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THE LORAN SYSTEM.

The Americans have developed a system of navigation for moving craft which is called the LORAN system. The position of the craft is determined by the time it takes for signals to reach it from known stations. It is, in fact, a time-delay system. When the relative times of arrival of pulses are observed, it is a matter of geometry only to determine the locus on which the craft lies. This locus is a hyperbola, with foci at the two transmitting stations. If three stations are used, the cut of these loci determines the position of the craft. By this method, a scheme of navigation is provided which only differs from other schemes of this type, such as the G system, in its range and accuracy. The range over sea from America is given as 700 miles, although 880 miles has occasionally been achieved. But this is the range over sea. At this range, of approximately 1100 km, the field strength is 10 μV/m for 100 kW radiated; so that this must be the minimum working field strength. If the system is to be used in England for navigating aircraft over land to the east of us, e.g. Germany, the transmission is over mixed land and sea, and there is no guarantee that the signal will be much stronger than with the G system.

The wavelength used with this Loran system is about 150 metres, and in virtue of using a longer wave than the G system, which is about 6 metres, the range is greater. Transmission curves, as a function of the wavelength, are shown in Fig. 1. It is fairly clear from this figure that the longer the wavelength the stronger the signal; but against this there is the fact that the longer the wavelength the more difficult it is to use beam methods, and the greater the noise. The Loran system can only be greatly superior in virtue of its accuracy at great distances. The accuracy of this system depends on whether the ground signal is used, or whether reflections from the E layer of the ionosphere are employed. The ground signals peter out at a distance of about 1100 km over sea and a very much shorter distance over land. If the system is to be used at greater distances, reflections from either the E or F layers must be employed. The ground rays should be sufficiently accurate for the purpose of accurate navigation. Reflected rays depend upon the ionosphere, which only reflects reasonably at night and which may vary irregularly. In fact, from experiments which have been done, it is probable that the time of arrival of an impulse from a definite station may vary an amount of the order of 10 to 15 microseconds. Thus, we can say that a percentage of the readings are within 5 microseconds, and so on. The curve showing the percentage of readings that (under undisturbed conditions) are within a given number of microseconds is shown in Fig. 2. This time stability has been measured on frequencies of 4 to 8.6 mc/s, and there is a probability that on the frequency of the Loran system the time stability will be of the same order.

As stated before, it was found that over sea, ground ray navigation was possible up to a distance of about 700 miles, and the system was originally intended for ground ray navigation alone. But later on, it was found that even the irregular reflections from the E region of the ionosphere were sufficiently accurate for a fairly good navigating system to be obtained. There was the suggestion that reflections from the lower regions of the E layer were relatively considerably more stable than reflections from the F layer, which are known to be unstable to the extent shown in Fig. 2. In support of this contention, there is the undoubted fact that direction finding on waves of the order of 500 m. or so is considerably more definite and accurate than direction finding on short waves of the order of 40 metres or so. We also found, in about 1922, that directions on very long waves, e.g. Carnarvon, were relatively stable. There is a reason for this. The irregularities which produce scattering are in the E layer, at heights, generally, from 100 to 130 km, say. They are relatively rare at lower heights. The lower regions of the E layer are ionised by ultra violet light during daytime and are relatively regular at night. The long waves which are reflected at the lower regions of the E layer, therefore, do not meet many irregular clouds (associated with Scattering and Abnormal E), and have, on this account, a relatively high time-stability. Pulses on long waves are likely to be relatively accurate in their time of arrival, and navigation is therefore likely to be more accurate if a longer wave is used.

The advantage of the s.s. Loran system lies in the fact that the waves are likely to be reflected from the E layer, in regions where this is relatively smooth. There are some practical measurements involved in the siting of the Loran transmitters, which, on account of the bulk of the apparatus for this wavelength, are likely to be difficult to obtain experimentally. Thus, we want to measure the time-stability, for upon this depends the accuracy of the system. To measure this time-stability, we compare a time of arrival on one aerial with that on another, these two aerials being separated by a distance d. The question is, how far are these two aerials to be separated before we can assume that the signal on A is entirely uncorrelated with the signal on B, and thus obtain a maximum time instability? Then, again, is the instability a function of the distance of the receiver from the transmitter? That is, does the accuracy of determination of the position of a craft depend upon its distance from the original transmitters? In a report given by Booker (see appendix) on the Loran system, as used in America, it is assumed that the inaccuracy does increase with the distance, and it has been stated that this accuracy is about 1% of the distance involved. Also, it is a question whether the accuracy is greater when the two stations are perpendicular to the ray, or along the ray.

