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EXPRESSION OF METRIC VALUES IN SCIENTIFIC PAPERS

At the Royal Society Empire Scientific Conference held in July, 1946, the following resolution was passed : " If textbooks and scientific data or memoirs are expressed in systems other than the metric, conversion factors or the metric equivalent should be included."* There is a variety of ways in which this can be done, and some of them were considered at a meeting held in the Royal Society's Rooms on December 12th, 1947, at which the Institution was represented.†

The National Physical Laboratory has now published a paper on " The inclusion of equivalent metric values in scientific papers." This paper should be studied by all engineers and especially by authors of papers for publication in the Institution's or other scientific Journals. It does not advocate that the existing system of British units should be replaced by the metric, but merely that numerical data when expressed in British units should be easily intelligible in countries which use the metric system. The procedure outlined in this paper is based on experience gained at the National Physical Laboratory, and it is suggested that this system should be reviewed, if necessary, at the end of a year of full-scale trial. The scheme is an important step towards international standardization, and should receive the support of all engineering institutions.

Although radio engineering probably makes more use of the metric system than any other branch of engineering, there are instances, notably wire tables and coil data, where the dimensions are customarily expressed in British units. Since in these cases it is inconvenient to use metric units, it is desirable to insert the equivalent metric values. Two methods of including the metric values are recommended, by parentheses and double entries in the text, or by tables of conversion factors. The circumstances governing the choice of either one method or both concurrently are discussed, and notes on graphs and diagrams are included.

It is suggested, therefore, that this scheme be introduced, where appropriate, into papers published in this Journal. It is recognized that this will give authors and editors a certain amount of extra work in the preparation of papers, but far less than the work which may be demanded of readers if it is not done. In order to lighten this task, the report contains an Appendix of the conversion factors from the British to the metric system for most of the physical qualities which are of frequent occurrence, and the Institution is prepared to provide a copy of the report to authors on application.

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* *J.Brit.I.R.E.*, Sept., 1947., p. 194.

† *J.Brit.I.R.E.*, March-April, 1948, p. 61.

THE MEASUREMENT AND SUPPRESSION OF RADIO INTERFERENCE*

With particular reference to domestic appliances

by

J. H. Evans† (*Associate Member*)

A paper read before the South Midlands Section on November 25th, 1948, *and before the Scottish Section on December 15th*, 1948

SUMMARY

The paper firstly outlines the nature of Radio Interference and the principles of measurement, goes on to describe measurement techniques as used by a manufacturer, and briefly reviews available methods of suppression and the difficulties encountered in their application. Finally, the paper considers recommended suppression limits and points out some anomalies caused by their specification.

1. Introduction

The ever increasing use of electrical apparatus, especially in the home, and the extension in the use and range of communication and broadcast frequencies has drawn attention to the necessity of dealing more effectively with the problem of radio interference.

Practically any electrical device, or circuit, is capable of causing interference with radio reception. Although apparatus, generally, may conveniently be classified in two groups, non-interfering and potentially interfering, it is surprising to find that many so called non-interfering items are, in practice, the worst offenders. For example, faulty lighting and power switches, plugs and sockets and defective wiring are known to cause severe interference with broadcast reception in many homes.

On the other hand, large electrical plant, although it may be a recognized offender, is usually installed so far away from listeners' dwellings that its effect on reception is negligible. However, the Electrical Industry does require to know the interference-producing characteristics of all its products, because the problem of suppression, when necessary, is largely an economic one, and in some cases changes in design may materially reduce the interference characteristic without greatly increasing the cost.

To enable the manufacturer to assess when a machine is adequately suppressed he must be able :—

(1) To measure the intensity of the interference generated by it under conventionalized conditions.

(2) To have some agreed standard to which he may make it conform.

These two problems are entirely separate and distinct, and will be considered as such.

2. The Nature of Interference

2.1. *Classification of Types*

To measure the intensity of radio interference necessitates a knowledge of its nature.

Interference may be broadly divided into two main classes :—

(1) Radiated—that is to say interfering voltages radiated directly from the machine into the receiving system.

(2) " Mains borne "—Interfering voltages transmitted from the machine to the receiving system via a common power supply system.

" Mains borne " interference is again subdivided into two forms :—

(1) Symmetric,

(2) Asymmetric,

the first being the interfering voltages appearing between the lines and the latter being those

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* Manuscript received December, 1948. U.D.C. No. 621.396.828.

† Research Laboratories, the British Thomson-Houston Co., Ltd.

appearing between the lines considered as a pair, and earth.

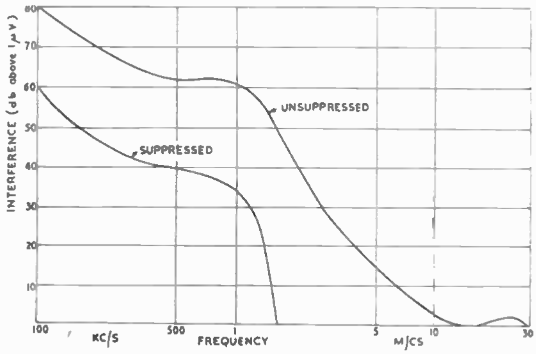
These three types cannot, of course, be separated into watertight compartments. For instance, interference may be coupled into a receiver by radiation from mains wiring. Conversely, the interference may originate as radiation from a machine, but be coupled into the receiver via the mains connection.

Again, the interference-producing voltages at the terminals of a machine may be symmetric but after some yards of conduit may appear asymmetric at a receiver.

It is necessary, therefore, to measure interference levels under closely controlled conditions, and these conditions must, of course, be related as nearly as possible to the probable conditions met in practice.

2.2. *Frequency Characteristic*

Interference is almost invariably caused by transients occurring in the current flow into the machine. These transients can cause interference directly or can shock-excite parts of the circuit of the machine into oscillation and so set up damped wave trains. It must be remembered that a machine may have a multitude of resonant frequencies throughout the spectrum even though its fundamental natural resonance may be of the order of a few cycles only, and oscillations may occur at every resonant frequency simultaneously.



TYPICAL INTERFERENCE SPECTRUM

Fig. 1.

The interference spectrum of domestic appliances is generally of the form of Fig. 1. It will be noticed that the general trend is a progressive falling off with increasing frequency.

The falling off is due to several causes, chiefly the decrease in the amplitude of harmonics, and also the increasing "self suppression" of the machine by its own self capacity. The shape of this curve varies very widely from one class of machine to another, of course, and levels vary by decades in frequency and orders of magnitude in amplitude. The variations between machines of similar construction are usually, however, fairly small.

From the foregoing it will be apparent that, as the interference forms a continuous spectrum, the interference power measured will vary according to the bandwidth of the measuring device. In other words, the measuring set, in effect, integrates a small portion of the spectrum and thus its bandwidth must be closely defined.

It follows then that interference may be treated by Fourier analysis methods, and its behaviour at any frequency predicted from the magnitude of its harmonic components about that frequency.

2.3. *Time Characteristic*

The interference itself may consist of an isolated peak or transient, as for example, in the case of a switch, occasional peaks, as from a thermostat, or continuous trains of peaks, as, for example, from electric motors. Each individual peak will, of course, have its appropriate frequency spectrum.

The annoyance value of the interference, naturally, increases with decreasing intervals between peaks and thus the last group is by far the most important.

As the measuring set may have to respond to isolated impulses its rectifier time constant must also be strictly defined. Similar impulses must charge the reservoir capacity to the same percentage of the peak value on every measuring set.

As interfering peaks are random in phase from one machine to another the effect of several interfering sources on a receiver at any frequency is the root of the sum of the squares of their interfering voltages at that frequency. The implications of this are rather important.

They are :

(1) In situations where interference is caused by a number of similar machines all must be suppressed to obtain a useful improvement in overall interference level. This effect is shown in Fig. 2, and has been confirmed by measurement.*

(2) Interference levels 10 db. or more down on another interference source may be neglected.

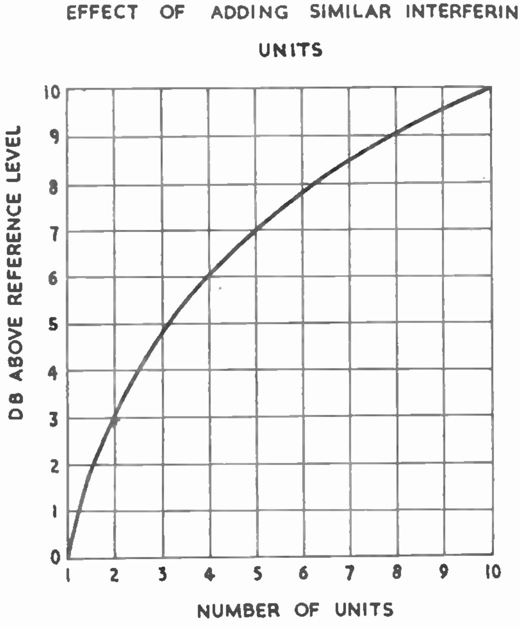


Fig. 2.

3. Interference Measurements

3.4. *Measurement Parameters*

In 1934 an international commission, known as the Comité International Special des Perturbations Radiophoniques, considered these problems, and recommended the various parameters for measurement.† The two already mentioned are :

(1) The bandwidth of the measuring device should be 9 kc/s, as this is the separation of broadcast stations, and is the minimum bandwidth necessary for pleasing reproduction of music.

(2) The time constants of the rectifier should be one millisecond for charge and 160 milliseconds for discharge, with an indicating meter time constant of 160 milliseconds.‡

These constants give a response closely allied to the annoyance value of the interference as assessed by the human ear.

3.2. *Field Strength Measurements*

For measurement of field strength only one other parameter is required to be defined : the distance from the machine at which the field is to be measured.

Interference field strengths, in common with other radio fields, are measured in volts per metre, but as interference is closely related to human perceptions, it is usually expressed in decibels above an arbitrary level of one microvolt per metre.

Thus the measuring device is fitted with a rod aerial of known effective length, and is calibrated on C.W. transmissions by standard methods.

But the directly radiated fields of domestic appliances are, in general, small, provided that large interfering voltages are confined to the machine itself and are not permitted to appear on the mains leads. Consequently, radiated fields will not be considered further in this paper, except in passing.

3.3. *Terminal Measurements*

As described previously, the machine generates interference both across its terminals and between its terminals and earth.

It has been found that the mean impedance the machine sees looking into the mains is about 150 ohms in either case and, accordingly, the networks of Fig. 3 were recommended for the measurements of interfering voltages. In practice, the two networks are combined by switching as shown in B.S.S. 727 (1938 edition). Interfering voltages are expressed in decibels above one microvolt.

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* Unpublished B.T.H. Research Laboratory report.

† *Proceedings of the C.C.I.F.*, Vol. 4, p. 258 (Budapest Meeting).

‡ Since increased to 500 milliseconds and greater than 250 milliseconds respectively.

The chokes serves a double purpose: firstly, they prevent interference from outside sources affecting the measurement; and secondly, they ensure at the same time that the machine sees the 150-ohm impedance.

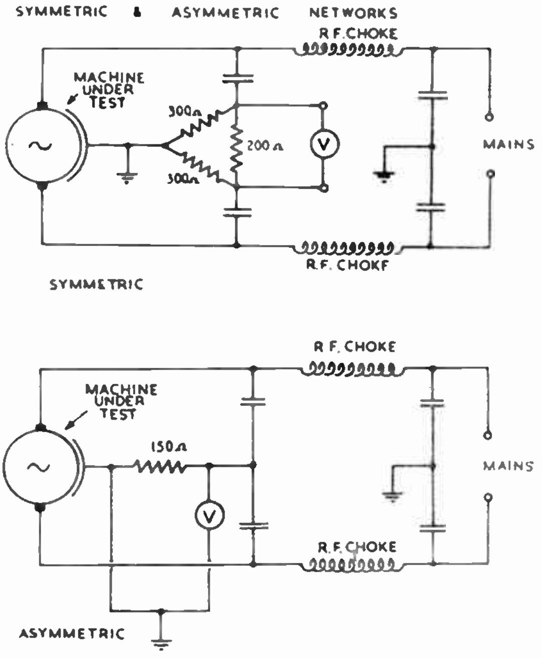

Fig. 3.

It will be seen that the circuit for measuring symmetric interference requires a balanced input into the receiver. This is fairly easy to achieve at low frequencies, and the method sufficed quite admirably for measurements on the two main broadcast bands. With the increasing use of higher frequencies, however, particularly for television, it became necessary to extend the frequency range of the measurement and the balanced input was found to be too critical to be practical.

Accordingly it was agreed to change the network to the circuit of Fig. 4, which, it will be seen, is very much simpler and only requires a 75-ohm line into a matched receiver. It also has the great merit of reducing the number of measurements necessary on multiphase apparatus. The obvious disadvantage is that the method apparently only measures asymmetric interference on either line.

In actual fact, however, this is not so. Referring to Fig. 5, the theoretical circuit of the measurement, it will be seen that if the symmetric interference level is appreciably higher than the asymmetric, the level read on the measuring device will be 6 db. less than the symmetric interference. In practice, however (neglecting the special case of unearthed appliances), the symmetric and asymmetric voltages are almost invariably of the same order, and there will be an apparent increase in asymmetric voltage. Numerous tests have been made to establish the importance of this effect, and the increase is generally of the order 3 to 4 db.

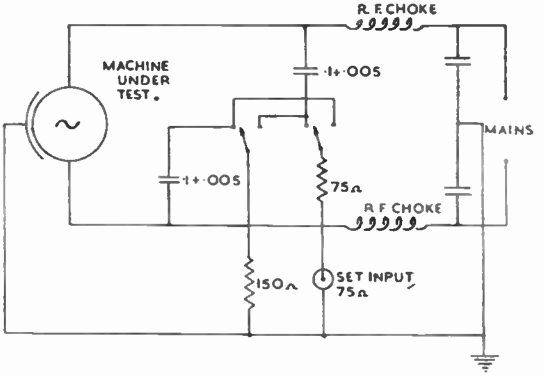

Fig. 4.

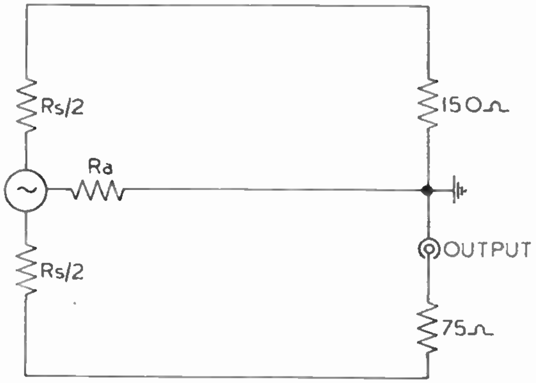

Fig. 5.

Incidentally, the receiver is usually affected more by asymmetric than by symmetric interfering voltages, and thus the new network corresponds more closely to the practical case than the old.

3.4. *The Interference Measuring Set*

3.4.1. *General*

The receiver used by the company with which the author is associated was developed from a similar design by the Electrical Research Association.* It is very specialized in its function and the main consideration throughout its development was accuracy and stability of calibration ; consequently the equipment is complex and somewhat bulky.

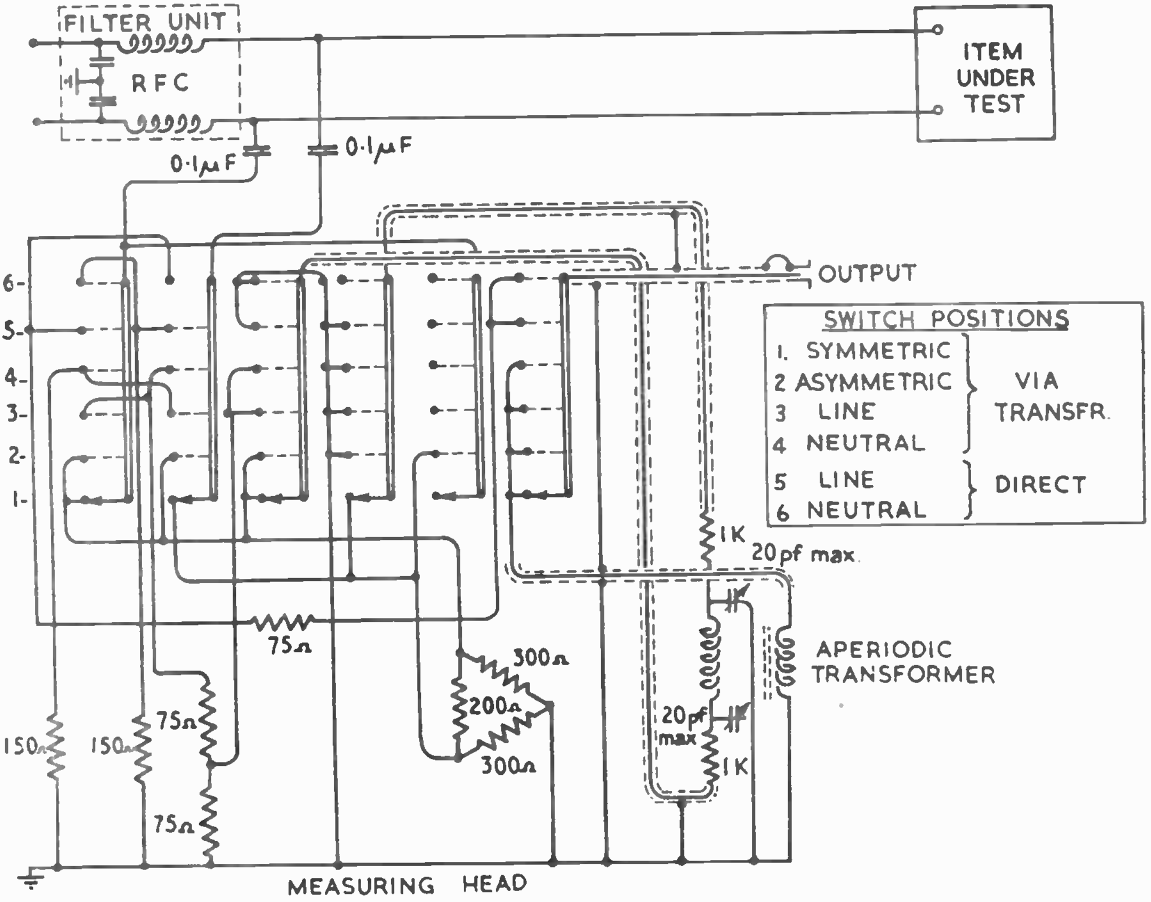

Fig. 6.

