Kirke ✓

The Institution of Electrical Engineers

FOUNDED 1871

INCORPORATED BY ROYAL CHARTER 1921

SAVOY PLACE, VICTORIA EMBANKMENT, LONDON, W.C. 2.

THE DESIGN OF TRANSMITTING AERIALS FOR BROADCASTING STATIONS.

BY

P. P. ECKERSLEY, MEMBER, T. L. ECKERSLEY, B.A., B.Sc., AND
H. L. KIRKE.

Reprint from the Journal of the Institution of Electrical Engineers, Vol. 67, No. 388,
April 1929.

THE DESIGN OF TRANSMITTING AERIALS FOR BROADCASTING STATIONS.

By P. P. ECKERSLEY, Member, T. L. ECKERSLEY, B.A., B.Sc., and H. L. KIRKE.

(*Paper first received* 23*rd November*, 1928, *and in final form* 13*th March*, 1929 ; *read before the* WIRELESS SECTION 2*nd January*, 1929.)

SUMMARY.

The paper is divided into two sections and a conclusion. The first section gives the theory of the aerial as a radiator, with special reference to its ability to radiate rays parallel to the surface of the earth at its base. An account is given of experiments with different types of aerial designed to achieve this result. The reduction of the indirect ray, that is the ray producing a component of radiation at angles less than 90° to the vertical, should produce less fading of signals, and theoretical predictions are made as to the extent of such reduction. An account is given of practical tests on the fading of signals from different forms of aerial. There is some discussion as to how the desired results can be achieved in practice, having special reference both to the use of T aerials and very high masts.

The second section deals with the theory of attenuation of waves having frequencies between 500 and 1 500 kilocycles per second, and gives a complete set of curves actually taken from a transmitting aerial near London.

The conclusion sums up the results and gives data to enable the broadcasting engineer to specify, in general terms, the extent of service area and the effectiveness of the service to be expected, using a given power, frequency of emission of carrier wave, height of aerial and earth conductivity.

SYMBOLS USED, AND DEFINITIONS.

$\frac{1}{4}\lambda$ aerial, an aerial having a vertical height $= \frac{1}{4}\lambda = h$.
$\frac{1}{2}\lambda$ aerial, an aerial having a vertical height $= \frac{1}{2}\lambda = h$.
h = physical height of the vertical part of an aerial.
λ = wave-length.
λ_0 = natural wave-length of an aerial.
f = frequency.
I = aerial current, defined as the maximum current in the aerial.
I_a = aerial current, defined as current at base of $\frac{1}{2}\lambda$ aerial.
Z = impedance of an oscillating circuit.
V = voltage between base of aerial and earth.
W_R = power radiated.
W = total aerial power.
E = field strength.
d = distance from the transmitting aerial at close ranges before attenuation is noticeable.
x = distance from the transmitting aerial at great ranges after attenuation is noticeable.
h_1 = effective height of aerial derived from the expression $E\lambda d/(377I)$.
R_D = dead-loss resistance of an aerial.
R_R = radiation resistance of an aerial.
R_T = total resistance.
η = relative power efficiency $= h_1^2/(\lambda^2 R_T)$.
σ = conductivity of the earth.
ϵ = specific inductive capacity of the earth.

SYMBOLS USED, AND DEFINITIONS—*continued*.

S = reduction factor for numerical distance d_n.
d_n = numerical distance $= (\pi x/\lambda)\left\{1/(2\sigma\lambda c)\right\}$ approx.
c = velocity of light.

INTRODUCTION.

Broadcasting problems, in so far as they concern the distribution of transmitting stations in any continent, have lately become acute. A few years ago listeners were content with a service of poorer quality, but, as has always been predicted, interest grows in the actual programme while it diminishes as to the technical aspects of the broadcasting service. This means that those who have listened for some years are less and less tolerant of interruption and poor-quality service. The increasing number of stations in any continental area vastly limits the number of available wave-lengths for that area and so imposes upon each organization the necessity of having fewer stations of higher power and of using shorter and shorter wave-lengths (if stations are not to be continuously heterodyned).

This paper deals with an important technical aspect of the problem of transmitter design—the design of the transmitter aerial. The proper method of attack against the problem of mutual interference between stations and the all too limited service area of stations is to attempt to design an aerial so as, ideally, to make it a radiator which only produces a direct ray or ground ray, i.e. a ray initially parallel to the earth's surface. It is the existence of the indirect ray which produces all the difficulties inherent to the production of a good broadcasting service, not only because such an indirect ray interferes with other very distant stations, but also because it produces fading and bad quality in the local service area. The paper shows that the direct ray, all important for broadcasting purposes, can be increased by using a particular type of aerial. By implication, the indirect or space ray is decreased. The degree of reduction of the space ray, however, is not anything like sufficient to prevent interference at night between relatively distant stations. Thus, even if special aerials are used, there is still imperative need for all Continental stations to adhere to an international plan for the repartition of the all too few available channels. The problem for the serious broadcaster, willing to conform to the technical implications of an international plan, is made unnecessarily more complicated by the attitude of those few who do not recognize the technical necessity for conformity to such a plan.

All energy radiated upwards is, in broadcasting, lost energy. Obviously the more an aerial can be made to radiate only in a direction tangential to the earth's curvature at the base of the aerial, the more the ideal conditions will be approached. If all the aerial energy could be directed to produce this type of radiation there would be no indirect ray, no fading of signals, less interference with certain other stations at night and greater power efficiency of the aerial. Certainly we might expect some interference, but at a skip distance, not everywhere as at present. Thus it is important for broadcasting engineers to consider the aerial only in regard to its ability to produce radiation normal to its vertical portion. It is further important, however, to enable an engineer to specify the extent of service area, to know the rapidity at which these rays will be attenuated. This paper thus deals, in the second section, with considerations of attenuation and gives a complete set of attenuation curves for various broadcasting wave-lengths.

SECTION 1.

THEORETICAL CONSIDERATIONS OF THE AERIAL AS A RADIATOR.

It has been shown * that radiation from an aerial situated at ground-level can be resolved into radiation due to the aerial itself, and radiation from an image of the aerial in the earth.

Consider that the aerial and its image are composed of elements dh of h, the height, each with elements of high-frequency current i; then the radiation in any direction can be calculated by adding vectorially the radiation from each element of height, provided the height above the earth of this element is small compared with $\sqrt{(\lambda d)}$, where λ is the wave-length and d is the distance of the point of measurement of the radiation from the aerial. Clearly, if the currents in the elements are in phase, the field strength on the ground nearby is the arithmetical sum of the radiations from the elements.

For aerials of vertical height h less than $\frac{1}{4}\lambda$ the space phase of the element currents in the real aerial and its image will not be sufficiently different to cause cancellation of radiation in non-horizontal directions. As h is increased to $\frac{1}{2}\lambda$, however, the maximum current I in the aerial is at a distance $\frac{1}{2}\lambda$ (180°) from the maximum image current. There will be, in this case, considerable cancellation of radiations at high angles. As h is still further increased, then, provided the currents are in phase all along the aerial, the cancellation will be greater still in all directions other than the horizontal.

Fig. 1 gives the vertical polar diagrams, calculated by Stuart Ballantine, for $\frac{1}{4}\lambda$ and $\frac{1}{2}\lambda$ aerials for the same field strength on the ground. It is assumed that the earth is a perfectly conducting medium. (Note that the vertical polar diagram of the $\frac{1}{2}\lambda$ aerial is flatter than that of the $\frac{1}{4}\lambda$ aerial, due to angular radiation cancellations.) It will be seen that radiation horizontally will be proportional to $\int i\, dh$. Consequently, a given field strength can be obtained by the use of a high aerial with small current, or a small aerial with large current, i.e. the metre-amperes must be the same.

All energy not radiated horizontally is, from the broadcasting point of view, wasted. It will therefore appear obvious that the high aerial with small current will be the most efficient.

Most wireless engineers have been educated to consider only the problems concerned with $\frac{1}{4}\lambda$ aerials. This is only necessary when very long waves are used. The radiation resistance R_R can, for $\frac{1}{4}\lambda$ aerials, be found from the expression 1 580 h_1^2/λ^2, where h_1 is the effective height of the aerial. Radiation efficiency has been expressed as $R_R/(R_R + R_D)$, where R_D is the dead-loss resistance. In the past it has been considered desirable to make this expression as nearly unity as possible; that is, to get as much radiated energy as possible from a given power. The broadcasting engineer, however, requires only ground radiation and is not concerned with total radiation, which might, as a *reductio ad absurdum*, be all in a vertical direction. Thus radiation efficiency is not so important as power efficiency to produce a given field strength on the ground.

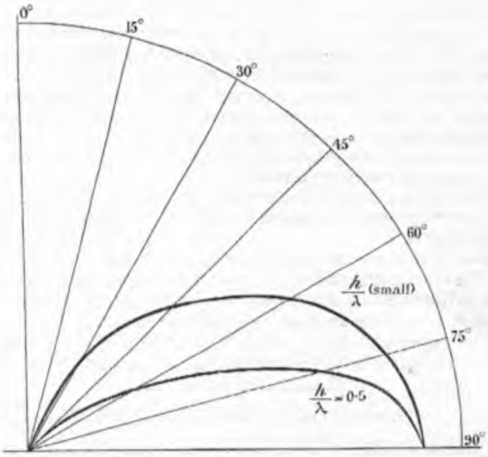

FIG. 1.—Vertical polar diagram of radiation for $\frac{1}{2}\lambda$ and $\frac{1}{4}\lambda$ (or less) aerials. Drawn for the same maximum radiation intensity in the horizontal plane.

The field strength on the ground for a given wave-length is proportional to metre-amperes ($h_1 I$). For a given power we must therefore produce a maximum value of $h_1 I/\lambda$. We must answer the question: What is the relative power required to produce a given value of $h_1 I/\lambda$ with $\frac{1}{4}\lambda$ and $\frac{1}{2}\lambda$ aerials? For the reasons explained above, increasing the height of the aerial, by producing cancellations of angular rather than horizontal radiation, flattens the vertical polar diagram while the ground vector proportional to $h_1 I/\lambda$ remains the same. Thus *less power is radiated with the high aerial while the horizontal vector remains the same.* This means that less power is required with a high aerial to produce a given value of metre-amperes. Analysing this in more detail, we can find a relative power efficiency for each aerial. For a $\frac{1}{4}\lambda$ aerial this efficiency is

$$\eta = \frac{A(h_1^2/\lambda^2)I^2}{(R_R + R_D)I^2} = \frac{\text{watts output}}{\text{watts input}} = \frac{Ah_1^2}{\lambda^2(R_R + R_D)}$$

where A is a constant.

---

* See Bibliography, (8).

Now if, on increasing h, the radiation resistance remained proportional to h_1^2 (given a constant small value of R_D) the above term would remain nearly constant for any value of h. But less power is radiated as we increase height and so R_R does not go up in proportion to h_1^2 but at a lower rate.

Consider then the term $h_1^2/(\lambda^2 R_R)$. This should be nearly constant for all aerials of height h less than $\frac{1}{4}\lambda$ but should increase rapidly thereafter. Stuart Ballantine has calculated $h_1^2/(\lambda^2 R_R)$ and Fig. 2 shows the results of his theoretical calculation.

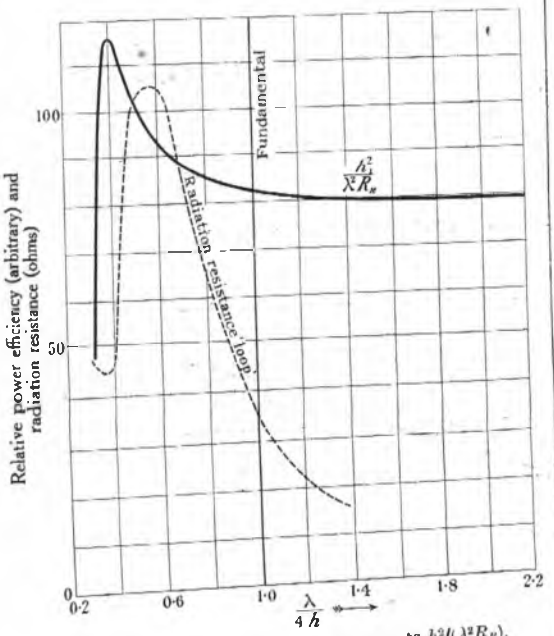

FIG. 2.—Ordinate (thick curve) represents $h_1^2/(\lambda^2 R_R)$.

h = height of vertical aerial.
λ = wave-length.
R_R = radiation resistance.
h_1 = effective height.

