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A STUDY OF WAVE SYNTHESIS BY MECHANICAL MEANS

PART II.—SOME USES OF THE SYNTHESIS MODEL, IN PARTICULAR THOSE RELATING TO WIRELESS PRACTICE

A description of a mechanical model designed by the Author for use at the Marconi College, to enable wave synthesis to be carried out easily was described in the June issue of THE MARCONI REVIEW, *and it was there mentioned that this would be followed by a second part in which the uses to which the model could be put would be described.*

This second part has for convenience been divided into sections, the first of which is given below.

Section 1—The Modulation of High Frequency Waves and the Relationship of Carriers to Side Bands.

WIRELESS practice concerns the art of communication using æther waves and comes under the heading of a signalling system.

Signalling systems in general are usually associated with the transmission and reception of waveforms of audio frequency, and we can assume that we are concerned in signalling frequencies from a few cycles up to 10,000, this band width being encountered in the transmission and reception of broadcast music, which probably represents the most complicated form of signal. When transmitting hand speed morse this may be considered as the signalling of a square wave of a few cycles per second the frequency depending upon the speed of sending.

Speaking quite generally one may conceive any signalling system as having two essential features :—

1. The means of transferring energy from transmitter to receiver ; in the case of ordinary speech between individuals this energy will consist of sound waves, in the case of land line working, current along conductors;

and in the case of wireless the propagation of electro-magnetic waves through the aether, to mention a few methods.

2. The second part, integral with the first, and no less essential if signalling is to be carried out, is the Modulation, which is the means by which intelligence is conveyed. As its name implies, this is the moulding of the energy (the first part), and as before mentioned will take the form of some audio frequency wave.

Both parts are of course complementary, one to the other, but they can be separated for the purpose of analysis.

We may divide signalling systems in three classes :—

(A) Non-carrier systems.

(B) Carrier systems.

(C) Suppressed carrier systems.

A non-carrier system is one in which energy transference only appears with the signal.

If, however, transmitter and receiver are linked, even though no signal is being made, we have what is known as a genuine carrier system.

We may yet have another case where, although no carrier links transmitter and receiver, it originally existed but has been suppressed. In such a case it will be necessary to incorporate the equivalent of the carrier at the receiver, and such a system would be called a suppressed carrier system.

Wireless is essentially a carrier system, but before discussing the features of the wireless case it may be of interest to say something of carrier systems in general.

As previously mentioned, in any signalling system we are interested in the transmission and reception of intelligence usually in the form of a wave. Such a signal may be a simple harmonic wave or capable of division in harmonic components. In the latter case the signal may be considered as a spectrum of frequencies.

We can transmit a signal along a communication channel with the least expenditure of energy when the datum line of the signal wave coincides with the zero line of disturbance in the channel. For instance, suppose one wishes to transmit a sine signal along a line. The signal could be sent by a transmitter changing the current in the line, first in one direction and then in the opposite direction, requiring a certain minimum expenditure of energy and, when no signal is being made, there is no current in the line. Thus, we can say that the datum line of wave coincides with zero line of current in the system and it is to be observed that in this case a reversal of phase takes place at the half cycle of signal. Such is an example of a non-carrier system. This changing line current, that is the signal, could be detected by a suitably designed receiver.

The carrier case would be one in which a D.C. current of sufficient amount was permanently flowing in the line so that the introduction of the signal merely augmented and diminished the original current called the carrier current. Thus in the carrier case a current always flows in the same direction and the carrier now forms the datum line for the signal wave.

Such a D.C. carrier can be eliminated from the line by using transformers, and can be added locally at transmitter and receiver. In this case we get an example of suppressed carrier system. Examples of all these cases are shown in Figs. 1a, 1b, 1c and 1d, and from them we can make the following observations :—

1. The signal made depends only upon the modulating component disregarding any peculiarities of the receiver.
2. The carrier current contributes nothing to the communication of intelligence, but merely forms a datum line for the signal wave.
3. The use of a carrier involves an additional expenditure of energy which may be very considerable.

It may be worth while pointing out now, that we can only talk of percentage modulation when we are discussing carrier systems. What we mean when we say that a carrier system is so much per cent. modulated is that the amplitude of the modulating component is that much per cent. of the original carrier, one hundred per cent. modulation meaning, therefore, that the peak value of the modulating component is equal to the original carrier value. The effect of this is that at one period the disturbance in the system is reduced to zero, and at some other period is built up to a value equal to twice the original carrier.

A carrier system is obviously a wasteful one and it is necessary to state why one has sometimes to use carriers, and the explanation will, it is suggested, be found at the receiver. Comparing the two line cases, for instance, we see that in the non-carrier system, for the receiver to detect the signal it has to be capable of following not only change of amplitude of current, but change of direction as well. This means considerable intelligence on the part of the receiver. On the other hand, if a carrier system is being used the receiver has only to be able to detect change of amplitude and no change of phase comes into the matter. Thus, the real reason why a carrier may be required is because the receiving system has not sufficient intelligence to do without it. Of course, if one can improve the mentality of the receiver sufficiently one can do without carriers, and in the ordinary line system there are many examples of "high-brow" receivers which dispense with carrier currents and thereby save a considerable amount of energy.

For instance, in the line telephone example given in Fig. 1a, where the receiver is unpolarised, it has only sufficient ability to understand change of amplitude and not change of direction. Hence, although the transmitter diaphragm flapping first in one direction and then in the other creates a reversed current in the line, this reversal of current does not means anything to the receiver and the signal appears distorted as shown.

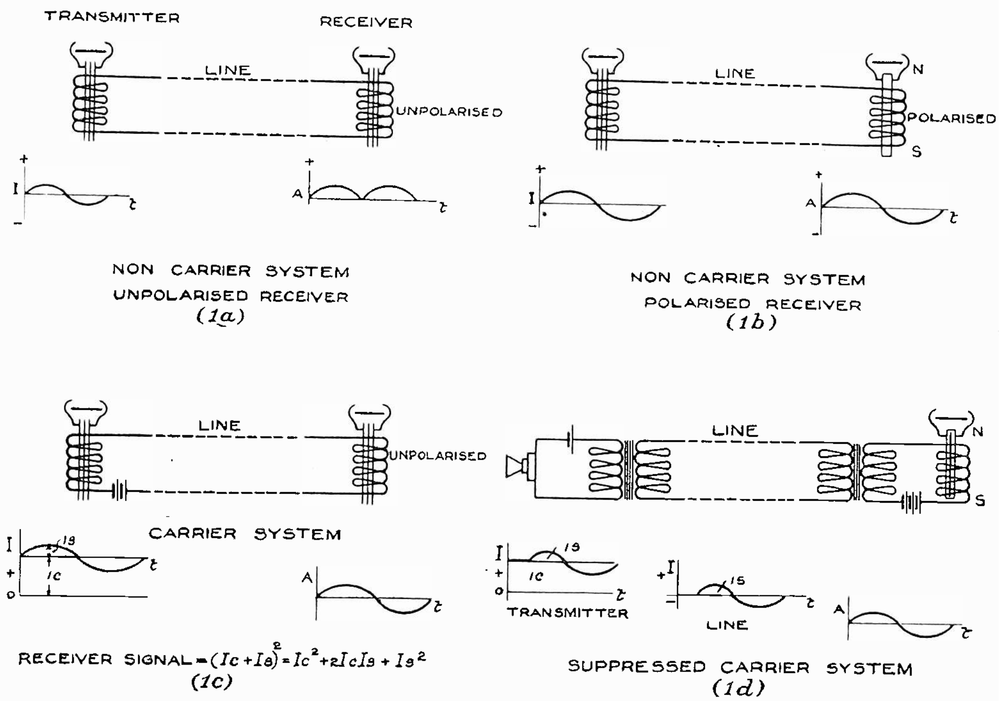


FIG. 1.

Fig. 1b shows a receiver with improved mentality, by polarisation with permanent flux, and in this case the reversal of current is now observed and correct reproduction results.

Had one of necessity to use the original type of receiver, the trouble could be overcome by adding a D.C. carrier as shown in Fig. 1c, although this carrier need not pass along the communication channel but could be localised to the receiver circuit as shown in Fig. 1d.

Wireless communication is essentially a carrier system for the same reason, that our receivers lack intelligence and because high frequencies are necessary for the transmission of the wave. Instead of a D.C. carrier we have an A.C. carrier creating an image wave, and because of this image wave, to demodulate, rectification is essential at the receiver. From which one can observe that since at the receiver the datum line of signal wave is above zero line of disturbance, we must have a carrier, at the receiver.

It is of interest to consider the relation of this A.C. carrier to the modulating component, and to discuss the possibilities of carrier suppression.

Up to the present time modulation of a high frequency carrier has been almost exclusively an amplitude modulation and there are two ways of visualising the effect of amplitude modulation on a carrier. The first is that the modulating component alters the amplitude of the carrier so that the envelope produced conforms to the signal required. In this case we conceive the original carrier merely being varied in amplitude in accordance with the signal wave. This method of visualising a modulated wave is quite helpful until one talks of Suppressed Carrier Systems and commences to analyse the distribution of power in carrier and modulating component, when it becomes rather involved.

But it is well known that one can analyse such a modulated wave into a spectrum of waves consisting of the original carrier and two sets of side bands.

It is not proposed to go into the spectrum analysis fully but merely to set out such features as may be necessary for discussion.

A signal wave may be analysed into a series of harmonic waves of definite frequencies and amplitudes and having set phases, and these plotted as a frequency amplitude spectrum, can be shewn diagramatically thus :—

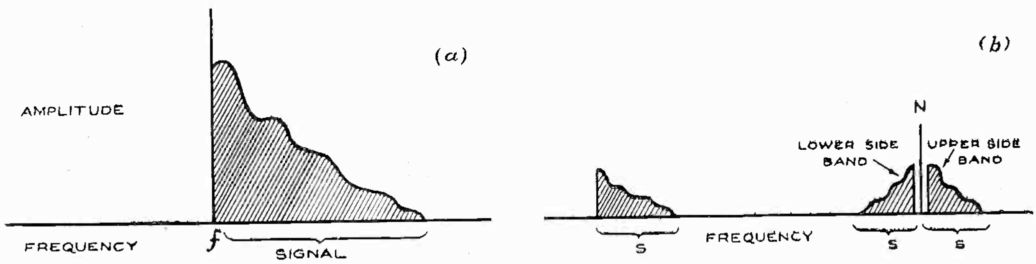


FIG. 2.