The complete equipment is housed in four main units :—

(1) The measuring head, which is usually left installed on a testing panel.

(2) The receiver proper.

(3) The power supply unit, which also contains the output meter.

(4) An adapter unit to cover frequencies around and below the intermediate frequency of the main receiver.

These will now be described in greater detail.

3.4.2. *The Power Supply Unit*

This is quite conventional except that the equipment may be supplied by A.C. mains of

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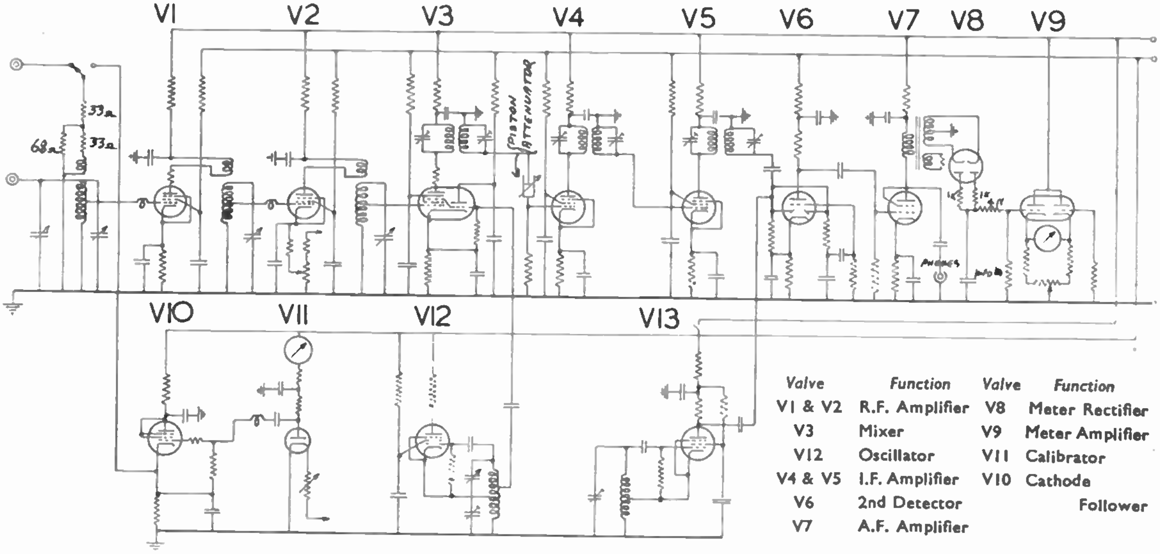
*Pearce, Turney and Smith, " Modifications to Reception Set R.206, Mk. I, for the measurement of Radio Interference." *Electrical Research Association Report M/T90.*

all the usual voltages or a 12-volt battery via a built-in vibrator. Rather elaborate H.F. filters are fitted in all supply leads, including heaters. Two H.T. lines are provided, one of which is stabilized by a neon discharge tube.

3.4.3. *Measuring Head*

The measuring head circuit is shown in Fig. 6 and incorporates both the networks described previously.



Valve	Function	Valve	Function
V1 & V2	R.F. Amplifier	V8	Meter Rectifier
V3	Mixer	V9	Meter Amplifier
V12	Oscillator	V11	Calibrator
V4 & V5	I.F. Amplifier	V10	Cathode Follower
V6	2nd Detector		
V7	A.F. Amplifier		

Fig. 7. Receiver Unit (Simplified Diagram).

The company with which the author is associated has records of measurements on practically every type of machine it has manufactured. When the change of network was agreed it was feared that all this experience might be wasted, as the full implications of the change could not be predicted.* Both networks were incorporated, therefore, to allow comparisons between old and new machines under identical conditions of test.

The balanced transformer design may be of interest. The out-of-balance component is better than 60 db. down on the required component measured in accordance with B.S. 727 (1937 edition) at various frequencies up to 2 Mc/s, and its loss varies from less than 2 db. below 800 kc/s to 5 db. at 2 Mc/s. The transformer complete would fit into a half-inch cube.

A 40 db. resistive pad, which can be seen in Fig. 10 lying in front of the receiver, may be fitted between the measuring head and the input of the receiver, if desired.

3.4.4. *Receiver Unit* (*Fig.* 7)

The R.F. circuit and mixer are fairly conventional, comprising two R.F. pentodes and a triode hexode, with separate oscillator.

There are six wavebands, continuously tuned from 600 kc/s to 30 Mc/s, with tuning coils mounted in turrets. The coil details vary from range to range, but are simplified in the diagram for clarity. The lower frequency range coils are damped to maintain the bandwidth wider than 9 kc/s, so that the bandwidth is determined by the I.F. amplifier only.

The intermediate frequency amplifier is fed via a piston attenuator which is calibrated directly in decibels. It has a maximum attenuation of 80 db. and is linear from 20 db. upwards; below this there is a correction factor increasing to some 3 db. at minimum attenuation. A photograph is shown in Fig. 8.

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*Several authorities made analyses of expected results, but it was not possible to obtain unanimous agreement.

The I.F. amplifier is fairly conventional, except that it will handle an overload of 40 db. greater than the C.W. signal that would give full output on the meter. This overload factor is necessary because, if isolated impulses are being received, the rectifying circuits will only be charged to a small percentage of the C.W. value.

Fig. 8.—Piston Attenuator.

It will also be noticed that there is a beat oscillator valve. This is tuned to the centre of the I.F. pass band, and ensures that an exact replica of interference at the input terminal is passed via the rectifier to the A.F. amplifier and meter. It also simulates the actual operating condition, as interference by definition can never exist unless a carrier is being received, but it has been shown that the presence or absence of a carrier makes no appreciable difference to the accuracy of the measurement of interference.*

The I.F. transformer tuning is arranged with the first two circuits overcoupled and the last one peaked. This provides an overall response curve as shown in Fig. 9, giving an integrated power bandwidth very close to 9 kc/s. To obtain and maintain this result it was found necessary to incorporate much more elaborate screening and filtering than is normally required for a similar receiver of the communications type.

The detector and output circuits are again fairly conventional. A telephone jack is provided for identification purposes, and to allow for this the A.F. transformer is kept permanently loaded by a 25-ohm resistor. The transformer response is level to within ± 0·3 db. between 40 and 8,000 c/s. It is, of course, essential that the A.F. circuits respond to the full bandwidth of the I.F. circuits. Naturally the meter rectifier time constants agree with the recommendations of the C.I.S.P.R., and critical values are shown on the diagram.

The meter valve is arranged to balance out standing current. The circuit used is not entirely satisfactory, as it suffers from warm-up drift necessitating the provision of a balance control on the front panel, but it has the advantage of simplicity and the variations are not large.

The meter itself was specially made for the equipment, having the time constants recommended by the C.I.S.P.R. These, incidentally, give a fast rise and slow fall, so that isolated impulses may be read easily. To the same end the scale, calibrated in decibels, is marked off alternately black and white so the height to which the pointer kicks may be readily assessed.

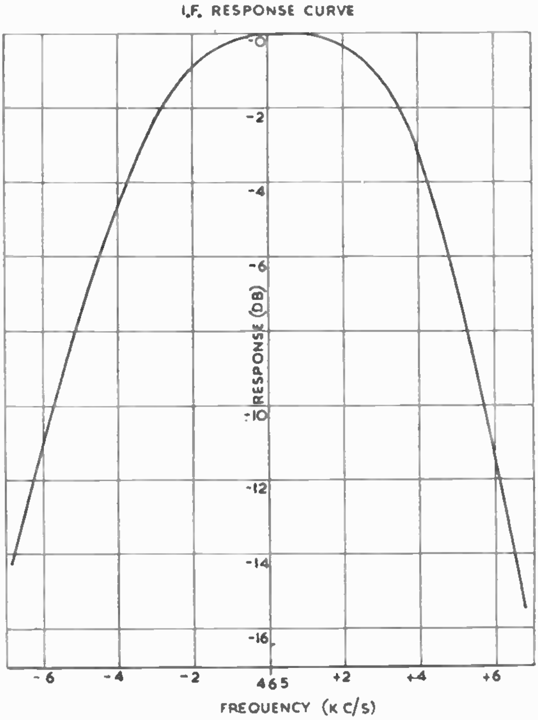

Fig. 9.

The measuring set is calibrated by means of a temperature-limited diode. As is well known, the noise output of such a device is constant over a far greater range than the frequency range of the measuring set. The output meter is switched

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* Gill and Whitehead. "Electrical Interference with Radio Reception." *J.I.E.E.*, Vol. 83, pp. 385-387.

to read the diode anode current, and the meter scale is marked with the setting up point required to give an output of 2 μV.

Such a calibration source is, of course, extremely accurate, and gives a permanently available indication of receiver performance.

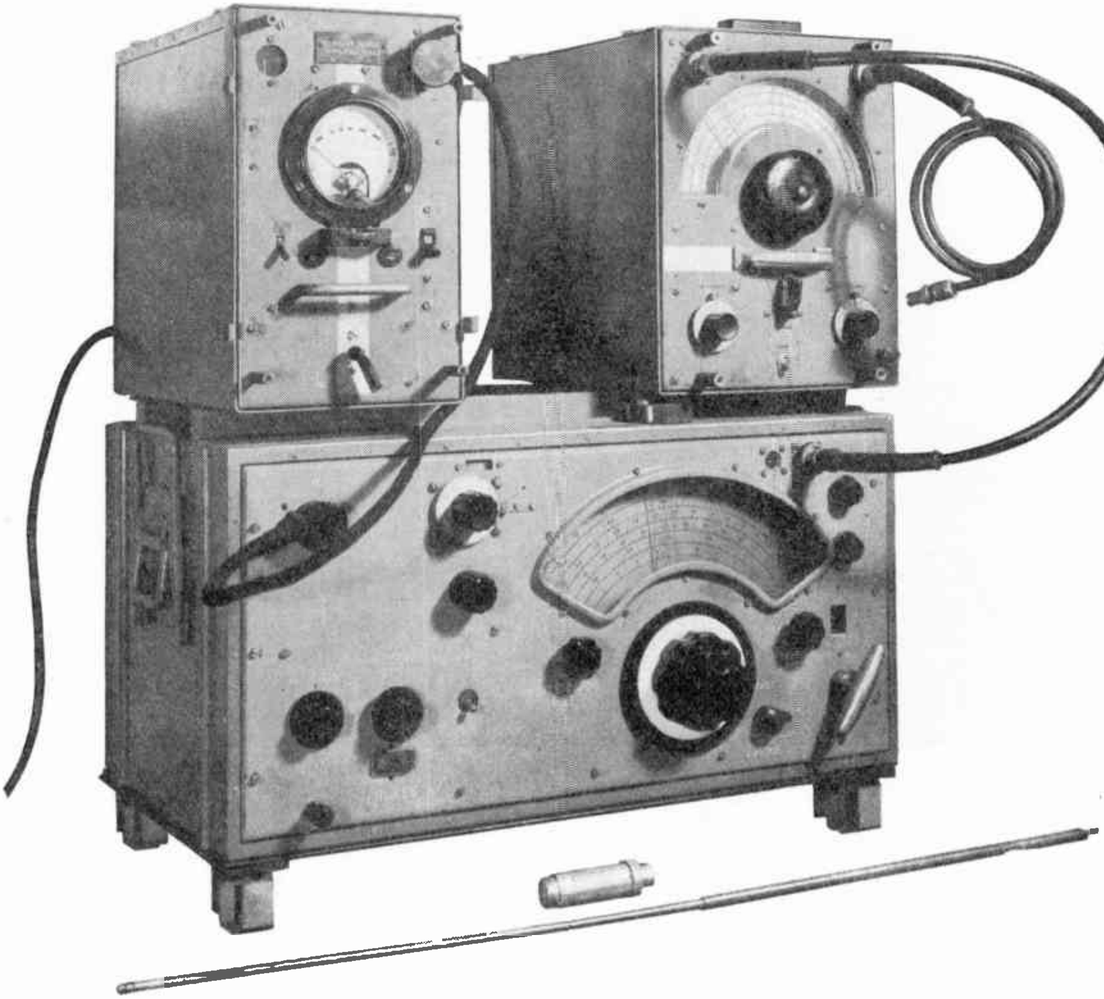

Fig. 10.—*Interference Measuring Set.*

3.4.5. *Low Frequency Adaptor Unit.*

This covers the frequency range 80 to 600 kc/s on three bands, using the main receiver as an I.F. amplifier.

The circuit is again quite conventional, one stage of R.F. amplification and a mixer giving an intermediate frequency of 700 kc/s, which is then fed into the measuring unit proper.

The R.F. circuits are heavily damped, but even then there is some bandwidth clipping, particularly in the lowest frequency range. This necessitates a correction factor,* but it never exceeds 1·5 db.† The bandwidth cannot be increased indefinitely, of course, owing to the consequent drop in sensitivity. The noise diode

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* The noise diode calibration takes bandwidth into account on smooth noise, but the correction is necessary on clicks or pulses.

† 0·8 db. over the range of B.S.S. 800.

calibration is used by plugging in the input lead to a socket on the main unit.

A photograph of the complete equipment is shown in Fig. 10.

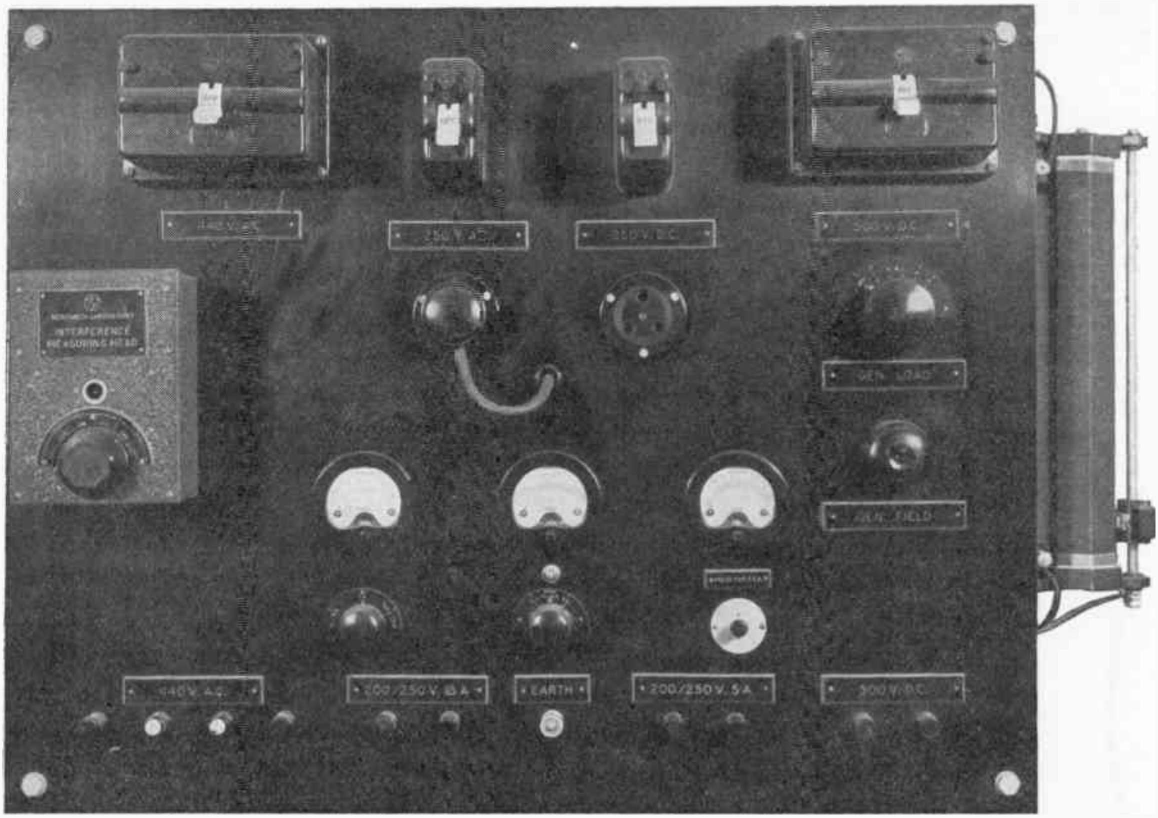

Fig. 11.—Interference Testing Panel.

