its front protected by a suitable decorative grille. The complete unit is shown in the two photographs, and it will be noticed that the attenuator and frequency switches are mounted on one side, and the small monitoring meter on the other. The case is held by the left hand, and the on/off switch (Sw 1) is a bell push operated by the thumb. This leaves the other hand free to adjust the level and frequency. The battery consists of three large 1½-V cells connected in series, and is accommodated in the lid. The main body of the box is completely sealed off to avoid changes in loudspeaker loading when the battery is replaced. The instrument would normally only be used to produce short bursts of tone from time to time, so many months of life could be expected from a set of cells. The consumption is approximately ¼ A.

This audiometer has been used successfully in the Audiology Department of a London hospital for some months. The principles of using such a device for testing the hearing of small children and clinical experience with it are described elsewhere.†

† P. Denes and M. Reed, "A Portable Free Field Audiometer," *The Lancet*, Vol. 2 (1959), p. 830, Nov. 14th.

BOOKS RECEIVED

Fundamentals of Radio and Electronics. Edited by W. L. Everitt. Completely revised and rewritten edition of this standard textbook, including much new material on transistors, monochrome and colour television, radar and navigational aids and industrial electronics. There is an introductory chapter on the elementary mathematics of radio and electronics. Pp. 805; Figs. 596. Price 57s 6d. Constable & Co., Ltd., 10, Orange Street, London, W.C.2.

Encyclopédic des Isolants Electriques. Succinct classification in 27 synoptic tables of electrical insulating materials, their physical and chemical properties, behaviour under operating conditions, and precautions to be taken in their application. Pp. 80. Price 22 Swiss francs. L'Association Suisse des Electriciens, 301 Seefeldstrasse, Zurich 8.

Corrosion of Metals by Vapours from Organic Materials, by Vera E. Rance and H. G. Cole. Booklet issued by the Corrosion and Electrodeposition Committee of the Inter-Services Metallurgical Research Council (Admiralty and Ministry of Supply) giving a survey of instances of corrosion, both under laboratory and service conditions, arising from vapours exhaled from woods, glues, varnishes, plastics, etc. The effect of volatile corrosion inhibitors on metals other than steel is mentioned. Pp. 25. Price 2s. H.M. Stationery Office, York House, Kingsway, London, W.C.2.

Fifteen Years of Semiconducting Materials and Transistors. A classified bibliography and author index compiled by N. L. Meyrick. Pp. 75. Price 5s. Newmarket Transistors Ltd., Exning Road, Newmarket.

Mobile Radio Telephones by H. N. Gant, A.M. Brit.I.R.E. A book written primarily for potential users outlining its possible applications and limitations, how to obtain a licence, performance requirements, installation, maintenance and testing. Pp. 125; Figs. 21. Price 21s. Chapman & Hall Ltd., 37 Essex Street, London, W.C.2.

Guide to Mobile Radio, by Leo G. Sands. Handbook of American practice describing systems, transmitters, receivers and maintenance. Pp. 160; Figs. 116. Price $2.85. Gernsback Publications Inc., 154 West 14th Street, New York 11.

Library Services and Technical Information for the Radio and Electronics Engineer. Primarily a catalogue of the books and periodicals available to Brit.I.R.E. members, but contains also useful information on other libraries, translation services, standards and specifications and international bodies concerned with radio and electronics. Pp. 72. Price 2s 6d. The British Institution of Radio Engineers, 9 Bedford Square, London, W.C.1.

Television Servicing, by Alex Levy and Murray Frankel. Illustrated index of typical faults and step-by-step procedures for servicing as applied in American television receiving sets. Pp. 534; Figs. 348. Price 43s. McGraw-Hill Publishing Co., Ltd., 95 Farringdon Street, London, E.C.4.

Principles of Electronics, by H. Buckingham, Ph.D., M.Sc., A.M.I.E.E., and E. M. Price, M.Sc.(Tech.), A.M.I.E.E. Second edition of this textbook for technical colleges includes new chapters on transistors and magnetic amplifiers. Test questions (and answers) are given for each of the 20 chapters. Pp. 419; Figs. 302. Price 17s 6d. Cleaver-Hume Press Ltd., 31 Wrights Lane, London, W.8.

A First Course in Television, by "Decibel." Complementary volume to "A First Course of Wireless" by the same author giving an elementary technical description of the essentials of monochrome and colour television systems and of the basic functions of receiver circuit elements. Pp. 149; Figs. 106. Price 15s. Sir Isaac Pitman & Sons Ltd., Parker Street, London, W.C.2.

Junction Transistor Electronics, by Richard B. Hurley. Exhaustive treatise on the semiconductor triode, its physical action and the design and performance of associated circuits for low and high signal amplification at low and high frequencies, switching circuits and transistor-saturable reactor circuits. Pp. 473; Figs. 240. Price 100s. Chapman & Hall Ltd., 37 Essex Street, London, W.C.2.

The Bomber's Eye, by Group Captain Dudley Saward, O.B.E. Personal account of the development, adoption and operational use of H_2S (airborne plan position indicator). Pp. 265 with 10 plates. Price 21s. Cassell & Co., Ltd., 35 Red Lion Square, London, W.C.1.

LETTERS TO THE EDITOR

The Editor does not necessarily endorse the opinions expressed by his correspondents

Early Public Address

REGARDING "Free Grid's" first item in the October issue, you may be interested to learn that my father, Fred Warren, provided p.a. for the General Election of 1922. Besides what could be called "mobile" gear for open-air meetings, he relayed the speeches of the meetings at the Luton Assembly Hall to the crowd outside. One speaker in this campaign was the late George Bernard Shaw.

I am currently engaged in locating as much information as possible on early p.a., for, in my capacity as Hon. Librarian of the A.P.A.E., I intend to have an historic exhibit at the 1960 Exhibition. I have contacted Mr. Peter Jensen, of Forest Park, U.S.A., for he recently wrote of providing p.a. as early as 1910, employing "a heavy duty (carbon) microphone, battery and sensitive receiver on a horn." He relates how this equipment was used for political work immediately after the first World War.

I would welcome any assistance and suggestions in connection with the proposed exhibit. Old gear is very hard to come by; I am trying to locate a copy of the instruction manual for the early Marconi gear, also Western Electric.

88, Wellington Street, Luton, Beds. HAYDON G. WARREN.

"*Hum, Rumble and Noise*"

IN his excellent article "Hum, Rumble and Noise," in the October issue, Mr Cooke states that hum due to the stray field from a turntable motor is reduced 2dB when the motor voltage is reduced from 240V to 200V. This is hardly more than the 1.6dB reduction one would expect if the stray-field/motor-current relationship were linear. In any case a reduction in motor power with consequent danger of increased wow and longer run-up time seems rather a high price to pay for such a small improvement in hum level; surely one does not notice a 2dB change at 50c/s. However, if Mr. Cooke's experience shows that this reduction is worth while, perhaps turntable manufacturers will consider increasing the turns on the motor windings to give a reduced stray field.

London, E.C.2. A. R. NICOLL.

The author replies:

Mr. Nicoll is correct in pointing out that the reduction in stray field is little more than that expected for a linear voltage/current/stray field relationship. It is, however, 25% more even with the high-class motor used for the tests. Other motors running well into saturation may well show a more pronounced reduction.

When serious hum is encountered, very possible reduction becomes worth while and a drop of 2dB certainly worth having.

The average synchronous or induction motor is not worried by the slight loss of torque resulting from a 20% reduction in voltage. Other factors, such as slippage between idler and motor shaft, usually have a greater effect.

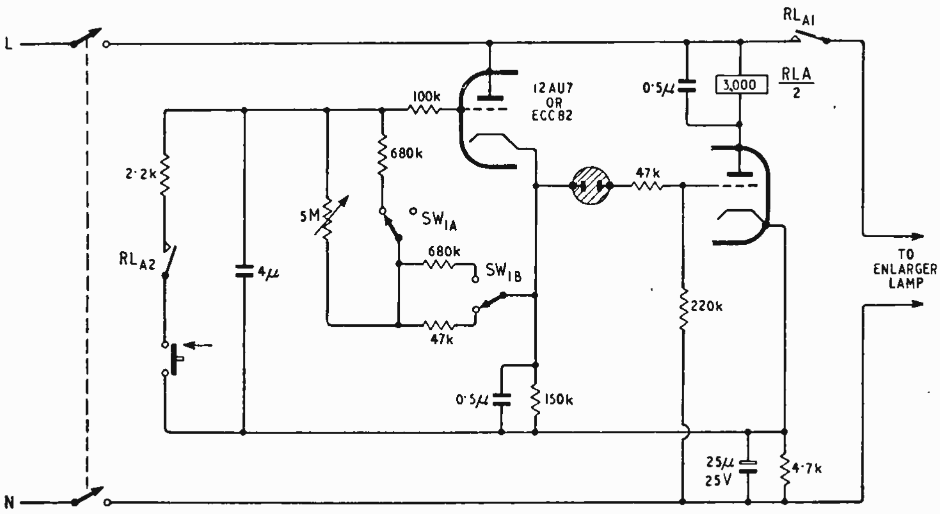
RAYMOND E. COOKE.