The actual width of the spectrum and the amplitudes of the different harmonics is dependent upon the character of the signal wave, and in practice (excluding television) music gives the widest spectrum and may cover a band of as much as 10,000 cycles.

The effect of modulating a high frequency carrier of, say, frequency n by such a signal, may be considered as producing a high frequency spectrum which is obtained

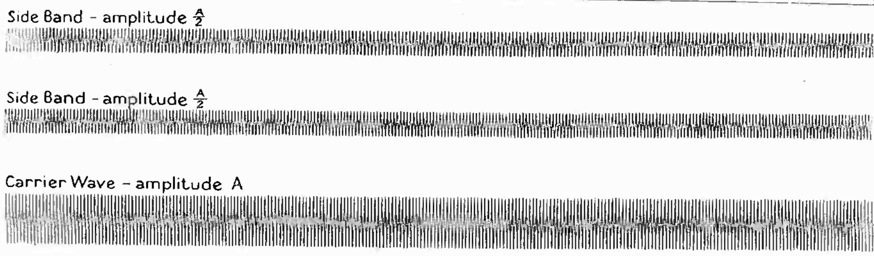
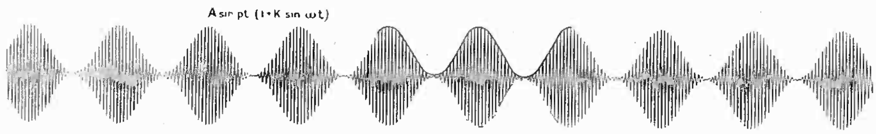


FIG. 3.

2A MODULATION - 100% CONTROL (K = 1)

Modulation of carrier wave by pure tone signal



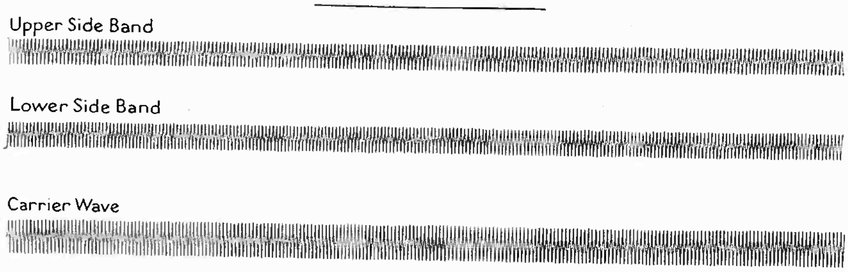
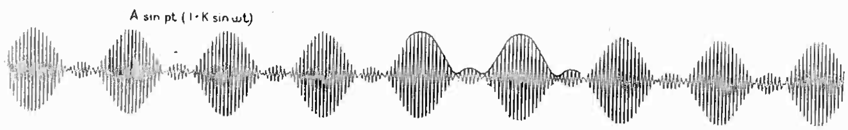


FIG. 4.

2B. MODULATION - OVER CONTROL - (K = 1·25)

Illustrating conditions which would give rise to distortion in Radio Telephony.



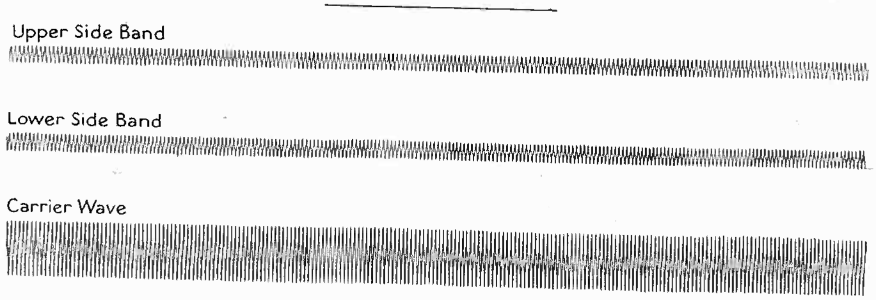
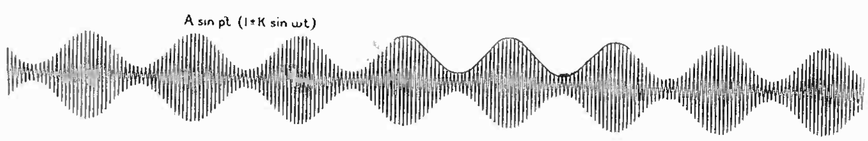


FIG. 5.

2C. MODULATION - UNDER CONTROL (K = 0·5)

Illustrating modulation conditions consistent with good quality.



by moving the signal wave along the frequency base by the amount of the H.F. carrier. In addition to this a reversed image spectrum is created on the lower side of the carrier as is shown in Fig. 2B, from which it can be seen that the high frequency spectrum is roughly twice the width of the signal band.

This high frequency spectrum thus consists of the following essential parts :—

1. The original carrier.
2. A band of H.F. waves obtained by the sum of carrier and signal frequencies, called the upper side band.
3. A band of H.F. waves obtained by taking the difference of the carrier and signal waves, called the lower side band.

The amplitudes of the side band waves depend upon the degree of modulation, and the power required to produce these side band waves represents the additional power necessary to effect modulation of the carrier.

To modulate one has to do work—one can either think of the work being expended in producing an alteration in the amplitude of the original carrier, or as producing an additional spectrum of high frequencies which, beating with the original carrier, produce the synthesis wave whose envelope after demodulation will conform to the desired signal, and for the correct reproduction of envelope all the components of this spectrum are required.

It is observed that only parts 2 and 3 introduced by modulation convey intelligence. Further, that the band width taken up is dependent upon the signal spectrum and is therefore independent of the frequency of communication.

It is of considerable interest to study the distribution of power in such a built up wave and to observe the effects of phase displacements. The simplest case of all is modulation of a carrier by a pure sine signal, producing a synthesis wave which can be expressed :—

$$Ft = A \sin pt\,(1 + K \sin wt) \quad \ldots \ldots \quad (1)$$

where A is the amplitude of carrier

p = 2π times carrier frequency (n)

K = factor of modulation being 1 for 100 per cent.

ω = 2π times signal frequency (f)

The expansion of the above gives us the separate carrier and side bands as

$$Ft = A \sin pt + \frac{KA}{2} \cos (p - \omega)t - \frac{KA}{2} \cos (p + \omega)t \quad \ldots \quad (2)$$

Thus if the carrier amplitude is 1, then for 100 per cent. modulation, each side band amplitude will be one half the carrier.

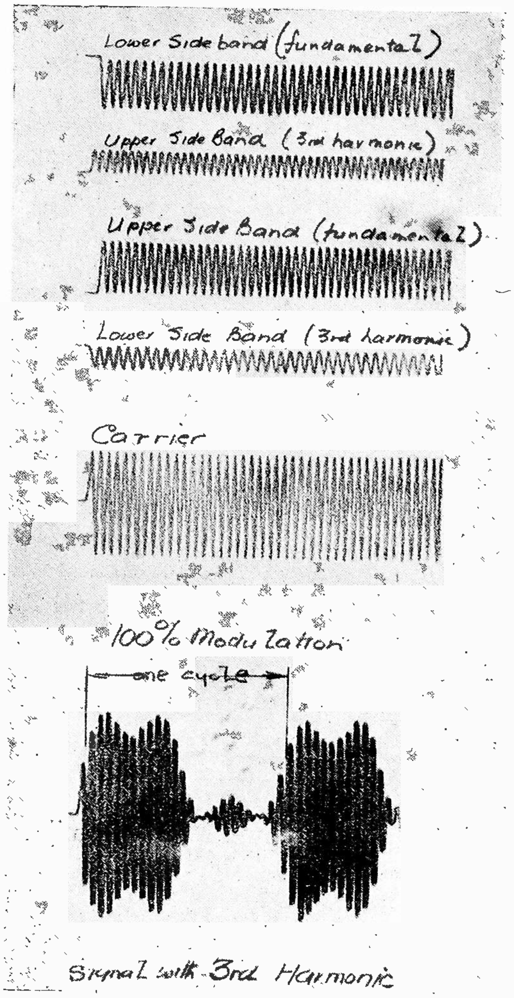


FIG. 6.

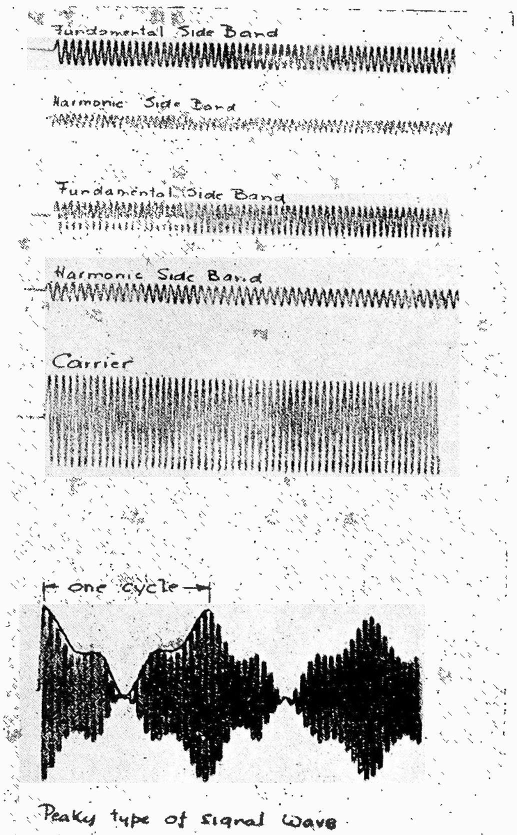


FIG. 7.

