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THE PRESIDENT'S CONVENTION MESSAGE.

Admiral The Viscount Mountbatten of Burma,
K.G., G.C.V.O., K.C.B., D.S.O., A.D.C., LL.D., D.C.L.

Whilst distance offers no obstacle to the radio engineer, there is no electronic device to ensure that I will be free to speak to you from India at the moment you are listening to this recording ! I have therefore had to confine myself to this elementary use of an amplifier circuit to convey to you my very best wishes for the success of the Convention which you are all attending.

Radio is one of the youngest branches of science and on the members of our Institution rests a great responsibility.

The radio industry is one of the largest in Great Britain and continued development in all branches of radio science is essential in order that production may be maintained at an economic level and at the same time pay for further research.

Future developments in radio science will play a great part in the future of civilisation. Further development must be encouraged and this will involve much energy and skill with a high standard of technical education. Given those assets, it is possible to think ahead, and to encourage this attitude is, or should be, one of the objects of learned societies.

It is, moreover, the function of such Institutions as ours to help bridge the gap between pure and applied science. In the sphere of pure science we have, as a nation, held our own. It is in the application of the results of fundamental research to industry that the Institution should be most active. Through new products, processes and services that science can create, we can benefit mankind.

In order to improve industrial efficiency, it is necessary to devise more scientific aids such as already exist in the field of electronics—a word which has become a common term for describing radio technique at work in ways other than communication. In fact, we no longer think of radio in terms of communication alone. No one acquainted with the marvels of radar, high frequency heating and various industrial electronic devices can dispute the fact that it is the young and imaginative brain which will be responsible for further ideas.

But we cannot expect development if the young engineer of today is subjected to the prejudices of an older man whose enterprise is circumscribed by older theories and training—no matter how well that training may comply with the needs of an older industry. Indeed, we stand on the threshold of revolutionary developments that call for the ingenuity of trained engineers with progressive minds able to convert to the uses of peace the scientific achievements of the war.

In the field of national defence, no one can overlook the tremendous part played by radio. The potentialities of what is, after all, a comparatively new branch of science were realised in the British Services many years before the outbreak of the last war and there is no doubt that the defence of this country, and indeed, the defence and co-ordination of the British Commonwealth of Nations will, in ever-increasing measure, depend upon utilisation of radio technique.

It is thought-provoking to realise that our defence costs around five hundred million pounds per year and that the efficient application of this vast amount is, in large measure, dependent upon adequate communication in one form or another.

Here again, radio aids are not confined to communication purposes. As the world now knows, the development of war-time radar or radio-location caused the Services to demand shorter wavelengths, requiring valves of higher power and greater sensitivity than had been thought possible. Shorter wavelengths gave greater precision in the control of gunnery and searchlights and improved conditions for locating submarines.

The radar system which played so prominent a part in the Battle of Britain used wavelengths of from 50 to 150 centimetres. You will recall that in the early days of radio-location, some twelve years ago, wavelengths of 1,200 centimetres were considered very short.

The developments between 1935 and 1940 were, however, still not final and there soon arose a demand for valves and circuits to work on wavelengths as low as 10 centimetres.

The application of the " resonant cavity " principle applied to magnetron valve design was the result of outstandingly brilliant research work undertaken at Birmingham University and from the labours of those scientists it was possible to produce a compact air-cooled valve of great power and suitable for airborne use.

This was one of the outstanding features in a combined operation of scientists and radio engineers which enabled the first functional prototype of 10 centimetre radar to be demonstrated in March, 1941. In January this year, I attended a course at the Naval Signal and Radar Schools at which I learnt that radar equipment has been developed and used down to a wavelength of 3 cms.

These isolated examples of war-time achievement were the result of co-operation between the Services and Industry, and between engineers and scientists of varied outlook. By such co-operation, British teams of research and development workers developed " quality " which overcame our great lack during the war—that of quantity. We were able to exploit our " quality " by loaning British engineers and research workers to all our Allies, who thus made a fine contribution to final victory.

The fruits of such work, however, were derived from the freedom of scientists and engineers to question and to experiment, with an opportunity to draw conclusions, unrestricted by any forces that would hamper liberty in thinking. The realm of study, investigation and development must be free.

Think of the strides which scientific discovery have made. Half a century or so ago, no scientist ever dreamt that there could be anything smaller than the atom, or that the atom itself could be broken up. Only in the last half-century have we discovered that the atom is itself built up of other particles.

Such discoveries are seldom the work of one man and are very often only appreciated after strenuous efforts by a team of men. In engineering development and production, team work is certainly essential and in the last century or so, the need for co-operation among like workers has been exemplified by the development and foundation of learned societies and institutions. Such societies as ours exist not only to impart knowledge and information, but to induce ordered thinking, analysis of problems and their reduction to fundamentals, critical observation, leading finally to the joy of achievement.

For these reasons I am sure you will agree that the Institution should hold Conventions every year in addition to the normal monthly meetings of the Sections of the Institution. I am looking forward to reading papers as they are published in the Journal of the Institution and wish you all success in your work.

TRANSMITTING VALVES FOR COMMUNICATION ON SHORT WAVELENGTHS*

by

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A Paper read before the Institution's Radio Convention held at Bournemouth, May, 1947.

SUMMARY

Section 1 deals with the requirements and properties of communication systems as affecting the choice of valves to be used as oscillators and amplifiers.

The chief feature which distinguishes the communication system from other fields of use of transmitting valves is the use of modulation to convey intelligence. The possible types of modulation are classified from the valve point of view as either amplitude or non-amplitude modulation. Whilst both types can be of video, sinusoid, or pulse form, only in the case of amplitude modulation does the form affect the operating conditions of the valve.

The types of valve suitable for use on short wavelengths may be classified as:

Space charge control valves.
Velocity modulation valves.
Magnetron valves.
Travelling wave valves.

All these share the common feature of a density modulation of the electron stream at the output electrode, but vary in the method of its production and its utilisation.

Following a brief indication of the principles of operation of the individual types, they are discussed from the points of view of operational frequency, power output, tunability, frequency stability, modulation possibility and purity, bandwidth, power gain, and economy.

It is concluded that all types have at present their own particular fields of operation. The space charge control valve, and in particular the triode, is outstanding for its versatility as oscillator and amplifier to frequencies in excess of 1,000 megacycles/sec. At higher frequencies, certainly above 3,000 megacycles/sec, the velocity modulation valve is necessary for amplification, whilst the magnetron, because of its higher efficiency, is better as an oscillator.

The full possibilities of the travelling wave valve are as yet unknown, but its outstanding feature of very wide bandwidth should make it pre-eminent for multi-channel communication at the highest frequencies.

Section 2 deals with the constructional features and performance of some of the more recent C.W. triodes viz. DET22, E1769, ACT22 and ACT23, which cover a range from 10 watts to 250 watts in anode dissipation.

These types are all of metal-glass construction, which is necessary to make the valve an integral part of the circuit. All make use of oxide coated cathodes.

Section 3 deals with the requirements of valves to be used as modulators for the various types of modulation.

(1) GENERAL DISCUSSION OF VALVE TYPES

((1.1) Introduction.

The use of the term transmitting valve implies a restriction of the present study to the use of valves under large signal conditions, corresponding to Class B or Class C operation in the case of triodes. The physical size and power rating do not necessarily enter, since these may be restricted by the operational wavelength. In addition, with the high effective power gain that can be obtained with the use of directive aerials, quite low powers can be used in the output of very short wave transmitters to give good ranges.

The term communications, again implies a further restriction to the cases of use for transmitting intelligence, which necessarily involves some form of modulation of the output power. This excludes the consideration of such large fields of use as industrial process heating and radar. The latter, of course, involves modulation, and, in the case of high repetition pulse rates, closely approaches the pulse modulation considered here, so that it is a fine point to determine the border line between them. The valves covered can, of course, be used for radar work, and, in fact, some of them were primarily developed for that usage. The field has, however, been covered very adequately in recent publications(¹), so that it can be excluded here.

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The problem of the modulation of valves at high frequencies is more complex than at lower frequencies. It involves all the problems occurring in the latter, together with those peculiar to the frequencies involved. It is the purpose of this first section of the paper to discuss the latter and other requirements of the valves. In order that this may be done, the various existing types of valve are classified into groups, and a brief description is given of their mode of operation.

It is unfortunate that at the present time the term modulation is uesd in connection with valves in two separate senses.

(*a*) Modulation of the carrier, meaning some form of variation of the envelope of the high frequency sinusoidal output from the valve. This is the form of modulation referred to above.

(*b*) Modulation of the electron flow in the valve, as indicated by such expressions as velocity modulation and density modulation.

It can truly be said that the signal modulation (*a*) equally well is due to a variation in the electron flow in the valve, but the difference is that whereas (*b*) occurs at carrier frequency, (*a*) occurs at signal frequency.

It is hoped that in spite of using the term for both meanings in what follows, it will be clear from the context what is meant in any particular case.

(1.2) Types of Signal Modulation.

A number of different methods of modulating the high frequency are in use at the present time, the running conditions of valves being influenced by which method is being used.

There are probably various ways of classifying the methods, according to the particular objective, but from the point of view of the valve (or the valve designer) there is no doubt that the main classification is :—

(*a*) Amplitude modulation.

(*b*) Non-amplitude modulation, which includes both frequency and phase modulation.

Each of these can again be divided, according to the complexity of operation, into

(α) Video modulation, which involves only amplitude variation.

(β) Sinusoidal modulation, which involves amplitude and frequency variation.

(γ) Pulse modulation, which can, if desired, involve amplitude, frequency and width variation.

It is, of course, possible to envisage more complicated forms of modulation, involving sub-carriers, in order to obtain more degrees of freedom, but from the valve point of view they would still be classified as (*a*) or (*b*) above. Objection may be raised to the classification of video as simpler than sinusoidal modulation. Admittedly, the sudden changes in amplitude in the video case necessitate wide bandwidths, but so also will the transient changes in sinusoidal amplitude if perfect reproduction is required.

It is not intended here to go into the question of the bandwidths required for the different cases, as this cannot be considered a valve problem. It is sufficient to note that large bandwidths, of the order of several or even several tens of megacycles are often needed. The use of the higher frequencies has given the possibility not only of obtaining these bandwidths, but also gives the space in the ether to use them.

It will be clear that non-amplitude forms of modulation will stress the current or emission properties of the valve in the same way as continuous wave operation. On the other hand, the forms of amplitude modulation will vary in their effect, and this must be taken into account when considering the operating conditions for any particular valve.

(1.2) Types of Valve.

Prior to the war, the field of communications was, with one or two exceptions, served almost in its entirety by triode and pentode types of valve. The steady trend, however, towards the use of higher frequencies, had seemed to indicate distinct limitations in the performance of these valves, one of the causes being the finite electron transit time between the electrodes. Attention had therefore been led to the possibility of designing valves which made definite use of this finite transit time, and devices distinct from the triode had appeared.

Whilst the mode of operation of these newer devices appears, at first sight, to be completely dissimilar to that of the older valves, there is one feature which they all must share in common. This feature is the production of a density modulated stream of electrons at the output electrode ; that is, if one considers the electron stream at that point, then its density will fluctuate in a periodic manner at the frequency it is desired to produce or amplify. It is in the manner of production of this density modulated stream of electrons, and in the way that energy is abstracted from it that the differences in the types arise.

At the present time there are three main types of valve available for the production of very high frequencies for communication purposes, whilst a fourth type is appearing on the horizon.

(1.3.1) Space Charge Control Valves.

These valves depend primarily on the direct production of a density modulated current by the action of a varying electric field on the potential minimum in front of a space charge limited cathode. The energy is abstracted from the electron stream by direct collection at the anode.

This class of valve embraces all normally used triodes, tetrodes and pentodes.

(1.3.2) Velocity Modulation Valves.

In this class of valve, an initial velocity modulation is converted into density modulation by allowing the electrons to travel along a drift tube under the action of a constant field, thereby allowing the faster electrons to catch up the slower ones. The energy is normally extracted by allowing the beam to pass through a resonator.

(1.3.3) Magnetron Valves.

In these valves, the electrons effectively rotate around the cathode as a cloud, which is bunched, i.e., density modulated, by the resonators which form the anode structure, and which, at the same time, extract the high frequency energy.

(1.3.4) Travelling Wave Valves.

In these valves a linear stream of electrons is first bunched, and then has energy extracted from it by the output electrode. This latter consists of a helix, which is used to conduct a travelling wave, and along whose axis passes the electron stream.

Other types of valve have, of course, appeared at various times, of which at least two deserve some mention. Firstly, there is the positive grid or Barkhausen valve, which was used so successfully in the centimetre wave cross channel link. This form of valve, however, can be looked upon as an elementary form of velocity modulation valve(2), by which latter type it is certainly superseded. Secondly, there is the inductive output valve(3), which uses space charge control to provide the density modulation, together with a resonator to extract the high frequency energy. The efficiency and operating frequency of the type do not appear to be as high as a correspondingly well designed triode.

(1.4) Valve Requirements.

Communication transmitters may vary in their valve complement from those using a single self oscillator at the output frequency to those using a relatively low frequency crystal controlled oscillator with a chain of frequency multipliers and amplifiers to reach the final output frequency. Whatever the complexity of the system, when it is desired to communicate intelligence reliably, there are a large number of factors which must be considered in deciding whether a particular valve or class of valve should be used. Conversely, for given valves the same factors will determine the complexity of the system.

(*a*) *Frequency of Operation.*

This will often restrict the possible choice of valves, since with most types the possible working frequency range is limited by constructional considerations.

(*b*) *Power Output.*

The valve must obviously be of such a rating that the required output can be obtained. It is usually advisable to design to a figure somewhat below the maximum rated output in order to allow for such factors as variation from valve to valve, the avoidance of complicated retuning when changing valves, and the inevitable fall in output at the end of life.

(*c*) *Tunability.*

There are two possible reasons for requiring tuning:

(1) In a multi-channel transmitter, to be able to tune rapidly from one frequency to another and maintain good efficiency.

(2) To be able to restrict the number of valve types by using the tuning to bring the valve of the nearest frequency class to the required spot frequency.

(*d*) *Frequency Stability.*

This will normally only be of importance when the valve is used as a self oscillator. It involves the consideration of changes due to thermal, mechanical, and electrical effects.

(*e*) *Modulation.*

The considerations under this heading fall into two parts, viz.:

(1) Purity, that is, how free from the other forms of modulation is the output when one particular form is required. This applies particularly to the case of amplitude modulation, where the production of frequency modulation would give unwanted sidebands with consequent distortion and waste of power.

(2) Linearity, that is, how closely is the output power over the modulation cycle proportional to the square of the input voltage.

(*f*) *Bandwidth.*

For the devices in which the output circuit is resonant, that is, all except the travelling wave valve, the bandwidth will determine and be determined by the loaded *Q* of the circuit, that is, the *Q* under working conditions. It will, therefore, be very much bound up with the requirements of power output and gain.

When modulation is carried out at low level and followed by a chain of amplifiers, it is the overall bandwidth that matters so that each individual stage must have a considerably wider bandwidth than is finally required.

(*g*) *Power gain.*

This will depend on the value of the load impedance, which is usually determined by the bandwidth required; and upon the electronic properties of the particular device. It is obviously desirable to have as high a gain as possible so that the number of valves used can be kept to a minimum. Especially is this so for the low level modulation case above, where increase of number of valves means a reduction in the value of the anode load to maintain the required overall bandwidth.

Where bandwidth is not the determining factor, increase in stage gain can often be effected at the expense of efficiency, especially by working a given valve at low power level.

In the case of frequency multiplication, a low power gain, or even a power loss is often tolerated because of the other advantages to be gained by using the initial oscillator at low frequency.

(*h*) *Economy.*

This will involve both the efficiency of the device as a converter of D.C. energy into high frequency energy, and also the cathode efficiency. That is, other things being equal, an oxide coated cathode will be more efficient in terms of electron current per watt of heating power than a thoriated tungsten filament, and the latter will be more efficient than a pure tungsten filament.

(1.5) Space Charge Control Valves.

The theory of operation of triodes, tetrodes, and pentodes at low and medium frequencies is so well known that no reference need be made to it.

As the frequency of operation is increased, two effects begin to be troublesome(4), causing loss of output and efficiency. The first of these is the inductance of the leads, which reduces the size of the circuits which can be attached to the valves, and causes unwanted couplings between them. The other is the finite time of transit of the electrons between the electrodes, which gives rise to increased losses at both the input and the output, resulting in reduced gain and efficiency.

The reduction of lead inductances is largely an electrical and mechanical problem, and in the case of triodes is dealt with in Section 2. For tetrodes, the difficulty of supplying an additional low inductance path to the screen grid, has so far led to the almost complete absence of this type for working above about 300 Mc/sec.

An alternative to the tetrode, which also gives screening between the input and output circuits, lies in the use of specially designed triodes in grounded-grid circuits, in which the input is applied at the cathode, and the output taken from the anode. This type of circuit can be used up to the highest frequencies set by the other valve limitations, and is assumed to be used in the following discussion.

An advanced type of tetrode, the Resnatron, has recently been described(5), which operates at frequencies in excess of 600 Mc/secs. So far, its application seems to be at very high power levels, because of the high anode and screen potentials necessary. In view of its limited use under these conditions, it will not be dealt with further here.

The minimisation of transit time limitations is also a mechanical problem of making valves with the necessarily close spacings between electrodes, and again is dealt with in Section 2. As a result of the improved technique in making and operating triode valves, the frequency of operation has been extended over the last few years to beyond 3,000 Mc/sec.

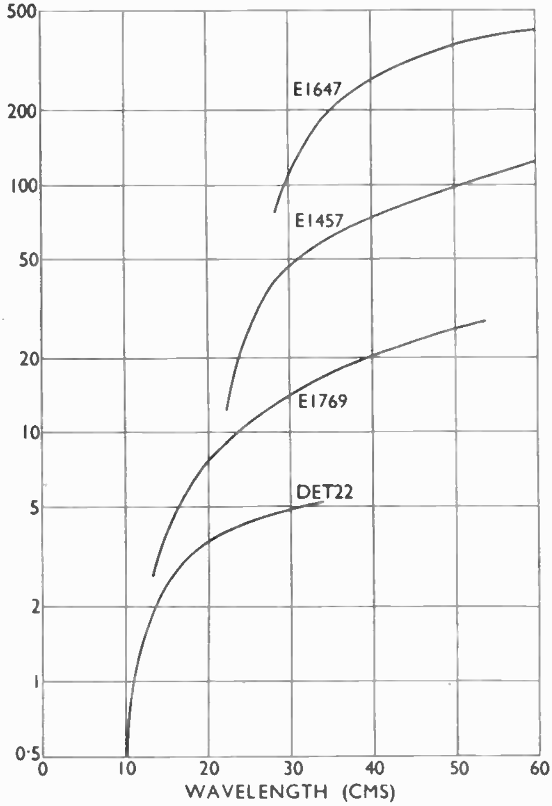

Fig. 1.—Typical performance curves of valves—types DET 22, E1769, ACT 22 and ACT 23 as C.W. amplifiers.

