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D. A. THORN, B.Sc. (Eng.), A.M.I.E.E. and
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A Paper read before the London Centre of the Institution on the 12th November, 1935.

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Introduction.

The use of radio links to provide long distance overseas telephone circuits for commercial purposes has been an accomplished fact for some years. In such cases wave-lengths of the order of 15-100 metres have generally been employed. With the development of the technique of ultra short waves, *i.e.*, wave-lengths of from 2 to 10 metres or frequencies of from 150 to 30 megacycles per sec., it was soon apparent that the provision of telephone circuits across river estuaries and short sea paths by means of radio links was an economical alternative to the usual submarine cable or devious land line connection. Ultra short waves possess peculiar technical advantages for this purpose, and these will be considered in this paper. The technique of ultra short wave links, particularly as applied by the British Post Office, will be discussed, together with descriptions of cases where such circuits have been installed both for experimental and commercial purposes.

Transmitters.

In general, any transmitter used for radio telephony may be considered to consist of two essential parts (*a*) the high frequency oscillator and (*b*) the modulator, their respective functions being the generation of the carrier frequency and the amplification of the speech power to such a level as is required to modulate the carrier wave.

The high frequency oscillator used by the Post Office for ultra short wave work is normally of the push-pull type using two separate triode valves and having the tuned circuit connected between the anodes. Fig. **1** shows in simplified form a typical

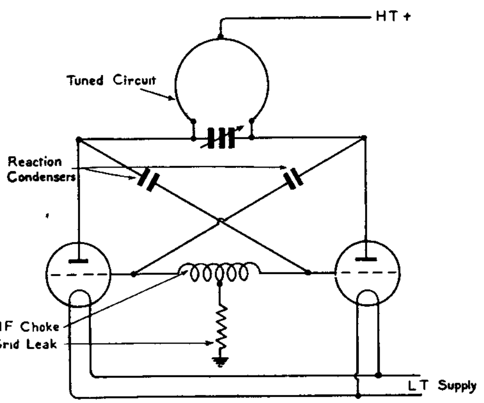


FIG. **1**.—TYPICAL ULTRA SHORT WAVE OSCILLATOR CIRCUIT.

circuit of this type. Reaction is obtained by means of fixed or preset type condensers which couple the anodes of each valve to the grid of the other valve. Grid bias is obtained by either separate resistance in each grid lead or a common leak connected to the centre point of a choke bridged across the two grids as shown in Fig. **1**. A three plate variable condenser is used in the tuned circuit, which, with one or two turn copper tube coils covers the required frequency range of from 30 to 150 megacycles per sec. The high tension supply is fed to the centre point of the tuning coil through a choke which prevents high frequency feed-back to the supply circuits.

The advantages of using the push-pull type of oscillator circuit are :—

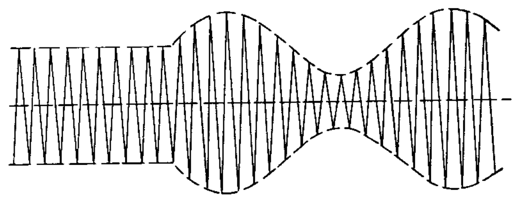
(*a*) A sufficiently stable high frequency oscillator, with reasonable efficiency, is obtained.

(*b*) A balanced output is obtained which is desirable for feeding the balanced transmission lines employed for coupling to the aerial system.

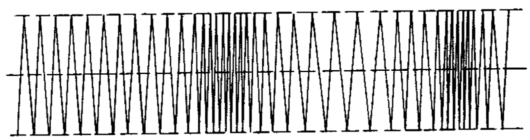
The output from the transmitter is taken from a coupling coil of similar dimensions to those of the tuning coil and which may be variably coupled to the tuned circuit.

A high tension voltage of 300 volts is usually employed, and with an input feed of 30 watts a high frequency output of about 7 watts may be obtained with optimum coupling. The valves used are of the V.T.24, or similar type.

In order to modulate the high frequency output produced by an oscillator, it is necessary to apply the modulating, *i.e.*, speech, power in such a way as to reproduce the speech characteristics in the high frequency output. This may be effected by causing the modulation to vary either (*a*) the amplitude or (*b*) the frequency of the high frequency oscillations. These two cases are illustrated in Fig. **2**(*a*) and (*b*) respectively. Amplitude modulation is invariably employed in practice as frequency modulation in-



(a) Amplitude Modulated Wave.



(b) Frequency Modulated Wave.

FIG. **2**.—CHARACTERISTICS OF AMPLITUDE AND FREQUENCY MODULATED WAVES.

volves difficulties both in transmission and reception besides resulting in a complex and widespread frequency spectrum.

Amplitude modulation may be applied to (1) the anode circuit, (2) the grid circuit or (3) the output of the high frequency oscillator. Anode modulation is at present employed on all the Post Office ultra short wave transmitters. Grid modulation has been tried, but difficulty is experienced in obtaining a sufficiently linear characteristic for all but low degrees of modulation. Case 3, which necessitates the development of a technique for varying the energy fed to the aerial system while maintaining the oscillator output at a constant level, has not yet been tried, but should, on general considerations, be capable of giving satisfactory results.

In order to obtain distortionless anode modulation it is essential that the relationship between the instantaneous voltage on the oscillator anodes and the high frequency output current or voltage should be linear. Fig. **3** shows a typical " load curve " for

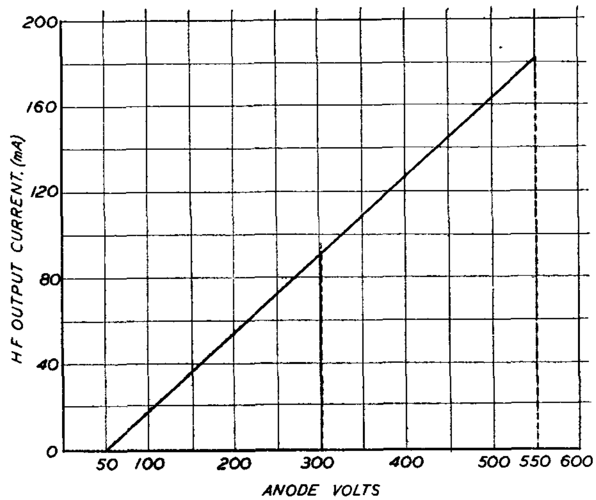


Fig. **3**.—Typical " Load Curve " of Ultra Short Wave Transmitter Oscillator.

an ultra short wave transmitter. For the case illustrated it is necessary to swing the anode voltage between the limits of 50 and 550 volts about the mean value of 300 in order to obtain 100% modulation of the output. For complete, or 100% modulation, the modulating or speech frequency power required is equal approximately to one half the input power to the oscillator. Thus with an oscillator input of 30 watts the speech frequency power required is of the order of 15 watts.

In the earlier transmitters the speech from the line or telephone was amplified by a conventional two-stage amplifier followed by two or more valves of similar type to those used in the oscillator stage and operating in parallel as class " A " amplifiers. Under these conditions approximately four valves in parallel are required in the final stage for 100% modulation of the oscillator. In the later developments a class " B " push-pull amplifier is used for the final modulator stage. In the particular amplifier used the grid bias is such that under static conditions a small anode current of the order of 6 milliamperes is obtained while on peak values of speech the current rises to 35 to 40 milliamperes. With this arrangement a very efficient modulator is realised, sufficient low frequency power being obtained from two valves in push-pull for complete modulation of the oscillator. A power valve operating as a class " A " amplifier is used to drive the class " B " stage and is preceded by a conventional two-stage amplifier. Figs. **4** and **5** show the circuit diagrams of transmitters employing the two types of modulator described.

Details of the construction and power supplies for these transmitters will be described later, in the sections dealing with the applications to working circuits.

Frequency stabilisation of the transmitter oscillator may be required for two purposes (*a*) to eliminate the frequency modulation which is usually present to a certain extent in an amplitude modulated oscillator and (*b*) to eliminate drift of the carrier frequency with time, or frequency changes brought about by

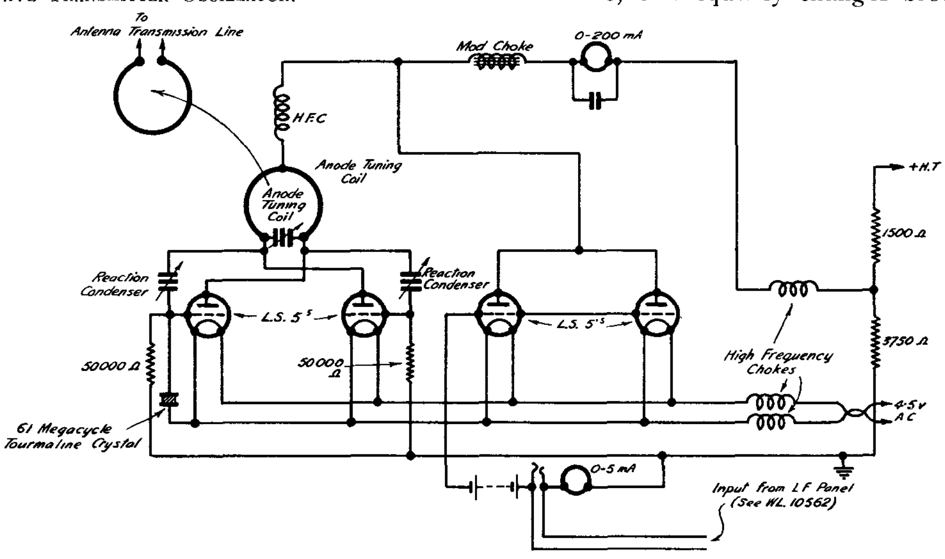


Fig. **4**.—All Mains Low Power Ultra Short Wave Transmitter with Crystal Control.

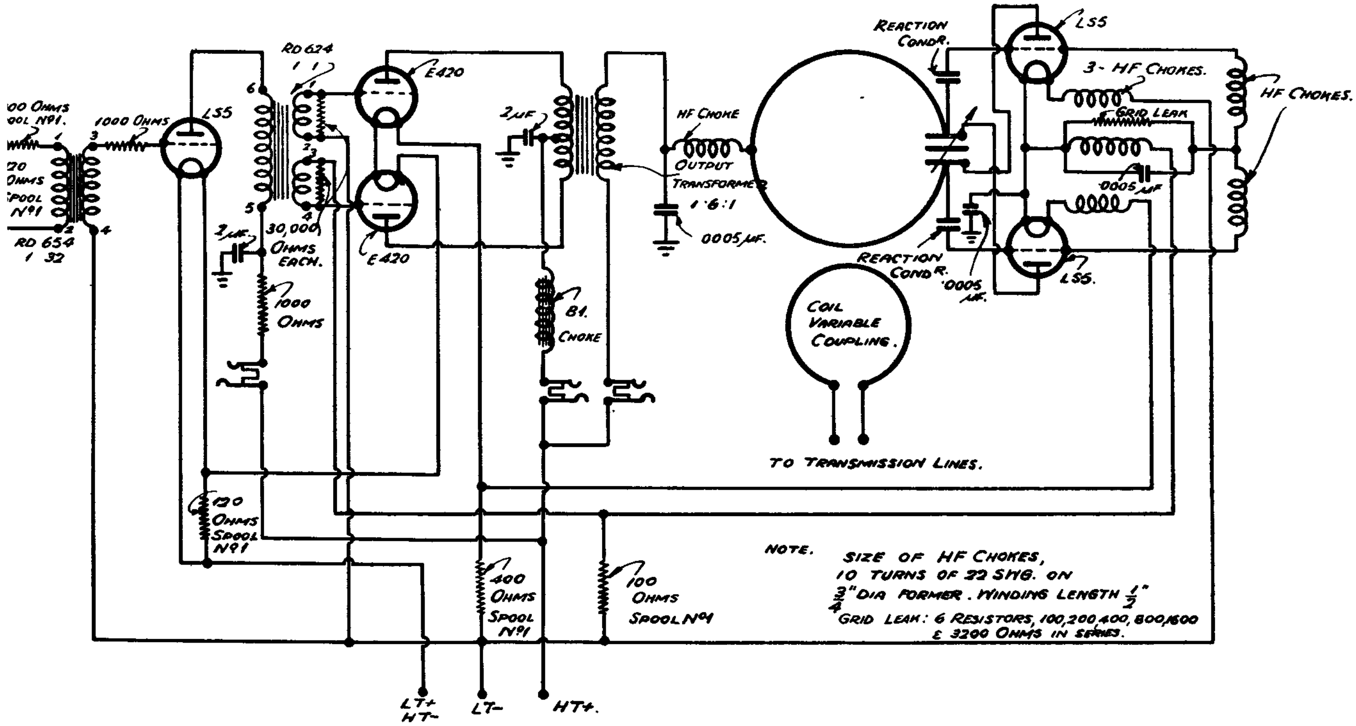


Fig. **5**.—Experimental U.S.W. Transmitter. 6-Circuit Type.

variations of air temperature or supply voltages. The effects of these two types of frequency change are dependent upon the type of receiver employed, but may conveniently be considered under the present heading.