To demonstrate a sine modulated carrier the machine is set up to accord with the mathematical expression, and in the examples shown the carrier frequency is 25. With a modulation frequency of 1, two side band frequencies of 26 and 24 will be produced, each of amplitude half the carrier, for 100 per cent. modulation.

The result of the addition of such a spectrum is shown in Fig. 3, the frequencies being carefully set not only as regards amplitude but also as regards phase.

In order to obtain exactly correct frequencies it is necessary to have a very fine adjustment of frequency for the carrier wave. This is accomplished by employing for the final carrier drive two opposed cone pulleys, each having a coning of $\frac{1}{16}$in. in 2in. width, so that by sliding a flat belt across the faces of these pulleys an exact frequency can be obtained. With such an arrangement, even after some 200 cycles, the three frequencies are still found to be substantially correct. It is observed that an accuracy of something like 1 part in 15,000 is obtained in this way.

The distribution of power in such a modulated wave will be proportional to the square of the individual waves, and it will be seen that in the above case there will be twice as much power in the carrier as there is in the two side bands together, *i.e.*, for the case of a sine signal. If we have a carrier 50 per cent. modulated, shown in Fig. 4, which is a more normal case for a broadcast set, then the amplitude of each side band will be a quarter the carrier amplitude for a sine signal, and hence the power in both side bands is only one-eighth of the carrier power.

If one modulates too deeply, side band power is produced in too great a proportion and the result is a distorted wave as shown in Fig. 5 where the signal impressed is a sine wave and the modulation 125 per cent.

The power proportion of carrier to side bands is, of course, not a constant for a given percentage modulation, but varies with the type of signal wave, the more peaky the wave form the less power required to produce it, for a given value of peak amplitude. It really comes to a question of wave area. This is shown in examples on Figs. 6 and 7. Fig. 6 shows a carrier modulated by a signal wave having a third harmonic with such a phase that the harmonic does not raise the peak of the wave but merely broadens it. In the case of such a signal having one harmonic, there will be two side band waves each side of the carrier, one pair for the fundamental and one pair for the harmonic as shown. Thus, for 100 per cent. modulation a fundamental signal amplitude of half the carrier can still be retained without over modulating, and the amplitude of carrier, fundamental side bands and harmonic side bands will then become as shown, *i.e.*, the fundamental side bands are half the amplitude of the carrier, and the side bands produced by the signal harmonic are one-sixth the amplitude of the carrier. The power distribution in such a wave will be 1 in carrier to ·555 in side bands, showing that because the wave is broader for the same peak value its power content is greater than in the sine case. Had the third harmonic been included such that it came in phase with the peak of the fundamental wave thus making the envelope peaky; with the same carrier (as shown in Fig. 7), it would be necessary to reduce the amplitude of the signal component to prevent over modulation. In this case each fundamental side band would need to be reduced to ·375 and each harmonic side band to ·125. The power content of the two side bands then becomes ·312 of the power of the carrier for

100 per cent. modulation. As it is usually necessary to allow for peaky type waves, the average level of modulation must be considerably lower than that calculated for the sine case.

Incidentally in the two cases just given (Figs. 6 and 7), if such waves were rectified and passed through a telephone, the effect on the ear would be the same although the strength of 6 would be a little greater than that given by 7. This point will be referred to later.

The type of modulation requiring the most power is a square wave, as it has the greatest area for a given maximum amplitude, and in this case the power in the side bands rises to equal that of the carrier, for 100 per cent. modulation. Thus, given the most favourable conditions there will always be as much power expended in the carrier as there is in the side bands, and usually the distribution of power is very much less favourable. When one considers the small amount of power that is used on the average to modulate a carrier it would appear that present systems are very inefficient.

In choke control, for instance, under the most efficient conditions for the modulator (50 per cent.), we use twice as much power as we are ever likely to be called upon to provide, *i.e.*, for a square wave, and under normal working conditions it is problematical whether the average useful power delivered from the modulator exceeds one-tenth of the carrier power.

Another point is the interference question. The "figure of merit" of a signal is not so much its strength as the ratio of its strength to interference. This ratio will be improved if all the transmitted power is put into the side-bands instead of using a large proportion in a carrier. Apart from the waste of power in the transmitted carrier, the present carrier and double side band working is a bad one because of the width of frequency band taken up, and in view of the ever growing crowding of stations it would appear that in the future some alteration in the modulation system must come about, where possible, so that the number of channels can be increased.

The foregoing is sufficient to show how uneconomic the present carrier system is, and it may be of interest to discuss the effect of carrier suppression. Because we are dealing with a spectrum of alternating current waves this involves a knowledge of the effects of phase relationship of the waves making up the band, and it is proposed to study this in detail in the next Section of the paper.

A. W. LADNER.

X.M.C.2 COMBINED TRANSMITTER AND RECEIVER

The most important conditions of service to be met by a set of the type of the X.M.C.2, which is primarily designed for installation on whalers, trawlers, tugs and lightships, etc., for intership and ship to shore communication, are as follows :—

1. *The apparatus must be capable of adjustment and operation by absolutely unskilled personnel.*
2. *The instruments will be installed in remote places far removed from any facilities for repair or expert advice.*
3. *The installation will be subject to extreme climatic conditions as regards temperature and humidity, and will be mounted, in general, in very confined spaces.*

Adequate provision is made in the design of the X.M.C.2 to meet these exacting conditions, and, as numerous good reports of its performance have been received, the description of the set given below may be found to be of general interest.

THE X.M.C.2 transmitter and receiver have been designed to permit intership and ship to shore communication to take place on any spot wave between 150 and 450 metres, using either telephony, interrupted continuous wave or continuous wave.

Power Supply.

The power supply to the transmitter is intended to be taken from the ship's mains, which are used to drive a motor generator, the motor of which is wound to suit the mains, and the generator to provide a high tension voltage of 2,500 volts for the anodes of the valves and a low tension voltage sufficient to charge the filament battery at the full rate when on the charge position, and at one-third the full rate when on the transmit position in addition to supplying the filament current for the valves.

A motor field regulator, H.T. generator field regulator, and L.T. generator field regulator are provided and are mounted on the motor generator unit.

Power of Transmitter.

The power of the transmitter is rated at 0·5 kilowatt from the output terminals of the generator. The total power to the anodes of the two transmitting valves is 438 watts.

Transmitter.

A simplified diagram of connections of the X.M.C.2 transmitter is given below

(Fig. 1). It will be seen from this that two valves are used, namely, an oscillator and a modulator. Marconi valves, type M.T.12a, are used in both cases. The aerial circuit consists of an inductance which is tuned by a variometer and tappings on the coil itself. Variably coupled to the aerial inductance is a coil, one end of which is earthed and the other end is taken to a tap on the closed circuit inductance. This latter is

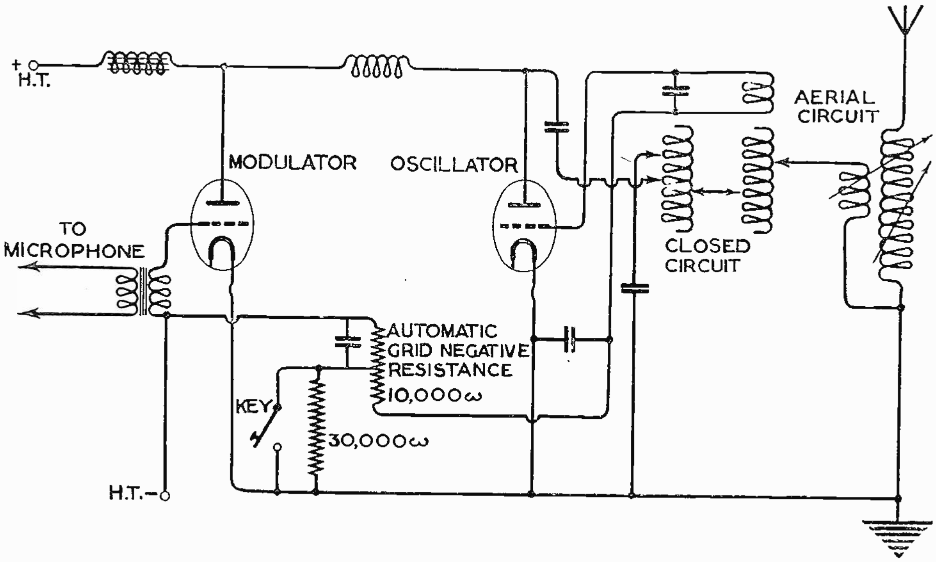
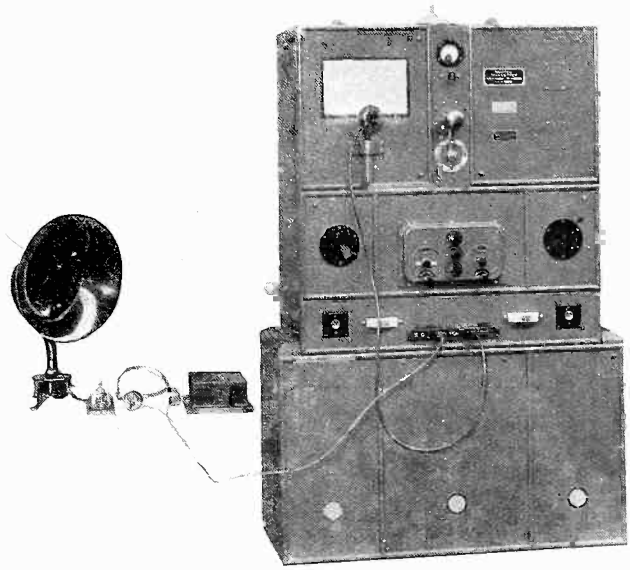


FIG. 1.

also tuned by means of a variometer, and an adjustable tap. Three tappings are taken from this closed circuit coil. One is taken to earth through the closed circuit condenser the value of which can be changed according to the wavelength required. One is taken to the anode of the oscillator through a condenser, and one is taken to the aerial coupling coil as has been previously mentioned. A variable reaction coil, shunted by a condenser, is connected between the grid of the oscillator and grid negative. When transmitting on C.W. the grid of the oscillator valve, which is permanently connected to negative H.T., is disconnected or connected to earth by means of the transmitting key.

