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THE MARCONI REVIEW

No. 72. *January-March, 1939.*

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THE IONOSPHERE

Short wave circuits operating between wavelengths of 10 and 100 metres (30 and 3 megacycles) are dependent, in the majority of cases, on reflections from the ionised regions or layers of the atmosphere collectively termed the Ionosphere.

In the absence of these reflections, communication by means of the ground ray alone is only possible up to comparatively short distances, the actual distances depending on such factors as the earth resistivity, the wavelength and the height of transmitter and receiver above the earth.

As the reflected rays are of major importance in these short wave communications, a study of the conditions existing in the ionosphere is essential to the study of short wave propagation.

Critical Frequency and Density Measurements at Vertical Incidence.

IN order to obtain values of the critical frequency and density of the reflecting regions, pulses are transmitted and the echoes from these layers are observed on a cathode ray oscillograph at a receiving station nearby.

As the radio frequency on which the pulses are transmitted is increased, a frequency will be reached at which there are insufficient electrons to cause reflection, and penetration of the layer will occur. This frequency is known as the critical frequency, at vertical incidence, for the layer under observation, and the density N in electrons per cubic centimetre of the gas constituting the layer can be calculated from the formula $N = 1.24 \times 10^4 f^2$, where f is the critical frequency in megacycles per second for vertical incidence for the ordinary ray.

Layer Height.

The delay time of these echoes from the various layers of the ionosphere gives the height at which reflection occurs with the following reservations.

Due to group velocity effects, the waves are retarded as the critical frequency is approached, their momentum being modified by the reaction of the electrons on the waves.

This means that, near the critical frequency, the delay time of the echoes is not a measure of the true height at which reflection occurs.

This variation of apparent height can be seen in the accompanying curve of frequency plotted against layer height (Fig. 1).

Even at frequencies lower than the critical frequency, the observed height of the layer will be dependent to some extent on the frequency, due to the fact that the higher frequencies penetrate more deeply into the layer than the lower frequencies. This can also be seen in Fig. 1.

Ordinary and Extraordinary Rays.

It will be seen from Fig. 1 that a splitting of the curves into two branches takes place as the critical frequency is approached. This is due to magneto ionic effects.

The two rays are known as the ordinary and extraordinary rays, and the separation between them is dependent on the strength of the earth's magnetic field.

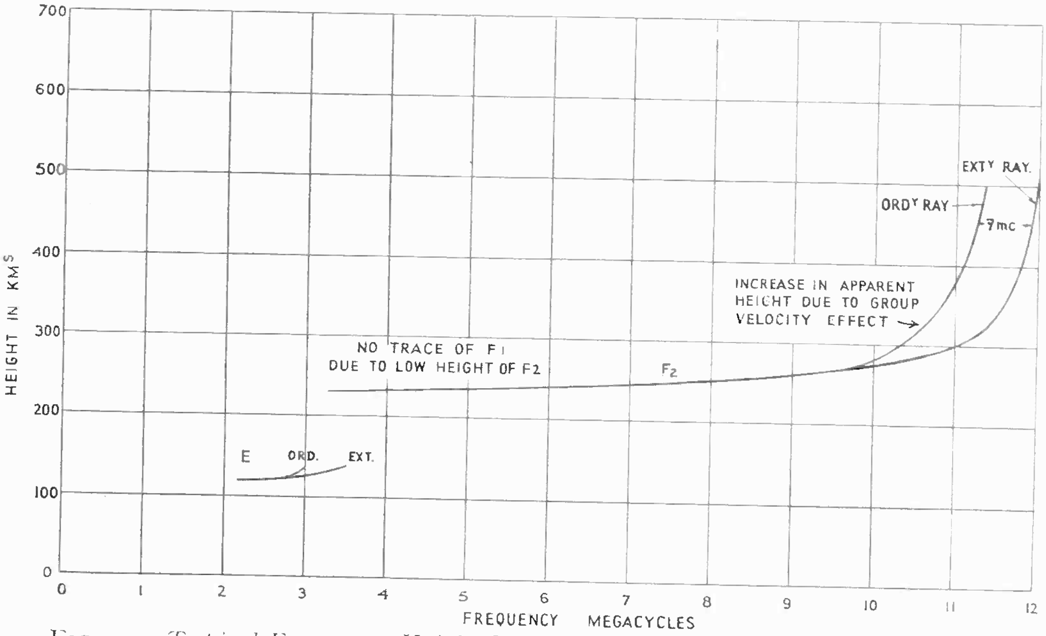

FIG. 1. *Typical Frequency Height Curve. Winter*, 1937, *Chelmsford, midday.*

In the Northern Hemisphere, at vertical incidence, the ordinary ray comes out of the layer with a left-hand sense of polarisation when observed from above, and the extraordinary ray with a right-hand sense.

In the Southern Hemisphere the reverse is the case.

The calculated value for this separation in England is .66 of a megacycle, which agrees very closely with the observed values.

The above effects only apply to frequencies above what is known as the gyro magnetic frequency which has a value of about 1.3 megacycles (227 metres) in this country.

The value of N in the formula previously given is calculated for the ordinary ray.

Conversion of Vertical Incidence to Oblique Incidence.

To enable these measurements of critical frequency at vertical incidence to be used in the study of propagation conditions at a distance, it is necessary to convert them to oblique incidence values. For a given density and height, the critical frequency for a layer will increase as the distance is increased.

D. F. Martyn has calculated these values for a flat earth, and N. Smith, of the Washington Bureau of Standards, has produced a mechanical method of calculating them for the curved earth case, employing a set of sliding curves. Millington, of the

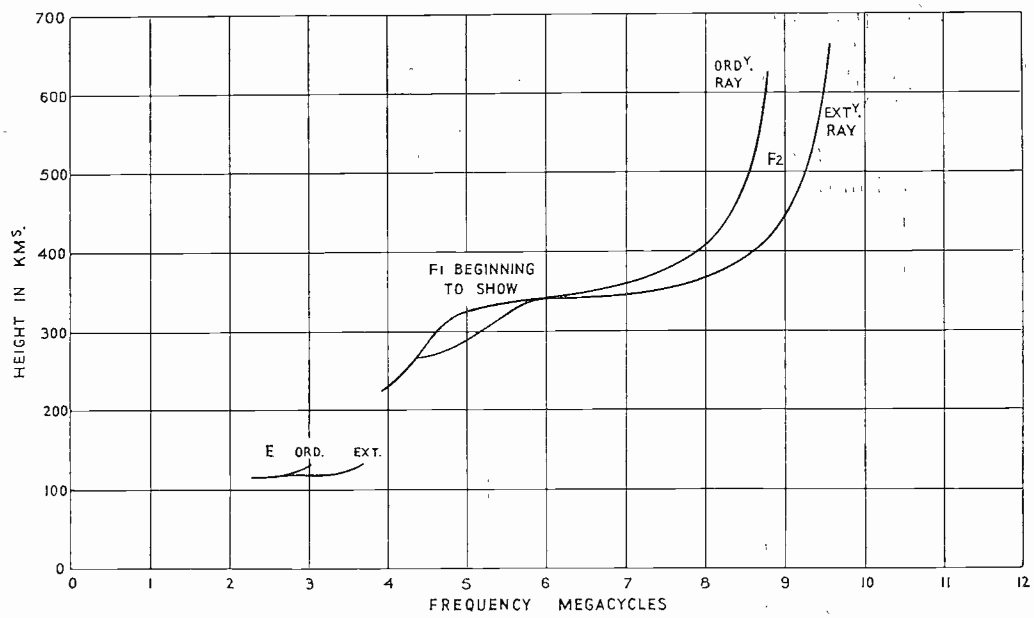

FIG. 2. *Typical Frequency/Height Curve. Spring, 1938, Chelmsford, midday.*

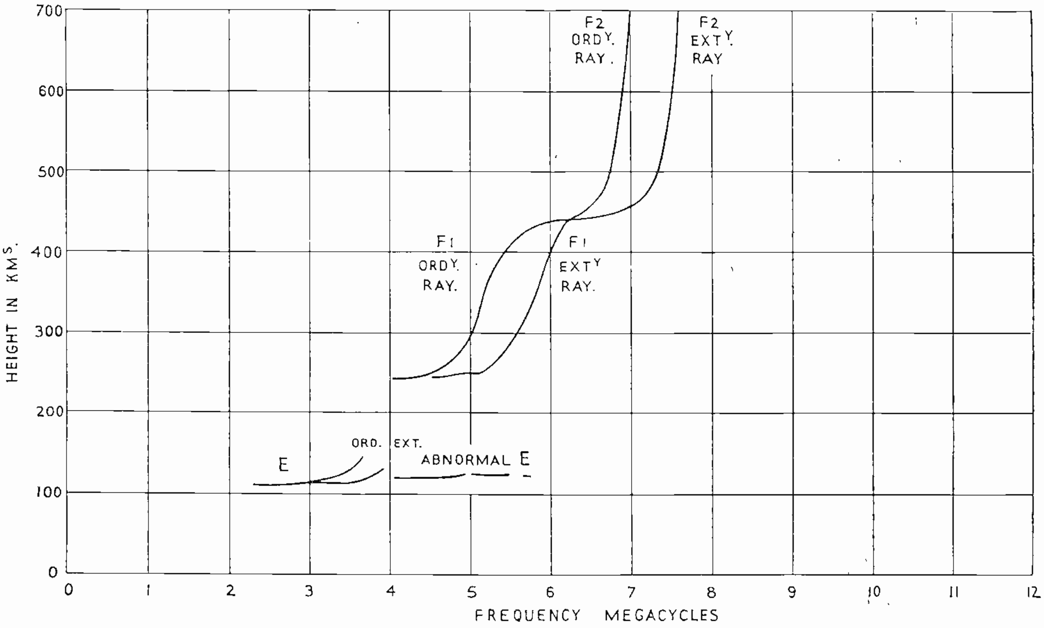

FIG. 3. *Typical Frequency/Height Curve. Summer, 1938, Chelmsford; midday.*

Marconi Company's Research Department, has also written a paper on the latter subject. This has recently been published in the Proceedings of the Physical Society.

The "skip" curves, or curves for maximum usable frequencies obtained in this way for various distances, wavelengths, seasons, time of the day and sunspot cycle, may be presented in various forms, and examples are shown in Figs. 4 and 5 for cases in which the "skips" are controlled by the F or F2 layers. The various layers are described in detail later.

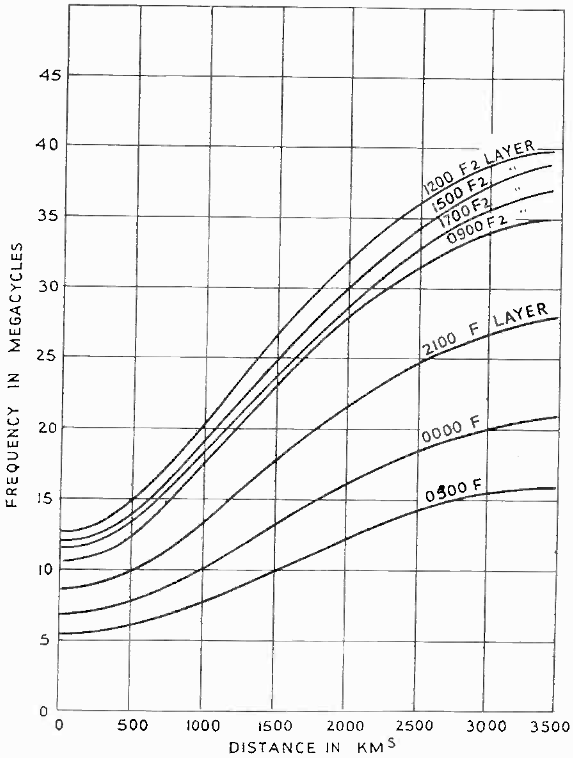

FIG. 4. *Maximum usable Frequencies for various distances at various local times. Equinox conditions, Washington,* 1937. *F*2 *and F layers* (*F*2 *day, F night*).

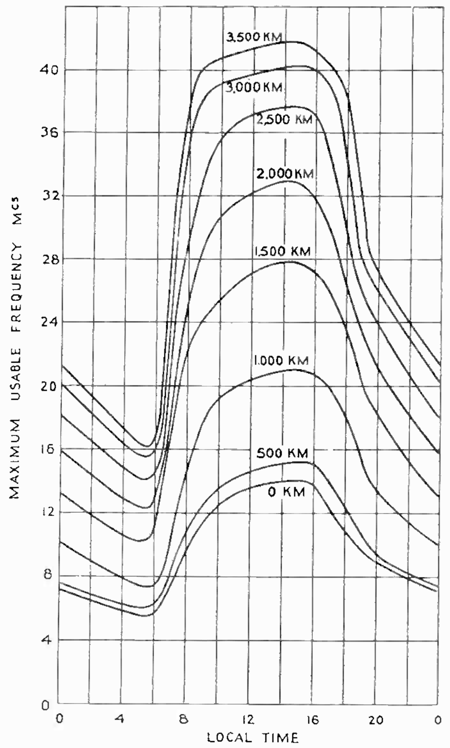

FIG. 5. *Washington, October,* 1937. *F*2 *and F layers* (*F*2 *day, F night*).

Curves of this type can be used in any part of the world, providing the local conditions of layer height and critical frequency for vertical incidence are known, and it is of great importance that as many observing stations as possible should be established in all parts of the world in order that complete information may be obtained.

Observations at vertical incidence by means of this pulse technique in various parts of the world during the past few years have given considerable information as to conditions existing at various times of the day and seasons, and over a considerable portion of the eleven-year sunspot cycle.

Reasons for some of the changes recorded appear to have been definitely established, and predictions based on the results obtained can be made with some confidence, but the reasons for some effects still remain obscure.

With regard to the changes connected with the sunspot cycle, the density of the reflecting regions has increased with the increase in sunspot numbers from minimum to maximum years. This is illustrated later in more detail.

It should be remembered that an increase in critical frequency is equivalent to an increase in density.

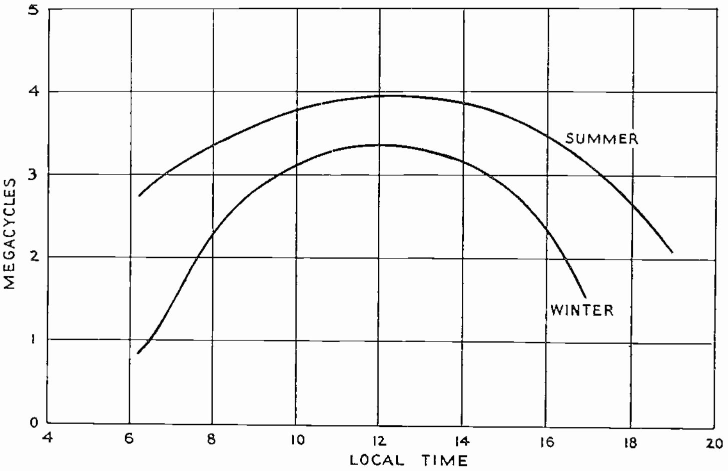

FIG. 6. *Diurnal variation in critical frequency. E layer (ordinary ray). Sunspot maximum years. Washington. Lat. 40 N.*

The Layers.

Three main reflecting regions exist in the ionosphere, the first at a mean height of 110 kilometres, known as the E layer, the second at a height of about 200 kilometres, known as the F1 layer, and the third at a mean height of 300 kilometres, known as the F2 layer.

The height and density of these layers vary with the time of day, time of year, sunspot cycle and latitude, and these conditions in turn decide which layers control the communications at various distances on various wavelengths.

The Normal E Layer.

The normal E layer, at a height of 110 kilometres, appears to be produced by ultra-violet radiation from the sun. This is indicated by the fact that the density increases with the altitude of the sun, reaching a maximum for the day at local noon (see Fig. 6). The density is also greater in summer than in winter at any place, and no normal E layer is found in the absence of the sun in Polar regions during the winter months.

Perhaps the most conclusive proof that this layer is produced by ultra-violet radiation is given by the reduction of E layer density at the time at which the moon's shadow reaches the E layer during a solar eclipse.

Any normal E ionisation at night is due to a residual of that produced during the day.

The data from various parts of the world appear to be consistent with regard to the dependence of the density of the normal E layer on the altitude of the sun, and one can predict the daytime critical frequency for this layer for any place and time with a certain amount of confidence. There will still be some uncertainty as to the exact values at various states of the sunspot cycle. Values obtained over a portion of the last sunspot cycle can be used to predict those which may be expected during the next cycle, but it is known that one cycle may vary considerably as compared with another as regards the sunspot numbers. This is illustrated in Fig. 7.

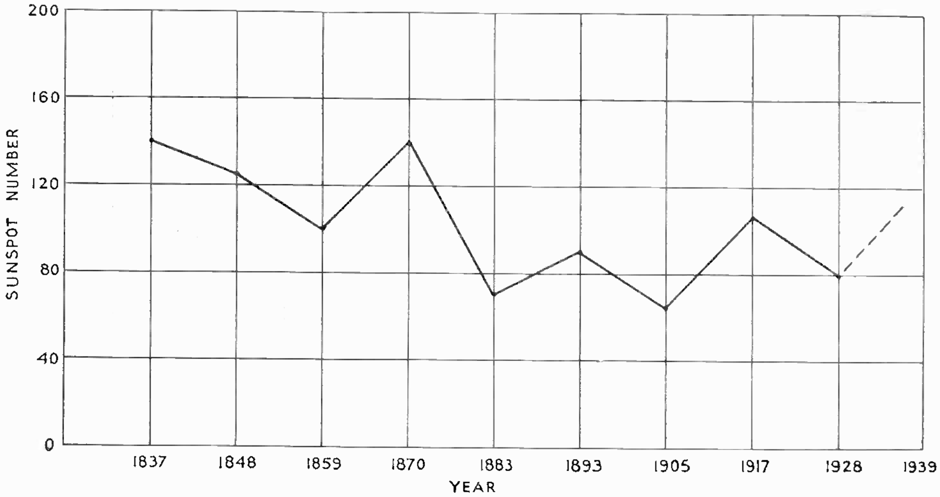

FIG. 7. *Sunspot numbers for successive sunspot maximum years.*

From available data on critical frequences of the E layer at various places and times, a curve can be plotted of critical frequency against the altitude of the sun. This is shown in the lower portion of Fig. 8.