The x axis of Fig. 2 is drawn on a scale of the ratio of $\lambda/(4h)$, and the y axis represents the expression $h_1^2/(\lambda^2 R_R)$ plotted on a purely relative scale. It is reiterated that this curve represents, in fact, $\int i\,dh$ and shows the increase of horizontal radiation due to the decreased total radiation for a given power as the number of elements dh_1 are added together vertically. A curve of radiation resistance is plotted for future reference. It is also a purely theoretical curve. It will be seen that the curve for radiation resistance gives a value, for $\frac{1}{2}\lambda$ aerials, *less than* that given, by 1 580 h_1^2/λ^2.

It will be remarked that after the value of h/λ is increased beyond 0·4 the expression $h_1^2/(\lambda^2 R_R)$ decreases abruptly. This is explained by realizing, as shown in Fig. 3, that the phase reverses in the upper part of a long homogeneous aerial unless precautions are taken to avoid this effect. The obvious line to take is to add (see Fig. 4) $\frac{1}{2}\lambda$ aerials, one above the other, and to introduce a "phasing coil" to reverse the phase at each join. This device has been adopted by Mr. C. M. Franklin in his beam system for short-wave telegraphy.

Fig. 5 shows the relative power required to produce a given field strength with different values of $4h/\lambda$ up to a value of 2. Obviously, from the expression for metre-ampere efficiency, $h_1^2/\left\{\lambda^2(R_R+R_D)\right\}$, the value of the dead-loss resistance R_D affects the result, and so curves are shown for various values of dead-loss resistance.

It will be seen that theoretically, and with 10 ohms dead-loss resistance, we save about 40 per cent of power by using $\frac{1}{2}\lambda$ instead of $\frac{1}{4}\lambda$ aerials to produce the same field strength at a given point. Fig. 6 shows the increase of field strength using different heights of aerial with the same aerial power, W.

Fading.—The flattening-out of the vertical polar diagram reduces the indirect ray and so should reduce fading. The curves in Fig. 7 give from theory the expected reduction at various distances of the indirect ray when using $\frac{1}{2}\lambda$ instead of $\frac{1}{4}\lambda$ aerials. It will be seen that the ratio of indirect to direct ray with a $\frac{1}{2}\lambda$ aerial is reduced, at 100 miles, to 0·05 of the ratio of the indirect to the direct ray when using a $\frac{1}{4}\lambda$ aerial—this assumes a height of Heaviside layer of approximately 100 km.

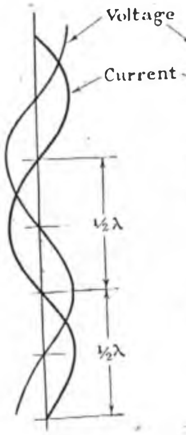

FIG. 3.—Current and voltage in a long uniform aerial.

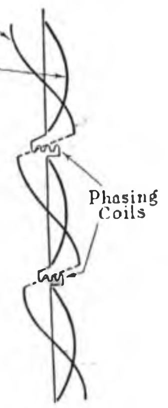

FIG. 4.—Current and voltage in a Franklin aerial.

Note on effective height.—There may be some confusion as to the meaning of h_1, the effective height. For instance, it is well known that the theoretical effective height h_1 for a $\frac{1}{4}\lambda$ aerial is $(2/\pi) \times$ actual height h. But it is important not to use this value for h_1 if an aerial less than $\frac{1}{4}\lambda$ in height has to be loaded by added inductance to give it the same natural wavelength as if it were a vertical wire of length $\frac{1}{4}\lambda$. Effective height is a misleading term for loaded aerials—effective current is more definite. This would mean the average value of the current in the vertical part of the aerial, and metre-amperes would be found by multiplying the actual height of the vertical part by the average current in that part.

Conversely, effective height could be worked back

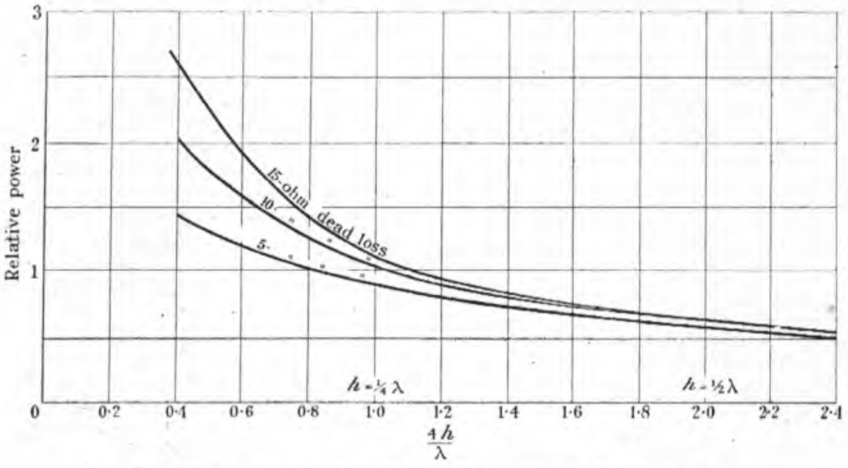

Fig. 5.—Relative power required to produce a given value of metre-amperes.

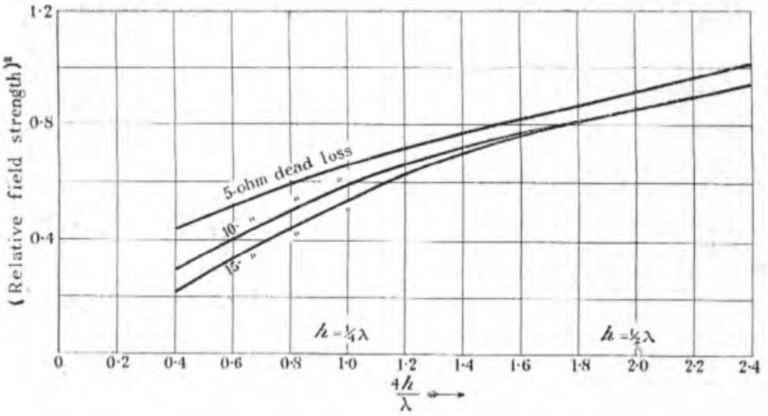

Fig. 6.—Relative field strength for a given power for various values of h/λ.

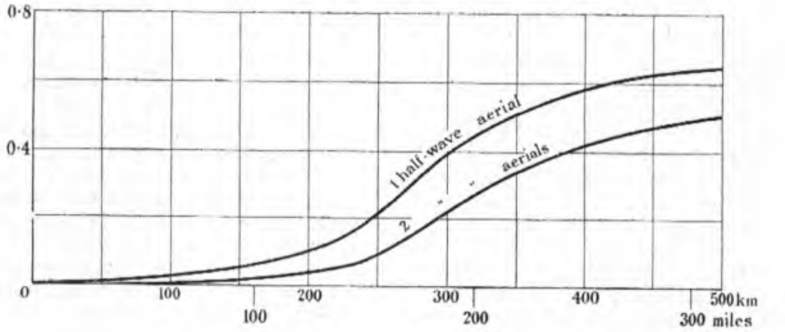

Fig. 7.—Relative reduction of reflected ray using one $\frac{1}{2}\lambda$ aerial and two $\frac{1}{2}\lambda$ aerials, as compared with unity for $\frac{1}{4}\lambda$ aerial.

from a measure of the field strength at a distance of a few wave-lengths from the aerial calculated from the formula $E = 377h_1I/(\lambda d)$, where d is the distance of the point of measurement from the aerial. The authors feel that effective height is best expressed therefore as $h_1 - E\lambda d/(377I)$ (I being the maximum current in the aerial, d the distance at which the field strength is measured, and λ the wave-length), whatever the form of aerial. Effective height taken in this way depends upon the distance d. This distance must be so chosen that the field strength at that distance does not suffer attenuation. In practice this distance is safely taken as 5 wave-lengths.

Experimental tests.—It was thought important to test this theoretical analysis in terms of full-scale experiments. To this end the British Broadcasting Corporation approached the Air Ministry with a view to hiring a captive kite balloon to support various lengths of aerials.[*] The site of the experiments was Larkhill near Amesbury, on Salisbury Plain.

The first experiment was to determine whether, for the production of a given field strength, the necessary power in the aerial was decreased, as theory indicated, by changing from a $\frac{1}{4}\lambda$ to a $\frac{1}{2}\lambda$ vertical aerial.

Difficulty was at first experienced in the mechanical arrangement for supporting the vertical wire of the aerial, but the final scheme adopted was to attach the earth end of the aerial wire firmly to an anchor on the ground, while 60 ft. of rubber shock-absorber was interposed between the balloon and the free end of the aerial.

The power was fed in from the B.B.C. transmitting lorry, which contains a 1-kW valve transmitter, the power being derived from an alternator clamped in the chassis and driven by the engine of the lorry.

The earth for the aerial consisted of 40 wires radiating from a point immediately under the aerial, each wire being 250 ft. long and buried in a plough furrow about 6 in. deep.

In order to take account of changing winds the lorry carrying the winding gear for the hauling up and down of the balloon was moved from place to place.

To leave no doubt as to the results, the usual wire hawser for the captive balloon was substituted by a hempen rope. No one made the ascent in the balloon, which was, as a matter of fact, condemned for purely service conditions.

It will be appreciated that one of the greatest practical difficulties was to take accurate readings of the current in the $\frac{1}{2}\lambda$ aerial, as the maximum current occurs half-way up the aerial. Specially large ammeters were, however, constructed and the readings were taken by telescope.

It was most unfortunate that after the first week the unusually fine weather broke. Great difficulty was experienced due to gales of wind, and a great deal of the time was wasted in waiting for "flying weather." On one occasion the whole rigging collapsed.

Method of Measurement of Constants of Aerials.

Power.—It was essential to have an exact knowledge of the power in the aerial. For the $\frac{1}{4}\lambda$ aerial this was obtained as follows: The circuit and current distribution were as shown in Fig. 8. The voltage (V) between aerial and earth, and the aerial current (I), were measured at various frequencies and Z, the impedance, was taken to be V/I. The aerial was said to be in tune when Z was a minimum. The power in the aerial was then $Z_{\frac{1}{4}\lambda}I^2$. For the $\frac{1}{2}\lambda$ aerial the connections were as shown in Fig. 9. Z was again compared with frequency and the aerial was said to be in tune when Z was a maximum. The power in the aerial was in this case the square of the current I_a at the base of the aerial multiplied by the total impedance, $Z_{\frac{1}{2}\lambda} = V/I_a$ (where $Z_{\frac{1}{2}\lambda}$ is a maximum).

Field strength.—The field strength was taken as the average of 6 measurements at different points on a circle around the aerial. Each reading was taken at 2 km from the aerial. The results are given in tabulated form on page 513.

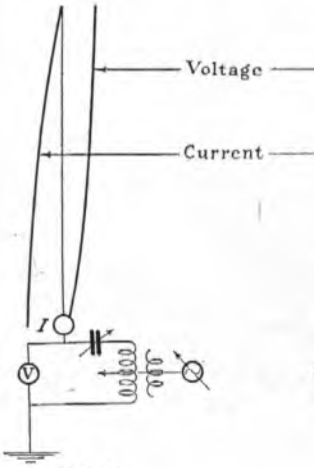

FIG. 8.

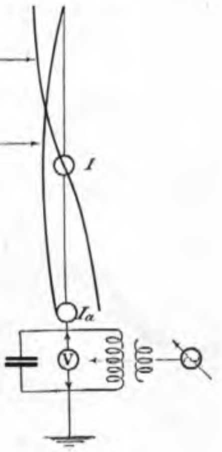

FIG. 9.

Observations on the Results.

Effective height.—It will be observed that theoretical and practical effective heights do not agree. This is a common occurrence—the practical effective height when not agreeing with the theoretical value always being less than the latter. There was a large wood near the site of the experiments, and the surface soil on Salisbury Plain is only 18 in. deep, hard chalk lying underneath. It is perhaps a question of earth resistivity, although theoretically this should not affect the results unless the resistivity is so high that $\sigma\lambda c$ is comparable with unity, σ being the conductivity of the earth and c the velocity of light. The results show that effective height should always be measured rather than assumed; in fact the choice of a site for a transmitter might well be determined, *inter alia*, by the measure of the effective height of aerials upon it. The effective height of an aerial at Brookmans Park, near London, used for the attenuation experiments, was the same both by measurement and theory. Mr. T. L. Eckersley has, however,

---

[*] The authors' most grateful thanks to the Air Ministry are expressed more fully in the conclusion to the paper.

measured the effective heights of aerials near Chelmsford. These showed a consistent error, always being less than the correct theoretical value. The reduction of effective height was in this case attributed to the effect of the supporting masts. It is somewhat distressing to find this ambiguity, because we have had to assume the theoretical value for h_1, in the radiation resistance of a $\frac{1}{2}\lambda$ aerial (see Fig. 2). Is this correct for the $\frac{1}{2}\lambda$ aerial if it is incorrect for the $\frac{1}{4}\lambda$ aerial? And what may be assumed to be the dead-loss resistance? In any case it is to be noted that the measured effective height of the $\frac{1}{2}\lambda$ aerial is practically twice that of the $\frac{1}{4}\lambda$ aerial. Measurements have been checked in all ways and there is no doubt as to their accuracy. The ambiguity must therefore remain.