3.4.6. *Performance of Measuring Set*

Frequency range	80 kc/s to 30 Mc/s.
Sensitivity	Signal to noise ratio better than 10 db. with 2 μV input.
Bandwith	9 kc/s.
Terminal input voltage range	1 μV to 1 V.
Field strength measurement range	1 μV/m above 1 Mc/s decreasing to 100 μV/m.
Estimated absolute accuracy .	Better than ± 2 db. on terminal measurements.

3.5. *Test Room*

The room in which precision measurements are carried out is lined throughout with sheet tin plate ; all joints are soldered, and the whole solidly earthed. The door fits into a recess, around the edges of which is metal braid to ensure a good electrical connection.

Mains enter the screened room via screened choke and capacity filters, and appear on the test panel of Fig. 12, which supplies D.C. and single- and three-phase A.C. Voltages can be varied by means of rheostats. The measuring head can be seen on the left of the panel. No field or noise voltages on the mains can be measured inside the screened room with any apparatus available.

Also fitted is a motor test set, comprising a separately excited generator working into a load. Both the load and field can be varied to accommodate all sizes of motor up to one horsepower. The field rheostat can be seen on the right of the panel.

On these assumptions the Test Set is designed to be pre-tuned to any frequency in the long wave band. The bandwidth is close to 9 kc/s over the tuning range.

A circuit is shown in Fig. 13. The rectifier time constants, meter and overload factors are very similar to those in the precision-measuring set. The attenuator is a ladder network with 10 db. steps, while the meter covers ± 10 db.

Fig. 12.—*Interference Test Set.*

3.6. *A Works Test Set*

The large interference-measuring set previously described is, of course, a precision instrument, and needs a skilled operator to handle it. Therefore, for factory use, where sampling tests have sometimes to be made, the test set of Fig. 12 was designed.

This is intended for use by semi-skilled operators, is entirely self-contained, is portable, has no correction factors and only operates on one frequency.

As will be seen, in general, suppression becomes increasingly difficult with decreasing frequency. Also, it is possible to select a test frequency for a particular appliance and be reasonably sure that if it passes at the test frequency, it will pass at all frequencies in the specified band.

The apparatus is set up by means of a standard signal generator, and all corrections, including the 6 db. for the test network, are taken up on the preset gain control. In use it is checked against a signal generator periodically, and the maximum error so far recorded over some 2,000 hours' running is less than 1 db.

Briefly the performance of the set is :

Frequency range (preset)	150-250 kc/s.
Bandwidth	9 kc/s.
Measuring range	34 to 80 db. above 1 µV (80 µV to 10 mV).

4. Interference Suppression

4.1. *Suppression Methods*

The actual suppression of machine interference has been extensively studied,* and it is not proposed to consider it in any great detail here.

In general, the suppression circuits available are those of Fig. 14. Their method of working is self explanatory. The condensers tend to short out symmetric and asymmetric voltages, and the chokes either increase the source impedance of the interference or provide attentuation by potentiometer action with the mains impedance. Usually the chokes are tuned, sometimes with external capacitors, but more generally with their own self capacitance, to give high attenuation over a small band of frequencies.

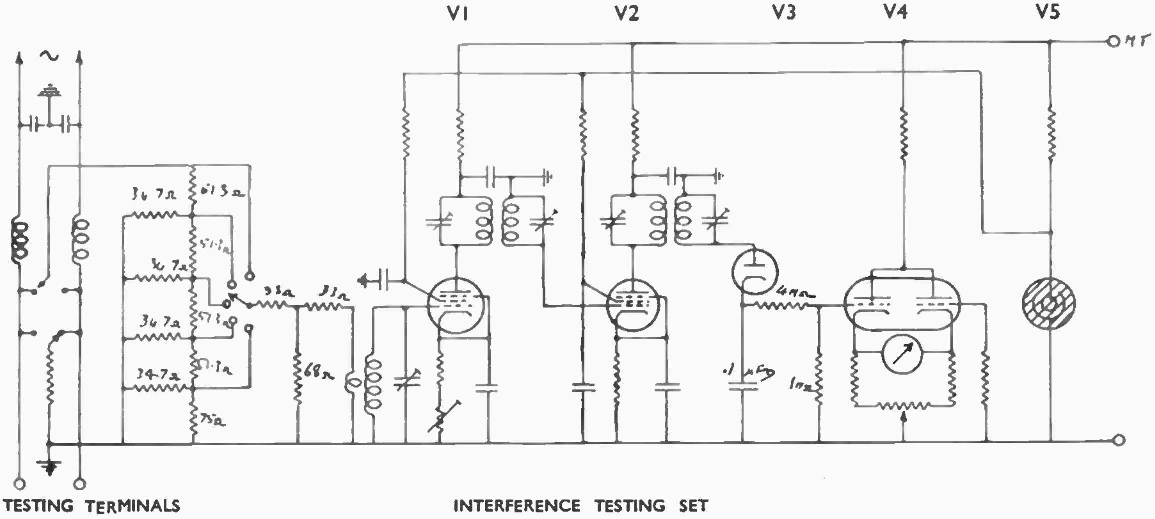

Fig. 13.

In large machines the cost of suppressors is trifling compared with the machine itself, and adequate suppression usually presents a straightforward engineering job.

On domestic appliances, however, which are almost invariably mass-produced, the cost of suppression may become an appreciable part of the cost of the machine. In addition, space is usually very limited, as appliances are generally required to be portable. Also, of course, raw materials are expensive and space consumes raw materials. Consequently, the smallest suppression unit is fitted which will adequately bring the interference below the recommended level and give a reasonable safety margin for different machines of the same type.

The circuit of Fig. 14b is adopted whenever possible, as the permissible voltage rating required for the symmetric capacitor is much lower than the asymmetric, and thus it is smaller and cheaper.† A typical suppressed characteristic is shown in Fig. 1. The assessment of the amount of suppression required in these cases entails a considerable amount of work on the effects of capacitor tolerance, and on the variations between similar machines.

4.2. *Effect of Unearthing the Appliance*

On domestic appliances the position is further complicated by the fact that these are frequently run unearthed. This results, firstly, in a reduction of the asymmetric interference, but this is no help to the manufacturer who, of course, must test his product under the worst condition. Secondly, and not so obviously, if the user is earthed and touches the casing of the machine he connects himself to the mains via the asym-

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* For instance, see J. H. Reyner, *Radio Interference—and Its Suppression* (Chapman & Hall, 1936).

† B.S S. 613, "Requirements for Radio Interference Suppression Devices."

metric suppression capacitor. Consequently, this capacitor must be limited to a safe value, specified at 0·005 μF.* Even at this, complaints are received of users suffering an electric shock, and a smaller value, of the order 0·001 μF, is desirable.

As 0·001 μF presents an impedance of some 800 ohms at 200 kc/s it is obvious that little suppression will result when the machine is looking into a 150-ohm line to earth. At 1 Mc/s the capacitor will be functioning to the extent of some 3 db. suppression, but in general the asymmetric capacitor is useless for the broadcast bands.

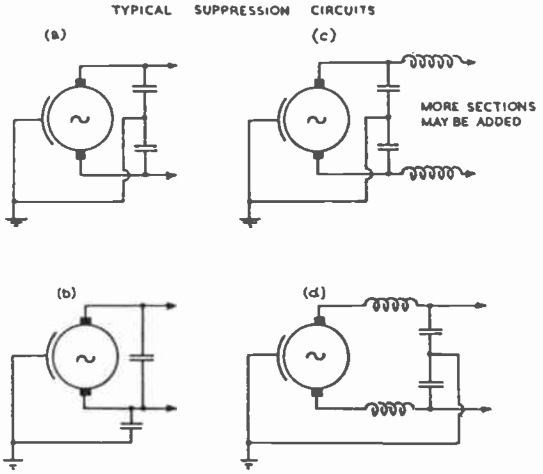

Fig. 14.

Where the capacitor is limited in value, suppression is usually carried out by combination filters of Fig. 14 (c) and (d). An example is shown in Fig. 15 which fits inside the handle of a vacuum cleaner. This gives some 20 db. suppression at 200 kc/s, but the unit is comparatively expensive. The best solution to the problem is by either complete elimination of external metal parts, or by insulating the inner from the outer metal case, both expedients allowing capacitor sizes to be increased by avoiding the possibility of the user suffering electric shock.

5. Specification of Suppression Requirements

5.1. *General*

As has been shown, the measurement of the intensity of interference, once suitable parameters have been agreed and defined, is a fairly straightforward engineering job. The assessment of the annoyance value of the interference is, however, a very different matter. The only competent judge of interference is the listener, and to this end a considerable amount of work has been carried out by the B.B.C. and others.

Fig. 15.—Typical vacuum cleaner suppressor.

Quite apart from the fundamental consideration of the differences between listeners themselves, the conditions under which the interference exists play an enormous part in determining its annoyance value.

5.2. *Effect of Signal Carrier Level*

Consider Fig. 16: this shows the interference, as measured in volts across the speech coil of the loud speaker of typical commercial domestic superheterodyne receiver, plotted against unmodulated input carrier level. The interfering source was a small motor, giving 6 millivolts of interference measured at the mains input of the receiver. This approximates to the worst condition normally likely to be experienced in practice, as more powerful interfering sources could be expected to be more remote and therefore interference would be attenuated before reaching the receiver. It will be seen that the interference rapidly becomes inaudible with increasing carrier level by A.G.C. action.

Assume, for the purpose of developing the argument, that interference 40 db. down on the

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* B.S.S. 613, " Requirements for Radio Interference Suppression Devices."

programme is completely inaudible and interference less than 20 db. down causes annoyance. In a normal-sized room the programme level in this particular case would be of the order 2·5 volts. By the foregoing assumption, the interference would be completely inaudible on a carrier level of 6,000 µV, and objectionable on a carrier of 1,000 µV. Such an effect could readily be caused by the difference in efficiency between a good and a bad aerial.

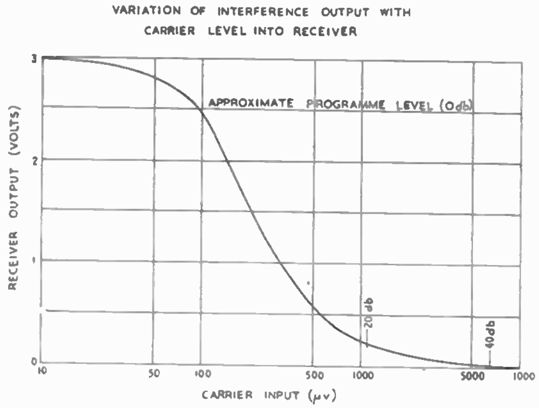

Fig. 16.

The converse is equally true. Consider two listeners with identical receivers and aerials in two different localities. The threshold of annoyance level of interference may vary by 40 db. or more, and is solely a function of geography.

5.3. *Effect of Duration of Interference*

Consider now an isolated click of short duration. Firstly, to be noticed, it has to be of comparable intensity to the programme at that time, and thus the probable threshold of perception level is bound to be high. Secondly, one isolated click has a very small annoyance value, small, for example, compared with the click of an announcer switching off his microphone or an extraneous noise in the studio. But if the click is repetitive the cumulative effect is very different. It causes annoyance merely by repetition, not by its intensity.

Take, for example, a house in a suburban road. The occurrence of light switch clicks is very infrequent. But consider the conditions in a block of flats. Switch clicks may now be far from infrequent, and although each individual switch offends but rarely, the cumulative effect may be very distressing.

5.4. *Recommended Limits*

Until fairly recently it has been assumed by most interested parties that the onus for suppressing interference lay entirely with the manufacturer, entirely disregarding the difficulties with which he has to contend. Now, however, it is realized that the listener can and should help himself, by the provision of an efficient aerial system.

In Germany, prior to the war, interference tests included an assessment of the effective height of the listener's aerial. It seems incredible to realize that for 90 per cent. of the cases investigated the mean effective height was 0·1 metre.* There seem to be no comparable data available in this country, but enquiries by the author and his colleagues amongst their friends and acquaintances gave a similar result.

Furthermore, the receiver designer can do a good deal to reduce the liability of his product to interference by the addition of screening and mains filters. Whether or not such a course is economically practicable, however, is debatable.

Recommended limits to which machines should be suppressed are published in B.S.S. 800. A new edition is at present in course of preparation and suppression limits are in a state of transition; but prior to the war the recommended limit was 500 µV. Various statistical sampling methods are also explained in the publication to allow for variations between similar machines.

Nevertheless, it must be realized that compliance of a machine with the requirements of B.S.S. 800 is by no means a guarantee that it will not interfere with radio reception. Conversely a machine may generate interference greatly in excess of the recommended limit and yet cause no annoyance whatever. Does such a machine cause radio interference in this particular circumstance, and should it be suppressed?

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* T. H. Kinman. *Publications of the B.T.H. Research Laboratories*, 1935.

6. Conclusion

It follows, as this paper has attempted to show, that although radio interference can be measured reasonably accurately and suppression requirements specified precisely, yet its annoyance value is a matter of human reaction, dependent on many factors, few of which can be covered by definition.

Impending legislation makes this point very important, and it is hoped that all concerned will interpret the act with the spirit of compromise that the vagaries of the subject demand.

7. Acknowledgments

In conclusion, the author would like to thank his colleague, Mr. T. H. Kinman, for his assistance and guidance in the preparation of this paper ; Mr. S. F. Pearce, of the Electrical Research Association, for his helpful and constructive criticism of the draft ; and Mr. L. J. Davies, Director of Research, the British Thomson-Houston Co., for permission to present the paper.

8. Bibliography

The bibliography on the subject of Radio Interference is most extensive, and space restrictions do not permit more than a small portion of it being included here.

The author has decided, therefore, in order to avoid the necessity of making a selection, only to include papers actually referred to in his text. As a matter of interest, reference 4, published in 1938, contains over 150 references to other papers.

1. *Proceedings of the C.C.I.F.*, 1934, Vol. 4 (Budapest Meeting).
2. B.S.S. 727 (1937), " Apparatus for the Measurement of Radio Interference."
3. Pearce, Turney and Smith, " Modifications to Reception Set M, R206, Mark I, for the Measurement of Radio Interference."
4. Gill and Whitehead, " Electrical Interference with Radio Reception."
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STUDENTSHIP REGISTRATIONS

Since the meeting of the Membership Committee on November 2nd, 1948, a total of 32 proposals for Studentship Registration has been received, and Council has now approved the registration of these, as follows :—

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The attention of prospective students is drawn to the fact that it is now required to have passed the Engineering Joint Examination Board's Common Preliminary Examination, or to be exempt therefrom, in order to be accepted as a student of the Institution.

Exemption can be obtained from the Common Preliminary Examination by virtue of Matriculation, School Certificate (passes with credit in Mathematics and a Science subject), Scottish Education Department's Leaving Certificate, Army, Navy and Air Force entrance examinations and other examinations, details of which can be found in the rules and syllabus of the Common Preliminary Examination, obtainable from the Institution.

The Engineering Joint Examination Board was originally formed by the Senior Engineering Institutions and the Common Preliminary Examination, or exemption therefrom, is now recognized by all professional engineering institutions as a necessary qualification for studentship registration.

DRY BATTERY CHARACTERISTICS AND APPLICATIONS*

by

N. M. Potter†

The purpose of this Paper is to explain how dry batteries work and to describe some of their characteristics and applications. Liberal use has been made of the literature on this subject. The author is especially indebted to a circular of the U.S. Department of Commerce[1], which was the source of much useful information and data.

Modern dry cells are a development of the discovery of a wet primary cell by Le Clanche in 1868[2]. Although a number of other types of wet primary cells were made by other inventors, Le Clanche's was the first practical cell.

It was twenty years later, in 1888, that Gassner[3] modified Le Clanche's cell and produced the first so-called " dry " cell. Gassner's modification was to use the zinc anode as the container, absorb the electrolyte in porous material and close the top of the cell with a sealing compound. This produced what was actually a " non-spillable " Le Clanche cell, but it became known as a " dry cell," a name that is still used to-day.

Gassner's contribution made possible a convenient portable form of packaged electrical energy, and gave birth to the dry battery industry, which started within a year or two of his discovery.

It is interesting to note that through all the intervening years there have been no fundamental changes from Gassner's original cell.

The magnitude of advances made in subsequent years may be judged from examples taken from a paper by Gillingham[4]. His performance figures relate to the better American brands available at the time, but are not confined to the product of any particular manufacturer.

The spontaneous shelf deterioration of dry cells of the ordinary No. 6 size for general purposes, occurring in 6 months, was reduced from 35 per cent. in 1901 to 25 per cent. in 1916 and to 7 per cent. in 1934.

In 1910, flashlight cells of the D size gave 260 minutes of service on the 4 ohm intermittent test, but in 1934 cells of this type yielded as high as 750 minutes.

Radio " B " batteries, which appeared about 1918, gave 377 hours on the 5,000 ohms continuous test, but in 1926 batteries containing the same size of cell gave 1,000 hours, and this was increased to 1,500 hours of service for batteries made in 1934.