"*Inexpensive Photographic Timer*"

THE problem mentioned by your correspondent H. d'Assis Fonseca in the June, 1959, issue can be overcome in what I regard as a more simple way, by separating the two functions of the circuit (timing and relay closure). One valve is used in a bootstrap charging circuit as before, to raise the cathode potential until the neon strikes. (The type is that used as a panel indicator light, e.g., Hivac CC7L.) This gives clean operation of the relay.

The use of only one valve in the timing circuit will necessitate some rearrangement of the timing components to give similar intervals. An alternative arrangement is shown, giving two ranges (1-10 sec. and 10-100 sec.) on one control knob with a range-change switch.

The second relay contact, in series with the push-button (this is considered preferable to a switch), ensures consistent discharge of the timing capacitor, although it could be omitted if one is prepared to hold the push-button in for a full second or so. This will admittedly allow more complete discharge to occur, permitting the use of lower value resistors in the timing circuit. The basic principle of Mr. Jowett's excellent circuit (August,



1958, issue) remains, whatever detail variations one chooses to use.

Croydon, Surrey. K. HARDISTY.

Electrocussion

MAY I humbly take "Free Grid" to task for seeming to condone careless handling of electrical and electronic equipment? In the Services we are taught that "Electric shocks are not an occupational hazard" and that the receipt of an electric shock should be followed by a post-mortem* to avoid repetition.

London. GEORGE M. SMITH.

* [Metaphorically and not literally, we hope. Ed.]

DUMMY AERIALS

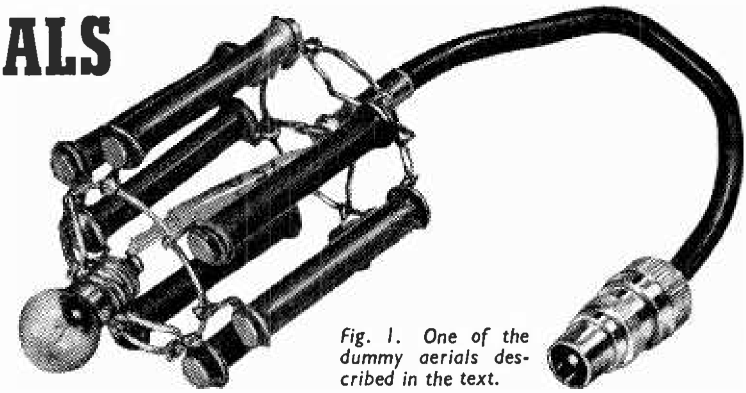


Fig. 1. One of the dummy aerials described in the text.

Resistive Load with Visual Indicator for Aligning Low-power Transmitters

*By H. B. DENT**

THE preliminary adjustments to a small radio transmitter often take a considerable time, and under no conditions should they be carried out with the normal transmitting aerial connected to the set. Adjustments can often be made with the d.c. input power to the valves reduced to below damaging "no-load" values, but eventually the time arrives when final adjustments have to be made on full power. Again a radiating aerial is undesirable as such adjustments can take longer than one realizes at the time and until it is required actually to transmit a message, or request a "contact" by means of a CQ call, all testing ought to be effected with a dummy load in place of the aerial.

Probably the most common type of dummy aerial load is an ordinary electric lamp of a wattage suitable for the expected power output of the transmitter. Lamps are all very well in their way and if output powers much over 15 watts are involved they form one of the most economical types of load to employ. However, with output powers under 15 watts, and with resonant aerials such as half-wave dipoles or Yagis, the opportunity is available to use simulated aerial loads which in the writer's experience are far superior to lamps and not unduly costly.

The dummy aerial illustrated in Fig. 1 was made for use with a small mobile v.h.f. transmitter-receiver giving 6 to 7 watts r.f. output, but others capable of dissipating 15 watts or so have also been constructed on similar lines.

As will be seen from Fig. 2 the device consists of a number of carbon-rod resistors connected in parallel and with a small flashlamp bulb, or similar low-current lamp, joined in series with them and with the input cable. The latter is a short length of 75Ω coaxial feeder terminating in a coaxial cable plug. Fig. 1 shows the actual form of construction adopted and its principal merit perhaps is that in addition to being a convenient form of assembly for a dozen or so resistors, it ensures that no matter how many resistors are used all are equidistant from the common point of attachment of the feeder cable. This can be important at v.h.f. since quite short lengths of wire have appreciable impedance and with connecting wires of different lengths some resistors would be dissipating more than their quota of the available r.f. power. As a result some will tend to become excessively hot if the power dissipated in the load is about the maximum for which it is intended.

* Amateur Radio Station G2MC.

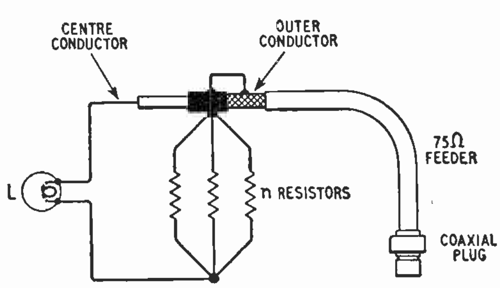


Fig. 2. Theoretical circuit of the dummy aerial.

The dummy aerial consists of seven 1-watt carbon-rod resistors connected top and bottom to $1\frac{1}{2}$-in diameter rings made from No. 18 s.w.g. copper wire. A short piece of $\frac{1}{4}$-in diameter copper tube is held centrally in the lower ring by means of four 18 s.w.g. wire arms soldered to the lower ring (see Fig. 1). Through this is threaded the coaxial cable after removing sufficient of the outer insulation to enable it to extend up the centre of the cylinder of resistors as far as the top ring.

The copper braid on the cable is unravelled down to the top edge of the $\frac{1}{4}$-in tube, twisted into pigtails and soldered to the 18 s.w.g. wire arms positioning the tube. The tube forms an anchorage for the coaxial cable at the same time preserving the symmetry of the assembly.

The indicator is a small flashlamp bulb, its centre pip being soldered to the centre conductor of the coaxial cable and its base ring joined by two short pieces of 18 s.w.g. wire to the top ring of the bank of resistors. It is quite safe to solder the wire supports to the lamp provided reasonable care is taken.

The reason a number of 1-watt resistors is used instead of one large fat resistor of the required wattage is perhaps best explained by reference to an article by Dummer[1] on the characteristics of resistors at very high radio frequencies. As the dummy aerial was primarily intended for use on 145Mc/s and higher, the type of rod resistor which was shown by the data in Dummer's article as being suitable for the purpose was employed.

Briefly stated, at frequencies of 100Mc/s and higher, long, thin carbon-rod resistors have better r.f. characteristics than short, fat ones. Some curves are given by Dummer from which it is possible to assess the effective r.f. resistance over a wide range of very high radio frequencies of different values of carbon-rod resistors of the "long and thin" variety, and from these it was deduced that about 85% of the d.c. resistance of a 1-watt resistor under 1kΩ in value would be effective at radio frequencies of the order of 145Mc/s, with a progressively falling percentage at higher frequencies.

In consequence of this, seven 1-watt carbon resistors of 560 ohms each (±5% tolerance) were used for the 7-watt dummy aerial. With all the resistors connected in parallel the d.c. resistance is nominally 80Ω, and 85% of this is 68Ω, which, with the little extra resistance of the series-connected flashlamp bulb, brings the total to close on the nominal 75Ω of the average halfwave dipole and the most common types of coaxial feeders.

As a point of interest, the d.c. resistance of small flashlamp bulbs varies considerably with the temperature of the filament Some of the 0.3-A type measured showed a d.c. resistance when cold of between 2 and 3Ω, and while a 3.5-V lamp should be 11Ω approximately when taking the full 0.3A, below full brilliance its resistance might be anything from 5 to 11Ω.

