OPTIMUM WAVE-LENGTH IN RADIOTELEGRAPHY.

By A. H. Taylor.

GIVEN a definite maximum of available power, and a fixed aerial system, the question as to a suitable choice of wave-length presents itself. The fairly well established facts influencing the choice of wave-length are as follows: First, the radiation of the aerial is greater for short waves. Second, the aerial current with a given potential maximum is greater for short waves. Third, the absorption is greater for short waves than for long ones. Fourth, the absorption increases with the distance.

Austin has investigated the formula[1] $I = \dfrac{kh_1h_2I_1e^{-\alpha D/\sqrt{\lambda}}}{\lambda D}$, where

h_1 = height of sender, h_2 = height of receiver,
λ = wave-length, I_1 = sending aerial current,
I_2 = received current through 25 ohms equivalent resistance,
D = distance between stations,
α = .0015 for transmission over salt water.

The lengths are all in kilometers and the currents in amperes. The constant K has been determined by Austin to be 4.25 for the flat-topped aerials on the cruisers used in his experiments.

As far as I am aware, no publication has been made of similar long distance experiments over land, from which K and α could be determined for any given character of soil and type of aerial. It is known that the absorption over land[2] is in general greater, although the surface absorption of the earth[3] has not been separated from the atmospheric absorption which produces the great difference between day and night messages.

The constant K would depend on local conditions at sending and receiving stations, and for properly located land stations should probably be a little larger than 4.25. The other factors of the formula have been found to be nearly correct for overland transmission and it is natural to assume that the received current will follow the same general law of variation over land distances as over the sea, especially over the flat prairie where the author's experiments are being undertaken.

[1] Austin, Bull. Bur. St., Vol. 7, No. 3, 1911.
[2] Zenneck, Hun. d. Phys., 23, 1907.
[3] Pierce, Wireless Telegraphy, p. 131, 1910 edition.

It has been shown by Austin[1] and others that within practical ranges of usefulness, nearly all detectors respond approximately in such a manner that the audibility A of the signal is proportional to the square of the received current. This makes the audibility inversely proportional to D^2, and directly proportional to i_1^2/λ^2, neglecting the absorption. The installation at the University of North Dakota is at present limited to 1 kw. output, furnished by a Type E self-controlling transformer on a 110-volt 60-cycle circuit. The primary condenser usually had a capacity of .02 Mf. and was coupled inductively to the aerial, loosely enough so

TABLE I.

λ = .400 km., C_1 = .01 Mf.

P Kilowatts.	I Aerial Current.	i^2/λ^2P.
.220	2.1	138
.320	2.6	132
.400	2.85	128
.500	3.1	120
	Average. . 130	

TABLE II.

λ = .457 km., C_1 = .02 Mf.

P Kilowatts.	I Aerial Current.	i^2/λ^2P.
.370	3.3	141
450	4.0	169
[illegible]	4.3	143
87[illegible]	5.7	177
	Average. . 157	

TABLE III.

λ = .560 km., C_1 = .03 Mf.

P Kilowatts.	I Aerial Current.	i^2/λ^2P.
.580	3.8	79
.685	4.2	82
.850	4.8	86
	Average. . . 82	

TABLE IV.

λ = .590 km., C_1 = .03 Mf.

P Kilowatts.	I Aerial Current.	i^2/λ^2P.
.570	3.75	70.5
.700	4.2	72
.800	4.6	76
1.050	5.4	76
	Average. . 74	

TABLE V.

λ = .660 km., C_1 = .02 Mf.

P Kilowatts.	I Aerial Current.	i^2/κ^2P.
.300	3.0	69
.380	3.4	69.5
.460	3.65	66.5
.620	3.9	56
	Average. . 65	

TABLE VI.

λ = .730 km., C_1 = .01 Mf.

P Kilowatts.	I Aerial Current.	i^2/λ^2P.
.252	2.35	41
.400	3.25	49.5
.500	3.45	44.6
.600	3.7	43
	Average. . 44.5	

TABLE VII.

λ = .390 km. Free aerial operated by induction coil on D.C.

P Kilowatts.	I Aerial Current.	i^2/λ^2P.
.140	2.85	382
.120	2.6	372
.065	1.7	315
	Average. . 356	

TABLE VIII.

λ = .390 km. Induction coil on A.C. 60-cycle.

P Kilowatts.	I Aerial Current.	i^2/λ^2P.
.037	1.35	323

TABLE IX.

Wave-length.	Av. i^2/λ^2P.	i/λ for P = 1Kw.
.730	44.5	6.65
.660	65.	8.06
.590	74.	8.6
.560	82.	9.05
.457	157.	12.55
.400	130.	11.4

[1] Austin, Bull. Bur. St., Vol. 6, No. 4, 1910.

that the two waves transmitted did not differ more than 7 per cent. The aerial was of the inverted L type, 27 meters high, 3 meters wide, 40 meters long, of 6 No. 14 aluminum wires. The vertical lead was a single No. 12 stranded copper wire. Its free wave-length was 390 meters. The following tables show the dependence of the factor i_1^2/λ^2 upon the power and upon the wave-length.