These, and similar questions, can be answered and understood if the complete theory of instability and scattering is known. Again, when the theory is known, small scale experiments with spaced frames at a distance of, say, about 50 metres apart, will give all the information desired. A theory of the lack of correlation and the effect of a fan of rays in scattering, has already been developed, and should be applicable in answering the various practical questions which crop up in dealing with the Loran system. A detailed discussion of this theory will be given in a later paper. It is, in my opinion, very relevant to the questions at issue.

The Loran system is only workable over sea on the s.s. Loran at night. This is because the ground wave over land is very highly attenuated and because the E layer reflects practically nothing in the day time.

We have some facts concerning the Loran system which it might be useful to discuss. These facts are illustrated in Figs. 1, 2, 3 and 4 and 5. In Fig. 1, we show the strength of the ground signal which is used on the Loran system on a frequency of 1.95 mc/s. The curves, Fig. 1. are shown for a given initial power and beam gain, so that they are all comparable. It is clear from these that the longer waves are less attenuated, even where there is transmission partly over land, and that, perhaps, when the receiver is not at a very great height the ultra-short waves are better than the longer waves up to distances of about 400 km. The ground ray is shown, and the figure is suitably labelled. It is clear from these that the use of a longer wave gives a greater range. The only disadvantages of the use of this long wave are in the impossibility of getting a suitable beam gain, and in the increase in noise. These two factors give a less signal-to-noise ratio than is indicated on the curves.

So far, we have dealt only with the Loran system, in which the ground ray is used. The less accurate s.s. Loran system, in which pulses reflected mainly from the E region of the ionosphere are used will now be discussed.

What we want to know is the range and accuracy of this system. Some knowledge of the range is obtained from material we have already secured. In Fig. 3 we represent the cases in which the American Loran transmitters have been heard in England. The figure also shows the times of sunrise and sunset at the receiver in England and, approximately, at the transmitters, on the western seaboard of America. It is clear from this diagram that signals are only received when darkness covers the whole route from America to England. Night conditions are required for E layer reflections. The signals from America are very variable. On some nights they are not heard at all. In Fig. 4 the number of nights in a month on which either one station or more than one station was heard is shown. In Fig. 5 the field strength of broadcasting stations at night is shown, this field strength being given only at times when it was measurable. It gives a good idea of what average field strength would be expected at a given distance, and the previous curves give the probability of signals being obtained. It is probable that the absence of signals is associated with disturbed magnetic conditions in the ionosphere, but results have not been completely analysed yet, and although we know that in disturbed conditions nothing was received, it does not imply that this is the only factor that will prevent signals from traversing the route. It seems probable the strong signals, and the liklihood of obtaining them, will be possible at between 2000 and 3000 km.

Then there is the question as to which polarisation for s.s. Loran systems should be used. I think it is probable that vertical polarisation is by far the best. Experimentally, it is found that a vertical transmitter of the B.B.C. is much better than a horizontal dipole. A reason can be given for this. It has been shown, both practically and experimentally, that what is reflected from the E layer is the ordinary ray. Therefore, we want a transmitter which will supply its energy mostly in the ordinary ray type. The ordinary ray type of transmission is a nearly plane polarised wave, in which the polarisation is parallel to the earth's magnetic field, and is therefore nearly vertical. A vertical transmitter supplies this. A horizontal one will not. It is therefore better to have a vertical transmitter in these latitudes, at any rate. Accuracy has not yet been completely determined, but the material on spaced frames we have already described should be suitable for assessing this accuracy. It looks as if both the material and the interpretation of this material can most readily be obtained and worked out here.

APPENDIX I

by DR. H.G. BOOKER.

NOTES ON LORAN PROPAGATION (2 MCS/SEC)

The maximum range for the ground wave over sea is considered to be 700 miles, though 880 miles has been obtained. For E layer the maximum range is found to be 1,400 miles. The accuracy is one per cent of the range.