From this curve one may predict the approximate critical frequency for a given place, knowing the altitude of the sun at the time. These values obtained from the curve have been used in the form of a sliding chart on transparent paper, which can be moved over a map of the world. The chart used for equinox conditions is shown in Fig. 9, set to midday G.M.T. The contours give the probable critical frequency for vertical incidence at any place for the E layer at that G.M.T. for daytime.

These will be less reliable near sunrise, as at this time they will depend to a certain extent on the previous history of the ionisation during the night.

A set of "skip" curves, as shown in Fig. 10, can be used with these charts to obtain the maximum usable frequency at oblique incidence at various distances on any route on which the E layer may control the "skip."

It is probable that E layer transmission, due to factors connected with attenuation, is normally of importance at comparatively short distances only, and in view of this, the contour value taken from the chart, when applying the skip curve, is that indicated by the mid point of the route.

The values on the charts are for the present sunspot maximum conditions, but those representing the conditions during the last sunspot minimum years (1933-1934) may be obtained by dividing the critical frequencies by 1.25. The critical frequency of the E layer at night, being dependent on recombination, steadily falls during the night, reaching values of the order of those used for medium wave broadcasting, but we have no extensive data on these night values, and they are of little importance in short wave communications.

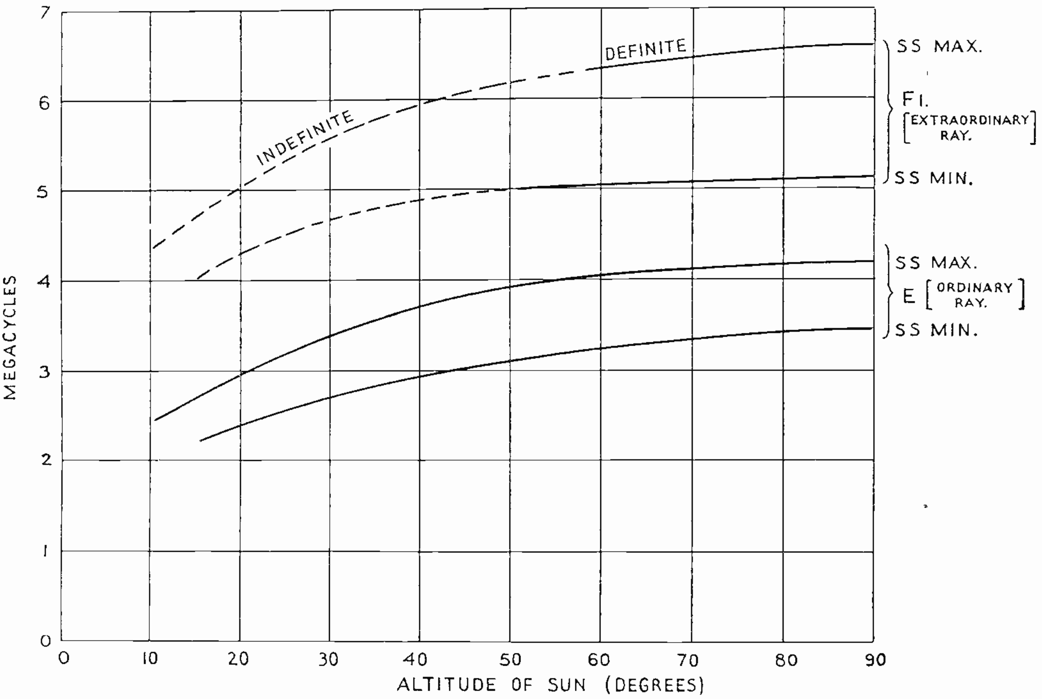

FIG. 8. *Variation of critical frequency for E and F1 layers with altitude of sun. Sunspot maximum and minimum.*

Abnormal E Reflections.

Reflections are sometimes observed from a height of 100-150 kilometres which are in some cases unconnected with ultra-violet radiation, since they may occur at night. These echoes differ from those received from the normal E layer in that they are received irregularly, and have no definite critical frequency.

This type of echo appears to be chiefly present during the summer day in Northern latitudes, and similar echoes, which may be of the same origin, are noted during the winter night, although they appear to be absent during the winter day. At present, with existing data, it is impossible to predict the extent of their influence on communications at any time or place.

It may be that the type of radiation producing this ionisation is always present, but that it can only become effective in producing a layer at this level when conditions in the upper layers permit.

On occasions when these echoes are present, frequencies may be used for communications far in excess of those normally used, but due to their irregular nature, they cannot be relied upon.

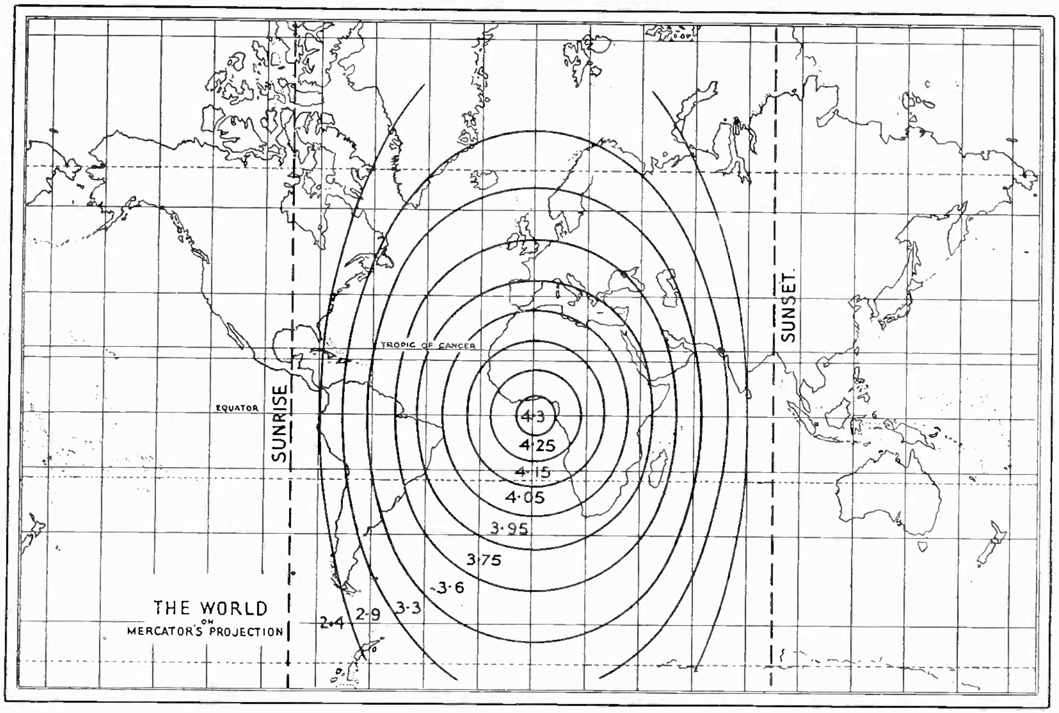

FIG. 9. *Contours for critical frequency for E layer (vertical incidence) in megacycles. Noon G.M.T., Spring and Autumn sunspot maximum conditions.*

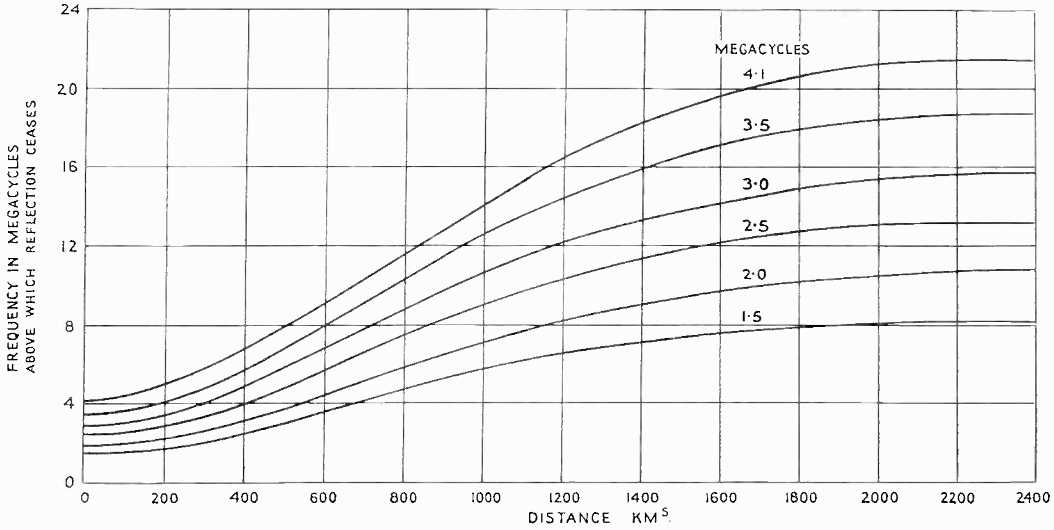

FIG. 10. *Skip curves for vertical incidence. Critical frequencies of* 1.5—4.1 *Mc. E layer height* 120 *kms. For use with contour charts for E layer.*

Abnormal E echoes were observed frequently during the Polar year ionosphere observations at Tromsö in Norway, and they have been recorded frequently in Australia, but they appear to be rare at Huancayo, Peru, latitude 10 deg. South, which may indicate some connection with magnetic latitude effects.

Reflections of the types mentioned above have been termed sporadic, or abnormal E, but the origin and type of the ionising agent still remain obscure, and it is difficult even to say whether the types observed in different parts of the world are necessarily the same.

The F1 Layer.

The F1 layer cannot always be observed as a separate layer, and it will be seen from Figs. 1, 2 and 3 that the critical frequency for this layer can only be definitely observed during certain seasons in these latitudes.

The ionisation of the F1 layer, like that of the normal E layer, appears to be chiefly dependent on ultra-violet radiation. Its density, when it can be observed, reaches a maximum about local noon, and the summer density is higher than the winter value at any place. As in the case of the normal E layer, there is no F1 layer during the Polar night. The height of the F1 layer changes very little with the time of the year or the sunspot cycle, but there may be considerable changes in the height of the F2 layer.

As the height of the F1 layer remains more or less constant at a height of 200 kilometres, and as the F2 layer may change, in Northern latitudes, from a height of about 400 kilometres in the summer months to about 200 kilometres in the winter months, there will be times at which the two layers become partially or totally superimposed.

This has occurred to such an extent in these latitudes during the sunspot maximum years that the critical frequency of the F1 layer cannot be observed during the winter months. This layer can still be partially observed during the spring and autumn, but it can only be observed as a separate layer with a distinct critical frequency in the daytime during the summer months when the F2 layer height normally reaches a value of about 400 kilometres.

In the tropics the F1 layer is observed during the day throughout the year, due to the fact that the F2 layer height is normally 300 kilometres, or greater, at all times of the year.

As a general rule it appears that the F1 layer can only be observed when the height of the F2 layer exceeds 300 kilometres.

The way in which the separation of the F1 and F2 layers varies with the season is illustrated in Figs 1, 2 and 3.

The F2 heights do not appear to be solely dependent on seasonal effects, but appear to be controlled to some extent by an annual effect. This annual effect tends to reduce the F2 heights in all parts of the world during the months of September to March. As the latter months are summer months in the Southern Hemisphere, it is probable that the F1 layer is less defined, or more intermingled with the F2 layer, in the Southern Hemisphere summer than in the Northern Hemisphere summer, but we are awaiting confirmation of this. An approximate relation between the critical frequency of the F1 layer and the altitude of the sun is given in the upper curves of diagram 8.

It should be understood that the foregoing relates to conditions during the daytime. At night only one layer is normally observed at any time and place known as the F layer. The latter may consist of the F1 and F 2 layers intermixed, but only one layer can be observed by the pulse technique. Both the E and F1 layers may control the communications at certain distances at times when the F2 densities are low during the day.

The F2 Layer.

The F2 layer does not appear to be dependent on ultra-violet radiation alone, but also on some type of corpuscular radiation which can be present in the absence of direct sunlight. This is indicated by the presence of this layer during the long night in the Arctic regions.

The density, in contrast to that of the E layer, is actually lower in the summer months than the winter months in our latitudes during the daylight hours, and is sometimes lower at local noon than during the hours preceding or following noon. With high altitudes of the sun, the F2 layer heights are frequently as great as 400 kilometres. The latter effects may be partly connected with expansion of the upper atmosphere due to a seasonal heating effect.

Another fact concerning the F2 layer is that the daytime density tends to be high in general in all parts of the world about the months of September and March, indicating some bi-annual effect in addition to a seasonal effect. This bi-annual effect may possibly be dependent on a solar latitude effect connected with the distribution of the active disturbed areas of the sun in certain solar latitudes which more nearly face the earth at these times of the year.

There are also indications of an annual effect which tends to increase the values of density of the F2 layer in the daytime all over the world between the months of October and February.

This latter increase of density might be attributed to a contraction of the F2 layer due to cooling effects in the Northern Hemisphere where it is winter at this time, but there are indications that the densities are also greater than would be expected in the Southern Hemisphere where it is summer during this period. The F2 layer heights also tend to be low all over the world at these times.

Observations also show that the F2 layer heights are considerably less during the months of September to April in sunspot maximum years than in sunspot minimum years, and the percentage increase in density of this layer during these months for sunspot maximum years, as compared with sunspot minimum years, has been much greater than that for the E or the F1 layer.

Sliding charts in conjunction with a map of the world have also been constructed and used for the F2 layer, but due to the variable nature of the latter, these charts are more complex than those already described for the E layer, and more world-wide data is necessary to make them complete.

Owing to the annual effect already mentioned, the F2 chart for summer conditions in the Northern Hemisphere cannot be used for the summer in the Southern Hemisphere, although the E layer charts already described can be interchanged in this respect.

Measurements Illustrating Seasonal and Sunspot Cycle Changes.

The changes which have taken place in the critical frequencies of the various layers at Washington during the last few years connected with changes in the sunspot cycle are shown in Figs. 11, 12 and 13.

To simplify Figs. 12 and 13, the extraordinary ray has been omitted.

Fig. 14 shows measurements made at Chelmsford from June, 1937, to June, 1938. The values of critical frequency in this article have been chiefly confined to midday, as there is hardly space to consider the diurnal changes in detail.

Scattering.

It has been known for a number of years that, in addition to the continuous reflections from the ionised regions, other reflections or (scattering) of a sporadic type are frequently observed. This scattering appears to be produced by electron clouds at a height approximating to that of the E layer, and is observed chiefly when high power transmitters are used.

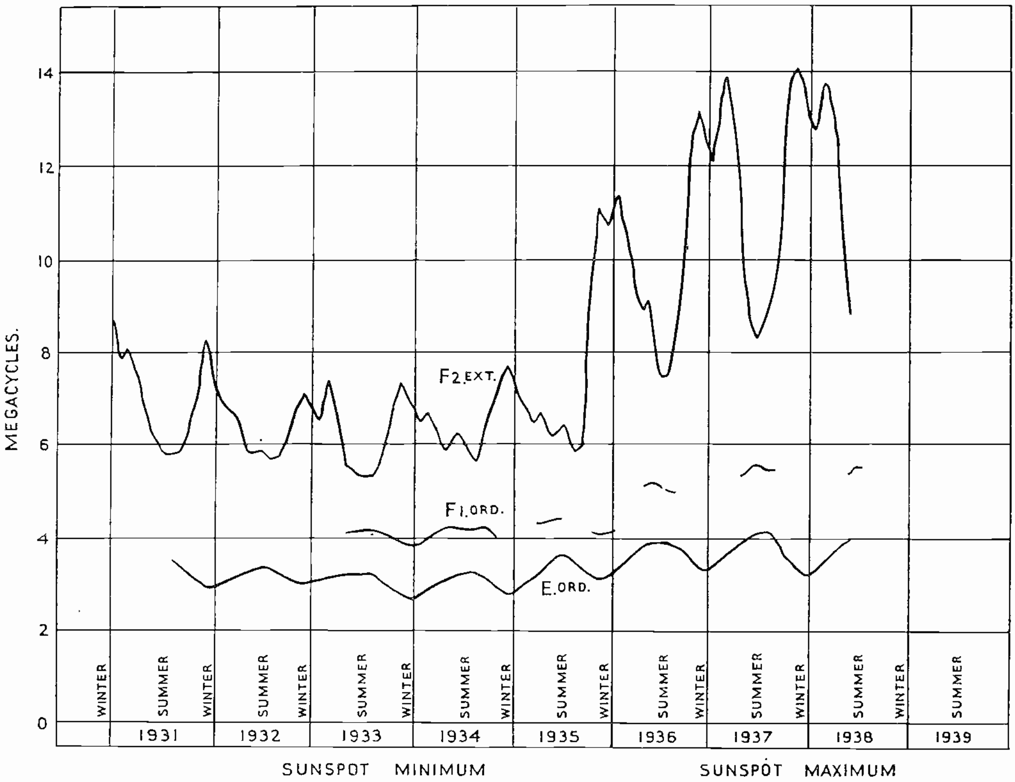

FIG. 11. *Variation of critical frequency with change in sunspot cycle. Washington midday values.*

In the case of a reflected ray communication having a skip for the F2 layer of, say, 1,000 kilometres, scattering can frequently be observed from short distances corresponding to the points at which the rays pass through the scatter region on their way to the higher F2 reflecting region. We have called this "short scatter" to distinguish it from scattering back, which may also be received from the points at which the rays reflected from the F2 layer again pass through the scatter region on their way to the earth at approximately 1,000 kilometres distance.