Where a super-regenerative receiver is used the effect of frequency modulation is to cause the signal output level to vary over the tuning range as shown in Fig. **6**, in which, for purposes of comparison, there is shown a curve of the signal output received using a frequency controlled transmitter. Drift of the transmitter frequency will result in a variation

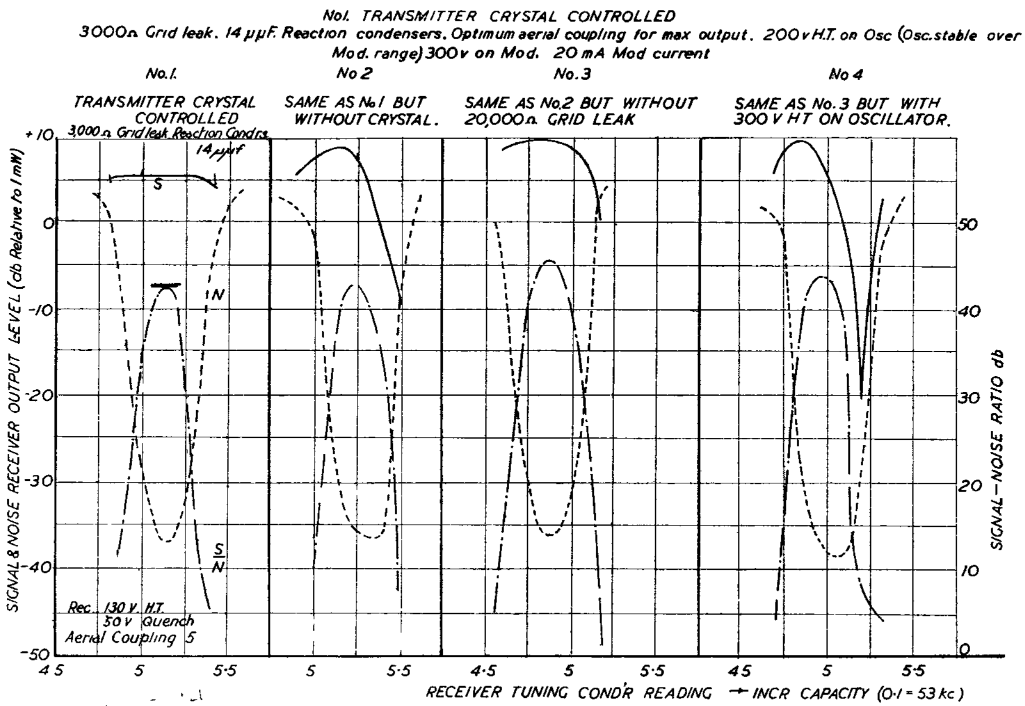


Fig. **6**.—Super-regenerative Receiver Resonance Curves showing Effect of Frequency Modulation.

in the signal output from the receiver owing to the latter working on a different point on its resonance curve. In the absence of frequency modulation a certain amount of carrier frequency drift may be tolerated without distortion or variation in the output signal level.

With a superheterodyne type of receiver, which, as will be seen later, is normally arranged to work with a relatively narrow band width, the effect of frequency modulation of the transmitter is to cause the carrier frequency to vary outside the limits of the receiver resonance curve causing bad distortion or complete loss of the received signal. The effect of frequency drift will, in the case of a superheterodyne receiver be similar to that of frequency modulation.

The self-oscillator type of transmitter is capable of adjustment to give almost complete freedom from frequency modulation and a sufficiently small frequency drift, but the condition is too critical for commercial use. Attention has therefore been directed to the use of piezo-electric crystals for the purpose of frequency control. The conventional system of using a quartz crystal of suitable frequency followed by successive frequency doubling stages, as used on short wave transmitters, has been tried, but owing to the multiplicity of the equipment required the scheme has not been used for commercial operation on ultra short wave transmitters. In the present stage of the art it is not possible to grind quartz crystals to oscillate directly on the transmitter frequency, and the most satisfactory method of controlling the existing type of transmitter is to use tourmaline crystals oscillating at the transmitter frequency. These have been used experimentally with very satisfactory results. The crystals are applied directly between the grid and filament of one of the oscillator valves as shown in Fig. 4.

The use of the " line " or " high Q circuit " method of frequency control as favoured in American practice, has been tried, but satisfactory results with circuits of reasonable physical dimensions have not so far been obtained.

The latest developments in ultra short wave transmitter design have been directed to the use of a quartz crystal oscillator working on a frequency of about 6 megacycles per sec., followed by frequency multiplying stages employing single pentode valves. The results so far obtained show considerable promise, but the scheme is not yet advanced sufficiently to warrant a detailed description in this paper.

Receivers.

In general radio receivers may be classified into three types (*a*) Straight receivers, in which the gain or amplification is obtained at the signal frequency, (*b*) Super-regenerative receivers, in which the gain is obtained by means of an oscillating detector quenched at a supersonic frequency and (*c*) Superheterodyne receivers, in which the gain is obtained at a frequency lower than the signal frequency. These three types will now be considered in detail as applied to frequencies in the ultra short wave band.

(*a*) *Straight Receivers.*

This type of receiver necessitates the design and construction of an amplifier to give adequate gain at the signal frequency. At the present stage this is not practicable at the frequencies under consideration and the straight receiver has not therefore been employed in ultra short wave circuits.

(*b*) *Super-regenerative Receivers.*

This type of receiver is particularly suitable for use on ultra short waves as the requisite gain can be realised with very simple circuit arrangements. A push-pull oscillating detector is used, the oscillations being quenched by injecting an oscillatory voltage at some convenient frequency into the anode circuit. Quench frequencies of between 5 and 60 kilocycles per sec. have been used, but the actual value does not appear to be critical over this range. Fig. 7 shows a typical receiver circuit from which

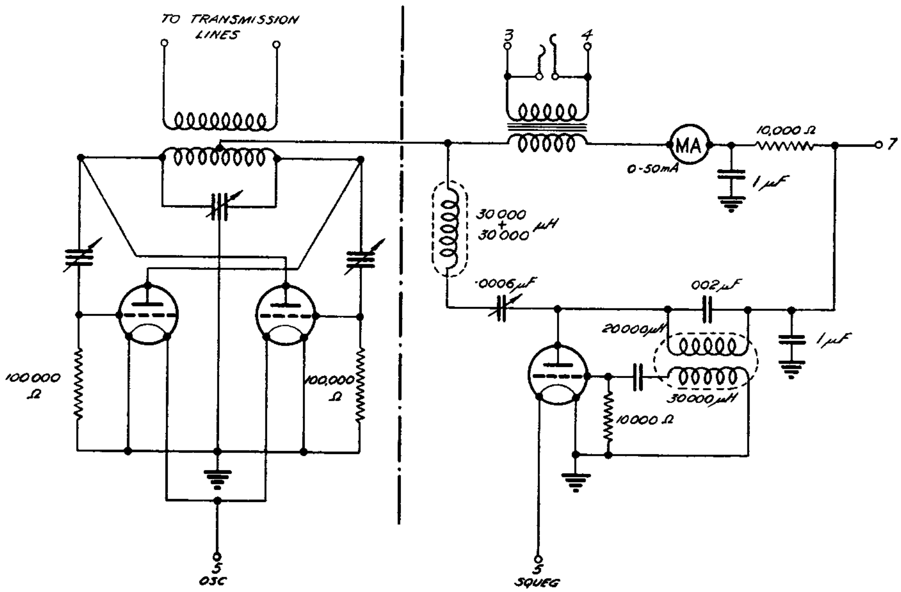


Fig. 7.—Schematic Diagram of Receiver for 2-way Circuit. Hutton and Dinas Powis.

it will be seen that a variable capacity reaction control is used. The aerial is usually coupled inductively to the tuned circuit through a coupling coil, but capacity coupling by means of condensers tapped on to suitable points on the anode coil may be used.

The mechanism of the operation of a receiver of this type is somewhat complex and has been the subject of several articles of a mathematical character by various authorities. The following simple explanation will, however, serve in giving an adequate conception of the operation of the receiver.

It is well known that with a simple detector circuit employing reaction, the receiver becomes more sensitive as the degree of reaction is increased. Ultimately the circuit oscillates and it is just before this point that the maximum sensitivity is obtained; the condition, however, is very unstable and accompanied by considerable distortion. If with the detector circuit set just in the oscillating condition, an alternating voltage is superimposed on the steady D.C. anode potential the oscillations will be permitted to build up during the positive half cycle and quenched in the negative half cycle, resulting in a high gain detector circuit, which is free from distortion and audible heterodyne whistles. The gain obtained in this way is some 60 db. greater than with a non-oscillating detector.

In the absence of an incoming carrier the super-regenerative receiver circuit operates at maximum sensitivity and a high level noise output is obtained. On tuning to the frequency of an incoming carrier, however, the noise is suppressed, the degree of suppression being proportional to the strength of the incoming carrier. If the carrier is modulated it is found that the receiver signal output level is independent of the strength of the receiver input over a wide range, thus giving an inherent automatic gain control feature. This is illustrated in the curve shown in Fig. **8**.

The ratio of the quench voltage to the D.C. anode potential applied to a super-regenerative receiver is not critical, but if too low, a phenomenon known as " multitunes " is observed. In this case several tune points separated by the quench frequency are obtained resulting in a considerable and rapid variation of the output signal over the normal bandwidth of the receiver. In the extreme case where a high quench voltage is used in the absence of any D.C. anode potential a wide bandwidth is obtained, together with normal tuning conditions. As an indication of the values usually adopted it may be mentioned that an R.M.S. quench voltage of 30 volts with a D.C. anode voltage of 60 gives satisfactory operation. There is no advantage to be gained from widening the bandwidth beyond a value such that normal relative frequency variations between the transmitter and receiver are covered, as there is then a risk of interference from an adjacent transmitter frequency. The bandwidth of the latest type of super-regenerative receiver is such that over a tuning range of $\pm$ 70 kilocycles per sec. the noise increase is only 6 db. while the signal output remains sensibly constant in the absence of frequency modulation of the transmitter.

The advantages of the super-regenerative receiver for use on ultra short waves may be summarised as follows :—

(1) Simplicity of construction.
(2) Wide bandwidth.
(3) An inherent automatic gain control.
(4) Absence of critical adjustments.

The only disadvantage is that the output noise level is high compared with that obtained from a super-heterodyne receiver working under the same conditions.

(c) *Superheterodyne Receivers (Double or Triple Detection).*

This type of receiver operates on a principle which will be familiar to many, namely, that of changing the incoming signal to a frequency at which adequate amplification can be obtained and at which tuned circuits giving the required selectivity may be realised.

Some four years ago a special type of triple detection receiver was built for experimental work over the waveband from 2 to 100 metres, but more particularly for use in ultra short wave reception.