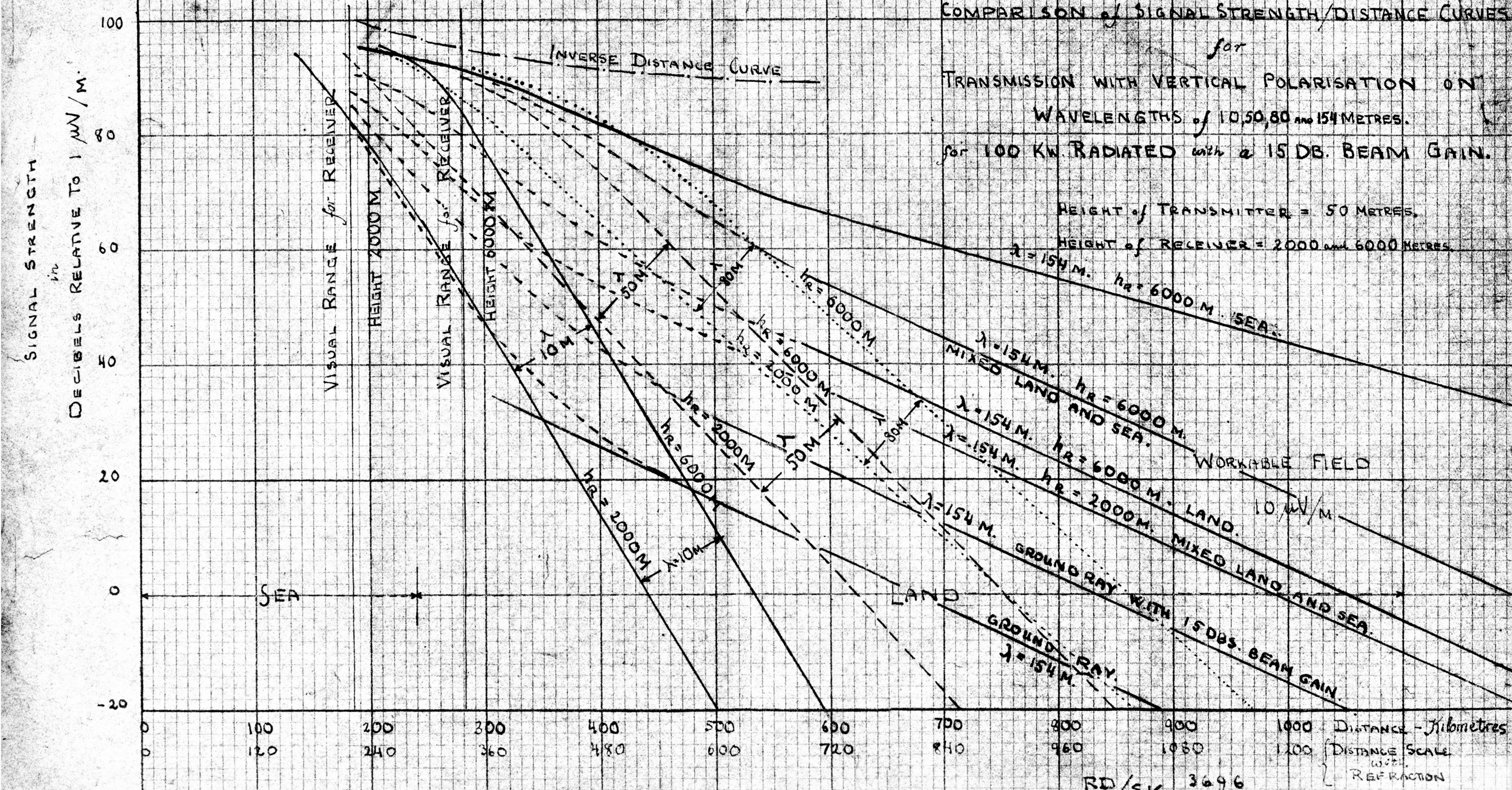
Pulses transmitted between ground stations for synchronisation show a lag behind the velocity of light when propagation takes place over land for a fraction of the distance. Seven months operational observations give a discrepancy several times the experimental error and indicate a velocity over land of 99 per cent of the velocity of light. A two day experiment carried out down Long Island over a 52 mile path tended to confirm this result.