The short scatter may be present at any time and on any frequency, but the second or distant scatter can only be observed on frequencies below the minimum usable frequency for the F2 layer, as the reflection from the latter is necessary to bend the rays down again to the scatter region below. The distant scatter also varies in strength with the wavelength and time of the day in the same manner in which a distant signal varies with these factors. When a beam transmitter is used, the scattering is more intense from that portion of the scattering region which is illuminated, as it were, by the beam.

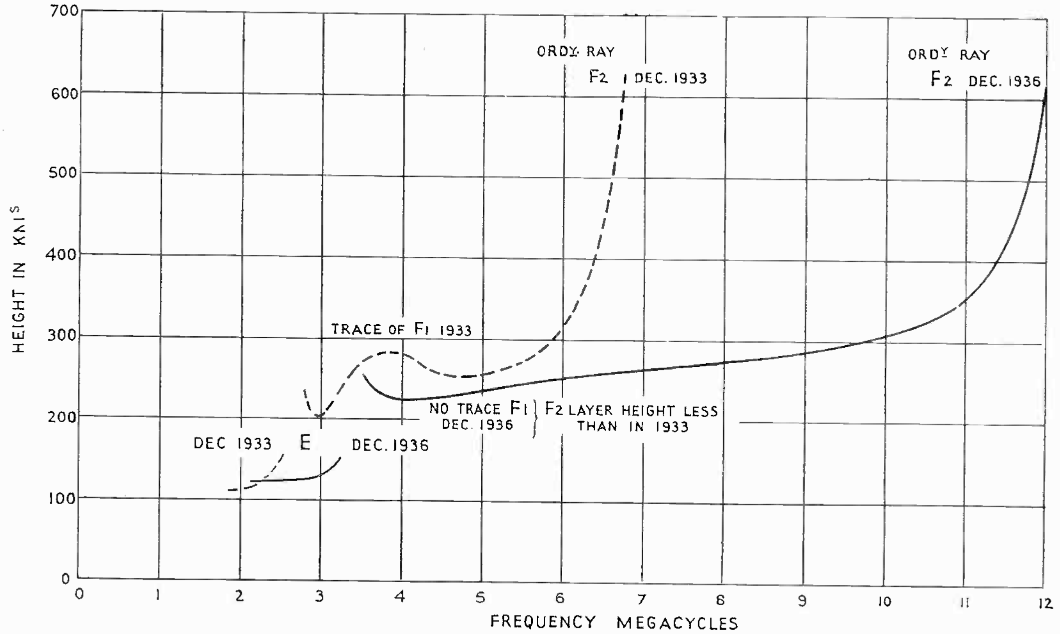

FIG. 12. *Frequency/Height curves showing increase of critical frequencies with change from sunspot minimum* (1933) *towards sunspot maximum conditions. Washington, Winter, noon values.*

Some years ago the short wave direction finder gave us a clue to the origin of this distant, more or less horizontal scatter, and it is difficult to convince some observers that it is not received from other layers of the ionosphere at great heights.

Effect of Solar Disturbances. Magnetic Storms.

Changes in height and density of the layers occur during magnetically disturbed times. These changes are of a complex nature, and the reasons for them are not fully understood.

As might be expected, they are more marked as one approaches the Magnetic Poles, very little change being noted in central latitudes.

The general effect of magnetic storms on the F2 layer is to decrease the critical frequency and increase its height in this country, but at Washington, especially during the winter months, these effects appear to be less marked, and there appears to be a tendency to the reverse effect at times.

Washington being differently situated with regard to the Magnetic Pole, it may be that there is an ion drift under certain disturbed conditions which decreases the ionisation in this country and increases it in other parts, forming zones of low and high density, with the result that the local noon value of critical frequency for the F2 layer during the winter in England may be several megacycles less than the local noon value in Washington for the same day. During disturbed conditions the critical frequencies of the E and F1 layers do not appear to be affected to the same extent, but a highly absorbing layer may be formed at times about the height of or below the normal E layer, which may result in a condition of no echoes on any short wavelengths.

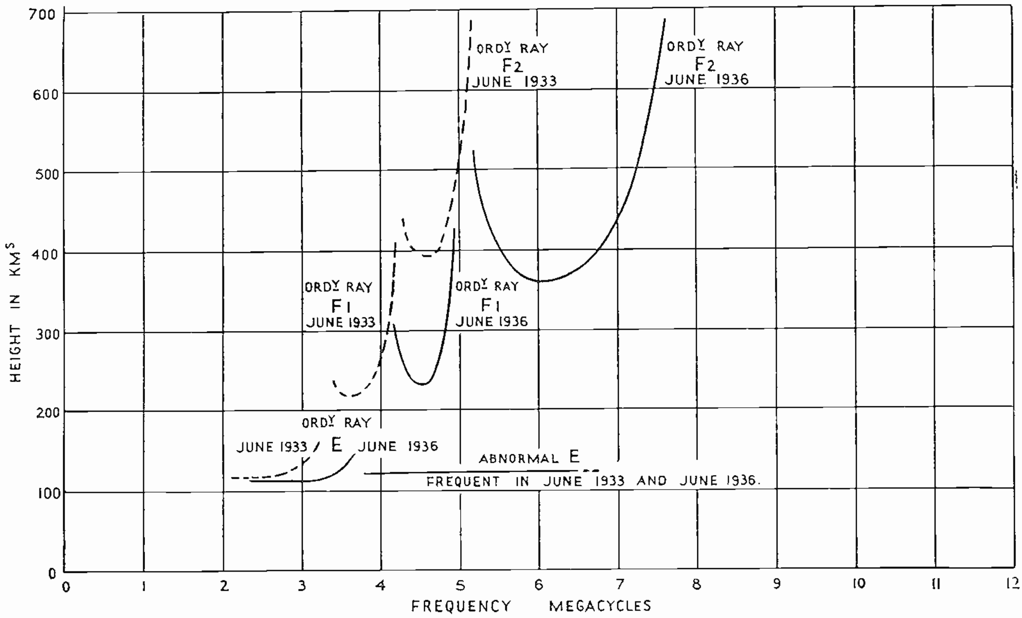

FIG. 13. *Frequency/Height curves showing increase of critical frequency with change from sunspot minimum* (1933) *towards sunspot maximum conditions. Washington, Summer, noon values.*

The departures from the mean annual curve for the F2 layer shown in Fig. 14 illustrate the variable nature of this layer from day to day. A typical example of the effect of disturbed conditions can be seen at the end of January, 1938, on the occasion on which the Aurora was observed in England.

On some occasions the increase in height of the F2 region during disturbed conditions has permitted the F1 layer to be observed during the day at a time when the F1 and F2 layers would normally have been superimposed.

On other occasions the critical frequency of the F2 region has been reduced until it coincided with or was actually less than the critical frequency of the F1 region. In the latter case, only one critical frequency for the F layers can be observed, the height indicating that this is the F1 layer.

The increase of height and decrease of critical frequency of the F2 region may be connected with heating effects due to the magnetic storms or possibly to some ion drift as suggested above.

Communications may suffer for several days and nights under magnetic storm conditions, but, as previously mentioned, these effects are chiefly confined to Polar magnetic latitudes.

Catastrophic Disturbances.

At times, fortunately comparatively rare, there may be a complete fade-out of signals on short waves.

This type of fade-out occurs suddenly and simultaneously at all places, and the recovery, which often takes place after only a few minutes, is almost as rapid.

The interesting point concerning this type of fade-out is that its effects are only observed over the portion of the world which is in daylight at the time, and the effects are not confined to the magnetic latitudes, in fact they are more marked in central latitudes.

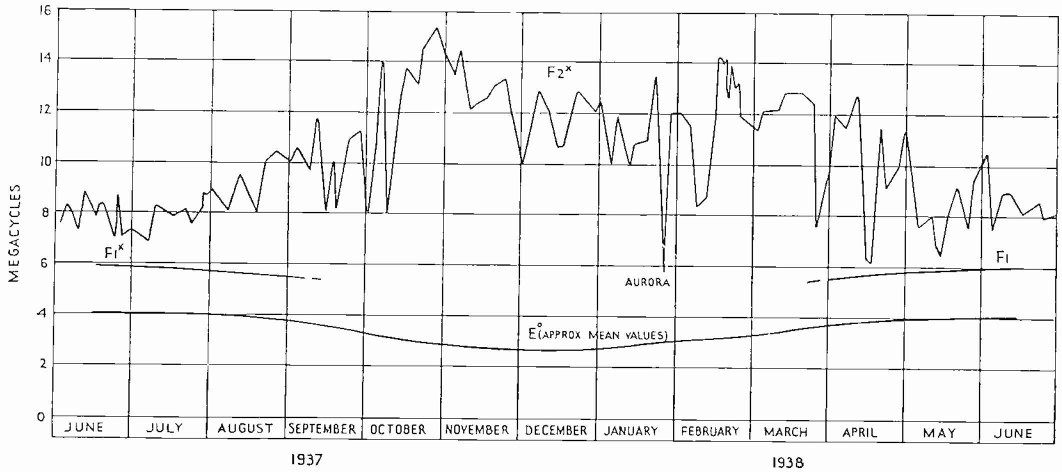

FIG. 14. *Critical frequency at midday. F2, F1 extraordinary ray ; E, ordinary ray. Chelmsford.*

These disturbances appear to be definitely connected at times with bright hydrogen eruptions on the sun. Short wave fades of this type appear to be caused by the formation of a dense absorbing layer in the lower regions of the ionosphere.

It is of interest that during this type of disturbance signal strength on long wave circuits is usually increased.

Factors Controlling Propagation.

Apart from these disturbed conditions, the normal factors controlling ionosphere propagation on short waves are electron limitation and attenuation. The former fixes the maximum usable frequency at any time, and the latter controls the signal strength received.

The attenuation appears to be mainly in the E layer, except possibly when working near the critical frequency of the F2 layer, and this attenuation is increased with every successive reflection, especially in the case of low angle rays which have to pass through greater distances in the E layer.

We have already collected a large amount of data in an attempt to predict the performance which may be expected on any short wave communication at any time, but, as may be gathered by this very brief outline, the whole matter is of a very complex nature, depending, as it does, on so many variable factors.

K. W. TREMELLEN.

VOICE FREQUENCY VOLUME CONTROL

The operating technique of speech control apparatus for broadcasting and radio-telephony plays an important part in ensuring that best use is made of advances in design. Present means available for minimising the difficulties of manual operation, and for providing automatic controls are described. This account of automatic control apparatus is concluded with a discussion of the new control methods required to meet the needs of semi-automatic operation. Finally, an appendix describes the methods adopted for accurate measurement of the high speed meter characteristics required for modern programme meters. The material for this paper has naturally been drawn from many sources and from much experimental work in the Marconi organisation. In this work, valuable suggestions were received from Mr. F. M. G. Murphy and many measurements were effected by Mr. M. W. Gough.

Introduction.

THE wide range of audio-frequency energy level tolerable to the human ear must be considerably reduced if satisfactory quality and efficiency are to be achieved by any of the methods of telecommunication. This reduction in the energy range has in the past been effected partly by apparatus limitations, but mainly by manual control. With the object of providing improved working automatic apparatus is being introduced, and this article is intended to present a general understanding of the subject of volume control and to describe apparatus used therefor.

Apparatus Requirements.

Considered over the period of a programme item or of a telephone conversation the range of energy level at the output of a microphone will seldom exceed 60 decibels. Thus, although a full orchestra is stated to be capable of a dynamic range of 110 decibels,(1)* it is probable that the room noise level prevents this being realised even should the musical score require it. In fact, in rooms with short reverberation times and probably also therefore low noise level, adequate contrast is obtained with a dynamic range of 30 to 40 decibels, while even in large halls a dynamic range of 60 decibels is adequate and is seldom exceeded.(2)

Nevertheless even when the dynamic range is normally small, sudden large increases of level may often occur, e.g., a speaker's cough, dramatic effects, etc., increases which require very rapid control if distortion is to be avoided in the transmission. In addition items of a programme may differ considerably in their mean energy level, and the speech level from telephone subscribers depends considerably on the line in use. Only slow speed control is necessary to compensate for these variations.

Now consider the transmission system. All systems introduce background noise, which may obscure the lower signal levels and which fatigues the ear. Thus it is desirable to transmit at a level which will provide as high a signal to noise ratio as possible. On the other hand with excessive inputs amplifiers, transmitters and receivers may overload and cause distortion, cross-talk between lines may lead to high noise level in neighbouring circuits, break-through may occur in disc recording, and certain transmitters may flash-over while in others circuit-breakers may operate to cause complete shut-down. There is, however, a time factor involved: the effect of an overload is dependent on its duration, since it is well known that the ear is

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* These figures refer to the references given at the end of this article.

tolerant of momentary distortion, and similarly circuit breakers require time to operate, flash-over voltages take time to build up. This time is short compared with the reaction time of a human operator, who cannot therefore provide adequate protection against overload due to sudden signal peaks without considerable rehearsal or undue restriction of the mean signal level. A human operator is however quite capable of controlling the mean level to compensate for slow changes.

Thus, according to the type of service required, control technique and apparatus may differ considerably. For line and radio telephone circuits control of the mean level is sufficient and the Volume Control Indicator has been developed to facilitate this. Distortion due to transient overloads is comparatively harmless, as with speech the dynamic range is small, and in conversation the ear has frequent intervals of relief. On the other hand for disc recording continuous control is necessary: the noise level is high, and a high mean level of recording is therefore necessary, while at the same time break-through between record grooves cannot be permitted. To assist him in his work the operator is allowed several rehearsals, and may follow the programme through from the musical score, and his Programme Meter is designed to give an indication of the peak levels. Additional control is sometimes provided by the Recording Engineer who observes the groove cut through a microscope.

The control of broadcast programmes is intermediate between these two. Within the service area the transmitter field strength is relatively high and received noise level is not therefore a controlling factor of first importance. Thus Programme Meters are again designed to indicate peak levels, so as to guard against transmitter overload, but continuous control is seldom necessary, the control setting for a particular item being found during rehearsal or known from experience.

Naturally, the reliability of a human operator is very dependent on the type of indicator which he uses, while the demands made on his attention and skill can be considerably reduced by the addition of some automatic control. The types of apparatus designed for these purposes are discussed below, and the repercussions that the introduction of full automatic control is likely to have on control technique are considered.

I. Level Indicators.

1. *Volume Control Indicator.*

Developed for line use, and largely retained for radio telephone controls, this type of level indicator gives a reading corresponding virtually to the mean level over a short interval. In earlier forms an anode bend detector was used, but a copper-oxide rectifier is now more often used. The meter damping and speed of operation are important, as readings are required to be reliable for changes of level in either direction, while observation must not be too tiring. In practice the damping is adjusted so that the sudden application of an input, which would give a steady reading of 50 per cent. full scale deflection, causes a maximum reading of 80 per cent. f.s.d. ($\frac{k}{p} = 0.163$. See Appendix). The calibration extends over a range of some 4-12 decibels according to the type of instrument.

2. *Programme Meter.*

The instrument developed for programme services is designed rather to indicate peak levels on a logarithmic scale, since the material is very diverse in character, and distortions must be prevented from affecting quality. Since the peak fluctuations are rapid and large, any attempt to provide rapid indication of their level changes in both directions would make the instrument unreadable or quickly cause eye fatigue. The onset of a level peak is therefore indicated quickly, without overswing, but the meter is slow in returning, and the meter scale covers a range far greater than that of the telephone volume indicator, usually some 30-40 decibels of approximately linear range.

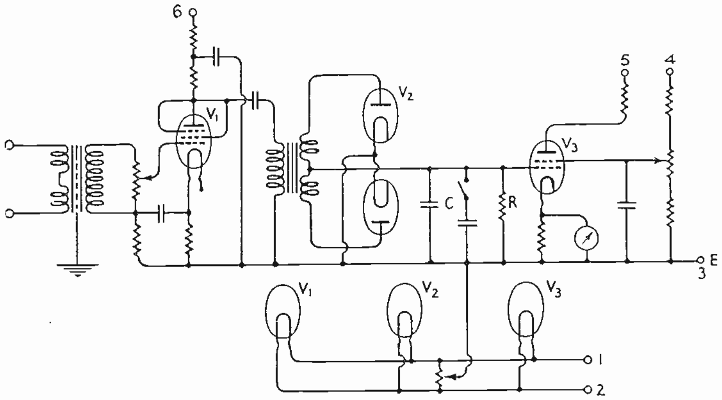


FIG. 1. *Programme meter.*

A version of the Programme Meter, known as a Modulation Monitor or Modulometer, is frequently used in transmitter input equipment. This differs from the Programme Meter mainly in the addition of a flasher or other alarm device, which indicates when some predetermined modulation is exceeded. The meter scale is often arranged to be linear in percentage modulation and not logarithmic.

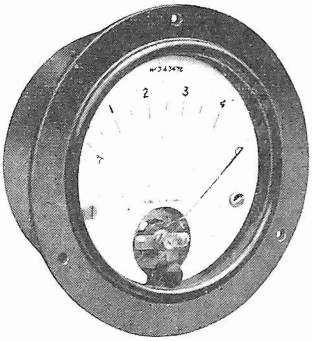


FIG. 2.