Modulation on telephony is accomplished by the choke control system. The anodes of the modulator and the oscillator are connected by a high frequency choke, and the H.T. supply to both the anodes is taken through an iron core choke. The high frequency choke is provided in the circuit to prevent the plate circuit of the modulator taking any of the high frequency power which the oscillator should be supplying to the aerial circuit. The action of the iron core choke is to present a high impedance to audio frequency currents, and to give the greatest variations of modulating voltage on the plate of the oscillator.

When transmitting on I.C.W. a buzzer which is in series with a third winding of the microphone transformer is keyed and impresses this voltage which is at the frequency of the buzzer on the grid of the modulator.



Receiver.

The X.M.C.2 receiver is designed to receive on all wavelengths of from 150—600 metres, and these wavelengths are covered in two ranges.

A diagram of connections is shown below (Fig. 2), and it will be seen from this that four valves are used in the receiver, the first being a screened grid high frequency valve transformer coupled to a grid leak detector valve, and followed by two transformer coupled note magnifiers.

The aerial is coupled to the first tuned circuit either directly by means of a coupling coil or through one of three fixed condensers, depending on the size of aerial employed.

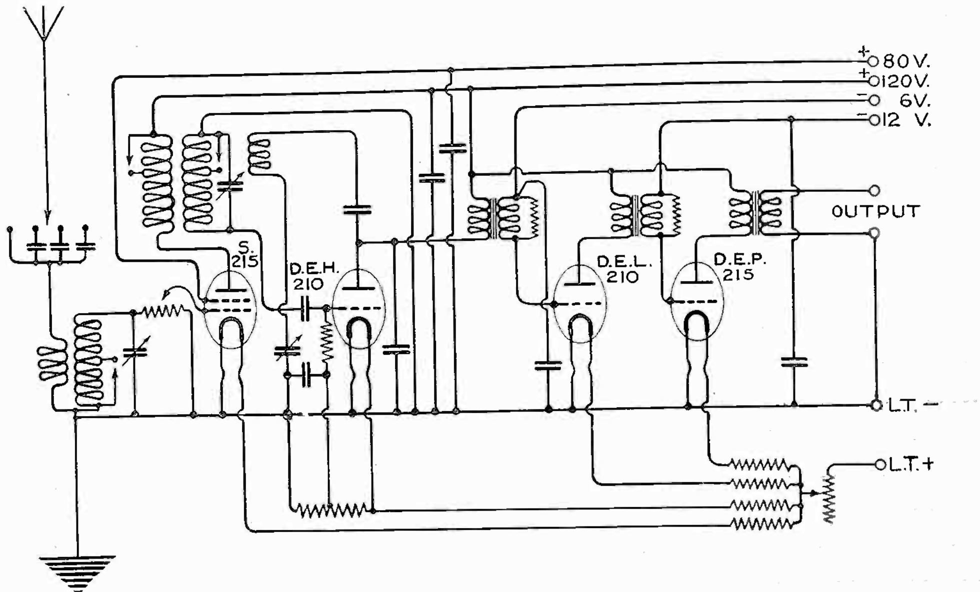
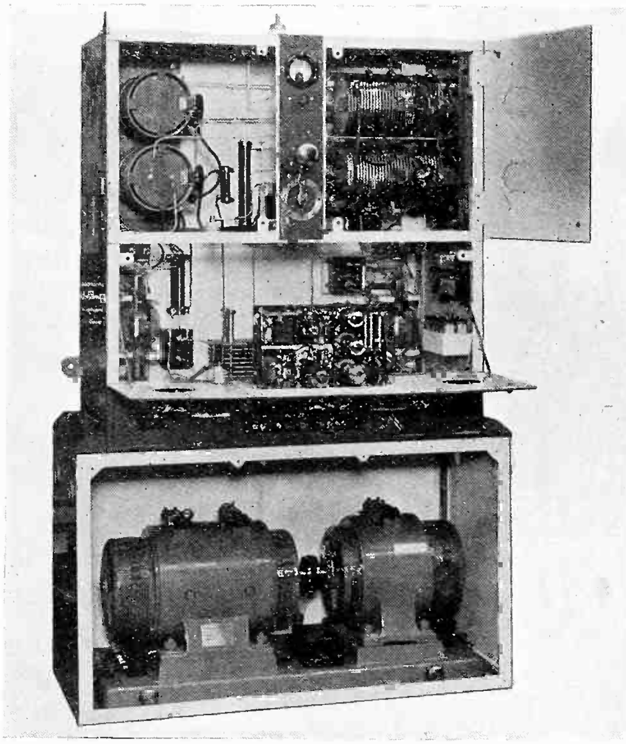


Fig. 2.

As the receiver will, in many cases, be used as a spot wave receiver, arrangements have been made so that when the receiver is adjusted to its correct wavelength, the waverange switch may be locked in position, and the single tuning control limited to give a small percentage search on either side of the spot wave.



The only adjustments then required are :—

(1) Volume control, by means of which overwhelmingly strong signals can be brought to reasonable strength smoothly and without distortion.

(2) Reaction control by means of a condenser supplied with a very smooth slow-motion device.

The high frequency circuits of the receiver are designed to obtain the selectivity arising from the use of two tuned circuits, while still embodying only one tuning control. The condensers tuning the H.F. valve grid circuit and the rectifier valve grid circuit are mounted on a common spindle. As the receiver may be used with various sizes of aerial, a fine tuning device is also supplied on the aerial circuit, to ensure correct "ganging" on any one particular wavelength. This is, in practice, used for fine tuning once the desired station has been found roughly. In the case of spot wave working, the two H.F. circuits are correctly "ganged" by this device on installation, and the fine tuning locked so that the number of tuning controls is still limited to one, excluding the reaction and volume control.

Receiver Aerial System.

The receiver will function satisfactorily with any aerial whose natural wavelength does not exceed the lower limit of the receiver waverange, *i.e.*, 150 metres. Under such circumstances no series condenser is necessary. In the case of an aerial being used whose natural wavelength does exceed this limit a suitable aerial series condenser must be connected in circuit.

THE DESIGN OF WAVE FILTERS

The following article has been written by an engineer of the British Broadcasting Corporation, and is published in these pages by the courtesy of that organisation.

Whilst professing no claim to originality, it is believed that this collection of material will be found to present, in a succinct form, much valuable data of use to the practical engineer interested in filter work from the Radio view-point.

General.

THE subject of this paper has been dealt with at great length by many telephone engineers, notably G. A. Campbell and O. J. Zobel of the Bell Telephone System. While the exposition of the theory has been dealt with by many others, yet it is possible that for the purposes of engineering design the subject can be somewhat simplified, in order that the methods adopted in practice when designing a filter structure to fulfil certain requirements may be more clearly seen.

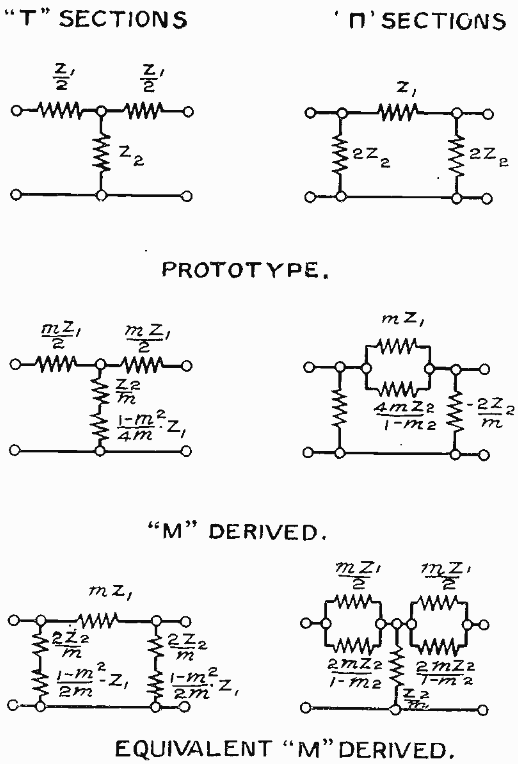
The object of this article, then, is to show the method of designing filter circuits from the engineering rather than from the mathematical point of view. It is not possible here to enter fully into every problem encountered in filter design, as many cases arising in practice require much manipulation of the circuit theory from which the fundamental formulæ for wave-filters are derived.

It should be noted that the structures discussed in this paper are for the most part "ideal structures," *i.e.*, the inductances and condensers associated with them are considered perfect, no resistance being present. The theory of dissipative filters shows that provided the dissipation is low, the behaviour of the ideal section is, in the main, representative of the former. Certain important cases of the dissipative structure are, however, discussed elsewhere in this paper.

The design of a filter is dependent upon two main considerations. The former is the behaviour of the filter at some definite frequency or frequencies (*i.e.*, frequencies of cut-off or of maximum attenuation), and from it can be computed immediately the attenuation and phase change characteristics as functions of frequency. The latter determines, together with the former, the size of the elements required to make up the structure. It is very important to note that it is unnecessary to know the size of the inductances and condensers forming a filter in order to predict the behaviour of the structure. It is therefore possible to predict the characteristics of any type of filter section from general considerations, the values of the inductances and condensers being fixed according to impedance requirements.

It should also be borne in mind that the expression "impedance of a filter" has no meaning unless some particular frequency is specified. When it is said that a certain filter has an impedance of, say, 600 ohms, what is meant is that the circuit to be associated with the filter should have an impedance of this value, or that the impedance of the filter at some fixed frequency is 600 ohms.

When, after study of the calculated characteristics of a filter, the sizes of the elements are computed from a consideration of the impedance of the associated



$$m = \sqrt{1 + \left[\frac{1}{U_K}\right]_{f = f_\infty}}$$

FIG. 1.

circuit, it is for the designer to decide whether the values of the inductances and condensers so found lie within the realms of practice or of absurdity. In the latter case, the impedance of the filter, or the type of section used, must be suitably modified.

2. Types of Filter Sections.

Filters may be classified into three main groups, from a consideration of their frequency characteristics—

(1) Low Pass.