(1.5.1) Frequency of Operation.

A triode can be operated at any frequency from zero up to the limit set by transit time or lead length, provided only that suitable external circuits are attached to the valve.

(1.5.2) Power Output.

The output power plotted against frequency for some of the modern short wave triodes is shown in Fig. 1, indicating lower limits of usefulness as transmitters as somewhere between 10 and 15 cms. wavelength for 1 watt output, between 20 and 25 cms. for 10 watts output and between 25 and 30 cms. for 100 watts output.

(1.5.3) Tunability.

It is, of course, one of the chief features of the triode both as an oscillator and as an amplifier, that the tuning circuits are external to the valve, and may therefore take any form suitable to the designer's needs. The waveband over which a circuit can be tuned is a matter of the designer's ingenuity and not a valve limitation. Wideband circuits have been described for use at the higher frequencies which cover a two to one spread in frequency.

(1.5.4) Frequency Stability.

Any relative movement of electrodes will affect the internal capacities and transit times, and therefore affect the frequency of operation. Whilst the special seals and low inductance leads will make for greater general strength than in low frequency valves, and give freedom from microphony, this will be offset to some extent by the use of finer grid wires. In addition, the valve capacities play a much bigger part in tuning the circuit, so that small changes in dimensions will have a larger effect.

Changes in dissipation in the electrodes will give rise to expansion or contraction. This change is usually fairly rapid, but is followed by a slower change as the attached circuit warms up. The overall effect is small; in the DET22, for example, a trebling of the input power produces rather less than 0.1% change in frequency.

Change of voltage on the valve will cause frequency change because of altered transit time, in addition to the thermal changes associated with the alteration in wattage. In the case of oscillators this is explained in terms of the total phase change of 2π radians that must take place in going round the circuit. At low frequencies this is made up from π radians shift in the valve and a further π radians shift in the circuit. At high frequencies, the effect is to increase the internal phase shift to more than π radians, to an extent depending on the transit time. When the latter is varied, the frequency must change in order that the phase shift in the external circuit, can adjust itself to make the total equal to the original 2π radians.

In the case of amplifiers, a steady change of voltage will not matter, but a continually varying voltage will give phase modulation due to the varying phase shift through the valve, which is equivalent to frequency modulation.

(1.5.5) Modulation.

Amplitude modulation can be carried out, as in the low frequency case, by application of the modulating voltage to any electrode. As pointed out above, in the region of transit time limitation, frequency modulation will be produced at the same time, increasing in percentage as the frequency is raised.

The use of this effect is probably the simplest method of producing frequency modulation. For example, with the DET22 valve, a frequency change of 100 Kc/sec. is produced by a change of voltage of approximately 1 volt at a wavelength of 10 cms. and by 10 volts at 25 cms.

The application of the reactance valve modulator at short wavelengths is not straightforward, but it is clear than any electronic device which can be controlled to produce a variable reactance at the frequency required could be used to provide frequency modulation.

With pulse amplitude modulation, amplifiers are more suitable than self oscillators, since the rise of the latter to full output usually takes a few tenths of a microsecond from the application of the pulse, whilst the presence of the drive at the required frequency in the former gives a much more rapid rise.

The linearity in the case of triodes is usually quite good up to fairly high percentages of modulation. The increase of frequency should not make any major differences in this respect.

(1.5.6) Bandwidth.

When a triode, the output of which may be represented as a capacitance C shunted by a conductance G, is used with a line circuit of length l and characteristic impedance $Z_0 = \frac{1}{G_0}$, then it may readily be shown that the bandwidth between half power points is given by

$$\Delta\omega = \frac{2G}{C + G_0\left(1 + \frac{\omega^2 C^2}{G_0^2}\right)\beta l}$$

where $\beta = \frac{2\pi}{\lambda}$ is the phase constant of the line.

From this it is readily seen that for wide bandwidth, a low value of valve capacity, C, is required. In addition, the minimum value of length l to give resonance should be used, i.e., the quarter wave mode is to be preferred. The characteristic impedance of the internal valve structure should therefore be made as low as possible in order that the first voltage node should be outside the valve up to as high a frequency as possible.

(1.5.7) Power Gain.

The power gain of triodes used in grounded grid circuits is inherently fairly low, because of the fact that the fundamental component of the cathode current has to pass through the input circuit. It will therefore be equal to the voltage gain diminished in the ratio of the anode to cathode currents, and for Class B and C amplifiers at low frequencies is determinable for any particular load from the valve characteristics. For the valves described later, it tends towards a value of 10 to 12 decibels at 500 megacycles/secs, and falls off at higher frequencies.

It may be noted that of the drive power, only that due to the grid current is lost, since that due to the anode current appears in the output circuit. This is not so in the case of the grounded grid frequency multiplier, since the anode circuit will be tuned to a different frequency. This, coupled with the usual difference in gain between amplifiers and frequency multipliers, makes the gain obtainable from the grounded grid frequency multiplier quite small.

(1.5.8) Economy.

The anode efficiency of triodes rises from zero at the limiting wavelength to a figure of the order of 50 to 60% at about three to four times this wavelength, and beyond this up to 70 to 75%.

(1.6) Velocity Modulation Valves.

The general principles of the operation of velocity modulation valves(6) may be explained with reference to the simplified diagram of Fig. 2.

Electrons from the cathode are accelerated to the first resonator, called a buncher, which is maintained at a suitable positive potential. The central, or capacitive portion of the resonator is of such a form, usually a grid, that the majority of the electrons can pass through. A radio frequency field, induced in the resonator by means of a coupling loop modifies the velocity of the electrons leaving the resonator, some having been accelerated and some decelerated. This is, of course, the velocity modulation that gives the device its name. The power required for this bunching is usually quite small, since approximately equal numbers of electrons give up and absorb energy in their transit through the resonator.

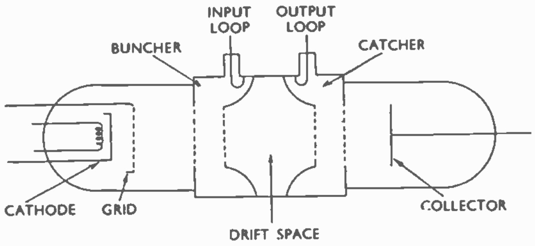

Fig. 2.—Simplified velocity modulation valve.

The electrons now travel in a uniform field towards the catcher resonator. During this period the faster electrons catch up and the slower electrons fall back on those with the mean velocity. In this way they tend to gather in bunches, i.e. the beam becomes density modulated, and at a certain distance the bunches gain a maximum density. If the catcher resonator, tuned to the frequency of the bunches is placed at this point, then energy will be given up, and may be extracted from the resonator by a coupling loop. The electrons are finally collected by an anode.

For operation as an oscillator, it is only necessary for some of the output power to be coupled back in the correct phase to the input resonator. An alternative method which is used for low power oscillator work is to use only the first resonator, and, by means of a reflector electrode at a slightly negative voltage, spaced at a suitable distance, return the electron beam in a bunched state through this resonator, which is thus used as both buncher and catcher.

It will be clear that the optimum length of drift space will depend not only on the D.C. potentials, but also upon the excitation voltage induced across the first resonator. The form of the density modulation in the beam is quite different from that obtained in triodes, being much more peaky in nature. In fact, when overbunched by working with a large excitation voltage each bunch can have more than one maximum of density(7).

(1.6.1) Frequency of Operation.

The lower limit of frequency of operation is set by the physical size of the device, particularly the length that has to be occupied by the drift space. Apart from becoming unwieldy, magnetic fields would have to be used to maintain the focus of a long beam.

The upper limit is set by the usual mechanical limitations of making and assembling small components, and is probably in the order of 30,000 Mc/sec. on continuous wave working.

(1.6.2) Power Output.

The power output at present obtainable, of the order of tens or hundreds of watts, is limited by the problems of obtaining high beam currents through the resonators, and in dissipating the high powers in the small structures, the sizes of which are dictated by the wavelength.

(1.6.3) Tunability.

Because the bunching effect in the drift space is a transit time phenomenon, the device can only work to optimum efficiency at one particular frequency. Tuning of the resonators may be used coupled possibly with some electrode voltage variation to tune over a range of about ± 10%.

In the case of reflex oscillators, variation of the reflector voltage may be used to alter the transit time in the drift space and thus alter the frequency over a fairly wide range, but the output power is usually rather small and does not really bring the type within the transmitting valve class.

(1.6.4) Frequency Stability.

As in the case of triodes, the mechanical structure should give freedom from microphony, the grids, if used, being the weakest point in this respect.

Since the transit time is an inherent feature of the valve the stability with change of applied voltage cannot be good, and in practice it is usually necessary to operate the valves from stabilised power supplies.

(1.6.5) Modulation.

Amplitude modulation may be carried out by variation of the acceleration voltage on the first resonator, or by using a grid in front of the cathode to vary the current through the resonator. Both produce concurrent frequency modulation, the first because of alteration of transit time, and the second because the variation in space charge passing through the resonator causes changes in the effective capacity.

Frequency modulation is obtained from the above amplitude modulation, the latter being effectively removed by the limiter present in the receiver.

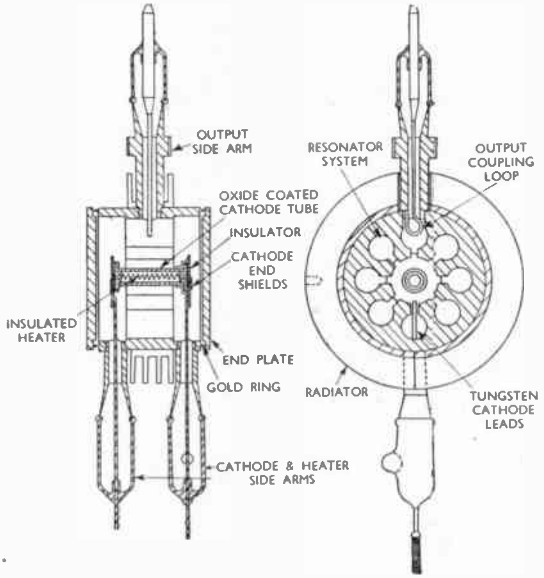

Fig. 3.—Construction of NT 98 magnetron.

(1.6.6) Power Gain.

The power gain obtainable with velocity modulation valves is very good, especially with frequency multiplication, and is one of the chief virtues of the type. It arises partly from the low input power as explained above, and partly from the peaky nature of the fluctuation of electron density as it reaches the output electrode. Gains of over a hundred have been quoted for plain amplification, and appreciable gains when working even up to the tenth or twentieth harmonics.

(1.6.7) Economy.

Whilst the theoretical efficiency of the device is quoted as being 58% for the fundamental and 30% for the tenth harmonic, these figures are never approached in practice, because of poor conversion to R.F. power, debunching, losses in resonators, etc. Practical figures may rise as high as 20% for the fundamental, but are usually below this figure.

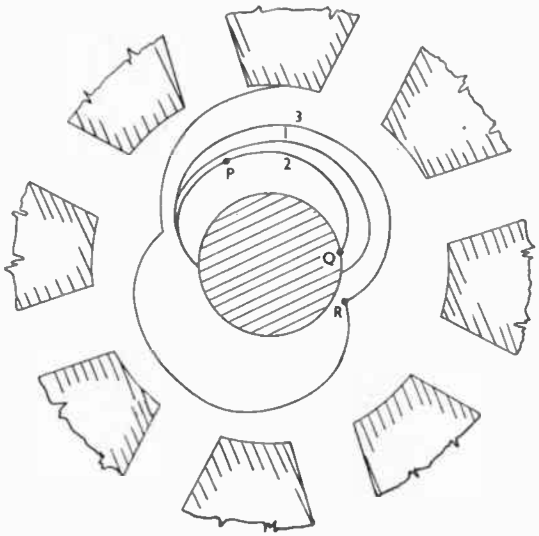

Fig. 4.—Simplified diagram of magnetron showing typical electron orbits.

(1.7) Magnetron Valves.

The multiple circuit magnetron(8) (Fig. 3) is a transit time oscillator, the principle of which may be explained with reference to Figure 4, which represents a simplified cross section of the valve. With D.C. on the anode, and with an axial magnetic field; the electrons emitted from the cathode would follow a path such as 1 in the figure. When the valve is oscillating, with alternate segments in phase, i.e., a phase difference of π radians between adjacent segments, there will be present a variable tangential component of the electric field as well as the constant radial one. The tangential component will change during an electron orbit, and if this change is such as to increase the energy of the electron above that corresponding to the potential at its position, it will return to the cathode with excess energy which will be given up as heat (orbit 2). If, however, the change is such as to decrease the energy of the electron, an orbit such as 3 will be followed, with zero radial velocity at R. If now, further loops can be followed by the electron with continued loss of energy, it will finally reach the anode, with an energy considerably below that corresponding to the anode potential. The lost energy appears in the oscillatory circuit, and is considerably in excess of that transferred to the cathode by the first class of electrons, so that the device will operate as a self oscillator. The sorting out of the electrons into two classes effectively means that treating the electron cloud rotating round the cathode as a whole, it becomes density modulated in the tangential direction.

If the spacing between alternate anode segments is s, then the stationary voltage wave on the segments can be regarded as being made up of two contra-rotating sets of potential waves travelling with velocity fs, where f is the frequency of oscillation. Of these, only the wave travelling in the same direction as the electrons need be considered. If it be assumed that all the electrons collected at the anodes are travelling tangentially with the velocity of the field, then their energy has its minimum final value of $0.5mf^2s^2$, compared with the value eV they would have had if no energy had been communicated to the high frequency field. Here e and m are the electronic charge and mass, and V is the mean potential of the anode. The efficiency of operation will therefore be given by

$$\eta \text{ max.} = 1 - \frac{0.5\, m f^2 s^2}{eV}$$

From this, it is seen that to obtain high efficiency, either high voltage or small spacing between segments must be used.

(1.7.1) Frequency of Operation.

For magnetrons working at good efficiency, it will be clear that mechanical considerations will limit the possible frequency range.

On the lower frequency side, the increased spacing between segments, indicated by the formula above, will make the structure very large, and whilst this may be possible for the valve, the magnet problem would present considerable difficulty.

At the other end of the scale, the very small size of the cavities and the close spacings give the upper frequency limit.

The practical range of use is probably from a few hundred megacycles up to several tens of thousands of megacycles.

(1.7.2) Power Output.

As most magnetron development work has been directed towards valves for use in pulsed radar equipment, little information is available on the upper limits of C.W. power output. Valves have been made giving an output of ½ kilowatt at a wavelength of 10 cms. What increase will be obtained with further development cannot be stated.

(1.7.3) Tunability.

As in the case of velocity modulation valves, since the output is extracted by resonators from a transit time bunched cloud of electrons, the magnetron must suffer from limitations in tuning range.

Actually, tuning has been carried out with cavity magnetrons by means of axially adjustable plates or fingers at the ends of the structure to vary the capacity or inductance of the resonators. By this means a range of ± 10% in frequency can be obtained. In view of the great degree of complexity in manufacture that this introduces, it is doubtful whether it is desirable or economic. The alternative of pretuning to a particular frequency by mechanical adjustment is perfectly feasible and probably a more economic thing to do. The load coupling can be used to pull the frequency to some extent as a final adjustment.

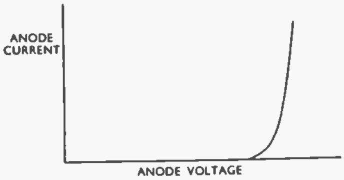

Fig. 5.—Typical current-voltage characteristics of a magnetron.

(1.7.4) Frequency Stability.

The absence of grids, and the general nature of magnetron construction should make for both mechanical and thermal stability.

The electrical stability is also good. The 10 cm. C.W. valve mentioned above works normally at 300 mA anode current. A variation of this from 150 mA to 450 mA, i.e., a ratio of three to one in power input, produces a 1.75 Mc/s change in frequency, i.e., ± 0.03%.

Since the magnetron is a self oscillator, a stable frequency is not obtainable by frequency multiplication from a crystal oscillator. A satisfactory alternative is to compare the output frequency with the natural frequency of a stable high-Q resonator, and by means of a discriminator circuit provide means for mechanically or electrically adjusting the magnetron tuning.

(1.7.5) Modulation.

Owing to the shape of the magnetron anode voltage anode current characteristic (Fig. 5), amplitude modulation of the output only requires a small swing of voltage, and the output power varies linearly with modulation voltage instead of according to the square law which is required by a normal receiver. Whilst this can be overcome by suitable non-linear modulation circuits, it represents a complication not present with other valve types.

This effect does not matter for pulse amplitude modulation, for which the magnetron is very satisfactory, in that the build up time is of the order of 1/100th microsecond at a wavelength of 10 cms.

Frequency modulation is possible but not easy to carry out. It can be done by loading one or more of the magnetron cavities by passing beams of electrons through them, since it is known that this will alter the permittivity of the vacuum. Alternatively this loaded cavity could be separate from the magnetron cavities, and coupled electromagnetically to one of them through a slot. Or again, since the frequency can be pulled by the external circuit, the electron loaded reactance can be coupled to this.

The frequency pulling that can be obtained is small, being of the order of ten to twenty megacycles per second at a wavelength of 10 cms. The amount of concurrent amplitude modulation obtained will depend on the detail design. Since the loading is essentially reactive it will depend on the loaded Q of the circuit, i.e., on the bandwidth.

(1.7.6) Bandwidth.

The optimum loaded Q value for maximum output has usually a value around 100, and this will therefore define the bandwidth in the usual manner, giving, for instance, a bandwidth between half power points of 30 Mc/s. at 10 cms. wavelength. The bandwidth can, of course, be made higher if the loading is increased, and lower output and efficiency tolerated.

(1.7.7) Economy.

The efficiency of the 10 cm. magnetron already mentioned is of the order of 50%.

(1.8) Travelling Wave Valves.

This type of valve has appeared so recently, and so little has been published regarding it(9), that since another paper in the Convention proceedings is dealing with the subject, only brief mention will be made here to its outstanding quality, viz., extremely wide bandwidth.