The design of a satisfactory Programme Meter presents some difficulties, as peaks of very short duration must be indicated, while peaks of longer duration must not give an unnecessarily alarming indication. The U.I.R.(3) recommend that impulses of longer duration than 10 milliseconds be indicated correct to 1 decibel. It will be seen that this requires a meter capable of extremely rapid operation, and special methods are necessary for checking the operating times of such instruments. A convenient method, which has been devised to avoid the necessity for a cinematograph camera or other elaborate equipment, is described in the Appendix.

A typical programme meter circuit conforming to the U.I.R. specification is shown in Fig. 1, and Fig. 2 shows the type of instrument used. The scale is marked at intervals of 4 decibels. The logarithmic scale shape is obtained by the use of a variable mu-valve as D.C. amplifier, and the time constants of the screen grid circuit are designed to increase the operating speed of the meter. Full-wave rectification is essential as programme material often comprises asymmetrical waves, and both positive and negative peaks are required to be recorded.

The relapse speed of the needle is made relatively slow, as this is found to be much less tiring to the eye. In addition there seems to be no reason for making the relapse time less than the reverberation time of the studio. A choice of speeds is generally provided, being controlled by the time constant circuit CR. The meter deflection is normally set to drop back 25 decibels in from 0.5 to 3 seconds,(3) (4) the faster relapse speeds being recommended only for recording instruments.

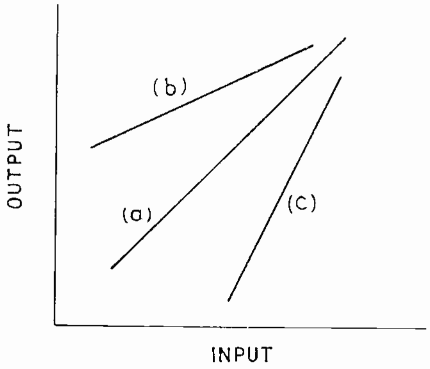


FIG. 3. *Ideal type characteristics.*
(A) *Normal amplifier.*
(B) *Compressor.*
(C) *Expander.*

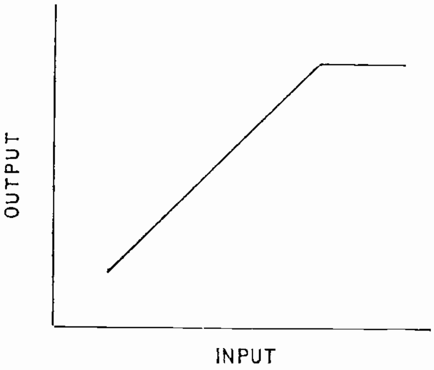


FIG. 4. *Ideal type characteristics. Limiter.*

II. Automatic Control Apparatus.

The introduction of automatic control demands new terms to describe the performance of such apparatus. The assumptions made with normal amplifiers are no longer true, for a feature of the new apparatus is that when the output is plotted against the input on a logarithmic scale, the characteristic is not equally inclined to the axes. Furthermore, the output for a given input is dependent on the immediate history of the system, so that the conditions of measurement must be specified, either as allowing time to settle down (static characteristics), or as with sudden level changes (dynamic characteristics). Definitions of terms used to aid descriptions in the literature of the subject are appended. The novelty of the subject is such that definitions differ between organizations, and other definitions may be found in the literature.

Definitions.

Analogous with amplification, compression factor is defined as the rate of change of output level with input level when these are measured on logarithmic scales at a given output or input, or as the ratio of change of output to change of input over a given range of input or output levels in decibels. In addition :—

An Amplifier is a device having a compression factor of unity (Fig. 3A).

A Compressor is a device having a compression factor less than unity. It thus reduces the dynamic range (Fig. 3B).

An Expander is a device having a compression factor greater than unity (Fig. 3C).

A Limiter has unity compression factor for inputs less than a certain value and compression factor less than unity, ideally zero, for larger inputs (Fig. 4).

A Noise Reducer has compression factor equal to unity for inputs less than a certain value greater than unity for higher input levels up to a second prescribed value, and unity for still larger inputs (Fig. 5).

A Constant Level Amplifier has compression factor less than unity, ideally zero, over a certain range of input levels. At levels below the range the amplifier has ideally considerable loss, the level curve being completed by a section of compression factor greater than unity, and a section of compression factor unity (Fig. 6).

The automatic control may be considered as being provided by a " Variable Attenuator," which is in the normal signal channel controlled by one or two " Operators," which may take the form of amplifier-detectors monitoring the input or output (Figs. 7, 8 and 9). In certain types of apparatus the Operator and Attenuator cannot be considered separately.

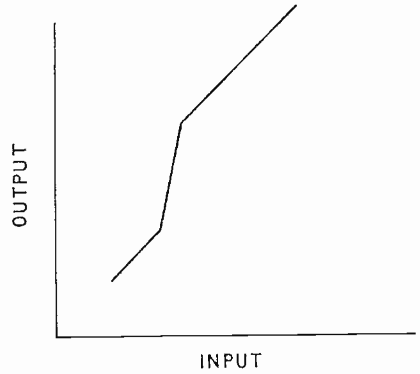


FIG. 5. *Ideal type characteristics. Noise reducer.*

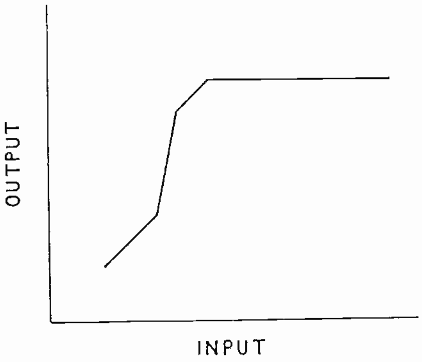


FIG. 6. *Ideal type characteristics. Constant level amplifier.*

The characteristics of the Variable Attenuator in the absence of control from the Operator are called the Static Attenuator Characteristic.

Characteristics measured with steady tone, which allow the Operator time to establish control, are called the Static Overall Characteristics. These naturally involve the Operator Static Characteristics.

With tone suddenly applied the Dynamic Characteristics are obtained.

Apparatus.

1. *Compressors and Limiters.*

These devices provide automatic control before transmission supplementary to the normal manual control, and so reduce the demands made on the operator's attention. Three such types of apparatus will be considered.

The first and simplest device, chiefly used for protecting a transmitter or a light valve, or for preventing break-through to an adjacent groove in disc recording, is known as a " peak chopper." This consists of a biassed rectifier system, or a gas discharge tube connected across the signal line, and so arranged that when the instantaneous voltage on the line exceeds a prescribed value, a low resistance shunt is placed across the line to prevent any increase in the voltage. This reduces only the peak voltage, and produces a square-topped wave at high levels. The harmonic distortion is high, but as no gain changes are made, this device is popular where sudden noises, such as shots, are to be handled. It can only be supplementary to the control engineer, and ensures that relaxed attention does not result in catastrophe.

The other two devices make use of an automatic operator, apparatus which measures the peak line voltage, and adjusts the loss of an attenuator accordingly. This can be arranged to perform the control changes much more quickly than a human operator, and also to effect precisely the correct change of level. As such a system is merely performing the function of a manual control, combined with a programme meter, and the eye, brain and hand of an engineer, the harmonic distortion of a steady programme is only that inherent in the circuits used, and may be made small. Naturally, if a change of gain is made, while this change is taking place there will be what is really distortion, the production of frequencies not present in the original, but this is only the same as that which would accompany the changing of an attenuator setting. Usually, too, if a sudden increase in level takes place, a short time elapses before the control operates, but provided that this time is less than some 20 milliseconds, no audible effect is produced. Also no danger to the transmitter is involved, as the effects of over-modulation—breakers tripping and the like—take a definite time to begin. This factor is taken into account in manual control, and corresponds to the time of integration of a programme meter.

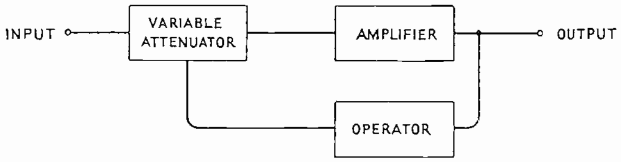


FIG. 7. *Compressors and limiters.*

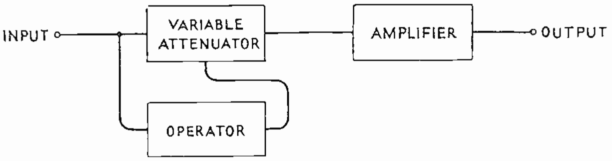


FIG. 8. *Expanders and noise reducers.*

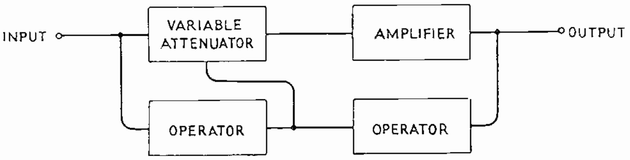


FIG. 9. *Constant level amplifier.*

Two main types of this automatic control have been used. The first, volume compression,(5), (6) consists of a circuit which varies the gain continuously as the level changes, in such a way that the transmitted level range is less than the programme level range. A typical compressor would reduce a 40 decibel dynamic range to 27 decibels, and hence would permit an increase of the mean modulation from 10 per cent. to 22 per cent. This, of course, corresponds to doubling the transmitter power. The effect of this compression is to reduce contrasts, but listening in small rooms normally heightens contrasts and reduced contrast is, in any event, preferable to loss of weak passages below noise.

The second type of automatic control is that termed limiting.(7) Here the control operates only at high levels, but instead of chopping peaks, the loss of an attenuator is quickly increased, just as the control engineer would turn down the output. Both compressors and limiters reduce the attenuation slowly after high level signals, and hence no distortion or audible effects are obtained during operation. Also, as the attenuator setting is determined by the peak line voltage and the attenuation is itself not determined by the signal, no change in " vertical balance " is produced. The relation between loud and quiet signals present together is maintained, as is the relation between the components of a compound tone. No change in note timbre or chord quality takes place. Listening tests with both a limiter of this type and a compressor having compression factor of 0.67 have shown that it is extremely difficult to tell whether such apparatus is in circuit or not. The effect on sudden very loud noises is perceptible, but muting for possibly half a second after an over-loud bang is preferable to the disturbance following on breaker pull-out or the like.

2. *Expanders and Noise Reducers.*

These devices are intended for use at the receiving or reproducing end.

Expanders are used at receivers for overcoming the effects of compression, and give an output range greater than the input range.(5), (8) The effect of compression and subsequent expansion on noise is of great interest. If a dynamic range of 40 decibels is to be transmitted or recorded, and after transmission a signal to noise ratio of 40 decibels is obtained, the lowest signal levels will be just equal to the noise level. If now the dynamic range is compressed to 27 decibels before transmission or recording, the lowest signal will now be 13 decibels above noise. If the reproduced signal is expanded to the same extent, so that a 40 decibel dynamic range is obtained, the noise will be brought to $13/0.67 = 20$ decibels below the lowest signal. An increase of 20 decibels in signal/noise ratio is by no means a negligible quality improvement.

Noise Reducers are used on radio-telephone circuits (9), (10) and to some small extent in broadcast receivers for reducing the gain in intervals of no signal and so relieving the ear. Listening tests show a useful improvement in the apparent signal to noise ratio.

3. *Constant Level Amplifier.*

A more complicated arrangement combines the noise-reducer circuit with the limiter, and gives small gain up to a chosen level, full gain at a slightly higher level, and at still higher levels constant output. This arrangement is intended to give constant output for signals in its working range, and in the absence of such signals to mute the system. Such an amplifier is used in circuits where levels must be maintained constant but singing might take place if the muting system were absent, owing to unchecked gain increase.(11)

Compressor Design.

Apart from the "peak chopper" all these automatic control devices are of generically the same design and therefore for convenience may be referred to as Compressors.

The methods adopted for realising these systems must now be considered. As has been said, circuits comprise an attenuator, and associated amplifier in the signal path, a measuring circuit and an operator for adjusting the attenuator. This picture shows why it is not of primary importance that compression or limiting should take place at precisely the same level at all frequencies. Provided that the attenuator circuits and any signal amplifiers are flat and distortionless, no loss of fidelity will be introduced save for the slight loss of contrast mentioned above. For operating convenience the control channel is made to have a flat frequency response, but increased protection is useful at very low frequencies.

The variable gain or loss element may take a number of forms.(7) An obvious one is a variable-mu valve, the gain of which depends on the bias applied to it ;

another uses such a valve as a variable resistance in a potentiometer network, the valve having feed-back from anode to grid, and having an impedance dependent on bias. Networks using lamp filaments heated by the signal current have been used. A number of networks of resistances and non-rectilinear resistance elements, such as copper-cuprous oxide rectifiers have been also used, and one of these has been chosen for use in Marconi gain control circuits.(12) The circuit comprises in one form a lattice network of metal rectifiers and resistances, and in a later type an equivalent lattice of resistances and Metrosil elements. These elements have a resistance depending on the current passed through them, so that a polarizing direct current can be used to vary the non-rectilinear elements of the lattice and thus to change the attenuation introduced by the network. The attenuation is a maximum for a particular polarizing current and thus the circuit can be worked with the loss either increasing or decreasing as the polarizing current is increased, according to the working point chosen. The attenuation is controlled by the polarizing current, which is derived from a D.C. amplifier valve in parallel with a shunt resistance: this shunt resistance settles the working point, the attenuation being then controlled by the bias supplied to the control valve. The relation between attenuation and polarizing current is shown in Fig. 10. An amplifier is bridged across the signal path at some convenient point, and the output is rectified by push-pull diodes. Full wave rectification is necessary as the polarity of the wave front may be positive or negative, and equal operating times are desirable for both conditions. The output is applied to the grid of the control valve. For apparatus having a smaller output range than input range, the control is bridged across the output: for compression factors greater than unity, the control is bridged across the input. The effect of a suddenly applied increase in level is shown in the photographs of Fig. 11. Here the output of a PS.9827 Limiter and " B " Amplifier, as recorded by a cathode ray oscillograph, are shown for various frequencies and level increases. The transient peak shown is too short to be audible, or to cause difficulties at the transmitter and would be much reduced if the level increase were made over several cycles, as would be the case in programme material.

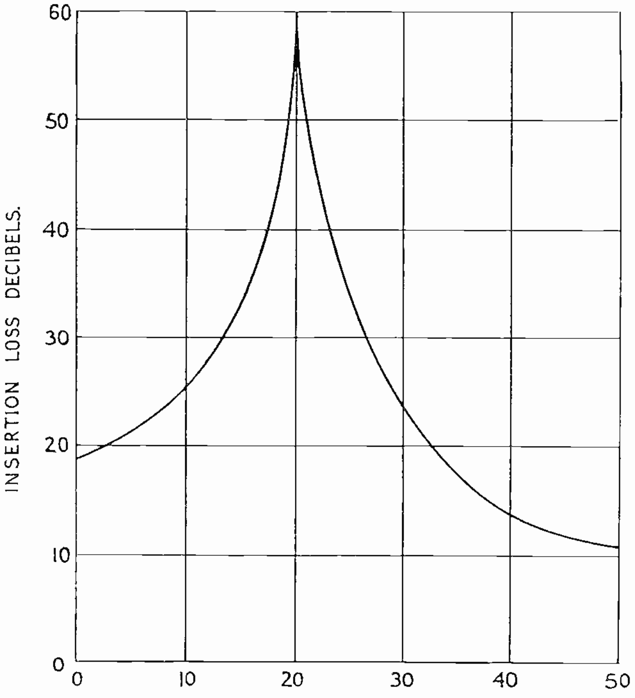


FIG. 10. *Current-loss characteristics of variable attenuator.*

The constant level amplifier requires two control chains, one bridged across the input and one bridged across the output. As the lattice is balanced with respect to the point of injection of control current, the change of control current does not produce a signal impulse, and instability is also prevented. Choice of the diode reservoir condenser and load resistance enable the operating time and relapse time to be adjusted. For example, the operating time of the PS.9827 Limiter and " B " Amplifier is about 3 milliseconds, and the relapse time 1.5 seconds.

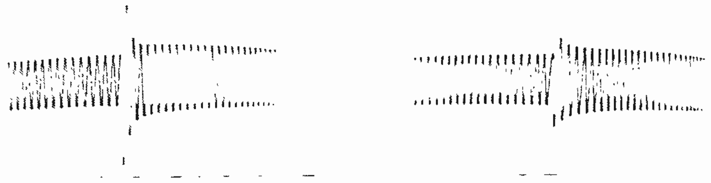
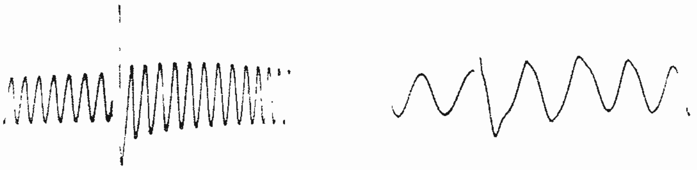


FIG. 11. (A) 1,000∿20 *db. increase in level.* (B) 1,000∿10 *db. increase in level.*



(C) 500∿30 *db. increase in level.* (D) 100∿20 *db. increase in level.*

If the conditions of operation of these systems are considered, it can easily be seen that if a compressor or limiter is controlled from the output, it is impossible for an increase in input to produce a decrease in output. To do so would entail a decrease in output producing an increase in attenuation, which does not accord with the form of the circuits used. If, however, a compressor or a limiter is controlled by the input, there is no reason why an increase in input should not result in a greater increase in attenuation. This would lead to a load curve having output increasing with increasing input, compared with the ideal of output constant with decreasing input. Similarly, with expansion circuits, if an increase in output is used to produce a decrease in attenuation, a further increase in output results. Such a circuit is inherently unstable, although the damping may be such that no " singing " takes place. If increased input is used to decrease the attenuation, the changing attenuation has no effect on the control operator and no instability is possible.