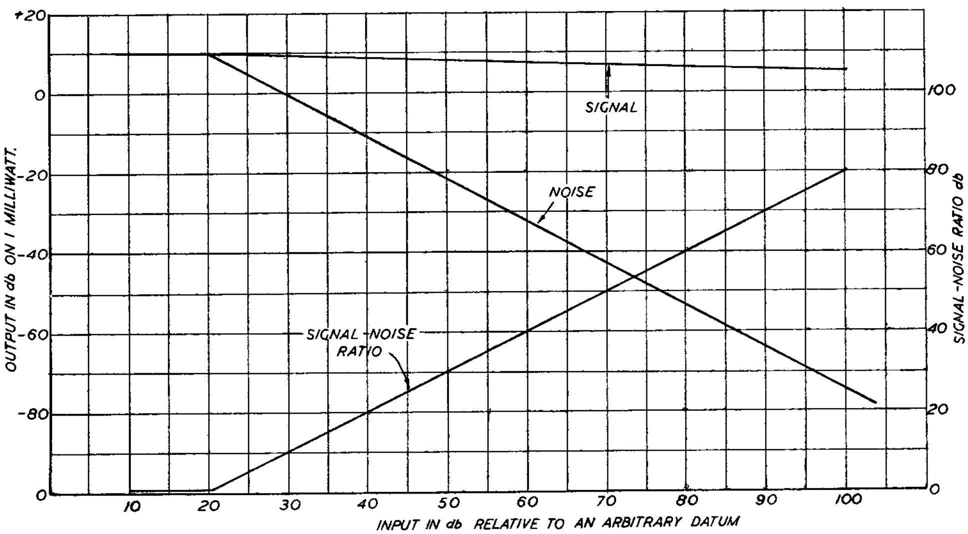
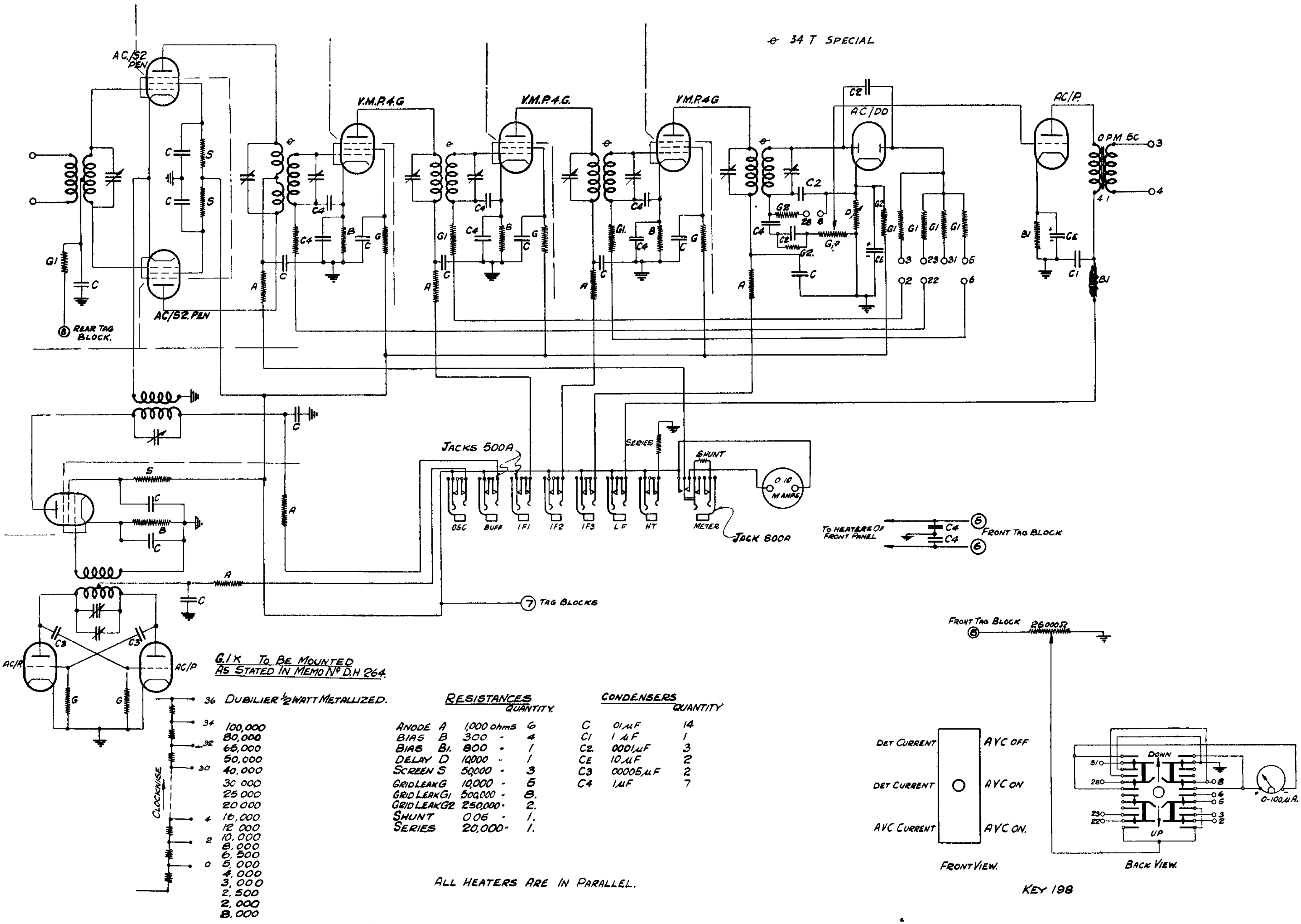


FIG. 8.—OUTPUT OF A SUPER REGENERATIVE RECEIVER FOR VARIOUS INPUT LEVELS.



RESISTANCES

			QUANTITY
ANODE	A	1,000 ohms	6
BIAS	B	300 "	4
BIAS	B1.	800 "	1
DELAY	D	10,000 "	1
SCREEN	S	50,000 "	3
GRID LEAK	G	10,000 "	5
GRID LEAK	G1	500,000 "	8.
GRID LEAK	G2	250,000 "	2.
SHUNT		0 05 "	1.
SERIES		20,000 "	1.

CONDENSERS

		QUANTITY
C	01 μF	14
C1	1 μF	1
C2.	0001 μF	3
CE	10 μF	2
C3	00005 μF	2
C4	1 μF	7

ALL HEATERS ARE IN PARALLEL.

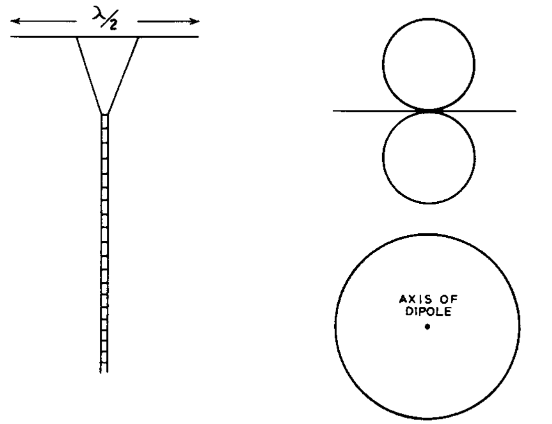
FIG. 9.—ULTRA SHORT WAVE DOUBLE DETECTION RECEIVER (3 MEGACYCLES I.F.).

This receiver incorporates two stages of frequency changing having intermediate frequencies of 20 megacycles per sec., and 300 kilocycles per sec., respectively. This receiver has given excellent results in general experimental work and field investigations, but is of too complex and costly a character to be considered as a type for use on normal commercial ultra short wave circuits. Improvements which have been carried out on this receiver from time to time have led to the conclusion that a simplified type of double detection superheterodyne receiver would have a particular field of application, especially for the longer distance ultra short wave circuits. Experimental results have shown that an improvement in the signal to noise ratio of some 10 to 20 db. over that obtained with a super-regenerative receiver may be realised; a fact which, as will be seen later, is of considerable value and importance.

Accordingly it was decided to develop a superheterodyne ultra short wave receiver suitable for commercial use. After many different circuit arrangements had been tried that shown in Fig. **9** was adopted for the experimental model. It will be seen that a conventional frequency changing system consisting of beating oscillator, buffer amplifier and first detector has been adopted in preference to a heptode or octode frequency changer as giving more satisfactory results. A four-stage intermediate frequency amplifier is shown in the circuit diagram, but the gain so obtained has been found to be far greater than that required. It is probable that three, or possibly two, stages of intermediate frequency amplification will be sufficient for use on commercial circuits. The intermediate frequency of 3 megacycles per sec. was chosen as giving adequate second channel selectivity while being a frequency at which the required gain and bandwidth is obtainable. A bandwidth of about 50 kilocycles per sec. will be used in practice. The intermediate frequency stages are followed by the second detector using a double diode triode valve to give automatic gain control, and one stage of low frequency amplification. This in turn is followed by a single valve output stage.

Aerial Systems.

The simplest type of aerial used for ultra short wave transmission and reception is the half wave dipole shown in Fig. **10**(a) connected to the radio equipment through a parallel open wire transmission line. The latter, if properly balanced to earth, does not in itself function as an aerial, *i.e.*, it will neither radiate nor receive, but serves only to feed the radio frequency energy to or from the dipole. The general charactristics of an aerial system are similar when used either for transmission or reception and only the transmission case will therefore be discussed. Considering an aerial of the type shown in Fig. **10**(a) suspended in free space the radiation character-



(a) TYPICAL DIPOLE AND TRANSMISSION LINE

(b) POLAR DIAGRAMS OF RADIATION CHARACTERISTICS OF λ/2 DIPOLE IN FREE SPACE

FIG. **10**.—SIMPLE HALF WAVE DIPOLE CHARACTERISTICS.

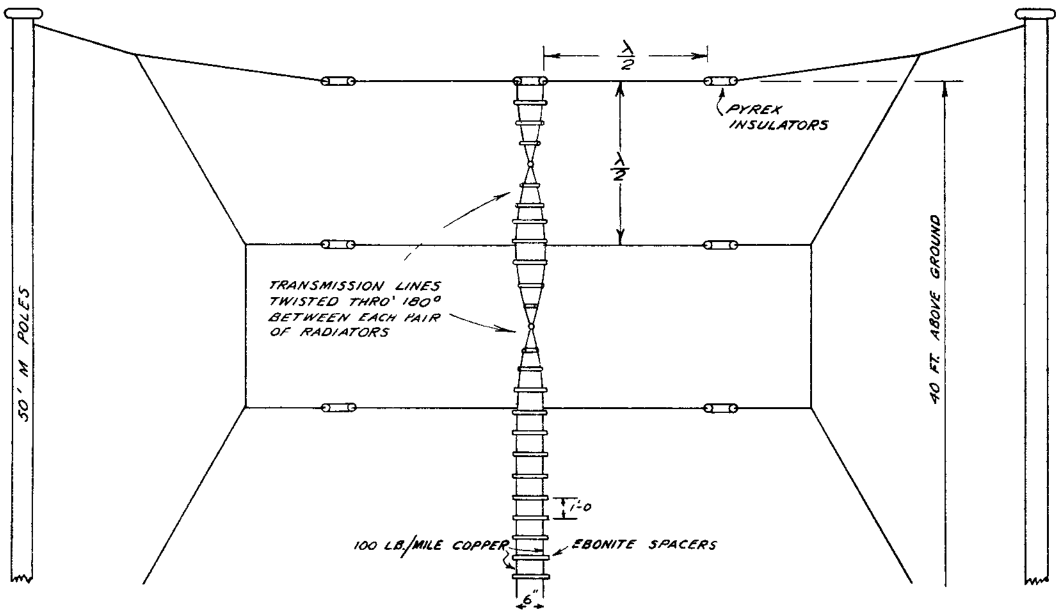


FIG. **11**.—ARRAY FOR ULTRA SHORT WAVE TRANSMITTERS AND RECEIVERS.