Hearing-aid batteries, with D.C. size cells, gave 18 hours of service in 1932. In 1935, similar batteries gave 50 hours of service.

These advances in the art have been accompanied by improved quality control, an important factor in assuring a dependable, uniform product.

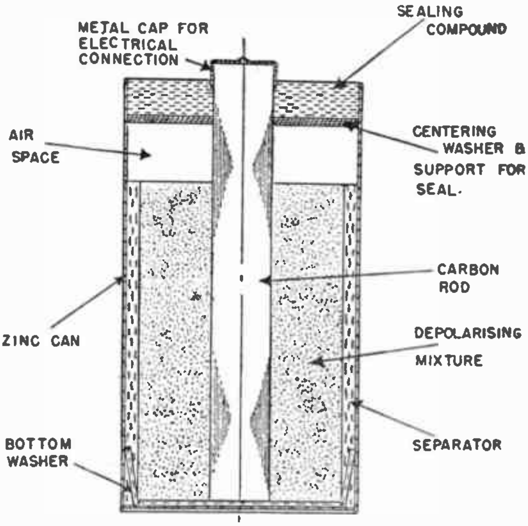

Fig. 1.—Structure of cylindrical dry-cell.

1. Construction

The construction of a typical type of cylindrical dry cell is shown in Fig. 1.

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* Reprinted from the *Proceedings of the Australian I.R.E.* January, 1946. U.D.C. No. 621.353.

† National Carbon Co. (India) Ltd.

The zinc can or cup serves as the anode (negative electrode) and as the container for the cell. The cathode includes the carbon rod (positive electrode) and the depolarizing mix. The separator may be a paste-coated absorbent pulpboard liner saturated with a solution of sal ammoniac and zinc chloride, or a layer of electrolyte paste made of a cereal flour and sal ammoniac-zinc chloride solution. The bottom washer centres the cathode and insulates it from the zinc anode. An air space is provided above the cathode to allow room for the expansion of electrolyte, etc., which occurs under certain conditions of use and storage.

The carbon rod acts as a chemically inert conductor to collect the current from the cathode material surrounding it. This cathode material, or depolarizing mix, contains manganese dioxide, to combine with the hydrogen that forms from the chemical reactions, and carbon to provide conductivity. It also contains some of the sal ammoniac and zinc chloride which, combined with similar materials in the separator, make up the electrolyte of the cell.

In the United States of America a committee consisting of representatives of the Government, battery manufacturers, and several large users of dry cells, reached an agreement in 1924 on a standard system of nomenclature for dry cells and batteries[5]. This same system has been used in the joint Army-Navy dry battery specification JAN-B-18, prepared and issued during the recent war. The sizes of cylindrical cells recognized as standard are listed in Table 1, which includes also the approximate volume and weight of the cells.

Theory of Operation

2.1. *Chemical Reactions*

The chemical reactions in a dry cell are exceedingly complex, and probably not fully understood. The two generally accepted fundamental reactions are as follows :

(1) $Zn + 2NH_4Cl = Zn\,(NH_3)_2Cl_2 + 2H$

The zinc dissolving in the ammonium chloride solution liberates hydrogen and forms a double chloride of zinc and ammonia. Manganese

TABLE 1. Sizes of Cylindrical Dry Cells

Cell Designation	Nominal Dimensions		Approx. Volume Cubic Ins.	Approx. Weight Pounds	Principal Uses
	Dia. Ins.	Height Ins.			
AA	$\frac{17}{32}$	$1\frac{7}{8}$	0·42	0·033	Flashlights, radio and miscellaneous
A	$\frac{5}{8}$	$1\frac{7}{8}$	0·57	0·045	Radio B Batteries
BB	$\frac{3}{4}$	$1\frac{5}{16}$	0·58	0·045	Flashlights, radio and export
B	$\frac{3}{4}$	$2\frac{1}{8}$	0·95	0·077	Radio B and C Batteries
C	$\frac{15}{16}$	$1\frac{13}{16}$	1·25	0·10	Flashlights
D	$1\frac{1}{4}$	$2\frac{1}{4}$	2·76	0·22	Flashlights and radio
E	$1\frac{1}{4}$	$2\frac{7}{8}$	3·52	0·28	Portable telephone
F	$1\frac{1}{4}$	$3\frac{7}{16}$	4·22	0·35	RR lantern, group and radio
No. 6	$2\frac{1}{2}$	6	29·3	2·2	Telephone, Ignition and general purposes
Miniature Cells					
R	$\frac{17}{32}$	$1\frac{5}{16}$	—	—	Mostly radio
P	$\frac{17}{32}$	1	—	—	Mostly radio
N	$\frac{7}{16}$	$1\frac{1}{16}$	—	—	Mostly radio
M	$\frac{17}{32}$	$\frac{3}{4}$	—	—	Mostly radio

dioxide, which is incorporated in the cathode, removes the hydrogen which would otherwise polarize the cell by forming an insulating layer on the cathode surface. This takes place according to the second reaction :

$$(2)\ 2MnO_2 + 2H = Mn_2O_3 + H_2O$$

The manganese dioxide is reduced to a lower state of oxidation and the hydrogen oxidized to form water.

While these equations represent the basic chemical reactions, other reactions, under certain conditions of discharge and degree of cell exhaustion, give rise to other products such as ammonia and various zinc complexes.

The zinc chloride present in the electrolyte is advantageous in several ways. It improves shelf life by reducing the zinc corrosion on open circuit. It tends to prevent loss of moisture from the cell by lowering electrolyte vapour pressure. Most important, perhaps, it combines with the ammonia that forms under certain conditions, which would otherwise polarize the cell. In this last reaction the manganese dioxide acts as a catalyst.

2.2. *Ionic Theory*

The zinc in contact with the solution of ammonium chloride becomes negatively charged because of the departure of positive zinc ions from its surface. As zinc dissolves in the solution, zinc ions, ammonia and hydrogen ions are produced, according to the ionic equations.

$$(3)\ Zn + 2^{+} \rightarrow Zn^{++}$$

$$(4)\ NH_4^{+} \rightarrow NH_3 + H^{+}$$

The carbon-manganese dioxide electrode in contact with the solution of ammonium chloride becomes positively charged as the result of at least two reactions. The first of these is shown in equation (5), where the hydrogen ions are discharged at the surface of the cathode and render it positive :

$$(5)\ 2H^{+} \rightarrow H_2 + 2^{+}$$

In the second reaction the manganese dioxide gives tetravalent ions which are reduced during the action of the cell to ions of a lower valency, and thereby furnish positive charges to the electrode :

$$(6)\ Mn^{++++} \rightarrow Mn^{+++} + 1^{+}$$

Apart from any theory, the fact remains that the manganese dioxide diminishes the polarization of the cell, and is at the same time reduced to a lower state of oxidation. And, if the positively charged electrode (carbon-manganese dioxide cathode) is connected with the negatively charged electrode (zinc anode) by an external conducting circuit, an electrical current will flow through the circuit from the zinc to the carbon. Within the cell, the current will flow from the carbon-manganese dioxide through the electrolyte to the zinc.

3. Electrical Characteristics

In the following discussion of the electrical characteristics of dry cells a number of curves and tables will be used to illustrate certain points. We cannot stress too strongly that such data are not indicative of battery quality. In fact, battery quality cannot be judged by a single curve, single figure or single characteristic. An accurate knowledge of the kind of work a cell has to do is essential before it can be designed. In many cases the initial service capacity may be of minor importance, being outweighed by considerations such as shelf life, reliability and uniformity.

3.1. *Voltage*

The open circuit voltage of a dry cell is the electromotive force when it is not producing any current. It is greater than the potential existing between carbon and zinc electrodes in a sal ammoniac electrolyte due to the influence of the manganese dioxide. The portion of the total cell voltage contributed by the manganese dioxide varies, depending on the source and previous history of the manganese dioxide, and on the composition of the electrolyte. As a result, dry cells which are nominally rated at 1·5 volts may give initial open circuit voltages anywhere between 1·5 to 1·6 volts, and occasionally even higher for very active depolarizers.

The closed circuit or working voltage of a dry cell is always less than the open circuit value by an amount determined by the current flowing through the cell's internal resistance, and by the polarization resulting from this current.

The working voltage of a dry cell declines progressively as the cell becomes exhausted. The rate of decline varies with cell size, cell formulation, rate of discharge, intermittency of operation, temperature, etc. Fig. 2 illustrates the change in shape of the working voltage curve for a No. 6 size cell as the load is varied. The 8-ohm load represents a heavy type of service. This results in a rapidly falling voltage curve. With the 512-ohm load, representing very light service conditions, the voltage is well maintained and remains above 1·3 volts through most of the discharge period.

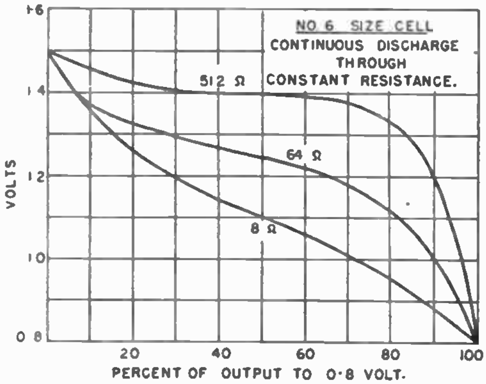

Fig. 2.—Working voltage of No. 6 size cells during discharge through various resistances.

3.2. *Amperage or Short-Circuit Current*

The maximum current which a cell can deliver is given by the following equation :

$$I_{max} = \frac{E}{r} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where I_{max} = maximum current

E = open circuit voltage

r = internal resistance

In making measurements the maximum current cannot be attained since the shunt and lead wires of an ammeter must necessarily have some resistance. This resistance, however, can be made very small, and it is standard practice to use a value of 0·01 ohm. The " short-circuit " current then becomes :

$$I_{sc} = \frac{E}{r + \cdot 01} \quad \ldots\ldots\ldots\ldots (2)$$

where I_{sc} = short-circuit (or flash) current.

There is no relationship between the current delivered by a dry cell on a short-circuit amperage test and the service capacity of the cell. At best, such a measurement is useful to dry battery laboratories in judging the uniformity of a particular lot of cells of a given formula or to show whether the cells can meet some specified condition requiring large flash current.

3.3. *Internal Resistance*

From earlier references to internal resistance, under the headings " Voltage " and " Short-circuit Amperage," it might be implied that r is a definite and constant physical quantity. Such, however, is not strictly the case. The resistance of a cell is usually defined by the equation :

$$r = \frac{E - E^{I}}{I} \quad \ldots\ldots\ldots\ldots (3)$$

where r and E have the previously defined significance and E^{I} = closed circuit voltage when a current I is flowing, but it can be shown experimentally that for various values of I different values of r are obtained, apart from any consideration of polarization phenomena. Larger values of r correspond to the smaller values of I. For this reason the many methods of measuring internal resistance, some very complicated, all yield different results. Probably the simplest method is to measure the cell's electromotive force E and short-circuit current I_{sc} and calculate the internal resistance r from equation (2).

In general, the internal resistance decreases as the size of a dry cell increases. This is shown in Table 2[1].

TABLE 2. Approximate Internal Resistance of Dry Cells

(Average cf several brands at 25°C, calculated from flash currents)

Size of Cell	Average Flash Current Amperes	Internal Resistance of single cell Ohms.
AA	4·6	0·311
C	5·4	0·284
D	6·6	0·227
F	8·8	0·173
No. 6	32·0	0·038

3.4. *Service Capacity*

Since dry cells are mostly used on circuits of which the resistance is constant, or nearly so, the capacity is usually expressed as the number of hours or days that the cell will continue to give service on such a circuit. The test which best represents any particular service is that which most nearly duplicates the rates of energy output of the battery when in actual use. There is no direct relation between the results of continuous tests and intermittent tests of longer duration.

For some purposes it is useful to express the capacity in ampere-hours. Since dry batteries are ordinarily tested on circuits of constant resistance, it is necessary to integrate carefully measured discharge curves to compute the average current, which is then multiplied by the hours of actual discharge to obtain the ampere-hour capacity. Table 3 shows the comparative ampere-hour capacity of small cells on the "Household-Flashlight Intermittent Test."

TABLE 3. Approximate Capacity of Small Dry Cells

(5 minutes discharge per day through 4 ohms per cell to 0·75 volt per cell)

Size of Cell	Approximate Capacity Ampere-hours
AA	0·4
A	0·6
B	1·1
C	1·5
D	3·4
E	4·3
F	5·2
G	6·1

The ampere-hour capacity obtainable from a dry cell of given size depends on several factors, including temperature, formula, physical construction, current drain, periods of use per day and cut-off voltage. For any specified discharge schedule there is an optimum value of current drain which will produce maximum capacity to a specified cut-off voltage. This is illustrated by the curve shown in Fig. 3. When the current is increased beyond approximately 9 mA the ampere-hour capacity decreases because of less efficient depolarization. With current drains below 9 mA the capacity becomes less due to the subtractive effect of shelf depreciation.

It is seldom practicable to operate dry cells under conditions conducive to the greatest efficiency. For most dry battery applications capacity measured in terms of time, rather than ampere-hours, is the determining factor. In Fig. 4 the data of Fig. 3 has been re-plotted with life in hours as ordinates. This curve shows that service life increases progressively and rapidly as the current is decreased below 9 mA, which is the value giving maximum ampere-hour capacity.

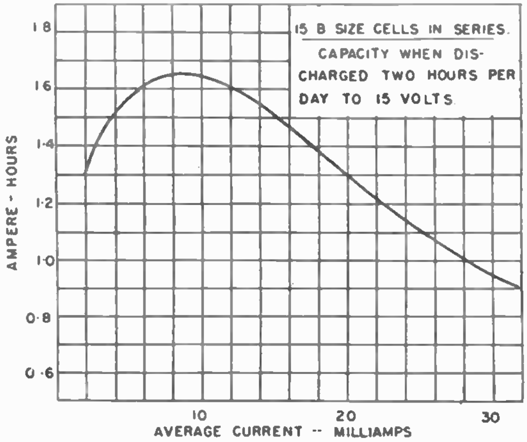

Fig. 3.—Effect of discharge current on ampere-hour output.

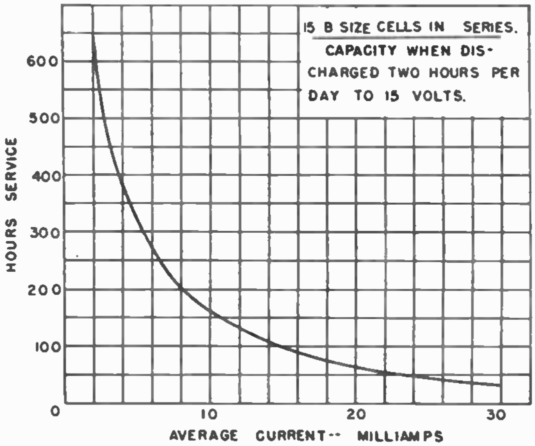

Fig. 4.—Effect of discharge current on service life.

Ampere-hour capacity is also dependent on the discharge-recuperation cycle. This characteristic is illustrated in Fig 5. The effects of shelf depreciation and of depolarization efficiency are clearly indicated by the reversal in relative positions of the three curves with increasing discharge current. With very low current values the period covered by the 2 hour per day discharge is of such long duration that shelf depreciation reduces ampere-hour output compared to continuous discharge. At higher currents, above 8 mA, the increasing efficiency as the type of discharge becomes more intermittent is due to more complete depolarization.

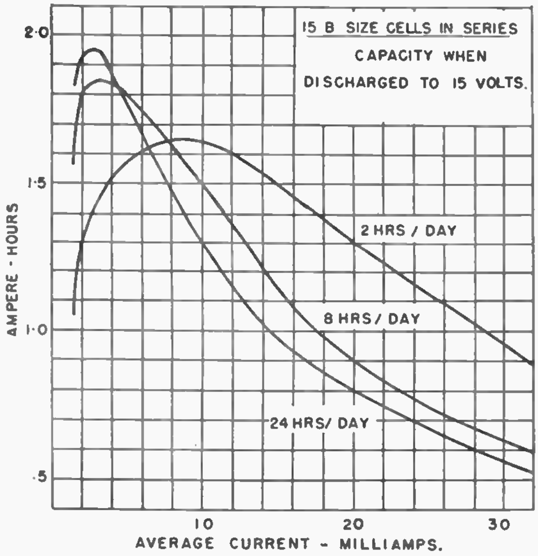

Fig. 5.—Ampere-hour output versus discharge current for various operating cycles.

Cut-off, or end-point, voltage is another major factor which determines the capacity of dry cells. The family of curves in Fig. 6 shows the ampere-hour capacities for three different cut-off voltages.

4. Effect of Temperature

Lower temperatures have a marked effect on the output of dry cells. In a Paper published in 1922[6] it was shown that dry cells become practically inoperative at a temperature of −21°C (−6°F). More recent investigations have confirmed this conclusion. There is a small amount of variation among different makes and types of cells, some being usable a few degrees lower than others. Exposure to very low temperatures, even for prolonged periods, does not cause permanent damage to dry cells, and they will be entirely normal after being thawed out.