Of course, the lamp is only an indicator of power in the dummy load, it is no use for quantitative measurements. However, if a few measurements are made with known amounts of watts (d.c.) dissipated in the load, and the brilliance of the lamp can be memorized, an approximate estimate of r.f. power in the load can often be made.

If exact measurement of power is needed for any purpose the method described in the article "Double Tetrode Oscillator"[2] can always be employed.

REFERENCES

[1] Dummer, G. W. A., "Characteristics of Fixed Resistors," *Wireless World,* June 1956, p. 263.

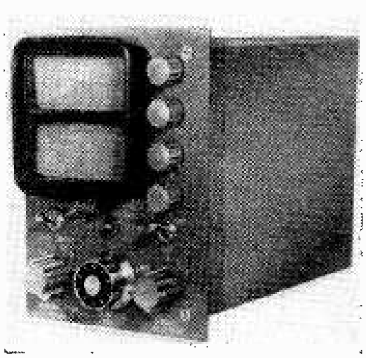
[2] Andreae, J. H., and Joyce, P. L., "Double Tetrode Oscillator," *Wireless World,* April 1958, p. 173.

Manufacturers' Products

NEW ELECTRICAL EQUIPMENT AND ACCESSORIES

Airborne Engine Analyser

A NEW instrument from Ultra Electric, Ltd., is the Engine Condition Analyser Type UE91, which displays in flight the outputs from temperature- and vibration-sensing elements applied to the engines of an aircraft. Up to 40 thermocouples and eight vibration transducers, shared between four engines, can be used, and the outputs from these are gated sequentially at 2,000 p.p.s. to provide Y-deflection on two cathode-ray tubes—one for temperature, the other for vibration. The X-deflection is a normal timebase, so that a row of square pulses whose amplitudes represent temperature and vibration is seen on the screen of each cathode-ray tube. Detailed examination of the temperatures associated with any one engine is catered for by switching in a "strobe" timebase. One horizontal line on the display gives the normal pulse-base positions for take-off, climb, cruise and descent (selection by front-panel switch) and readout of any individual temperature is accomplished by lining up another line with the top of the equivalent pulse. The vibration display is of first-order amplitudes of vibration only (those vibrations corresponding to engine-rotation speed) and in this case a horizontal line provides a danger-warning facility.



Ultra engine-condition-analyser display unit.

The equipment uses transistors extensively and it is contained in two "boxes" weighing 23 lb (9.1kg) without cabling. Power consumption is 60VA at 115V, 400c/s.

Precision Digital Turns Counter

A CONTROL which records visibly the whole number and fractions of turns made to a multi-turn component such as, for example, a helical potentiometer, is now obtainable from General Controls, Ltd., 13-15 Bowlers Croft, Honywood Road, Basildon, Essex.

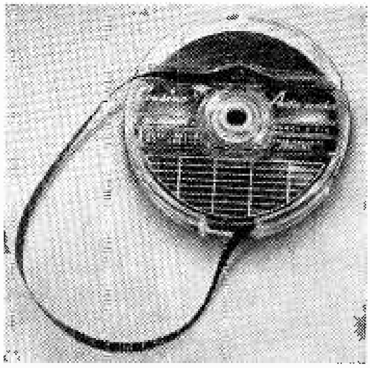
In the model illustrated (CM3) three digital dials engraved with easily-read figures record up to a maximum of 10 turns (3,600° rotation of spindle) the dials showing full turns, tenths and hundredths of a turn respectively. This model has a shaft lock incorporated for a ¼-in spindle.

Digital dials are black with white figures and the overall depth is 1.37in. The accuracy of reading is ±0.002 turn.

General Controls precision turns counter with three digital dials.

Tape Loop Cassette

PHILIPS are now marketing a tape loop cassette, Type EL3963/00, which, though intended primarily for use with their AG8108G tape recorder, can also be used with certain other recorders in which the spool drive spindle on which the cassette is placed can be locked stationary during recording or playback, and in which, in addition, the tape travels from left to right. The cassette contains 190ft of long-playing tape, and this can be played at 1⅞, 3¾ or 7½in/sec thus giving 10 minutes playing time at 3¾in/sec with proportionate times for the other speeds. Both sides of the tape are coated with magnetic oxide and one side is coated with graphite to reduce friction between adjacent layers of tape. The playing time can thus be doubled by breaking the loop and giving one end of the tape a 180° twist before resplicing so as to connect together the two sides of the tape. The locked recorder spool spindle has a friction pad placed over it so as to hold still the nylon cassette spindle (which is joined to the upper cassette flange). The cassette



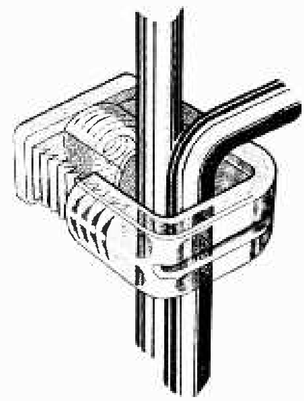
Philips Continuous Tape Cassette.

spindle fits in a hole in a truncated conical nylon collar which is joined to the lower cassette flange. This lower flange and the conical collar rotate as the tape moves; the collar being made conical so as to incline the inner turns of the tape away from the central spindle. The EL3963/00 cassette costs £5, and is marketed by Philips Electrical, Ltd., Century House, Shaftesbury Avenue, London, W.C.2.

Polystyrene Cable Clamp

THE "Quickclip" is designed for the clamping of bunches of cables or multi-wire harnesses in such a way that the replacement or addition of individual wires can be carried out with the minimum of difficulty.

Moulded from high-impact polystyrene, the clamp is in two parts, a U-shaped top (serrated across the inside of the "legs") and a base which fits into the upper portion. The base carries serrations on the outside edges and can be held in position either by a woodscrew or a bolt, for which the base is threaded. The clamp can be released by working it from side to side, so releasing the grip of the serrations.

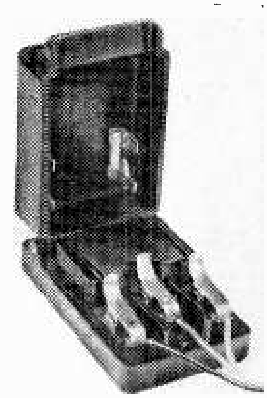


Alma Components "Quickclip" cable clamp.

The "Quickclip" is marketed by Alma Components Ltd., of 551, Holloway Road, London, N.19, and is available in sizes suitable for cables from $\frac{3}{16}$-in diameter (14s 3d per 100) to $1\frac{1}{4}$-in (67s 6d per 100).

Safety Mains Connector

THE "Safebloc" is designed for the safe, quick and easy temporary energising of mains-powered apparatus without the bother of fitting a plug. It consists of a moulded plastics box carrying the stationary contacts of a double-pole switch mechanism and three "bulldog-type" colour-coded clips for quick connection to bared flexible-cable ends. In the deep lid are mounted the moving contacts of the switch and clips to accept cartridge fuses to BS1392 (ring-main plug fuses, ratings 2 to 13A) and the lid is so hinged that raising it disconnects from the exposed metal work both live and neutral poles of the mains supply. The unit carries holes for mounting screws and terminals are provided for the connection of the supply, at the rear, under a removable plate. Maximum rating is 250V, 13A, a.c., and the manufacturers are Rendar Instruments Ltd., Victoria Road, Burgess Hill, Sussex.



Safety mains connector with lid open. Closing lid applies power to cable clips.

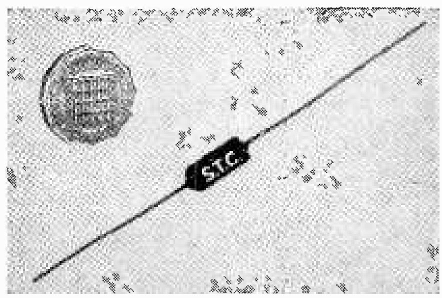
Silicon Resistors

A NEW type of silicon resistor, designated the "Silistor," and having pronounced positive resistance/temperature characteristics should prove particularly useful in transistor circuitry. The law governing its change in resistance with temperature is approximately as follows:—

$$R = R_{25}\left(\frac{273+T}{298}\right)^{2.3}$$

where T is the temperature in degrees C and R_{25} is the resistance at 25°C.

Resistance range at present available is 10Ω to 470Ω.



Standard Telephones "Silistor" a new silicon resistor.

Further details are obtainable from Standard Telephones and Cables, Ltd. (Transistor Division), Footscray, Sidcup, Kent.