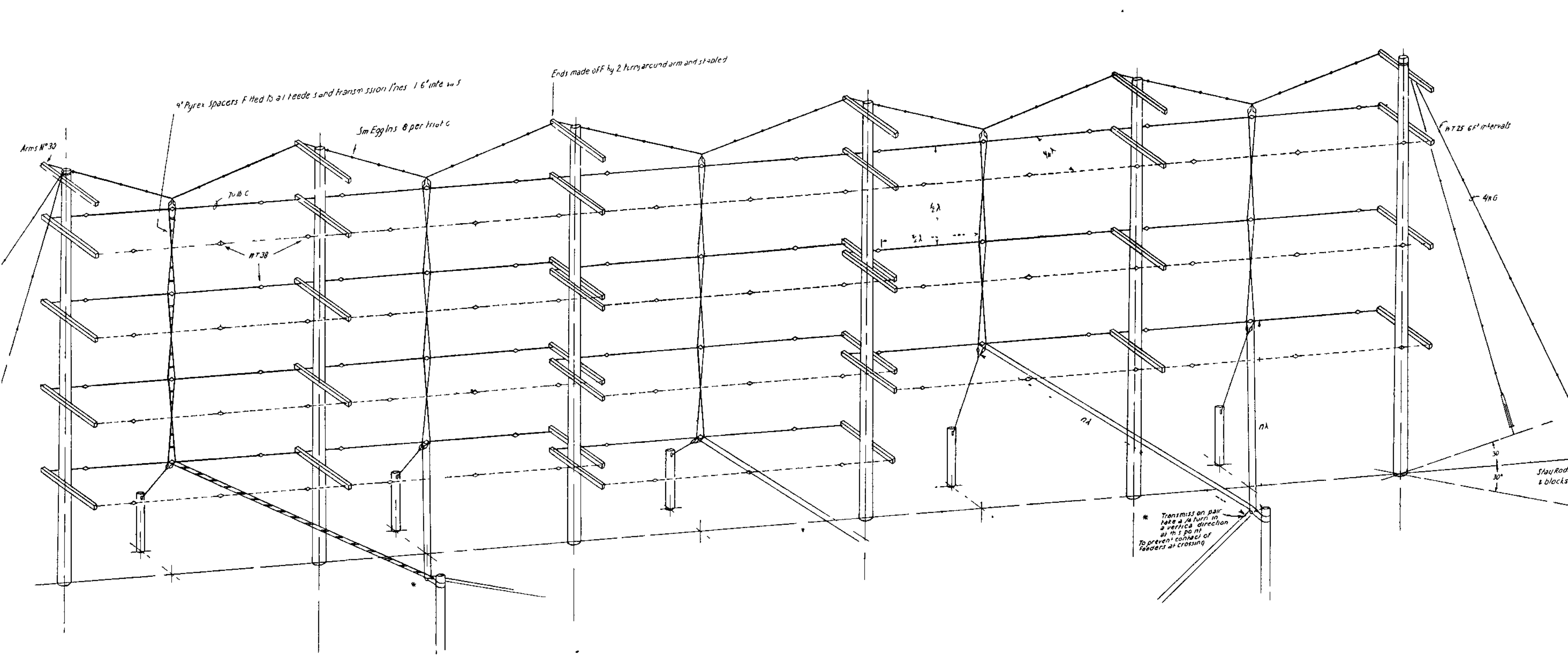


Fig. 12.—U.S.W. Arrays. Stranraer-Belfast. Typical Arrangement.

istic will take the form of a figure eight as shown in Fig. **10**(*b*). In the practical case, however, this radiation characteristic is modified owing to the proximity of the earth from which reflections will occur. A mathematical analysis of the effect of earth reflections and the height of the aerial above the ground is given in Appendix I. The general conclusion gathered from theoretical considerations, and confirmed by practical observation, is that it is desirable for the aerial system to be situated on sloping ground so that the direction of maximum radiation is in a horizontal direction, *i.e.*, towards the distant receiving aerial.

These observations apply more particularly to horizontally polarised radiation, *i.e.*, where the axis of the dipole is in a horizontal plane, but similar considerations will hold in the case of vertical polarisation. Experience has shown that in general horizontal polarisation is to be preferred.

A number of simple half wave dipoles may be connected together in such a manner that the radiation from the respective elements are in phase in the desired direction, but tend to cancel out in all others. A very considerable increase in the energy radiated towards the distant receiving aerial is thus realised although the total radiated energy is approximately the same. An aerial system of this type is known as an array and a typical structure is shown in Fig. **11**. The effective gain obtained from an array depends upon the number of radiators used, a 3 db. improvement normally being obtained by doubling the number of elements. It will thus be appreciated that there is a practical as well as economic limit to the size of array which may be employed. In practice arrays of up to 48 elements in size, giving a gain of 17 db. over a single element, have been constructed and used on commercial services.

In a practical case one half of the elements may be placed approximately a quarter of a wave-length behind the other half; only the latter being energised by direct connexion to the transmitter. The rear elements thus act as reflectors and a typical array showing the type of construction used is illustrated in Fig. **12**.

Propagation.

It is partly the peculiar propagation phenomenon of ultra short waves which renders them especially suitable for short telephone links across river estuaries and sea channels. The peculiarity lies in the fact that only the ground wave persists, there being no known reflections from any ionised layer in the upper atmosphere. Thus the field is normally considered to exist only to an optical distance. This fact allows several telephone links to be worked on the same wave-length provided they are not within optical range of one another. Circuits can be worked over distances which are in excess of the optical distance, but the received field strength is of a low order with normal transmitter power and is subject to fading.

The two distinct cases of propagation over (*a*) Optical and (*b*) Non-Optical paths will now be considered in further detail.

(*a*) *Optical Path.*

The maximum field strength E in volts per metre at a distance D miles in free space from a half wave dipole is given by the equation :—

$$E = 4.35 \times 10^{-3} \frac{\sqrt{W_T}}{D} \text{ volts per metre......(1)}$$

where W_T is the power radiated in watts.

Owing to the proximity of the earth the field strength near the earth's surface is always below the value given by equation (1). For distances up to 40 miles the field strength has been found to vary inversely as the square of the distance and for horizontal polarisation has been found to approximate to the value given by the equation :—

$$E_1 = 3 \times 10^{-3} \frac{\sqrt{W_T}}{D^2} \text{ volts per metre.........(2)}$$

The curves of equations (1) and (2) are shown in Fig. **13**.

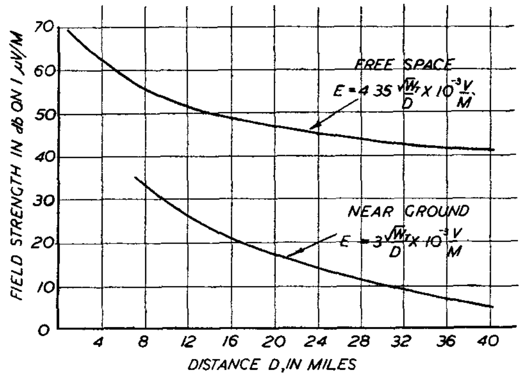


FIG. **13**.—FIELD STRENGTH FROM 1 WATT TRANSMITTER (USING SIMPLE DIPOLE AERIAL).

(*b*) *Non-Optical Path.*

When the distance between the transmitter and receiver is such that there is not an optical path, the fact that there is a field strength of receivable value from the transmitter may be attributed to either reflection, refraction or diffraction.

It has already been stated that reflection from an ionised layer above the earth's surface, such as that experienced on short and medium wave-lengths, is unknown.

Refraction round the earth's surface is considered to occur owing to the variation of the dielectric constant of the atmosphere with height above the earth. The effect of refraction is to increase the effective optical distance by bending the line of propagation round the surface of the earth.

Diffraction or scattering of radiation round the earth's surface also takes place and the effect on the propagation is usually considered to be of the same order as that due to refraction.

Fading is experienced on ultra short waves, but whereas on short waves it is due to the interference between the direct and indirect or between the various indirect rays it cannot, in this case, be due to the same cause, as there is no reflected ray. It seems probable that the fading on ultra short waves is due to a change in the effective refraction which in turn is due to a change in the dielectric constant of the atmosphere over the path between the transmitter and receiver.

Application to Four-Wire Telephone Circuits.

When a radio circuit becomes a link in a telephone circuit it is desirable that it should restrict as little as possible, if at all, the facilities of the circuit of which it becomes a part. Thus a radio link in a junction circuit where C.B.S. or C.B. working is employed should provide equivalent signalling facilities. Where the radio circuit becomes part of a repeatered trunk line the question of D.C. signalling no longr obtains, and no additional equipment need be provided for the 500/20 cycle ringing facilities.

In radio circuits, whatever their length, noise is the limiting factor; that is to say the signal to noise ratio is the criterion of its suitability for commercial operation. On long wave circuits such as the 60 kilocycle transatlantic circuit atmospherics are the chief source of noise, while on short waves of from 15 to 100 metres, the noise may be due either to atmospherics or may originate in the first circuit of the receiver. On ultra short waves atmospherics are not experienced and the noise is wholly receiver noise. In a correctly designed and adjusted superheterodyne receiver the noise is due to thermal agitation in the first circuit. The power of the first circuit noise is a definite fixed quantity for any given absolute temperature, and the signal strength must be considerably higher for satisfactory working. The noise may be regarded as equivalent to cross-talk noise in which case the radio signal should, for commercial operation, be some 55 db. above the level of the first circuit noise.

Up to the present time only super-regenerative receivers have been used on commercial circuits. With this type of receiver the noise still originates in the receiving circuits, but owing probably to the peculiar mechanism by which the amplification is obtained, the inherent noise is considerably higher than that from a superheterodyne receiver.

Having obtained the requisite signal to noise ratio over the radio link, it may then be included as part of a four-wire telephone circuit and will function in effect as a four-wire repeater.

Modulation Level.

On ultra short wave radio links working over optical distances of up to about 40 miles the power of the radio transmitter should be kept low for economic reasons. Transmitter output powers cf up to 5 or 6 watts have usually been employed and with this low power, and using a super-regenerative receiver, it is necessary to modulate the transmitter completely in order to obtain a satisfactory signal to noise ratio. The speech power received at the input to the radio equipment is a very variable quantity and it is necessary when first setting up the circuit to adjust the low frequency gain in front of the transmitter, so that the loudest talkers just fully modulate the transmitter. The problem can best be understood by reference to Fig. 14. The case considered is that in which, by fully modulating the transmitter, a signal to noise ratio of 55 db. is obtained. The

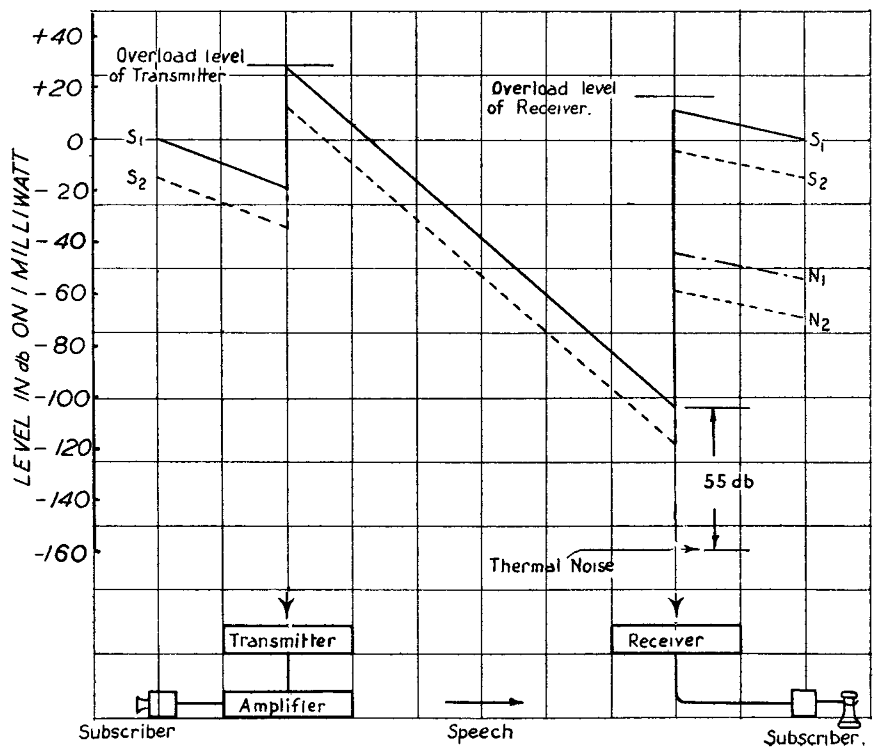


FIG. 14.—LEVEL DIAGRAM OF U.S.W. CIRCUIT.

overload point of the transmitter is assumed to be + 27 db. on 1 milliwatt, total side band power, the carrier power being + 30 db. on 1 milliwatt. If the highest speech level at the input to the transmitting equipment is − 20 db. on 1 milliwatt the gain in the transmitter from low frequency input to high frequency output must be 47 db. The receiver gain is considered to be so adjusted that the transmission equivalent of the overall circuit is zero. If, however, the input to the transmitter is − 35 db. on 1 milliwatt it would be necessary in order to load the transmitter fully and so obtain the optimum signal to noise ratio, to increase the gain in the transmitter to 62 db. and reduce the receiver gain by 15 db. so that the overall circuit equivalent remains at zero.