The other valve types discussed have all used relatively sharply tuned circuits to extract the power from the density modulated electron flow. In this type, a travelling wave is guided along a helix surrounding the electron beam, and effectively extracts energy continuously from it, after the initial bunching. Since waves of all frequencies will pass along a transmission line with the same velocity, the device should largely act as an untuned amplifier with uniform gain at all frequencies. There are, of course, upper and lower limits in practice, the upper one due to drop in field strength on the axis of the helix, and the lower one due to an insufficient number of wavelengths along the helix. Rather closer limitations come in due to the terminations or aerials at the ends of the helix, which couple the valve into the input and output lines (or wave guides), being effectively tuned circuits.

These effects, however, are hardly limitations at all when compared with the other types of valve, and bandwidth figures of 800 Mc/sec. at a frequency of 4,000 Mc/sec. have been quoted for experimental samples of the type.

Conclusions.

From the above discussion, it may be concluded that at the present time no one type is predominant over the whole field. There is no doubt that for frequencies up to some hundreds of megacycles per second, the space charge control valve is the only possible choice. Even beyond this up to one or two thousand megacycles per second, it remains first choice for many applications, because of its tunability and general versatility.

In the region above one or two thousand megacycles, the velocity modulation valve and the magnetron become essential. The magnetron would probably be chosen as a self oscillator because of its higher efficiency. For amplification and frequency multiplication only the velocity modulation tube is possible, and here it makes up for its relatively low efficiency by the high gain obtainable.

The position to be occupied by the travelling wave valve is not yet certain, but its outstanding feature of very wide bandwidth should ensure for it a permanent place beside the other types.

(2) SOME RECENT TRIODES FOR SHORT WAVE WORKING.

(2.1) General.

The problems which arise in the design of triode valves to work at higher frequencies fall into the four following classes:—

(2.1.1) Electronic.

As explained in earlier sections, the finite transit time of the electrons gives rise to additional losses at the grid and anode, and therefore to reduced efficiency and gain.

To reduce the transit time, either the electrode clearances can be reduced, or the applied voltage increased. However, from a combination of the equation for the transit time between cathode and grid (which is the major part of the total time), viz.:

$$T = 6.6 \times 10^{-10} \left(\frac{d}{I}\right)^{1/3} \text{ secs.}$$

with the usual three halves power law for the emission current density,

$$I = 2.34 \times 10^{-6} \ \frac{V^{3/2}}{d^2} \ \text{amps/sq. cm.}$$

where d is the grid cathode spacing in cms. and V is the effective grid voltage, it may readily be shown that for a given size of valve, increase of applied voltage will give

$$\text{Anode wattage} \propto \frac{1}{T^5}$$

On the other hand, for a given applied voltage, decrease of electrode spacing gives a much smaller rate of increase, viz.:

$$\text{Anode wattage} \propto \frac{1}{T^2}$$

From this it will be seen that it is usually better to meet the requirement of increase of frequency by reduction of clearances, in order that the thermal problems at the anode should be minimised. With these small clearances, the above equations show that the current density required from the cathode will be increased for a given applied voltage. To enable this to be done, the technique of producing oxide coated cathodes has been improved, and peak currents of the order of one ampere per sq. cm. under C.W. conditions are now common practice.

(2.1.2) Electrical.

Under this heading fall the requirements of low interelectrode capacity, small lead inductances and good matching of the valve to the external circuit.

The reduction of electrode size required above, aids in reducing capacities. Indeed, it is a well-known principle that if all dimensions of a valve are reduced in proportion, the capacities will be reduced in the same ratio, but the valve currents and conductances will remain the same, provided, of course, that the cathode can supply the increased current density.

The other two requirements are jointly fulfilled by the use of new techniques in making glass to metal seals of disc form, such that continuous connection is made all round an electrode rather than merely at one or two points.

(2.1.3) Thermal.

The small electrodes needed from both electronic and electrical considerations, still have to dissipate the same power as those of older type valves. The electrode design must therefore be such that thermal conduction and radiation maintain the working parts at a sufficiently low temperature. In the case of grids, this is to avoid primary emission from the wires, which become activated by material evaporated from the cathode. In the case of the anode it is to avoid evolution of gas or excessive temperature of the glass to metal seals.

(2.1.4) Mechanical.

It will be clear that the use of grid wires of sizes down to 0.03 mm. and grid cathode clearances down to 0.07 mm., involves mechanical work of the highest order, both in producing the components, and in jigging them for assembly. Especially is this so in the case of the metal-glass envelopes, on whose accuracy of construction, in some cases, the spacing and alignment of electrodes are largely dependent.

Table I.

Characteristics of Short Wave Triodes.

Valve Type	ACT23	ACT22	E1769	DET22
Heater Voltage	13.5	6.3	6.3	6.3
Heater Current (Amps)	2.9	4.0	1.0	0.4
Maximum D.C. Anode Voltage	1,000	600	400	350
Maximum Anode Dissipation (Watts)	250	75	20	10
Amplification Factor	40	22	35	30
Mutual Conductance (mA/V)	30 (at 1,000v. 250 mA)	20 (at 500v. 100 mA)	12 (at 250v. 40 mA)	7 (at 250v. 30 mA)
Anode Grid Capacitance (pF)	16.5	6.5	2.0	1.1
Grid Cathode Capacitance (pF)	22	13.5	4.5	2.2
Anode Cathode Capacitance (pF)	0.4	0.3	0.04	0.02
Cathode Area (sq. cms.)	6.8	2.0	0.5	0.14
Grid Cathode Spacing (mms.)	0.25	0.25	0.2	0.07
Grid Anode Spacing (mms.)	1.0	0.5	0.5	0.25
Grid Wire diameter (mms.)	0.15	0.05	0.05	0.03

(2.2) Valve Types.

Table I sets out the details of ratings and some other relevant particulars of four recent triodes in which the above problems have been solved to a sufficient extent to enable the valves to work at frequencies up to 2–3,000 Mc/sec. The upper limit of frequency, as shown already in Fig. 1, is naturally higher for the smaller valves with their closer clearances. The valves (Fig. 6) form a series with increasing anode dissipation from 10 watts to 250 watts, and are such that each valve may be used as a driver for the next larger one. The series is capable of extension to higher powers but it must be expected that each further step will bring a correspondingly reduced upper limit of frequency.

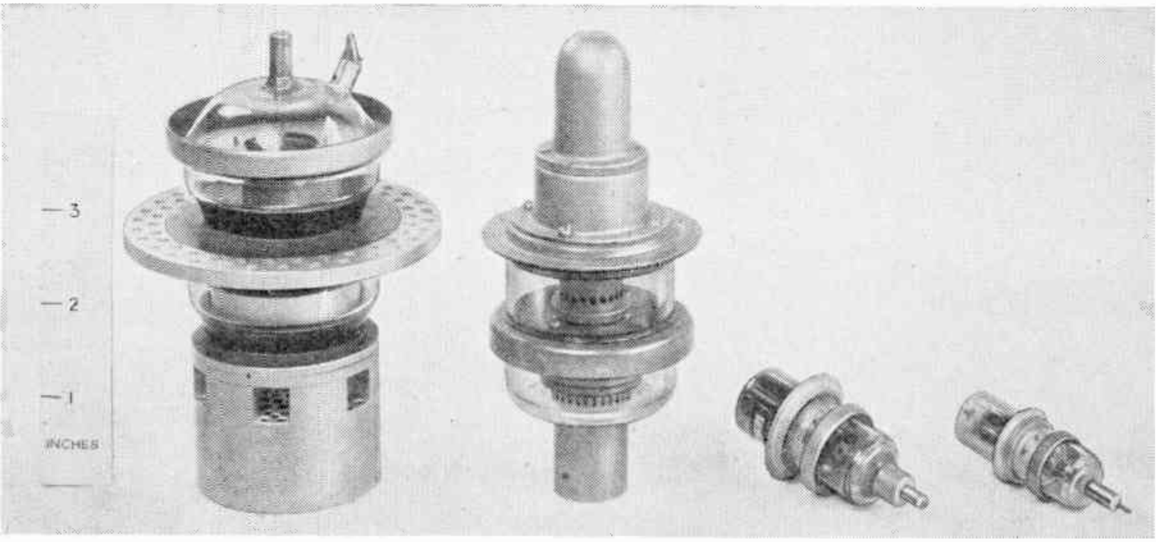

Fig. 6.—Some recent short wave triodes.

(2.2.1) DET22.

The DET22 is the smallest valve of the range, having an anode dissipation of 10 watts, with a planar electrode construction as shown in Fig. 7. Adequate cooling and low inductance are combined in the design of the anode and grid discs, which are made from 0.35 mm. copper, and sealed directly through the tubular glass envelope. The anode disc is shaped to form the anode surface directly, whilst the grid disc is in the form of an annulus to which the grid is subsequently attached. The working surfaces of these two discs are located in relation to each other to an accuracy of ± 0.002 cms.

The cathode consists of a short nickel cylinder, one end of which is closed and oxide coated, the other end being covered by a baffle after the insulated helical heater is inserted. The flat grid is constructed by winding molybdenum wire on to a molybdenum frame, copper brazing the wire to the frame in a hydrogen furnace, and then removing the wire from one side. The cathode and grid are mounted from wires sealed through a glass button, the clearance being adjusted to an accuracy of ± 0.001 cm. Intermediate glass beads are provided in the grid supports both for insulation, and to ensure that no internal wires are of such length that they are self resonant at the highest frequencies of operation.

For final assembly this structure is sealed into the envelope with the grid correctly located against the grid disc. Short strips of pure tin are attached to the grid supports adjacent to the disc, so that the tin will melt when the valve is baked during pumping, and thus give good thermal and electrical contact.

The maximum frequency of operation of this type is 3,700 Mc/sec.

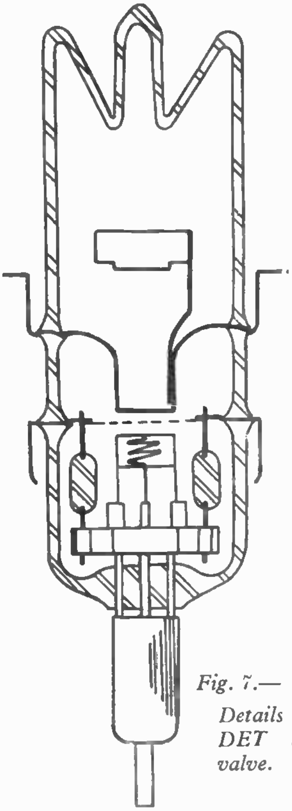

Fig. 7.—Details of DET 22 valve.

(2.2.2) E1769.

The construction of this type is very similar to that of the DET22, but the cathode has over three times the emitting area, requiring a larger diameter bulb and bigger copper disc seals. A further change is made at the cathode support, which in this case is of thin-walled copper tube sealed directly through the end of the glass envelope. The filament lead passes up the centre of this tube, being insulated from it by a further internal glass to metal seal.

Because of the larger electrodes, the valve is capable of an anode dissipation of 20 watts, but the larger clearances used give an upper frequency limit which is a little below 3,000 Mc/sec.

(2.2.3) ACT22.

The ACT22, with an anode dissipation of 75 watts, is the largest of the planar electrode types. Its construction (Fig. 8) is radically different from the two smaller types. The flared copper thimble which forms the anode is sealed to a re-entrant portion of glass at one end of the envelope; whilst copper plated nickel iron discs are used for the grid support and cathode mounting flange.

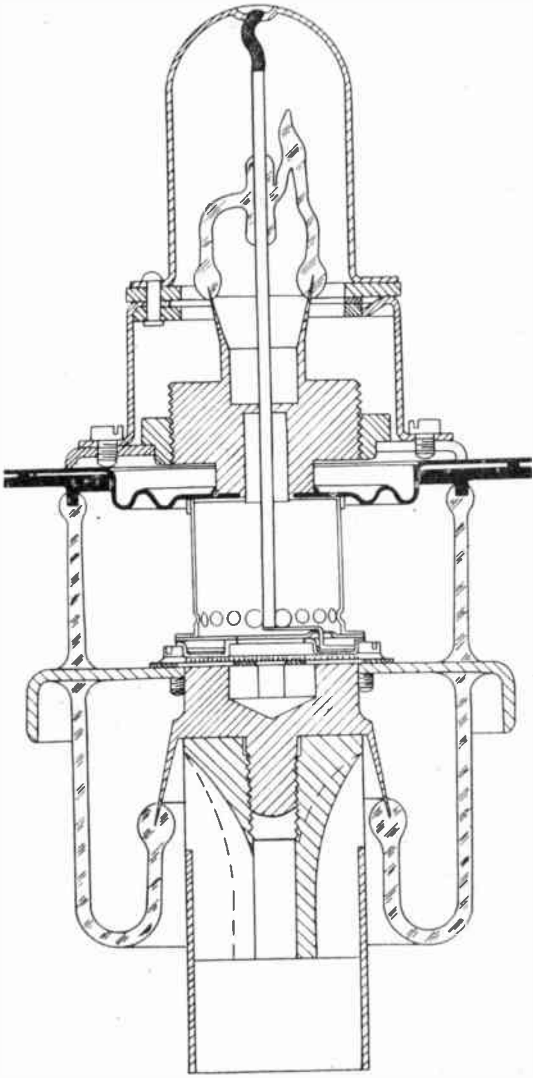

Fig. 8.—Sectional view of ACT 22 valve.

The cathode is in the form of a shallow annular box, with oxide coating on the end face. This is mounted on a short cylinder of nichrome, which is perforated immediately below the cathode to reduce heat conduction. The grid consists of molybdenum wire on a molybdenum frame as in the smaller valves, but, because of the larger size, a strap is left in place across the middle of the grid, at right angles to the direction of winding. This reduces the span of the wires and thereby gives improved rigidity and thermal conduction.

The grid is fixed to its disc by four screws, and subsequent soldering with pure tin takes place during processing as in the case of the DET22.

A novel feature of the valve is that the cathode is attached to a flexible diaphragm, with an external nut and threaded member as shown to adjust the grid cathode spacing. This clearance is kept large during processing and adjusted to the correct value during testing.

The final seal on the valve is made by the gold wire process between the cathode flange and the flexible diaphragm.

The maximum frequency of operation is of the order of 1,500 Mc/sec.

(2.2.4) ACT23.

The ACT23, with an anode dissipation of 250 watts, differs from the other valves in that the electrodes are of cylindrical form (Fig. 9). In the envelope, copper feather edge seals are used for the anode and grid connections, where adequate thermal conduction is required, and a copper plated nickel iron disc for the cathode connection.

The cathode is an annular box, of which only the outside surface is oxide coated. It is mounted on a nickel tubular support, with a perforated nichrome section immediately next to the cathode. Surrounding this cathode is a squirrel cage grid, which is kept cool by thermal conduction down the short grid wires to a tubular copper support which is mounted on the copper grid flange. From this the heat is conducted to the external radiator.

The anode consists of a short section of thick walled copper tubing, through which the heat developed is conducted to a copper end plate. This latter serves both as a vacuum tight closure for the valve, being gold wire sealed to the flange carrying the copper feather edge, and as support for the anode radiator which is soft soldered to it after the valve is pumped.

The upper frequency limit of operation is of the order of 1,500 Mc/sec.

(3) MODULATOR VALVES.

(3.1) Amplitude Modulation.

The methods of amplitude modulation on short wavelengths are largely the same as those in use on longer wavelengths, and in general not dependent on the type of oscillator or amplifier valve used.

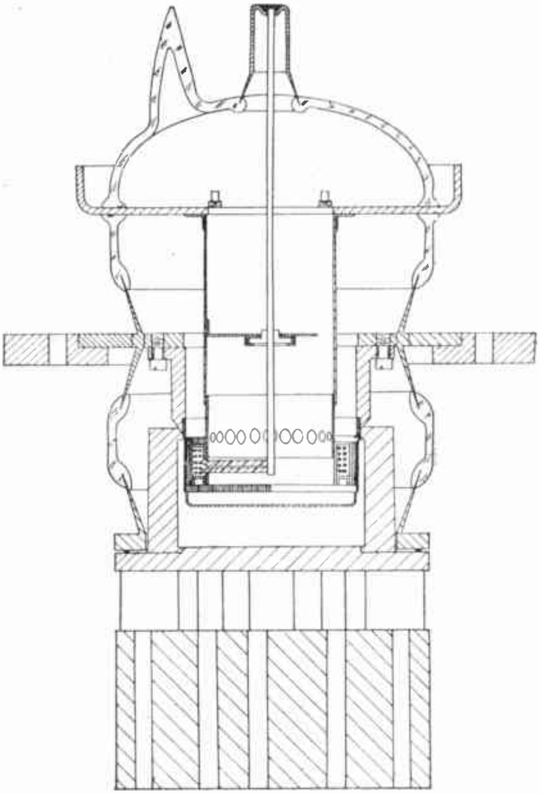

Fig. 9.—Sectional view of ACT 23 valve.

Two alternative methods of operation are possible:

(*a*) variation of voltage on one or more of the valve electrodes, thereby altering the current flowing through the valve and varying the power available.

(*b*) variable absorption of power in a controlled load which is suitable coupled to the output circuit.

For case (*a*) the difficulties that arise at high frequencies are not due to the latter as such, but rather to the use of the wide bandwidths which are then available, and which necessitate lower effective impedances. For correct matching, this means that the modulator also must have a low impedance, i.e., it must work with low voltage and high current. The low voltage is an advantage in that smaller clearances and higher sensitivity can be obtained. The higher current on the other hand requires more emission. If the anode voltage is low enough, this will allow the use of oxide cathodes with consequent economy of production of the high current required.

For case (*b*), since the absorber forms part of the R.F. circuit, it must be equally as good a high frequency valve as the one being modulated. In practice, only the space charge control valves seem immediately applicable to absorption modulation. Velocity modulation valves could be used by introducing suitable coupling between the output and input resonators to render the device degenerative. Magnetron and travelling wave valves being essentially regenerative cannot be used. The variation of resistive loading will almost certainly be accompanied by variation of reactive loading so that frequency modulation will be produced in addition to amplitude modulation.