Miniaturized Reference-Voltage Unit

DESIGNED for operation from 28-volt d.c. supplies, the miniature reference-voltage unit illustrated provides an output of 9.4V ±5% with a stability within ±1mV for input voltage variations of ±10%. This is achieved by use of a Zener diode regulator and a silicon reference element.

The unit, which is designed for mounting on printed-circuit boards, measures $1\frac{1}{4}$in high and 1in in diameter. It is encapsulated in epoxy resin with wire connecting leads at the base. The price; about £36.

Bulletin SR401, obtainable from the International Rectifier Co. Ltd., Oxted, Surrey, contains full details.

Miniature reference-voltage encapsulated unit for mounting on printed-circuit boards. (International Rectifier Co.)

Mechanical "Circuits"

By "CATHODE RAY"

THE ELECTRICAL ANALOGY IS NOT FOOLPROOF

I FORGET when I first met the idea that there is a precise and complete analogy between electrical and mechanical systems. I suppose our very first lessons in electricity always liken voltage to force or pressure, resistance to friction, inductance to inertia, and so on. Later we learn that the equations stating the general relationships between these quantities are exactly the same for electrical circuits as for mechanical devices. Analogies of this kind between different sciences appeal to me, if only because they reduce the total number of different things to be learnt. And they make a tidy mental pattern. But this one particularly pleased me, because electrical engineers (starting later) have overtaken mechanical engineers to such an extent that it is often worth while translating mechanical quantities into electrical to get the benefit of the highly developed state of electrical circuit analysis and measurement techniques. Since electricity is a comparatively mysterious thing, explained in the first instance by mechanical analogies, this strikes me as pleasantly ironical.

In our own field of sound reproduction, where the key devices are partly electrical and partly mechanical (" electromechanical transducers," as the professionals call them) it is helpful to be able to include everything in one lot of units and equations, and sometimes to find that dodges which are commonplace in electrical circuitry can be used to good effect in their mechanical equivalents. An example of this occurred about 30 years ago, when a mild technical sensation was aroused by the invention of a pickup arm designed as the analogue of a non-reflecting transmission line.

The same idea has been extended to acoustics, so that it is now no surprise to be offered apparatus for measuring acoustical impedance in acoustical ohms. In what follows, " mechanical " should, where the context permits, be deemed to include " acoustical."

Distant View

From a little distance all this looks intellectually and practically satisfying. But then the Editor came along, and, hinting that behind this neat and orderly façade a certain amount of confusion reigned, bade me expound the matter clearly. This I was reluctant to attempt, because to confess the truth the subject had never really progressed in my mind beyond the very-nice-idea stage. I had assumed that since every mechanical quantity has its electrical analogue all one had to do was apply the familiar electrical equations and circuit " know-how " to mechanical systems in which one might happen to be interested. At the same time, however, such equivalent circuits as I had seen didn't look particularly obviously the analogues of the mechanical or acoustical systems concerned. In any case, for causing one's supposed mastery of a subject to melt rapidly away there is nothing like trying (a) to put it to practical use or (b) to teach it.

However, my own self-inductance (or inertance, as the acoustical equivalent is called) having been overcome, Lenz's law will ensure that I carry on relentlessly in spite of all protests.

Disenchantment

The first thing was to " gen up," and having long connected the whole business with the name of Olson, and his book " Dynamical Analogies " having been favourably reviewed both on its first appearance in 1942 and in revised and enlarged form only a few months ago, I turned naturally to that work, especially as a quick glance showed neat comparative tables and lots of diagrams presenting the mechanical and acoustical equivalents of the three primary electrical elements (R, L and C) and almost every typical combination of them.

Even in this conservative country, and even in physics as well as electrical engineering, there has been a general change-over in textbooks from c.g.s. to rationalized m.k.s. units. Our present subject, in which units are vitally important, would seem to be a " natural " for m.k.s. throughout, and to see a book on it coming from America at this late date still adhering to c.g.s. " abamperes," " abohms," etc., was quite a surprise.

Perhaps, however, Mr. Olson is not fully to blame for this, because on consulting British Standard 661 : 1955 (Glossary of Acoustical Terms) I saw with pained astonishment that what is called the acoustical *ohm* is a c.g.s. unit. This term being also an international standard, there would obviously be a difficulty in changing over from it to an m.k.s. unit which would have to bear the same name while being one thousand million times larger. If the c.g.s. unit had been called anything at all, it ought to have been called an acoustical abohm. How silly can people be when they establish standards?

However, that was merely a ripple to disturb the deep sea of confident expectancy with which I approached the reading matter accompanying

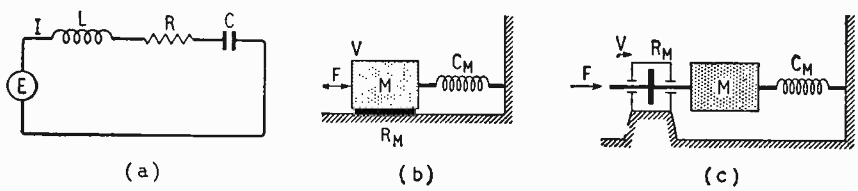
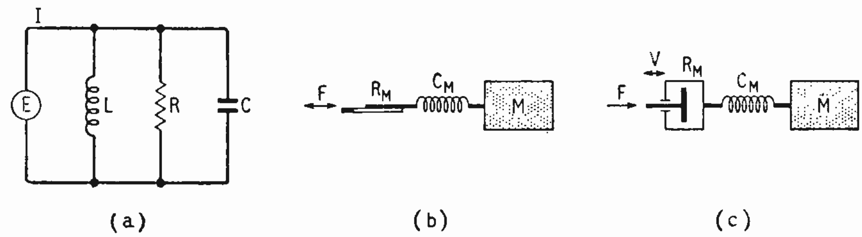


Fig. 1. Electrical series circuit (a) and mechanical equivalent according to (b) Olson and (c) Bloch.

Fig. 2. Electrical parallel circuit (a) and mechanical equivalent according to (b) Olson's conventions and (c) Bloch.



Olson's intriguing comparative diagrams. Anyway, using wholly c.g.s. units is better than the usual horrible mixture, in which various constants appear. Most of Olson's equations would be the same in m.k.s.

In my youthful innocence of long ago, the attractiveness of this analogue idea had lain in the fact that, it having once been established that certain electrical quantities were exact analogues of certain mechanical quantities, and having learnt all the electrical relationships, one would thereupon be in possession of all the mechanical relationships, merely by substituting the appropriate symbols. To take an easy example, suppose it has been established that mass is analogous to inductance, velocity to current, and force to e.m.f. Knowing that the r.m.s. e.m.f. E needed to pass an r.m.s. current I at frequency f through an inductance L is

$$E = j2\pi fLI = j\omega LI \quad .. \quad (1)$$

one thereupon knows without further ado that the force F needed to make a mass M vibrate with r.m.s. velocity V at frequency f is

$$F = j2\pi fMV = j\omega MV \quad .. \quad (2)$$

Results derived from (1) and other electrical equations can be translated into mechanical counterparts merely by changing symbols, for mathematical derivations obviously depend in no way on the symbols that may have been used. An older generation of electrical engineers denoted current by C and capacity (as they called it) by K, but the change-over to I and C respectively didn't make it necessary to establish all their relationships afresh.

Most of "Dynamical Analogies" consists of a fourfold* repetition of statements and equations, down to the smallest detail, only the quantities and their symbols being different. Once the reader has caught on to the analogy idea further repetition seems to me to be, like that practised by the Pharisees, vain. The space that could have been saved might well have been devoted to explaining what was far from obvious to me at least, namely how Mr. Olson arrived at the particular mechanical arrangements he depicts as analogues of the electrical circuits alongside. It would also have been profitable to discuss what one should do in practice about the fact (which I happened to know, but is mentioned) that for the type of friction illustrated the mechanical counterpart of Ohm's law is notably untrue. And in view of the literature which has been reaching me for some time past dealing with the design of transistor equipment as a heat-disposal problem, with "thermal ohms," etc., I'd have liked to see thermal "circuits" included in the new edition. However, this is not supposed to be a book review, and I mention these things merely to exemplify the disappointment the earnest seeker after knowledge can find even with the most highly praised authorities.

* Electrical, mechanical rectilineal, mechanical rotational and acoustical.

At this unsatisfactory moment I turned to a paper by Bloch** who soon convinced me that there is more to this new idea than I had gaily run off with years ago, and that one must really sit down and think it clearly through, especially as regards "rates of exchange" between electrical and mechanical quantities. He also overcame my considerable sales resistance to the recognition and use of a second system of analogues developed by Firestone as long ago as 1933—the inverse of the more popular one which Bloch calls the "direct analogy," and which Olson considered to be the only one worth discussing in his 1943 edition***. In what follows my grateful acknowledgements are due mainly to Firestone and Bloch.