Automatic Technical Operators.

Technical operators are employed on overseas radio circuits to ensure that the radio transmitters are always fully loaded, thus enabling the best signal to noise ratio to be obtained as discussed in the previous section. The provision of staff to compensate by means of manually operated gain controls for the wide variation in speech input level to the transmitter, cannot be economically justified on ultra short wave circuits, but the provision of automatic equipment known as an " automatic technical operator " is being considered for circuits where a good signal to noise radio cannot otherwise be obtained economically.

Voice Operated Devices.

Voice operated devices which are associated with telephone circuits are normally of two kinds, echo suppressors and stabilisers. Echo suppressors are made necessary by the electrical length or propagation time of certain line circuits, but the electrical length of radio circuits being always very small the provision of echo suppressors is not necessitated by the introduction of the radio link. Stabilisers, which normally hold one side of a four-wire circuit closed until the speech opens up a path for itself, are necessary if automatic technical operators are employed. The use of stabilisers, together with technical operators, besides enabling the transmitter to be fully loaded and so allowing a signal to noise ratio lower than 55 db. to be used, permits the overall circuit to work at a gain so providing the facility that a weak speaker's volume may be brought up to normal.

Automatic Gain Control.

Even over optical distances it is not possible to provide a perfectly constant input to the receiver so that the low frequency gain between transmitter input and receiver output would vary unless steps were taken to provide some form of automatic gain control.

Automatic gain control consists essentially of a means of varying the receiver gain in such a manner that the low frequency output remains constant whatever the radio frequency carrier input level. Super-regenerative receivers have a logarithmic detection characteristic and as such inherently give a constant output over a wide range of carrier input levels. Superheterodyne receivers require special provision to be made for automatically changing the gain as has been shown in a previous section.

Over optical paths automatic gain control is not essential as the receiver input variations are small. It is, however, a desirable feature in order to ensure stability of the overall circuit.

Over non-optical paths automatic gain control of the receiver is essential, owing to the wide variations of the receiver input caused by fading.

Ringing and Supervisory Facilities.

If the radio link forms part of a trunk circuit 500/20 cycle ringing will be provided, in which case the radio equipment will not need any modification. There is one important condition to be observed, however, and that is that the ringing tone level should not be higher than the highest level of speech. This is essential since, as has been discussed previously, the transmitter low frequency gain is adjusted so that the transmitter is fully loaded on peak levels of speech. The highest speech level may on certain circuits be low and the ringing tone level in these cases should therefore be correspondingly low.

Where the radio circuit is part of a junction circuit working under C.B.S. or C.B. signalling conditions, the full facilities may be provided by arranging that the insertion of the plug into the calling jack starts up the transmitter and so gives a signal at the distant exchange, the receiver being permanently switched on. The answering signal is given by starting up the transmtter in the reverse direction.

The direct transmission of 17 cycle ringing over a radio link is not possible owing to the high loss on the radio equipment at this frequency, thus precluding the use of radio links on magneto signalling junctions without the provision of special equipment.

Dialling over radio junctions has not so far been investigated, but there appears to be no reason why a suitable tone system could not be developed should the necessity arise.

Secrecy Equipment.

Except in the most isolated parts it is desirable to incorporate secrecy equipment with the radio link, so that in the event of the reception of transmissions by any unauthorised station the speech may be wholly unintelligible. Two types of secrecy equipment are suitable for use on ultra short wave radio links, namely, inverters and " channel switching."

Inverters of a simplified type incorporating copper oxide rectifiers have been developed which are suitable for use on radio links where only one or two channels are provided. The general scheme of the inverter is shown in Fig. **15**. It will be observed that the frequency is changed once only, this feature allowing the cost of the equipment to be greatly reduced compared with the more general type of inverter which uses double frequency changing.

Where several radio channels are in operation a scheme which ensures secrecy without the use of inverters has been developed whereby the land lines are switched to the various radio channels in turn so that should an illicit receiver pick up the speech from

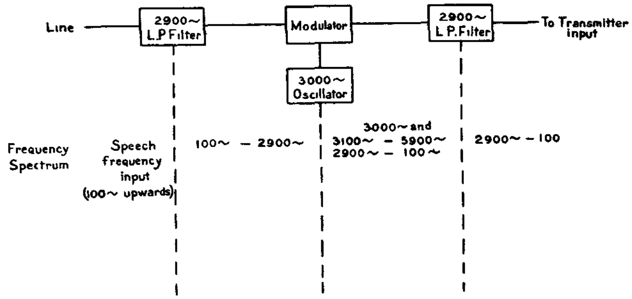


Fig. 15.—Block Schematic Diagram. Simple Inverter.

any one radio channel, scraps of several conversations will be heard which will be wholly unintelligible. The frequency with which the channels are switched is not critical, but is usually of the order of 30 times per minute. Clicks and interruptions introduced by this scheme are negligible, normal automatic telephone type switching equipment being used.

Multi-Channel Working.

Where more than one radio circuit is required between any two points, the apparatus may be one of two general types. The type which has so far been employed by the Post Office, and will be described later in this paper, is that which uses a separate carrier frequency for each channel, the speech modulation being effected directly on the carrier. The other type, of which a 9-channel example is now in course of construction, and has been developed by the Standard Telephone and Cable Co., Ltd., employs a sub-carrier system, only one main radio carrier being used. Various advantages are claimed for the two systems, but until experience has been obtained under working conditions, it is not possible to say which will be preferred for future use.

Experimental and Commercial Circuits.

Dollis Hill—St. Albans Radio Station Experiments.

The first experiments over a distance of greater than 3 or 4 miles were carried out in September, 1930, between Dollis Hill and St. Albans Radio Station. The transmitter was located at Dollis Hill and a portable receiver was used at St. Albans. The tests showed that the use of simple arrays was an improvement over the simple half wave dipole, both at the transmitter and receiver. It was also established that the plane of polarisation remained unchanged. Good intelligible speech was obtained over the non-optical path of 14 miles.

Southend-Sheerness Experiments.

The provision of a radio link between Southend and Sheerness, a distance of some 7 miles across the Thames Estuary, seemed a case in which certain advantages would be realised over the circuitous route taken by the normal junction circuits.

Tests were carried out between the exchanges at Southend and Sheerness in October, 1930. A circuit with a signal to noise ratio of 22 db. was obtained using single half wave dipoles on a wavelength of 5 metres. This figure was considerably lower than that expected and was found to be due to the very unfavourable site which the Southend Exchange provided. The interference noise from the ignition systems of motor vehicles in the neighbouring streets indicated the undesirability of locating aerial systems in towns or near busy roads.

Tests were carried out on 3 and 5 metres, the 5 metre transmissions proving the superior.

Dollis Hill-Colney Heath Circuit.

The first experimental two-way ultra short wave telephone circuit was set up between Dollis Hill and Colney Heath, over a distance of 13 miles, in May, 1931. The path was non-optical, but was considered suitable for carrying out the initial tests of a two-way circuit. These tests included the determination of the frequency and physical spacings required between the transmitter and receiver at each terminal. Further tests were also made which confirmed that the received field was due to the direct ray and not to any reflected ray.

Cardiff-Weston-super-Mare Circuit.

The success of the experimental circuit between Dollis Hill and Colney Heath indicated that a commercial radio telephone link operating in the ultra short wave band was a practical proposition, and it was therefore decided to establish such a circuit across the Bristol Channel to provide a junction between the Cardiff and Weston-super-Mare exchanges. Sites giving an optical path for the transmissions were selected for the radio stations, that on the Weston side being at Hutton and that on the Cardiff side at Lavernock, both being some four miles from the respective telephone exchanges. In order to eliminate any possibility of cross-talk between the local transmitter and receiver two portable battery huts were erected to house the transmitting and receiving equipment respectively, the spacing between the two huts being 100 yards. Cables were laid between the two huts for the requisite telephone and power connections, a two pair overhead route being provided to extend the land line circuits from the nearest available route. The power lines were run on the same poles as the telephone circuits as an exceptional measure to provide the requisite power supply. Two 50 ft. medium poles were provided in front of each hut to support the aerial systems which initially consisted of simple half wave dipoles. The radio transmitters operated from the 230 volt A.C. mains through suitable rectifying equipment, giving a 300 and 120 volt high tension supply for the oscillator and modulator, and line amplifier stages respectively. A.C. was used for heating the cathodes of the valves, V.T. 24s being used in the former stages and ML 4s in the latter. The radio receivers were operated entirely from secondary cells which were provided in duplicate, one set being on discharge, while the other was being charged from rectifiers off the A.C. mains.

The receiver filament current was maintained constant by means of barretters, while the high tension voltage was maintained at 100 volts by means of a special valve stabiliser which is described in Appendix II.

Associated with the receiver was a volume indicator for low frequency measurements and lining-up purposes together with a conventional low frequency amplifier which was used to adjust the speech output level to give the requisite overall circuit gain. On the initial tests a signal to noise ratio of about 45 db. was obtained which was satisfactory for working a commercial telephone circuit. The transmitter input amplifier was set to such a gain as to give optimum loading of the transmitter on the highest level of speech received from the adjacent exchange while the receiver amplifier was adjusted to give an overall transmission equivalent of about 6 db. for the four-wire circuit. With the co-operation of the Traffic Branch the circuit was brought into experimental service for telephone connections between Cardiff and Weston-super-Mare in October, 1932. At this stage standard 500/20 cycle trunk ringing was used, but owing mainly to the ringing tone level being considerably higher than the peak speech level the operation was not entirely satisfactory. For this reason, and also in order to give standard C.B. signalling facilities, it was decided to employ the third wire signalling system as used on the physical junction circuits between the respective exchanges.

It was not desired to investigate the problem of providing C.B. signalling over a radio circuit until the success of the radio equipment from the point of view of speech transmission had been established. With the radio equipment operating as described above an average period of operation of 265 hours without any attention to the radio equipment was obtained, the limiting factor being generally the life of the transmitter oscillator valves. This was, on an average, 860 hours. Owing to the fact that all the valves did not fail at the same time the period of operation of the circuit without attention was less than the average valve life. As the general stability of the radio equipment had proved satisfactory it was decided to endeavour to obtain longer lives for the transmitter valves by underrunning at 4.5 instead of 5.5 volts on the filaments and 125 volts instead of 300 on the anodes. In order to compensate for the consequent reduction in power, simple six-element arrays were erected at each station for both the transmitters and receivers. The gain of these arrays was such that a signal to noise ratio of 50 db. was realised. The result of this power reduction was to increase the lives of the transmitter valves to 3000 hours, resulting in an average period of operation without attention of over 1000 hours, corresponding to continuous operation for about six weeks. In one case the circuit operated for nearly four months without any attention whatever.

In November, 1934, the circuit was closed down and later the radio stations were dismantled as the equipment was of an experimental character and had not been designed for commercial use for long periods. In all the circuit had been in operation for over two years and had proved the practicability of ultra short wave radio links, at the same time supplying much valuable data for future design.

Six Circuit Equipment.

The successful results of the Cardiff-Weston circuit led to the decision to investigate the practicability of providing multi-channel circuits operating within the ultra short wave band. A basic design for a twelve circuit scheme was evolved, having the frequency allocations shown in Fig. **16**. A detailed

Circuit No.	Channel No.	Wave-length in metres.	Frequency in megacycles per sec.	Spacing in megacycles per sec.
1	1*	4.16	72.0	
	2*	4.24	70.8	1.2
2	3	4.32	69.5	1.3
	4	4.40	68.2	1.3
3	5*	4.48	67.0	1.2
	6*	4.56	65.8	1.2
4	7	4.64	64.7	1.1
	8	4.72	63.6	1.1
5	9*	4.80	62.5	1.1
	10*	4.88	61.5	1.0
6	11	4.96	60.5	1.0
	12	5.04	59.5	1.0
7	13*	5.12	58.6	0.9
	14*	5.20	57.8	0.8
8	15	5.28	56.9	0.9
	16	5.36	56.0	0.9
9	17*	5.44	55.2	0.8
	18*	5.52	54.4	0.8
10	19	5.60	53.5	0.9
	20	5.68	52.8	0.7
11	21*	5.76	52.0	0.8
	22*	5.84	51.4	0.6
12	23	5.92	50.7	0.7
	24	6.00	50.0	0.7

* Channels used on 6-Circuit Scheme.