The E layer at very oblique incidence is found to behave in a manner a good deal more reliable than might have been anticipated from soundings made at vertical incidence. The average height of the E layer for the Loran is found to be 90 kilometres with a probable error of 3 kilometres. It is considered that sky-wave synchronisation is possible at night for transmitters separated by between 1,000 and 1,300 miles, and that a Loran navigational system could be set up for central Europe giving an accuracy sufficient to navigate to a town.

The following Figures should accompany this report:-

Fig. 1. RD/3696
2. RD/4098
3. RD/4247
4. RD/4248
5 RD/4258

FIG: 1.

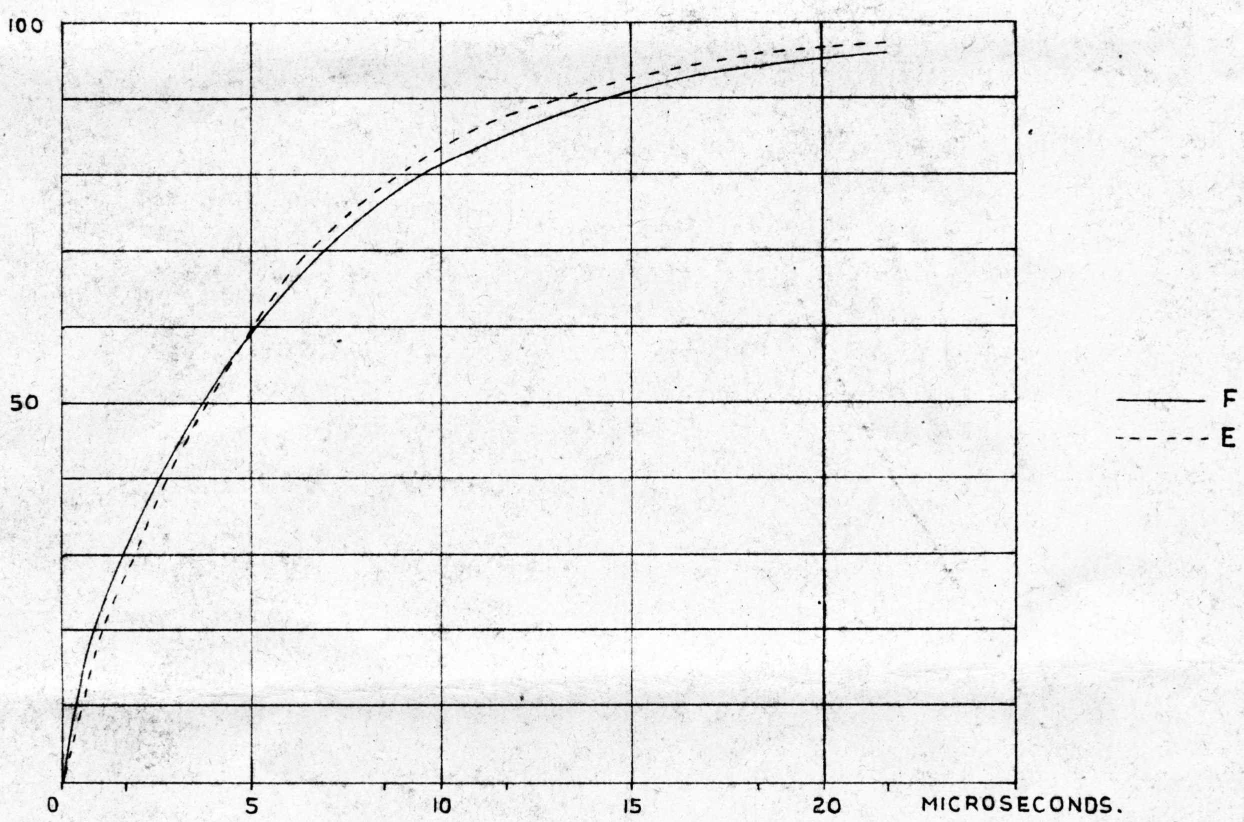


COMPARISON of SIGNAL STRENGTH/DISTANCE CURVES for TRANSMISSION WITH VERTICAL POLARISATION ON WAVELENGTHS of 10,50,80 and 154 METRES. for 100 KW. RADIATED with a 15 DB. BEAM GAIN.

