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The Reliability of Short-Wave Radio Telephone Circuits *

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From empirical measurements of noise-to-signal ratio made during the routine operation of short-wave radio telephone circuits there is obtained a general relation between percentage lost circuit time and transmission improvement in decibels. In this relation "percentage lost circuit time" is the percentage of time that the noise-to-signal ratio is considered unsatisfactory. No attempt is made to define such a standard quantitatively.

If, from past experience with a long-range, short-wave telephone, telegraph or broadcast circuit, it is known that the circuit is unsatisfactory a certain percentage of the time, the above-mentioned relation may be used to estimate the effect of transmission improvement upon this percentage of unsatisfactory or lost time. For a given circuit the variation in percentage lost circuit time, as the standard for the tolerable service is changed by a given number of decibels, may also be estimated.

There are included estimates of the relation between the number of lost time intervals of various lengths and transmission improvement.

INTRODUCTION

WITHIN a comparatively few years short-wave radio telephone circuits have become an important part of the international communication network. These years have represented a wide variety of experience ranging between the quiet and the disturbed extremes of an eleven-year sunspot cycle. An attempt is made here to review some of this transmission experience in a quantitative way and show certain relations that may be useful in the engineering of short-wave circuits.

During a magnetically disturbed year, such as 1930, a low-power short-wave transmitter with a simple antenna arrangement would have provided very uncertain means for communication across the North Atlantic. The percentage of time that such equipment could transmit what according to lenient standards in terms of noise-to-signal ratio are useful telephone signals, would have been very low. If the power of the transmitter were increased or a directive antenna employed to reduce the noise-to-signal ratio the percentage useful time would, as based upon the same standards, be increased or conversely the percentage lost time decreased. Any improvement which will decrease

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the noise-to-signal ratio at the receiver output will accomplish a certain increase in usefulness of the circuit.

It is difficult to set down noise-to-signal ratios that may be employed to distinguish between satisfactory and unsatisfactory service. Such requirements would be different in the cases of telephone, telegraph and broadcast circuits. They would also depend to a considerable extent upon the facilities that it is technically and economically reasonable to provide. During times of magnetic disturbance radio telephone circuits are continued in service when noise conditions are very appreciably worse than would be tolerated on wire telephone circuits. In this emergency situation it is, of course, necessary to maintain service on the radio links as long as communication can be carried on with a reasonable degree of satisfaction.

Without a quantitative definition of the boundary between satisfactory and unsatisfactory service in terms of noise-to-signal ratio it is possible to determine from an analysis of past operating experience what percentage of the time a certain circuit was unsatisfactory. With such information available it would be useful to know how much this percentage could be reduced by the application of transmission improvements. There is developed below a form of "reliability" curve that makes it possible to estimate approximately the effect of such transmission improvements in terms of decibels upon the percentage of unsatisfactory or lost circuit time.

As a background for the following discussion it will be helpful to review briefly the conditions experienced on a typical short-wave circuit and the way in which these are related to the present analysis. For example, the instability of short-wave transmission over the North Atlantic path is well known. There are days when these transatlantic short-wave signals are remarkably good and others during times of magnetic disturbance when they are exceptionally poor. Between these two extemes is a wide range of circuit conditions. The situation is illustrated in idealized fashion by Fig. 1. The ordinates here represent average noise-to-signal ratios as measured on successive days at the receiver output and curve *A* of Fig. 1 (a) shows how this average might vary over an interval of many days. A certain noise-to-signal ratio such as is indicated by the horizontal line B might be specified as the highest value tolerable for a useful circuit according to some predetermined standard. Then the width of the cross-hatched intervals *C* represents the lost circuit time.

Fig. 1 (b) is the same as 1 (a) except that here a transmission improvement of x db has been applied so that the noise-to-signal ratio at the receiver output is on all days reduced x db and the curve *A* is