FIG. **16**.—FREQUENCY ALLOCATION FOR 12-CIRCUIT MULTI-CHANNEL SCHEME.

design was developed for equipment to provide six circuits using the frequencies marked with an asterisk. By choosing alternate pairs of frequencies in this way it was possible to prove the practicability of working with the adjacent channel frequencies required for twelve circuits.

A brief description of the six circuit equipment will now be given.

Fig. **17** shows a front view of the transmitting equipment. Steel panels using back and front construction for the apparatus are employed throughout, the units being mounted on racks of overall height, 6 ft. 6 ins. The right hand rack accommodates the six transmitters to which the aerial transmission lines are connected through terminals on the backs of the respective panels. The left hand rack is used for the metering, control and fusing of the supply circuits. Miniature type circuit breakers are used for distributing the high tension supply and these have proved preferable to fuses in view of the relatively high voltage involved and have given every satisfaction in practice. Fig. **18** shows a front view of the receiving equipment. The general type of construction is the same as that employed for the transmitting equipment. On the right hand rack are the six receivers which are connected, as in the

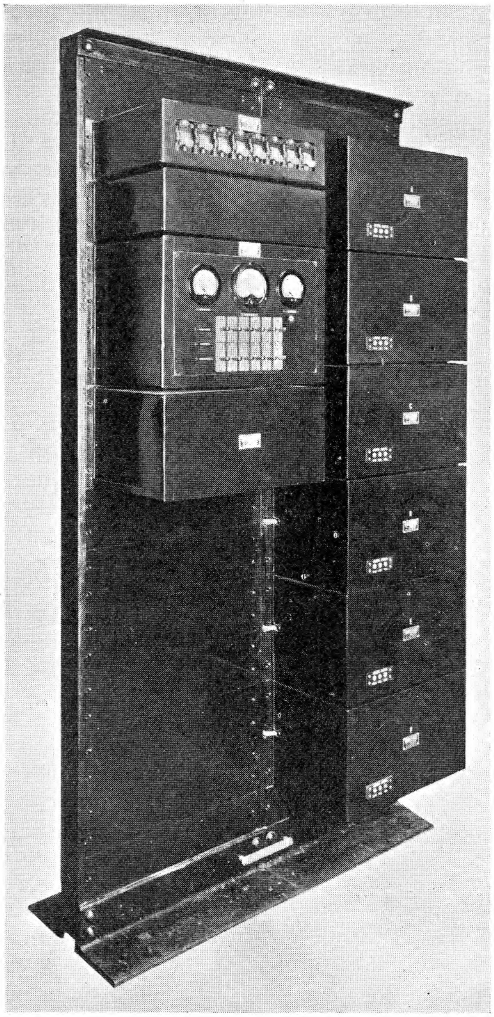


FIG. 17.—SIX-CIRCUIT EXPERIMENTAL ULTRA SHORT WAVE EQUIPMENT.
TRANSMITTER BAYS. FRONT VIEW.

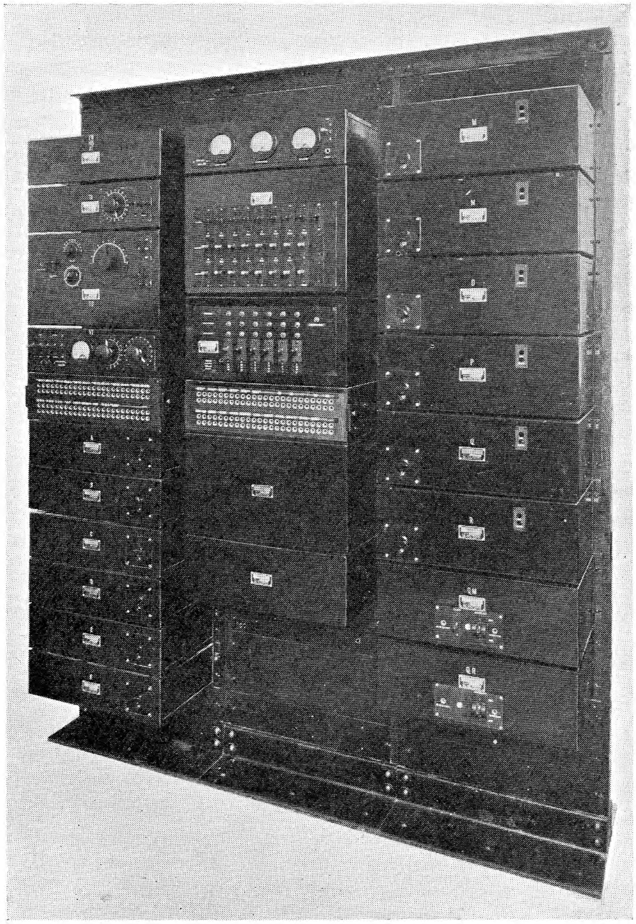


FIG. 18.—SIX-CIRCUIT EXPERIMENTAL ULTRA SHORT WAVE EQUIPMENT.
RECEIVER BAYS. FRONT VIEW.

case of the transmitters, to the aerial transmission lines at the rear. Below the receivers are mounted the two quench frequency oscillators, one main and one reserve. Being common equipment on which the operation of all six circuits would depend, it was considered advisable to provide for an automatic change-over to a reserve quench oscillator in the event of a failure of the main oscillator. Each unit consists of a single oscillator valve driving a class " B " push-pull amplifier so that the anode current in the latter stage is a measure of the 15 kilocycle output. An interlocked relay system has been incorporated so that when the output of the main oscillator falls to a predetermined value, the reserve oscillator is brought into use and the main equipment switched off. This has proved very satisfactory in practice, the change-over causing no appreciable interference to a working circuit. The centre rack accommodates the metering, control and fusing equipment for the power supplies, together with two jack strips in which are terminated the respective receiver outputs and the " Go " and " Return " trunk lines. The left hand rack accommodates the low frequency measuring equipment consisting of a heterodyne oscillator, amplifier and volume indicator giving a range of measurement of from -60 to $+30$ db. on 1 milliwatt. On the lower part of the rack are situated the six transmitter line amplifiers connected to the respective transmitters over an interhut cable. These are accommodated with the receiving equipment so that all level control and measuring points may be easily acessible for adjustment and routine tests. A series of jacks above the line amplifiers provide access to the amplifiers and transmitter inputs for measurement and monitoring purposes. The testing and measuring equipment is also terminated on jacks in the same strip.

Previous experience had shown that where continuous operation is required it is desirable to have some form of reserve or standby power supply to cover the occasional periods when the public supply is not available. It was therefore decided, for the six circuit equipment, to adopt a floating battery scheme, the batteries being of such a size as to give an eight hour standby on continuous full load. In order to maintain a battery fully charged under floating conditions, the voltage per cell should be maintained at approximately 2.15 volts. The drop to 2 volts per cell when the power supply failed could be accommodated without undue deterioration of the circuits. It was intended originally to provide the facility whereby individual circuits could be switched off during light traffic load and, consequently, it was necessary to arrange for the charging current to be maintained at such a value as to keep the battery at 2.15 volts per cell independent of the load. A charging scheme incorporating a " Thyratron " or grid controlled mercury rectifier was developed for the high tension supply, details of which are given in Appendix III.

As this equipment was of an experimental nature, and in view of more recent developments is unlikely to be repeated, no useful purpose will be served in giving a detailed circuit description in this paper.

A suitable rectifier of this type, for use with the low tension batteries, was not available at the time the equipment was designed and accordingly a straightforward copper oxide rectifier scheme with manual control was adopted.

The six circuit equipment just described was installed in June, 1934, for experimental purposes, across the Bristol Channel, between Backwell Hill and Castleton, over an optical path of 18 miles. A considerable amount of experimental work was carried out and various modifications made to the equipment. By the end of November, the equipment was in a condition to enable extended stability trials to be contemplated. At that time, however, there was an urgent demand for additional telephone circuits across the North Channel, between Scotland and Ireland, where sites for radio stations were available, and huts and aerials were in course of erection, with a view to providing six ultra short wave radio circuits at some later date. It was then decided to transfer the equipment from the Bristol Channel to the North Channel sites. The work was commenced on the 2nd December, and, with the willing co-operation of the District and Headquarters' staffs concerned, the first radio trunk circuit was established between London and Belfast on the 23rd December, and by Christmas Day five circuits were available for traffic, the sixth being retained as an order wire between the two radio stations. Later the sixth circuit was brought into use for traffic purposes. With the exception of a few days when aerial modifications were being made, the circuits have been in continuous operation for some ten months.

Shetlands Phonogram Equipment.

A demand arose for a phonogram circuit for the transmission of telegrams between Lerwick and Housay, an island in the Out Skerries of the Shetlands, a distance of 23 miles, the path being optical. After making preliminary measurements with portable equipment, it was decided to provide the service by means of an ultra short wave radio link. The main considerations were that the apparatus should be cheap to instal and maintain. For these reasons the equipment was made as simple as possible, and, as only a phonogram service was required, a simplex circuit was provided.

The equipment was so designed that the same components were used for either transmitting or receiving by the operation of a single change-over switch. The general lay-out of the apparatus is shown in Fig. **19**, and is seen to consist of three units, the transmitter-receiver unit, the time switch and the microtelephone. The equipment is normally switched off, the time switch starting up the receiver for one minute each hour. A circuit is incorporated in the receiver so that, should it be desired to establish communication, the distant station may start up its transmitter and so energise the calling circuit in the receiver. This circuit is so arranged that a bell is rung should the distant transmitter start up while

FIG. **19**.—5 METRE TRANSMITTER/RECEIVER.

the receiver is switched on for the one minute period. The time switches are so set that one receiver is switched on at the hour and the other at the half-hour. Thus, although the receivers are in operation for only one minute each hour, the facility of hourly calling is provided in each direction.

The circuit diagram is shown in Fig. **20**. In the transmitting condition, the two valves are arranged to function in push-pull as the transmitter oscillators. A third valve has the microphone in the grid circuit and is arranged for anode modulation of the oscillator. In the receiving condition the first pair of valves comprise the oscillating detectors of a super-regenerative receiver. The third valve supplies the quench voltage and the fourth is used in the calling circuit. As has been seen earlier, when a carrier is received on a super-regenerative receiver, the noise drops. This absence of noise is arranged to allow a relay in the anode circuit of the calling valve to release and so make a circuit for the operation of the calling bell.

A secondary cell supplies the filament power and lasts for some two months without recharging, while dry cells are used for the high tension supply and give a life of about six months. This circuit was installed in November, 1934, and has been in operation giving satisfactory service for the last twelve months

Shaftesbury-Guernsey Circuit.

It was decided in January, 1934, to investigate the possibility of providing an ultra short wave radio telephone circuit between Guernsey and the mainland. The position of the Channel Islands with respect to the mainland is such that the shortest distance from Guernsey to the English coast is about 80 miles. The highest point on Guernsey, 250 ft. above sea level, and the highest point on the coast of the mainland, 600 ft. above sea level, do not provide an optical path.

The first step in determining whether such a circuit would be feasible was to instal a transmitter, having an output of about 10 watts, at Fort George on Guernsey. Field strength measurements of these transmissions which were sent out on wave-lengths of 3, 5 and 8 metres, were made along the south coast of the mainland. Fading was experienced on all three wave-lengths, the 3 metre transmissions being heard at only one point, while the 5 and 8 metre transmissions were heard consistently. On account of the fading it was essential to take a series of measurements over a period of several weeks, in order to determine the reliability of the transmissions. This series of measurements was made at Compass Cove, near Dartmouth, over a total period of two months and indicated that it should be possible to set up a circuit if array systems were used at each end of the circuit.