For all forms of amplitude modulation by variation of voltage, if a reasonable gain is required with wide bandwidth, it is well known that the modulator valve must have high mutual conductance and low inter-electrode capacitances. The same conditions hold if the modulator valve is used as a cathode follower to provide a low impedance driver, which is usually necessary

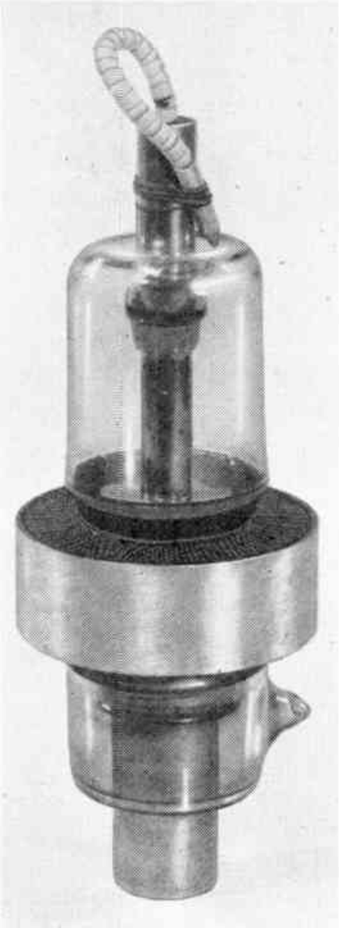

Fig. 10.—Modulator valve, type E1752.

in order to maintain reasonable linearity with the non-linear load presented by an oscillator or amplifier. For either case, it is desirable that the drive power required from the sub-modulator should be as low as possible. That is, the modulator grid should, if possible, not be driven into grid current.

These considerations have led to the design of a medium power triode modulator, the E1752, which Fig. 10 illustrates, and Fig. 11 shews the characteristics. With a grid cathode capacity of approximately 20 pF and grid anode capacity of 15 pF, the slope of 28 mA/volt gives a ratio of mutual conductance to capacity which compares favourably with that obtained by low power video tetrodes. The high anode dissipation of two kilowatts enables an output of 1,000 volts to be obtained across a resistance of less than 600 ohms, with continuous operation at any point of the load line. This renders the valve extremely suitable for video working, both as amplifier and cathode follower, though of course it may equally well be used as a sinusoidal or pulse modulator.

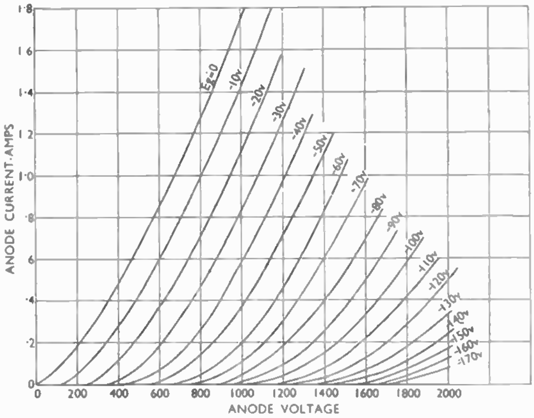

Fig. 11.—Typical characteristics of E1752 valve.

On the constructional side, the E1752 possesses a large cylindrical oxide coated cathode supported on a tubular structure from a copper thimble at one end of the system, and a squirrel cage grid held directly on a somewhat larger copper thimble at the other end. The copper anode forms the central portion of the envelope. Cooling radiators are fixed to both anode and grid.

(3.2) Pulse Amplitude Modulation.

Pulse amplitude modulation for communication differs from that used in radar, mainly in the duty cycle. Thus, whereas in radar, figures of 250 to 1 up to 4,000 to 1 were in common use, for communication the normal figure is much more like 10 to 1, in order that as much information or as many channels as possible can be used.

The pulse modulator valve should therefore be designed to withstand somewhat higher voltages and to have higher emission than would be normal for its size, in order that the 10 to 1 duty cycle can be exploited. The valve will usually be a triode or tetrode amplifier acting as the output valve in what is in effect a video frequency amplifier. This output valve will give across its anode circuit the necessary pulse voltage to modulate the chosen R.F. device.

When used in this manner, with the anode current cut off between pulses, it has to be remembered when fixing the running conditions, that the current from the modulator valve has to charge up the stray shunt capacities across the load. Two effects arise from this, viz., limitation of the rate of rise of the pulse, and increased dissipation in the modulator.

For low impedance loads, as usually arise in the case of space charge control valves, valves have not so far been designed specifically as pulse modulators. The E1752 above could be used, though not as ideal for the purpose as a tetrode. For higher impedance loads, as presented by the other types of valve, the modulator valves developed for radar could have been used, but the majority of these types have become obsolescent. Their re-introduction or replacement will depend on the future trend of pulse modulation systems.

(3.3) Frequency Modulation.

Little can be said about this at the higher frequencies as little has as yet been published.

The easiest method, though not efficient, is to make use of the inherent frequency modulation that occurs when amplitude modulating, allowing the receiver limiter to remove the latter.

The alternatives, as used at lower frequencies, of using electronic reactances have not so far been developed for the higher frequencies. The valves used, would of course, have to be especially designed to work at the frequencies involved.

One method which can be used has been mentioned in connection with magnetrons, and consists of altering the resonant frequency of a resonator by passing a beam of electrons through it, thereby altering the permittivity of the vacuum. The development of this to provide practical frequency modulation will require a considerable amount of detail work.

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CONVENTION DISCUSSION

W/Cdr. S. G. Morgan : Apart from gross neglect (or over-running), what are the major causes of breakdown in these types of triode ; in particular, what forms of breakdown are normally the result of insufficient cooling ?

Mr. L. W. Meyer (Member) : What is the deciding factor in the choice of a copper/soft glass seal in view of the temperature limit imposed by this form of seal (as contrasted with say, a tungsten/hard glass seal) ?—Is it thermal conduction ?

Mr. A. V. J. Martin (Associate) : What is the frequency limiting factor in parallel-plane electrode valves ?

Dr. M. J. O. Strutt : Has Mr. Aldous in his experiments used still smaller clearances than he stated in his paper ?

REPLY TO THE DISCUSSION

Mr. W. H. Aldous : In reply to W/Cdr. Morgan, one would say that breakdown, as such, is unlikely to occur other than by over-running. Excessive applied voltages will cause electrical breakdown to occur across the close internal clearances, whilst excessive heater voltage will reduce the emission life of the oxide cathode. Insufficient cooling may give rise to softening of the valve, or to cracking of the envelope, depending on the rise of temperature involved. The normal maximum working temperature of the metal parts recommended is 140°C.

With regard to Mr. Meyer's query, the use of copper is mainly determined by its good thermal properties, and the use of soft glass by its match to the expansion of the copper plated nickel iron components. The temperature at which seals are made to hard glass is normally too high for pre-plated components to be used.

In reply to Mr. Martin, the limiting frequency is at present imposed by transit time, and not by the attached circuit. Closer clearances, as in Dr. Strutt's question, have been used experimentally, but these lead to very great mechanical difficulties in assembly.

GRADUATESHIP EXAMINATION

May, 1947

PASS LIST (First List Only)

Ninety-six candidates appeared for examination at Centres throughout the British Isles. The attendance returns for Overseas Centres are not yet complete.

Candidates who have passed the complete Examination, or having been exempted from part have now passed the remaining subject(s), and are therefore eligible for transfer or election to a grade of membership other than Student.

BAKER, Henry Louis. London, N.W.6.
CADOGAN, Alexander Joseph (S). London, S.W.11.
CRITCHLOW, Philip Sydney. Tipton.
GILLETT, William Francis Henry. Wembley.
GREGORY, Henry (S). Croxley Green.
HARRIS, John (S). London, W.9.
HEISLER, George Henry (S). London, N.W.6.
HOLDEN, Stanley (S). Westcliff-on-Sea.
HUMPHREYS, Edward Kenneth (S). Torpoint.
KENDALL, James Samuel (S). Birmingham 17.
KOVACS, Albert Frank (S). Hatch End.
LAMBERT, John Robert (S). Hereford.
LEWIS, Reginald George. London, S.E.27.
MANGRU, Soney James (S). Colwyn Bay.
MANNIX, Timothy Patrick (S). Lancaster.
NORMAN, Geoffrey Percy (S). Epsom.
NORMAN, John (S). London, S.W.12.
O'CONNOR, Bartholomew John (S). Dublin.
PITTENDRIGH, Lenus Walter Duff (S). Didcot.
RHODES, Arthur John. Prestwick.
ROGERS, James Albert (S). Brighton.
THOMAS, William Derrick (S). Rutherglen.
WARD, Douglas Arthur (S). London, N.13.
WARD, Michael Marshall. Bournemouth.
WILKINS, Peter Granville. Burghead.

The following candidates have passed Parts I, II and III.

FELTON, Norman Frank. Twickenham.
JARMAN, Richard (S). Hounslow.
O'CONNELL, Terence Francis Kevin (S) London, W.9.

The following candidates have passed Parts I and II.

OGILVY, Harry (S). Leicester.
PALMER, Donald Ridgeway (S). Twickenham.
PUGH, Jonathan Edward Tudor (S). Llanidloes.
TINSEN, Leonard (S). London, S.W.12.
VISSER, Nicolaas (S). London, S.W.2.

The following candidates have passed Part I only.

BAMPFIELD, Geoffrey (S). Huddersfield.
BARTON, Richard (S). Dublin.
FAHY, John Joseph (S). Craughwell.
HARRINGTON, Philip (S). Curragh.
HODGES, Norman Francis (S). Stourport-on-Severn.
McDONNELL, Patrick Joseph (S). Nenagh.
MELINN, Michael Gerard (S). Curragh.
MOLD, Donald Douglas (S). Bingley.
O'BRIEN, Terence Joseph. Dublin.
SIMMONDS, Derek James Charles (S). London, N.8.

The following candidates have passed Part II.

FOSTER, Anthony Charles (S). London, S.E.19.

JAMES-TREVOR, Alexander Prydderch (S). London, W.2.

MURISON, Stanley Chandler (S). Surbiton.

PYNE, Michael. Dublin.

SEK, Stanislaw (S). Trimley Heath.

STRETTON, Arthur Lionel (S). Nottingham.

WILKINSON, Stanley Henry (S). Three Bridges.

WITCHELL, Alfred Reginald Thomas. Loughborough.

The following candidates have passed Part III.

BOND, William Harold (S). Bexhill-on-Sea.

LANGTON, Charles Hazelhurst (S). Stalybridge.

LIGHT, Thomas (S). Rochdale.

MATHEWS, Leonard Frederick (S). Leeds, 6.

MONAHAN, Leo Joseph (S). Dublin.

The following candidates have passed Parts II and III.

BURGESS, Philip Hugh George (S). Christchurch, [Hants.

CLARKE, Donald (S). Attleborough.

COWLIN, Michael Laidlaw (S). Rickmansworth.

DOYLE, Eamon Daly. Dublin.

DUNCAN, Malcolm John (S). London, N.13.

EDWARDS, Ronald Douglas. Bristol, 4.

FLAUM, Ronald Raphael (S). Ilford.

FREUND, Kurt (S). London, N.5.

KING, Kenneth Maurice (S). Exmouth.

PASFIELD, Darrel Edgar (S). Daventry.

PEARSON, Arthur William (S). Salford, 6.

PURDON, Reginald David James (S). London, S.W.2.

REED, Douglas (S). Southport.

WILLIAMS, Kieran Francis (S). Dublin.

The following candidates have passed Parts II, III and IV.

HUDGELL, Ernest John (S). Rainham.

CROW, Stanley George (S). London, N.9.

A further list will be issued when scripts from candidates overseas have been examined.

GRADUATESHIP EXAMINATION, NOVEMBER, 1946

The following candidates were successful in the November, 1946 Examination.

Passed entire examination

WARDALE, Alan Henry. N.S.W. Australia.

Passed Part II

MONAHAN, Leo Joseph. Dublin.

PROCTOR, Anthony Charles. London, N.W.9.

These are in addition to those published in the January/February 1947 issue of the Journal.

THE ALLOUIS (FRANCE) SHORT-WAVE BROADCASTING CENTRE*

by

M. Matricon, D.Sc.†

A Paper prepared for the Institution's Radio Convention held at Bournemouth, May, 1947.

The French Short-Wave Broadcasting Station at Allouis, erected on the territory of Mehun-sur-Yèvre, near Vierzon (Cher) (before the second World War), presented the first high power broadcasting centre of its type.

As early as the beginning of 1945, the French broadcast authorities resolved to erect in the same place a station of similar technical features for overseas broadcasting.

This station, " Allouis O.C. III," is at present in course of completion and is due to be put into operation before the end of the present year.

It is now proposed to give a brief survey of the station and to describe its main features.

I.—The Allouis O.C. III Centre consists substantially of two separate transmitters, each one equipped with its own power supply to ensure its independent operation, and of one spare supply common to both transmitters.

Each transmitter consists of three H.F. chains, any two of which can be connected at will on two independent L.F. chains. Since each group of H.F. and L.F. chains has its own power supply, the station can transmit simultaneously four programmes which can be radiated on four directional aerials which may be selected from among the twelve rhombic antennae provided.

The power output of each transmission varies according to the frequency, but it is never less than 100 kW. on the shortest wavelength and can be raised up to 150 kW. on the 50 m. wavelength. The operating frequencies range from 6 to 21 Mc/s and can be chosen out of 24 fixed frequencies located in the regular broadcasting bands.

The plant is located in a reinforced concrete four-storey building, as follows :

The basement contains the water flow control room, the cable ducts to the ground floor and the heating and air conditioning equipment of the building.

The ground floor contains the heavy equipment needed for controlling, transforming and distributing the primary power, the rectifiers and H.T. filters, the modulating apparatus and the automatic starting and regulating devices.

The intermediate floor houses the hydraulic equipment of the transmitters, such as piping, hose coils, checking units and safety devices, as well as the bias supplies and the cable ducts to the transmitters.

The main floor contains the transmitters, the control desks, the antenna switches and the forming stand for the continuously-evacuated demountable valves.

The building stands in the centre of a plot of several hundred acres over which the twelve rhombic aerials already mentioned are erected.

II.—Electric power is provided from a transformer substation at a distance of one kilometre from the transmitter building : two overhead incoming lines operating at 90,000 and 30,000 V. respectively, are provided.

From the sub-station two separate three-phase cables

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* U.D.C. No. 621. 396. 712 (44) Manuscript received March, 1947.
† Compagnie Française Thomson-Houston.

(one as spare) carry to the transmitter an overall power of 2,600 kVA. at 5,500 V.

A transformer unit, located within the building, feeds:

Through a 380 V. circuit, the transmitter auxiliary circuits, pumps, filament transformers, bias and intermediate voltage supplies, servomotors, signal lamp circuits, etc. The available power is 500 KVA. from two units, each corresponding to one group of transmitters.

Through a 200/115 V. circuit, the Centre auxiliary services (heating and air conditioning, workshop lighting, etc.) as well as a few special circuits (forming stations, diffusion pumps for evacuating the demountable valves, water distiller, etc.). The available power is 225 kVA.; sufficient to feed the whole of the station 115/200 V. circuits.

The apparatus comprising the above transformer unit (transformers, switches, oil circuit breakers) are provided in duplicate and the L.V. circuits are connected to suitable power boards, viz.: one 380 V. board and one 115/200 V. board containing the sets of switches, contactors and measuring apparatus related to the low voltage input circuits of the transformers and the outgoing feeders. A mercury vapour rectifier, supplying 75 Amp. at 115 V. is provided for the D.C. circuits and the automatic control circuits of the transmitters.

In case of a failure in the H.V. mains, the emergency lighting circuits and the diffusion pumps are fed from a generating set consisting of: one 30 H.P. petrol engine; one 19 kVA. 115/200 V. 3-phase alternator, with an automatic starting device, and a normal-to-emergency automatic switching device.

The design is such that the circuits concerned are fed from the emergency set less than 30 seconds after interruption of the mains voltage.

The rectifiers supplying high voltage D.C. to the power stages are directly fed from the incoming voltage of 5,500. They are 350 kW. units, each equipped with three grid-controlled mercury pool bulbs, which can supply 12,500 V. at 36 Amp. These rectifiers feed directly at 12,500 V. the intermediate stages and the H.F. and L.F. power stages. A 4,000 V. supply is tapped off the first bulb to feed directly or through voltage dividers the 1 kW. H.F. stages as well as the intermediate and sub-modulator L.F. stages.

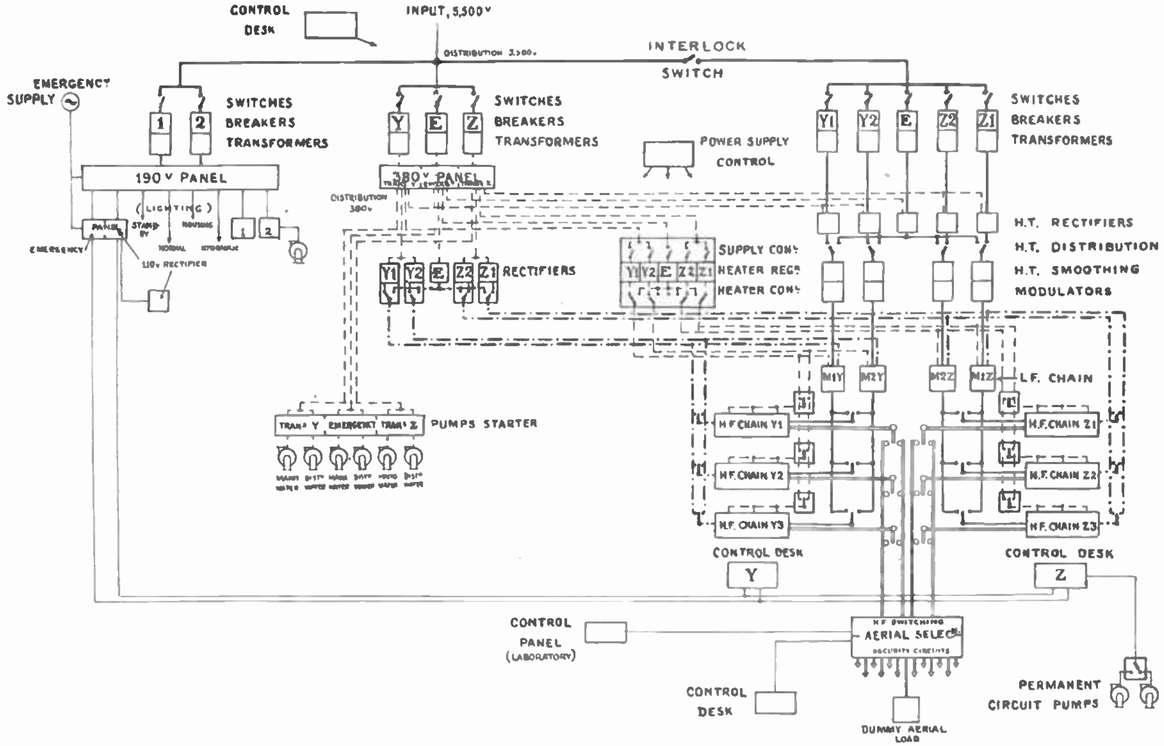

Fig. 1.—General arrangement of station.