(2) High Pass.

(3) Band Pass [Band Elimination].

These three groups are further sub-divided into two types—

(A) The prototype, or simplest possible section representative of the group.

(B) The derived type (or "M derived" types, obtained from a modification of the prototype).

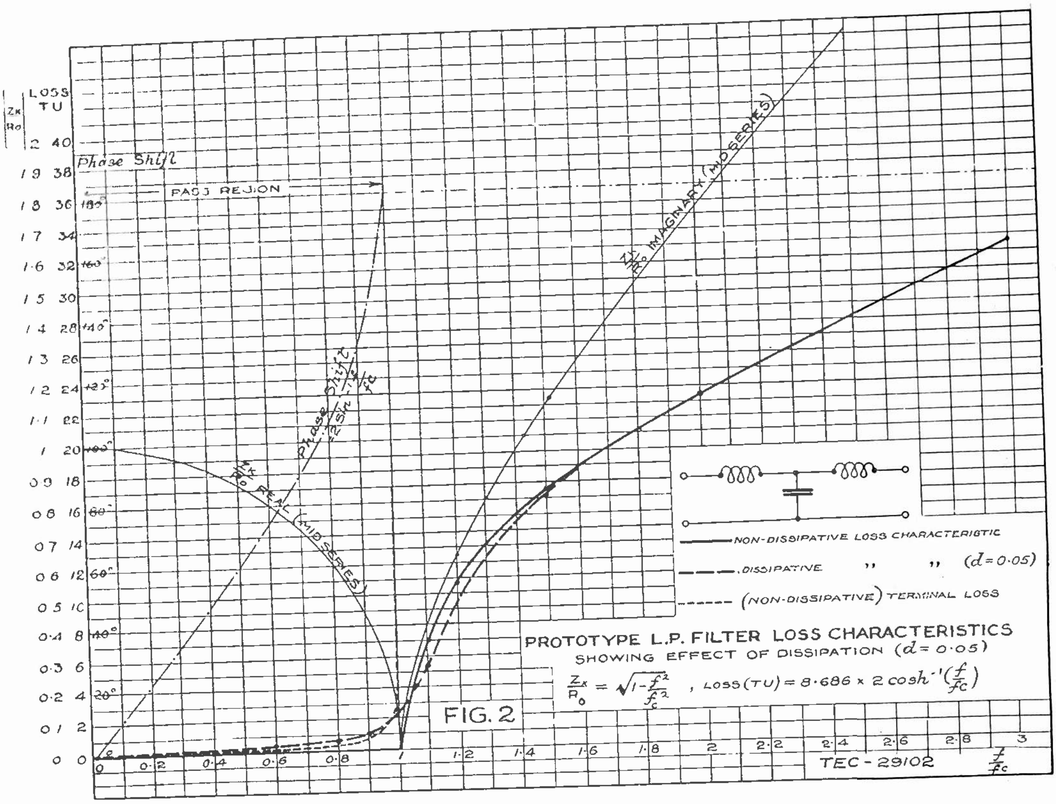


FIG. 2

The prototype section is important, in that from it is obtained an infinite number of possible "derived" sections having very useful properties. The majority of filters used for telephone transmission purposes are composite, *i.e.*, made up of several dissimilar types having different attenuation characteristics but the same characteristic impedance. Prototypes alone are seldom used except in cases where discrimination between two remotely separated frequencies is desired, *e.g.*, filters for smoothing rectified A.C., etc.

In the theory of networks it is known that many types of section exist, which can be made equivalent as regards attenuation and phase-shift, although their impedances may be different functions of frequency. The main three types met with in practice are :—

(1) T, or mid-series sections.

(2) Π, or mid-shunt sections.

(3) Lattice, or bridge sections.

The first two types are closely analogous, and are shown represented on Fig. 1. The third type is shown on Fig. 7, illustrating a phase shifting network.

The derivation of the T and Π section is obtained from the general theory of networks as applied to an infinite number of sections having series impedances of Z_1, and shunt impedances of Z_2. The T section is then a symmetrical section taken at the mid-point of two adjacent series arms, while the section is the electrical equivalent of a symmetrical section taken at two adjacent shunt sections. The values of the series and shunt arms in the two sections are therefore $\frac{Z_1}{2}$ and Z_2 in the former, and Z_1 and $2Z_2$ in the latter case.

3. Formulæ for Wave Filter.

The expression connecting the impedances Z_1 and Z_2 with the attenuation and phase change can be shown to be

$$\sinh \frac{\Gamma}{2} = \sqrt{\frac{Z_1}{4Z_2}} \quad \ldots \ldots \ldots \ldots \ldots \ldots \quad (1)$$

where $\Gamma = A + iB$

Γ is the propagation constant,

A is the attenuation constant, expressed in napiers

or $\log_e \left| \frac{\text{Voltage into filter}}{\text{Voltage out of filter}} \right| = A = 8{\cdot}686 \times A$ Transmission Units.

and B is the phase constant, expressed in radians, giving the amount of phase shift through the section.

This expression is true for both T and Π sections.

If in the above equation we equate A to zero, then we have the condition for no attenuation in the section. The solution of the equation then becomes

$$\sinh \frac{iB}{2} = i \sin \frac{B}{2} = \sqrt{\frac{Z_1}{4Z_2}} \quad \ldots \ldots \ldots \ldots \ldots \quad (2)$$

or

$$-\sin^2 \frac{B}{2} = \frac{Z_1}{4Z_2}$$

The limits of $\sin^2 \frac{B}{2}$ are zero or 1.

Hence for zero attenuation in the section,

$$\frac{Z_1}{4Z_2} \text{ must lie between 0 and } -1 \quad \ldots \quad (3)$$

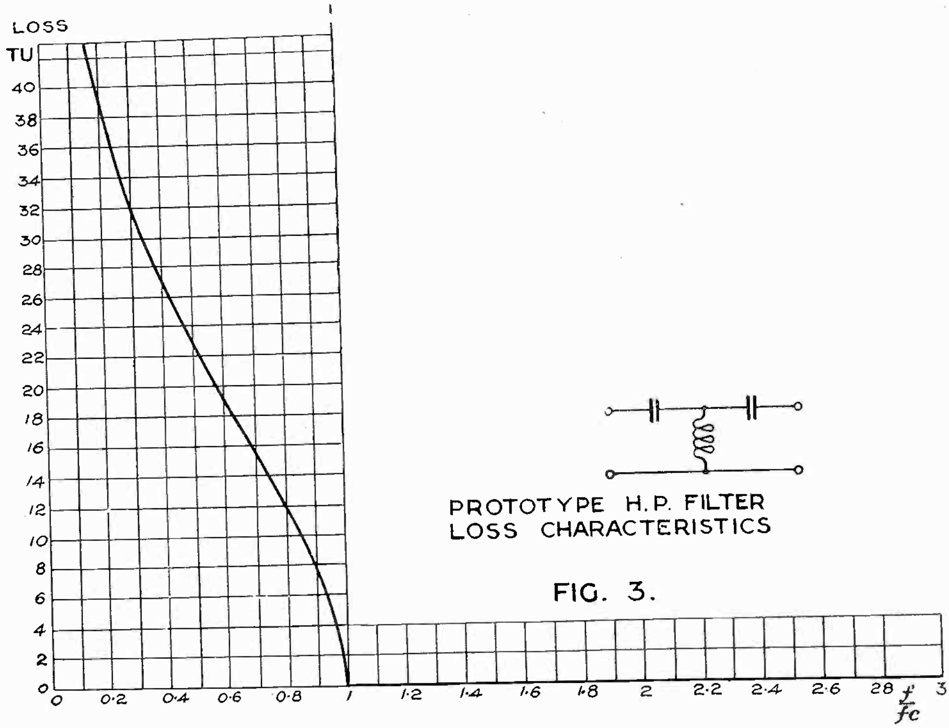
The ratio $\frac{Z_1}{4Z_2}$ is usually designated by U, and has great importance. The value of this ratio can be expressed in terms of any frequency f, and the frequency or frequencies of cut-off of all prototype sections. For example, let the prototype low pass section be considered. Then

$$Z_1 = i\omega L_0,$$

$$Z_2 = \frac{1}{i\omega C_0},$$

Hence

$$U_k = -\frac{\omega^2 L_0 C_0}{4} \quad \ldots \quad (4)$$



PROTOTYPE H.P. FILTER LOSS CHARACTERISTICS

FIG. 3.

(The suffix k indicates the value of U for a prototype section and the suffix m the value for an m derived structure.)

But the frequency of cut-off f_c of a low pass filter is obtained from a solution of equation (3)—

$$\frac{\omega^2 L_0 C_0}{4} = 0 \quad \text{or} \quad -1, \quad \text{whence } f_c = 0 \quad \text{or} \quad \frac{1}{\pi\sqrt{L_0 C_0}} \quad \cdot\cdot \quad (5)$$

Substituting (5) in (4), we have

$$U_k = -\frac{f^2}{f_c^2} \quad \cdot\cdot \quad \cdot\cdot \quad \cdot\cdot \quad \cdot\cdot \quad \cdot\cdot \quad \cdot\cdot \quad \cdot\cdot \quad (6)$$

This illustrates the method of finding U for any filter section. The following table gives the value of U_k expressed in terms of f and f_c for the prototype low pass and high pass sections and for the prototype band pass section shown in Fig. 12, band pass section No. VII. The table also shows the attenuation as a function of the ratio of frequency to frequency or frequencies of cut-off.

PARAMETERS OF PROTOTYPE SECTIONS.

Section.	U_k	A
Low Pass	$-\frac{f^2}{f_c^2}$	$2\cosh^{-1}\sqrt{U_k}$
High Pass	$-\frac{f_c^2}{f^2}$	$2\cosh^{-1}\lvert\sqrt{U_k}\rvert$
Confluent Band Pass ..	$\dfrac{-\left[\frac{f_m}{f} - \frac{f}{f_m}\right]^2}{b}$	$2\cosh^{-1}\lvert\sqrt{U_k}\rvert$

where $b = \left[\frac{f_2}{f_m} - \frac{f_m}{f_2}\right]^2$ where $f_m^2 = f_1 f_2$, f_1 and f_2 being the upper and lower cut-off frequencies.