The "direct" or "classical" analogy is the one we are probably all more or less familiar with, in which the analogous quantities are:

Electrical	*Mechanical*
E.m.f.	Force
Charge	Linear Displacement
Current	Velocity
Resistance	Resistance
Inductance	Mass
Capacitance	Compliance
Reactance	Reactance
Impedance	Impedance

Fig. 1 shows Olson's comparison of a simple 3-element series circuit (a) with its mechanical analogue (b) and also (c) Bloch's version of the same. I have taken some liberties with the original letter symbols to facilitate comparison, and for the same reason have turned (c) on its side. The only real difference between (c) and (b) is that Olson shows mechanical resistance as friction between mass and ground, which is very "non-ohmic", whereas Bloch represents his by a dashpot, which does obey the mechanical Ohm's law reasonably well.

It is a pity, of course, that the symbol for inductance looks like a spring, which is the mechanical analogue of capacitance, and that the symbols for a mechanical resistance look like capacitors; but only the simple are likely to be misled by this.

Series or Parallel

At first glance both of these mechanical systems have a series look about them, so one may easily imagine one has got the idea and could recognize any mechanical "series circuit" at sight.

If so, examination of the mechanical equivalents of a parallel circuit, Fig. 2, will prove disconcerting. (Olson unfortunately shows no "direct" mechanical

** A. Bloch. "Electromechanical Analogies and their Use for the Analysis of Mechanical and Electromechanical Systems," *Journal I.E.E.*, Part 1, April 1945, 157-169.

*** In 1952 he added a chapter on the "mobility analogy" (so named by Firestone), which is Bloch's "inverse analogy." He distinguishes Bloch's "direct analogy" as the "classical."

analogue for exactly this circuit, but if he had it would almost certainly have looked like (b). Both this and (c) must be imagined as floating horizontally in space, presumably in an interplanetary vehicle unprovided with artificial gravitation.) Again, both of them look rather like series arrangements. Compared with Fig. 1, the main difference seems to be that the order of the three elements has been altered (M being shifted one place to the right), which to the electrical mind would appear unimportant. There is also an absence of the "earth connections" seen in Fig. 1. Ordinary intellects, at least, may feel that

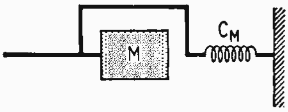


Fig. 3. The mass (M) and compliance (C_M) in Fig. 1 are not, as might be supposed, in series, but in parallel, as can be seen by re-drawing thus.

some explanation is needed to restore confidence in their ability to write down by inspection the electrical equivalent of a mechanical system, or vice versa.

The principle of an electrical series circuit, of course, is that the same current flows through all the elements, but the voltage across each is proportional to its impedance. In a parallel circuit, on the contrary, the same voltage comes across all the branches, but the current through each is proportional to its admittance.

Now the analogue of current is velocity, and in Fig. 1 (b) and (c) it is clear that the to-and-fro velocity being imparted to the mass is the same as the *difference* in velocity between the two "terminals" of the resistance and of the compliance. As one terminal of each of these two elements (in both diagrams) is "earthed", the velocity of the mass is the same as that of the moving end of the resistance and compliance. It is perhaps a little less obvious that the force applied to each element is proportional to its impedance. But if you imagine any one of the mechanical elements to have a relatively very high impedance you will see that little force will be left for the others (and consequently little movement of any of them), just as in the electrical circuit.

Compare Fig. 2. It is easy to see that if any one of the elements has a much greater impedance than the others its velocity (reckoned differentially between the two terminals in the cases of the resistance and compliance) is relatively small, and that more generally the velocity is inversely proportional to the impedance of that element individually, instead of being the same for all as in Fig. 1. That each receives the same force may be less obvious, because one may at first suppose that each element in the string absorbs some of the force. In this we may perhaps have in mind the use of springs and shock absorbers to protect us from the bumps imparted to the wheels of our car by the road. But the function of the springs is not to pass on less force to us than they receive from the road but to reduce the force the road applies, by giving way to it. Also the mechanical circuit of a car is complicated by the large mass of its chassis interposed between ourselves and the road, which, as we shall see, makes its equivalent circuit not wholly parallel. No; the only element which can receive more force than it passes on is mass, and that is in the last position in both (b) and (c). Assuming the other two have no mass at all, any force they receive must be balanced by an equal and opposite force.

The first general conclusion we draw from all this is that whereas in wholly series or parallel electrical circuits any element can be interchanged with any other without making any electrical difference† in mechanical circuits the order in which the elements are connected is vitally important.

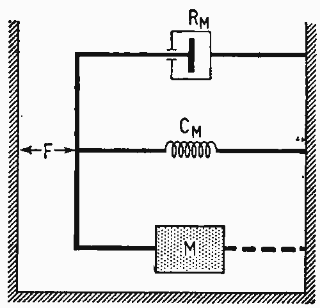
This leads to the next conclusion, which is that we electrical people must be very careful about treating the mechanical links between mechanical elements as if they were wires joining electrical elements. Lack of such care would lead us to suppose that all the mechanical circuits shown so far were of the series type.

The startling thing (unless you have been bright enough to run on ahead, or know it beforehand) is that Fig. 2 (b) and (c) *are* series circuits, although their electrical equivalent is a parallel circuit. And the mechanical analogues of the series electrical circuit in Fig. 1 are parallel circuits.

The truth of the latter statement may not spring at once to the eye. But just as a battery cannot apply its e.m.f. to a circuit if only one of its terminals is connected, so a force cannot be brought to bear unless it is "connected" in two places. In Fig. 1 it must therefore be anchored somewhere to the frame or "earth" represented by diagonal shading. Otherwise it would just push itself away. So in both (b) and (c) it is exerted directly across resistance R_M.

The series appearance of M and C_M is also misleading. So far as C_M is concerned, the body of M is acting merely as a mechanical coupling, and the true situation is more clearly shown in Fig. 3, which is essentially identical. The same principle applies to R_M in Fig. 1(c). So the same force applied to

Fig. 4. By re-drawing Fig. 1(c) in this way, the parallel arrangement is quite clear.



R_M is also applied directly across C_M, which is therefore in parallel.

But what about M? In Fig. 3, as in Fig. 2, it seems to have only one "terminal." And certainly it does seem to be the odd man out, since it can accept a force without passing any on to anything else. It seems almost as if it had some kind of invisible link with "earth." And although it may appear to you a bit of a fiddle to assume such a link and represent it by a dotted line as in Fig. 4, under the more respectable name of "concept" it has the authority of Dr. Bloch, who shows that it is not altogether unjustifiable. Besides, it works.

So, just by looking at Fig. 1(b) and (c) a little

(*continued on page 573*)

† In practice, of course, real components as distinct from theoretical circuit elements have stray capacitances, which are additional circuit elements and do often give significance to the order in which the components are connected.

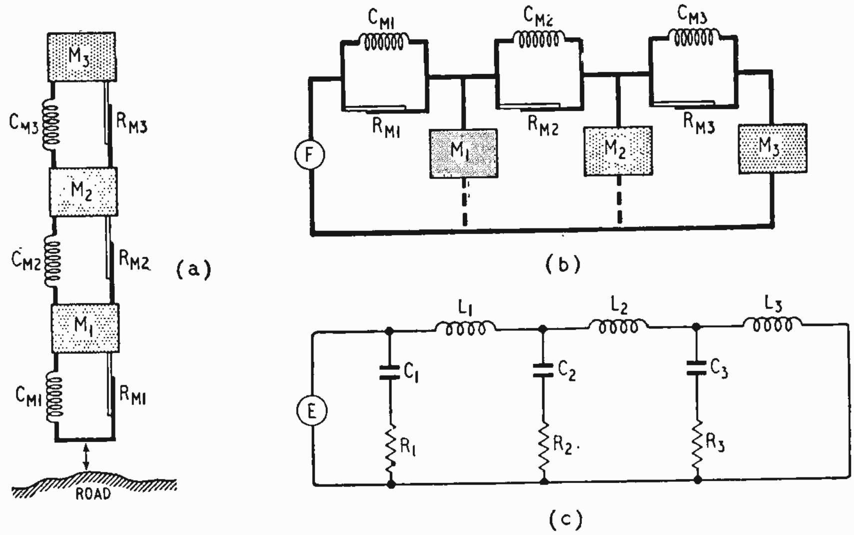


Fig. 5. The mechanical contrivances between the road and your body (M_3) when you are motoring are shown in simplified form at (a). Redrawn to bring out the mechanical "circuitry" they appear at (b). (c) is the result of translation into electrical components and connections.

differently, we find ourselves with a parallel mechanical circuit as the analogue of a series electrical circuit.