Each of these rectifiers comprises: one H.V. 3-phase oil-cooled transformer; one metal cabinet containing the three rectifying bulbs and auxiliaries; one set of switches and safety devices for changing over from the normal rectifier to the emergency rectifier.

The transformers are fitted with taps to adjust the D.C. voltage to the optimum value and the rectified voltage is varied through the action of the control grids, which are also used for D.C. cut-off in case of a current surge.

The protecting device includes an arrangement which, in case of a surge of short duration (such as, for instance, a " Rocky point " discharge) re-applies automatically and progressively the voltage after cutting off, but without operating the H.V. circuit breaker. However, the latter is actuated after three successive operations of the voltage re-application device.

There are five of the above rectifiers, four being allotted to the L.F. chains (one for each chain). The fifth is used as a spare for any of the other four. Such an arrangement is generally provided for all the power supplies in the station. In the case of the filament heating supplies no spares are provided in the individual units. These contain as many filament transformers as there are valves in position. When an L.F. modulating chain is switched from one H.F. chain to the other, the change-over is effected on the relatively low-current circuits feeding the primaries of the filament transformers.

The primary voltages of these filament transformers are automatically regulated through induction regulators controlled by voltmetric balances. Thus, the filament voltages are kept constant within ± 1 %, even for variations in the mains voltage of up to ± 12%. The power taken for heating the filaments of a chain is about 60 kVA.

The application of voltage to the filaments is effected progressively through resistors inserted in the primary feed of the filament transformers. Heating is started for the whole chain at once and the voltage build-up is accomplished by short-circuiting the above resistors through contactors controlled by servomotors.

There are five starting devices, that is, one for each chain and one kept as spare.

The other power supplies (bias, anode and screen voltages for the small stages) consist of natural-cooling dry rectifiers. These are of ample dimensions so as to give very long service.

III.—The heat dissipated in the water-cooled valves and power circuits is disposed of through a double hydraulic circuit.

In the first circuit, distilled water flows through the water jackets of the transmitting valves and the H.F. inductances of the power stages, for dispersing the heat dissipated in those elements to a heat transfer unit.

In the second circuit, raw water from the outdoor pools is passed through the transfer units. The heat thus collected is dissipated by spraying the water into the air through nozzles situated above the outdoor pools.

The hydraulic plant consists of:

(*a*) The water flow control room, containing in triplicate (one for each transmitter and one spare):

One 10 cu.m. distilled water tank.

A motor-driven pump for distilled water (output 65 cu.m. per hour).

One 2 cu.m. ballast tank, to prevent the sudden

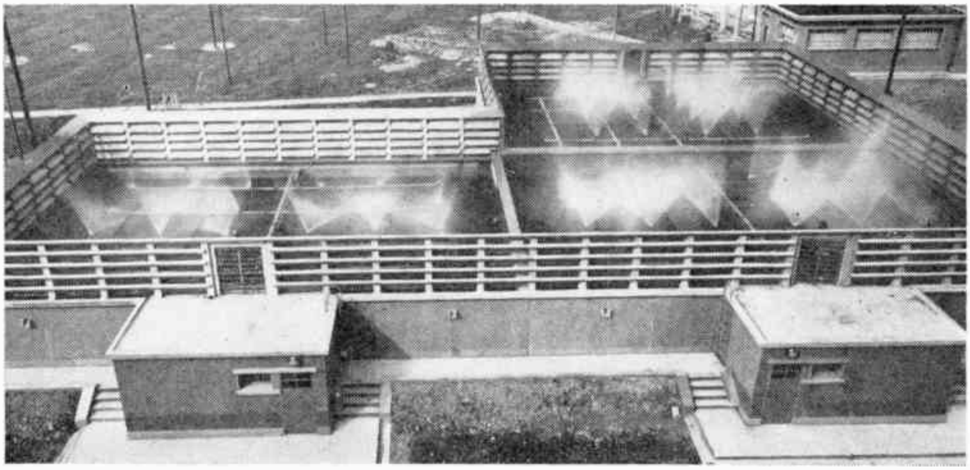

Fig. 2.—Outdoor refrigerating pools.

stoppage of the circulating water in case the pump fails to operate.

One 500,000 calories per hour heat transfer unit.

A motor-driven pump for raw water (output 130 cu.m. per hour).

(*b*) The water equipment of each transmitter, including :

Twin tube ceramic insulating coils.

Water flow control and safety units.

System of pipes and valves.

Permanent refrigerating circuit for cooling the diffusion pumps used for evacuating the demountable valves. This circuit includes ;

Two distilled water pumps (output 5 cu.m. per hour) (one in use and one spare).

One 1 cu.m. tank.

(*c*) Electrically heated distiller with an output of 60 lit. per hour.

Outdoor cooling pools, with nozzles.

Pumping station, which is at a distance of two Km. from the Broadcasting Station site. It is fitted with a water softening plant.

The control and safety units consist of the following :

Water flow : One direct reading measuring instrument and one waterflow failure relay on every valve or set of series-fed valves. These relays operate an alarm signal and after a given interval they shut off the transmitter when the waterflow falls below three-quarters of the normal value.

Temperature : One direct reading instrument on the main incoming and on the main outgoing pipes of each transmitter, and one waterflow failure relay on every valve or set of series-fed valves.

Pressure : One direct reading pressure gauge on the distilled water main pipe of each transmitter.

The above equipment is supplemented by signalling boards fitted with signal lights corresponding to the flow and temperature relays, thus making it possible to locate failures quickly.

IV.—The modulation process used is straightforward anode control of H.F. power stages. Each of the four L.F. chains receives the modulating signals from a speech input panel, where the cables from the modulating centre in Paris terminate. The input unit comprises the line amplifiers, equalizers and limiters, through which the modulating signals at the input of the transmitters are adjusted to a definite level.

The unit comprises also the instruments for checking the radiated power.

The remaining stages in each chain include substantially :

An input amplifier.

One intermediate amplifier.

A sub-modulator stage equipped with water cooled valves.

One modulator stage or L.F. power stage, which feeds, through a modulation transformer, a circuit including inductance and capacity and inserted in the High Voltage feed to the H.F. power stage.

The modulator is arranged to operate in class B, therefore with a high efficiency. It is equipped with a pair of TH 104 3-phase filament valves.

Heating all filaments in the transmitter on raw alternating current involves a fairly high background noise as the unavoidable consequence of the magnetron effect. To obtain a high quality modulation in spite of the heavy distortion incurred when the operating point of the valves is adjusted for economical operation and in spite of the background noise caused by alternating current heating, a very high degree of negative feed-back is necessary.

In the present case the negative feed-back circuit which involves all the H.F. and L.F. stages is set to a feed back ratio of 20 db. This brings the background noise down to acceptable values.

The background noise level, referred to the 100 per cent. level at 1,000 c.p.s., is :

—55 db. without psophometric filter,

—70 db. with psophometric filter.

Besides its effect on the background noise, the special negative feed back circuit adopted also reduces the harmonic distortion and the differential distortion which is so objectionable when broadcasting orchestral music. All such arrangements, which are systematically applied in the various stages of the transmitters, are conducive to a high quality modulation over the whole range of amplitude and frequency values universally acknowledged as useful in broadcasting technique.

Within such range, as limited by the points shown on the curve, the amplitude response is constant within ± 0.5 db and the level of non-linear distortion is less than 2 per cent. within the whole audible band 30—5,000 c.p.s.

V.—In each of the transmitters, three H.F. chains are assigned as follows to the broadcasting frequency bands :

1st chain	21 and 17 Mc/s.
2nd chain	15, 11 and 9 Mc/s.
3rd chain	9, 7 and 6 Mc/s.

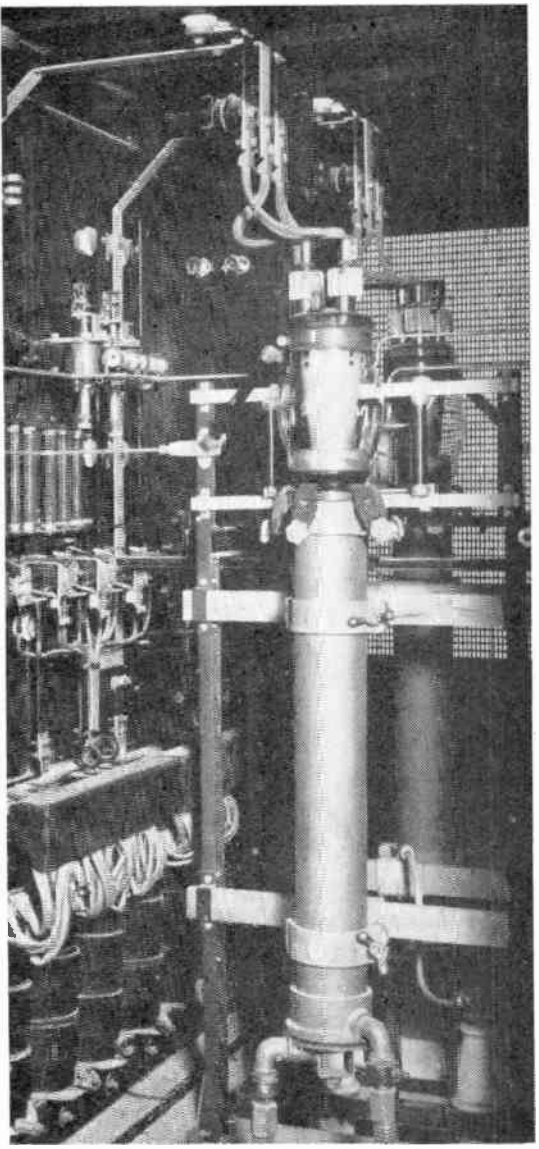

Fig. 3.—View of a modulator.

Also, each group of transmitters can radiate 12 crystal stabilized frequencies.

Viz.:	1st chain	3 frequencies.
	2nd chain	6 frequencies.
	3rd chain	3 frequencies.

Each frequency is generated by a crystal-controlled pilot, permanently fed from its own power supply, comprising: oscillator, thermostat, separator and frequency doubler and amplifier.

Three emergency self oscillators (one for each H.F. chain) allow, in case either of failure of a crystal or of transmission on an unforeseen frequency, operation of those chains on any frequency within the assigned bands.

There are, therefore, for the whole station 24 crystal stabilized pilots and 6 self oscillators with 30 power supplies. These elements are enclosed in two desk-shaped casings and any pilot can be switched on the required H.F. chain through hand operated switches.

Every care has been taken to give the transmission a very high frequency stability (1 in 10^6).

The remaining stages in each chain comprise in succession:

Another frequency doubler, one 1 kW. amplifier, one 10 kW. amplifier or intermediate stage, equipped with water cooled valves, and a power stage equipped with a set of two TH 304 continuously evacuated demountable valves.

The power stage occupies two sections of the transmitter housing: one section contains the triodes on their trolley, the grid circuit and the neutrodyne capacitors, the other contains the anode oscillating circuits and the coupling elements to the outgoing feeders. These circuits consist of balanced inductors (made of twin tube through which flows the cooling water of the transmitting valves), and of tuning, also symmetrical with respect to earth. The inductances are adjusted step by step: accurate tuning is made through adjustment of the capacitors.

The anode circuit is coupled to the outgoing feeder through an inductive loop which is an element of an impedance matching circuit. The characteristic impedance of that part of the feeders which is within the buildings is 450 ohms.

All the controls which have to be adjusted when changing the transmission frequency are brought out to the front of the unit and the meters are located above them, even if they are related to stages located on the rear of the unit.

The necessary by-passing circuits are, of course provided.

Through a broad glazed window, the operator is enabled to check by sight the motion of the elements operated in the power circuit enclosure.

As everywhere else in the transmitter, an efficient interlocking system, in which mechanical means only are used, prevents access into the units where second class voltages are present as long as those voltages are not cut off and any leads which might remain energized after cutting off are not properly earthed. Once the safety precautions are secured the gates can be unlocked and access is made possible.

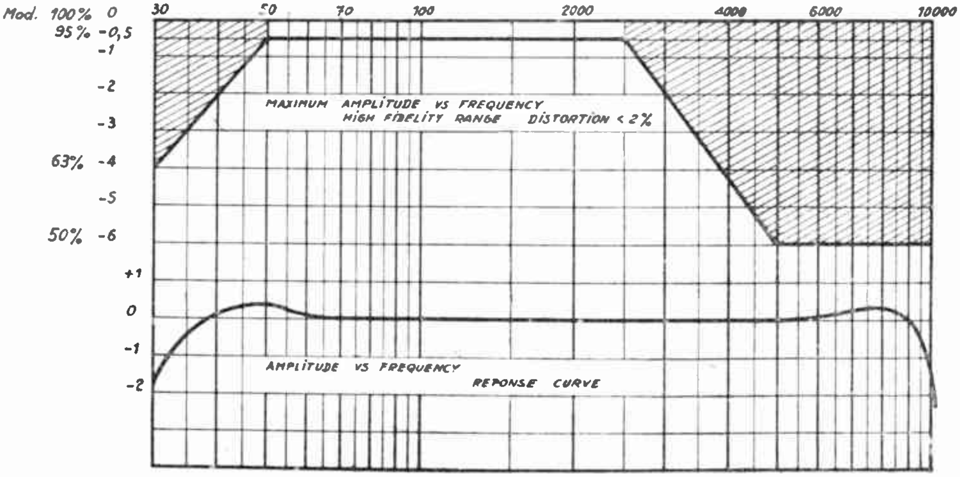

Fig. 4.—Schematic curve of the amplitude-frequency response.

VI.—The TH 304 valves mounted on the H.F. power stages are of the continuously evacuated demountable type.

These transmitting valves, as they appear on the schematic sectional view, comprise the following parts from bottom to top :

(1) One translucent fused silica tubular element, also used for connection to the pumps.
(2) An anode consisting of a copper tube held between flanges which carry connectors for the inlet and outlet of the cooling water.
(3) A translucent fused silica tubular insulator, to ensure continuity of the vacuum enclosure between anode and grid.
(4) Copper rings, used as grid supports.
(5) One translucent fused silica annular tube, used as insulator and cathode support.
(6) Copper elements, used as cathode supports and leads for filament heating current.
(7) The inside parts of the valve : cathode, grid, various screens to shield the insulators against thermal radiation from the cathode and metal deposits.

The general dimensions of the transmitting valves are determined by the electro-technical considerations which define the structure : grid, cathode, anode ; by electrical considerations relating to insulation spacing, dielectric losses and current density and by mechanical and thermal considerations, concerning the setting together of elements, the vacuum tightness and the disposal of the dissipated heat.

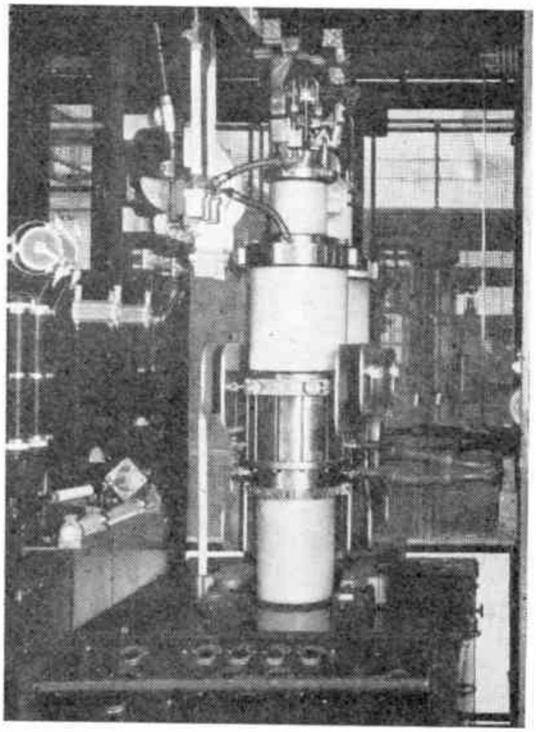

Fig. 5.—View of the triode cubicle in the power stage.

The size of the insulator which separates the anode from the grid support on the outside, depends upon the voltage normally applied in the modulation crest between those two electrodes.

It is necessary, if tuning is to be made easy, that the potential of the grid terminal should not differ appreciably from that of the grid itself. This makes it imperative that the inductance of the connection between the grid proper and the grid terminal be kept as low as practicable. Therefore, the active part of the grid must start as close to its outer support as possible : this has made the use of a re-entrant anode necessary, part of which is made as an appendage protruding within the grid support insulator. Such an arrangement is not easily made vacuum tight and it could be successfully performed only because in a demountable valve it is not necessary at the start to de-gas the anode by raising its temperature to a high value ; the various parts could therefore be set together by soldering. Until the time has come to put the valve in operation, the anode is not submitted to heating, which might impair the soldered joints. Obviously, in a sealed valve, such an arrangement would present difficult problems.

Figure 7 shows the parts of a demountable valve, excepting the active parts of the filament and grid. The anode is shown twice : on the left, with the water jacket ; on the right, after the water jacket has been removed.

The pumping equipment is set together on a trolley, which is used also as a support for the valves. The trolley is movable so that a set can be quickly taken out when out of order, for instance as a consequence of one valve cathode being worn out. A spare trolley with valves ready to operate can be immediately substituted.

The pumping unit consists of the following equipment :

One rotating pump automatically started by a vacuum measuring apparatus. The pump brings the pressure down to about 10^{-2} mm. Hg.

A mercury vapour diffusion pump, bringing the pressure down to a negligible value as compared with the mercury vapour tension, which is 10^{-3} mm. Hg. This pump operates even under a primary back pressure of say 15 mm. Hg. : this emphasizes the very high safety margin provided when compared with the pressure normally obtained from the rotating pump.

This mercury vapour pump effects the preliminary vacuum necessary to the successful operation of an oil diffusion pump which evacuates directly the transmitting valves.

An ionisation micromanometer gives a permanent indication of the pressure in the pipe connecting the valves to the pumps.