An objection(6) raised against control of limiters from the output is that it is impossible to obtain absolutely constant output with variable input, as small changes of output are required to control the attenuation. The increased operating ease, and particularly the lack of critical adjustments render this of small importance, as by adequate amplification in the operator circuits a sufficiently constant output may be obtained. A further objection which has been raised is that the backward control is inherently unstable, owing to the presence of feedback from the output through the operator to the variable attenuator. It is stated that to protect against this such smoothing of polarizing current is required that high speed operation is impossible. In practice, apart from difficulties encountered when development was first begun on these devices, no trouble has been encountered from this effect. The only requirement is that balance of the variable attenuator transformers should be good, and with normal production transformers no difficulty has been experienced in either a limiter or a compressor having operating times of 3 milliseconds. The addition of a small " threshold " bias to the compressor has been found desirable to avoid effects when only circuit noise is present, but the only effect of this " step stabilization " is to simplify operation of the compressor. It may be noted that the compressor described in the reference given is also potentially unstable, as although control is taken from the input to the variable loss network, no buffer amplifier is interposed between the control input bridging point and the variable attenuator.

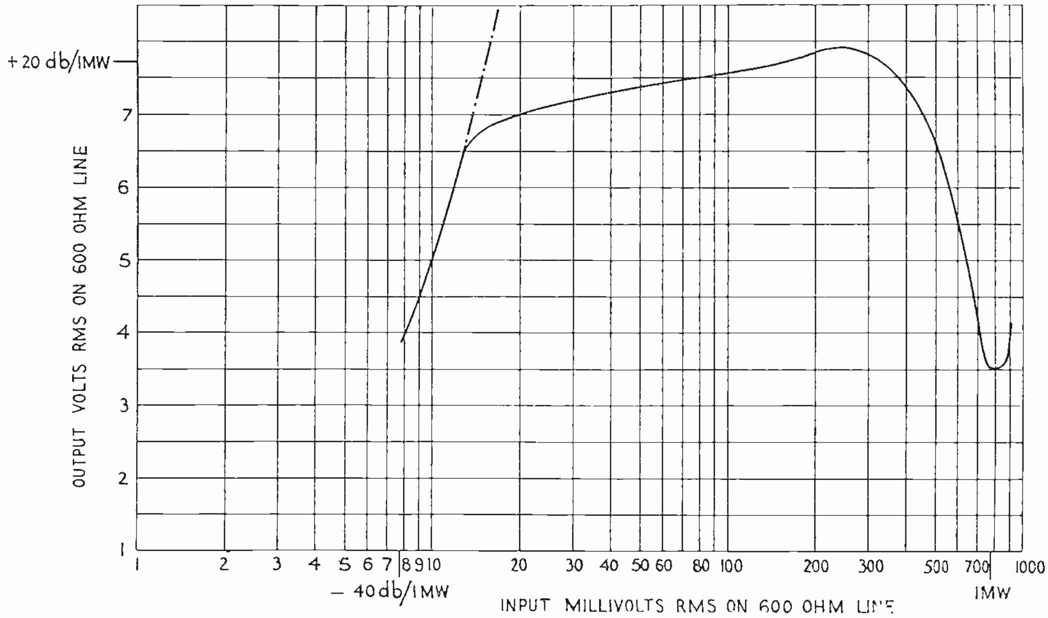


FIG. 12. *P.S.9827 limiter and B amplifier load characteristic.*

In considering the measured load characteristics of this class of equipment, confusion sometimes arises. The normal requirement of apparatus used in speech circuits is that the load curve should be equally inclined to the input level and output level axes. Departure from this linearity is normally marked by distortion. The static overall load curves of level controlling amplifiers are not thus linear, but this does not imply distortion, as, if the load curve is measured with the polarizing current of the attenuator network held constant, the usual linear form is obtained. The physical interpretation of the non-linear load curve is that it is the upper boundary of a series of linear load lines. Which of these linear load lines applies depends on the polarizing current, and so on the working level. Thus, if the polarising current is allowed to change when the frequency response is being measured, the frequency response of the control chain will be implicit in the result. The frequency response which has real significance is that measured with constant polarization.

An equipment typical of those described is the PS.9827 Limiter and " B " Amplifier. This gives a maximum output of 100 mw. with a gain of 50 decibels. The limiting threshold may be anything above —30 decibels/1 mw. on the incoming line. Continuously variable gain controls provide independent variation of limiting threshold and output. The limiting characteristic is shown in Fig. 12, and is such that for an overload of 24 decibels, the output rises only 2 decibels. Thus if the absolute maximum modulation for transmitter safety is 112 per cent., the input voltage can rise to that which would correspond, in the absence of the limiter, to 1,170 per cent. modulation. Modulation below 90 per cent. would be unaffected, and 100 per cent. would only be reached by a voltage corresponding to 360 per cent. The protection produced by such a device is obvious. It will be noted that at high input levels an increase in input results in a decrease of output. This is produced by the self-balancing effect of the network at high signal levels, when the D.C. polarization is near that for balance. This effect has been used in peak limiters, where the distortion is not important, and a limiting characteristic is required without the use of polarizing current.

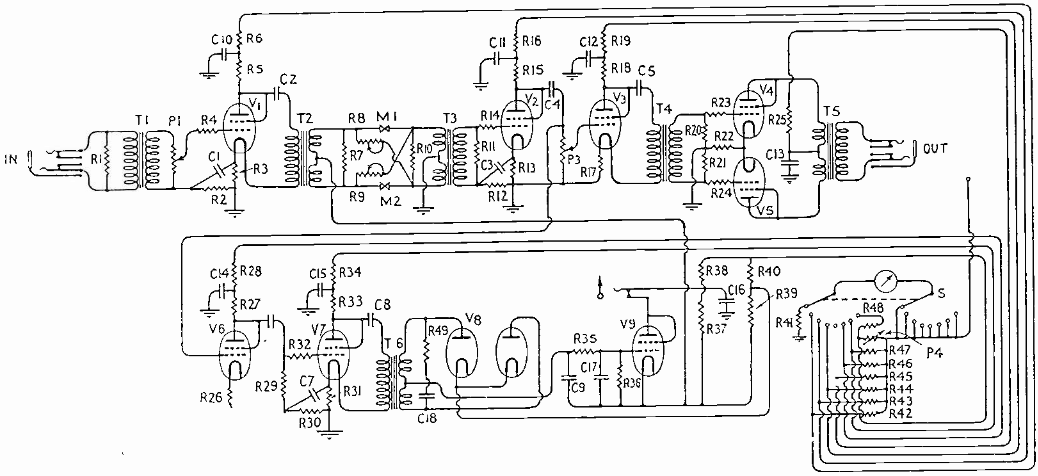


FIG. 13. *P.S.9827 limiter and B amplifier.*

The circuit of the PS.9827 Limiter and " B " Amplifier is shown in Fig. 13, while Fig. 14 is a photograph of one model in which a Programme Meter meeting the U.I.R. recommendations has also been incorporated. A key is provided by which the Programme Meter may be switched to either the input or the output of the limiter, or may be used independently. The Programme Meter controls and the high speed instrument are on the left of the panel, while the limiter controls and indicating meter are on the right. The controls can generally be pre-set, as adjustment is seldom necessary in service.

Fig. 15 is a photograph of a simpler Limiter, PS.9361, having only a small gain and restricted working range.

Changes in Control Technique.

With the introduction of Limiters the need for careful manual control of programme peaks disappears, though when the dynamic range is large and the final noise level likely to be high, control should still be maintained with the object of increasing the lower levels. This is a task for which the Programme Meter is no longer a suitable indicator as the relapse time is too slow, and it is possible that the telephone Volume Control Indicator will prove more satisfactory. When a compressor is employed, the dynamic range may be so reduced that continuous control is no longer necessary, adjustment of the mean level of a programme being sufficient. It is unlikely that fully automatic control will give satisfactory quality without compensation at the receiving end for the loss of contrast.

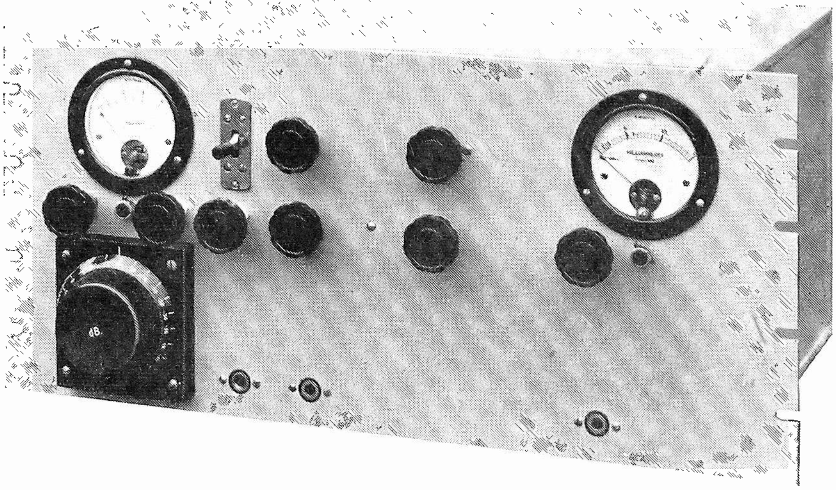
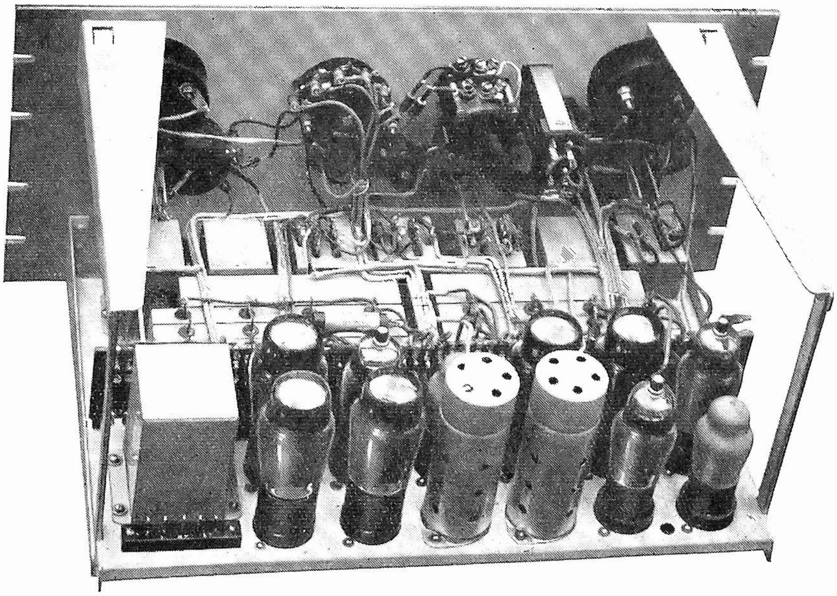


FIG. 14.

Front view.



Back view.

This loss of contrast may become noticeable with Limiters. In America, where the revenue of broadcasting stations is particularly dependent on service area, there is a tendency for control engineers to increase their mean modulation regardless of programme quality knowing that the Limiter is protecting the transmitter from shut-down.(13) This tendency must always be guarded against, and it is therefore recommended that Limiters be regarded as studio apparatus under the supervision of the Control Engineer, with provision for monitoring the Limiter output both aurally and with the Programme Meter. A Programme Meter has been incorporated in one model of the PS.9827 Limiter and " B " Amplifier, so that this can be readily accomplished—a key is provided so that the Programme Meter may be bridged

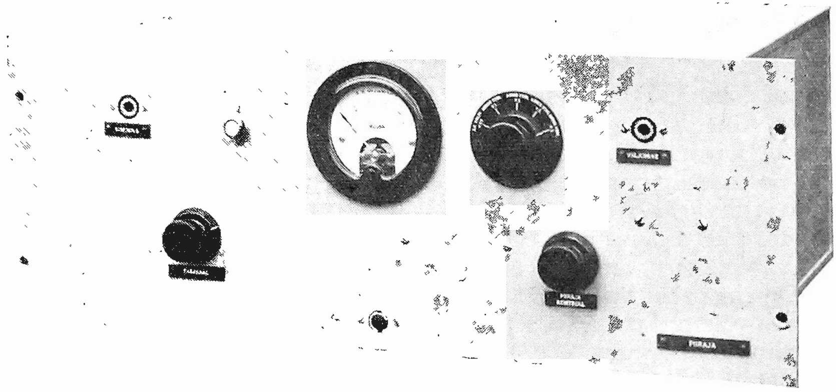
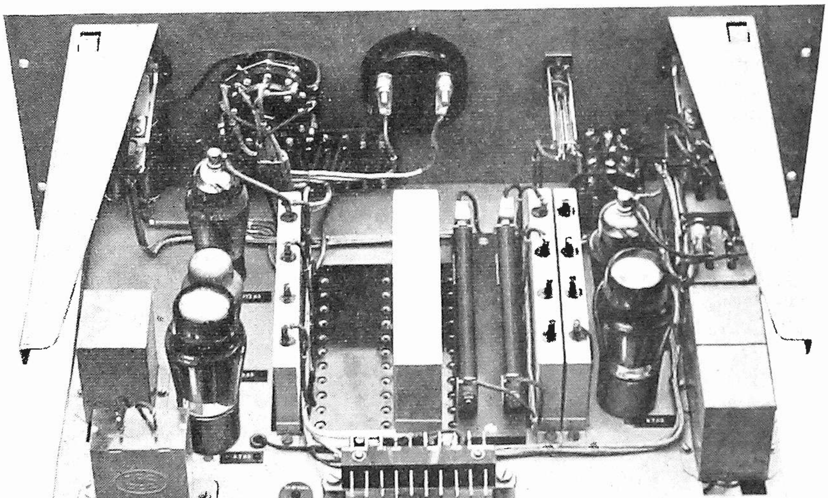


FIG. 15.

Front view.



Back view.

either across the input or output of the Limiter and pre-set attenuators permit the same reading to be obtained in the two positions when the level is below the threshold of limiting. Above this level the readings will naturally differ by the amount of compression. The time of integration of this Programme Meter has been made relatively great, so that, while conforming to the U.I.R. recommendations, the response to the very short initial pulse passing through the Limiter is small.

Naturally, it is permissible to associate the Limiter with the transmitter provided the Limiter is to operate solely as a protective device, and the same low mean modulation is to be maintained as would be required in its absence, but such use is not economic. Furthermore, knowledge of the existence of the Limiter may lead to carelessness on the part of the Control Engineer, who no longer has a true check on the nature of the outgoing programme. For this reason, although the PS.9361 Limiter and the PS.9827 Limiter and " B " Amplifier are suitable for use at the transmitter, it is preferred that they be mounted in the Studio Control Room, protection of the transmitter against disturbances on the line or maladjustment of levels being furnished by some simple protector, such as a gas-discharge tube. Such a protective system should not be allowed to operate in normal practice, as high distortion will be produced.

The amount of compression permissible due to the use of a Limiter is of course entirely arbitrary ; American practice seems to show that some three to six decibels may be allowed for normal programmes. The loss of dynamic range of the programme does not necessarily imply a loss of contrast at the receiver, as the improved signal to noise ratio may lead to an actual overall increase. Aural monitoring at the Limiter output, where noise resulting from the transmission is absent, will not show this increased contrast, and will therefore be more sensitive to excessive use of the Limiter. On the other hand it must not be forgotten that prolonged listening to programmes with reduced contrast will result in enhanced differential sensitivity of the ear, and thus the Control Engineer may become too tolerant. Frequent use of the Programme Meter key is therefore desirable.

As the Programme Meter when bridged across the output of the Limiter has a fixed maximum reading, the setting up of this may be regarded as a " lining-up " adjustment, and the Programme Meter may be kept normally bridged across the Limiter input. A check on the operation of the Limiter is then provided by the indication of the polarizing current meter, which reads the current supplied by the operator to the variable attenuator. If desired, the scale of this meter may be calibrated to read the amount of compression introduced. It would also be possible to fit some sort of flasher or other alarm to indicate either when the amount of compression is excessive or when the operation of the Limiter becomes too frequent.

From these remarks, it will be seen that the introduction of automatic controls at low frequencies has given rise to many questions in operating technique and has placed more exacting requirements on the accuracy of the daily alinement of levels throughout the system. In place of the present practice of making routine level adjustments at one level only, the use of these automatic controls has made it highly desirable to adjust at two or more test levels of tone. For example, with limiters in circuit, it must be certain that the limiting is effective in the neighbourhood of 100 per cent. modulation and also that signals for, say, 80 per cent. or 90 per cent. modulation are not limited. The practical procedure may therefore be the use of test tone levels designed for 100 per cent. modulation, for 80 per cent. modulation and for 10 per cent. modulation so that protection and linearity are assured in the required regions.