Duality

Some while ago‡ I dealt with duality—that sort of inverse analogy that exists between the following electrical quantities:

Current, I	Voltage, V or E
Resistance, R	Conductance, G
Inductance, L	Capacitance, C
Reactance, X	Susceptance, B
Impedance, Z	Admittance, Y

If any equation connecting any of these quantities is true, it is equally true if all the quantities in it are replaced by those on the same line in the opposite column. To take the simplest example, Ohm's law is expressed by the familiar equation

$$E=IR$$

Making the exchange as described, we get

$$I=EG$$

which is also true, and is sometimes more useful; for example, in parallel circuits. Each of these two equations is said to be the dual of the other. Moreover, if the same exchanges are made in any circuit, *and series and parallel connections are interchanged*, the result is the dual of that circuit. The advantage of this procedure is that all the equations relating to one circuit can be adapted to its dual circuit by transforming them into their dual equations. This may save a lot of work ("Two formulæ for the price of one") as well as tidying up the whole matter in one's mind.

Now in working out the "direct" analogy between electrical and mechanical circuits or systems, on the familiar basis of voltage being analogous to force and current to velocity, we have arrived at the rather upsetting conclusion that the analogue of an electrical series circuit is a mechanical parallel circuit, and vice versa. Does this mean that all the relationships in an electrical circuit, say, have to be transformed into their duals before they apply to its mechanical analogue? Well, no; we have already checked that Fig. 4 behaves like a series circuit, in spite of its appearance, so that (for instance) adding more resistances apparently in parallel would *reduce* the velocity imparted by a given force, just as adding series resistances in Fig. 1(a) reduces the current imparted by a given e.m.f. So Fig. 4 is a parallel circuit in appearance but a series circuit in behaviour. Whichever it is called is therefore liable to mislead. To avoid such confusion, Bloch calls it "co-resistive," in contrast to Fig. 2(c) which is "co-yielding"—in each case like its electrical analogue.

So far as the algebra is concerned, then, the direct analogy is sound, in spite of the apparent oppositeness of circuit structures.

Simplified Example

There is more to come than we can cram into this month's space, so let us just consolidate the position reached by taking a familiar example, even though it might be reckoned more in the province of *The Autocar* than *Wireless World*. A car is of course a very complicated mechanical system, but for the sake of example let us consider only the parts concerned in the insulation of the inmates from the roughness of the road.

These are represented by the conventional picture symbols in Fig. 5(a). There are first the tyres, which form a compliance (mechanical capacitance) C_{M1} yielding to the vertical forces applied by road bumps. They support the mass of the wheels, axles, etc., M_1. The "tuned circuit" so formed is damped by the frictional and viscous losses in the rubber. These losses, which make the tyres warm up in action, are represented by R_{M1}. On top of this is another similar circuit (but with different magnitudes) formed by the springs, chassis, and dampers. These in turn support the upholstery, with its combined compliance and damping, and lastly you, gentle reader, the mass M_3.

To prepare this diagram for translation into the equivalent electrical circuit, all we need do is draw dotted lines from the masses to the other terminal of the mechanical generator, which in this case being the road is literally "earth." For this purpose it is rather more convenient to rotate the diagram through 90° (b).

The last step is to replace the mechanical circuit

‡ *Wireless World*, April 1952, and "Second Thoughts on Radio Theory," Chap. 35.

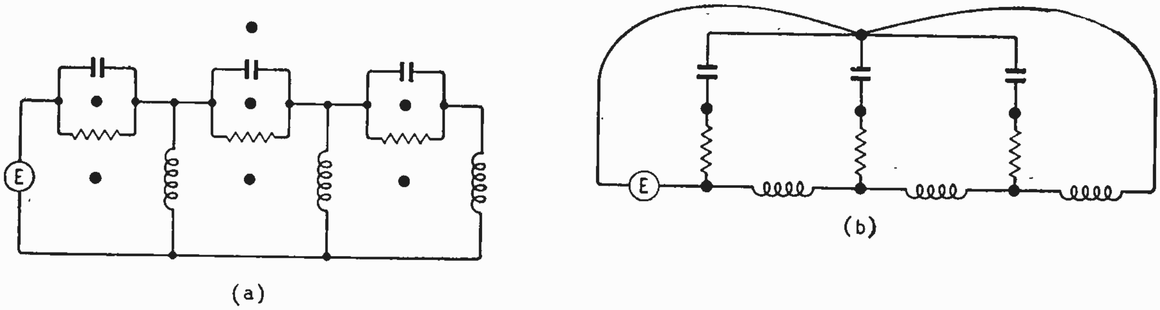


Fig. 6. For the sake of the weaker brethren the metamorphosis from Fig. 5(b) to (c) is here eased by intermediate stepping stones. At (a) the mechanical elements have been changed to electrical with the same (now incorrect) connections. Changing these over from series to parallel and vice versa, with the help of the black dots, we get (b), which in tidier layout is Fig. 5(c).

elements by their electrical equivalents (compliances by capacitances, etc.) and at the same time change series connections to parallel and vice versa. Fig. 5(c) is the result, but in case you are not used to this sort of thing and would like to make the two changes separately, Fig. 6 shows these. At (a) the transformation to electrical elements has been made without any change of "wiring." At the same time I have put a black dot inside each closed mesh of the circuit. That is part of a foolproof scheme for drawing dual circuits. All one has to do is look at each circuit element in turn, note the pair of dots between which it lies, and join those dots with a wire containing the same kind of element. (In a true dual circuit it would have to be the opposite kind of element but here we are only concerned with the connections.) You would do it with ink on a pencil diagram, or with a different colour; but not having that advantage in print I have drawn the second diagram separately around the same dot pattern at (b). This only needs turning upside down and straightening out a bit to be the same Fig. 5(c) that the brighter boys got in one move.

It is now easily recognizable by *Wireless World* readers as a low-pass filter. When we ride over cobblestones or frozen snow ridges our teeth are not likely to chatter, but we may hear some of the lower regions doing so, because of the relatively large high-frequency "current" in the first stage of the "filter."

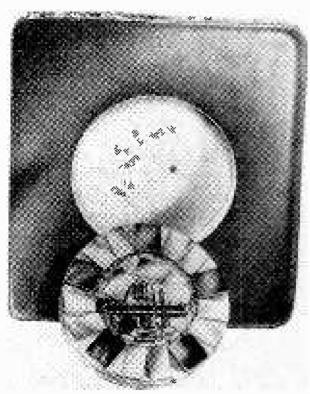
We can follow this analogy through and perhaps get some bright new ideas as to how cars should be sprung. But to do the thing properly, especially in our own field, we need to know more than just how to draw diagrams. Next time we shall see how to deal with calculations.

Crash Position Indicator

A HIGH-SPEED modern aircraft can be totally destroyed in as short a time as 100msec. This rather frightening fact assumes further importance when it is recalled that search aircraft and ships have passed within short distances of survivors without finding them. The well-known Sarah rescue beacon does much to reduce the risk of such an occurrence but, as it is usually attached to survival equipment within the aircraft, it is possible that it could either be damaged; or the survivors, perhaps unconscious, might not be able to set it in operation.

To make detection more certain, Ultra Electric, Ltd., have introduced a new distress beacon known as "Crash Position Indicator" (C.P.I.). This is constructed over a "plate" aerial and encapsulated in plastics foam which is covered with a laminated-nylon skin. The whole forms a flat section which fits into the aircraft skin, and, when released automatically from a crashing plane, it tumbles through the air to reduce its speed to a value low enough to land without damage. Satisfactory operation occurs even if the C.P.I. lands in water or on marsh, for it floats with 80% of the volume of the unit above the surface.

Transistors are employed in the equipment except in the transmitter which uses two valves in a tuned-line oscillator circuit. An interesting power-economy feature is that the valve heaters are switched on and off by transistors; in this way an operating life of 100 hours is achieved. C.P.I.'s transmissions are completely compatible with the N.A.T.-accepted "Sarah" search and homing equipment.



Ultra C.P.I. (Crash Position Indicator) in and out of its foam-plastics case. Transmitter and switching transistors are mounted on a flat panel backing "plate" aerial, with storage batteries round the edge. Ranges up to 70 miles can be achieved.