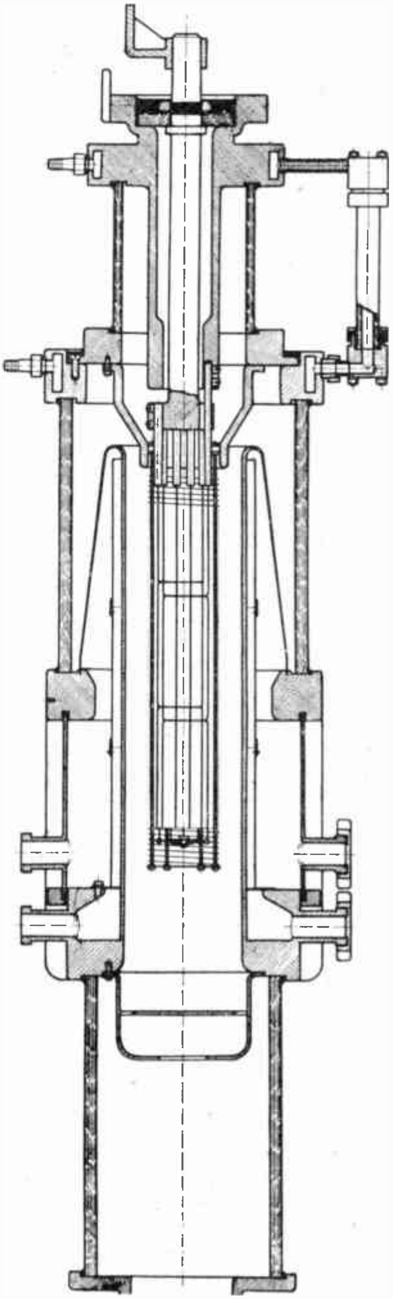

Fig. 6.—Schematic section through a high power demountable triode valve.

The whole system operates under control of relays which afford numerous checks and control the safety devices which check on the vacuum, the flow of cooling water and the heating voltages.

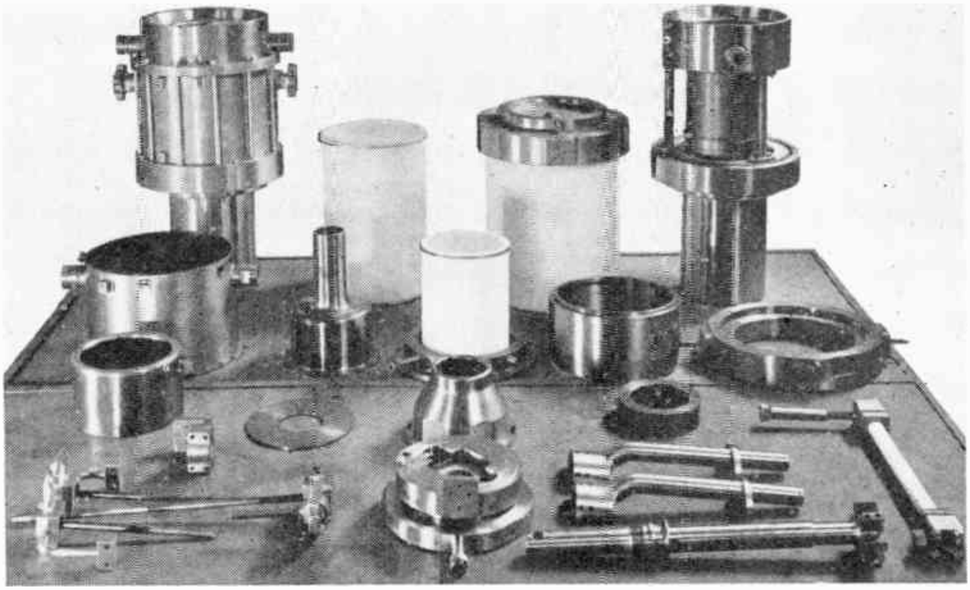

Fig. 7. — The component parts of a demountable triode valve.

The station with its six H.F. chains permanently ready to operate comprises six trolleys, each carrying a pair of demountable valves. Also, to meet any operating emergency, two forming stands (one for each transmitter) are provided. These stands are enclosed in wire net cubicles, each containing the following equipment :

Two 3-phase triode filament transformers, with their servomotor driven induction regulator to raise progressively the filament voltage.

One 17,000 V. single-phase oil cooled transformer, to supply anode current, with its servomotor driven induction regulator.

A trolley with the pair of TH 304 triodes to be formed.

An oscillating circuit for the dynamic formation of the triode valves.

A system of water pipes and H.F. leads.

A power board with the devices for application of tension, control adjustment and safety.

Thus, two spares trolleys, ready to operate, are available at any time in the station. A maintenance and repair workshop is also provided.

VII.—Twelve directional rhombic antennae are distributed over the ground according to the desired directions of radiation.

The connection to these aerials raised a switching problem in the solution of which the following requirements had to be considered :

Four transmissions should be operated simultaneously and it should be possible to direct each transmission on any of the aerials.

Operation should be thoroughly automatic and controlled from the central desk.

It should also be possible to operate the switches by hand from a place outside the high voltage cubicles.

During a transmission, it should be possible to switch the other three transmissions on any of the idle aerials, without stopping the transmission in progress.

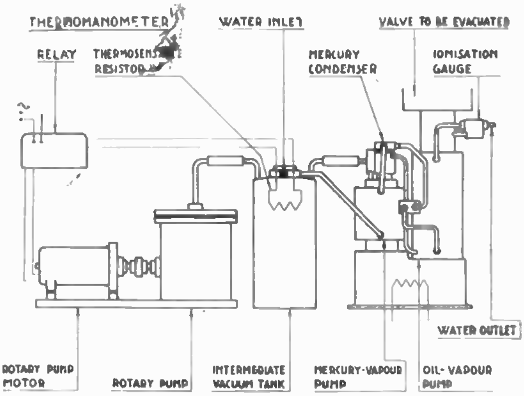

Fig. 8.—Diagram of a pumping set.

The switching arrangement ought to cause as little impedance irregularity on the transmission lines as possible, so that the variation of the standing wave ratio be less than 10 per cent. Again, the interaction between feeders should be as small as possible.

Here are the arrangements adopted to meet these requirements :

The switching pattern uses only double-throw switches, except for the selection of chains.

These switches are controlled through servomotors of the railway signal type.

Control of the servomotors is centralised on a desk with lighted synoptical diagram, which reproduces the basic pattern.

The operations effected are reproduced on a signal lamp wall board, which includes a synoptical diagram for checking.

The servomotors are duplicated with band controls operating directly on the line switches.

The switches are of a special design ; they are mounted on steatite insulation and are arranged to add very few angles in the lines.

Switching is effected through a system of four indoor feeders of 450 ohms characteristic impedance, enclosed in screening ducts and used as " bus bars." These bars run round the transmitter room.

The operation of the switching arrangement is firstly to connect a bar to a transmitter, and next to connect on the bar the transmission line leading to the selected aerial. Operation is as follows :

The operator designs on the desk the pattern to be effected by conveniently placing the switches, figured by connecting links ; a number of signal lamps are lighted, on the desk as well as on the boards above the elements to be controlled. The control circuits of the corresponding servo-motors are then closed.

After the operations are concluded and the servomotors have come again to rest, all signal lamps must be out, except those showing the aerial or aerials on duty.

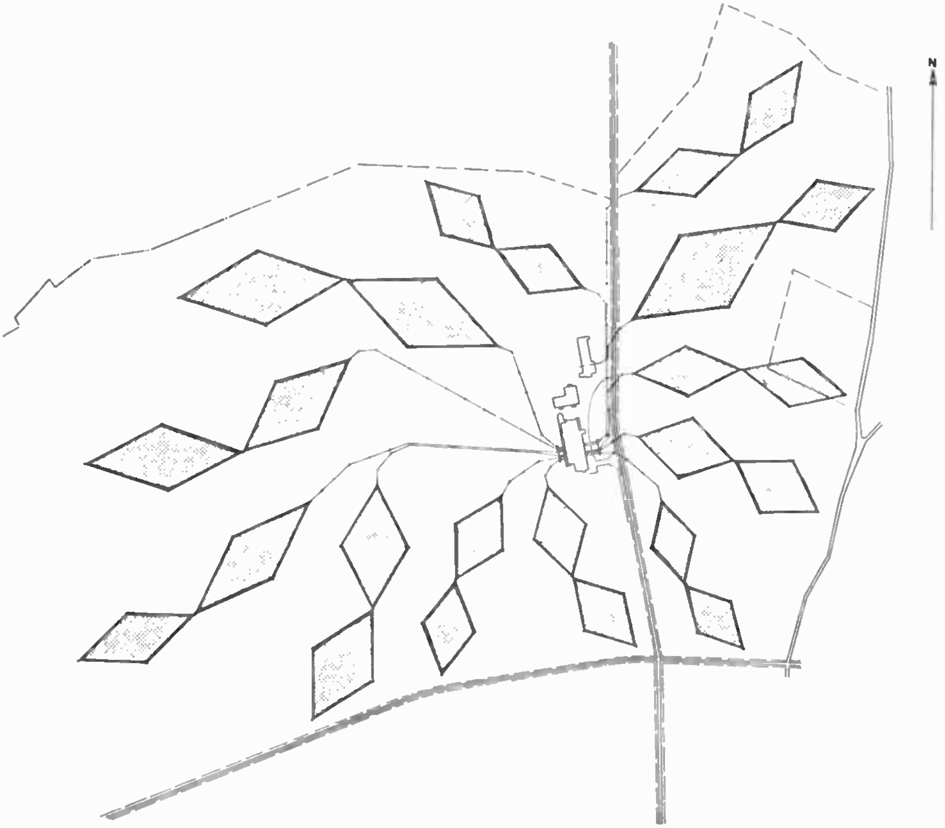

Fig. 9.—Schematic arrangement of aerials round the building.

Should the operation be made by hand, the operator must turn such handles situated on the line ducts as correspond to a lighted lamp until the lamp is extinguished. When all lamps are off, one may be sure that all the feeder switches are in the position chosen according to the pattern showing on the control desk. For checking purposes, the pattern is reproduced at a large scale on the wall board.

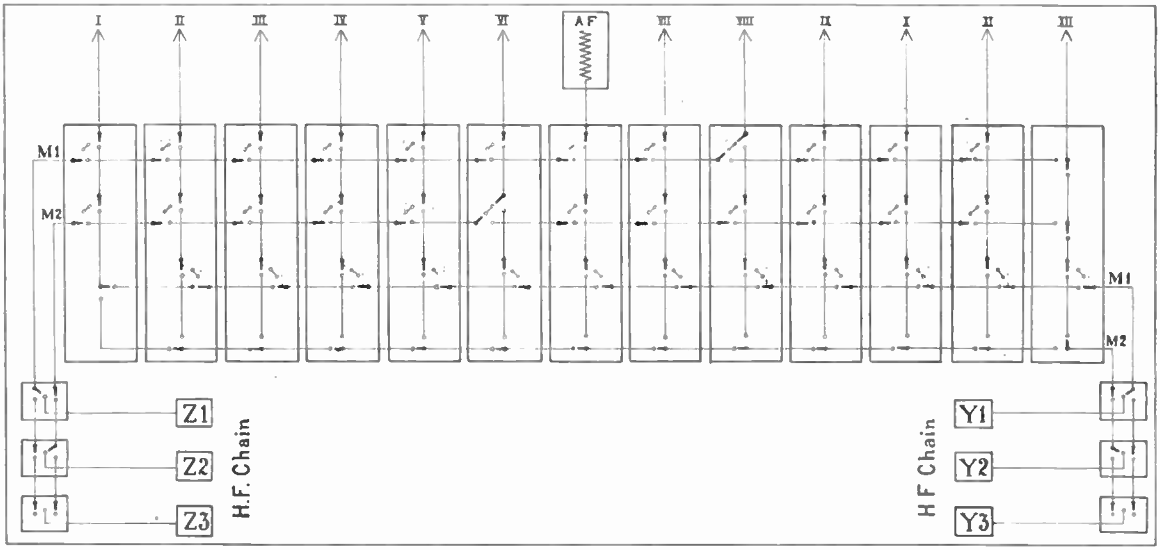

Fig. 10.—Pattern of antenna switching.

The outdoor lines to the rhombic aerials are two wire overhead lines of 600 ohms characteristic impedance. They consist of 4 mm. wires, 450 mm. apart. Matching between these lines and the indoor lines of 450 ohms impedance, is effected through two wire delta-shaped lines with progressively varied spacing. The length of these lines is less than 50 m. and matching is effected for all values of input impedance of the aerial lines comprised between 440 and 870 ohms in modulus and ± 20° in argument.

The design provides for a dummy antenna built to dissipate 200 kW. and which may be connected to any H.F. chain. This antenna is enclosed in a wire net cubicle and comprises :

A water cooled resistor, one set of matching inductors and capacitor, and a control and checking panel, including a water flow-meter and an accurate thermometer.

NOTICES

Obituaries

The Council records with deep regret the death, after a long illness, of Arthur William Cragg (Associate), of Stockwell, London.

Mr. Cragg was elected an Associate of the Institution in July, 1941, and for some time before his death he had been seriously ill in a sanatorium. He died at the early age of 30 years.

The Council also regret to learn of the death of Major Henry Hepburn Heath (Associate Member), of Tonbridge, Kent.

Major Heath was elected an Associate Member in November, 1943, whilst serving as a regular officer in the Royal Regiment of Artillery. In 1940, he installed the first army radiolocation equipment to be used in Malta and on his return to England became Chief Instructor of a Division under Major-General Archibald, M.C.

At the time of his death, Major Heath was only 32 years of age.

Library

It is proposed to issue a Library Bulletin once a month giving the latest book additions, the titles of articles in Journals received, and news of the Library generally.

This Bulletin will only be sent to those members who are interested, and any member wishing to receive it regularly should advise the Librarian as soon as possible, giving name, address and membership grade.

Use of the Metric System in Technical Papers

During the session of the Royal Society Empire Scientific Conference held last July, which was devoted to the consideration of greater uniformity in standards of measurement, the following resolution was adopted:

> "If textbooks and scientific data or memoirs are expressed in systems other than the metric, conversion factors or the metric equivalent should be included."

The object which it was intended to achieve by the resolution was to make British scientific papers more intelligible to those overseas readers who are only familiar with the metric system.

A joint memorandum on this subject has been addressed to the Institution by the Royal Society, The British Association for the Advancement of Science, The British Standards Institution, and The Department of Scientific and Industrial Research.

It is intended, as far as possible, to implement the resolution in reports of D.S.I.R. work published through H.M. Stationery Office, either by giving the metric equivalents of data expressed in British units or by the provision of a table of conversion factors. The Royal Society is also proposing to implement the resolution in its own publications.

The Institution has been invited to appoint representatives to attend a meeting to discuss any points of difficulty arising and to work out a uniform system which can be recommended to all publishers, journals and textbooks.

Elections and Transfers to Membership

Limited space in the Journal has prevented publication of the lists subsequent to June 3rd, 1947, but a list, up-to-date to September 1st, will be published in the October Journal.

Year Book

As stated in the Annual Report, work on the compilation of the Year Book has commenced and, subject to availability of paper, it is hoped to be able to publish a revised Year Book at the beginning of next year. The work of the Publications Officer will be greatly eased by members returning, as quickly as possible, the form for inclusion in the Year Book, which accompanies this Journal.

Institution Section Meetings

Complete details of the various Section Meetings are not yet available, but as soon as all arrangements have been completed, they will be published in the Journal.

Meanwhile, the new Session of the London Section will, of course, be inaugurated by the Annual General Meeting at the London School of Hygiene and Tropical Medicine, Keppel Street, W.C.1, and will be followed by a Paper, "*The Applications of Crystal Rectifiers at Frequencies up to* 10,000 *Mc/s*," read by Mr. J. H. Evans (Associate Member).

At the November meeting of the London Section, Mr. G. L. Hamburger (Member) will read his Paper, *An Automatic Frequency Response Curve Tracer*. It will be remembered that Mr. Hamburger read the first part of this Paper before the Institution's Radio Convention in May, but on November 13th, 1947, the completed paper, i.e., parts 1 and 2, will be given.

As usual, all London Section Meetings will commence at 6.0 p.m.

A new Provincial Section has been formed to serve the Liverpool area and will be known as the Merseyside Section. The meetings will be held at rooms of The Liverpool Engineering Society, 9, The Temple, 24, Dale Street, Liverpool, 2. The Secretary is Mr. J. Gledhill, B.Sc., A.M.Brit.I.R.E., 123, Portelet Road, Liverpool, 13.

Meetings of this new Section have been fixed for November 12th and December 10th, 1947 and January 7th, February 18th, March 17th, April 14th and May 12th, 1948. Details of Papers to be read will be announced later.

A ONE KILOWATT V.H.F. FREQUENCY MODULATED TRANSMITTER*

by

J. B. Lovell Foot†

A Paper read before the Institution's Radio Convention held at Bournemouth, May, 1947.

CONTENTS

INTRODUCTION.

For the past ten years there has been increasing activity in the V.H.F. field. Communication transmitters are now extensively used in police installations operating in the allotted bands between 78 Mc/s and 100 Mc/s. These are chiefly anode modulated and operate with a power of about 100 watts for the H.Q. station and 10 watts for the mobile transmitter.

The audio characteristic of a set for this purpose is designed to give a maximum intelligibility on speech; the modulator is limited in frequency response and would therefore be unsuitable for the transmission of broadcast programme material. This paper deals with the first of a new range of transmitters now under development for high fidelity broadcast use. The experience gained from the development of Police equipment has been of value in the present designs.

The bandwidth required for high fidelity broadcasting on A.M. is about 30 kc/s: this is difficult to obtain in the overcrowded medium and high frequency ranges without considerable interference, and for this reason V.H.F. transmissions are coming into use for this purpose.

Bandwidths of about 200 kc/s allow high deviation ratio F.M. systems to be used, this is possible on V.H.F., and the advantage of low background noise peculiar to this system can be gained.

The transmitter described is an F.M. set, the deviation ratio is 5 and the power output to the aerial is 1 kW.

The requirements of the transmitter can be summarised as follows :—

(*a*) Good centre frequency stability.
(*b*) High fidelity of audio response with a good signal-to-noise ratio.
(*c*) A ready means of monitoring, including a certain knowledge of the extent of deviation.

Added to these there are, of course, the requirements for all similar apparatus :—

(*d*) Good reliability.
(*e*) High overall efficiency.
(*f*) Ease of handling and servicing.
(*g*) Compactness, with pleasing appearance.

(2) LAYOUT OF TRANSMITTER.

The illustration, Fig. 1, shows the general appearance of the transmitter. The cabinet is 6 ft. 6 ins. high by 3 ft. wide and 2 ft. 3 ins. deep.

Physically the set is divided into three parts :—

The bottom portion houses the "Power Supply Unit."

The middle portion contains the modulation, low power driver, monitoring and calibrating section. (For the sake of brevity this is subsequently referred to as the "Driver Unit.")