It was not found possible to obtain a permanent site at Compass Cove, thus necessitating the selection of an alternative site. Whilst looking for a permanent site, it was found that the field strength some 25 miles inland and 800 ft. above sea level was of a similar order to that observed earlier in the year, near the coast. As the negotiation for a permanent inland site seemed an easier matter than the acquisition of a coastal site, it was decided to set up a receiving station near Shaftesbury. Measurements made at this site during the summer of 1934 showed the field to be as high as that obtained at Compass Cove during the spring of the same year, and it was therefore decided to instal the equipment necessary for a two-way circuit working on a wave-length of 5 metres in the one direction and $5\frac{1}{2}$ metres in the other direction.

Fig. **21** shows a view of the receiving equipment, the lay-out of the transmitting rack being similar.

Fig. **21**.—Receiving Equipment. Guernsey-Mainland Ultra Short Wave Circuit.

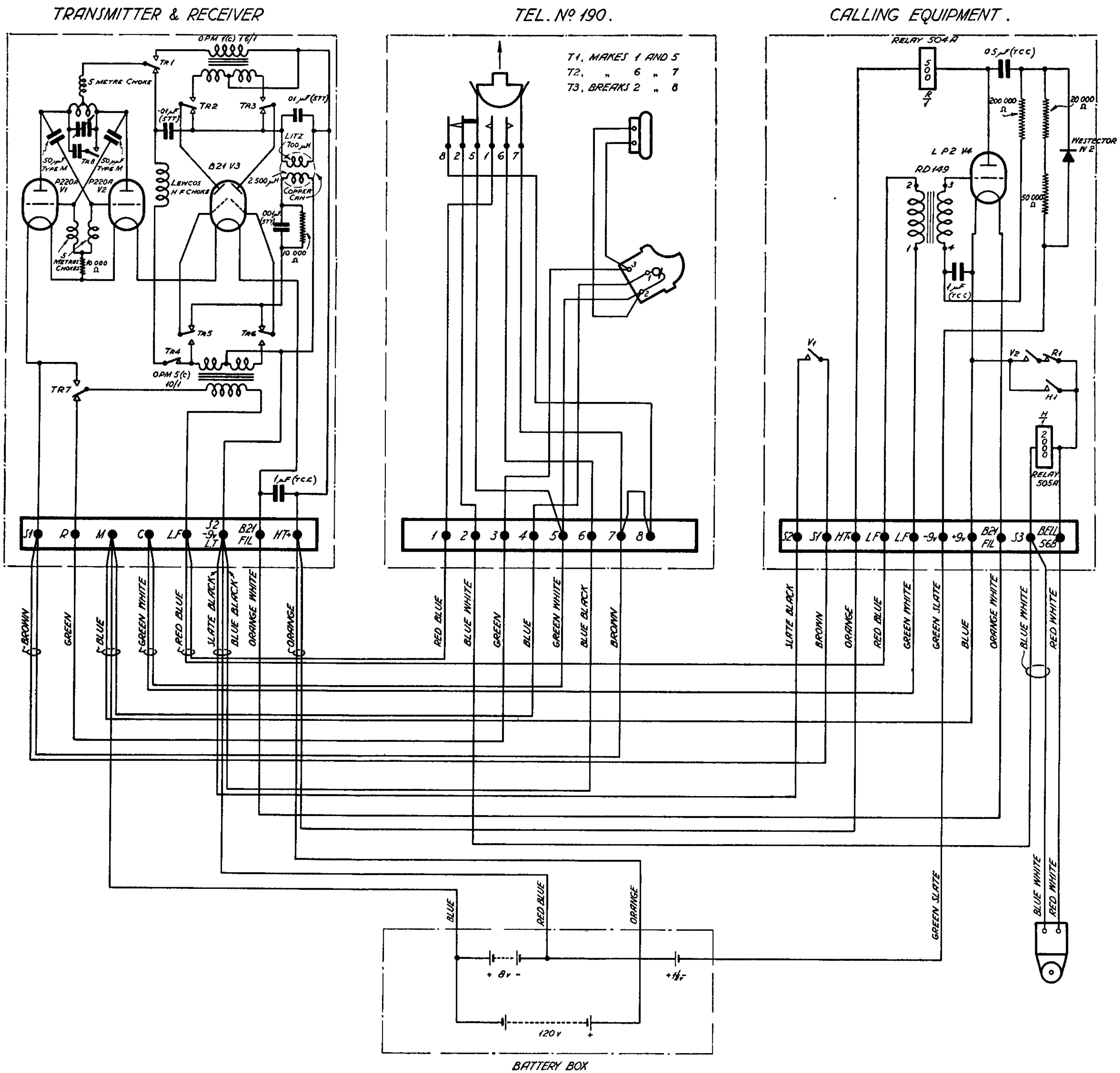


FIG. 20.—WIRING DIAGRAM OF SHETLANDS. U.S.W. TRANSMITTER/RECEIVER.

Copper oxide rectifiers are used to float the high and low tension batteries used for the power supplies.

The two-way circuit was established in December, 1934, but the results obtained were disappointing, it being found that the field strength was considerably lower than that expected from the measurements made during the summer months. Observations were continued into the spring of 1935, and the field strength gradually improved until by the end of March it was sufficiently high to warrant the use of the circuit for traffic purposes on an experimental basis.

Secrecy on the circuit is provided by the use of simple inverters.

Since April, 1935, the circuit has handled a considerable amount of traffic, and it has been possible to observe the behaviour of the transmission under working conditions throughout the summer months. Attempts have been made to correlate the field strength variations with varying atmospheric conditions, but without any great success.

During the summer of 1935 measurements were made at a coastal site in order to see whether less fading is experienced by working on the coast some 25 miles nearer the transmitter. An analysis of these measurements showed that the fading is less and the average field greater at the coast. Owing to the varying nature of the field it has taken some months to obtain adequate data to establish these points.

Up till now the Guernsey transmitter has been delivering 10 watts of high frequency power to the aerial system, but in a few weeks it is hoped to instal a higher power crystal controlled transmitter, giving an output of up to 500 watts.

Receivers of the superheterodyne type are also in course of construction, and will give a considerable improvement in signal to noise ratio.

It is anticipated that the use of the coastal site, together with the higher power transmitter and improved receiver will provide a circuit capable of handling commercial traffic for 24 hours a day throughout the whole year.

Work in other Countries.

Experimental work on ultra short wave radio telephone circuits has been carried out by various foreign administrations and a list of circuits, which are known to have been established, is given in Appendix IV. In general this work seems to have progressed along similar lines to those followed by the British Post Office, but the general tendency seems to have been towards the adoption of more complex equipment than that used in this country, particularly as regards the use of voice operated switching devices for stabilisation of the four-wire circuit.

Conclusion.

In conclusion, the authors wish to acknowledge the contributions to the development of ultra short wave radio circuits on the part of many present and past members of the Radio Branch of the Post Office Engineering Department.

Appendix I.

The Design of Array Systems using Horizontal Elements.

From theoretical considerations of the effect of reflections from the earth's surface immediately in front of array systems, two curves have been obtained which enable the most effective system to be chosen.

Curve 1 is shown in Fig. **22**, the factor $\left(\frac{h}{\lambda} + \frac{n-1}{4}\right)$ being plotted against ϕ, the slope of the ground in front of the array, to satisfy the condition that the maximum radiation shall be in a horizontal direction. The terms in the factors are :

h = height of the lowest element of the array above the ground, in metres.

λ = wave-length in metres.

n = the number of tiers of elements in the vertical plane.

Curve 2 is shown in Fig. **23**, the gain in db. of the array system being plotted against the slope of the ground for various values of n, assuming that the conditions specified in Curve 1 have been satisfied.

From a general consideration of Curve 2 it will be seen that the greatest gain is obtained with a small value of ϕ, and a large value of n. Unfortunately, it is difficult to fulfill the conditions imposed unless very high poles are used.

For example if :—

$\phi = 5°$, $n = 6$ and $\lambda = 5$

from Curve 1, $h = 0.75$ metres,

and the height of the highest element is 22.25 metres or 73 ft. which would necessitate the use of poles some 85 ft. in height.

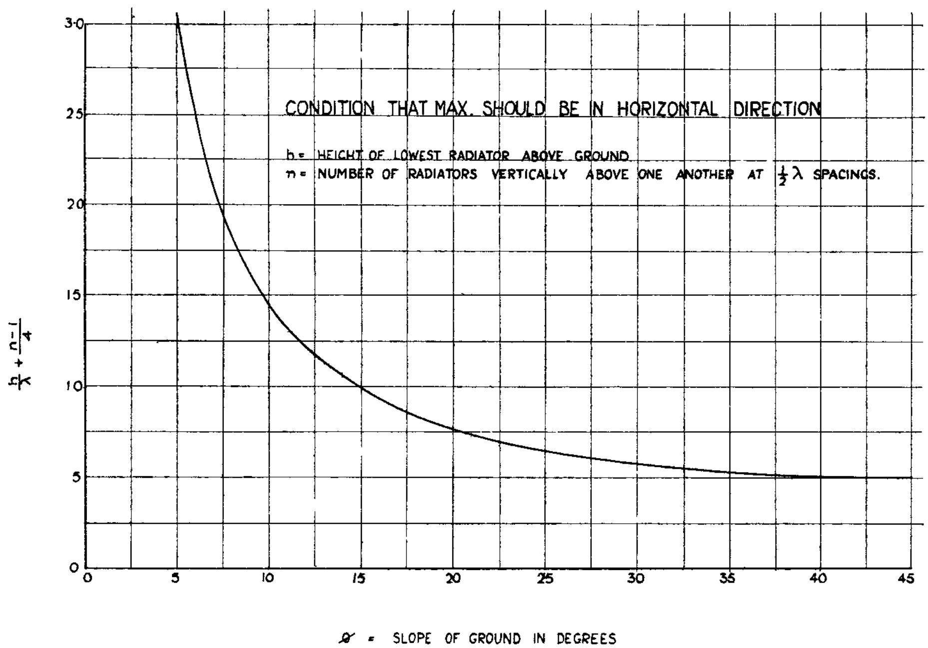


FIG. 22.—HORIZONTAL TYPE ARRAYS ON SLOPING GROUND.

A more usual case will now be considered where the poles are of a reasonable height.

Assuming that the slope of the ground on the site to be used is 10 degrees, then, from a consideration of Curve 2, it will be seen that nothing is to be gained by making n greater than 3.

From Curve 1, $h = 4.75$ metres

therefore the height of the highest element = 9.75 metres or 32 ft., in which case 40 ft. poles would be adequate for supporting the array system.

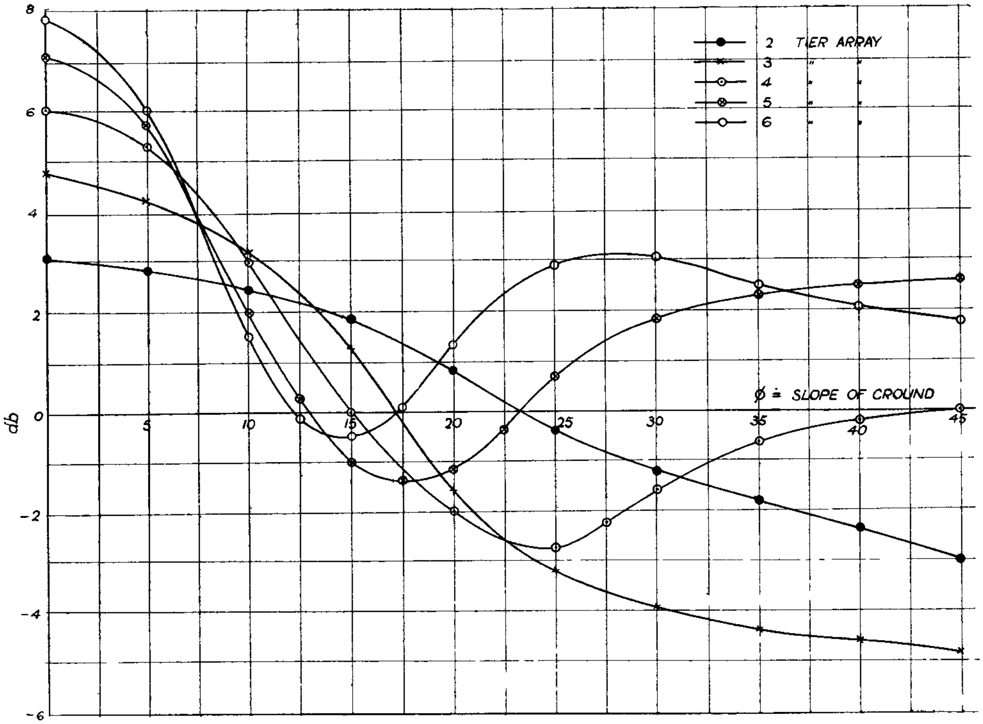


FIG. 23.—HORIZONTAL TYPE ARRAYS ON SLOPING GROUND.