4.1. *Voltage*

The electromotive force of a dry cell, that is, the true open-circuit voltage, decreases about 0·02 volt when the temperature is decreased from 25°C (77°F) to −20°C (−4°F). This represents an average of approximately 0·0004 volt per degree centigrade. Although only of academic moment, it is interesting to note that Vinal reports potentials slightly greater than normal at −112°C (−170°F) and a reversal to −1·4 volts at −170°C (−274°F). For practical purposes the terminal working voltage of a cell or battery is of more significance than the e.m.f. Table 4 shows the results of measurements on a size F cell under varying conditions of temperature and load. These data do not apply directly to other sizes of cells, but a rough approximation may be made by assuming the load to be inversely proportional to the ratio of their volumes.

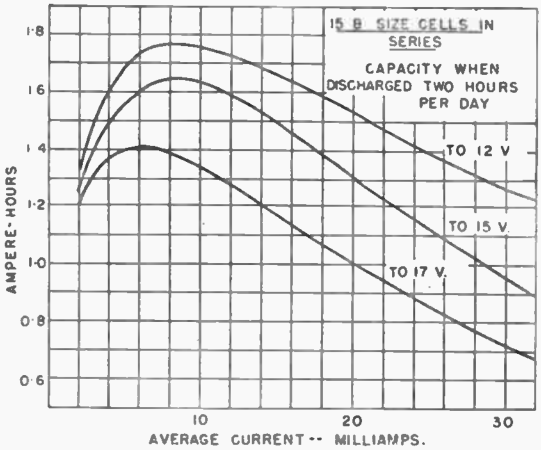

Fig. 6.—Ampere-hour output versus discharge current for various end-point voltages.

The open circuit voltages of Table 4 show a drop of only 0·014 volt for a temperature change from 25°C (77°F) to −20°C (−4°F). That this is less than the previously stated figure of 0·02 volt is attributable to inherent

TABLE 4. Initial Voltages of a Size F Dry Cell

Under Varying Conditions of Temperature and Current. Terminal Voltage at Indicated Drains

Temperature		Open Circuit	20 mA	50 mA	75 mA	100 mA	140 mA
°C	°F						
30	86	1·645	1·641	1·632	1·621	1·612	1·605
25	77	1·644	1·639	1·628	1·617	1·607	1·599
20	68	1·643	1·637	1·624	1·613	1·603	1·591
10	50	1·641	1·634	1·620	1·605	1·592	1·579
0	32	1·640	1·631	1·614	1·595	1·581	1·568
−10	14	1·639	1·627	1·605	1·584	1·564	1·537
−20	−4	1·530	1·61	1·59	1·56	1·54	1·52
−25	−13	1·622	1·60	1·57	1·54	1·51	1·49
−30	−22	1·610	1·49	1·28	1·10	0·96	0·86

differences in materials and construction of the cells used for this particular series of measurements. It thus becomes apparent that the relative changes produced by temperature or current drain are more significant than the actual voltages.

4.2. *Current*

Low temperatures have a much greater effect on the flash or short-circuit current than on the electromotive force. Table 5 gives the average results of short-circuit current measurements, as defined in Section 3, sub-section 2, for No. 6 and D size cells. Here again, the proportional changes produced by temperature variations are of more importance than the actual readings. The table shows that the percentage change for cells differing in volume by a ratio of 10 to 1 is essentially the same at corresponding temperatures above 0°C (32°F). At lower temperatures the smaller cell is more seriously affected.

TABLE 5. Flash (short-circuit) Currents of Dry Cells

(Average of several brands)

Temperature		Flash Current amp.	No. 6 Cells	Size D Cells	
°C	°F		Percentage of Current at 26°C	Flash Current amp.	Percentage of Current at 25°C
40	104	35·3	112	7·7	117
30	86	33·2	105	7·0	106
25	77	31·6	100	6·6	100
20	68	29·7	94	6·1	92
10	50	25·7	81	5·2	79
0	32	21·6	68	4·2	64
−10	14	17·6	55	3·1	47
−20	−4	10·0	32	1·0	15
−30	−22	1·0	3	0·1	1·5
−40	−40	0·1	0·3	0·0	0·0
−50	−58	0·0	0	—	—

If the flash currents of various sizes of cells are known at specified temperatures, an approximation of their performance at other temperatures may be made on the basis of this table.

4.3. *Internal Resistance*

Decreased flash current at low temperatures is the result of increased internal resistance of the cells. Table 6 gives the average results of internal resistance measurements, based on the short-circuit current method on No. 6 and D size cells.

TABLE 6. Internal Resistance of Dry Cells
(Flash current method, average of several brands)

Temperature		No. 6 Cells		Size D Cells	
°C	°F	Average Resistance ohms	Percentage of R at 25°C	Average Resistance ohms	Percentage of R at 25°C
40	104	0·033	87	0·195	86
35	95	·034	89	·202	89
30	86	·036	95	·214	94
25	77	·038	100	·227	100
20	68	·041	108	·246	108
15	59	·045	118	·264	116
10	50	·049	129	·291	128
5	41	·055	148	·322	142
0	32	·061	161	·362	159
−5	23	·068	179	·424	187
−10	14	·077	203	·493	217
−15	5	·095	250	·733	323
−20	−4	·144	379	1·551	684
−30	−22	1·5	4,000	15·6	6,900
−40	−40	15·0	40,000	—	—

When apparatus is designed to operate momentarily on a relatively large current, the internal resistance of the cells becomes important. Since it has been shown that the internal resistance increases at reduced temperatures, design calculations should always be based upon the lowest temperature likely to be attained by the battery. This is not necessarily the lowest temperature to which the battery is exposed, as it does not take the temperature of its surroundings immediately and thermal insulation is helpful.

4.4. *Service Capacity*

The effect of temperature on the service capacity of dry cells closely follows its effect on short-circuit amperage and internal resistance. Table 7 expresses capacity vs. temperature, as percentages of the normal service at 21°C (70°F), for a 22½-volt battery containing F cells on the basis of the 1,250-ohm continuous test to a cut-off voltage of 15 volts. The data may be applied to other sizes of cell and different service conditions, provided that some allowance is made for shelf deterioration. With light loads and intermittent discharge schedules the heat, which would be expected to improve efficiency, may accelerate moisture loss and wasteful chemical action to such a degree that the service will be considerably less than normal. This factor assumes increasing importance as cell size is reduced due to the inherent poor shelf life of small cells.

The data of Table 7 demonstrate the importance of maintaining a standard uniform temperature for dry cell and battery service capacity tests. The generally accepted standard is 21°C (70°F).

TABLE 7. Effect of Temperature on the Capacity of Dry Cells

(Tests on a 22½-volt unit of F cells discharged continuously through 1,250 ohms to 15 volts)

Temperature		Capacity (as per cent. of value at 70°F)
°C	°F	
38	100	140
27	80	115
21	70	100
16	60	90
4	40	69
−7	20	48
−18	0	27
−29	−20	6

4.5. *Storage*

In previous sections we have mentioned shelf life or shelf depreciation in dry cells. This refers to the length of time they can be stored without serviceability decreasing by more than a specified amount. The depreciation is usually determined by delayed service tests after specified periods of storage at 21°C (70°F). The depreciation is greatly accelerated by higher temperatures and retarded by reduced temperatures. Table 8 gives the average results for a large number of No. 6 cells stored at several temperatures. Flash current, shown as percentages of initial, is used as the criterion of deterioration. Although the difference between the highest storage temperature, 40°C (104°F) and the lowest, 9°C (48°F) is not very great, the effect on the cells is considerable. Those which were stored at 9°C were in better condition at the end of 5 years than the others at 40°C after one year.

5. Other Forms of Construction

The foregoing discussion has dealt with dry cells of cylindrical form. Radio " B " circuits, and certain other applications, require high voltage batteries. Packing these conventional cylindrical cells into a rectangular container, and connecting them in series was the first and obvious construction. This results in considerable idle volume made up of the space between the circular contours of the cells, insulation around the cells and intercell connecting wires, assembling clearances, and the volume of the outer case material. The mix represents 35 per cent. of the volume of a cylindrical cell. When the cells are assembled

TABLE 8. Effect of Temperature on Deterioration of No. 6 Dry Cells in Storage

(Average values of open-circuit voltage and percentage of initial for flash currents*)

	40°C (104°F)		20 to 25°C (68-77°F)		9°C (48°F)	
Storage Times Years	O.C. Voltage volts	Flash Current per cent.	O.C. Voltage volts	Flash Current per cent.	O.C. Voltage volts	Flash Current per cent.
0	1·58	100	1·58	100	1·58	100
1	1·43	28	1·54	83	1·57	91
2	1·27	5	1·51	59	1·55	76
3	—	—	1·49	33	1·54	58
4	—	—	1·48	22	1·53	44
5	—	—	1·46	12	1·52	31
6	—	—	1·28	—	1·48	19

*The flash currents were measured at 20 to 25°C by the method specified for short-circuit currents in Section 3, sub-section 2.

into a " B " battery this 35 per cent. becomes only about 25 per cent. of the total volume of the battery.

5.1. *Flat-cell Batteries*

The first step in improving multi-cell batteries was the introduction of flat cells, in the United States of America, by the National Carbon Company about 20 years ago. This represents a radical departure from the orthodox type of battery both from a structural and service standpoint. Its construction is somewhat similar to the classical voltaic pile. The conventional zinc can is replaced by a flat sheet of zinc coated on one side with a layer of carbon (Fig. 7). This so-called " duplex " electrode serves as the series connection between cells. The metal side is the active anode of one cell while the other side is the inert carbon collector for the adjacent cell.

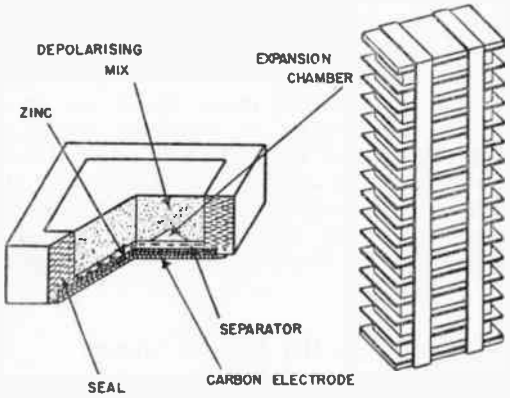

Fig. 7.—Structure of flat-cell, and flat-cell assembly.

A 22·5-volt " B " battery section is formed by stacking 15 of the flat cells, compressing the stack and tying it with strips of paper tape. The negative end of the unit starts with a plain zinc sheet followed by a separator, mix cake and " duplex " electrode which completes the first cell and starts the second. This sequence is continued until a " duplex " electrode completes the 15th cell and forms the positive terminal of the stack. For a 45-volt battery two of the 22·5-volt sections are placed side by side in a cardboard container, which is then filled with sealing compound. Expansion space is provided in each cell by moulding depressions in the mix cake.

The mix occupies about 31 per cent. of the total battery volume, an increase of 25 per cent. compared to a cylindrical cell battery. A corresponding increase in service capacity is obtained. There are several other interesting features of this construction[7], one of which is the constant cathode area. With a cylindrical cell the cathode area remains constant regardless of the depth reached by the depolarizing reaction. The current density, therefore, decreases continuously throughout the life of the cell.

Although this type of flat cell represents a considerable improvement over conventional batteries it still has an appreciable proportion of idle volume. This is mainly due to the sealing compound which surrounds the mix cakes. For the cell size illustrated in Fig. 7 the mix volume would be increased by about 60 per cent. if the mix cake could be extended to the edges of the " duplex " electrode. The proportion of sealing compound volume to battery volume becomes greater as the battery size is reduced, because practically constant sealing margins are necessary to prevent intercell electrolyte leakage. This fact has prevented application of this construction to batteries smaller than the so-called medium-duty and heavy-duty " B " batteries.

In 1938, the 1·4-volt line of radio receiver tubes was introduced in the United States of America. These new tubes were a vast improvement over battery types previously available from an " A " and " B " battery current consumption viewpoint. Together with various circuit refinements they offered the possibility of cutting receiver power demand to one-half or even one-third of its prior value. This brought forth renewed interest in portable receivers, and they appeared in considerable quantities in 1939.

The battery industry soon contributed to this trend by introducing a new form of flat cell battery[8] of greatly reduced size. This was accomplished by eliminating the relatively wide sealing margins around the cells, reducing the thickness of the carbon electrodes, and locating the expansion space around the edges of the cells, where it takes no more room than is necessary for normal clearances between the battery assembly and its outer container. These changes increased the amount of mix to 50 per cent. of the volume of a completed battery ; this is 60 per cent. more than in the older type of flat cell battery and twice as much as in a cylindrical cell battery of equal size.

The elements of a single cell of the new type are shown in Fig. 8, and Fig. 9 shows the construction of a multi-cell " B " battery. The peripheral wrappers of thin rubber or plastic around the separate cells solved the very important problem of preventing electrolyte leakage between adjacent cells, which would short-circuit and rapidly destroy the involved cells. The wrapping forms a yielding mechanical seal which readily accommodates electrolyte expansion and tends to force the electrolyte back into the cell when expansion ceases.

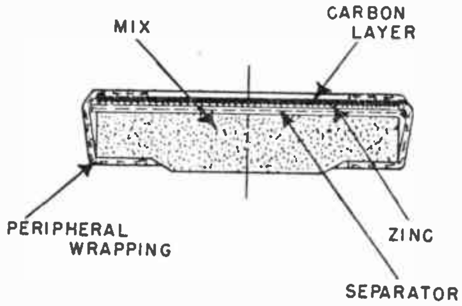

Fig. 8.—Structure of wrapped type flat cell.

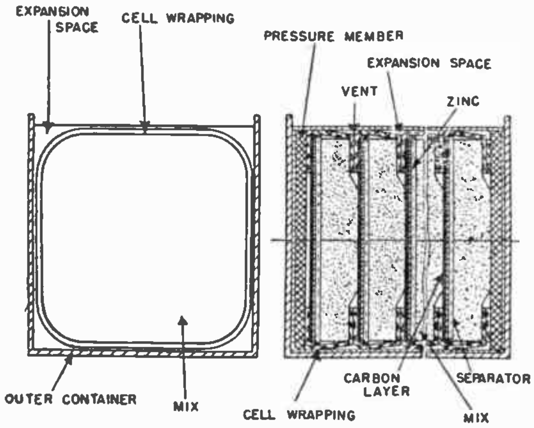

Fig. 9.—Structure of wrapped-cell type of battery.

The new construction also lends itself to the manufacture of much smaller batteries for " personal " portable receivers, hearing-aid instruments, and even pocket-size receivers.

6. Applications

Pessimists have predicted the death of the dry battery industry each time that power units have been devised to replace the dry cells being used for some flourishing application.

The present demand is mainly for the operation of flashlights, rural and portable radio receivers, hearing aids, rural telephones, and for many uses by the armed services and other Government departments.

6.1. *Equipment Design Considerations*

Most of the present applications for dry batteries are either relatively simple, such as for flashlights, or, like telephone operation, are well understood and standardized through long usage. Furthermore, these applications are only concerned with inexpensive low voltage batteries. Multi-cell radio batteries, on the other hand, are a relatively expensive form of electrical power and it becomes most important that they be used to the best advantage. Frequently this has been overlooked, or assigned a role of mino importance by the radio industry.

Even before the introduction of 1·4-volt tubes the trend in 2-volt set design, in America, was towards lower operating costs. Class B output systems, excellent at high power levels but mediocre at normal listening volume, fell by the wayside. With them went the " C " batteries that had to be discharged in step with falling " B " voltages by compromise methods. Self-bias, which replaced the " C " batteries, greatly improved set performance at reduced " B " voltages and resulted in service life increases of up to 50 per cent. for the " B " batteries, which could now be used to much lower voltages before replacement. Audio power sensitivity was improved by the use of new tube types, and the amount of power output required was reduced by the development of more sensitive speakers. Quite a few sets of different makes and models appeared requiring only 90 instead of 135 " B " volts. In 1937 Temple[9] showed that savings of 50 to 60 per cent. in receiver " B " battery current could be made by selective over-bias of pentode output tubes. He also showed that acceptable levels of power output could be attained with surprisingly low " B " drains.

The selective over-bias system is worthy of special note. This feature appeared under several names such as the "Economizer," "Battery Saver," etc., and has since been used in many 1·4-volt receivers. The circuit is very simple and inexpensive. In its usual form, the output tube bias resistance, in the "B" return, is in two sections, one of which may be shorted by means of a switch. With new "B" batteries and the switch open, the output tube is over-biased, thus reducing "B" current and increasing "B" battery life. The power output is reduced and distortion increased somewhat but not sufficiently to affect the output from the average listener's viewpoint. As the "B" voltage falls with battery use the switch may be closed, which, by reducing the bias resistance and bias voltage, permits full use to be made of the service capacity still remaining in the "B" battery.

TABLE 9. Resistance Required to Simulate Discharged Radio "B" Batteries

Volts per 22½-volt Section	Resistance per 22½-volt Section	
	Farm type Batteries	Port. type Batteries
	ohms	ohms
22½	0	45
20	10	60
17	50	110
15	110	175
12	250	330

When a battery-operated radio receiver is being designed, the conscientious design engineer will investigate set performance throughout the working voltage range of the batteries. To provide a suitable voltage supply for this investigation, it is necessary either to obtain a set of "B" batteries which have been discharged on radio service to the voltage desired, or else to use a method simulating discharged batteries. It is not satisfactory to reduce the voltage of fresh batteries by rapid discharge, because the internal resistance of a battery discharged in this manner is not as high as that of one normally discharged over a long period of time. A convenient method is to tap fresh heavy duty batteries and insert the appropriate values of external resistance, as shown in Table 9.