General.—Assume the aerial in both cases to have a 10-ohm dead loss. It is not an unlikely figure and it is perfectly just to assume the same loss in both aerials, the major loss in any aerial system being due to the field intensity around the aerial. It will then be seen (Fig. 5) that the ratio of power with $\frac{1}{4}\lambda$ to $\frac{1}{2}\lambda$ aerials to produce a given field strength with a 10-ohm dead loss is theoretically 1/0·61, and in the practical measured case 1/0·625—a remarkable confirmation if a 10-ohm dead loss is a fair assumption. Putting the matter still more generally, it can be seen that at any rate there is a substantial gain in the use of $\frac{1}{2}\lambda$ aerials.

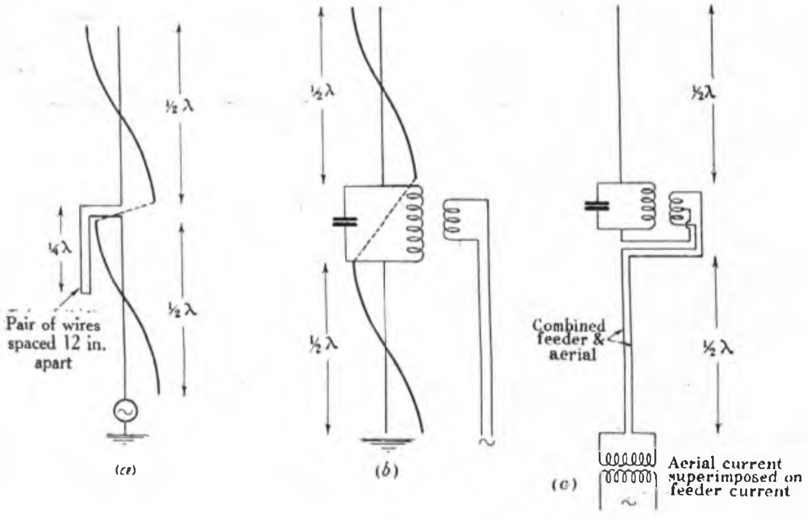

FIG. 10.—Types of circuit.
Circuit (*b*) is the most promising.

The analysis has been based on the assumption that the aerial behaves as if it were situated on a perfectly conducting plane and that the effect of the loss due to the imperfect conductivity of the earth can be represented by a constant part of the dead loss R_D (taken in this case to be 10 ohms). The Sommerfeld theory provides the necessary mathematical facility for calculating the earth loss, and it would appear from an analysis made by one of the authors that this assumption is very nearly correct. Further, the assumption appears to be justified by the results of the experiments.

Tests with Franklin aerials.—It is now obvious both theoretically and practically that relative power efficiency increases as the height of the aerial is increased. If, however, h extends much above a value of $\frac{1}{2}\lambda$ the phase of the current in the upper part changes over and a rapid decrease of direct ray radiation takes place (see Fig. 3). If, however, the phase of the voltage can be abruptly reversed from one $\frac{1}{2}\lambda$ aerial to another, the predicted and observed improvement is still further manifest. It is thus necessary to arrange some electrical device which at the join of the two $\frac{1}{2}\lambda$ aerials reverses the phase of the voltage (see Fig. 4). Mr. C. M. Franklin who, with his beam aerials for use with ultra-short waves, uses, on occasions, as many as three $\frac{1}{2}\lambda$ aerials, one above the other, introduces what he terms a " phasing coil " at the join of each aerial. In effect he " wraps up " a $\frac{1}{2}\lambda$ aerial in such a way that it will have the " surge impedance " of a wire $\frac{1}{2}\lambda$ in length, but will not, however, produce any radiation. He uses a cylindrical former, but the wire is run up and down the former much as the filament of an incandescent lamp is hung upon its supports. His first attempts to use a circular coil of conventional form were, it is understood, unsuccessful. The object is to produce a system having a surge impedance (L/C ratio), in the wrapped-up wire, of the same value as if the wire were straight. It was the object of the authors' experiments to produce Mr. Franklin's system with frequencies of the order of 1/10th of those used in the beam system of wireless telegraphy. In the various attempts (made in the intervals between violent gales) their efforts were entirely abortive. Several forms of phasing device were used. Without being joined to the $\frac{1}{2}\lambda$ aerials these appeared to have the correct surge impedance, but when connected to the actual aerials they did not behave rationally.

Fig. 10 shows the various methods tried or proposed. System (*a*) was proposed by Mr. T. C. Macnamara of the B.B.C. Development Department, but had been used by Mr. T. L. Eckersley on frequencies of 20 000 kilocycles per sec. (15 metres) with complete success. Mr. T. L. Eckersley's bifilar phasing device was pulled out at right angles to the aerial. This was impossible mechanically with the dimensions necessary for wave-lengths of the order of 300 m and with a kite-balloon support. Perhaps the failure of the authors' arrangements can be attributed to inductive effects between the aerial and the phasing system. Arrangement (*b*) was also tried without success, but probably the surge impedance was not correct. The other arrangements are proposed for future experiments either using masts or in periods of finer weather.

Experimental Fading Tests.

Owing to extremely bad weather conditions it was only possible to carry out one fading test. This test was to compare fading from a vertical $\frac{1}{2}\lambda$ aerial with that from a T aerial supported by 70-ft. masts. The T aerial had a natural wave-length of 288·5 m (the wave-length used) and was loaded with inductance. The power in the two aerials was not measured. The metre-amperes were, however, measured and the ratio was approximately 2 : 1 in favour of the $\frac{1}{2}\lambda$ aerial, for the same total power input to the transmitter.

SCHEDULE OF TESTS WITH $\frac{1}{2}\lambda$ AND $\frac{1}{4}\lambda$ AERIALS.

Type of aerial, h/λ	Height of aerial, h	Wave-length, λ	Voltage (V) between base of aerial and earth	Current at base of aerial (I_a for $\frac{1}{2}\lambda$ aerial)	Aerial current I (max. current in aerial)	Impedance		Power in aerial
						$\frac{1}{4}\lambda$ aerial, $Z_{\frac{1}{4}\lambda} = \frac{V}{I}$	$\frac{1}{2}\lambda$ aerial, $Z_{\frac{1}{2}\lambda} = \frac{V}{I_a}$	$\frac{1}{4}\lambda$ aerial, $W = Z_{\frac{1}{4}\lambda} I^2$
	metres	metres	volts	amp.	amps.	ohms	ohms	watts
$\frac{1}{4}$	70	288·5	108	—	2·6	41·5	—	281
$\frac{1}{2}$	140	288·5	1 350	0·375	2·1	—	3 600	—

Type of aerial, h/λ	Power in aerial	Field strength, E, at 2 km	Effective height (practical), $h_1 = \frac{E\lambda d}{377\,I}$	Effective height (theoretical), $h_1 = \frac{2}{\pi}h$	Radiation resistance			Total resistance, $R_T = \frac{W}{I^2}$
					$\frac{1}{4}\lambda$ aerial		$\frac{1}{2}\lambda$ aerial	
	$\frac{1}{2}\lambda$ aerial, $W = Z_{\frac{1}{2}\lambda} I_a^2$				Practical, $R_R = \frac{A_3^* h_1^2}{\lambda^2}$, where $h_1 = \frac{E\lambda d}{377\,I}$	Theoretical, $R_R = \frac{A_3 h_1^2}{\lambda^2}$, where $h_1 = \frac{2}{\pi}h$	Theoretical, from Fig. 2	
	watts	mV/metre	metres	metres	ohms	ohms	ohms	ohms
$\frac{1}{4}$	—	64	38	43·5	27·5	35	—	41·5
$\frac{1}{2}$	506	109	79·5	87·0	—	—	103	115

Type of aerial, h/λ	Dead loss resistance			Metre-ampere efficiency, $\frac{h_1^2}{\lambda^2}R_T$, where $h_1 = \frac{E\lambda d}{377\,I}$	Relative watts in aerial to produce given field strength		Relative field strength at same distance with equal power	
	$\frac{1}{4}\lambda$ aerial		$\frac{1}{2}\lambda$ aerial					
	$R_D = R_T - R_R$ R_R (practical)	$R_D = R_T - R_R$ R_R (theoretical)	$R_D = R_T - R_R$ (theoretical)		Practical	Theoretical	Practical	Theoretical
	ohms	ohms	ohms		watts	watts	mV/metre	mV/metre
$\frac{1}{4}$	14	6·5	—	$4 \cdot 17 \times 10^{-4}$	1 000	1 000	1	1
$\frac{1}{2}$	—	—	12	$6 \cdot 66 \times 10^{-4}$	625	610	1·26	1·28

* A_3 is a constant.

The method of conducting the tests was to transmit speech and gramophone records for periods of one half-hour on each aerial alternately. There was an interval of about 5 minutes while changing over from one aerial to another.

Receivers, equipped with meters for measuring rectified current, were set up at the various B.B.C. stations. A number of amateurs similarly equipped co-operated in the experiments. Readings were also taken at the Radio Research Board's station at Peterborough.

The two transmitting aerials were near enough to one another to cause distortion of their vertical and horizontal polar diagrams unless precautions were taken. The 70-ft. aerial was therefore left disconnected from earth when idle and the vertical $\frac{1}{2}\lambda$ aerial was earthed when idle. The tests were conducted between the hours of midnight and 5 a.m.

Results of the Tests.

Fading is expressed as a percentage variation of the rectified current in a given receiver. There was no fading at 50 miles. At 65 miles the $\frac{1}{2}\lambda$ aerial gave from 20 to 25 per cent fading, while the 70-ft. aerial gave a 30 to 40 per cent fading variation. At 75–80 miles the fading was more pronounced with the low aerial but at 100 miles there was little difference in signal strength on the two aerials, and the fading was less (but not pronouncedly so) with the $\frac{1}{2}\lambda$ aerial.

It appears that at close ranges the ratio of down-coming direct ray was twice as great with the 70-ft. aerial as with the $\frac{1}{2}\lambda$ aerial.

There is very little evidence to go upon, but one might generalize by saying that it appears as though the upward radiation was for a given power appreciably the same for both aerials, but, as has been proved by other experiments, the stronger direct ray (for a given power) made a less apparent fading. The curves in Fig. 7 receive, therefore, no confirmation in the practical experiment. It would be wrong to place too much reliance upon the results of one experiment undertaken in somewhat trying conditions, but further experiments will be undertaken in the future using high masts. This will allow a more leisurely investigation of the whole problem of fading influenced by the aerial design.

Practical points arising from the results.—The outstanding fact is that high aerials appear to be necessary. High aerials imply high masts, and high masts demand high costs. The wave-band allocated for broadcasting is approximately between 550 and 200 m, or roughly 1 800 ft. to 650 ft. This entails masts for supporting $\frac{1}{2}\lambda$ aerials of from 900 to 325 ft. high or, allowing for sag, 1 000 to 400 ft.

Assuming that two $\frac{1}{2}\lambda$ aerials could be used, masts 2 000 to 750 ft. high would be required. Mechanical and economic conditions, however, impose a limitation of, say, 800 ft. high for the highest mast. This means that Franklin aerials cannot be used for wave-lengths greater than about 700 ft. (213 m) in length, but that $\frac{1}{2}\lambda$ aerials can be used on most wave-lengths. Masts are extremely costly, and one naturally asks whether some compromise cannot be adopted, and whether indeed the T aerial is not a more practical form of aerial.

The point at issue is: With a given height of mast, what is the best form of aerial? The importance of obtaining a maximum ground ray and minimum indirect ray would seem to override all questions of economics, and only the mechanical limits of mast height (or prohibition by flying authorities) should set a barrier between the ideal and the actual. Nevertheless, owing to mechanical limits the masts will always be shorter than is theoretically desirable. Thus we turn to the T aerial as a compromise arrangement.