Where compressors are used with a very small Compression Factor, with suitable Expanders at the receiving end, as for example in radio-telephone channels, aural monitoring at the Compressor output, or at the output of a receiver not provided with an Expander can provide no indication of quality, nor can the receiver output level and noise be a useful guide in services using Noise Reducers for reception. All such equipment should preferably be included in the terminal equipment where the operator can monitor on the receiver side of the Noise Reducer, or can make use

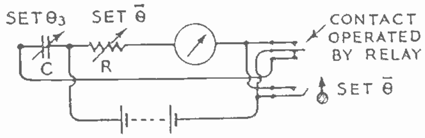


FIG. 16. *Circuit for determination of meter constants.*

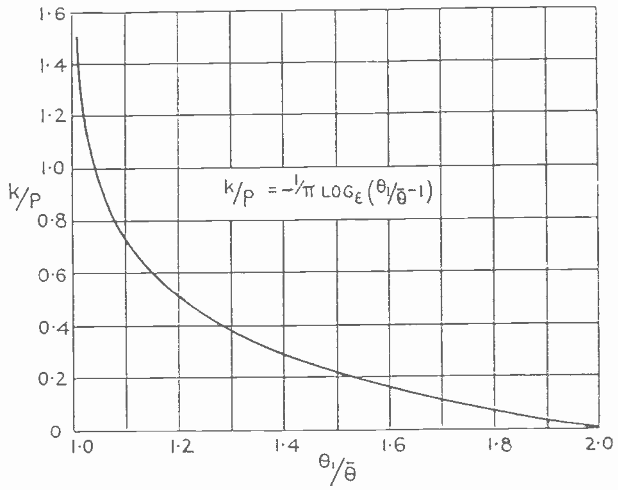


FIG. 17. *Relation between meter constants and overswing.*

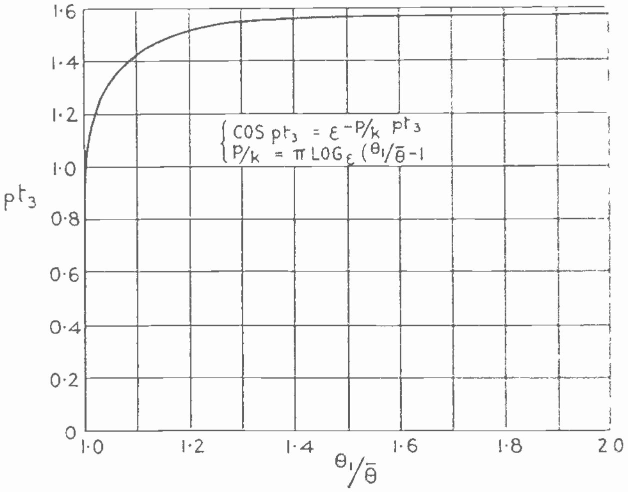


FIG. 18. *Meter operating speed with circuit of* FIG. 16.

of his Receiving Expander when monitoring on the output of the Transmitting Compressor.

The full advantages of the new devices described in this article will not be immediately realised, for caution is necessary when introducing experimental equipment into systems in service, while, on the other hand, operating experience is essential to successful evolution.

APPENDIX.

Method for Measurement of Meter Characteristics.

For modern programme meters and volume control indicators, the indicating instruments are specified in terms of their behaviour under transient conditions such as they face in operation. Direct measurement of such behaviour is, however, difficult without high-speed photography.

It has been found that by assuming a simple law, this difficulty of measurement can be avoided. The indication is observed with steady current and with the same current suddenly applied. Finally the meter is connected to a condenser-resistance circuit, alternately charged and then discharged through the meter and the resistance and capacity adjusted until stated deflections are obtained. Given these observations and curves derived from the assumed law, the meter behaviour for transient conditions can be readily found.

Symbols.

D is the operator $\frac{d}{dt}$

k, n and α are meter constants.

θ is the meter deflection.

I is the current through the meter.

$\bar{\theta}$ is the steady state deflection for steady current I_0.

θ_1 is the maximum deflection for current I_0 suddenly applied.

θ_2 is the maximum deflection for current I_0 applied for duration t_1 only.

θ_3 is the maximum deflection obtained in the condenser discharge test with the circuit of Fig. 16.

$p = \sqrt{n^2 - k^2}$

t_2, t_3 are the times at which θ_2, θ_3 are observed, $t = 0$ being the instant at which the relevant switch is closed.

Formulæ.

Taking the meter behaviour as given by

$(D^2 + 2kD + n^2)\ \theta = \alpha I$

1. $$\frac{\theta_1}{\bar{\theta}} = 1 + \epsilon^{-k\pi/p}$$

2. $$\text{Cos}\ pt_3 + \left(\frac{n^2\,RC}{p} - \frac{k}{p}\right)\text{Sin}\ pt_3 = \epsilon^{(k-1/RC)\,t_3}$$

3. $$\frac{\theta_3}{\bar{\theta}} = \frac{k}{p}\,\epsilon^{-kt_3}\ \text{Sin}\ pt_3,\ \text{when}\ n^2\,RC = k.$$

4. $$k = \frac{1}{RC\left(1 + \frac{p^2}{k^2}\right)};\quad p = \frac{p}{k}\cdot\frac{1}{RC\left(1 + \frac{p^2}{k^2}\right)};\quad n = \sqrt{k^2 + p^2}$$

5. $$\frac{\theta}{\bar{\theta}} = 1 - \epsilon^{-kt}\left(\cos pt + \frac{k}{p}\sin pt\right)$$

6. $$\frac{\theta_2}{\bar{\theta}} = \epsilon^{-k\,(t_2-t_1)}\left\{\cos p\ (t_2 - t_1) + \frac{k}{p}\sin p\ (t_2 - t_1)\right\}$$
$$- e^{-kt_2}\left\{\cos pt_2 + \frac{k}{p}\,\text{Sin}\ pt_2\right\},\ \text{where Sin}\ p\ (t_2 - t_1) = \epsilon^{-kt_2}\ \text{Sin}\ pt_2.$$

7. $$\frac{\theta_3}{\bar{\theta}} = \frac{n^2}{\frac{1}{R^2C^2} - \frac{2k}{RC} + n^2}\cdot\left\{\epsilon^{-1/RC\,\cdot\,t_3} - \epsilon^{-kt_3}\ \text{Cos}\ pt_3 + \epsilon^{-kt_3}\left(\frac{1}{pRC} - \frac{k}{p}\right)\text{Sin}\ pt_3\right\}$$

Graphs.

1\. above is plotted in Fig. 17, and determines $\frac{k}{p}$ from the observed deflections θ_1 and $\bar{\theta}$.

2\. above is plotted in Fig. 18 for the particular case when n^2 RC $= k$.

3\. above is plotted in Fig. 19, by using the graph of Fig. 18, and serves to give the value of θ_3 to be obtained in the circuit of Fig. 16, from the observed values of θ_1 and $\bar{\theta}$.

4. above are plotted in normalised form in Fig. 20, so that when the test circuit of Fig. 16 has provided the resistance and capacity values, the meter constants can be determined.

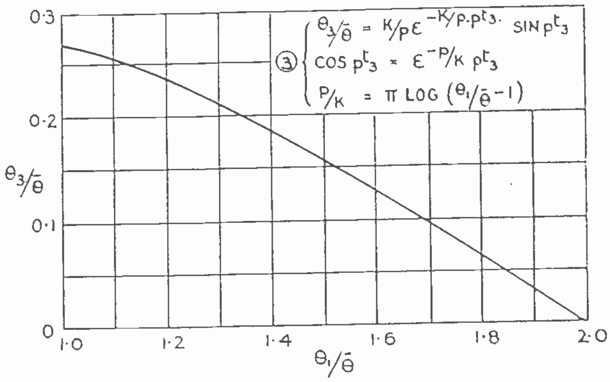


FIG. 19. *Maximum meter reading with circuit of* FIG. 16.

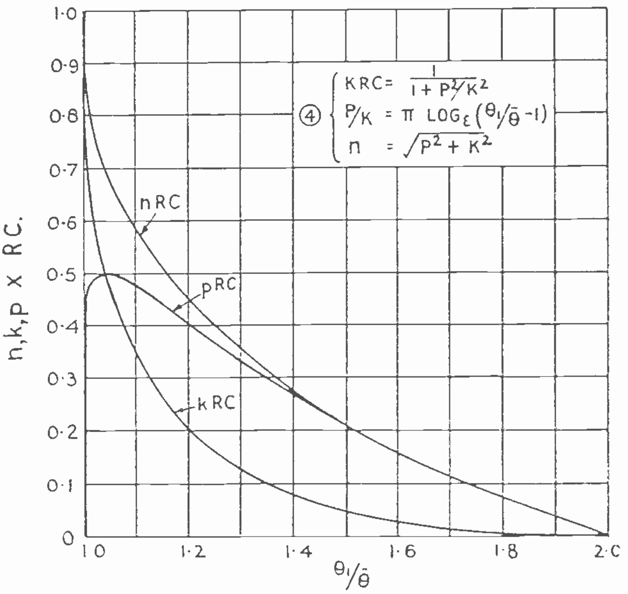


FIG. 20. *Evaluation of meter constants from test figures.*

5. above is plotted in Fig. 21, which, given the meter constants, shows the time t taken by the meter to reach a deflection θ when I_0 is suddenly applied.

6. above determines the response to a pulse of current I_0 for a duration t, and is of much interest. Fig. 22 shows the time at which maximum deflection is attained, and Fig. 23 the extent of this maximum deflection.

7. above is the general form of 3 above, and enables the behaviour of the complete meter and associated circuits to be determined.

Procedure.

Suppose that it be required to find the pulse duration necessary for a certain meter to reach 80 per cent. of the steady deflection which would be obtained if the same current were continuously applied. The meter is assumed to be such that k, n and a are constant. The procedure is as follows :-

Apply current I_0 suddenly to the meter and note the maximum deflection θ_1 and the final steady deflection $\bar{\theta}$.

From Fig. 19 obtain θ_3 and, using the circuit of Fig 16, adjust R with the key operated to set the meter to give a steady reading of $\bar{\theta}$. Then with the key normal and the relay contact changing over at any convenient low frequency, adjust C so that the meter reaches a peak deflection of θ_3. The operation of the relay contact should be such that in one position the condenser C can discharge fully through the resistance R and the meter, while in the other position it can be charged fully by

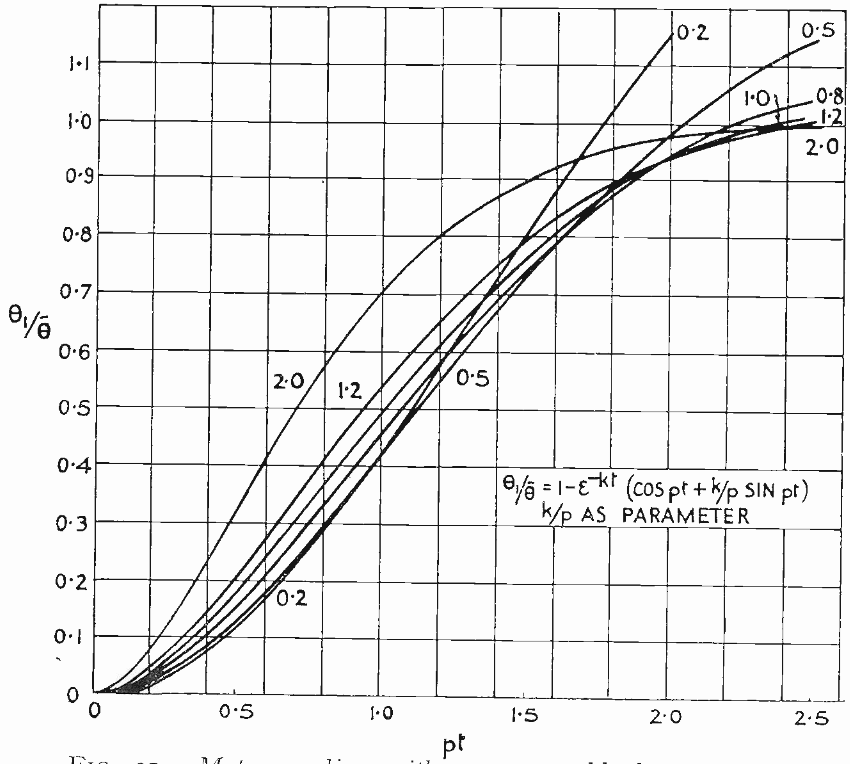


FIG. 21. *Meter reading with current suddenly applied.*

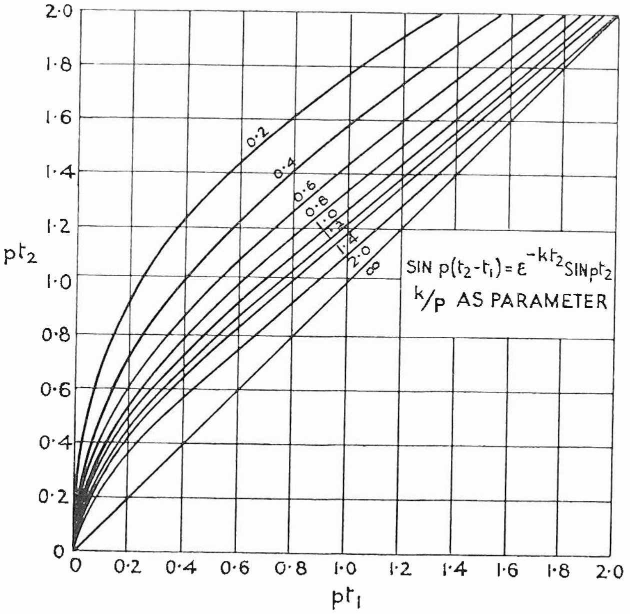


FIG. 22. *Meter operating speed with current pulse applied.*

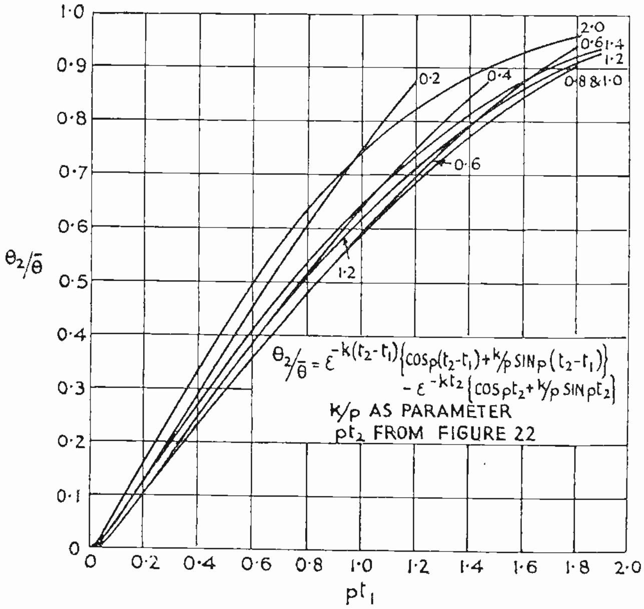


FIG. 23. *Maximum meter reading with current pulse applied.*

the battery and the meter pointer has time to return to zero deflection. Note the values of C and R, that for R including the resistance of the meter.

From Fig. 20 obtain p, and from Fig. 17 obtain $\frac{k}{p}$. The required time t_1 for $\frac{\theta_2}{\theta} = 0.8$ can now be obtained from Fig. 23.

It will be noted that the above method of determining the meter constants is no longer possible if the meter is over-damped, but this condition seldom arises with high-speed meters.

Typical Results.

The following table gives the values of k/p and p for a number of typical meters, together with the necessary duration of a pulse to give 80 per cent. of the steady state deflection.

	$\frac{\theta}{\theta}$	$\frac{k}{p}$	p	t_1 (for $\frac{\theta_2}{\theta} = 0.8$)	
Meter No. 1 ..	1.37	.32	9.7	129	milliseconds.
,, ,, 2 ..	1.14	.63	15.0	96.7	,,
,, ,, 3 ..	1.12	.68	18.7	78.6	,,
,, ,, 4 ..	1.135	.64	45.4	32.2	,,
,, ,, 5 ..	1.05	.96	33.4	45.0	,,
,, ,, 6 ..	1.015	1.35	20.4	68.6	,,

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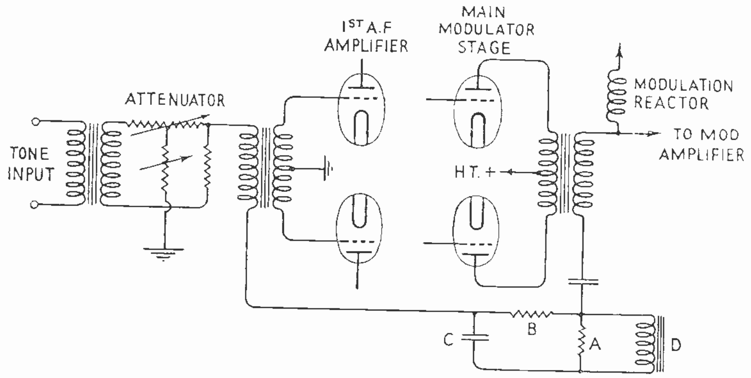
Since the above was written, the October issue of the Bell System Technical Journal has been received, containing articles by S. B. Wright, on "Amplitude Range Control," and by A. C. Norwine on "Devices for Controlling Amplitude Characteristics of Telephonic Signals." These two articles are of considerable interest and give clear distinction between the different types of Automatic Volume Control. Useful lists of reference are also added.