In simulating a discharged battery the following points are important First, only fresh "heavy-duty" batteries should be used, their resistance being negligible. Second, if intermediate voltage taps are used the added resistance must be distributed between the taps in proportion to their respective voltages. Third, voltage readings should be taken only under load and across the battery cable terminals so as to include the voltage drop of the load current through the added resistances.

Conclusion

Because of the large numbers of variables affecting their performance it becomes apparent that dry batteries and the equipment they will be called upon to operate cannot be designed independently. Close technical co-operation between the individual design organizations is essential to obtain the best possible results, to give the greatest benefits to the ultimate consumers, and for the future success of the industry as a whole.

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3. Cooper, *Primary Batteries*, p. 3, 1917; Ayrton & Mather, *Pract. Elec.*, p. 192, 1912.
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7. Hundley, "A Radio 'B' Battery of Flat Type Construction," *Trans. Electrochem Soc.* 68 219-229 (1935).
8. French, "Improvements in 'B' Battery Portability" *Proc. I.R.E.* (*U.S.*) Vol. 29, No. 6 (1941).
9. Temple, "The Importance of Power Efficiency in Battery-operated Receivers," *Proc. I.R.E.* (*U.S.*) Vol. 25, p. 1,098 (1937).

NOTICES

Obituary

Council records with regret the death of Mr. E. A. J. Rogers (Associate) at the early age of 27.

Mr. Rogers, who joined the Institution as a Student in 1940, was a Television Development Engineer at Kolster Brandes, having previously been an Instructor in Radio at Southampton University.

The Royal Society

At the 286th Anniversary Meeting of the Royal Society, the following were elected as Officers and Council for the ensuing year.

President : Sir Robert Robinson

Treasurer : Sir Thomas Merton

Secretaries : Sir Edward Salisbury,
Professor D. Brunt

Foreign Secretary : Professor E. D. Adrian

Other Members of Council : Professor J. D. Bernal, Professor G. R. Cameron, Sir James Chadwick, Professor S. Chapman, Professor H. Devenport, Sir Frank Engledow, Professor W. E. Garner, Professor A. C. Hardy, Sir Norman Haworth, Dr. C. H. Kellaway, Professor G. F. Marrian, Sir William Stanier, Dr. H. G. Thornton, Professor C. E. Tilley, Dr. A. E. Trueman, Professor S. Zuckerman.

Instruments and Measurements Conference, Stockholm

The Swedish Royal Academy of Technical Sciences (IVA) and the Swedish Association of Technical Physicists (TFF) are planning an international conference on instruments and measurements to be held from May 10th to 15th, 1949, in Stockholm.

The programme will include subjects pertaining to instruments and technique of measurement and related subjects. The preliminary programme includes symposia on

1. Industrial Spectroscopy.
2. Testing of Materials and Mechanical Measurements.
3. Industrial Control.
4. Metrology.

The official languages of the conference are English, German, French and Swedish. Contributions in the shape of papers or discussions of papers should be in any of those languages, preferably in English. Papers offered to be read at the conference should be sent in before April 1st, 1949, at least in abstracts. The full text, with illustrations and complete for publication, should be sent in before the end of the conference.

Membership dues are 10 Swedish crowns, to be paid before the opening of the conference.

An international exhibition of instruments and laboratory equipment will be arranged under the sponsorship of IVA and TFF from May 7th to 15th in adjoining buildings. Members of the conference are admitted to the exhibition free of charge.

It would be appreciated if members of the Institution who offer papers to this conference would send copies of their papers to the Publicaions Officer of the Institution.

World Engineering Conference

Since publication of the Institution's Annual Report, enquiries have been received regarding the work of the World Engineering Conference. Enquiries in Great Britain should be addressed to the Secretary of the British Committee, World Engineering Conference, 82 Victoria Street, London, S.W.1.

National Committees have now been established in the following countries :—

Belgium, Egypt, U.S.A., France, Great Britain, Hungary, Iran, Italy, Poland, Switzerland, Czechoslovakia, Colombia, India, Lebanon, Philippines, Rumania, Syria, Turkey, Uruguay.

Information regarding the addresses and Officers of the various National Committees may be obtained on application to the Secretary-General of the World Engineering Conference, 77 Avenue Raymond Poincare, Paris 16e.

The World Engineering Conference is holding its second International Technical Congress in Cairo from March 20th-26th, 1949, and the programme of the conference together with all other relevant information may now be obtained on application to the British Committee.

Library Journals

The following journals are now available for reading and reference in the Institution's Library. Library hours are Monday to Friday, 9.15 a.m. to 5.30 p.m. Saturday, 9.15 a.m. to 12.30 p.m.

RADIO

Electronic Engineering
Wireless World
Wireless Engineer
Proceedings I.R.E., U.S.A.
Electronics
Proceedings I.R.E., Australia
Annales de Radioelectricite
L'Onde Electrique
La Radio Française

ELECTRICAL ENGINEERING

Electrical Review
Post Office Electrical Engineers' Journal
Engineering Journal of Canada
Cables et Transmission
Bulletin Scientifique

SCIENCE

Nature
Journal of Scientific Instruments
Review of Scientific Instruments

SOUND

Journal of the Acoustical Society of America

TECHNICAL REVIEWS

G.E.C. Journal
Marconi Review
R.C.M.F. Bulletin
Philips Technical Review
Bell System Technical Journal
R.C.A. Review

KINEMATOGRAPHY

Journal of the British Kinematograph Society

AMATEUR RADIO

R.S.G.B. Bulletin
Short Wave Magazine
QST

ABSTRACTS

Index Aeronauticus
B.I.M. Management Abstracts

GENERAL

B.B.C. Quarterly
London Calling

Mr. Geoffrey Parr

Mr. Geoffrey Parr (Associate Member), who is well known among members as the Editor of "Electronic Engineering" is resigning that position, where he will be succeeded by Mr. H. G. Foster, M.Sc., late of Birmingham University.

Mr. Parr is joining Messrs. Chapman & Hall, publishers, as Technical Director.

British Standards Institution

At a meeting of the General Council on November 9th Mr. Roger Duncalfe was elected Chairman in succession to the late Sir Clifford Paterson, F.R.S.

Radio Research Special Report No. 16

Produced by the Department of Scientific and Industrial Research, Radio Research Special Report No. 16—"A Method of Determining the Polar Diagrams of Long Wire and Horizontal Rhombic Aerials" presents in a convenient form a generalized analytical method of calculating the polar diagram over a wide band of frequencies of any long wire or horizontal rhombic aerial system.

The report may be obtained from H.M. Stationery Office, York House, Kingsway, London, W.C.2, price 9d. (by post 10d.): a copy is also available in the Institution's Library.

Building and Engineering Exhibition, May 1949

The third Annual Exhibition of the "Britain's Best" series, featuring building materials and equipment, light engineering, services and supplies, will be staged at the Horticultural Hall, Westminster, London, S.W.1, from May 16th to 27th, 1949.

This exhibition has, as in previous years, been timed to follow immediately the British Industries Fair when there will be a large number of visitors from the British Commonwealth and overseas countries in London. Plans have been made to ensure that these overseas visitors will be informed of this Exhibition.

DEVELOPING AN INDICATOR FOR H_2S EQUIPMENT*

by

R. T. Croft (*Associate Member*)

During the early war years, intensive research in direction finding and ranging by means of pulsed radio waves had laid the foundation for many ingenious and interesting pieces of equipment.

Not the least impressive among the developments in this direction was that system known by the code name H_2S, which, in its succession of marks, gave added advantage to our forces in their struggle for supremacy.

This system, designed for use as an airborne equipment, subscribed to what may be termed conventional radar practice in that it comprised a rotating directional aerial (scanner), fed by a transmitter/receiver producing radio frequency power at wavelengths measured in centimetres by utilizing the pulsed magnetron technique, driven by a trigatron modulator.

A returned " echo," after detection by the transmitter/receiver during its listening period between output pulses, was passed on to a receiver amplifier working on the superheterodyne principle and amplified to an extent rendering the signal capable of being used for presentation to the indicating unit.

Auxiliary units in the equipment consisted of a waveform generator to provide the necessary time bases, triggering and timing circuits, etc., one or more power units, and a master control unit to give switching facilities and for setting up bombing or homing runs.

The equipment was so divided, rather than built *en bloc*, for various reasons, perhaps the most important of these being that it enabled some form of weight distribution to be achieved in aircraft installations, because crews' quarters should ideally contain only those instruments capable of presenting useful information in a tangible form, and to make for ease of servicing and maintenance. (It is interesting, in this connection, to proceed to the logical conclusion of such an argument and consider breaking down the components of each instrument into sub-assemblies of " brick " form, each capable of direct replacement in the event of a fault.)

All these instruments were, of course, the subject of much development and research, but the particular unit with which this Paper will now be concerned is the indicator, one of the items, the development and "engineering" of which has been the author's immediate concern.

Specification

The basic requirements for operation of such an indicator, assuming it to be of the P.P.I. type, are :

(1) A rotating time base shall be provided, sweeping a line from the axial centre of the tube face to the periphery, the time constants, or scale, of this base being capable of strict control and accuracy.

(2) This time base shall be capable of swinging, or rotating, about the centre point of the tube in strict synchronism with the scanner revolutions.

(3) The electron beam in the tube shall be capable of intensity modulation by a reflected signal derived from a burst of energy produced by the transmitter, directed and received by the scanner.

(4) Facilities for inserting a signal at predetermined points along the time base in order to give range markers, etc., and means of expanding the scale of the time base to cover various ranges.

Given these conditions, if the C.R.T. be biased back so that the time base is only just on the threshold of vision, then a signal returned from a target can be made to intensify the trace, and show up as a bright spot, at the particular :—

(*a*) direction in plan that the scanner was looking during transmission and reception of the pulse, and

(*b*) distance along the time base, commencement of which was synchronized with the transmitter firing, and therefore corresponding to range.

If now the afterglow period of the fluorescent

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* Manuscript received August, 1947. U.D.C. 621.396.933 : 621.396.624.

coating on the tube face be of sufficient duration to retain the image until the time base comes around to repeat the stimulus, and if it be imagined that echo signals are being received in strengths, and from directions, corresponding to the physical features of the terrain beneath the scanner, then the composite pattern of light and shadow on the screen may be interpreted as a form of map, whose detail and definition depend to a large extent on the design of video amplification, etc., and the resolving qualities of the tube being used.

The particular indicator under consideration was to provide, by means of a 6-in. cathode ray tube, a P.P.I. display of the panorama beneath the aircraft, and also, a 2½-in. tube which would, operated as an A-scope, give an indication of height from outstanding objects. It is convenient, in describing some of the details of this indicator, to treat the two tube circuits separately.

The P.P.I. tube to be used was the first of its kind to be incorporated in an H_2S equipment, and differed from the tubes used in earlier marks by reason of the fact that it was of the magnetically deflected type, whilst retaining electrostatic focusing, and was adapted for the application of an "after-accelerating" voltage of +3·6 kV, the cathode/grid electrode assembly running at −3·3 kV.

This arrangement, giving a vertical 7 kV gradient across the tube, greatly improved the definition of the tube, for as is well known, the higher the velocity of electrons striking the screen, the smaller the number required to produce a given intensity of scintillation. Therefore, a smaller cathode hole can be used, and since focussing for smallest spot size means reducing the cross-section of the electron beam to the size of the cathode hole, a much smaller spot size can be obtained, giving a more finely grained picture.

It was not possible to retain electrostatic deflection under these conditions, since large deflecting forces become necessary at high electron speeds, calling for large deflecting voltages, and defocusing becomes more apparent when the beam is travelling, and being gradually bent, through the two sets of plates.

However, as the duration of travel through the deflecting field produced by an electromagnet is shorter than that through two sets of plates, less defocusing occurs when the magnetic system is used, and since the coils themselves are external to the tube, the time base circuits can run at a low voltage. Moreover, as the D.C. resistance of the coils is low, they present a low impedance to an amplifier working into them, and the necessary high currents required to deflect the beam can be obtained.

The rotating P.P.I. time base was obtained by taking a voltage waveform from the waveform generator unit and amplifying and converting it to a current waveform by means of a scan amplifier. The output from this amplifier was passed to the rotor of a magslip situated on and driven at the same speed as the scanner. This waveform induced current in the two magslip stators in strengths corresponding to their degree of coupling with the rotor. Since these stators were connected back through two pairs of transformers to the outer ends of the deflector coils, it will be seen that a diametrical scan was developed.

The inner ends of the deflector coils were connected to D.C. points on the cathode load of the scan amplifier, one connection being to a fixed point, and the other to the slider of a potentiometer in each case. The setting of these potentiometers caused a rise or fall in the standing current in the deflector coils and so served as centring controls independent of signals applied to the amplifier grid.

This scan amplifier (see Figs. 1, 2, 3) consisted of two 807 beam tetrode valves in push-pull, the output transformer having a split secondary. One half of the secondary was connected to ground

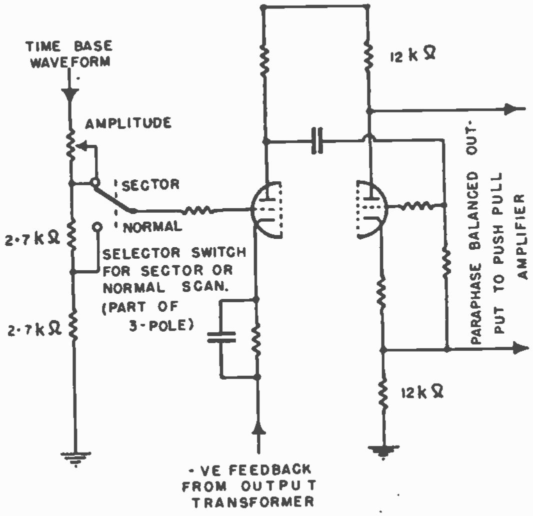

Fig. 1.—P.P.I. scan pre-amplifier and phase splitter.

through a low resistance and in series with the cathode of the pre-amplifier. This introduced negative feedback and made it possible to get an even frequency response for the scan waveform frequency components. Incorporated in the feedback line was a filter to minimize self-oscillation caused by harmonics introduced by way of the output transformer itself.

The 807's were driven by a double triode valve, the first half of which was used as a pre-amplifier, the second stage as a phase splitter, i.e., an equal load was connected in both anode and cathode circuits, the resultant anti-phase balanced outputs being R/C coupled to control grids of the two 807's.

This arrangement enabled a push-pull driven transformer to be dispensed with, but no gain is obtainable from a stage so connected. In fact a loss is experienced, giving a gain figure of approximately 0·9.

Great care was necessary to avoid modulating the current through the tetrodes with screen supplies and it was found necessary to drive the pre-amplifier, the phase splitter and the tetrode screens from a separate stabilized supply separate, that is, from the 807's anode supply.

The cathodes of the 807's were made common, and a series load consisting of four small resistances was connected to ground in parallel with the two centring potentiometers previously mentioned, the whole network being well decoupled.

The ends of the deflector coils mentioned as terminating at fixed points along the cathode load were actually connected via two poles of a three-pole c/o switch, so that connection was made when the switch was in the normal position.

When the switch was changed over, however, the coil connections were taken to the respective sliders of a two-pole, eight-way, wafer-type switch and in this position gave a facility known as sector scanning.

Operation of the sector switch through the eight cardinal compass points had the effect of injecting eight different combinations of current through both the vertical and horizontal deflector coils, the different scans of these currents causing the starting point of the time base to move to a point on the periphery of the tube face corresponding with the setting of the switch. At the same time as the sector position itself was selected, the third c/o pole connected the grid of the scan pre-amplifier to

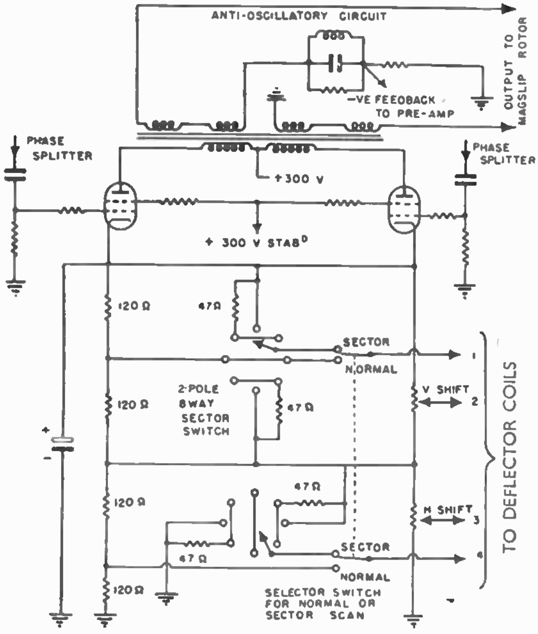

Fig. 2.—Push-pull scan amplifier.