GAIN IN HORIZONTAL DIRECTION OF 2, 3, 4, 5 & 6 TIER ARRAYS OVER 1 TIER ARRAY WHEN CONDITIONS SHOWN ON FIG. 22 ARE SATISFIED.

Appendix II.

Theory of Voltage Stabiliser or Compensating Device.

Fig. **24** shows the circuit arrangements of two forms of compensating device.

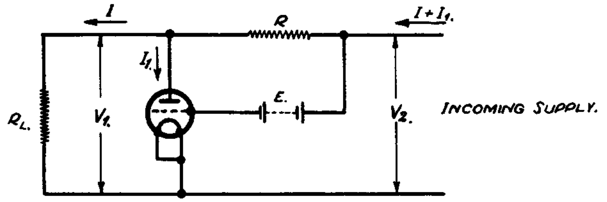


FIG. 1.
COMPENSATING DEVICE, TYPE 'A'.

V_2 = VOLTAGE OF INCOMING SUPPLY.
V_1 = " ACROSS LOAD (R_L)
E. = " OF STANDARD BATTERY.
R_L = LOAD RESISTANCE.
R = COMPENSATING RESISTANCE.
I. = LOAD CURRENT.
I_1 = CURRENT IN COMPENSATING VALVE

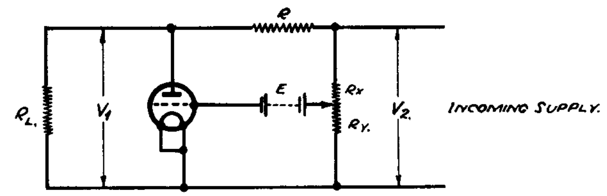


FIG. 2.
COMPENSATING DEVICE, TYPE 'B'.

FIG. **24**.—SCHEMATIC DIAGRAM OF COMPENSATING DEVICE FOR H.T. SUPPLY.

Using the notation given in Fig. **24**, the potential of the grid of the compensator valve is $V_2 - E$.

When the valve is working on the straight part of its characteristic

$$I = A + B\,(V_2 - E) \quad \ldots\ldots (1)$$

A and B being constants.

$$\& \; I = \frac{V_1}{R_L} \quad \ldots\ldots (2)$$

$$\& \; V_2 = V_1 + (I + I_1)R \quad \ldots\ldots (3)$$

Substituting these values of I and I_1 from (1) and (2) in (3) we have

$$V_2 = V_1 + \frac{V_1 R}{R_L} + AR + BV_2R - BER$$

$$\therefore \; V_2\,(1 - BR) = V_1\left(1 + \frac{R}{R_L}\right) + AR - BER \ldots (4)$$

If therefore $1 - BR$ is made equal to zero, V_2 vanishes from the expression and hence V_1 is independent of V_2. Since B is the mutual conductance of the valve under working conditions, R must be made equal to the reciprocal of the mutual conductance.

The variation of V_1 with change in R_L can be deduced as follows :—

If $1 - BR = 0$ from equation (4) we get

$$V_1\left(1 + \frac{R}{R_L}\right) = BER - AR = E - AR$$

since $BR = 1$.

$$\therefore \; V_1 = (E - AR)\frac{1}{1 + \frac{R}{R_L}} \quad \ldots\ldots (5)$$

$(E - AR)$ is a constant quantity determined by the initial set up of the apparatus.

$$\therefore \; V_1 \propto \frac{1}{\left(1 + \frac{R}{R_L}\right)}$$

Therefore although V_1 is independent of the variation of V_2 for any given load R_L, a change of R_L is reflected in V_1. It should also be noted that V_2 can be of the form $V_2\,(1 + k \sin \omega t)$ and the device will compensate correctly providing $2KV_2$ does not exceed the grid swing which can be applied to the valve without distortion.

For the alternative arrangement of the device which possesses the advantage of requiring a smaller grid bias battery, it can easily be proved that R must be made equal to $\frac{1}{KB}$ to maintain V_1 independent of V_2. The value of K is $\frac{R_y}{R_x + R_y}$.

Appendix III.

Constant Voltage Rectifier using a " Thyratron " or Grid Controlled Mercury Vapour Rectifier.

Fig. **25** shows the simpiified circuit arrangement of a constant voltage rectifier used for floating a battery on a variable load.

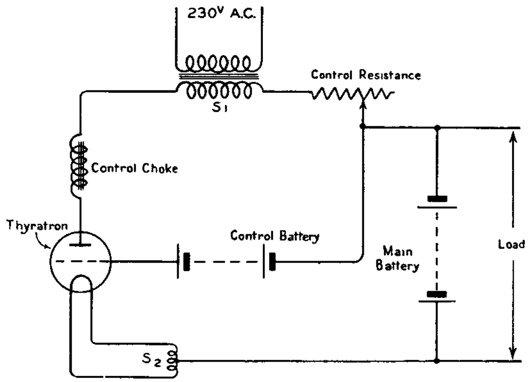


FIG. 25.—SIMPLIFIED CIRCUIT DIAGRAM OF " THYRATRON " RECTIFIER FOR FLOATING BATTERY SCHEME.

In a grid controlled mercury vapour rectifier or " Thyratron " working with a given D.C. potential on the anode, a current will only flow between the anode and cathode if the grid bias potential is less negative than a certain critical value. The value of this critical grid voltage is dependent upon the characteristics of the " Thyratron " and ambient air temperature. Once a current flows between the anode and cathode the value of the current is independent of the grid voltage, except at extreme negative values, and depends only on the anode circuit load and the voltage drop between anode and cathode. The latter is relatively low, being of the order of 10 to 15 volts.

If an A.C. voltage is supplied to the anode of a " Thyratron " the tube will strike at a certain point on the positive half cycle depending upon the grid potential. Thus a pulse of current will be obtained, the effective value and duration of the pulse being dependent upon the grid voltage.

In the arrangement shown in Fig. **25** the grid potental is determined by the voltage difference between the main battery and a reference battery consisting of dry cells. The polarities are such that a fall in the main battery voltage causes an increased charging current and *vice versa.* The degree of control is very close and from no load to full load on the battery its voltage may be maintained to within $\pm \frac{1}{2}\%$.

The maximum charging current is limited by a series choke and control rheostat.

SUMMARY OF ULTRA SHORT WAVE TELEPHONY CIRCUITS OPERATED BY OTHER ADMINISTRATIONS.

Location.	Transmission Between	Distance in Miles.	Wave-length in Metres.	Date Inaugurated.	Power.	Type of Transmitter.	Type of Receiver.	Aerial System in use.	Voice Operated Device.	Is Continuous Monitoring and adjustment of Levels carried out.
Hawaiin Islands	Oahu & Kauai	94	6.35 6.50	1932	No definite information, but an output of 75 watts used in experiments.	Modulated Power oscillator, long line frequency control.	Double Detection receiver. Enclosed in a temperature controlled, heat-insulated box.	Probably R.C.A. Model "B" directive antenna.	Not stated, but from details given probably necessary	Station staffed continuously for maintenance purposes.
	Oahu & Lani	85	5.70 5.55	Proposed						
	Oahu & Molokai	85	5.95 5.80	1932						
	Oahu & Hawaii	190	a { 8.03, 8.27 b { 8.53, 7.80	1932						
	Oahu & Maui	120	a { 7.58, 7.38 b { 7.18, 7.00	Proposed 1932						
	Hawaii & Maui	73	6.06 6.20	Proposed 1932						
	Molokai & Maui	56	1.3 1.36	April, 1935						
France	Nice and Corsica	110	7 60 8 30	June, 1932	Input 150 watts.	Master oscillator with one or two stages of amplification and final power stage.	Double Detection.	Not stated. Probably "saw-tooth" antenna and reflector.	Yes.	Not known definitely, but thought to be.
Italy	Vatican and Castel-Gandolfo	12.5	0.50 approx.	November, 1932	Output $3\frac{1}{2}$ watts. Input 55 watts.	Push-pull electron oscillator.	Push-pull electron oscillator with supersonic plate bias.	Cylindrical parabolic.	Not stated, but almost certainly Yes.	Not known.
	Rome and Sardinia	168	0.50 approx.	Not in operation Nov., 1932. Thought to be one way channel.	Not known	Probably same as above.	Probably same as above.	Probably same as above, but possibly more than one.	—	Not known.
Japan	Niigata and Sado	28	4.6 or 5.8	Only experimental one way.	—	—	—	—	—	—
Gt. Britain and France	Straights of Dover	21	0.18	Not in operation. Experimental only (Apr. 1931).	0.5 watt radiated.	—	—	Parabolic reflector.	—	Yes.
Spain	Barcelona and Majorca (3 circuits)	120 approx.	3.4 to 4	Not known.	Not known	Crystal controlled.	Double Detection.	Not known.	Not known.	Not known.
U.S.A.	Green Harbour and Provincetown	25	4.6 & 4.75	July, 1934.	15 watts radiated.	Crystal controlled.	Double Detection.	Horizontal arrays.	No.	No.

A SHORT SUMMARY OF THE DISCUSSION.

The most important part of the discussion was in connexion with possible reflection, refraction and diffraction of ultra short waves. There appeared to be some difference of opinion as to possible reflections from ionised layers, but the position was summarised by Dr. Smith-Rose who stated that the views of certain speakers were based on observations at about 7.5 metres, whereas the present paper is concerned with wave-lengths of about 5 metres. He thought that the authors were probably correct in asserting that no reflections occur, but he preferred not to be dogmatic as fresh evidence is continually being discovered. Theoretically, both refraction and diffraction may account for transmission over non-optical paths, diffraction being probably of greater importance. Fading effects, however, could not be caused by diffraction, but on the other hand, the refractive index of the lower atmosphere does not account, in magnitude, for the actual fading which occurs.

The same speaker also discussed the field strength attenuation curves given in the paper and stated that the inverse square law, deduced experimentally for waves propagated over the earth's surface, is justified by theory.

Other speakers discussed very early experiments with ultra short waves, even down to 1 cm., using spark transmitters, and it was pointed out that the power generated in such apparatus was of the same order as that now used. Modern improvements lie principally in the use of efficient transmitting and receiving antennæ and very sensitive receivers.

The possible use of " straight " receivers for the frequencies under consideration was mentioned and it was stated that such amplifiers were practical at 5 to 7 metres. Differences between the so-called " High Q " and " Line " methods of ensuring frequency stability were mentioned and the terms were explained as follows :—

" *High Q.*" The use of a resonant (tank) circuit of very low decrement.

" *Line.*" A transmission line, open or short circuited at the far end is coupled to the oscillator.

Both methods involve large dimensions.

The advantages which would accrue from the linking up of the Scottish Isles to the mainland by radio links were explained, and it was stated that considerable developments in this direction were to be anticipated.

Possible difficulties in connexion with the group modulation of a multi-channel system were mentioned, with particular reference to the large degree of modulation required by the authors. This is important if a 2 to 1 ratio between the modulating frequencies is used.

Interference with radio services by diathermic apparatus, now in common use, was also mentioned.

Authors' Reply to Discussion.

Replying to the discussion, the authors affirmed that there is no known case of reception of 2 to 6 metre transmissions at great distances. They did not consider the use of " straight " receivers to be practicable at 4 metres.

A further possible cause of fading was suggested. The beam from the transmitting array is not sufficiently narrow to limit it to one path and fading could be caused by the presence of two paths between the arrays.

In connexion with the remarks on the use of spark transmitters in the early ultra short wave experiments, the authors pointed out that with modern equipment continuous waves, capable of modulation, are generated.

Further details of the proposed 9-channel system were given. The sub-carrier frequencies are about 300 kc/sec. and so a 2 to 1 ratio is avoided.

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