At this stage and without experimental verification it would appear best so to arrange a T aerial that the current in the vertical part is maximum at the greatest possible height from the earth. Care must, however, be taken to see that the ends of the horizontal part of the top hamper are not brought so near to the masts as to induce mast currents and so produce shielding and/or loss. The whole question is not significant if $h < \frac{1}{4}\lambda$.

It must be insisted that the higher the masts the greater the metre-ampere efficiency. This point will be reverted to in the conclusion of the paper, when service area will be predicted in terms of 800-ft. and 500-ft. masts (supporting vertical aerials) for all broadcast medium wave-lengths.

It is pertinent at this point in the paper to ask whether the masts could not themselves be used as aerials. The authors, after consideration, believe that, although at first sight attractive, the method is not to be recommended as sound engineering practice, chiefly because of the entire lack of flexibility. Wave-lengths change from year to year, and any broadcasting organization finding itself forced to particular waves for certain stations might suffer. We must realize that high insulated masts are not easy to construct mechanically, and that an electric as well as a mechanical strain on the insulator might bring disaster. The effect of the stays is incalculable and might be deleterious. Wooden masts with a conducting core are attractive in theory but always present the risk of fire. Further, the life of such masts might be short and their cost for great heights greatly in excess of that for steel masts. If, however, dual masts carrying the conventional type of aerial are to be used, it is particularly important to guarantee that they will not cast shadows of a serious nature. This trouble has been acute at the Daventry broadcasting station and a repetition of the difficulties would be foolish. It is therefore imperative to insulate the mast. It is suggested that the masts could be tuned to have a natural wave-length, when unearthed, equal to the wave-length used, so that no current would flow in the mast when earthed.

SECTION 2. ATTENUATION OF WAVES.

The ideal problem of the transmission of electric waves over a uniform semi-conducting plane has been completely worked out by Sommerfeld * in the case where the aerial is small in height compared with the wave-length and is situated on the ground, and has been extended by Mr. T. L. Eckersley † to the case where the aerial (of similar dimensions) is situated at any given height above the ground. This ideal theoreti-

---

* See Bibliography, (2).

† *Ibid.*, (3).

cal case should represent to a first approximation the actual case in so far as the resistivity in the ground is uniform.

Sommerfeld has put his formula in a form suitable for calculation. The amplitude of the waves (for a given value of metre-amperes) must obviously be a function of the distance x, the wave-length λ, the earth's conductivity σ, and the earth's inductivity ϵ. He shows that the signal intensity is only a function of the quantity d_n, which he calls the "numerical distance" and which involves the above quantities in the following way:—

$$d_n = \frac{\pi x}{\lambda} \cdot \frac{1}{2\sigma\lambda c} \quad \text{very nearly}$$

i.e. within about ½ per cent on the broadcast band of wave-lengths [for σ of the order ½ × 10^{-12} (electromagnetic units)]. c is the velocity of light.

The term involving ϵ, the specific inductive capacity, is unimportant except on the very short wave-band, i.e. 10 to 20 m.

Sommerfeld's expression may be put in the form

$$E = A\left(\frac{1}{2d_n} + \frac{1.3}{2.2d_n^2} + \frac{1.3.5}{2.2.2d_n^3} + \ldots\right)\frac{e^{2\pi jx/\lambda}}{x} *$$

When d_n is large (say greater than 10),

$$E = A\,(u + jv)$$

where $$u = 1 - 2d_n + \frac{2.2d_n^2}{1.3} + \ldots$$

and, when d_n is small,

$$v = \sqrt{(\pi d_n)}e^{-d_n}$$

E may therefore be put in the general form (A and A_1 being constants)—

$$E = A_1\left(\frac{h_1 l}{\lambda}\right)\frac{1}{\lambda^2}F_1\left(\frac{x}{\lambda^2}\right) \quad . \quad . \quad . \quad . \quad (1)$$

(except for the exponential factor, which does not affect the amplitude). The quantity $h_1 l/\lambda$, mentioned previously in the paper, is the similarity factor for all aerials, and expresses the metre-amperes. It gives the initial power radiated and is the multiplier for all attenuation formulæ.

The form of expression (1) shows how it is possible to derive, by means of a simple construction, the curve for any wave-length when the attenuation curve for any one wave-length is known. This constitutes the short cut to a determination of the service area of a broadcasting station for any wave-length, for it is only really necessary to determine an irreproachable attenuation curve for *one wave-length* or to test the uniformity of the district on two fairly widely-separated wave-lengths.

The following analysis only applies to frequencies in common use to-day for broadcasting transmitters. Suppose we have one accurately determined mean attenuation curve for the district for a given wave-length. The curve for this wave-length (λ_A) is plotted; then the curves for all other wave-lengths are derived as follows:—

Let A B C (Fig. 11) be a curve for $\lambda = \lambda_A$, then the curve for $\lambda = 2\lambda_A$, for example, can be constructed as follows:—Let O be a point on the curve A B C for a distance x; then transfer O to O′ at a distance ($4x$) and reduce O′ to O″, where P′O″ = ¼ P′O′, then O″ will be a point on the curve for $\lambda = 2\lambda_A$. In this way, by choosing a series of points O on the original curve A B C we get a series of points O″ on the curve for $\lambda = 2\lambda_A$. These two curves will give the field strengths for two "similar" stations of λ_A and $2\lambda_A$ respectively.

Barfield * has argued that there may be an extra loss, due to trees and vegetation, etc., which must be considered together with the resistivity of the earth.

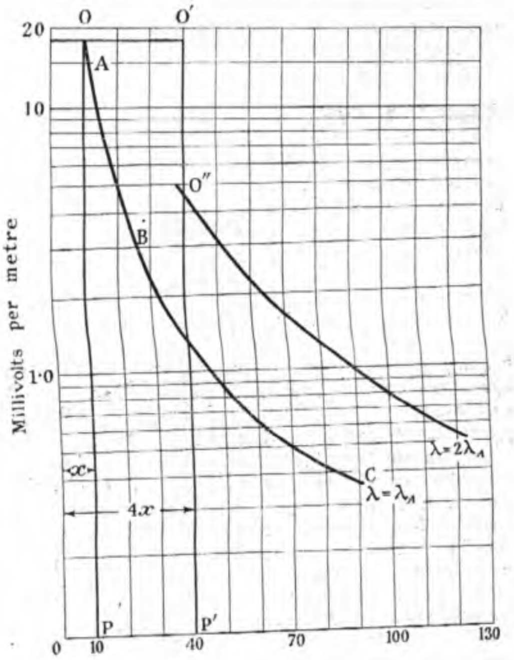

FIG. 11.

Forest land is known to be particularly effective in increasing the attenuation. In any case, to complete the information, curves should be drawn for different earth constants and different earth surface conditions. The only quantity that matters is the effective earth resistivity, which includes the vegetation loss. Whether this latter behaves in the same way as the actual conductivity as regards frequency-change, i.e. whether it is justifiable to include it with the earth resistivity, remains to be seen.

To take account of changes in earth conductivity we must alter the form of our equation.

We have $$E = \frac{A_2}{x}F_2(d_n) = \frac{A_2}{x}F_2\left(\frac{x}{\sigma\lambda^2 c}\right)$$

---

* See also R. L. Smith Rose and R. H. Barfield: *Journal I.E.E.*, 1926, vol. 64, p 767.

* See Bibliography, (5).

where $A_2 \propto h_1 l/\lambda$, x is distance, σ is the earth's effective conductivity, and c is the velocity of light.

This shows that if we increase the conductivity n^2-fold and reduce the wave-length $1/n$-fold, keeping A_1 and x constant, $\sigma\lambda^2$ remains constant, and therefore the field strength remains the same.

Thus the same set of curves gives the field strength in every case, and we only have to alter the wave-length labelling. For example, a curve representing the field strength for the wave-length λ_1 with the normal conductivity σ_1 will also represent the field strength for n times the wave-length and $1/n^2$ times the conductivity.

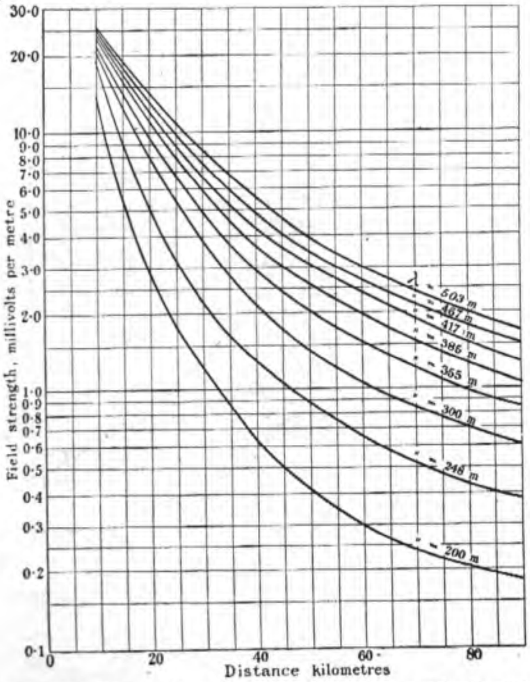

FIG. 12.—Mean attenuation curves in the northerly and westerly directions.

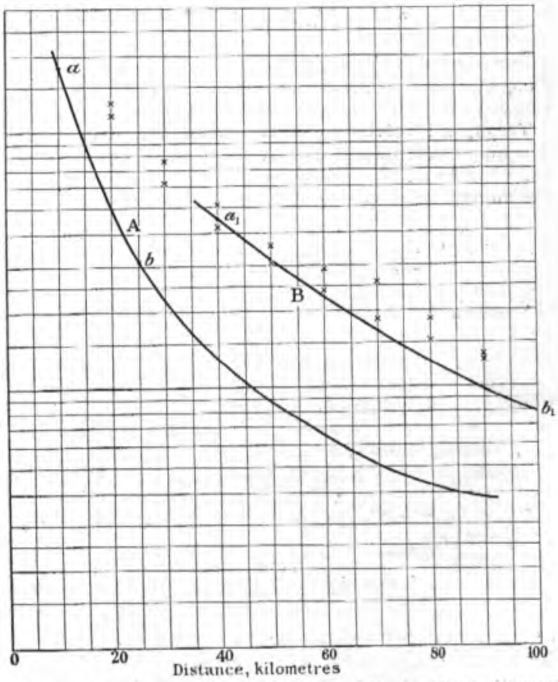

FIG. 13.—Experimental verification of theory of exterpolation of one attenuation curve on one wave-length to another on a second wave-length.

In practice it would be usual to make a measurement of the signal strength in a proposed district, from a transmitter of a known value of metre-amperes on a given wave-length.

If the conductivity in this district is different from the normal it will not lie on the normal curve for λ_1, but will lie on a different curve for, say, λ_2. Then if all the wave-lengths on the normal set of curves are altered in the ratio λ_2/λ_1 this new set of curves will represent the complete data for the district.

It will be seen that the whole of the transmission data for any district can be made to depend on a single fundamental curve. Deviations will no doubt occur due to lack of uniformity, hills, valleys and forests, but the curves will provide a basis from which to estimate the deviations due to these disturbing factors.

These considerations are based on the possibility of neglecting the specific inductive capacity ϵ compared with the quantity $2\sigma\lambda c$. But it is as well to point out that where the earth resistivity is more than 100 times its normal value, ϵ and $2\sigma\lambda c$ will become comparable and deviations from the above will appear.

If $\sigma\lambda c$ is large compared with ϵ, the specific inductive capacity of the earth, the earth behaves as a perfect conductor. Taking the effective value of σ (for England) as 10^{-13} C.G.S. units, then $\sigma\lambda c$ is of the order of λ in metres, i.e. is a large quantity compared with ϵ, which is of the order of 5 to 10. The authors consider, however, that it is not likely that $2\sigma\lambda c$ will be comparable with ϵ in European countries, although it might occur in transmission over the African deserts. They know of no proposals to feed the nomad tribes of that region with a broadcasting service, however.

Experimental tests.—The British Broadcasting Corporation undertook to attempt to find in a given territory attenuation curves for all frequencies of emission between 500 and 1 500 kilocycles per sec. To this end a site was chosen (which will ultimately become the site of the London regional transmitter) near Potters Bar on the north side of London for the erection of an aerial, the radiation from which could be measured in terms of field strength up to a distance of 100 km. The aerial consisted of 95 ft. of vertical wire and was of the same form for all wave-lengths. The masts were 110 ft. high and were placed 300 ft. apart, and their base and the stays were insulated from the ground.

Tests made near to the aerial showed that radiation was strictly equal in all directions.