H. JEFFERSON.
C. D. COLCHESTER.

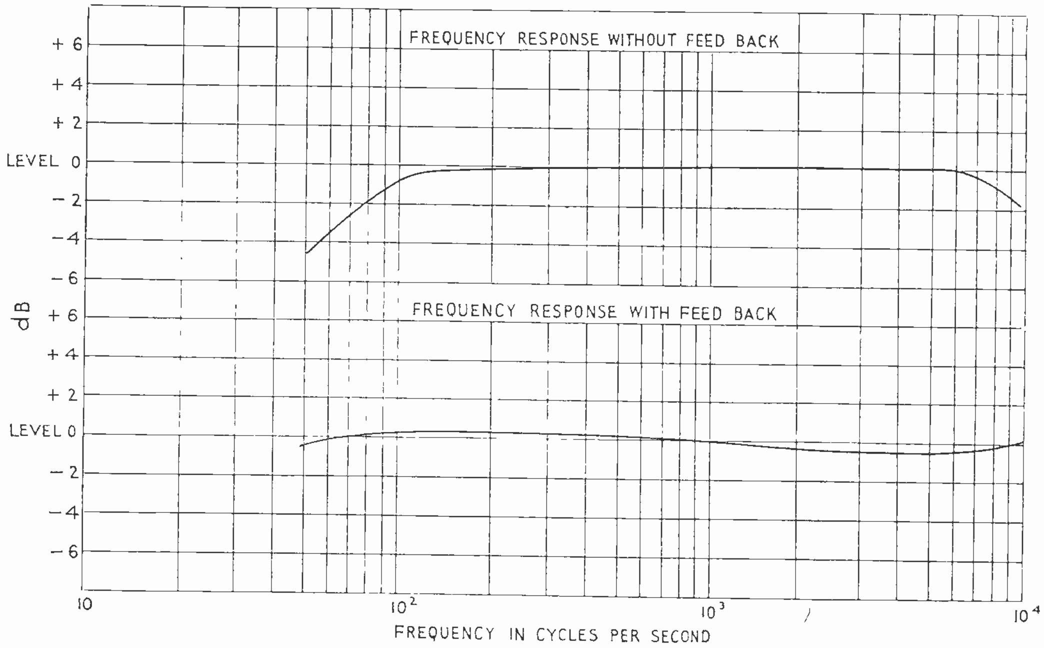
AN ECONOMIC FEED BACK CIRCUIT

The following note describes a feed back circuit developed by V. J. S. Sandy and J. Twatt, of the Marconi Company, which is designed to correct for distortion introduced by the main modulator transformer and possesses certain advantages over the more usual circuit which operates on the valve side of this transformer.

THE diagram of the circuit proposed is shown in Fig. 1.



The feed back voltage is obtained from a resistance in series with the secondary of the main modulation transformer. It is placed in the earthy side of the blocking condenser and is not therefore subjected to high voltage. The resistance is of low ohmic and is only called upon to pass the current in the transformer secondary.



The wattage dissipated in the resistance is therefore small, enabling a small and cheap component to be employed. The feed back voltage is fed into the primary of the line to grid transformer of the first audio frequency amplifier. The extra resistance introduced into this circuit is so small that the 600 ohm line termination is not affected. Furthermore, the attenuator is resistance loaded.

In order to ensure stability in operation a resistance and condenser network is placed across the feed back resistance. The values of the resistance and condenser network can be chosen to provide a desired amount of audio frequency discrimination. In this way the frequency response can be levelled up at the higher end of the band.

In order to improve the response of the low frequency end, a choke is placed across the feed back resistance. This choke is of low ohmic resistance and consists of a few turns of thick wire on a single laminated iron limb. The working voltage of this component is again small, enabling a small and cheap component to be used.

In Fig. 2 are shown two frequency response curves, one without the feed back circuit and one with the feed back circuit introduced into a transmitter applying 2 kw. of unmodulated power to the aerial circuit. Harmonic distortion tests have also been carried out at 1,000 cycles and a table of the results obtained is shown below :—

HARMONIC DISTORTION TESTS ON 1,000 CYCLES.

Without feed back.		With 4.5 dbs. of feed back.	
% Mod.	Distortion.	% Mod.	Distortion.
100%	3.5%	100%	2.2%
89%	3.0%	90%	1.9%
82%	2.6%	80%	1.7%
61%	2.2%	70%	1.4%
53%	2.7%	60%	1.3%
44%	2.35%	50%	1.5%
		40%	1.2%

GRID CONSTRUCTION IN THERMIONIC VALVES

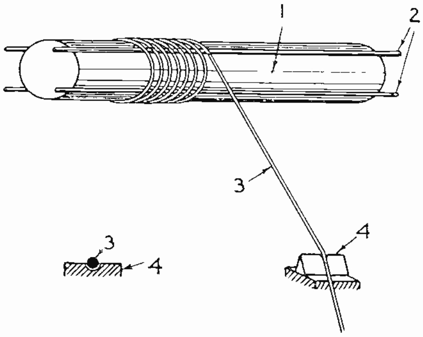
The following note describes a recent Siemens Halske invention of interest.

IN valves for electron apparatus, where a control grid is used, the characteristics of the apparatus may be affected undesirably by the emission of the control grid itself. This emission depends normally on the material out of which the grid is constructed and the temperature which it assumes under working conditions. To minimise the effect due to the first, certain substances having very slight emission, such as nickel-manganese, are very often used for the construction of the grids. The subject of this patent deals, in a novel fashion, with an attempt at reducing the temperature which the grid assumes.

Previous constructions to reduce the grid temperature consisted sometimes of carrying off the heat by means of supports made of good conducting meterial or by placing cooling vanes on the supports. Now if we assume that the cathode consists of an infinitely large plane surface in front of which a grid wire is placed at any distance, the temperature taken up by the wire is given by the formula

$$T_g = \sqrt[4]{\frac{\alpha_k}{2}} \cdot T_k,$$

where T_k is the cathode temperature and α_k a function of the radiation of the cathode which we may term the specific capability of radiation. Thus T_g depends only on the cathode temperature and α_k. Clearly, even if, for example, the grid can radiate its heat freely outwards T_g may reach inadmissible values, even if the supports are made of good conducting material. Now the invention disclosed in this specification makes use of the fact that the grid temperature is independent of the specific radiation capability α_g of the grid wire material where α_g is constant over the whole surface of the grid wire, this independence being due to the fact that both the absorption of heat and also the radiation are proportional to this specific capability of radiation.



Quite another state of affairs exists, however, if the side of the grid wire turned towards the cathode and that turned away from it have different powers of radiation.

If, for example, the side of the grid wire turned to the cathode should be absolutely reflecting, the grid would take the temperature of its surroundings or at most that of the walls of the apparatus. It is therefore possible to obtain advantageous effects by treating differently the two sides of the wire. In practice the invention may be fulfilled in various ways. The grid may, for instance, be coated with a good radiating substance, e.g., carbon, but before winding the grid wire in the manufacture of the grid, this coating may be rubbed off to produce different values of a_g on the two sides of the wire. The figure shows a simple form of the arrangement. (1) is the winding mandrel to which the supports (2) are attached. Round the supports of the mandrel is wound the grid wire (3) which is taken over an apparatus (4) which rubs off the good radiating coating on one side.

Another possibility is to assemble the grid completely before treatment and then to provide it with a good radiating coating which is removed either chemically or mechanically on the inner side of the grid wires. The coating may also be applied to the grid from outside by some process of spraying.

In this manner the temperature assumed by the grid in practical apparatus may be considerably reduced, it having been shown, for instance, that a grid, which without adopting the measures described would acquire a temperature of 400 deg. C., attains, on the grid wires being suitably treated, a temperature of only 300 deg. C.

PATENT ABSTRACTS

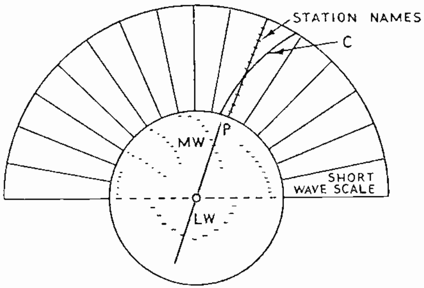
Under this heading abstracts are given of a selection from the most recent inventions originating with the Marconi Co. These abstracts stress the practical application of the devices described.

SHORT WAVE TUNING SCALES

Application date, February 20th, 1937. **No. 490,400.**

Patent issued to Marconi Wireless Telegraph Co., Ltd., and J. D. Brailsford.

This invention gives a method of magnifying the traverse of an indicator over the short wave scale so as to allow marking of the positions of individual broadcasting stations.



Patent No. 490,400.

The short wave scale as shown in the figure consists of a series of radial lines across which moves a cursor line, C, attached to the capacitor rotor spindle. If necessary the cursor may be fixed and the scale movable. The spacing between the radial lines is chosen to give the desired magnification of the short wave scale and the cursor shape is such that it leaves the bottom end of one line as it enters the top of the next. The cursor itself is curved so that equal movements of its point of intersection with any radial line corresponds to equal angular movements of the capacitor rotor.

It is suggested that the cursor line should be a shadow thrown on to the short wave scale by lamps placed immediately behind a shaped piece of metal secured so as to present an end-on view to the scale.

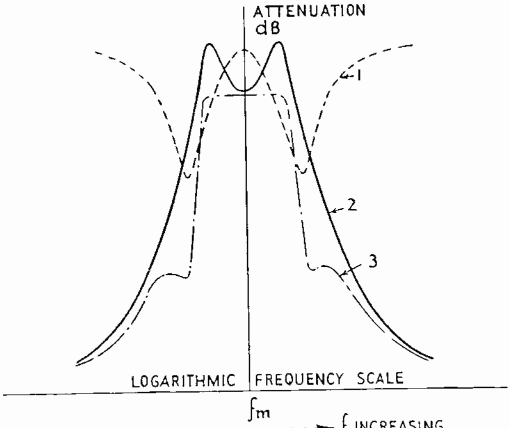
ELECTRIC FILTERS

Application date February 20th, 1937. **No. 490,819.**

Patent issued to Marconi Wireless Telegraph Co., Ltd., and N. M. Rust and J. D. Brailsford.

Attempts to improve the sharpness of cut-off of a band pass filter consisting of a tuned transformer by increasing the Q of the primary and secondary coils generally leads to considerable variation in attenuation over the pass band. A double humped frequency response is obtained with maximum attenuation at the mid-frequency of the pass band.

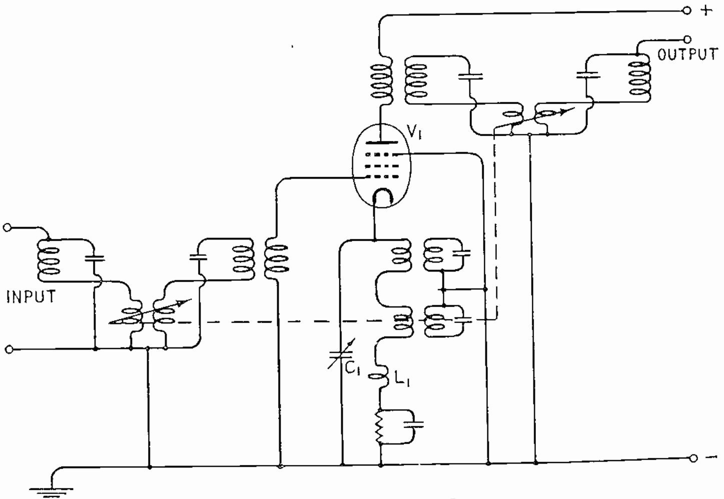
The purpose of this invention is to produce sharp sided selectivity curves with a flat pass band region. Tuned circuits in the cathode lead are used to provide frequency selective feedback, and are arranged to have a low impedance at the mid-frequency and maximum impedance at the edges of the pass band. The frequency characteristic (curve 1 in the figure) of the cathode circuits when added to that of the band pass filter (curve 2) contained in the anode circuit, results in an overall frequency response (curve 3), which has a flat top and sharp sides. The cathode circuits may consist of two parallel circuits connected in series, a parallel circuit paralleled by a series circuit, or two tuned circuits tightly coupled. The first circuit may be directly or transformer coupled to the cathode.



PATENT NO. 490,819.

A suggested form of circuit incorporating frequency selective feedback is shown in the figure. The inductance L_1 neutralises an undesirable reactance component introduced by the transformer coupling, and the parallel trimmer capacitance C_1 controls the symmetry of the cathode rejection curve. Variable selectivity is obtained by varying the mutual coupling between the band pass filters and it will be found that the flat top and sharp sides are preserved as the selectivity is varied.

It is noted that change of bias on the valve V_1 varies the cathode feedback. Increase of mutual conductance increases the cathode feedback and reduces the pass band by attenuating the extreme frequencies. Hence application of an A.V.C. bias to the valve produces automatic selectivity as well as automatic gain control.



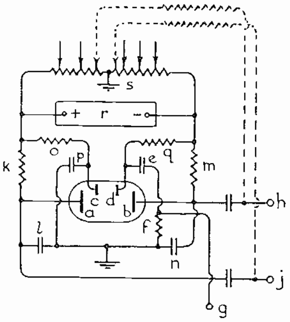
PATENT NO. 490,819.

TELEVISION RECEIVERS

Application date March 16th, 1937. **No. 492,278.**

Patent issued to Marconi Wireless Telegraph Co., Ltd., and D. J. Fewings.

This specification describes an improved saw-toothed wave oscillator in which a resistance-capacity charging circuit is associated with a discharge tube which discharges the condenser just before a predetermined voltage has been set up across the condenser. The discharge tube comprises two sets of electrodes, the first between which the condenser actually discharges and the second pair which are closer together than the first pair and between which an auxiliary discharge initiates the main discharge.



PATENT NO. 492,278.

In the figure A and B represent the two main electrodes and C and D the auxiliary electrodes. Synchronising pulses are applied to the junction of the condenser E, and the resistance F, through a connection G. Saw tooth waves for application to the deflector plates of the associated cathode ray tube are taken from terminals H and J. The main time constant circuits consist of resistances and capacities K, L and M, N; there are also time constant circuits O, P and Q, E, F associated with the auxiliary electrodes C and D. These time constant circuits are so dimensioned that the potentials between the main electrodes and the auxiliary electrodes reach their respective breakdown values at almost the same time, and in such a manner that the discharge between the auxiliary electrodes will take place just when the discharge between the main electrodes is ready to occur. Thus the auxiliary discharge initiates the main discharge, the auxiliary discharge itself being initiated by the application of properly timed synchronising signals applied to G. The source of potential for the discharge tubes and also if necessary for the cathode ray tube is indicated at R and a potentiometer device for applying the various voltages to the cathode ray tube at S.

As will be seen the voltage upon one of the deflector plates in the cathode ray tube will rise from approximately earth potential to some predetermined positive potential and the other deflecting plate will fall to approximately the same negative potential, until such time as the discharge takes place and the condensers discharge.

The resistance F controls the time occupied by the auxiliary discharge and the value of this resistance should be so chosen that the auxiliary discharge continues for a short time after the main discharge has ceased.

As a modification to this the auxiliary discharge may be arranged to be continuous and the auxiliary electrodes may consist of two rings disposed on the common axis between the main electrodes. The time constant circuits associated with the main electrodes are so chosen that the discharge between the main electrodes can be initiated by energy derived from a synchronising signal, this signal being applied in such a manner as to concentrate the discharge between the auxiliary electrodes along the axis which constitutes the shortest path between the main electrodes.

TRANSMITTER POWER AMPLIFIERS

Application date April 6th, 1938. **No. 493,368.**

Patent issued to Marconi Wireless Telegraph Co., Ltd., and N. H. Clough.

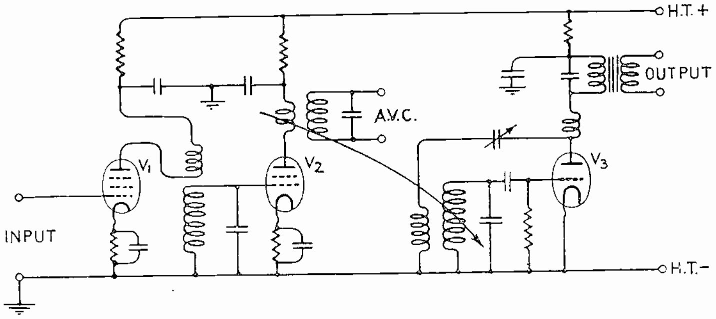
This patent proposes circuits to eliminate a large number of the intermediate stages in a power amplifier system. The scheme embodies a master oscillator with or without frequency doubling stages, an interrupter stage consisting of a valve with a series anode inductance, and a main power amplifier with output L.C. circuit tuned to the radiated frequency. In the quiescent condition the interrupter stage has a steady feed passing through it, and the previous master oscillator, or master oscillator and driving source, is arranged to cause a sudden cessation of feed through the interrupter valve for short periods of each cycle, by suitable choice of grid bias in the interrupter, and by picking out only the peaks of the wave. The action on this interrupter valve is similar to the breaking of an inductive circuit by a switch. Thus a large " flick " E.M.F. is built up across the inductance at the same frequency sufficient to drive a large power final amplifier stage.

RECEIVERS

Application date April 6th, 1937. **No. 493,370.**

Patent issued to Marconi Wireless Telegraph Co., Ltd., and R. B. Armstrong.

Receivers having controllable reaction and automatic gain control present certain difficulties to the designer. It is not usually possible to obtain adequate voltage for A.G.C. operation direct from the detector input circuit, for the latter requires only a small voltage (less than one-tenth volt) for satisfactory operation. This is particularly true of a self-oscillating detector for C.W. heterodyne reception and large input signals cause locking when attempts are made to obtain the normal 1 kc. beat note. Amplification of the A.G.C. voltage is not economic since it does not contribute to any other improvement in receiver performance. Reaction increases the A.G.C. voltage and hence no effective increase in overall gain is registered. Furthermore the oscillatory voltage of the self-oscillating detector operates the A.G.C. and reduces appreciably the gain.



PATENT NO. 493,370.