The practical significance of the foregoing equations is shown on Figs. 2 and 3, showing respectively the characteristics of low pass and high pass prototype sections. It should be noted that the characteristics hold good for all ideal prototype sections of the particular group, irrespective of their impedance or value of cut-off frequency, as for those two groups the attenuation has been shown to be a function of the ratio $\frac{f}{f_c}$. The meaning of the broken curves on Fig. 2 will be discussed later.

On Figs. 8 and 9 curves relating U $\left(= \frac{Z_1}{4Z_2}\right)$ with attenuation have been drawn. The significance of these curves is that for any ideal filter whatever, if U be calculated for any particular frequency, then from that value of U the value of the attenuation of the section can immediately be found. The use of these curves avoids to a great extent the recourse to a table of hyperbolic functions demanded by the equation for attenuation as a function of U.

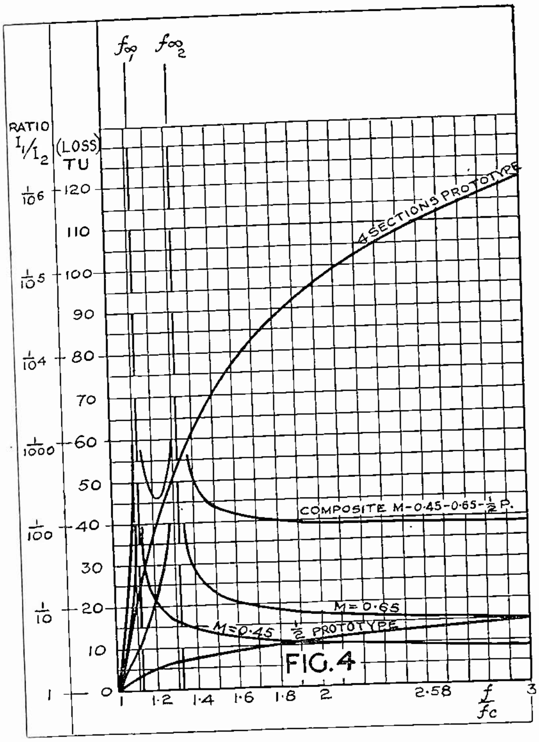


FIG. 4

In passing, it should be noted that f_c, the frequency of cut-off does not mean that at the frequency f_c attenuation is present. In an ideal filter f_c is the boundary at which the pass region ends and the attenuation begins; hence the attenuation starts from zero at the frequency of cut-off.

4. Effects of Dissipation on Prototype Sections.

In a prototype section the only sudden transition point lies at the cut-off frequency boundary or boundaries. The effect of resistance unavoidably present in the inductances of the section (that in the condensers can in most cases be neglected) is most marked in this region. On Fig. 2 the broken curve shows the effect of dissipative inductances on the attenuation constant of a prototype low pass filter. It will be seen that with the particular quality of coils used, the filter has begun to attenuate even in the pass region until at the frequency of cut-off the attenuation has risen to 2½ TU. The effect of the resistance present is negligible for values of f/f_c higher than 1·5.

The same type of effect occurs in other types of filter sections, but does not seriously affect the behaviour of the filter, except at frequencies near cut-off or "infinite attenuation."

5. Impedance Variation in Prototype Sections.

The expression for the iterative impedance of a T network is

$$Z_k = \sqrt{Z_1 Z_2 (1 + U_k)} \qquad (7)$$

similarly for a Π section

$$Z'_k = \sqrt{Z_1 Z_2 / (1 + U_k)} \qquad (8)$$

It should be noted that in the case of the prototype sections with which we are dealing, the product of Z_1 and Z_2 is a constant, independent of frequency. In the case of the low pass and high pass sections, for example, it is seen that

$$Z_1 Z_2 = \frac{L_0}{C_0}, \quad \text{or if} \quad Z_0 = \sqrt{Z_1 Z_2}\,;\; Z_0 = \sqrt{\frac{L_0}{C_0}} \quad \ldots \quad \ldots \quad \ldots \quad (9)$$

where L_0 and C_0 are the elements of the section.

Hence we can write

$$Z_k = Z_0 \sqrt{1 + U_k}\,; \quad Z'_k = Z_0 / \sqrt{1 + U_k} \quad \ldots \quad \ldots \quad \ldots \quad (10)$$

where Z_0 is of the dimensions of a resistance, say R_0.

Note that $Z_k Z'_k = Z_0^2$

If then we give U_k its value in terms of frequency ratios, we can trace the variation of the characteristic impedance with frequency. On Fig. 2, the ratio $\frac{Z_k}{Z_0}$ is plotted against $\frac{f}{f_c}$, the law in this case being

$$Z_k = Z_0 \sqrt{1 - \frac{f^2}{f_c^2}}$$

In the low pass case obviously $Z_k = Z_0$ if $\frac{f}{f_c} = 0$, *i.e.*, at zero frequency. At the frequency of cut-off $Z_k = 0$, or $Z'_k = \infty$. From the frequency of cut-off as $\frac{f}{f_c}$ increases $\left(1 - \frac{f^2}{f_c^2}\right)$ becomes negative and the iterative impedance becomes imaginary.

It can be shown that all ideal filters have real values of iterative impedance in their pass regions and imaginary values in attenuation regions. Further, the limits of the value of the impedance may be zero or infinity.

It is therefore apparent that the attenuation curves shown on Figs. 2 and 3 do not depict the entire behaviour of the filter section. It is obvious that there will be a further loss through the filter, owing to its impedances ceasing to match that of its associated circuits.

The dotted curve on Fig. 2 shows the attenuation in the pass region due to the change of iterative impedance Z_k. Such attenuation is known as "terminal loss." A curve giving the terminal loss between two circuits as a function of the ratio of their impedances (for real values of impedance) is given on Fig. 10. In the case of an ideal filter the terminal loss at the frequency or frequencies of cut-off is theoretically infinite; on Fig. 2 the terminal loss curve will be seen to rise very steeply as the frequency of cut-off is approached. In practice, however, the smallest amount of dissipation in the filter diminishes very considerably the maximum value of the terminal loss, so that its presence is made known by a progressive increase of attenuation in the neighbourhood of the cut-off frequency rather than by any sudden rise in attenuation.

The value Z_0 is usually loosely described as the impedance of the filter. It has been shown that the true characteristic impedance Z_k is a function of frequency, having the value Z_0 as one of its limits. It will be shown later that it is possible with the use of "equivalent *m* derived" sections to make Z_k nearly equal to Z_0 over a large part of the pass region, hence avoiding terminal losses.

6. The Derived Type of Filter Section.

On Fig. 1 are shown the T and Π networks in which Z_1 and Z_2 represent the elements of a prototype filter section. In a prototype section, the frequency or frequencies at which the attenuation is a maximum (infinite in the case of ideal filters) are either at zero or infinity. The object of deriving a new type of structure is to make the attenuation a maximum at some finite frequency f_∞, the suffix ∞ denoting that the attenuation should be infinite at this frequency.

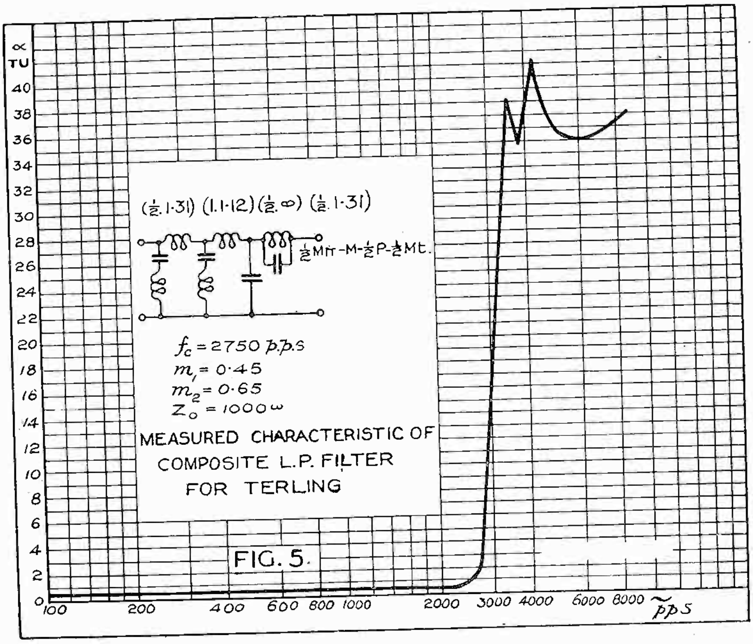


FIG. 5.

The derivation of such a type of section is rendered easy by the use of a parameter "*m*," which is determined from a knowledge of the frequency of cut-off and the frequency at which infinite attenuation is required. The properties of the "*m* derived sections" as regards their attenuation-frequency characteristic, are shown on Fig. 11, which represents a family of curves for five values of *m* for all ideal low pass and high pass "*m*" derived sections.