In effect the method of procedure was to adjust the current in the aerial so that the field strength was the same whatever the frequency of emission at the same point close to the aerial. This meant that the term $h_1 I/\lambda$ was adjusted to be the same for every wave-length. We can thus say that the curves are taken for the same radiated power at all wave-lengths. It was seen that the points do not lie by any means on a smooth curve.

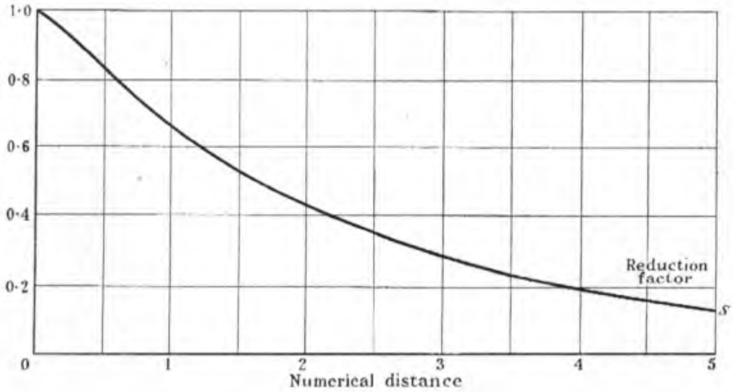

FIG. 14.—Sommerfeld's theory.

Intelligent interpolation, however, gave a family of smooth curves for two directions, as shown in Fig. 12.

The difficulty of taking readings in a densely populated country such as that found around London cannot be exaggerated, and the authors feel somewhat diffident in placing too much reliance upon the results. At points a few wave-lengths apart the field strength may vary 50 per cent, even though care is taken to avoid the proximity of telephone wires, houses and trees. It is, however, interesting to test the Sommerfeld theory in terms of actual results. To this end see Fig. 13 and take curve "A." This curve is the mean measured attenuation curve for $\lambda = 248$ m. It is a smoothed curve giving the average for two directions from the transmitter and is in fact taken from Fig. 12. Curve "B" is this curve transferred by the method described above to a wave-length of 496 m. The crosses represent the observed values of the field strength on 503 m for two directions, i.e. for all practical purposes the same as for the 496-m curve.

The observations on the two wave-lengths were corrected to the same value of $h_1 I/\lambda$ so that they should be comparable, and, if the theory is correct, observed points should lie along the curve "B." The agreement, it will be seen, is very fair, the divergence of the curve from the mean of the points being of the order of the "scatter" of the points.

We have so far considered the experimental verification of the theory of transference of the points from one curve to another for different *wave-lengths*. It is also important to see whether the theory of transference of points for different values of σ is correct in practice. Although not a great deal of accurate experimental data is available it is nevertheless interesting to consider the question of the value of σ, the earth's conductivity, as derived from the experimental results. An analysis can be given as follows:—

Any two transmitters having the same value of $h_1 I/\lambda$, i.e. the same metre-amperes factor, can be said to be similar transmitters, and we can therefore write

$$\frac{377\, h_1 I}{\lambda} = B \text{ (a constant)} \quad . \quad . \quad . \quad . \quad (2)$$

therefore $E = (B/x)\, S$, where x is the distance of the point of measurement from the aerial.

If there were no earth losses and other losses on the surface of the earth due to houses, trees, etc., the field strength would be given by $E_0 = B/x$.

The multiplier S can therefore be called the reduction

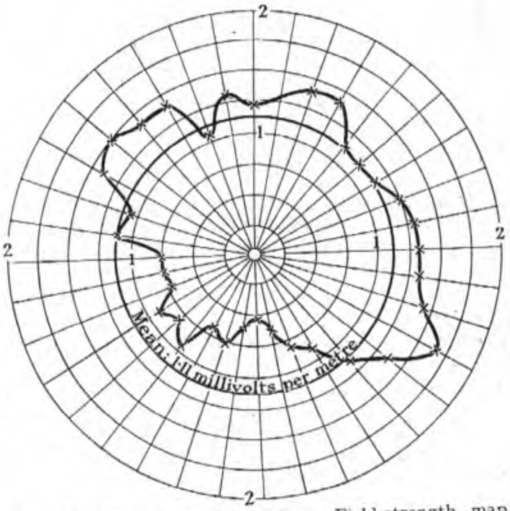

FIG. 15.—Brookmans Park site. Field-strength map at 40 miles with 10 amperes in the aerial, 388 metres, 780 kilocycles per sec., and 60-ft. masts.

factor and is shown by Sommerfeld to be a function of the quantity d_n, the numerical distance, where $d_n = (\pi x/\lambda)\left\{1/(2\sigma\lambda c)\right\}$ (see page 515).

Fig. 14 gives the relation between S and d_n and is derived from the Sommerfeld theory. It is now our object to test the accuracy of the Sommerfeld attenuation formula and to determine the necessary value of σ.

Take the mean attenuation curves shown in Fig. 12. With $x = 60$ km and $\lambda = 248$ m, $E = 0 \cdot 63$ mV/metre. Therefore from these curves we find a value of σ of 10^{-13}. The value of σ found, as a result of our experiments, lies between the wide limits of from $0 \cdot 66$ to 5×10^{-13}, given by other observers and found by different methods. It is suggested that it is premature to assume that the total value of σ can be accurately subdivided into, for instance, earth loss and vegetation loss. In the generality of cases it would seem unnecessary to assume that there is any loss over and above the earth loss.

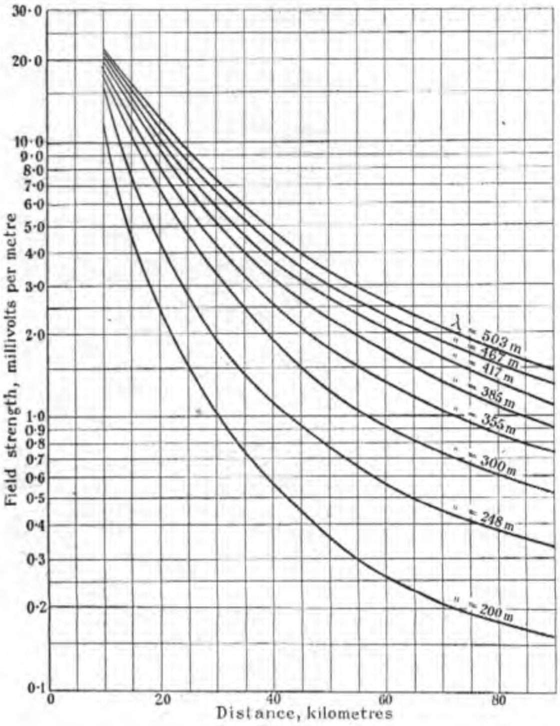

FIG. 16.—Mean attenuation curve for ¼λ transmitting aerial with 10-ohm dead loss and 1 kW input to aerial.

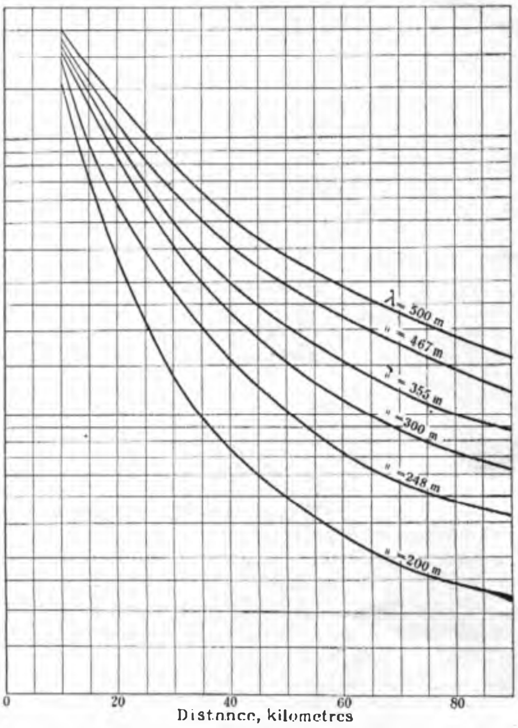

FIG. 17.—Theoretical field-strength curves for various wave-lengths using a vertical aerial 400 ft. high (500-ft. masts) having a constant dead loss of 10 ohms. All curves for 1 kW input to aerial.

Since these curves are for a radiated power of 1 kW, E_0, the field strength apart from attenuation, will be given as

$$E_0 = \frac{377\sqrt{\left(\frac{1\,000}{1\,580}\right)}}{60} = 5 \text{ mV/metre}$$

therefore $S = E/E_0 = 0 \cdot 126$.

From an extrapolation of Fig. 14, $d_n = 5 \cdot 2 = \dfrac{\pi x}{2\pi^2 \sigma c}$

therefore $\sigma = 10^{-13}$

with $x = 60$ km and $\lambda = 503$ m,

$E = 3$ mV/metre and $S = 0 \cdot 6$.

From Fig. 14, $d_n = 1 \cdot 22$, and $\sigma = 10^{-13}$.

Exceptions to this are found, however, where the waves traverse large cities or deeply wooded country. More and more "irreproachable" attenuation curves must be taken before this point can be accurately determined, but the labour involved is so considerable that some years must pass before the figures can be expressed with any real certainty. It will, however, be realized that Fig. 14 gives a broadcasting engineer data of the right order needed to forecast the service area of any broadcasting station using wave-lengths of between (say) 600 and 200 m. It is reiterated that service area cannot truly be accurately defined. Service area is merely a convenience of expression and gives "service" in extremely general terms. An "A" service area for one particular listener might not provide sufficient field strength to give uninterrupted reception, whereas a

"C" service might be quite sufficient for another listener. The field strength from a given transmitter may vary 50 per cent at two points a few wave-lengths apart and, although radiation may be initially equal round the aerial, the polar diagram, taken at some tens of miles' distance, of a typical broadcasting station is by no means circular. Fig. 15 gives a polar diagram for an aerial the initial radiation from which is strictly symmetrical in all directions. Incidentally, Middlesex lay on the south side of the aerial, which explains the large degree of concavity of the base of Fig. 15.

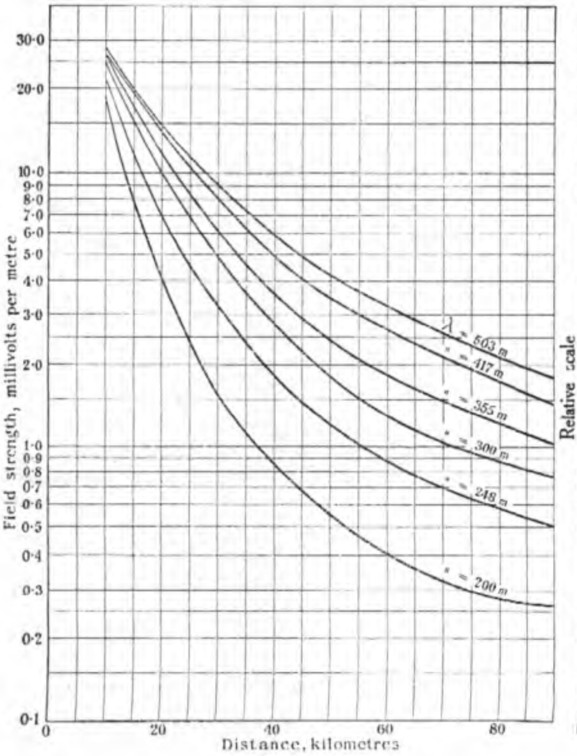

Fig. 18.—Theoretical field-strength curves for various wave-lengths using a vertical aerial 700 ft. high (800-ft. masts) having a constant dead loss of 10 ohms. All curves for 1 kW input to aerial.

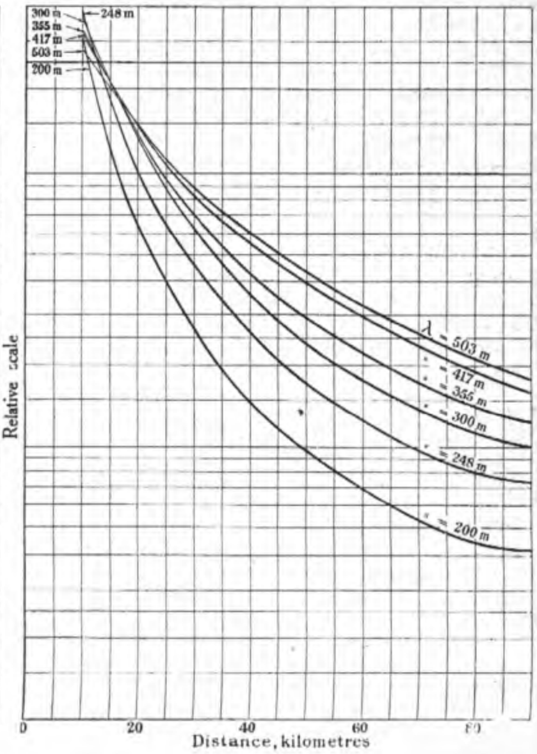

Fig. 19.—Family of field-strength curves taken from Fig. 18 but multiplied by a factor proportional to $1/\sqrt{\lambda}$ to take account of the lower interference level at shorter wave-lengths.