HEIGHT of TRANSMITTER = 50 METRES.

HEIGHT of RECEIVER = 2000 and 6000 METRES.

RD/SK 3696



PERCENTAGE OF ECHOES WITHIN A CERTAIN TIME OF THE MEAN.

FIG. 2.

ACKBRIDGE

ATAPLATED

DATA FILE

INDEX REF.

USED ON

DRAWN

TRACED

CHECKED

APPROVED

ISSUE No.

C.N. No.

DATE

SHEET No.

CONTIN. ON

R.D. 4098

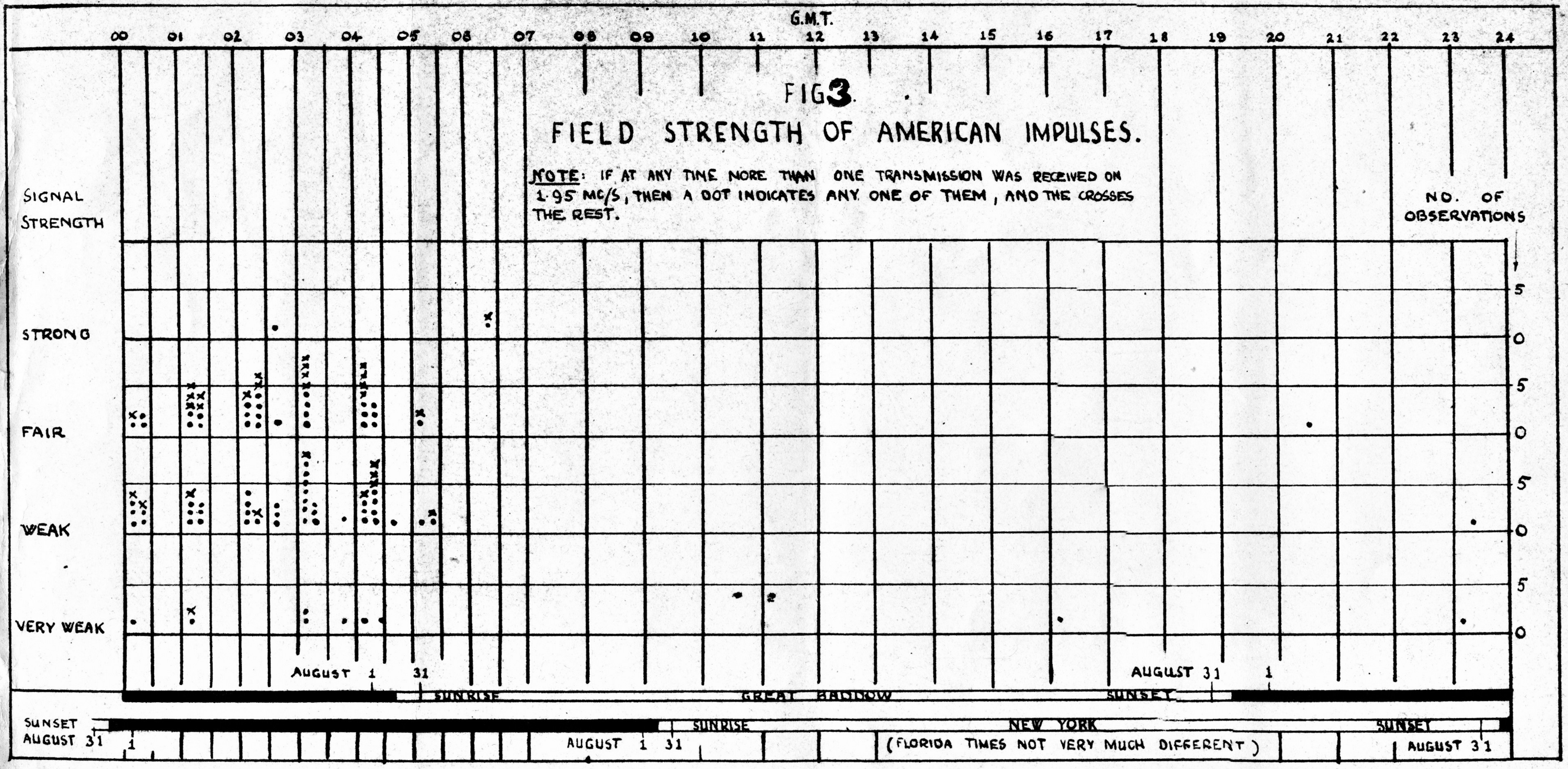


FIG 3.