The top portion contains the last two stages of frequency doubling and the Power Amplifier Stage, which will be termed the "P.A. Unit."

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*U.D.C. No. 621.396. 619.13. 029.6 Manuscript received April, 1947.

†The Research Laboratories of the General Electric Co., Ltd., Wembley, England.

The driver and P.A. units are fitted on runners and can be readily withdrawn from the front for servicing. Although the back and side plates are detachable, all normal servicing can be carried out from the front and the cabinet may be placed against a wall or close to other apparatus.

Casters are fitted at the bottom and means are provided for taking the weight off these after the set is installed.

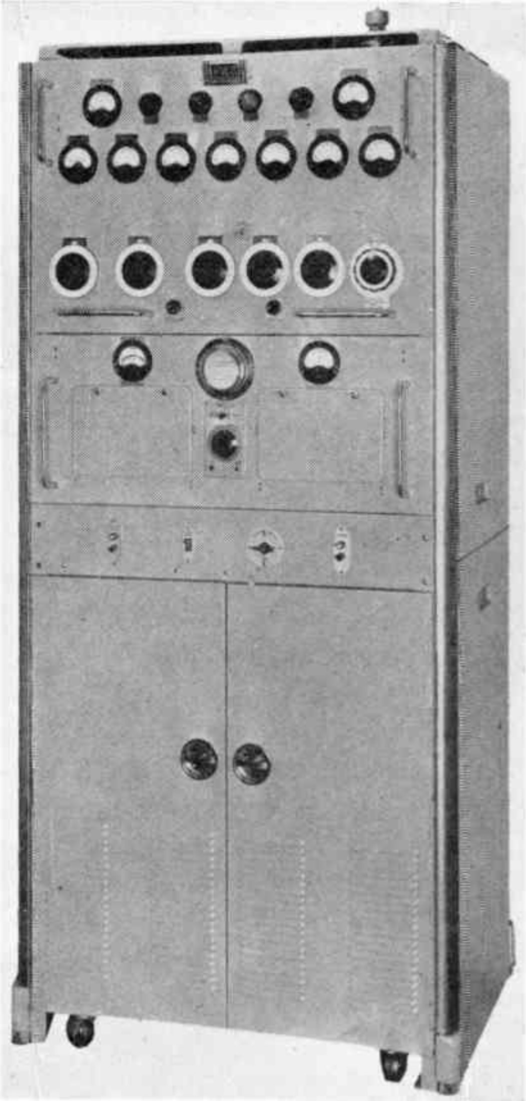

Fig. 1.—General appearance of the transmitter.

The driver and P.A. units are locked into position and can be released by a simple mechanism operated from behind the power unit doors.

(3) THE POWER SUPPLY UNIT.

Illustration Fig. 2 shows the set with the power unit doors open and the driver and P.A. units partly withdrawn.

The power equipment is completely enclosed in a box. All fuses and interconnection leads are attached to the front plate. The top plate, rear and side plates of the box are easily detachable and their removal exposes the contactors, transformers, rectifiers, smoothing circuits, a blower and other associated components. This includes a heating element for use when the transmitter is operated in a humid atmosphere. It comes into action when the transmitter is shut down, and prevents condensation by keeping the internal temperature a little above the ambient temperature.

The power unit is not dealt with in detail as this follows normal practice.

The input is three-phase 400 V. 50 c/s. and the overall power required for 1 kW. R.F. output is about 4.5 kW.

The main H.T. is 2,800 volts ; this is supplied from a three-phase bridge rectifier. As the ripple amplitude is low and the frequency high with this circuit, considerable economy in the size of smoothing components is obtained.

The lower voltage transformers which supply H.T. to the driver unit are fed from a voltage stabilising transformer. All rectifiers are of the selenium type.

Push button switches for operating the contactors and a star-delta switch for providing low-high power are situated on a strip above the power unit doors. Interlocking makes it impossible to switch direct to high power. The operator is therefore given the opportunity of seeing that the transmitter is correctly tuned in the low power position each time the set is switched on.

(3.1) The Cooling System.

The valves employed in the P.A. unit require forced air cooling. This is provided by an impeller type blower situated in the power unit box. Air is sucked into this box through two air filters, which are readily detachable for cleaning and can be seen mounted in the space behind the power unit doors. The incoming air serves to cool the power unit components and is then driven via trunking to a box on the underside of the P.A. unit tray. From here it is distributed to the valve anodes and exhausts at the top of the cabinet.

An air pressure safety contact interlocks with the power supply, since filaments and H.T. must not be

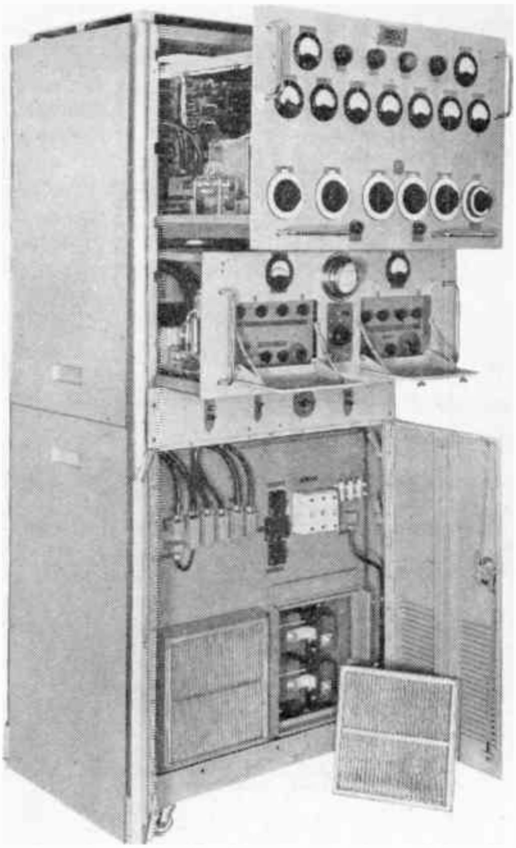

Fig. 2.—The transmitter, showing interiors of power supply, driver and P.A. units.

applied unless air flow is sufficient to keep the anode temperature below 140°C. An air pressure meter is also provided to give an indication of the extent of dust clogging in the air filters. A sliding joint in the air trunking allows the P.A. unit to be withdrawn.

(4) PERFORMANCE.

Before describing the driver unit a brief note on performance is necessary.

The transmitter is designed for operation on frequencies up to 100 Mc/s. The details given later apply to a particular case where the transmitter was set up for use on 90 Mc/s., with provision for use on 45 Mc/s. by cutting out one stage of frequency multiplication. The frequency deviation representing 100% modulation is ± 75 kc/s. This applies to both 90 and 45 Mc/s. operation.

Pre-emphasis or linear audio characteristics are available. In the first case, a choice of two time constant circuits is provided. These are 50 μ sec. advocated by H. L. Kirke, of the B.B.C.[*] or 75 μ sec. in use in America. In the case of the " flat " characteristic a frequency range of 30 c/s. to 15 kc/s. is obtained within 0.5 db.

The use of pre-emphasis is to provide a better signal to noise ratio for an overall system. As there is a uniform distribution of noise over the R.F. pass band of the receiver, there will be an unequal distribution of noise after discrimination in the audio output. The noise output at any particular audio frequency is proportional to that frequency. It is therefore desirable to de-emphasise the high frequencies relative to the low frequencies at the receiver end and to apply pre-emphasis at the transmitter to restore overall uniformity of frequency response. Since the maximum peak amplitudes on programme usually occur in the speech frequency range a certain degree of pre-emphasis is possible without the need for reducing the average modulation. This is discussed in Kirke's paper.

Frequency stability will be dealt with under the heading of centre frequency control, but it should be pointed out here that a high standard is required. The F.C.C. specification allows only ± 2 kc/s., i.e., 1 part in 45,000 at 90 Mc/s.

(5) THE DRIVER UNIT.

The physical arrangement of the Driver Unit can be seen in the illustration Fig. 2. The chassis is arranged in two parts with controls requiring infrequent adjustment mounted behind the two drop doors.

A cathode ray oscilloscope forming part of a monitor is placed in the middle of the panel.

All components liable to be affected by vibration are in the left-hand section which is anti-vibration mounted.

In a station where it is desired to use the driver unit in a control room separated from the main transmitter (supposing the 1 kW. set forms only a part of a higher power transmitter) this could be done with only a small amount of modification. The self-contained nature of the driver unit will be apparent.

Electrically the driver unit consists of three main sections. These are :

(*a*) The modulation and R.F. stages that subsequently drive the P.A. unit.

(*b*) The centre frequency control circuit.

(*c*) The modulation monitoring circuit with cathode ray oscilloscope.

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[*] H. L. Kirke—" Frequency Modulation: B.B.C. Field Trials "—B.B.C. Quarterly, July, 1946.

A method is provided in this section for calibrating the monitor, so that it will accurately indicate modulation amplitude (deviation).

(5.1) Modulation and R.F. Stages.

The Modulation and R.F. Stages are shown in block form in Fig. 3. These consist of a push-pull modulation amplifier with gain control feeding a push-pull reactance modulator. The latter forms a part of the master-oscillator frequency determining circuit, and causes the oscillator to deviate from its mean frequency by an amount proportional to the voltage applied to the reactance modulator valve grids.

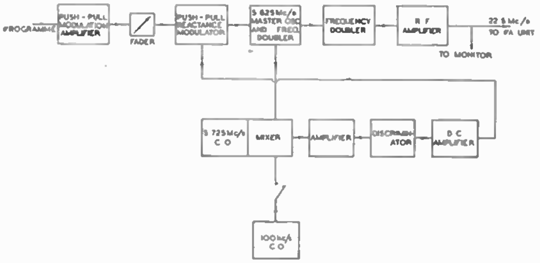

Fig. 3.—Block diagram of the driver unit modulation and drive channel (top section), centre frequency control (bottom section).

The master-oscillator has a mean frequency of 1/16 of the final frequency (when this is 90 Mc/s.) or 5.625 Mc/s. The deviation for 100% modulation at the oscillator frequency is $\pm \frac{75}{16}$ kc/s. = about ± 4.7 kc/s. This becomes ± 9.4 kc/s. when the transmitter is required to operate at 45 Mc/s.

Frequency doubling is carried out in the anode circuit of the oscillator, which in turn drives a frequency doubler followed by an amplifier.

The amplifier forms the final stage of the driver unit and feeds out at 22.5 Mc/s. to further frequency doublers in the P.A. unit. A 75 Ω concentric feeder connects the two units together and the power level at this point is about 10 watts.

(5.2) The Centre Frequency Control Circuit.

Since the frequency of the master-oscillator is required to deviate from a mean value up to ± 9.4 kc/s. a direct method of crystal control would become complicated.

The simplest direct method of crystal control involves phase modulating a crystal oscillator and then frequency multiplying until the required deviation is obtained.

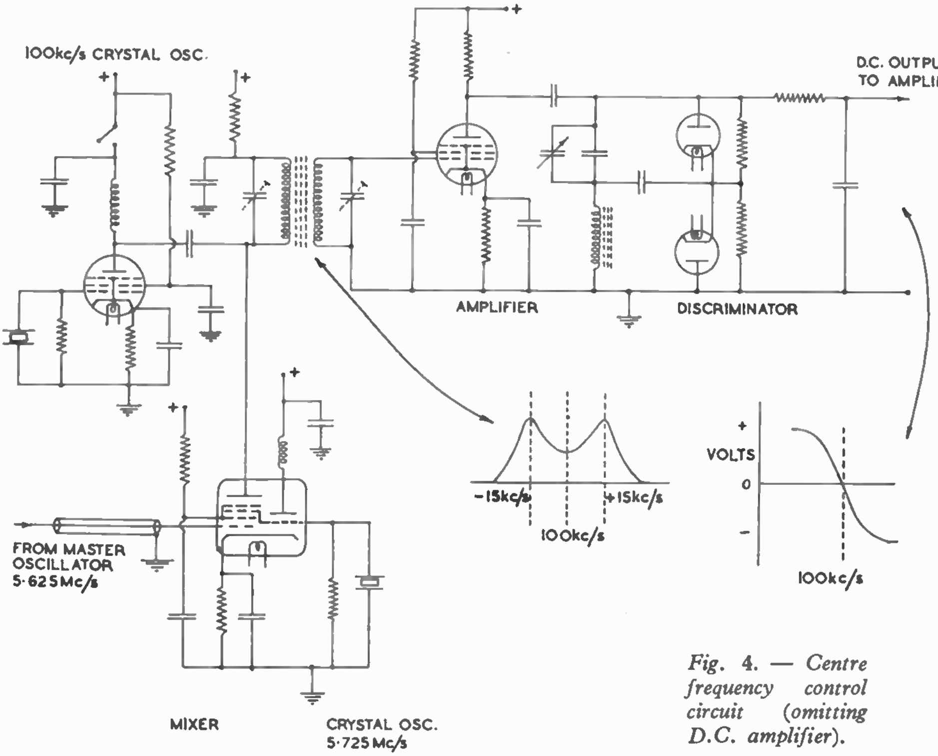

Fig. 4. — Centre frequency control circuit (omitting D.C. amplifier).

In this method, owing to the fact that only a limited phase modulation is possible without serious distortion, a multiplication of about 4,000 is needed and, in order to obtain the required centre frequency, one or more heterodyne frequency changers are normally necessary.

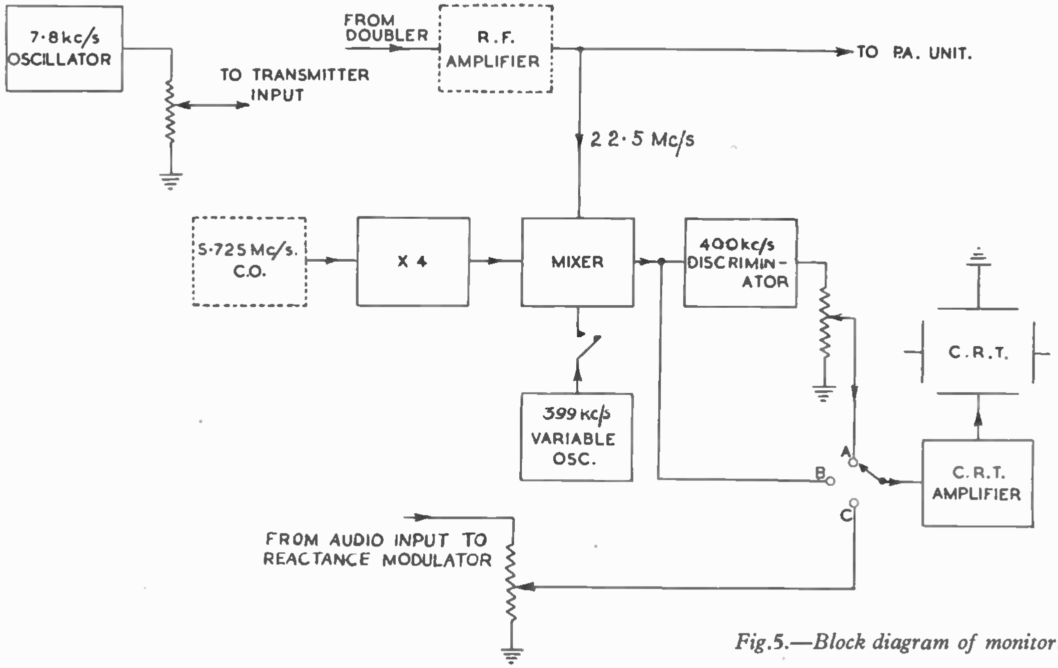

Fig.5.—Block diagram of monitor.

One indirect method of producing a stable centre frequency at present used is as follows:

A sample of the oscillator output is frequency divided in small steps down to a few kc/s. The frequency of this sub-harmonic is then compared with that of a stable oscillator and the difference frequency used to produce a rotating field in the windings of a motor. This is made to correct the oscillator tuning.

Both of these systems suffer from a disadvantage since large numbers of valves are required and must therefore be prone to breakdown. A typical example of the second of these methods employs 17 valves in the control circuit. Another drawback is the presence of closely spaced sub-harmonics in the output of the transmitter which are difficult to eliminate. This is particularly the case with the direct method.

The system employed in this transmitter is an indirect method of control and has been referred to as the constant difference frequency method. A small output from the master-oscillator is mixed with output from a stable crystal oscillator. The beat frequency produced is amplified and applied to a frequency discriminator. A D.C. output is obtained from this, which is zero when the oscillator to be corrected is " on " frequency and positive or negative, depending on whether the frequency is too high or too low. The D.C. voltage after further amplification is passed through a circuit of large time constant to eliminate any audio voltage components, and then applied to the grids of the reactance modulator valves. The reactance modulator changes the oscillator frequency in a direction to correct for " off-tune."

Clearly, since the presence of a correcting voltage depends on oscillator " off-tune," the arrangement can never do more than reduce the error frequency. With the arrangement employed here, however, an improvement ratio (control ratio) of 2,000 is achieved and the error becomes very small compared with errors from other factors controlling overall stability. The number of valves employed in this system is 6, including diodes.

The signal in the control channel is frequency modulated, with the same deviation as the master oscillator. This deviation is large compared with the mean frequency of the channel (100 kc/s). Nevertheless, it was found possible to design a discriminator with a satisfactory characteristic using only the simple tuned circuit described below.

It is necessary to remove the second harmonic of the control channel signal, as this, too, is frequency modulated (over twice the range) and by producing sidebands falling within the acceptance band of the discriminator would be liable to influence its output and shift the mean frequency when modulation is applied.

The use of control channel frequencies of 1—2 Mc/s which avoid this trouble, has the disadvantage that the stability of the transmitter depends to a much larger extent on the stability of the discriminator circuit.

For example, suppose the master-oscillator is 5.6 Mc/s. and the control channel 1.4 Mc/s., then if we can assume a similar stability for both oscillator and discriminator, the drift can only be reduced in the ratio of these frequencies or to $\frac{1}{4}$, however perfect the frequency correction may be.

The control channel circuit shown in Fig. 4 has been found to give satisfactory operation. It gives an improvement ratio of $\frac{5600}{100} = 56$ and since a ready means of setting the discriminator frequency is made available, only short term drift has to be considered.

The discriminator drift can be corrected as follows :—

A 100 kc/s. crystal is switched to apply input to the control channel. The tuning of the discriminator is then adjusted so that zero D.C. output appears at the output terminals of the control channel. This is indicated on a central zero meter.