DECEMBER MEETINGS

Tickets are required for some meetings; readers are advised therefore to communicate with the secretary of the society concerned.

LONDON

4th. I.E.E. Medical Electronics Group.—Discussion on "Nuclear magnetic resonance" opened by Dr. N. Sheppard and Dr. R. E. Richards at 6.0 at Savoy Place, W.C.2.

4th. Television Society.—"Television in Germany" by Dr. Rolf Möller (Fernseh G.m.b.H.) at 7.0 at the Cinematograph Exhibitors' Association, 164, Shaftesbury Avenue, W.C.2.

7th. I.E.E.—"Frequency patterns for multiple-radio-channel routes" by B. B. Jacobsen at 5.30 at Savoy Place, W.C.2.

9th. Women's Engineering Society.—"Radar and telecommunications research and development" by Dr. Elizabeth Laverick at 7.0 at "Hope House," 45, Great Peter Street, Westminster, S.W.1.

10th. Physical Society Acoustics Group.—"The architectural design of broadcasting studios" by Alexander Brown at 5.30 at the Imperial College of Science and Technology, Prince Consort Road, S.W.7.

10th. Brit.I.R.E. Computer Group.—"The simulation of nuclear reactors and power plants" by W. J. G. Cox and J. Dowsing at 6.30 at the London School of Hygiene and Tropical Medicine, Keppel Street, W.C.1.

11th. Institute of Physics.—"The ultrasonic camera—an alternative approach to ultrasonic testing" by J. F. Sayers (Atomic Energy Research Establishment) at 6.0 at 47, Belgrave Square, S.W.1.

11th. I.E.E. Graduate and Student Section.—"The trends of electrical progress and their implications" by Sir Willis Jackson (president) at 6.30 at Savoy Place, W.C.2.

14th. I.E.E.—Discussion on "Why Hi-Fi?" opened by P. P. Eckersley at 5.30 at Savoy Place, W.C.2.

15th. Institute of Physics.—"Tubes for colour television" by K. G. Freeman (Mullard Research Laboratory) at 5.30 at 47, Belgrave Square, S.W.1.

15th. Brit.I.R.E.—Symposium on "Magnetic recording techniques" at 3.0 and 6.0 at the London School of Hygiene and Tropical Medicine, Keppel Street, W.C.1.

16th. I.E.E.—"The laying of submarine cables" by Capt. W. H. Leech at 5.30 at Savoy Place, W.C.2.

16th. Brit.I.R.E. Medical Electronics Group.—"Measurements in the presence of noise" by Dr. D. A. Bell and Dr. G. D. Dawson at 6.30 at the London School of Hygiene and Tropical Medicine, Keppel Street, W.C.1.

17th. British Computer Society.—Discussion on "Conversion between analogue and digital representation" at 11.0 at the Northampton College of Advanced Technology, St. John Street, E.C.1.

18th. B.S.R.A.—"Sound reproduction: things we forget to remember" by Percy Wilson at 7.15 at the Royal Society of Arts, John Adam Street, W.C.2.

29th. Radar and Electronics Association.—"High-quality sound broadcasting" by Dr K. R. Sturley (Engineering Training Department, B.B.C.) at 7.30 at the Royal Society of Arts, John Adam Street, W.C.2.

BIRMINGHAM

8th. Brit.I.R.E.—"The development of h.f. tape recording" by P. J. Guy at 7.15 at the Matthew Boulton Technical College, Suffolk Street.

BRISTOL

8th. Television Society.—"The design of experimental tuners for bands 4 and 5, television receivers" by K. H. Smith (Siemens Edison Swan) at 7.30 at the Hawthorns Hotel, Clifton.

17th. Brit.I.R.E.—"The transistor and its use in communication and control equipment" by E. Wolfendale at 7.0 at the School of Management Studies, Unity Street.

CAMBRIDGE

7th. I.E.E.—"Rockets and satellites" by Dr. R. L. F. Boyd at 6.30 at the Technical College.

8th. I.E.E.—"The reliability of components" by G. W. A. Dummer at 8.0 at the Cavendish Laboratory, Free School Lane.

CARDIFF

17th. British Computer Society.—"Mechanical translation of languages" by Dr. J P. Cleve (University Computation Laboratory, Southampton) at 6.30 at University College.

CHELMSFORD

8th. I.E.E. Graduate and Student Section.—"The bond disc with particular reference to the f.m. regulator" by S. J. Read at 7.0 in the Electricity Showrooms.

CROYDON

17th. Association of Supervising Electrical Engineers—"Electronics in industry" by S. R. Rose (Croydon Electronic Machines) at 8.0 at the Greyhound Hotel, High Street.

EDINBURGH

18th. Brit.I.R.E.—"The digital voltmeter" by J. A. Irvine and D. A. Pucknell at 7.0 at the Department of Natural Philosophy, The University, Drummond Street.

GLASGOW

17th. Brit.I.R.E.—"The digital voltmeter" by J. A. Irvine and D. A. Pucknell at 7.0 at the Institution of Engineers and Shipbuilders, 39 Elmbank Crescent.

LIVERPOOL

10th. Society of Instrument Technology.—"New simple transistorized industrial instruments" by A. Green at 7.15 at the M.A.N.W.E.B. Industrial Development Centre, Paradise Street.

MANCHESTER

9th. I.E.E.—"New amplifying techniques" by C. W. Oatley at 6.15 at the Engineers' Club, Albert Square.

10th. Brit.I.R.E. — "Learning machines" by P. Huggins at 6.30 at the Reynolds Hall, College of Science and Technology, Sackville Street.

NEWCASTLE UPON TYNE

7th. I.E.E.—"Dielectric materials—trends and prospects" by C. G. Garton at 6.15 at the Rutherford College of Technology.

9th. Brit. I.R.E.—"Micro miniaturization" by H. G. Manfield at 6.0 at the Institution of Mining and Mechanical Engineers, Neville Hall, Westgate Road.

RANDOM RADIATIONS

By "DIALLIST"

Lunar Television

PHOTOGRAPHING the far side of the moon, developing the pictures and transmitting them over a distance of more than a quarter of a million miles to the earth must be the most remarkable achievement ever accomplished with the aid of wireless. A general account of the whole procedure was given in *Soviet News* of November 5th. The stopping and starting of the "lunik's" rotation, the tilting of its business end first away from the sun and then, more exactly, to face the moon, the triggering of the camera shutter for the various photographs that were taken, the starting, control and stopping of the developing process and finally the actual transmission of the pictures themselves were all done by radio control. The pictures were transmitted in black and white using a flying-spot scanning tube and photo-multiplier in a way similar to that used for films by ordinary television stations but some thousands of times slower. Long- and short-distance transmission were used, both the speed of transmission and the number of lines transmitted being changed according to the transmission distance. The maximum number of lines transmitted was 1,000. The received signals were recorded in as many as four different ways; on film, on tape, on long-persistence tubes and on electro-chemical paper using pen recorders.

Transistor Progress

THE manufacture of transistors has shown such expansion in this country that the British Radio Valve Manufacturers' Association (B.V.A.) is to hand over to a new association, the Electronic Valve and Semiconductor Manufacturers' Association (V.A.S.C.A. for short), its responsibilities for semiconductors and also for industrial valves and c.r. tubes. The B.V.A. is to continue its interest in the valves and c.r. tubes used in domestic sound and television equipment. One hopes that the greatly increased manufacture and use of transistors will lead in due course to even greater reductions in their price. This should happen as better and more efficient methods of making them are developed through the co-operation of members of V.A.S.C.A. It won't, I think, be many years before the valve radio receiver becomes something of a museum piece. Some parts of the television receiver present problems with which only valves can still now deal: I'm thinking in particular of the line and frame scans and of the provision of e.h.t. voltage for the c.r. tube. Still, problems are there to be solved and back-room boys are there to solve them.

V.H.F./F.M. in France

FROM the editorial of a recent issue of the French monthly *Radio Constructeur et Dépanneur* I gather that v.h.f. sound broadcasting is not very popular in France. That's curious when one thinks of how well it's gone down in this country and in Germany. The writer of the article is puzzled by the rarity of the v.h.f. aerials in areas served by f.m. stations and asked various people—retailers, listeners and servicemen—if they could offer any explanation of this lack of interest. Among the reasons suggested is one which comes as a great surprise: listeners in some areas said that the quality of the musical transmissions was very poor, being definitely below the standard of local a.m. broadcasts. If that's really so, one can't wonder that the number of v.h.f./f.m. listeners is small. But I very much doubt if the transmitters are to blame; it seems more likely, don't you think, that the frequency-modulation portion of some French a.m./f.m. receivers is not so good as it ought to be.