The value of *m* is given by the general equation

$$m = \sqrt{1 + \left(\frac{1}{U_k}\right)_{f = f_x}}$$

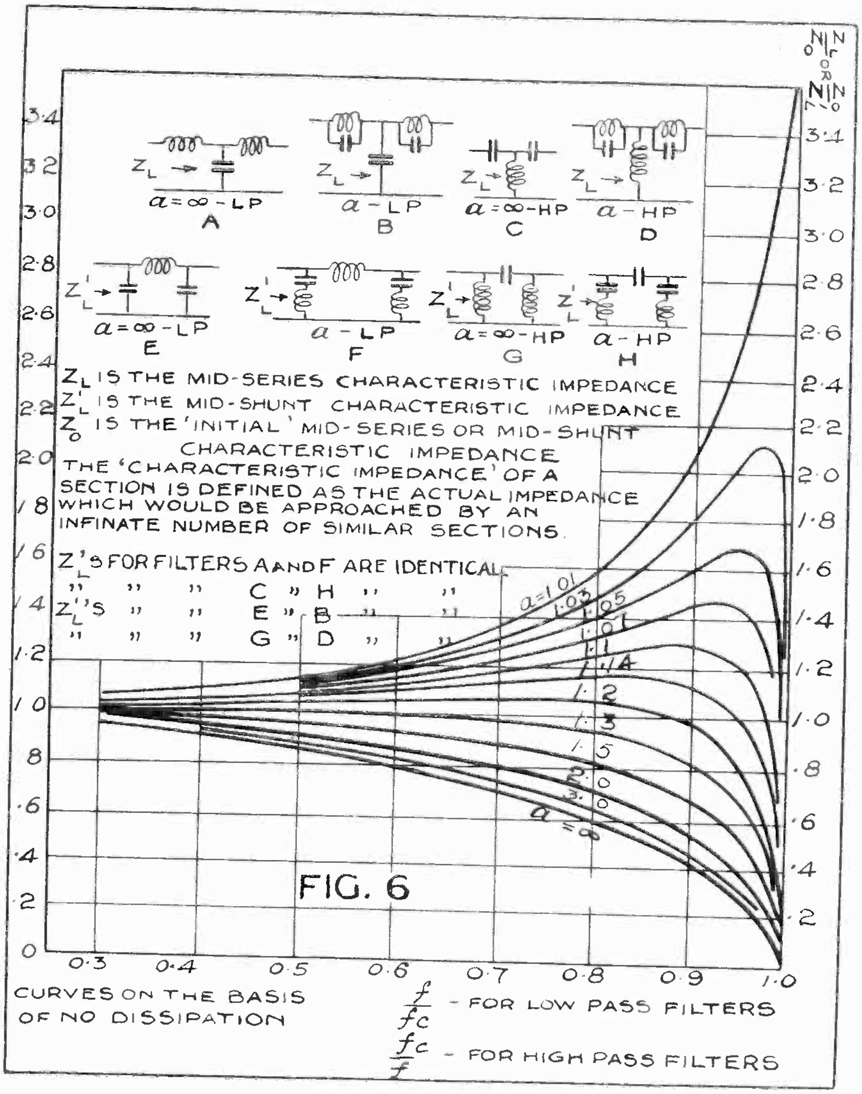


Fig. 6 is taken from "Telephone Transmission Circuits," by K. S. Johnson, *vide* Bibliography at end of article.

where $U_k \underset{f=f_\infty}{=} \frac{Z_1}{4Z_2}$ for the prototype section at $f = f_\infty$.

If we consider a prototype T section, and multiply the impedance of the series arm by m, and divide that of the shunt arm by m, it will be evident that in order that the expression for Z_k as a function of Z_1 and Z_2 in the new structure may be identical for that of the prototype, some third element will be required. It can be shown that this third element is in the shunt arm, and must be equal to $\frac{1 - m^2}{4m} \cdot Z_1$.

Similarly in the case of the Π section an extra element is required in parallel with the series arm, of value $\frac{4m}{1 - m^2} Z_2$. If $m = 1$, the structure reverts to the original prototype. (See Fig. 1.)

It will be seen that the extra element required in the one arm is always some fraction of that in the other arm of the prototype. For example, in the low pass prototype T section, the added element is an inductance in the shunt arm, in series with the already existing condenser. The circuits so formed are thus either series resonant circuits in the shunt arm or parallel resonant circuits in the series arm (see Fig. 6, filters B and F).

It is self-evident that at the resonant frequencies of these circuits in the shunt or series arm their impedances will be zero or infinity respectively, so causing the attenuation at these frequencies to be infinite.

The value of m thus controls the value of the extra element to be added, and the computation of all the elements of the " m derived " section is merely a question of simple arithmetic, when the values of the prototype section have been obtained, and the value of m calculated from initial data.

Further, the characteristic impedances of " m derived " sections obey the same rule as the prototype from which they are derived, hence a composite structure can be made up without serious internal reflections taking place between adjacent sections.

On Fig. 12 the values of m in terms of frequency of cut-off and frequency of infinite attenuation are given for the various types of derived section.

From Fig. 11 it will be seen that the values of attenuation at the frequency $f = f_\infty$ all theoretically reach infinite values. Owing to dissipation this does not hold, and for a given quality of inductance used, the value of maximum attenuation decreases rapidly as m decreases.

Fig. 13 shows the locus values of the maximum attenuation in dissipative filters for various ratios of $\frac{\omega L}{R}$. This curve is used in conjunction with Fig. 11.

(To be Continued). W. PROCTOR WILSON.

MARCONI NEWS AND NOTES

THE MARCHESE MARCONI

Senatore Marconi has received many honours from countries throughout the world. A list of these honours perhaps more than anything else epitomizes at once the service Senatore Marconi has rendered to science and mankind, and the universal recognition of the outstanding character of his work. In 1909 he was nominated by the King of Italy to a seat in the Italian Senate, and since the publication of the last number of THE MARCONI REVIEW the King of Italy has been pleased to confer upon Senatore Marconi another high honour in the hereditary title of Marchese as a further recognition of his life's work.

The Marconi Beam as a Link in World Wide Broadcasting.

A striking instance of the value of the Marconi Short Wave Beam system as a link in world-wide broadcasting was given on Sunday, July 7th, when the Thanksgiving Service in Westminster Abbey, London, for the recovery of the King was broadcast.

The King's recent serious illness had aroused the deepest feelings of concern in the hearts of British people throughout the world, which was shared by the people of all countries. There was, therefore, a widespread desire to hear the broadcast of the Thanksgiving Service, and an arrangement was made between the British Post Office, the British Broadcasting Corporation and the Marconi Company and its Associates for the broadcast of the Westminster Abbey service to be relayed to Canada by means of the telephone channel of the Marconi-Mathieu Multiplex Beam transmitter. So clearly were the signals received in Canada that not only was the service re-broadcast in that Dominion, but it was relayed through the Canadian Beam transmitter to Australia for re-broadcast in Australasia.

Although the Marconi-Mathieu Multiplex transmitter at Bodmin had been previously used for a series of very successful wireless telephony tests with Canada, it had not hitherto been employed for broadcasting. This was, therefore, the first time that it had been used as a link in a broadcasting chain. The result fully confirmed all expectations, the broadcast, both in Canada and Australia, being of the finest quality.

Details of the transmission are as follows: The service was transmitted from London to Bodmin by Post Office landline, and was there connected to the telephone side of the Marconi-Mathieu Multiplex Beam circuit for transmission to the Canadian Beam Receiving Station near Montreal. There the signals were transferred to the landline and passed along to the Canadian National Railway's and the Canadian Marconi Company's broadcasting stations by means of which they were broadcast throughout Canada. The Canadian Marconi Company's Beam station was also used to relay transmission across the Pacific to La Perousse, Sydney, Australia, and from Sydney it was re-broadcast throughout Australia and to neighbouring countries by the stations of Amalgamated Wireless (Australasia), Ltd.

The event was unique in the history of broadcasting. Letters from all parts of the Dominion have poured into the offices of the Canadian Marconi Company congratulating the Company upon the success of the re-broadcast, and expressing gratitude for the opportunity of listening to such a fine programme, and it is understood that Canadian listeners have commenced an active agitation for more inter-Empire broadcast programmes by Beam.

The comments on the quality of the transmission were that, in the opinion of the listening public, this broadcast was far better than any overseas broadcast hitherto attempted on the American continent, and was equal to a first class local broadcast.

That the excellence of this transmission was due to the Beam link is demonstated by the fact that listeners who attempted to pick up the transmission direct found that conditions were poor.

This experience shows that the use of the Beam system will be essential as a link in any satisfactory scheme of Imperial broadcasting.

Canadian Broadcasting Commission's Report.

The success of the broadcast of the Thanksgiving Service gives point to a paragraph which appears in the London *Observer* for July 14th, giving a forecast of the report of the Royal Commission appointed under the chairmanship of Sir John Aird, at the beginning of this year, to examine various methods of broadcasting control, and to submit to the Canadian Parliament recommendations to govern the future broadcasting policy of the Dominion. This Commission having taken a preliminary survey of radio broadcasting conditions in Canada, visited broadcasting centres in the United States of America, Great Britain, France and Germany.

According to the *Observer*, the Canadian Broadcasting Commission has now indicated, through its Chairman, the principles of its report. This will point out that although Canada has some excellent broadcasting stations, she is largely dependent on American programmes, and desires an increase in her own chain of broadcasting stations.

The *Observer* adds : " There is a general desire for British programmes to be transmitted by Beam wireless, and we are encouraged to look forward to the day when Empire programmes will be exchanged regularly between the Empire States."

Telephony by Beam.

The broadcast of the Thanksgiving Service having been so successful, it occurred to the engineers operating the service that a test might be made of the apparatus for telephonic conversation between England and Australia via Canada. The test thus proved extremely successful, and for the first time a sustained telephonic conversation was engaged in between the two countries over this long route. July 7th will thus become important in wireless history as the date of the first duplex telephone conversation between England and Australia.

In this connection it is interesting to note that with rather experimental arrangements at Poldhu, the Marconi experimental station in Cornwall, intelligible speech was transmitted for the first time in history from England to Sydney on Friday, May 30th, 1924.

If apparatus similar to that used at Bodmin on July 7th had been available on the direct Australian Beam circuit, similar conversation could have been carried on direct with Australia without the intervention of any intermediate station, and this would be the normal method of carrying on wireless telephone communication with Australia.

A valuable point proved by Sunday's experiment was, however, the possibility of using the route through Canada as an alternative to the direct route to Australia, and the excellence of the voice reproduction and the ease of communication on this occasion demonstrated very clearly that the Beam without doubt will be the best method of carrying on long distance wireless conversations.

The Marconi Company to supply the Vatican Wireless Station.

The order for the wireless station which is to be erected in the Vatican City for the use of His Holiness the Pope and the Vatican State, has been placed with Marconi's Wireless Telegraph Company, Limited. The manufacture of the apparatus for this station and the plans for its installation have already been put in hand, and will be carried out with the greatest possible expedition.