There was some irregularity in the action of the zinc spark gap which may account for the variation in the factor $i^2/\lambda^2 \cdot P$, but as a first approximation I propose to call this factor a function of λ but not of P. It represents the intensity or energy radiation factor for a given wave-length and determines the audibility of the signals received at short distances, where the absorption may be neglected. For minimum energy required to produce audible signals at moderate distances, it is evident that the wave-length .457 km. is best. This conclusion has been verified by an operator at Inkster, N. D., thirty-five miles distant, receiving messages sent from the university at 100 watts power.

It is hardly fair to include the data for the free aerial, operated by the secondary of an induction coil directly connected to the aerial, since the maximum amount of energy which can be radiated by the system is reached in the case of direct current and interrupter at 140 watts and with alternating current at 65 watts. This low limit is due in the latter case to arcing at the spark gap and in the former case to limiting insulation. The very high value of $i^2/\lambda^2 \cdot P$ which is obtained by this simple coupling recommends it for very short range work, not requiring much power. It is interesting to note that this factor is not very different for D.A. and A.C. although the spark frequency is much higher for A.C.

In regard to the data on the coupled aerial it is to be noted that at $\lambda = .400$ km. there were so few turns used on the secondary helix that the degree of coupling was insufficient. The radiant efficiency factor increases to a maximum and then falls off rapidly as the wave-length approaches the free wave-length of the aerial where the coupling is zero.

Austin puts $I_2 = 4 \times 10^{-5}$ through a receiving aerial of 25 ohms equivalent resistance as sufficient for good communication. Assuming this value we have

$$D = \frac{4.25 k_1 h_2 \epsilon^{-\frac{4D}{\sqrt{\lambda}}}}{4 \times 10^{-5}} \frac{i_1}{\lambda}$$

for the maximum distance for good working. This can be readily solved by successive approximations, and it is at once evident that this distance is not necessarily greater for the short waves which give the strongest signals at closer ranges. The factor i_1/λ, determined for the maximum power of the station, may be regarded as the *distance factor*, since it would determine the maximum distance through non-absorbing space, as approximately, for night transmission at sea. For such transmission the shortest wave possible with proper coupling will again give the best result. Also, if the heights h_1 and h_2 are not sufficient to give a range of over say 200 km. the absorption factor $\epsilon^{-aD/\sqrt{\lambda}}$ will be so small that the distance factor i/λ, greatest for short waves, will control the result. The same argument holds for very low power stations. As a sample calculation, the working distance of this station, sending at 1 kw. to a similar aerial is calculated for different observed values of i/λ at different wave-lengths.

Assuming temporarily $K = 4.25$, $\alpha = .0015$:

λ	i/λ maximum	D (K. M.)
.457	12.53	343
.560	9.05	320
.590	8.66	312
.660	8.06	307
.730	6.65	272

It will be noted that the sending range for 1 kw. is the maximum obtainable with the shortest practicable wave-length, 460 meters. $\lambda = .450$ to .600 probably would give very nearly the same working range for this station to a similar one. It is to be noted that the wave-length $\lambda = .457$, for which $i^2/\lambda^2 \cdot P = 157$ will give at close range twice the audibility of $\lambda = .590$, for which $i^2/\lambda^2 \cdot P = 74$, although their maximum working distance is not much different.

If we assume with Austin that 1×10^{-5} amperes give the limit of extreme audibility, the wave-length for maximum distance is still .457, as Table XI. shows.

λ	D
.457	702
.560	640
.590	648
.660	643
.730	617

Table XII. gives the variation of extreme range of audibility with wave-length for $P = 4$ kw., on the assumption that the quantity $i_1^2/\lambda^2 \cdot P$ is constant for λ constant, and that i_1/λ is proportional to $\sqrt{P}$.

λ	D
.457	905
.560	860
.590	859
.660	865
.730	828

These conditions could probably be realized closely with a transformer of the same type, but of higher power. There is, within the limits of experimental error, but little preference for any wave between $\lambda = .457$ and $\lambda = .660$, although the audibilities at close range have the ratio $157/65 = 2.4$ in favor of $\lambda = .457$.

On increasing the height of the aerials longer waves will obviously be necessary, but the concomitant increase in power and range will also throw the optimum towards longer wave-lengths. As far as this station is concerned, it is evident that the shortest wave-length consistent with good coupling gives the best result under all conditions, *unless* the absorption is very much greater than the assumed value, in which case a somewhat longer wave will be better. Experiments are now under way which will test these points as far as is possible for a station of this low power.

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