Conclusion.

The paper contains too little experimental verification of the theory outlined therein. A conclusion should, however, deal with generalities, and it is obvious from what has gone before that certain incontrovertible principles can be stated. It is time that they were stated before more damage is done by organizations who appear to concentrate on making an undignified scramble for the all too-limited facilities rather than thinking how best to use what are, in plain fact, the actual facilities available.

The facts which emerge are these:—

(1) The design of aerials for broadcasting should aim at using the energy to produce the strongest possible horizontal radiation while diminishing upward radiation.

(2) To produce this desirable end, high aerials are a *sine qua non*.

(3) Nothing, however, that is done with special aerial design will prevent a serious limitation of service area, relative to that obtained with the longer waves, when the shorter waves are used.

(4) That, nevertheless, organizations must employ such waves which are more efficiently used by the employment of high aerials.

Responsible technical authorities have in the past been chary of using waves below 300 m for their broadcasting stations because of their expectation that such stations will have too limited a service area under practical conditions. This may be true in certain cases, but it is to be remembered that limitations are inevitable and it is better to have a limited service than one which suffers continual interference. The use of shorter waves is perfectly economical in densely populated districts. It is hoped that this final analysis will help engineers to gauge the extent of the usefulness of all waves so that existing facilities may be most efficiently used.

To this end we may combine theoretical analysis and the practical results set out in the foregoing. A set of curves is therefore given which show, at any rate to the right order of magnitude, the "effectiveness" of the different wave-lengths for the production of service area.

It is not easy to find a basis of comparison for the "effectiveness" of the various wave-lengths, as conditions of listening vary in different districts and areas. The point finally to be held in mind, however, is that the excellence of a service from a broadcasting station (apart from the quality of transmission, which is the same, practically speaking, for all wave-lengths) can only be judged by the degree of interruption experienced by the majority of listeners. It is for this reason that Capt. P. P. Eckersley * defines service area in terms of signal strength alone, but points out that densely populated areas (where worse background noise exists) require a greater field strength than that necessary for rural districts. But both natural and man-made static diminish as the frequency to which the receiver is tuned becomes greater. The authors have therefore taken this factor of diminishing interference as being proportional to the square root of the frequency of the carrier wave.

The final analysis therefore is given as follows (see Figs. 16, 17 and 18):—

(1) A set of curves (Fig. 16) for a $\frac{1}{4}\lambda$ aerial with 10 ohms dead loss for 1 kW *input* to the aerial.

(2) A set of curves (Fig. 17) using a vertical aerial 400 ft. high having a constant dead loss of 10 ohms and 1 kW *input* to the aerial.

A set of curves (Fig 18) with the above conditions, but with a vertical aerial 700 ft. high.

(3) The curves of Fig. 18 are multiplied by a factor to increase their apparent "effectiveness" as suffering less interference when the wave-length is shorter (see Fig. 19). Thus, using $\frac{1}{4}\lambda$ aerials, it requires, for a given service, say 25 kW, but with 800-ft. masts this station, for the same service, can be run on 10 kW.

The last set of curves (Fig. 19) show that the broadcasting engineer need not so greatly fear to use waves below 300 m. The use of the shorter waves must come; it is hoped that this paper may be of help to those who will one day have to use them.

The thanks of the authors are specially due to the Marshal of the Royal Air Force, Sir Hugh Trenchard, Chief of the Air Staff, for his interest in their work and his permission to use the kite balloon so invaluable for their experimental work. They would further like to extend their warmest thanks to Flight-Lieut. E. B. Turner and the officers and men under his command for their unfailing courtesy and kindness during the course of the "balloon" experiments. Mention should be made of the work of Messrs. T. MacLaren and H. S. Walker of the British Broadcasting Corporation, who were responsible for the field-strength measurements. The painstaking nature of this work cannot be over-emphasized. Actually the field-strength measurer travelled 28 000 miles in the course of the investigations. Mr. T. C. Macnamara has already been mentioned as having materially helped in the suggestions as to the best methods of carrying out the experiments.

A tribute must be paid to Mr. N. Ashbridge (Assistant Chief Engineer), to Mr. H. Bishop (Senior Superintendent Engineer) and to Mr. R. T. B. Wynn, all of the British Broadcasting Corporation, both for their suggestions and for their help in organizing the fading tests.

The authors' thanks are also due to Marconi's Wireless Telegraph Co., Ltd., for their co-operation in parts of the work.

Finally the authors would like to express their thanks to all those who participated in the fading tests, particularly many amateurs and the Radio Research Board observers at Peterborough.

BIBLIOGRAPHY.

(1) S. BALLANTINE: *Proceedings of the Institute of Radio Engineers*, 1924, vol. 12, p. 836.
(2) A. SOMMERFELD: *Annalen der Physik*, 1909, vol. 28, p. 665.
(3) T. L. ECKERSLEY: *Journal I.E.E.*, 1927, vol. 65, p. 600.
(4) R. M. WILMOTTE: *ibid.*, 1928, vol. 66, p. 617.
(5) R. H. BARFIELD: *ibid.*, 1928, vol. 66, p. 204.
(6) P. P. ECKERSLEY: *ibid.*, 1928, vol. 66, p. 501.

DISCUSSION BEFORE THE WIRELESS SECTION, 2ND JANUARY, 1929.

Dr. R. L. Smith-Rose: The paper follows a trend which has been perceptible for some time in the policy of the chief engineer of the B.B.C., i.e. that broadcasting must utilize only the direct wave in order to give satisfactory service. To get these direct waves to the listener necessitates taking into account the attenuation of the waves due to the resistance of the earth, and that is a subject which, curiously enough, was neglected for some 20 years in the early development of wireless communication. In the early days of wireless it became so easy to transmit messages over long distances that the engineers responsible for the development of the subject neglected the study of attenuation; and it was not until the inception of broadcasting in about 1922 that attention was once more fixed upon the problem of attenuation of waves travelling over the ground. It was then realized how important it was to obtain a knowledge of the magnitude of losses due to the finite resistance of the earth. As the result of that appreciation, a number of papers in which the results of the study of attenuation have been set out have recently appeared. I should like to emphasize one point with regard to aerials, showing that one must not always expect theoretical results to work out in practice. In connection with some work we have recently been doing with Prof. Appleton, we have transmitted to him from the National Physical Laboratory, using a practically vertical aerial, from which one would not expect much radiation

---

* See Bibliography, (6).

vertically upwards; yet at King's College, only 10 miles away, waves were received which had been deflected from one of two ionized layers,[*] and the angles which those waves subtended with the vertical could not have been more than 2° in one case and 5° in the other case. The strength of the downcoming waves at those angles was comparable with the direct wave which was sent to King's College along the ground. Passing to the second portion of the paper, dealing with attenuation, we find a very interesting method for obtaining a whole family of attenuation curves for different wave-lengths, provided that we have one reliable curve as a basis. Incidentally I do not quite understand why the term "irreproachable attenuation curve" is stressed so much, because we are not provided with a country which is flat and uniform to an "irreproachable" degree. We should require such a country before we could apply some of the equations, which imply transmission over a perfectly uniform and flat country. We have to accept the earth as it is; and, as there are irregularities on it, I think that we can put up with some irregularities in the results obtained in transmitting over its surface. A very extensive study of attenuation has been carried out during the past few years by Mr. Barfield, who has obtained results which have been published in the *Journal*,[†] showing in great detail attenuation curves which have actually been measured in various directions on the London broadcasting transmitter. Yet, as far as I can gather from the paper, the results of his work do not appear to have been used by the authors. I suggest that they might have enhanced the value of their calculations considerably if they had made use of those results. The work was carried out under the auspices of the Radio Research Board, and it was not directed entirely to obtaining mere academic knowledge. We appreciated the practical aspect of the matter, and thought that the results would have been of some use to such organizations as the B.B.C. in connection with the problems presented in this paper. The results obtained by Mr. Barfield show quite definitely that attenuation varies in direction from the transmitter, and that the attenuation curves could be deduced from Sommerfeld's theory, provided the proper values of conductivity were inserted. Those values do not vary to any greater extent than the values obtained in the paper. I suppose that the real problem before the broadcasting engineer is that he must supply a minimum field strength over a given area. It does not matter whether the field strength is 100 per cent greater than that minimum at some places, since the listener will be satisfied. It does matter, however, if someone within that area is getting a smaller field strength, so that probably it is the worst conditions, corresponding to the lowest value of earth conductivity, which have to be taken into account, although I am not quite sure that an average value would not be more feasible to work upon. I do submit, therefore, that if more attention had been given to the results which have already been published, they would have been useful in connection with this problem. The experiments described in the paper do not give results of a high order of accuracy, but I would not criticize this feature as I am well aware, from practical experience, of the difficulties accompanying measurements of attenuation. The authors appreciate this matter, because on page 517 they say "It was seen that the points do not lie by any means on a smooth curve. Intelligent interpolation, however, gave a family of smooth curves for two directions, as shown in Fig. 12." I was puzzled at first as to what "intelligent interpolation" meant, but when I read a little further on (page 518) that they were using that curve and an equation from Sommerfeld's theory to calculate the conductivity for two different wave-lengths, and that the value of σ obtained was identical in each case, then I realized what great intelligence had been put into the interpolation. The order of error in the results is shown, incidentally, by the curve "B" in Fig. 13, in which case some of the points appear to be as much as 50 per cent off the curve. I stress the point, therefore, that although this curve is taken as a basic calculation, it is not irreproachable, and I think that it is not superior to similar curves which already exist.

Mr. R. M. Wilmotte: I wish first to refer to the question of the term "effective height," with which term the authors do not agree. I think that most people disapprove of this term; it is misleading, but I do not think that the authors have obtained a satisfactory solution of the problem. First of all, from simple measurements of field strength one is led into very great difficulties. Even at 5 wave-lengths, as is mentioned here, there are apparently considerable discrepancies in the measurements obtained. I might mention a paper by Ratcliffe and Barnett,[*] in which they found a big variation, which, up to now, has not been very satisfactorily explained. I believe that it is due to the actual size of the aerials, the upper portion interfering with some lower portion. But if we depend on the value of the effective height as determined by measurement, it is necessary either to find out the reasons for these discrepancies or to refrain from making any distinction, and so leave it to posterity to make such a definition when the theory is further cleared up. The use of the term "effective current" was recently suggested to me, but I do not think that it is very suitable, because the effective current is not a property of the aerial alone and is, in that respect, unsatisfactory. Possibly some such term as "radiation constant" or "radiation factor" or "radiation strength of the aerial" might be more suitable; but I think that the current should not be an integral part of the definition. In any case the direction for which the value is applied should be stated as well as the point of the antenna system where the current is measured, for the term becomes meaningless in the case of directive or even partially directive systems. In a recent paper[†] I used the term "directive efficiency" for an aerial, meaning the ratio of the energy transmitted over the whole space by the aerial to the energy transmitted in the direction required; and I think that term is useful. In other words, if E_0 is the field strength in the direction required at the distance r, the directive efficiency is $E_0^2r^2/\iint E^2dA$.

---

[*] See *Nature*, 1927, vol. 120, p. 330.

[†] *Journal I.E.E.*, 1928, vol. 66, p. 204.

[*] *Proceedings of the Cambridge Philosophical Society*, 1926, vol. 23, p. 228.

[†] *Journal I.E.E.*, 1928 vol. 66, p. 955.