Tidying up the Television Receiver

THE use of the short-necked 110-degree cathode-ray tube and of more and more miniaturized components has much improved the appearance of this year's 17-inch and 21-inch television receivers. And as transistors come increasingly to take the place of valves, those of the not-so-distant future will doubtless be still neater and more compact. Ingenuity has largely overcome the difficulty of obtaining dead-sharp definition near the vertical edges of big c.r.t. screens, and it seems to me that the best receivers of to-day give just about as good a picture as it's possible in practice to get with 405-line scanning. But the picture isn't everything in TV reception, and in some of the cheaper mass-produced table models the accompanying sound leaves much to be desired. I'm thinking of sets made not only in this country but in other countries, too. It costs money to provide good audio output, and to designers of low-priced sets every penny must always be an important consideration. And, too, there's the question of the space available. Reduce the size of your table model cabinet to the smallest possible dimensions and there's hardly room enough for a good-sized loudspeaker. It's different with sets of the console type, for the lower compartment may contain nothing but the output transformer and the loudspeaker. Nor is it so important for the price of a console to be kept as low as possible, for it is to some extent looked on as being in the luxury class of set.

Future of the TV Aerial

EVEN the most dyed-in-the-wool TV enthusiast could hardly claim that the Yagis which now assert themselves so conspicuously on the skylines of our towns and villages are things of beauty. My forecast is that as time goes on they'll gradually become less and less in evidence. I don't mean that there will be fewer TV sets, for that certainly won't happen. I think that new ferrite materials may lead to wider use of indoor aerials in places where signal strength is good and that more and more of the areas troubled by ghosts, interference and weak signals will be served by master aerials placed in trouble-free spots and providing piped TV. Then again, increasing use is likely to be made of communal aerials serving blocks of flats, groups of houses and even whole housing estates. I for one certainly wouldn't mourn the demise of the domestic roof-top TV aerial as we now know it.

Bigger and Bigger Units

WE'RE all familiar with such mega-units as the megacycle and the megawatt. But a prefix which multiplies by a mere million wasn't found big enough to meet all today's needs, and giga (symbol G) with its multiplication by 10^9 appeared some time ago in such terms as Gc/s. Today, in France at any rate, that prefix has been found inadequate for certain purposes. The French Electricity Supply Authority now measures the combined output of its generating stations in TWh, or terawatt-hours, the tera-prefix indicating multiplication by 10^{12}. One can't somehow help wishing that the new prefixes hadn't been such linguistic barbarisms as they are; but that, I suppose, is just one of those things.

UNBIASED

By FREE GRID

Mute Monument

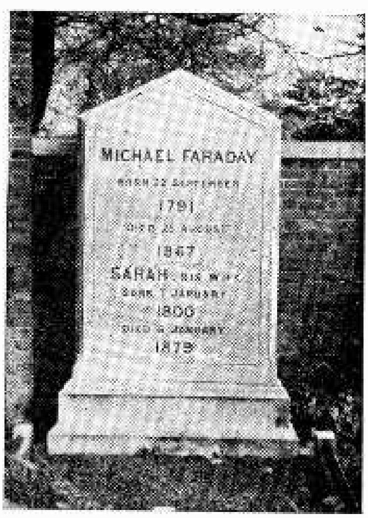
I SUPPOSE that everybody has heard of Karl Marx, and anybody passing his tomb in Highgate Cemetery will not need to be told who he was. It is otherwise, however, with a man buried in the same cemetery whose grave many people must pass each year without realizing what a great debt they all owe to him for so many of the comforts in their homes, which are due to his genius in discovering and investigating electromagnetic induction.

Faraday's simple headstone, although well kept, is in great contrast to the flamboyant bust of Marx, but it tells the passer-by nothing about the benefits his work conferred on the world which, of course, are not limited to the field of electricity.

When I passed it with Mrs. Free Grid a few months ago I paused awhile and remarked to her that I thought few people who enjoyed the comfort of electric lighting in their homes as well as heating, sound broadcasting and television realized they owed it all to him.

To my astonishment she flatly contradicted my statement that Faraday was at the back of all the modern electrical comforts we enjoy. She pointed to the date of his death as recorded on the headstone, and said it was obvious that he could have had nothing to do with radio. She added that she had always understood Edison to be the pioneer of incandescent electric lighting.

Summoning up all my reserves of patience—which as a married man are naturally considerable—I tried to explain that all the electrical comforts we enjoy at home depend on an adequate supply of power from the mains, and that if Faraday had not discovered and investigated the phenomenon of electromagnetic induction there would be no generating stations.



Faraday's simple headstone which is cared for by the Faraday Society.

By this time several people, attracted by the argumentative tone of my voice, had stopped to listen. When Mrs. Free Grid suddenly produced her transistor portable and asked what generating stations had to do with that, there were murmurs of agreement from the women in the little crowd. Why is it, I wonder, that females, despite their dislike of their own sex—so strongly exemplified in canine females—will always rally to each other's side in an argument with a man?

It was useless for me to point out, as I did, that there were many instances of the principle of induction in her little portable. She promptly produced a pocket torch and asked what there was in that for which we could thank Faraday. Eventually I made a dignified retreat on the grounds that a cemetery was no place for wordy warfare.

Radio Relics Club

MY recently expressed opinion that F. H. Haynes pioneered the use of the loudspeaker in politics seems to have been rather wide of the mark as is made quite clear by Haydon G. Warren, of Luton, who in his letter to the Editor (see page 566) states that p.a. equipment appeared in the U.S.A. as early as 1910. It is rather surprising to learn this. I happened to be in Washington and New York ten years later during the presidential election campaign of November, 1920, in which Harding was elected, and I cannot remember seeing any sign of p.a. although ordinary broadcasting was going strongly. I do recollect, however, buying a moving-coil loudspeaker then (the old horn-type Magnavox), which I still have, and also my first electric razor—a murderous device worthy of Sweeney Todd himself.

If the use of p.a. equipment dates from 1910 or earlier, I wonder when the first complete radio receiver—as distinct from components—was offered for sale to the public. Many people might be inclined to say May, 1922, when the P.M.G. of the day made his first public announcement of the forthcoming broadcasting service which commenced regular operation six months later. However, to my own recollection, complete sets were on sale a couple of years after the end of the first World War. Several firms—and in particular that of Leslie McMichael—offered for sale ex-W.D. a.f. amplifiers with detector and tuner added.

But sets were on sale even before the first World War, as I recollect one being marketed and advertised in *Wireless World*. It consisted of a combined magnetic detector and tuner. Its primary purpose was to receive time signals from the Eiffel Tower (call sign FL).

Long before that even, units consisting of a coherer and decoherer, all parts neatly mounted on a baseboard, were on sale. I published a photograph of one of these a few years ago. It certainly had no tuning arrangement, but such a refinement was hardly necessary in those days of shock excitation from a plain-gap and plain-aerial spark transmitter. The earliest set was undoubtedly the resonator ring of Hertz in 1888, but it was certainly not on sale to the public.

Personally I should like to see the formation of a Radio Relics Club which would establish and maintain a central museum for all such relics including literature. There are, of course, radio relics in the Science Museum, but since it caters for *all* branches of science it is impossible for adequate space to be set aside to show any large quantity of radio relics. The Royal Photographic Society sets us an example, as it has a museum for old cameras and other photographiana.

I, for one, have a few old relics such as one of the earliest all-mains sets marketed, which Mrs. Free Grid is constantly threatening to throw out. No doubt many of you are in a similar predicament and would be glad to find a home for your relics.

Technical Adam Wanted

I WISH there could be some official body to regulate the nomenclature of things in the field of radio and electronics as soon as they are invented. I have often felt this, but I am made to feel it more strongly still by reading in an otherwise respectable newspaper all about the working of an instrument which it describes as an encephalogram. This word is usually used for the record which the machine makes. It is not the name of the machine itself, any more than the word oscillogram is the name of an instrument.

What, then, *is* the name of the equipment which produces an encephalogram? On the analogy of an oscillograph we must, I suppose, call it an encephalograph. But a "telegraph" isn't the name of the machine which transmits a telegram; or is it? We need somebody or some body to deal with these matters as authoritatively as Adam did with the naming of the birds and the beasts (Genesis, II, 20); but he was lucky, as his wife was not then in existence to disagree with his names.