FIELD STRENGTH OF AMERICAN IMPULSES.

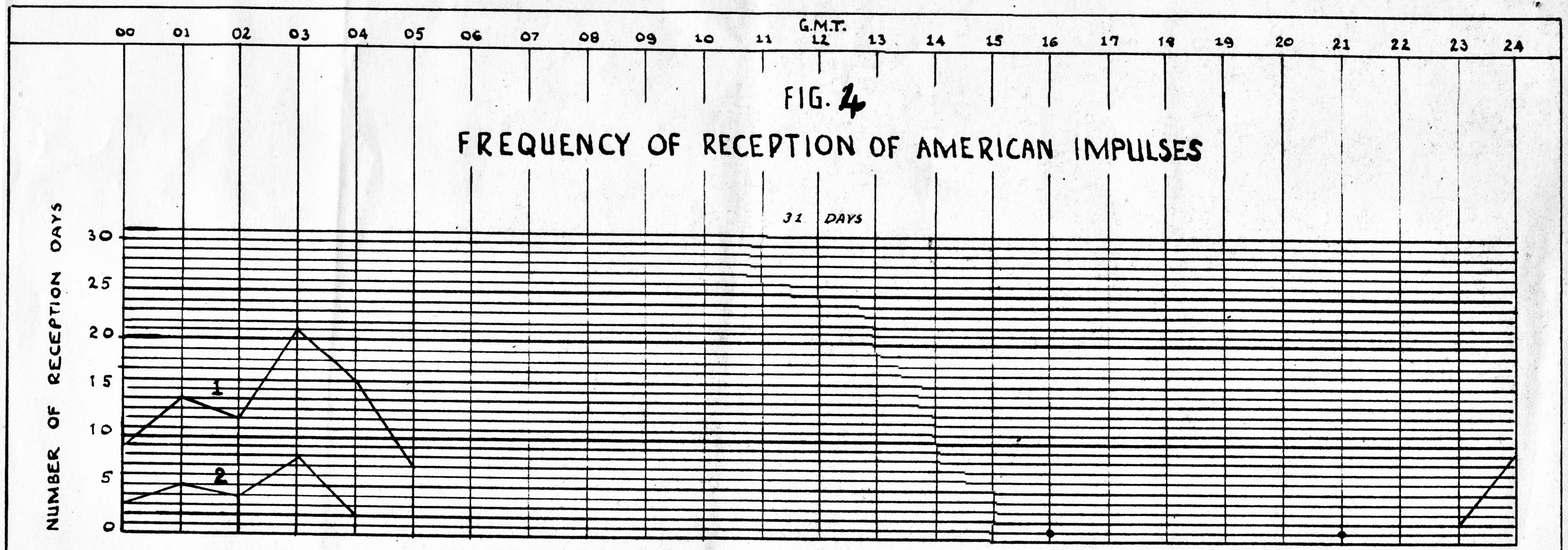
NOTE: IF AT ANY TIME MORE THAN ONE TRANSMISSION WAS RECEIVED ON 1·95 MC/S, THEN A DOT INDICATES ANY ONE OF THEM, AND THE CROSSES THE REST.

GREAT BADDOW. AMERICAN IMPULSES ON 1·95 MC/S. AUGUST, 1943

RD/SK 4247

FIG. 4

FREQUENCY OF RECEPTION OF AMERICAN IMPULSES



GRAPH 1 GIVES THE NUMBER OF DAYS ON WHICH THERE WAS RECEPTION.
GRAPH 2 GIVES THE NUMBER OF DAYS ON WHICH MORE THAN ONE TRANSMISSION WAS OBSERVED ON 1·95 Mc/s.

GREAT BADDOW AMERICAN IMPULSES ON 1·95 MC/S. AUGUST, 1943.