Referring to page 512, it is interesting to find that the experimental field strength from a $\frac{1}{4}\lambda$ aerial is half that from a $\frac{1}{2}\lambda$ aerial. In other words, there is a constant factor in error in measuring effective heights at a given point, for I presume that those ratios were referred to some given point. If this was carried out at several points it would be of interest to know to what degree of accuracy the values agreed with one another. Mr. Munro made some measurements, in connection with a paper by Mr. Barfield [*] some time ago, on a **T** aerial in which he increased the length of the horizontal portion. I calculated how the effective height should vary with the increasing length of the horizontal part; and the correspondence between these calculations and the actual measurements was quite astounding. It was far closer than the experimental accuracy to which Mr. Barfield thought the experiments were true. As a matter of fact, that curve has been published in the *Journal*.[†] The interesting point is that it shows that the current in the two quarter-waves forming the half-wave must be in phase. If they were not in phase, one would not obtain this doubling of field strength when the aerial is doubled in length. The main conclusion reached in the paper is not new, in so far as it was already known that, if one wanted a good directivity in a given direction, say horizontally, one had to employ a high aerial. I do not mean that it was experimentally known, but it was certainly theoretically known. In the recent paper which I have already mentioned, I showed mathematically that if one wanted a beam in a given direction the best way of setting the aerial was to spread it—preferably in a line perpendicular to the direction in which the beam was required. In this case when we require the beam in all directions horizontally, the only way to obtain the condition deduced theoretically is to spread it in a vertical direction. That is the conclusion to which the authors have come. The authors use $\frac{1}{4}\lambda$ and $\frac{1}{2}\lambda$ aerials. It would be better if they could get a more uniform distribution of the current all along the aerial. That might be done by cutting, by means of phasing-coil arrangements, those parts of the aerial in which the current was of small value, so that one could have a little more effective height than if the current were sinusoidal, as occurs in the case of a perfectly straight wire.

Mr. R. H. Barfield: My chief interest centres on the attenuation results obtained by the authors, and I am glad to see that, in measurements in the country north of London, they found the same value for the conductivity of the earth as I obtained in my experiments in the same area published in the *Journal* [‡] about a year ago. The present paper is supplementary to mine in that it contains measurements on a great number of different wave-lengths in one or two directions, whereas I measured the attenuation in a number of different directions on one or two wave-lengths. I infer that the authors' uncertainty about the effect of trees refers only to the evidence of their own experiments. The evidence on this point contained in my paper already referred to is, I think, very nearly conclusive, and I will here take the opportunity of summing it up. The attenuation (that is the departure from a constant "intensity × distance" product) in the country south of London is from 4 to 5 times as great (at, say, 100 km) as the attenuation in the country to the north of London at the same distance. This result, by the nature of the experiments, is entirely independent of any "town effect" or transmitter characteristic. There are only two possible explanations of this fact. The first is that the earth in the southern Counties has an average conductivity of about one-third of that in the northern Home Counties, and considerably below the lowest value yet observed for any kind of soil in England. The second is that objects on the surface play an important part in determining attenuation and that their density is greater in the south than in the north. Of these the first (as I showed in my paper) has no experimental evidence at all to support it; while on the contrary an increasing number of conductivity measurements made recently show that such a state of affairs is very improbable. We find, in fact, that almost every kind of soil has a conductivity from 3 to 5 times as great as that which on this view would be required for the southern districts. In support of the second and only alternative, we have the fact that there is undoubtedly more vegetation in the southern Counties. While a calculation based on observations made on individual trees shows that in this type of country tree absorption should actually predominate over earth absorption, other surface objects apart from vegetation can almost certainly be left out of consideration. The tree or vegetation hypothesis therefore holds the field without a rival, and surely cannot be described as premature. But we now have further evidence. Following out a suggestion made by Prof. E. V. Appleton[*] (in the discussion on my paper) we have carried out two sets of experiments. The first was to measure the energy absorption due to a given tree, and this we found definitely to be greater by about 30 per cent in the summer than in the winter. We did that with two typical kinds of trees. Secondly, during the last year, at the Radio Research Station at Slough, Mr. Munro has been very carefully measuring the field strength of the Bournemouth broadcasting station during the whole year week by week, and we find that we can detect a definite seasonal variation of attenuation, which, taken in conjunction with the first experiments, we naturally ascribe to the alteration of the intervening vegetation with the seasons. These results we hope to publish in full in due course. The value of the curves in Fig. 10 for forecasting is limited if one does not know the conductivity of the ground over which one is forecasting. Is one to take the limiting values of σ given by the authors? If so, the limits of the forecast will be very wide indeed. If not, we must take the value of σ represented by the curves (Fig. 10) themselves. Supposing we use those curves this way to forecast the attenuation of field strength over a county like Surrey or Sussex, we should find at distances of, say, 100 km that the forecast value is 4 or 5 times too large. We might well forecast a "B" area where a "C" area would be obtained in practice. Hence in addition to those curves some guide as to how to estimate the conductivity is very necessary. The experi-

---

[*] *Journal I.E.E.*, 1928, vol. 66, p. 204.
[†] *Ibid.*, 1928, vol. 66, p. 215.
[‡] *Ibid.*, 1928, vol. 66, p. 204.

[*] *Journal I.E.E.*, 1928, vol. 66, p. 216.

ments and conclusions in my paper provide a first approximation to such a guide. If, however, the B.B.C. repeat their experiments over wooded country, as I hope they will, we shall undoubtedly get further valuable information.

Mr. E. H. Shaughnessy: I imagine that Captain Eckersley will make good use of this paper in his negotiations with other broadcasting authorities, and if he can prove that a 200-metre wave is quite satisfactory, I think that he will do valuable work. Apart from that, I am glad to see that the engineers of the B.B.C. are taking this matter very seriously. An efficient design of aerial may save very large sums of money, as it will be possible to employ less power.

Mr. F. H. Amis: The paper is evidently a further step on the part of the B.B.C. to improve their already excellent service by gaining such information as will enable them to utilize their transmitters to the best advantage, and by endeavouring to reduce interference. The paper serves a useful purpose in emphasizing the fact that the higher efficiencies which it is economically possible to obtain with the shorter wave-lengths do, to a certain extent, counteract the disadvantages connected with the use of these wave-lengths. On page 508 the authors infer that by endeavouring to obtain a maximum ratio of radiation to total resistance, engineers have been endeavouring to obtain the greatest amount of radiated power irrespective of whether the power is radiated at ground-level or at an angle. It is, I think, generally appreciated that the only way to gain accurate information as to the effective height of an antenna is by measurements of field strength. Such field measurements are necessarily carried out at ground-level and therefore the radiation resistance is calculated on the above basis, from which it surely follows that the figure obtained for efficiency is in terms of the maximum power radiated at ground-level and the total power put into the antenna. This appears to be the only way of obtaining information as to whether a radio transmitting station is serving an area to the limit of its capabilities. As pointed out by the authors, the higher type of antenna certainly does yield a relatively greater field strength than does the normal antenna of $\frac{1}{4}\lambda$ or less. The authors' claims are well supported by some experiments made in Sweden, where a change from a good vertical $\frac{1}{4}\lambda$ antenna to a $\frac{1}{2}\lambda$ T antenna produced an average increase in field strength of about 25 per cent. On changing the antenna to a vertical $\frac{1}{2}\lambda$ type, however, the increase of field strength over that obtained with the $\frac{1}{4}\lambda$ antenna was of the order of 70 to 80 per cent. A wave-length of approximately 260 m was used for these tests and the total input power to the antenna was the same in all cases. One is frequently faced with the problem of increasing the efficiency of an antenna which is supported by masts only high enough to support a $\frac{1}{4}\lambda$ antenna. In such a case, the increase which can be obtained obviously depends upon the amount of dead-loss power. This dead-loss power is more or less proportional to the amount of absorbing mass and, as such absorbing masses are generally near the base of the antenna, to the amount of current at the base. This is illustrated by some measurements in which I took part a few weeks ago in Sweden. In this case the masts were just high enough to support the $\frac{1}{4}\lambda$ vertical antenna of a station operating on a wave-length of approximately 260 m. By turning this into a $\frac{1}{2}\lambda$ T antenna an average increase in field strength of about 80 per cent was obtained. It is thought that the greater part, at least, of this increase was due to getting the maximum current higher up the antenna and thereby reducing considerably the amount of absorption due to the building, etc. It will be noted that in the earlier experiments made in Sweden the above change only yielded an increase in field strength of 25 per cent. The difference is thought to be due to the difference in the amount of absorbing mass near the bottom of the antenna in each case. A further increase of 15 per cent in field strength from the antenna which had already yielded 80 per cent increase when turned into a $\frac{1}{2}\lambda$ T antenna was obtained on turning it into a multiple tuned antenna with three down-leads, and it is interesting to note that no directional effects resulted. The only other point I want to mention is that I was rather disappointed to see that the tuned-mast idea had been turned down without a trial.

Lieut.-Col. A. G. Lee: The first section of the paper deals with the design of a transmitting aerial from two points of view, the first being to reduce the indirect ray with the object of reducing the long-distance range of the station, and thus temper its properties of interfering with other broadcasting stations, and the second being to design the aerial for a maximum horizontal radiation, this being the only portion which is effective in a local broadcasting system. With regard to the first object, a reference to Fig. 7 shows that at 300 miles' distance the calculated indirect ray for a $\frac{1}{2}\lambda$ aerial is 0·7 of that given by a $\frac{1}{4}\lambda$ aerial, an order of difference which I am afraid would have no appreciable effect on the European broadcasting difficulties. Further, the experimental results on page 514 do not corroborate the calculations, even in regard to the fading effects at moderate distances. I therefore think that no case has been made out for the high mast, with its enormous cost, as a solution of the interference problem. On the second point, a reference to the table on page 513, giving the experimental results, shows that, employing the same power for a $\frac{1}{4}\lambda$ and a $\frac{1}{2}\lambda$ aerial, the relative field strengths at a given distance are 1 and 1·26 respectively. The difference in mast expenditure to produce this result is probably eight times greater for the $\frac{1}{2}\lambda$ than for the $\frac{1}{4}\lambda$ aerial, so that the problem resolves itself into a simple economic one when all the data are known. The annual charges on mast expenditure persist throughout the year, as their name implies, whereas the expenditure on power is only incurred while the station is in operation. The difference in plant expenditure due to the requirement of increased input power in the $\frac{1}{4}\lambda$ aerial case is small but easily calculated. I should be surprised to learn that the 800-ft. masts were justified from this point of view.

Mr. T. McGrath: During the experiments did the authors find that transmission was better when the aerial was at an angle to the vertical, especially at that angle in line with the vertical component of the earths' magnetism, or in the plane of the dip or inclination? The possibility of the earth's magnetism tending to increase the service area by assisting the field-strength E might have been considered. Secondly, I should like to know whether the humidity of the atmosphere during the tests affected the transmission. I think that humidity plays an important part, and that in the design of a transmitting aerial care should be taken that the effect of humidity should be eliminated, if possible, and that insulators should be made with a surface which will not retain moisture.

Mr. K. Sreenivasan (*communicated*): I am not able to follow the authors in what they say regarding the surge impedance. When a straight wire is rearranged in any manner, its L/C ratio is bound to change, so that the chances of securing the original ratio cannot be very great. In the measurement of the constants of the aerial above and below the fundamental frequency, the method of added reactance and resistance of known values is possible, although considerable care has to be exercised during the experiment, as shown by J. K. Catterson-Smith.* As a result of their experiment, can the authors state whether the ratios of the current at the base of the aerial are equal to the corresponding ratios of the measured field intensity at a given distance, everything else remaining the same and the observations being made quickly one after another? In view of the difficulties and the complicated arrangement needed in the balloon experiment, it would appear that reasonably tangible results would be obtained by stretching the aerial and its accompaniment horizontally. It would then be easier to support the phasing coils and introduce extra $\frac{1}{2}\lambda$ units without too much trouble, in addition to other minor advantages. The horizontal polar diagram would then roughly correspond to the vertical diagram of the actual aerial, and the effect of the addition of phasing coils and additional lengths of aerials would give useful information. The distribution of current along different parts of the aerial could also be studied in this manner. I do not know what effect the proximity of the earth would have, but I am inclined to think that it could be allowed for. The measurements made on the London transmitter of the B.B.C. by Mr. Barfield, and the remarks of the authors, lead one to think that a solution of the mast problem lies in using wood. The absence of white ants, and the general climatic conditions of England, appear to be favourable to wooden masts. As masts are not built to last for more than a very few decades, the only objection to such masts seems to be the risk of fire. Care being taken to have the minimum amount of metal in the structure in order to avoid eddy-current heating, a good case can be made out for wood, especially when the transmitter is not in the middle of a busy city but somewhere out in the open. The 220-metre trellis masts of San Paolo form a good instance. There are two points in connection with the $\frac{1}{2}\lambda$ and $\frac{1}{4}\lambda$ aerials on which I should like some information. At the top of the first column of page 512, ambiguity about the effective height of aerials in spite of careful check measurements is emphasized. I wonder whether this slight discrepancy partakes of the nature of the end-effect familiar in sound pipes, where the resonant wave-length is slightly greater than four times the length of the sounding tube. In view of the difficulties of introducing phasing coils between two $\frac{1}{2}\lambda$ aerials at broadcast frequencies, is it not possible to connect two or three similar non-radiating units in series with each other? The difficulties of supporting these and of any inductive effect they might have on the aerial lengths would, I venture to think, be reduced. More extensive data are required before confidence can be placed in the method of deriving field strengths at different wave-lengths from observations at one wave-length. Is the method adopted here based on the proportionality of λ^2/d^2 as indicated by the example given?