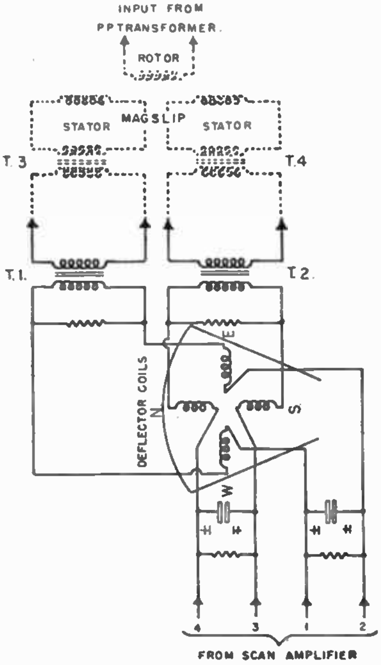

Fig. 3.—Diametrical scan.

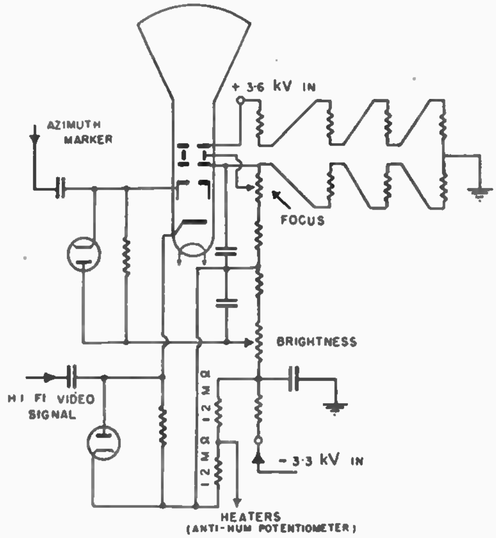

Fig. 4.—P.P.I. tube : Gun circuits.

give twice the input voltage so that now the time base worked right across the tube.

This arrangement effectively increased the diameter of the tube face by a factor of two, although of course, only a quadrant of the scanner area could be presented from any of the section points.

The three-pole c/o selector switch function was early obtainable by using a PO type key, but the sector switch itself presented more difficulty, due to the fact that it was required to be continuously rotatable in 45-degree steps through 360 degrees to correspond with the eight cardinal compass points.

Most wafer switches are arranged to move through 30-degree steps, and using one of these would have meant that two south positions were unavoidable, and the switch marking could not have lined up with the direction of scan.

It was considered desirable to avoid gearing an ordinary switch to give the required result, if possible, mainly because of lack of panel space at this point, and because of the added parts to be made at a time when swift action was necessary.

Further investigation revealed that one manufacturer marketed a switch with wafers pierced at every 15 degrees, the idea being that contacts could be mounted on each side of the stator. All that was necessary now was to produce a " click plate " for 45-degree steps and make up the switches using every third contact mounting hole.

Power Supplies.

The + and −3·5 kV potentials were produced by orthodox transformer rectifier means in a separate power unit, along with the necessary valve anode and bias supplies, etc. A filament transformer, however, was changed and fitted within the indicator, and this transformer included two windings, running at 3·5 kV and 2 kV respectively, serving the filaments of the two cathode ray tubes.

The positive 3·6 kV supply was connected direct from the input plug (a standard W type) to the " after accelerator " on the tube. A suitable resistive bleeder load was connected to ground from this point to ensure constant loading on the E.H.T. rectifier in the power unit and to act as a safety device. A tapping point was provided halfway down this load to provide a 2 kV connection for use with a new tube which had been envisaged for the height tube position and was to have a similar " after-accelerator."

The negative 3·3 kV supply was similarly connected except that, of course, in this case part of

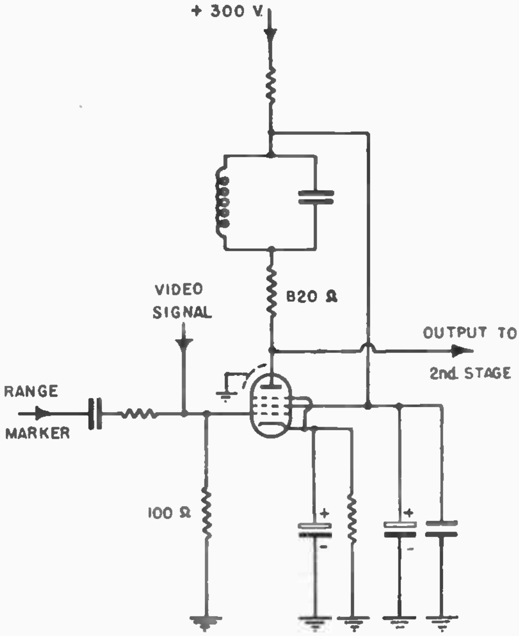

Fig. 5.—High fidelity video amplifier : 1st stage.

the load consisted of potentiometers, with controls brought out through the front panel, to give brightness and focus controls. The load, also, was much more broken up to provide the fixed potentials necessary for other electrodes in the tube. Reference to Fig. 4 shows this arrangement, and also indicates the positions of decoupling capacities found necessary between grid and cathode, etc. This circuit also shows the method of coupling signals from the video amplifier via D.C. restoration diodes to the cathode and modulator of the tube.

Video Amplifier

The next most important requirement was for a video amplifier to drive the cathode of the P.P.I. tube, modulate the electron beam, and cause a brightening of the trace at the particular point in its scan when a sufficiently distinctive echo was received from a target. A signal of about 1 volt amplitude from the TR box was available at the grid of the first stage, and the base of the tube was some 50 55 volts. The amplifier was to have a nominally level response (plus or minus 2·5 d.b) over a frequency range of from 12 to 30 Mc/s. This amplifier was finally arranged (see Figs. 5, 6, 7) in the form of a three stage R/C coupled type, the first two stages being provided by EF50 high-frequency pentodes, followed by an output stage using an 807 beam tetrode. All three stages were provided with resonant circuit anode correction, and effective decoupling capacities were provided by means of electrolytic condensers.

Very great care was found to be necessary, both in the case of the layout of the decoupling, etc., on the first two stages, and more particularly with regard to stray capacities in the anode circuit of the output valve. The resonant circuits were designed to take the form of a few turns of wire on moulded formers, the wire ends being brought out to tags situated on a cheek which was cemented to the end of the former.

Small disc-type condensers were then soldered directly across these tags, and the sub-unit was positioned in such a manner as to reduce the length of all connections to a minimum.

The output was taken from the anode of the 807 tetrode output valve, the connection to which on these valves is at the top of the envelope, via the final resonant circuit, the load and the high voltage coupling condenser to the tube cathode electrode connection. Minimum self-capacity of all these

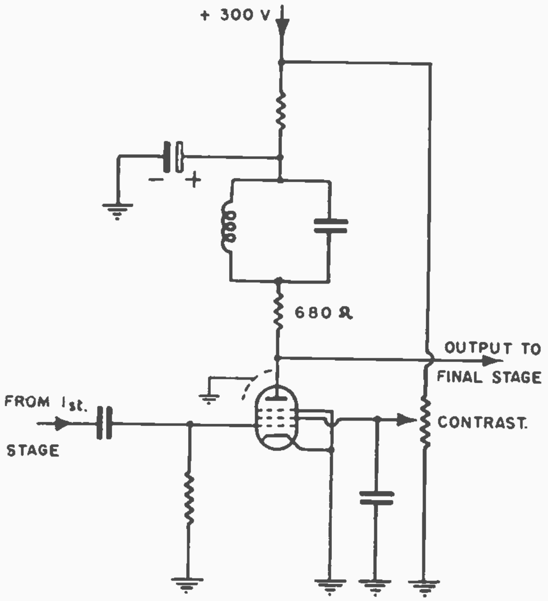

Fig. 6.—High fidelity video amplifier : 2nd stage.

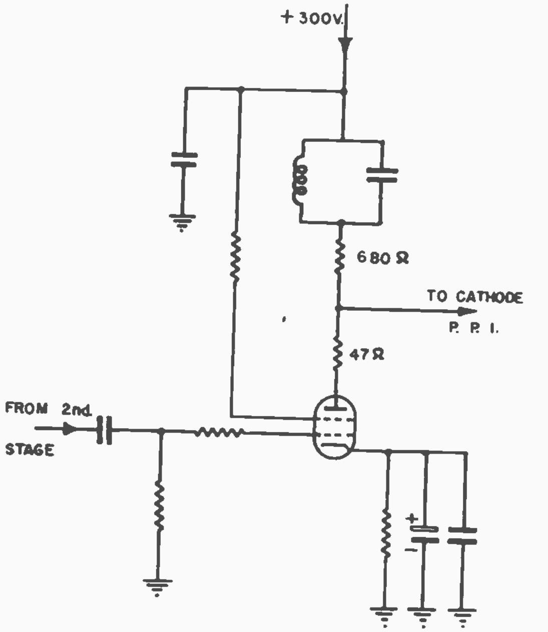

Fig. 7.—High fidelity video amplifier : output stage.

components was of paramount importance, and to keep connections as short as possible the 807 was tilted through the panel separating the amplifier from the high-voltage compartment surrounding the tube base. This panel was designed as an integral part of the chassis, and reducing capacity between it and the video output stage was found essential if the response curve was not to wilt at the higher frequency end of its spectrum.

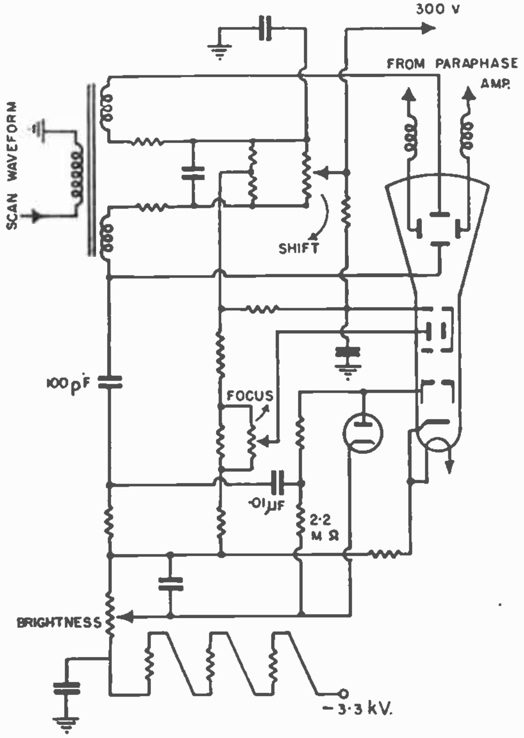

Fig. 8.—Height tube : shift and gun circuits.

Meanwhile, separate range marker signals, derived from the waveform generator, had been mixed at the grid of the first valve in this amplifier, giving rise to a concentric ring marker indicating range on the tube face.

A separate marker was available in the form of a bright-up waveform added to the trace via the grid, showing a particular direction of travel of the aircraft, and triggered by the scanner each time it passed the dead ahead position.

The height tube, which displayed a height marker on one side of the time base against mixed video signals and range marker on the other, was an electrostatically deflected type with the cathode assembly running at −2 kV and an earthy anode. Its circuit is shown in Fig. 8.

Again, in this case, the scan waveform was derived from the waveform generator and was applied across the primary of a scan transformer within the indicator. The secondary of the transformer was split, the outer ends applying a push-pull scanning voltage to the appropriate deflector plates. The inner ends of the secondaries were taken through a potentiometer to which could be applied a D.C. voltage which governed the level at which each plate sat and so could be used to position the spot in the vertical plane.

The combined range marker and video signals from the transmitter/receiver used at the grid of the first stage of the P.P.I. video amplifier were also taken through amplifier/cathode-follower (Fig. 9) stages to one valve of a paraphase amplifier (Fig. 10), with D.C. restoration, and thence taken to one Y plate in the height tube.

A separate height marker derived from the waveform generator was applied to the other valve in the paraphase amplifier and coupled to the remaining Y plate in the height tube, see Fig. 10.

The scan waveform was also used to provide blackout on the flyback of the time base by applying it, after suitable modification, to the grid of the tube, so biasing the tube back beyond the threshold of vision during the period of flyback.

The D.C. electrodes were connected suitably as indicated in Fig. 8, which also shows the flyback blackout circuit and D.C. restoration diode.

The −2 kV supply was taken from the same source as that used for the P.P.I. tube, suitable dropping resistors and decoupling being provided, as shown.

When an outline of this information had been received, layout work was at once commenced with a view to producing a prototype indicator within the shortest possible space of time.

All indicating units for previous marks of H_2S had been built to a standard size, viz., 12 in. × 9 in. × 18 in. long, and to ensure interchangeability in aircraft mounting, this unit was to be no exception.

The first attack was made on arranging a mounting for the P.P.I. tube enabling it to be withdrawn through the front panel. The usual method up to this time was to fit and remove a P.P.I. tube backwards from inside the set, but since we now had the deflector coil assembly in its adjustable mounting around the barrel of the tube, frontward withdrawing was indicated.

Thereupon an assembly was devised to consist of the rubber housing for the tube, fixed by four hollow bolts to a flanged tray which contained four leaf springs designed to form a retaining device for a rotatable perspex dial. The dial turned in a machined hole in the tray, and left a compass rose on the periphery of the dial open to view against a fixed cursor.

Attention has already been drawn to the care needed in the layout of the Hi-Fi amplifier. This probably was the subject of more development than any other individual circuit within the indicator.

High voltage points were carefully positioned since the instrument was to be tested at altitudes of up to 40,000 ft. with the corresponding low air pressure at that height.

At this time, no particular emphasis had yet been laid on the modern concept of the tropicalization of electronic equipment, and the unit was designed with the usual insulating sheets beneath component boards, bitumin-dipped transformers, laminated switches, and with none of the passivated finishes now in use.

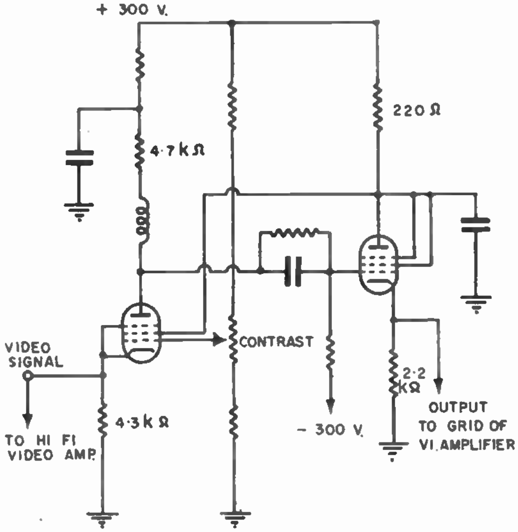

Fig. 9.—Height tube: video signal, cathode follower amplifier.

However, in 1945, when production of these units was in full swing, it became apparent from reports on various equipments in service in the Far East that a new and powerful enemy to reliability and service performance was at hand.

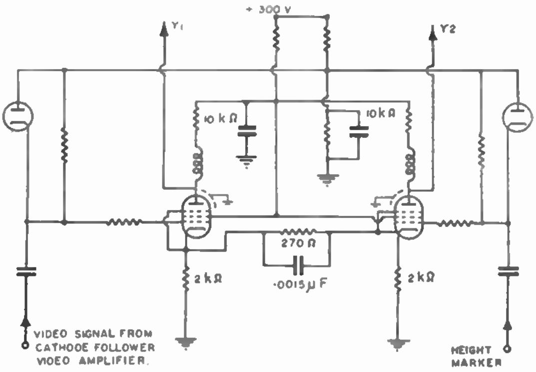

Fig. 10.—Height tube: paraphase amplifier

Accordingly, investigation was made and all possible data secured in order to carry out necessary modifications to the indicator and to render it capable of giving more useful service under the conditions in which it was to work.

These modifications consisted in the main of developing suitable hermetically sealed transformers to replace the bitumin-dipped types, determining an efficient plating protection for metal chassis, etc., for which chromate passivated zinc plate was most favoured, and the removal of insulating panels and back-to-back component boards.

Meanwhile, tropicalized components themselves, condensers, resistors, switches, etc., were appearing in greater numbers and larger variety. A changeover was therefore made as a sufficient stock of any particular component known to be superior was gathered.

Care was exercised in the selection of metals which were to be in juxtaposition to ensure that contact potentials did not rise to a value which would cause corrosion to take place.

After an interim period, during which time a hybrid sort of unit was produced, production swung over to the new type. Exhaustive tests were carried out in a tropical chamber designed and built on the site, and the unit took its place among the other parts of the equipment designed and in production at that time.

Acknowledgments

The author is indebted to members of the research staff of T.R.E. for the use of circuit diagrams, and to the chief scientist, Ministry of Supply, for permission to publish this paper.

GRAPHICAL SYMBOLS FOR FILTERS AND CORRECTING NETWORKS*

by

G. H. Foot

Introduction

The British Standard Symbols† for Filters and Correcting Networks are unsatisfactory because they are limited to a few simple types. Moreover there is no rational manner in which they can be modified to illustrate new developments or special facilities. As they are also not particularly easy to draw or to understand, as they can be confused with the British Standard Symbols for alternating currents, and as they fail to give much information which is desirable, it is suggested that they should be replaced by a comprehensive system to be described.