RD/SK 4248

LONG DISTANCE NIGHT B'CAST TRANSMISSION

FEB - APRIL 1933

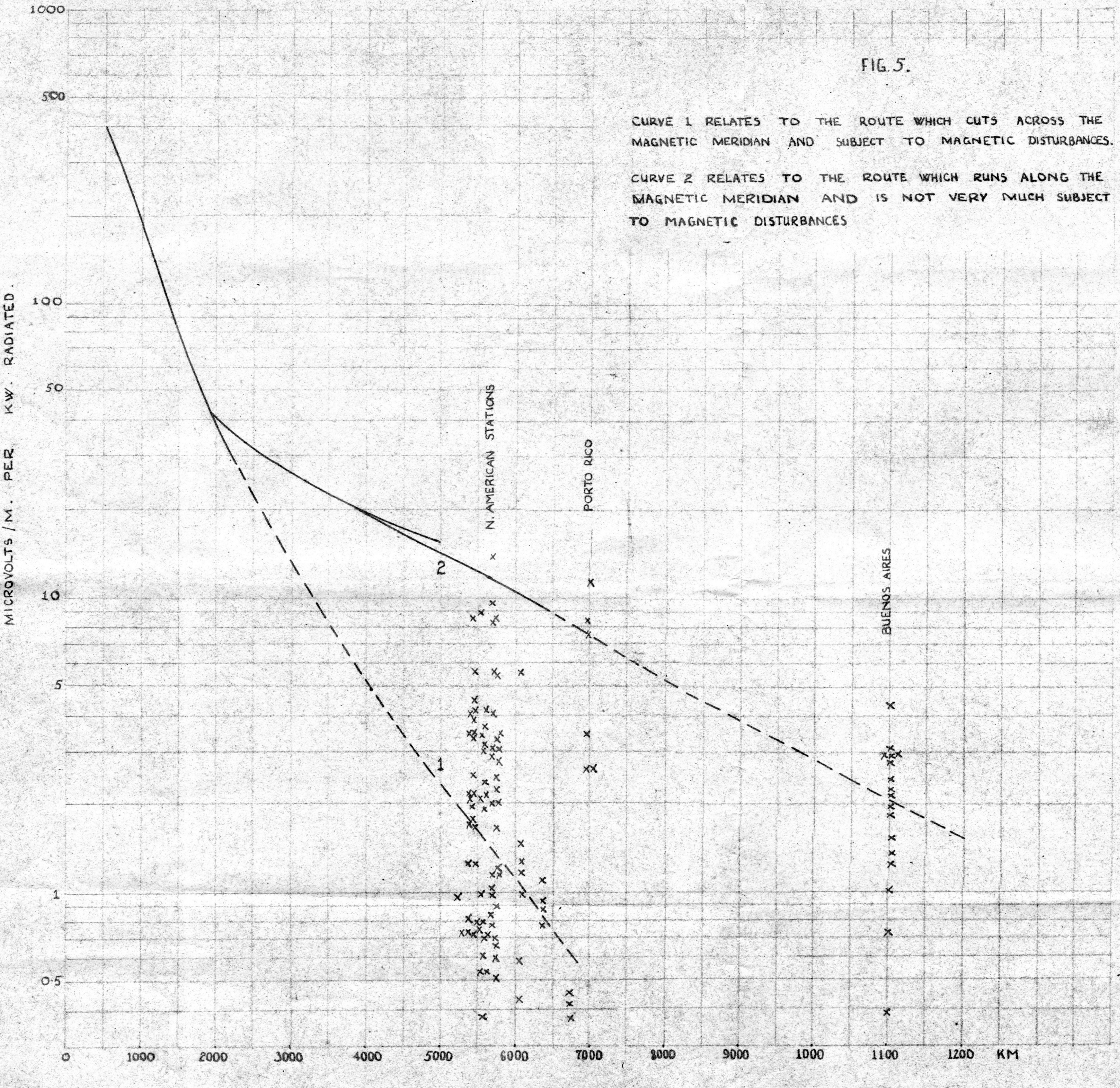


FIG. 5.

CURVE 1 RELATES TO THE ROUTE WHICH CUTS ACROSS THE MAGNETIC MERIDIAN AND SUBJECT TO MAGNETIC DISTURBANCES.

CURVE 2 RELATES TO THE ROUTE WHICH RUNS ALONG THE MAGNETIC MERIDIAN AND IS NOT VERY MUCH SUBJECT TO MAGNETIC DISTURBANCES

RD/SK 4258