Captain P. P. Eckersley and **Messrs. T. L. Eckersley** and **H. L. Kirke** (*in reply*): There appears to be a feeling in the minds of some who have taken part in the discussion that nothing in the paper is new, but that the proofs of the correctness of supposedly long-advanced theories set out in the paper are open to doubt. The British Broadcasting Corporation, however, undertook the work because there seemed to be a good deal of theory not established in practice. For instance, it is doubtful if full and sufficient proof of the relative effectiveness of $\frac{1}{2}\lambda$ and $\frac{1}{4}\lambda$ aerials existed before the so-called "balloon experiments." Further, the curves in Figs. 12, 16, 18 and 19 have never been published, as far as we are aware, in their present form—a form useful to engineers. This will answer Dr. Smith-Rose where he says that he cannot see their superiority to others. Mr. Barfield established that attenuation was different in different directions; which means, if the Sommerfeld theory is accepted, that earth resistivity varies in different parts of the home counties. We show in the paper that, given a certain earth resistance, actual service area can be accurately predicted knowing the number of kilowatts in the aerial, the mast height, wave-length, etc. Mr. Barfield obtained results on only one wave-length.

Dr. Smith-Rose does not fully understand the term "irreproachable attenuation curve." We mean by this a curve taken along a certain line, so carefully that it gives a value (or several values) of σ for one wave-length along that line, and only along that line. If this is done, the engineer who finally is responsible for practical results is able, by means of the paper and the data given therein, to forecast his service along that line for any other wave-length in the broadcasting band. By taking irreproachable curves in many directions the service area at any wave-length and with any mast height can be sufficiently forecast. From an engineering point of view it was therefore essential to supplement Mr. Barfield's valuable and interesting work by obtaining data useful to engineers. Mr. Barfield proved that, given some radiation (in his case from the roof of a large shop), then attenuation was different in different directions. This paper proves that, given the knowledge of certain quantities, service area can be forecast reasonably accurately.

With regard to the so-called vegetation theory, we submit that this is only proved to the extent that it shows that attenuation increases where there are large agglomerations of trees. The point which we wish to emphasize is that few trees on one kind of earth might give the same attenuation as many trees on a different

---

* *Journal of the Indian Institute of Science*, 1926, p. 21.

kind of earth. There are no data to allow the calculation of attenuation in terms of trees, different kinds of earth, height and extent of hills, etc. We must to-day find attenuation curves experimentally and calculate σ, which finally allows us to predict service area on any wave-length over a given terrain. In some recent measurements it was proved that a certain mountainous but treeless ground gave much greater apparent attenuation than flat but wooded ground in the south of England. In short, the vegetation theory, if it merely says that forests on a given type of ground give greater attenuation, is proved. If the vegetation theory is said to be so complete that it enables the broadcasting engineer to separate by calculation tree losses from all other losses, then the theory is by no means proved.

With reference to Dr. Smith-Rose's remarks, we should like to point out that the "intelligent interpolation" only appeared by chance to be so intelligent. The curves were, in fact, first drawn from experimental points, the value of σ being thereafter calculated.

The part of the paper most susceptible to criticism is that dealing with fading. We agree therefore with much of Col. Lee's reasoned criticism. No case has been made out that the $\frac{1}{2}\lambda$ aerial will produce daylight conditions at night, or that the curves of Fig. 7 are verified. The first part of the paper, however, sets out a policy, namely, that of relying upon the direct-ray service for broadcasting. We have proved that the $\frac{1}{2}\lambda$ aerial increases the ground ray, so, presumably, it decreases the space ray. This is to the good, but from the experimental fading tests the degree of effectiveness in reducing the interference-producing qualities of the space ray at long distances is negligible.

Col. Lee thinks that the question is purely economic and asks whether it is better to spend money on high masts or on high power. But this is not the whole of the question because, although our experiments do not give an indication of much reduction of the space ray at large distances, there is sure evidence of its reduction at shorter ranges. At any rate it is certain that the higher-angle radiations must have been reduced because the ground ray has been increased. Power does not determine the limits of pure service area because of the interference by indirect ray with direct ray. This interference is independent of the power, but is directly dependent upon the ratios of these quantities. The use of higher masts would therefore appear to be justified as a means of increasing the service area, which would otherwise be limited by fading at its outer boundaries.

The solution of the pure economic problem cannot be written down in general terms because there are so many variables, e.g. required service area, value of σ, cost of power, cost of masts, etc. It can be said, however, that the higher mast (considered from the purely economic standpoint put forward by Col. Lee) is more and more valuable as the power of the station is increased. An 800-ft. mast costs the same for a 100-watt as for a 100-kilowatt station, but the power costs are a thousand (or more) times greater in the latter case.

We agree with Mr. Wilmotte that "effective current" is, perhaps, not a good term; we did not recommend it. The ratio of theoretical to measured effective height for the two aerials was certainly, as Mr. Wilmotte supposes, derived from measurements taken at the same points. We still maintain that effective height should be measured for each and every aerial when it has a very practical meaning for the wireless engineer. While discussing this question we should like to point out that the figures given by Mr. Amis may be a little misleading, as Captain Eckersley has the authority of Mr. Lemoine, who is in charge of the technical side of Swedish broadcasting, for saying that they have not been quite correctly quoted. No doubt, however, in general they confirm much of our work.

With regard to surge impedance and Mr. Sreenivasan's criticism, we would point out that, in order to obtain correct results with Franklin aerials, it is theoretically necessary that the phasing units have the same surge impedance as the active aerials. If the surge impedances differ, reflections will occur and the current in the various $\frac{1}{2}\lambda$ aerials will not be the same.

As stated by Mr. Sreenivasan, the L/C ratio of a wire changes when the wire is rearranged in any manner. Under practical conditions, however, the change is small and can, in fact, be compensated to some extent by a change in gauge of wire.

When comparing $\frac{1}{2}\lambda$ and $\frac{1}{4}\lambda$ aerials the current at the bases of the aerials cannot be used for comparison. It is necessary to consider the current at the current antinode. This is expressed as I in the formula $E = 377hI/\lambda$.

With reference to the measurement of aerial constants, the apparent impedance at the base of the aerial gives sufficient data for calculation when we are considering pure $\frac{1}{2}\lambda$ and $\frac{1}{4}\lambda$ aerials. The value of $\sqrt{(L/C)}$ can be found for a $\frac{1}{2}\lambda$ aerial from $V/I = \sqrt{(L/C)}$, where V = voltage between the base of the aerial and earth, and I = current at the current antinode (see Figs. 8 and 9).

Mr. Sreenivasan suggests wooden masts. We fear that this suggestion is impracticable owing to the high cost and the fire risk. It is, however, only fair to say that the German administration uses 200-ft. wooden towers. One still doubts the practicability of 600-ft. to 800-ft. wooden towers.

Answering Mr. McGrath, it did not occur to us to go to the expense of holding a flexible wire some hundreds of metres long "in the plane of the dip or inclination" to see if the earth's magnetism would increase the service area. Further, there was little time to investigate the question of humidity and its effect upon insulators, because the balloon did not ascend during very damp weather. As far as we are aware, however, porcelain insulators as used in nearly every wireless station in the world are not liable to absorb moisture and even when wet on the surface do not, when properly designed, greatly influence the radiation constants of an aerial.

It should be mentioned that Dr. Balthasar van der Pol, jun., communicated to the Physical Society, in 1917, a paper on the wave-lengths and radiation of loaded antennæ which covered much of the subject dealt with in the first section of our paper. The interested reader is referred to the paper above mentioned. The assumption in this and other theoretical papers has been that the earth is perfectly conducting. It is interesting to notice that the results of experiments mentioned in our paper prove that the radiation from an aerial is the same as that which would occur if the earth were perfectly conducting, and that the effect of the imperfect conductivity of the earth can be expressed as a constant additional aerial resistance.

We think it would be of interest to quote extracts from the translation of a letter to one of the authors received from Prof. Dr. Ing. A. Meissner of the Telefunken Gesellschaft: "The paper's special value for us is not only that it has shown without doubt that the best solution of the broadcast antenna question is to have the mast as high as possible, but also because the field strength at different distances from the transmitter can be determined in advance for any single wave out of the complex curve material. With regard to the masts and the question of antenna height in particular, an experimental comparison of ¼λ and ½λ antennæ for the broadcast range was lacking. And here it was exactly your balloon experiment that we needed. The principle of employing masts as high as possible was actually introduced into broadcast practice by the Telefunken themselves, but rather because of conviction of the correctness of the principle than on the basis of deciding experiments. The experiments which Telefunken have carried out here in March 1926, and later in conjunction with the Telegraph-Technical authorities, suffered under the disadvantage that there was not such a perfect method then available for measuring field strength as the B.B.C. now have. That it was not possible to employ antennæ shortened to ½λ for the broadcast range before 1926 was due to the fact that transmitters with separate control only came into use for broadcasting after this time. Then it was recognized that such an antenna, the tension nodes of which were at the earthing-point—the ammeter in the earth lead showing therefore no current—could be perfectly excited by a transmitter if the latter was separately controlled. From the intermediate-circuit current and the anode current of the last valve-stage, one could recognize that the antenna had taken up the full amount of energy. The best experimental verification of the point of view that you have put forward in your work is in the results which have been obtained with the Budapest broadcast transmitter, which was completed 3 or 4 years ago and which is well known on account of its great range. Here there are two masts, each of 150 m height. The fundamental wave is 555·6 m. The natural period of the antenna is 930, and the shortening 400 cm. According to detailed reports of the Hungarian post and telegraph authorities, with 15 kW continuous-wave loading in the antennæ the field strength at a distance of 50 km from the transmitter is up to 30 mV per metre, at 100 km up to 10 mV per metre, and at 150 km from 1 to 5 mV per metre. It is stated that fading occurs first at 150 km. A similar antenna is to be built immediately in Oslo; two 150-m masts with a power wave of 496·7 m. With this wave-length one can hardly go higher than 150 m. One is limited in the choice of height, as the natural period of the insulated mast should not come in the region of the transmitting wave-length. In this case the field strength loses its symmetry round the transmitter. The field strength is stronger in the direction of the mast, and weaker in the direction at right angles to it.* In order to have a technically practicable mast, one is forced to the compromise of making tho mast smaller than ½λ, and the antenna at the top in the form of a **T**, so that the centre of gravity of the upper half of the ½λ antenna still lies at nearly the same height that it would do if the vertical antenna wire were contined upwards to a length of ½λ. Since 1927 the German Telegraph Technical Minister, Mr. W. Schäffer, has also introduced into German broadcast transmitters the principle of making the fundamental wave equal to 0·6 of the natural frequency of the antenna. Here free-standing masts of 100 m height are employed. With regard to the development of broadcast antennæ, one question still remains open: is a horizontal antenna which is supplied by power leads at the centre better than a vertical one? According to experiments which were carried out in 1926 in relation to the introduction of horizontal antennæ for the short waves, the horizontal antennæ appeared to be superior to the vertical ones, even in the region of the broadcast wave-length, if they wero brought up to a height of ¼λ above the ground; and, surprisingly, both in a direction at right angles to the plane of the mast and also in the direction of that plane. On account of the complication in antenna building, no further experiments were carried out with such antennæ. When these experiments with horizontal antennæ are settled—though, indeed, they need not lead to a solution of the antenna problem—we shall have done everything possible as regards broadcast antennæ."

Dr. Meissner informs us that certain German broadcast transmitters use a fundamental wave equal to that of 0·6 of the antenna. The paper shows, however, that this is based more upon the idea of having a high radiation resistance than of producing a stronger ground ray.

Dr. Meissner suggests the use of a horizontal antenna. This should be investigated because it might have great practical value. The investigations on the design of antenna for broadcast transmitters are by no means complete. It is hoped, nevertheless, that the present paper will do something to help the broadcasting wireless engineer in the design of his aerial and the prediction of service area.

---

* H. M. O'Neil: *Proceedings of the Institute of Radio Engineers*, 1928, vol. 16 p. 873.

Printed in Great Britain by
UNWIN BROTHERS, LIMITED, LONDON AND WOKING