The Valve Symbol

It will be useful to consider the reasons for the success of the conventional method of representing a thermionic valve. Four lines are used to show the three electrodes of a triode and its envelope. The nature and function of each electrode is suggested by the type of line, and the circle surrounding them indicates the boundary of the evacuated space. The external connections are shown by taking short lines to this boundary, and these can be numbered to correspond with a standard valve base. The valve characteristics may be specified sufficiently by giving the values of the principal valve parameters. More often the code of the valve is quoted, and this information must be obtained from the maker's catalogue.

Such a symbol has proved to be very satisfactory. In a simple way it gives a great deal of information, and this is presented so that it can be understood by technologists without difficulty. Also, and this is very important, the method of modifying the symbol for more complicated and special types of valves, is obvious. The interpretation of the modified symbols is usually manifest and ambiguity is unlikely. The symbolization of screened-grid and pentode valves, and valves with metallization, indirectly heated cathodes, gas-filling, and variable-mu properties has not been difficult. Many other variants have been treated successfully, including types which are really several valves in one with internal connections and screening. By modifying the shape of the envelope, the symbol for a cathode ray tube was devised.

All the valve symbols discussed have been found to be satisfactory for the pencil sketches of engineers, yet they are scarcely altered when carefully drawn. The attempts of draughtsmen to make improvements in detail, and the divergences resulting from the independent progress of different countries have not caused any confusion.

The Rectifier Symbol

The solution of the problem of the valve symbol is apparently simple and obvious, but in it can be discovered the cardinal principle to be followed in successful electrical symbology. It is necessary that a symbol enable the apparatus it represents to be identified, and its essential characteristics to be ascertained, without the need for memorizing an arbitrary code. This can be done by basing it on the physical structure of the apparatus. The symbol becomes an elementary picture of the equipment. Sometimes this is not convenient because nothing characteristic of the apparatus is denoted by its construction, or because different arrangements are used to develop the same property. An example is the rectifier, where the symbol diagrammatically represents its performance. When the rectifier is of the multiple type however, the symbol is repeated to indicate the relative positions of the plates. The combination of the electrical and mechanical properties thus portrayed has been found to present the information which the engineer must have, without including anything unessential.

The Basis of the Proposed New Symbols

The shape, size, and mechanical details of a filter (or correcting network) do not determine its electrical behaviour. The value of the filter is assessed after examining its attenuation-frequency characteristic, which is usually given graphically. To an engineer nothing is more strongly associated with a filter than this graph, and nothing more quickly conveys the essential information about

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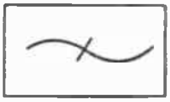
*Manuscript Received : March 1948.

†*British Standard Graphical Symbols for Telecommunications.* No. 530—1948

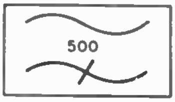
performance than a glance at it. It is on this graph that it is suggested the filter symbol should be based. Additional particulars will be necessary, for example details of the external connections and a description of the construction as far as it affects these. The symbol should therefore include this information.

British Standard Symbols for Filters and Correcting Networks

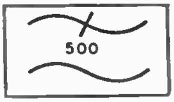
Filter—General Symbol.



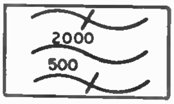
Filter—High-Pass—Cut-off frequency indicated.



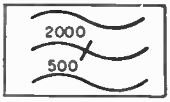
Filter—Low-Pass—Cut-off frequency indicated.



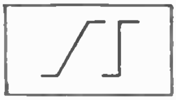
Filter—Band-Pass—Cut-off frequencies indicated.



Filter—Band - Suppressing—Cut - off frequencies indicated.

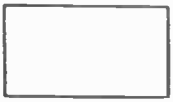


Correcting Network.

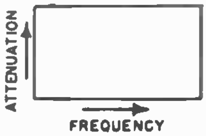


Suggested New Symbols for Filters and Correcting Networks

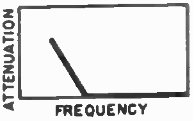
The physical boundary of the filter (or correcting network) is indicated by a rectangle.



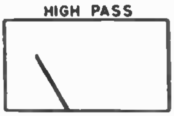
To represent the attenuation-frequency characteristic this rectangle is considered to be a sheet of graph paper on which a graph is drawn with the origin in the lower left-hand corner. The lower edge will be a frequency axis, and the left-hand edge an attenuation axis.

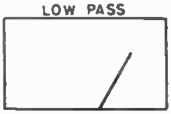


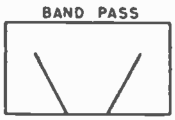
A high-pass filter will therefore appear as

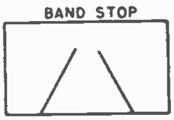


The thickened line is not necessary, and various types of filters are depicted as follows,



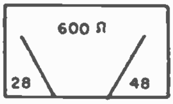




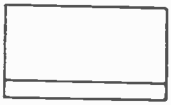


The cut-off frequencies are inserted in the acute angle between the axis and the line, and are given in kilocycles/sec. The characteristic impedance is written over the pass-band.

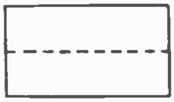
Example 1.—A band-pass filter with a pass-band between 28 kc/s and 48 kc/s, and with a characteristic impedance of 600 ohms.



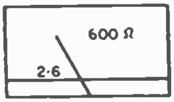
If the filter is unbalanced this is shown by a line representing the earth line.



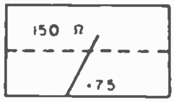
If the filter is balanced this is shown by a line in the centre of the rectangle. If a physical earth connection is provided the line is solid ; otherwise it is dotted.



Example 2.—An unbalanced high-pass filter with a cut-off frequency of 2·6 kc/s, and a characteristic impedance of 600 ohms.

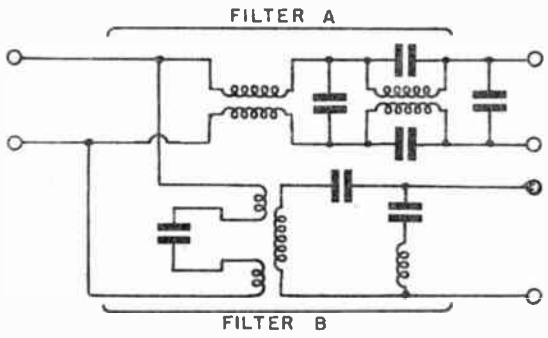


Example 3.—A balanced low-pass filter (no physical earth connection) with a cut-off frequency of 750 c/s, and a characteristic impedance of 150 ohms.



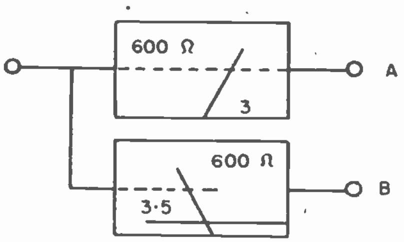
The advantages of the proposed system of symbols are evident when it is extended to illustrate rather more complicated filters. Filters similar to that described in the next example are in common use, but the existing symbols are quite inadequate to give the information which is generally required.

Example 4.—The circuit diagram of a pair of filters used for separating a voice frequency telephone circuit from carrier circuits operating on the same cable pair, is given below.



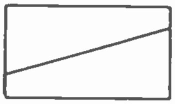
Filter A is a balanced low-pass filter with a cut-off frequency of 3 kc/s, a characteristic impedance of 600 ohms, and no physical earth connection. Filter B is a high-pass filter with a cut-off frequency of 3·5 kc/s and a characteristic impedance of 600 ohms. It has a balanced input where it is connected to the low-pass filter, but one of the coils is used as a transformer and an unbalanced output is provided.

The method of representing these filters with the proposed new symbols is as follows,

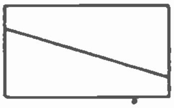


Correcting Networks

The symbol for correcting networks is based on the attenuation-frequency characteristic of the network. This avoids the considerable limitation of having only one symbol for every network, irrespective of the type of correction it provides. Thus networks with more attenuation at high frequencies than at low frequencies are represented

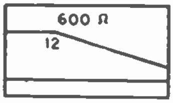


and if the attenuation is less at high frequencies than at low frequencies then the symbol becomes

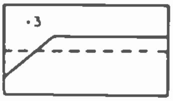


It will be observed that a correcting network can always be distinguished, because the line representing the attenuation goes from side to side of the rectangle. In a filter symbol this line rests on the bottom of the rectangle.

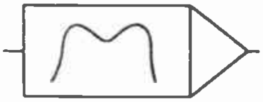
Example 5.—A 600/ohm unbalanced correcting network has a constant attenuation to 12 kc/s. The attenuation then decreases as the frequency is raised.

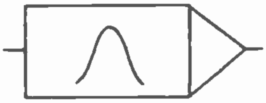


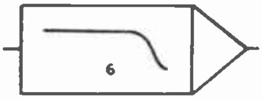
Example 6.—A correcting network of the balanced type (no physical earth connection) has a constant attenuation above 300 c/s, but below this frequency the attenuation decreases as the frequency is lowered.



It is usual to obtain the response of radio receiving apparatus as the voltage gain at various frequencies for a constant output. This has lead to the custom amongst radio engineers of plotting the gain-frequency characteristic, and this will be a mirror image of the attenuation-frequency characteristic. Such apparatus should however, be regarded as amplifiers with various types of response curves. They could conveniently be symbolized in the manner shown by the three following sketches, which will be self-explanatory.







It is not our purpose at the moment to be concerned with this type of symbol, except to show how it could be included in the scheme. It will be sufficiently obvious that the combination of the rectangle with the usual triangular sign removes any possible ambiguity, as well as providing a uniform and valuable method of representing amplifiers, comparable with the method for representing filters already discussed.

Many other variations might be described, but not advantageously at the moment. They might easily confuse the reader as to the basis of the proposed plan. Indeed as it is claimed that the new symbols can be developed logically as required; no elaboration is necessary.

Summary

As the British Standard Symbols for Filters and Correcting Networks are inadequate, new symbols are proposed. It is shown how the scheme can be extended to include amplifiers.

The advantages of the new symbols are:

(1) They are based on performance graphs, which display information which an engineer requires, and which he associates closely with the apparatus itself.

(2) The understanding of the symbols does not depend on memorizing an arbitrary code.

(3) They give information often required, but for which no provision is made in the British Standard Symbols.

(4) The elaboration of a symbol to illustrate a new development or a special feature, is a natural and logical process. An error in the interpretation of a modified symbol is improbable.

(5) The new symbols are very simple, and confusion with other symbols is impossible.

(6) The proposed scheme is flexible, and likely to be adequate for future requirements.

BOOK REVIEWS

Microwave Receivers. Edited by S. B. Van Voorhis. McGraw-Hill Book Company. 618 pp. 48s.

This book is volume 23 of the Massachusetts Institute of Technology Radiation Laboratory Series. The series, which is to contain 28 volumes, will provide a conspectus of radar and other developments in the field of microwave communications which have resulted from the war of 1939-1945, and the present work is one of a number dealing with various aspects of microwave reception. It is concerned with the design, testing and performance of receivers at frequencies between 200 Mc/s and 1,000 Mc/s. In the first nine chapters, the receiver is discussed stage by stage in a very competent way, and with an emphasis on practical details rather than on theoretical considerations. A short chapter on the mechanical construction of receivers is then followed by two chapters dealing with test equipment, and the remainder of the book is devoted to detailed descriptions of various special types of receivers which were developed during the war.

The treatment is, in general, clear and concise, and there are many excellent diagrams and photographs. In their efforts to be complete, the authors have perhaps included an unnecessary amount of detail in places. For example, there are several photographs of complicated pieces of equipment, viewed from underneath ; these have the appearance of three-dimensional jigsaw puzzles, and do not really help the reader to understand the operation of the circuit which they represent. Similarly, the explanations of some admittedly intricate circuit devices occasionally lapse into jargon ; on p. 74, we find the following admonition : " A deadener must be used here, since one poke from the phantastron has an even chance of reversing the HR without reversing the TSS, thereby destroying the phase relation between the two."

This is a good book ; it breaks a lot of new ground—particularly in its very full treatment of 10 cm and 3 cm receivers—and it will be a useful work of reference.

J. M. A. L.

Elements of Radio Servicing : William Marcus and Alex Levy. McGraw-Hill, 1947. 27/-. 475 pp. 378 figs.

This well-illustrated and excellently produced American book is devoted mainly to the superheterodyne receiver. The faults and troubles associated with this widely used instrument are dealt with in a logical and practical sequence working from the power and output stages, and so to the aerial input circuit—a method favoured by many service engineers.

Early chapters cover, briefly, essential test equipment with emphasis on the signal generator and its application, while two chapters deal with car radio installations and power supplies. As twelve chapters are devoted to the main theme of the superheterodyne receiver and its troubles the authors' aim is well carried out, but it may have been better to have chosen a more concise title for the book. There is no information given on servicing battery receivers, T.R.F. circuits, pickups, motors, etc., so that a more informative title could have been " Servicing the Superheterodyne Receiver."

Similarly, the chapter titles are not always appropriate. Chapter 15 is entitled " Further Notes on the Converter—Variations," but only four pages deal with this theme, the remaining twenty-three pages covering multi-band receivers, push-button circuits, permeability tuning, etc.

A few inconsistencies occur, such as Ma for milliamps instead of *m*A, while in an Appendix dealing with symbols and abbreviations milliamps are given as *ma*. In the same Appendix volts are given as *v*, but in diagrams the correct symbol V is employed.

However, these are small points and the book should prove invaluable and is confidently recommended to senior service engineers, especially those preparing for the R.T.E.B. Radio Servicing Certificate examination.

E. J. G. L.

Applied Electronics. By D. Hylton Thomas, M.Sc.(Tech.), B.Sc.(Eng.), A.M.I.E.E., A.M.I.R.E.

Blackie & Son, Ltd. xi + 131 pp. Price 7s. 6d.

This short work is intended for students who are reading for an engineering degree or other comparable examinations. It aims to strike a mean between the specialist textbook and the general textbook, whilst adopting the viewpoint of an engineer rather than that of a physicist. It may be said that this aim has been admirably achieved, within the limits imposed by price. The statement in Ch. I that the kinetic energy of a moving electron is given by $\frac{1}{2} mv^2 = e\text{E}/300$ will give rise to some perplexity in the student's mind, and no doubt a future edition will rectify this. Ch. II on valves is surely too short ; the examples given at the end refer to inductive anode loads and two forms of equivalent circuit, but the reader searches in vain for discussions of these. Ch. III on cathode ray tubes might well deal with several points which bother the enquiring mind; examples are such matters as what happens to the beam electrons after they hit the screen, how the beams of a double-beam tube can show deflections due to the live plate potentials being negative with respect to the splitter plate, and how a synchronized trace is held in synchronism against an appreciable tendency to wander. In Ch. V the importance of adequate heating times for cathodes of gas-filled devices might be explained more fully. The chapters on gas-filled rectifiers, electric discharge lamps, photoelectric cells, rectifiers and miscellaneous devices are all too short, but contain the essentials. In view of the low price the author has undoubtedly provided the student with a most informative brief account of the subject. An enlarged second edition will be called for in due course ; when the author prepares this he would be well advised to conform rather more strictly to the standard symbols and abbreviations laid down by the B.S.I. E. A. H.

Chambers's Six-Figure Mathematical Tables : L. J. Comrie, M.A., Ph.D. 2 vols. 42/- each.

These tables, consisting of two volumes of 600 pages each, have been produced as a supplement to electronic computers by an authority on the subject.

Volume I contains 8-figure logarithms and logarithms of trigonometrical, hyperbolic and gamma functions, with some smaller tables o constants. Volume II contains tables of trigonometrical functions, circular functions, natura logarithms, powers, roots, etc. In addition, ther is a comprehensive explanation covering 26 pages

The tables are clear and concise, and designe for maximum ease in reference. The author is t be congratulated on a real achievement in table making. J. D. S.

Pulse Generators. Edited by Profs. Glasoe an Lebacqz.

McGraw-Hill. 1948. 741 pp.

This work is Volume 5 of the Radiatio Laboratory Series. As is the case with othe volumes already published in this series, it is th product of a team of writers recording their war time work at the Radiation Laboratory o microwave-radar ; however, radar is not the onl use for the pulse-modulators and pulse-transformer here described and analysed, and the authors whilst basing their examples on their radar practice, have made a most valuable record of theor and design which is of general application. Afte an introductory chapter there are three parts :– (I) Four chapters on pulse-modulators usin high-vacuum tubes as switches. (II) Six chapter on pulse-forming artificial lines, associated circuit and switches other than high-vacuum tubes (III) Four chapters on pulse transformers. Ther are two appendices : (A) Measurements and (B pulse computations. A notable feature throughou is the large number of graphs and oscillograms.

A certain amount of overlapping and change o style is apparent when moving from one autho to another, but this is not troublesome. Th emphasis is chiefly on high-power practice althoug of course, the theory is of wider utility. As is t be expected, U.S. practice predominates. It is tru that the techniques on the two sides of the Atlanti often converged, but they were not always the same and some more attention might usefully have bee given to this and to the pioneer practice whic existed before the Radiation Laboratory was se up (e.g. the Admiralty use of artificial line networks), particularly bearing in mind that th bibliography given is almost wholly restricted t U.S. research reports.

The book can be confidently recommended bot to the specialist and to the student.

L. W. M.