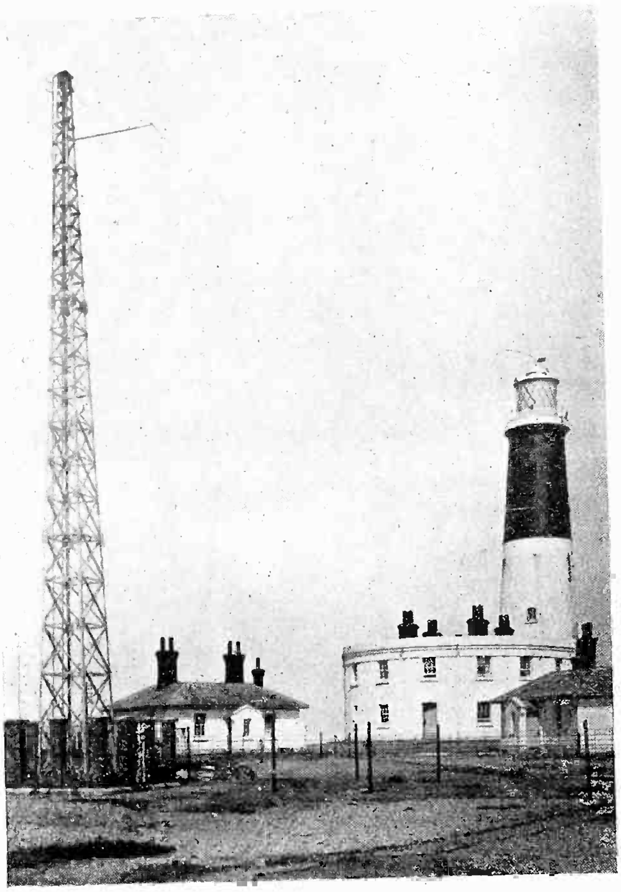
The station will embody the latest improvements in wireless design and construction, and it is receiving the personal supervision of the Marchese Marconi. Communication will be carried out both by telegraphy and by telephony on the short wave broadcast principle, and the range of the station will be world-wide.

International Lighthouse Conference.

The first International Lighthouse Conference was convened by the Corporation of Trinity House and held in London from July 8th to July 12th.

At this Conference, at which all the principle foreign nations were represented, technical matters relating to lighthouse illuminating apparatus, fog signals and other subjects concerning lighthouse administration were discussed.

The value and use of wireless formed one of the most important subjects considered, and the importance attached to wireless was shown by the fact that the special session at which the subject of wireless was discussed was more largely attended than any of the others.



Dungeness Lighthouse and Beacon Aerial System.

In opening the Conference, the President, the Duke of Connaught, said that within the last few years one of the greatest safeguards to the well-equipped vessel had been evolved in the form of direction finding by wireless, and the establishment round the coasts of wireless beacons by means of which the mariner could fix his position, particularly during fog, which is one of the worst trials to be encountered at sea.

Vice-Admiral Mansell, C.B.E., M.V.O., Deputy Master of Trinity House, who presided at the special wireless session, opened the discussion by saying that the introduction of wireless fog signals was perhaps the greatest advancement in modern aids to navigation. These radio beacons were now becoming general along coast lines where aerial fog signals had previously been established. Though other systems of directional wireless were being experimented with the beacon type of wireless fog signal had so far been universally adopted.

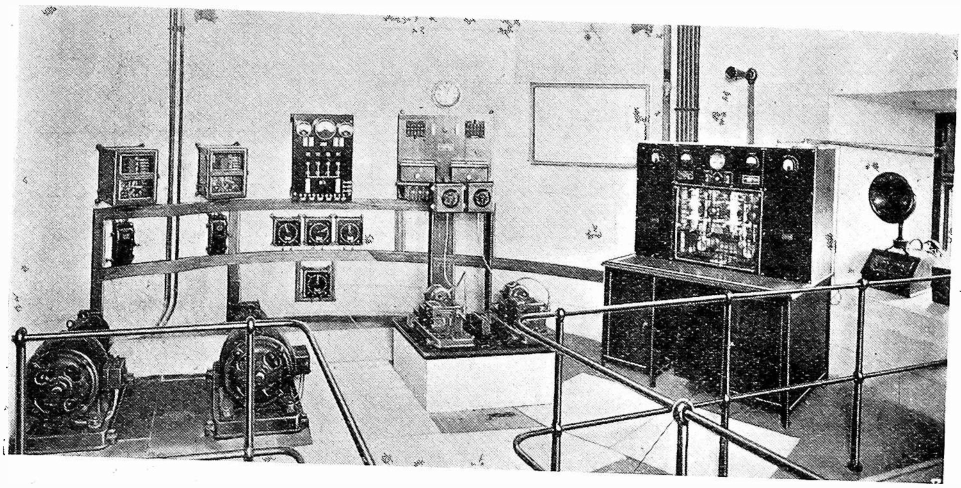
Mr. J. P. Bowen, Engineer-in-Chief to Trinity House, who entered fully into the subject, referred to the rotating Beam transmitter, the rotating loop beacon and the all-round beacon transmitter, and said it was the all-round beacon which had, up to the present, been universally adopted by those countries which had developed or were developing a programme of wireless fog signals, and it was this type which had so far been selected by Trinity House. Though requiring the provision of a somewhat expensive Direction Finding instrument on board ship, some of its advantages were :—

1. Comparatively low initial cost.
2. Low power and consequent low maintenance cost.
3. Automaticity and hence no additional personnel.
4. Availability for shore or lightship stations, and
5. Range of utility.

Moreover, a ship provided with a Direction Finder could take bearings on other ships in fog or ascertain the position of a ship in distress.

The whole equipment was automatic in operation from start to finish, and placed under the control of a master clock which governed the times and periods of transmission. All running machinery was in duplicate, and thus equipped practically no attention to the plant was required other than general maintenance, making the whole foolproof as far as possible.

Dr. Putnam of the United States said in his country there were 60 wireless beacons, and wireless seemed the only possible system now for sea signals.



Marconi Wireless Beacon Station, Type W.B.2, installed for Trinity House at Dungeness.

Visit to Dungeness Beacon Station.*

The Marconi Company has installed a number of wireless beacon stations around the coasts of Great Britain for the various lighthouse authorities, and the delegates to the International Lighthouse Conference visited the wireless beacon station which had just been completed at Dungeness, a photograph of which is published on this page.

* A technical description of the Marconi W.B.2 Beacon Transmitter appeared in MARCONI REVIEW No. 9.

On another day the delegates paid a visit to the Marconi Works at Chelmsford, where they saw wireless apparatus of all kinds, including that for lighthouse services, being manufactured, and witnessed demonstrations of reception from beacon stations on direction finding receivers, the reception of Auto Alarm distress calls, telephony with wireless installations suitable for harbour and lighthouse services, and automatic calling apparatus used with these installations to avoid the necessity of a continuous wireless watch being maintained.

Wireless on Trawlers.

The use of wireless equipment on fishing vessels has now been an established practice over a sufficient period and in a sufficient number of cases to render possible an examination of its utility.

Reports received by the Marconi International Marine Communication Company from a number of steam trawlers on which Marconi apparatus is installed indicate clearly that its value is very considerable. Units of fishing fleets have been enabled to communicate throughout their operations and, by exchanging reports of fishing conditions, to concentrate on the grounds where working was found to be most profitable at the time.

In addition, by keeping in touch with the owners, the trawler skippers have been enabled to obtain last-minute market reports and to land their catches at the ports where prices were most favourable.

By providing these services, the wireless installations have generally proved to be extremely profitable investments for trawler owners, while the convenience of wireless communication in other ways is also appreciated among the fishing fleets. A very complete service of weather reports, independent fishing reports, and time signals is made available by wireless, and these auxiliary services have on occasion proved of incalculable value.

Practically all the Marconi-equipped trawlers carry ¼ kilowatt transmitters of the quenched-gap type, with 2-valve receivers—Type M.R.4C—having a wave range of 200 to 3,000 metres. With this apparatus trawlers are able to communicate with other trawlers and with land stations over distances of 200 to 300 miles and more.

A number of trawlers are also fitted with Marconi direction finders and direction indicators. These instruments provide at an economical cost an invaluable aid to navigation, independent of weather conditions, and in addition enable a vessel when called to any particular fishing ground by a sister-ship to proceed directly there by following the wireless bearing of the calling transmitter. In this way a trawler fleet, large or small, can be concentrated with the minimum of delay on the most profitable fishing grounds.

The following extracts from reports recently received from Marconi-equipped trawlers demonstrate the practical utility of wireless apparatus to fishing fleets.

"After two days unprofitable fishing in the vicinity of St. Kilda the Captain requested me to enquire from some other trawlers the nature and amount of their catch. Having received the information required and found that results were no better than ours, the Captain gave orders to steam to the Minch, and after the first day's work the Captain found the results were very much better. I then called up another of our trawlers and gave the information that the results of the catch were very good. This eventually brought her to the grounds where we were, and after a few days in the above vicinity we sailed for Fleetwood, leaving the other trawler with what is hoped to be good fishing grounds where she would not have been but for our wireless."

"We received information from another of our trawlers where a fair living was to be had at fishing. This information was acted upon with result of a decent trip. Also information was passed on by me as I was control ship to all our other ships, three of them taking advantage of it."

"On leaving Fleetwood we received information of good fishing from the other vessels of the Company. We proceeded to position given and found fishing very good. We arrived in Fleetwood with a good catch of fish."

"Information was received by us of good fishing from two other vessels of our fleet. We proceeded to the position given at Black Rock grounds and made a good catch."

"We have been herring fishing this trip. We received markets from the owners which helped us to make moderate prices."

"The wireless has been of great value during the past trip—positions, soundings, etc., being received as to the whereabouts of good fishing."

"Good fishing news was received and we proceeded to the position given with the result that a very good catch was obtained."

"Communication was established with all coast stations passed within range. Communication was also established with all trawlers of this Company. All fishing reports exchanged satisfactorily."

"We reported good fishing at St. Kilda to all ships—two of our trawlers steamed 100 miles to our position, thus benefiting by the information."