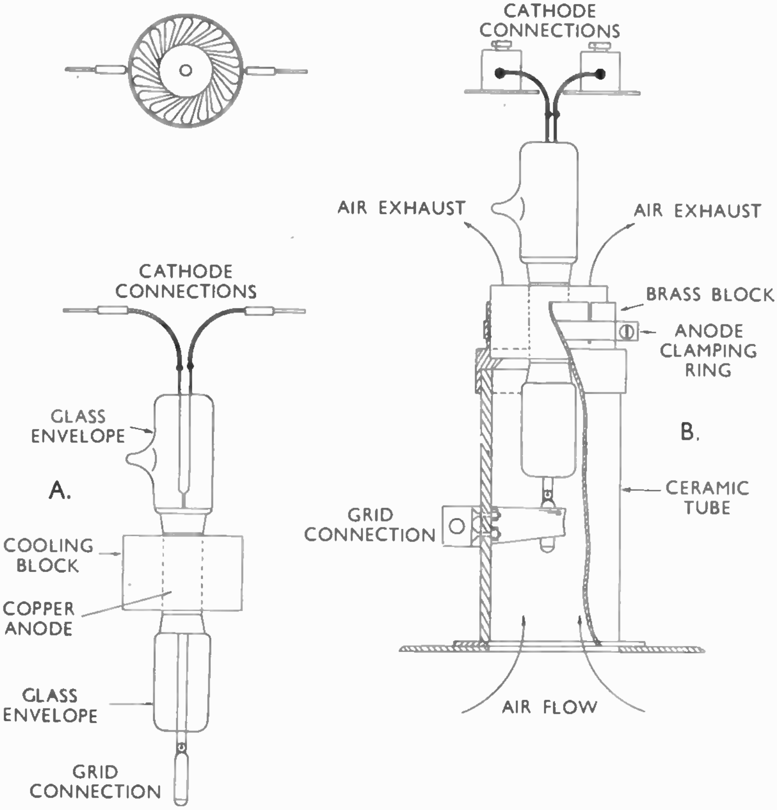

Fig. 6.—Diagram showing Osram ACT19 valve and holder arrangement.

The controlling crystal oscillator is a B.T. cut quartz plate mounted in a temperature controlled oven. This has a frequency stability of about ± 20 c/s. under working conditions.

As seen in Fig. 4 the beat frequency appearing in the anode circuit of the mixer is fed by means of a band pass circuit to the grid of an amplifier. This has a peak separation of about 30 kc/s. and gives good rejection to the harmonics of the control frequency, also to any audio frequency voltage produced by the mixer. The discriminator in the anode circuit of the amplifier consists of a series tuned circuit resonant at 100 kc/s. A diode placed across each element produces two equal and opposite D.C. voltages at the resonant frequency of 100 kc/s. At frequencies above or below the voltages become unequal and the resulting difference voltage will be positive or negative depending on whether the frequency is above or below.

(5.3) The Modulation Monitoring Circuit.

Figure 5 shows a block diagram of the monitor. Monitoring is carried out using a separate channel which operates at 400 kc/s. A sample of the output from the 22.5 Mc/s. circuit used to feed the P.A. unit, is applied to the grid of a mixer valve together with quadrupled output from the 5.725 crystal oscillator. The 400 kc/s. beat produced is independent of the operating frequency of the transmitter since the M.O. and C.O. are " tied " together by the control channel frequency. A discriminator followed by an audio amplifier provides output for a display on a cathode ray tube.

This cathode ray tube can be switched for other purposes. For example, it can be switched to position C to display the input signal to the transmitter and since separate gain controls are provided in the C.R.T. input circuit, both input to the transmitter and output from the monitor can be set to produce equal deflection. If a means for calibrating is provided this will give a direct measure of percentage modulation.

Calibrating can be carried out quite easily with sinusoidal modulation.

Use is made of the carrier disappearance effect fundamental to F.M. The whole of the power appears in the sidebands at certain fixed ratios of peak deviation to modulating frequency. The first carrier disappearance occurs when the peak deviation becomes 2.405 times the frequency of modulation. So if a means of indicating the carrier amplitude is provided it can be used for calibrating the oscilloscope.

This is done by beating down the frequency in the monitor channel by injecting into the mixer an input from an oscillator whose frequency can be set to about 399 kc/s. A beat of about 1 kc/s. is then obtained between this and the normal channel frequency. This output, suitably filtered, is used as a measure of carrier amplitude and switched via position B to the C.R.T. oscilloscope.

Since the deviation for 100% modulation at the point of monitoring is $\pm \frac{75}{4}$ kc/s = ± 18.75 kc/s. (for 90 Mc/s. operation) the modulation frequency will be $\frac{18.75}{2.405} = 7.8$ kc/s. An oscillator of this frequency is built into the set and can be switched to the input of the modulator for this purpose.

(6) THE P.A. UNIT.

Figure 6A shows the valve used throughout this unit. The physical layout of the circuit is largely governed by the valve connection positions since connecting lead lengths are of vital importance at these frequencies.

The valve employed is the Osram ACT19 which is a triode with low inter-electrode capacities and a mutual conductance of 3.1 ma/volt. It operates at 2,500 volts, and as an amplifier at 90 Mc/s. provides a power gain of about 10. The anode circuit efficiency is roughly 60%. The cathode is directly heated and requires 60 watts of heating power. As seen in the figure the grid and cathode connections are brought out at opposite ends of the glass envelope; the anode cooling block is in the middle. This has radial cooling fins inside a brass tube.

A special valve holder has been developed which consists of a ceramic tube through which the cooling air is forced from the air box previously mentioned. A metal tube with a clamping strap is secured to the top of the ceramic tube and serves to grip the anode and make connection with the circuit. Figure 6B shows a holder with valve in position.

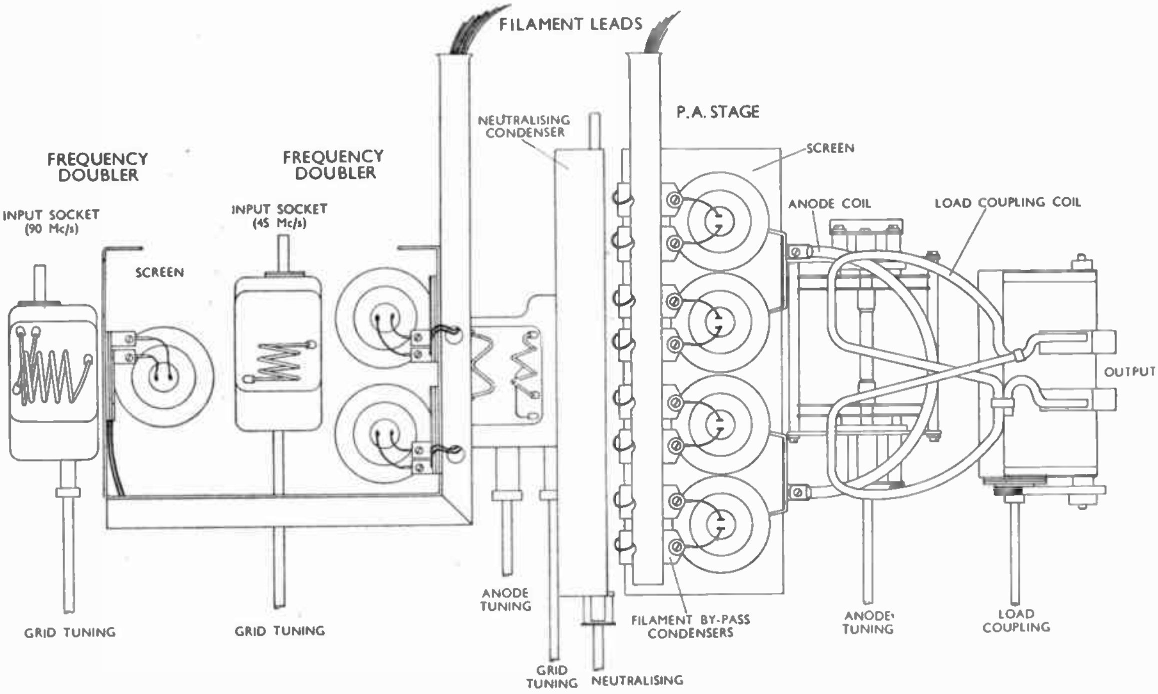

Fig. 7.—Layout of P.A. unit.

(6.1) The P.A. Circuit.

The circuit arrangement of the P.A. consists of a 75 Ω input arrangement (energised from the Driver Unit) which drives a single ACT19 frequency doubling. This in turn drives a paralleled pair of ACT19 valves also frequency doubling. Output from these at 90 Mc/s. is transformer fed to the tuned grid circuit of the P.A. which consists of 4 valves arranged in parallel push-pull. The P.A. grid to anode capacity is neutralised by a ganged condenser adjustable from the front panel. The capacitors are cross-connected from grid to anode, and in order to keep their physical size as small as possible, which is necessary at these frequencies, the D.C. potential is removed.

Lumped L.C. circuits are used and have proved to be very satisfactory for frequencies up to 100 Mc/s. These occupy less space than line circuits and allow a more simple method of load coupling to be employed. Figure 7 shows the layout of the P.A. unit in plan.

The P.A. stage valves are arranged in line. The anodes of the pairs are strapped together and lugs provide anchor points for a detachable anode inductance coil. A length of feeder connects an adjustable coupling coil with suitable aerial feed connectors on the top of the cabinet. This feeder may be an unbalanced 75 Ω link used in conjunction with a plug and socket, or a 300 Ω balanced pair feeding to terminal posts.

In order that the valves should share the load equally, it was found necessary to provide separate grid leak bias resistors for each. This method is convenient as it also allows separate grid current metering to be carried out. A separate filament heating winding is provided for each valve in the P.A. unit, and sufficient cathode bias included to keep the anode dissipations of the valves to a safe value if failure of the drive should occur. In the case of the P.A. amplifier only, this cathode bias is short-circuited by contacts carried on a relay which operates on grid current in the P.A. stage. This allows a better efficiency to be obtained during operation.

A high tension current overload relay is provided as protection against a mistuned anode circuit or a valve breakdown.

To operate the transmitter at lower frequencies such as 45 Mc/s., drive is taken from the driver unit direct to the second doubler stage in the P.A. unit by changing the feeder from one input socket to another. The first doubler stage is then rendered inoperative and three of the coil units which are screwed into position are changed. The frequency deviation of the master-oscillator in the driver unit is then doubled to produce ± 75 kc/s. at 45 Mc/s. mean frequency.

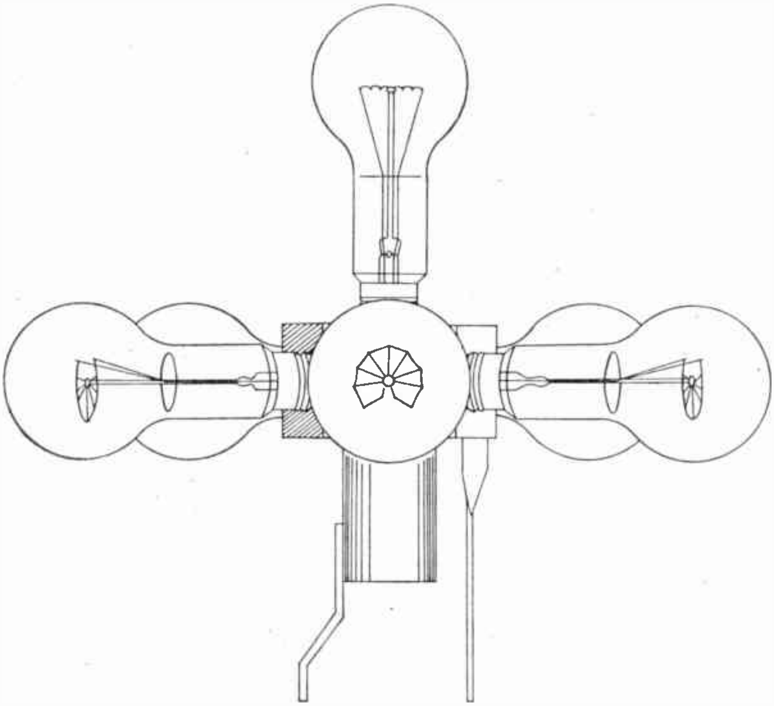

Fig. 8.—Dummy load consisting of six 300W. 100V. gasfilled lamps, side view.

(7) DUMMY LOAD FOR USE WITH THE TRANSMITTER.

During the setting up and testing of a transmitter, the problem of making a suitable dummy load is bound to arise. Particulars of an arrangement found very suitable for this frequency and order of power are as follows :

It is very desirable to have an immediate indication of power output such as is obtained from a lamp and for this reason various types of lamps were tried. In general it was found that 240V. lamps were unsuitable since the R.F. voltage developed across the lead-through wires was too high. The formation of an internal arc or softening of the glass at the pinch, quickly caused the lamp to go " soft."

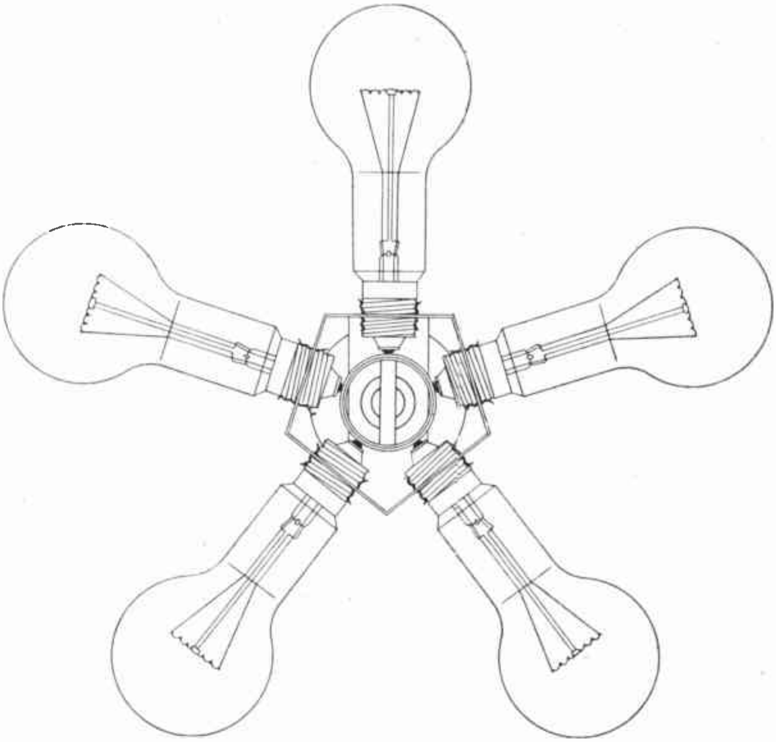

Fig. 9.—Dummy load viewed from below.

100 volt, 300 watt gasfilled lamps fitted with Edison screw caps were found to give a reasonable life provided they were run at not more than 200 watts each. This necessitated the use of five or six lamps. It was found that these were best run in parallel and with the arrangement shown in Figs. 8 and 9, shared the load equally. The centre contact of each lamp is in good thermal contact with a copper tube of sufficient size to conduct heat away. If attention is not paid to this point a blower must be used to keep the cap cool or the insulator in the cap will break down and the solder will melt.

This load presents a low impedance but no difficulty was found in coupling to the transmitter.

The load is used supported on copper strip connections from the balanced load terminals on top of the cabinet. The capacity of the lamp holder unit was arranged to approximately tune out the inductance of the lamp filaments on 90 Mc/s. An additional 30 $\mu\mu$F. was shunted across these connections when operating at 45 Mc/s.

CONVENTION DISCUSSION

Mr. D. A. Bell : The author has mentioned a figure of 0.5% for the harmonic distortion at full modulation. How far does negative feed-back in the modulator contribute to achieving this low figure ? In applying pre-emphasis, I believe some reduction in average signal input is necessary (as suggested in the report on the M.B.C. field tests of F.M. in U.S.A.). This is because the high frequencies, which are themselves of small amplitude, may occur at the same time as the low frequencies which contain most of the energy in speech and music transmissions.

Mr. W. M. Dalton (Associate Member) : When the panels are pulled out the connecting leads tend to be abraded. What method of avoiding such abrasion is preferred by the author ?

It is noticed that an overcoupled transformer is used in Fig. 4. Are overcoupled transformers used in any of the power amplifier stages ? Such transformers can produce oscillations in transmitter stages when the anode circuit is tuned slightly below the middle of the hump. The phase of an overcoupled transformer shifts inside the hump, the degree of shift depending on the degree of overcoupling.

Mr. J. A. Sargrove (Member) : I feel that the design using standardised (identical) transmitting valves is admirable, but the complexity of the monitor seems to be frightening.

Could not the monitor be made fundamentally more simple than the actual transmitter ; also why not monitor at a high voltage level and apply the signal directly to the deflector plates of the C.R.O. ?

REPLY TO THE DISCUSSION

Mr. J. B. Lovell-Foot : Replying to Mr. Bell, the distortion produced in the modulation system is small compared with the overall distortion quoted, since this is mainly produced in the audio amplifier. Comparison of the reactance modulator characteristics with and without negative feedback show only a slight difference. A curve taken over four times and full modulation range shows that the second harmonic distortion cancels out, due to the push-pull arrangements, and that about 2.6% third harmonic remains. Over the working range, this represents about 0.04% distortion.

The point about connecting leads which Mr. Dalton raises has been carefully considered in the design, and their arrangement in this transmitter would appear satisfactory. Abrasion of the cables is avoided by providing between the cabinet and the connecting plugs, loops of just sufficient length to allow the panels to be withdrawn as far as the limit stops. When a panel is removed from the cabinet, the plugs are taken out of the sockets and remain with the cables inside the cabinet. The cables are self-supporting and retain their approximate positions.

Concerning overcoupled transformers, the point raised is an interesting one. There are only two coupled circuits in the P.A. stages and these are both under-critically coupled. The overcoupled circuit employed in the frequency control channel (Fig. 4) operates at a low-frequency (about 100 kc/s). No tendency to oscillation has been noticed due to the effect mentioned in any of these.

In connection with Mr. Sargrove's remarks about the monitor, the main feature is that it is readily calibrated for deviation amplitude by an infallible method. Any subsequent departure from calibration is apparent since dissimilarity of amplitudes would occur when comparing the modulation voltage on the reactance modulators with that measured at the output of the monitor. I am in favour of simplification and the method suggested appears attractive at first sight, but close examination reveals many problems. The monitor would also require retuning if the carrier frequency were changed. This is not the case with the arrangement employed.

Excluding apparatus required for calibration, the additions provided for the monitor consists only of a quadrupler, a mixer, a discriminator, and a CRT with amplifier.