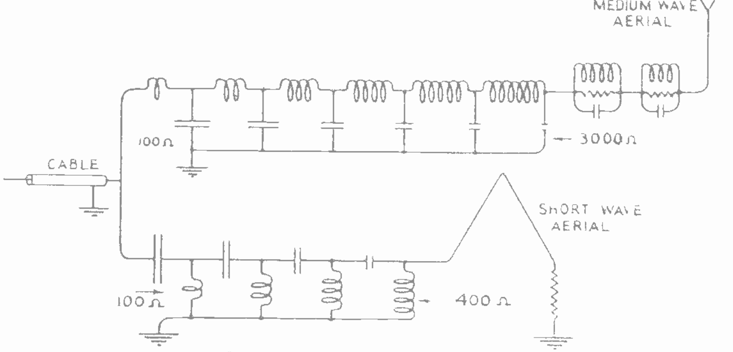
A method which overcomes these defects is described in the specification. Referring to the circuit diagram in the figure, V_1 is the R.F. valve, which normally supplies the detector valve V_3 input. Interposed between these two is an amplifier stage, the output from which supplies the A.G.C. voltage. Loosely coupled to the same output is the detector input and the coupling is adjusted so that the output voltage from V_1 equals the input voltage to V_3. Adequate A.G.C. voltage is hence obtained, and the amplifier circuit (valve V_2) improves the selectivity of the receiver. The loosely coupled detector circuit produces the required small signal voltage so that locking in the self-oscillating condition is largely eliminated. Furthermore the A.G.C. voltage is almost unaffected by reaction.

AERIAL CIRCUITS

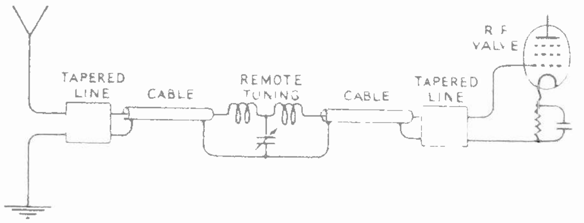
Application date April 15th, 1937. **No. 493,860.**

Patent issued to Marconi Wireless Telegraph Co., Ltd., and N. M. Rust and J. F. Ramsay.

Connection of an aerial to a receiver from a distant point involves difficulties in correct impedance matching, energy transfer, and tuning. The object of this invention is to surmount these difficulties by the use of tapered artificial lines for matching aerial to cable and cable to first tuning circuit. A tapered artificial line consists of a series of progressively changing sections of inductance and capacitance. Generally the inductance component increases as the capacitance decreases and vice versa. Impedance transformation is thus obtained in progressive steps and in addition high, low or band pass frequency characteristics may be produced. Such tapered lines may be used to couple a symmetrical dipole of approximately 75 ohms to an unsymmetrical cable of 100 Ω characteristic impedance as shown in the first figure. The inductances in the arm connected to the cable central conductor progressively increase, whilst the inductance in the other series arm and the shunt capacitances decrease.



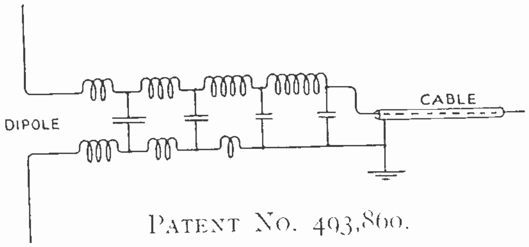
PATENT No. 493,860



PATENT No. 493,860

Two aerials of differing characteristic may be coupled to the same cable as in the second figure. The tapered line from the long and medium wave aerial steps the impedance from about 3,000 Ω at the aerial to 100 Ω at the cable. It has a low pass characteristic and hence offers a high impedance to the frequencies from the short wave aerial. The tapered line from the latter steps the impedance from 400 ohms at the aerial to 100 ohms at the cable, and has a high pass characteristic offering a high impedance to frequencies from the other aerial.

By using tapered lines for matching the cable to aerial and the cable to the grid of the first R.F. valve remote tuning control is greatly facilitated. Owing to the tapered line terminations the cable is terminated into its characteristic impedance so that the remote tuning control unit may be previously calibrated and inserted in the cable at any point as shown in the third figure. Since the characteristic impedance of the cable is low maximum current transfer is required and the tuning circuit must be a series resonant circuit.



PATENT NO. 493,860.

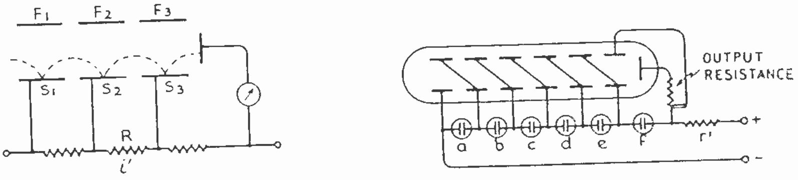
The specification concludes with a short résumé of the theory of tapered lines and gives a numerical example of the design of one such line.

ELECTRON MULTIPLIERS

Application date April 15th, 1937. **No. 493,861.**

Patent issued to Marconi Wireless Telegraph Co., Ltd., and G. B. Banks.

This invention relates to electron multipliers of which a well known form is shown in the first figure wherein F_1F_2 . . . are the field electrodes and S_1S_2 . . . the secondary emitter electrodes.



PATENT NO. 493,861.

A defect of such multipliers, where potentials on the individual secondary emitter electrodes are obtained from potentiometers, is that the voltages do not remain constant owing to the fact that each secondary emitter electrode takes current and so automatically alters its potential. Suppose that the current through the whole potentiometer due to the potential applied across its ends is given by i and that the electron current between, say, S_2 and S_3 is given by i', then the electron current will give rise to a current flow through R of i'. This current will oppose i and therefore the actual potential applied between S_3 and S_2 is $R\ (i - i')$. Obviously i' in varying, will cause variations in this potential.

The suggestion contained in this specification therefore is to substitute the potentiometer by a series of constant voltage resistive devices, preferably consisting of gas filled discharge tubes, which, as is well known, are admirably adapted to this purpose.

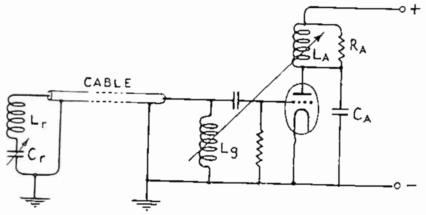
One way of carrying out the invention is shown in the second figure wherein the potentiometer is now replaced by a series of discharge tubes, *a*, *b*, *c*, etc., in series with which is a ballast resistance r'. In this way an electron multiplier may be easily produced in which the voltages on the secondary electrodes may be substantially independent of variations in current.

RECEIVER TUNING CIRCUITS

Application date April 15th, 1937. **No. 493,862.**

Patent issued to Marconi Wireless Telegraph Co., Ltd., and J. F. Ramsay.

This specification describes a method of obtaining remote control of an oscillator by means of a variable reactance at one end of a cable, the other end of which is connected across the grid coil of the oscillator. The variable control reactance consists of a comparatively large inductance (L_r) in series with a small variable capacitance (C_r). In the circuit diagram shown in the figure, the oscillator is of the tuned grid type with the cable and terminating control impedance forming the capacitive reactance tuning the grid coil. The electrical length of the cable is important and should be one quarter of the wavelength of the lowest frequency of the range over which it is desired to operate the oscillator. The cable then functions as a transformer reflecting a capacitive reactance much greater than C_r across the oscillator grid coil L_g. Owing to the frequency characteristics of cables having electrical lengths comparable with the wavelength of the applied frequency, the reactance of the cable for fixed values of L_r and C_r is capacitive and equal in value to the inductive reactance of L_g at a theoretically unlimited number of frequencies and oscillation may occur at any one of these frequencies. Terms are suggested to designate the particular oscillation frequency, thus "first mode operation" indicates that the oscillator is operating at the lowest of the possible frequencies; "second mode operation" indicates oscillation at the next highest frequency and so on.



PATENT NO. 493,862.

The first mode frequency range for a given change of C_r is generally small and is not used, but the second mode range gives quite a suitable frequency variation and is recommended in the specification. For second mode operation the cable functions as a quarter-wave transformer for the lowest frequency with maximum value of C_r and as a half-wave transformer for the highest frequency with a small value of C_r.

To ensure that the oscillator operates on the second mode, the anode circuit is broadly tuned to the highest frequency in the second mode range by the addition of the capacitance C_A and resistance R_A across the anode coil L_A.

The oscillator operates best at frequencies above 2 Mc., so that if it is used in a frequency changer unit a high intermediate frequency must be employed. The specification suggests an I.F. of 2 Mc. and a second mode oscillator range of 2.15 to 3 Mc. for covering the long and medium wave broadcast bands. The entire oscillator range can be obtained with a remote variable capacitance (C_r) having a maximum value of 50 $\mu\mu$F. With suitable padding capacitors, a standard type of tuning capacitor may form C_r, and the ganging error for the medium wave band can be reduced to less than 1 per cent.

It is noted that the electrical length of any short cable may be increased to the required quarter-wavelength value by the addition of an artificial line.

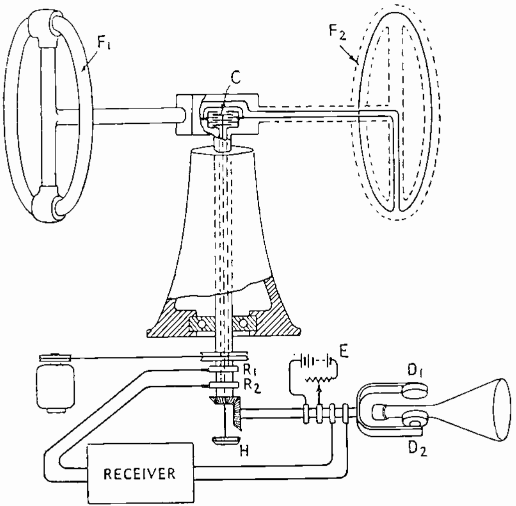
DIRECTION FINDING APPARATUS

Application date April 23rd, 1937. **No. 494,263.**

Patent issued to Marconi Wireless Telegraph Co., Ltd., and S. W. H. W. Falloon.

This patent describes a system for a visual reading direction finding apparatus suitable either for a rotating spaced frame system, or for the more orthodox and simple Bellini-Tosi or Adcock fixed aerial systems.

One circuit for a spaced frame D.F. is shown in the figure. F_1 and F_2 are two screened spaced loops supported by a horizontal tubular frame and made rotatable in a horizontal direction about a central axis, the loops being connected by leads through the screening tube to a tuning condenser C located at the axis of the system, it being possible to vary the condenser by an extension handle, H. The output from this spaced frame system, either from a capacitative or inductive coupling, is taken by two screened leads inside a vertical shaft as shown and connected to the input of an ordinary receiver through slip rings R_1R_2, the mechanical arrangement being such that to whatever position the frame may be orientated, the tuning of the system and the coupling to the receiver remains constant. Thus if an aural signal is being recorded rotation of the system would give the normal figure of eight diagram. This frame system is provided with gearing which rotates at the same time the deflector system of a cathode ray tube, the tube itself being stationary, such that one revolution of the frame is equal to one revolution of the cathode ray deflector system, and such that any angular position of frame corresponds to a similar angular position of the deflector system.



PATENT NO. 494,263.

The deflector system of the cathode ray tube is of the magnetic type, and has a twofold action.

First, a magnetic coil D_1 is connected through slip rings to a direct current supply E, the amplitude of which can be fixed to any desired value. This deflector system by itself would deflect the spot outward to a radius determined by the current adjustment. Thus rotation of the system with no incoming signal would show a spot travelling round the screen at a given radius dependent upon the D.C., which would develop into a continuous circular track if the rotation was fast enough, or if the screen fluorescence was made persistent.

The second deflector coil D_2 is connected through another pair of slip rings to the output from the receiver and so arranged that the rectified signal output causes a spot deflection in the opposite direction to the deflection caused by the D.C. source. Further, the receiver is arranged so that substantially constant output is obtained except at very low levels approximating to zero signal. This means that when the frame system is rotated, a deflection will be obtained which causes the spot to move round a circular path at a radius equal to the difference between the deflection caused by the D.C. and the signal. But since the spaced frame system has a figure of eight diagram a sharp output radial excursion of the spot will occur when the frame system passes through its minima positions, the sharpness being dependent upon the setting of the saturated output stage. Thus if the cathode ray tube is engraved with an angular scale round its periphery, the bearing of the station being received can be directly read visually.

It will be seen that an ingenious part of the system is the adoption of maximum deflection for zero signals, so that even if proper saturation is not obtained at the receiver output, it will not affect the length of the visual pointer being produced since this is a function of the D.C. only, but merely the dimensions of the central " boss," as it were, of the pointer. In consequence the tip of the indicating pointer can always be made to register closely to the scale engraved on the end of the tube.

If the system is used with an ordinary Bellini-Tosi or Adcock system, a bi-directional or uni-directional figure will be obtained depending upon whether a simple frame or combined frame and vertical system is being used, but unless special limiting devices are incorporated the figures obtained will have loop dimensions and not a sharp line.

BOOK REVIEW

WIRELESS DIRECTION FINDING, 3rd Edition, By R. KEEN

(pp. 803 ; figs. 549) London, ILIFFE AND SONS, LTD., 25s. net.

IN reviewing this book, one is at once impressed by the increasing dimensions of each successive edition. It is to be hoped that the title of the present edition will be retained in the future. The author has wisely omitted extensive references to directional reception as related to arrays associated with the various types of commercial communication services. The subjects which have been covered are already extensive enough and the book would tend to become unmanageable in size if such arrays had been included in the present edition.

The new edition keeps to the original objects outlined in the preface to the first edition and should be acceptable to practically every type of reader, including the research worker. To the latter the carefully arranged bibliography will be most helpful.

Before discussing the subject matter one cannot help expressing the view that the author will in later editions be faced with two alternatives. Either the theoretical and descriptive sections will have to be reduced in size, or two volumes, one devoted to theory and the other to practice, will become necessary. The ever widening field covered by D.F. will inevitably cause the author some misgivings when the time arrives for a fourth edition.

The work opens with a brief introduction and historical survey of direction finding from the earliest days and does not waste valuable space in attempting to provide a complete history. The following chapter concerns itself with an all-too-brief section on the propagation of electromagnetic waves, and will certainly assist the reader to appreciate the more general factors involved in wave propagation, the chapter closing with much new material relating to short waves. The fundamental transmission mechanism associated with D.F. involving, as it does, a clear understanding of the propagation of electromagnetic waves, this chapter which is devoted to its theoretical study is in some respects rather incomplete. It is fully appreciated that fresh knowledge is always accumulating on this most complex subject.

Chapters 3 and 4 deal with the directive properties of aerials and frame aerial reception respectively. The former chapter, covering first principles, is excellent, but Chapter 4 seems to contain rather a mixed collection of useful information, and other matter more suited to an appendix.

Chapter 5 describes the theory of the Bellini-Tosi system in its various forms, the measurement and reduction of instrumental errors in the radiogoniometer, and finally multi-channel reception upon a common Bellini-Tosi aerial.

Chapter 6 deals chiefly with polarisation errors, night effect and other allied phenomena. The author wisely limits the treatment of coastal refraction, which still requires further mathematical and experimental investigation before it can be fully understood. The chapter includes a considerable amount of new material and by the aid of liberal references the reader should become thoroughly acquainted with the subject. The next chapter briefly outlines the theory of the Adcock aerial in its various forms, but in view of space limitations the reader is necessarily referred to suitable references. One section deals with octantal spacing errors associated with the Adcock aerial, but the author omits to point out that such calculated errors cannot be used as corrections under certain conditions even when allowing for the ray angle, so that an erroneous construction may be placed on the curves of Fig. 256.*

Chapters 8 and 9 cover maps and shore stations respectively, the former being essential to those applying direction finding to the various services, while the latter is particularly useful to the operator and installing engineer.

Chapter 9 occupies no less than 96 pages and is fully descriptive. It embraces such topics as sites, installations, calibration, correction of errors, and in fact most of the information which the student or engineer requires concerning medium wave loop, Bellini-Tosi and Adcock installation.

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* F. J. Coales, I.E.E. Wireless Section, Vol. 7, Page 292. A Note on the Theory of Night Errors in Adcock Direction Finding Systems.

Chapter 10 contains an admirable description of short wave direction finding methods by means of loops, Adocks, and spaced loop arrangements. Much of the information is quite new and will be of great interest to those wishing to study the probable applications of short wave D.F. It is of interest to point out that when the 2nd edition was published the short wave D.F. outlook was not very promising. Chapter 11 is solely devoted to ship D.F. installation and covers the ground in a most interesting manner. The subject of corrections is dealt with very fully and cannot fail to appeal to Marine D.F. workers. The following chapter covers both omni-directional and directional beacon transmitters and outlines the international regulations relating to such navigational aids. This section is in some respects complementary to Chapter 11. A fair amount of space is given to radio range beacons, which are so extensively used in America.

Chapter 13 deals very lucidly with the application of D.F. to aircraft. Much new descriptive matter covering typical installations has been added since the last edition. The material is up to date and includes a short section on quadrantal and octantal errors introduced by the metallic members of an aircraft. The simple treatment shown in Fig. 406 is most instructive.

The next chapter deals with the theory and practice of direction and position finding and should be of great use to the navigator and aerodrome control officer.

In Chapter 15 the subject of approach and instrument landing systems is treated in a most informative way and presents current practice as it exists at the time of writing the review. The art is, however, in a state of flux so that this chapter may soon want revision.

Chapter 16 is used as a survey and handles in a concise manner other D.F. systems, including direct reading processes. The author has been well advised to devote a special chapter to this survey. It would make for confusion if the various special processes were mentioned indiscriminately throughout the volume. There is a strong tendency throughout the manual to mention interesting but non-essential matter at an inopportune moment, so that the survey chapter is well worth while.

The volume concludes with a useful chapter upon field and nautical astronomy. As previously mentioned, a very complete bibliography accumulated over a period of many years concludes the work; the author has thus placed the reader in touch with most of the worth-while references which the student can pursue. The index is adequate and has been compiled with the same thoroughness as the main body of the book; the whole treatise has been practically re-written since the last edition and is almost free from misprints.

The volume can be recommended with every confidence to those for whom it has been written; it is a worthy successor to earlier editions and will fill a useful place upon the bookshelf of any technical library or direction finding station.

S.B.S.