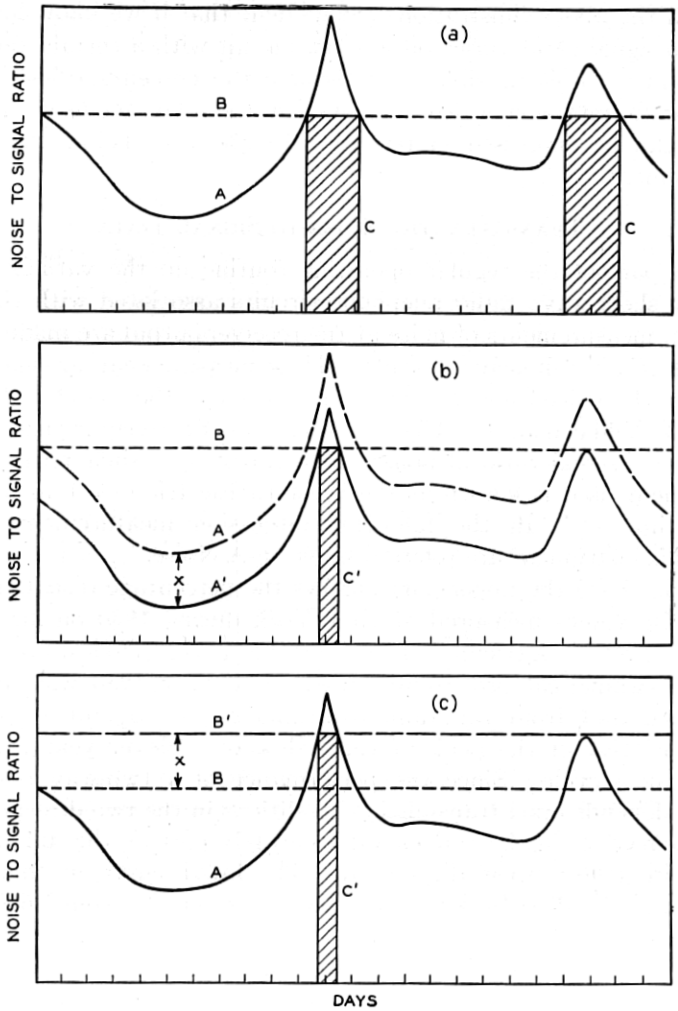

FIG. 1—Idealized illustrations of (*a*) the day-to-day variation of noise-to-signal ratio and its effect upon lost circuit time, (*b*) the effect upon lost circuit time of transmission improvements and (*c*) the effect upon lost circuit time of a change in the maximum tolerable noise-to-signal ratio.

consequently lowered to position A'. Assuming the noise-to-signal requirement B remains the same the lost time is reduced to the interval C'. If instead of applying a transmission improvement we increase the tolerable noise-to-signal requirement for a useful circuit or degrade the standard requirement by x db in the case of Fig. 1 (a), the horizontal line B is shifted upward x db as shown in Fig. 1 (c) and the lost time corresponds to that for the case of x db transmission improvement in Fig. 1 (b).

From the above illustration it is evident that if we know how the noise-to-signal ratio varies on a given circuit with a certain terminal arrangement, it is possible to determine the percentage lost circuit time for an improved or degraded system, the relative effectiveness of which can be expressed in terms of db above or below the initial arrangement.

TRANSATLANTIC NOISE-TO-SIGNAL DATA

As a part of the regular operating routine on the various transoceanic short-wave radio telephone circuits associated with the Bell System, measurements of noise at the receiver output are made at approximately half-hourly intervals. These measurements are made at a point in the voice-frequency wire circuits where the speech volume is normally held constant. They are therefore effectively measurements of noise-to-signal ratio although not expressed in such terms. The instrument used is known as the Western Electric 6-A Transmission Measuring set.[1] In the following discussion measurements made with this instrument are referred to as "6-A Noise."

In Fig. 2 (a) the upper curve shows the percentage distribution of 6-A noise values measured at New York during 1930 on an 18-mc. London-New York circuit. These and the curves to follow are plotted to an arithmetical probability scale. The year 1930 was severely disturbed and from the radio transmission standpoint is perhaps representative of the peak of the well-known eleven-year magnetic disturbance cycle. Since the performance of a two-way telephone circuit depends upon transmission conditions in the two directions the upper curve of Fig. 2 (a) does not accurately portray the full effect of the noise factor upon the circuit. The lower curve in this figure represents the distribution of the higher of simultaneous[2] 6-A noise values measured at New York and London. The small difference between the two distributions is evidence that the most important influence—that of magnetic disturbance—affects the transmission in both directions coincidentally.

It will be noted that these 6-A noise curves of Fig. 2 (a) and of the following figures bend downward in the region of low 6-A noise and upward where the 6-A noise becomes high. There is reason to believe that these bends are introduced by the terminal equipment and that the actual noise distribution of interest here approaches a straight line on the probability scale used, or in other words is a fortuitous

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[1] L. Espenschied, "Methods for Measuring Interfering Noises," *Proc. I.R.E.*, Vol. 19, p. 1951, November, 1931.

[2] Measurements less than seven minutes apart at the two ends of the circuit were treated as "simultaneous" in this analysis.

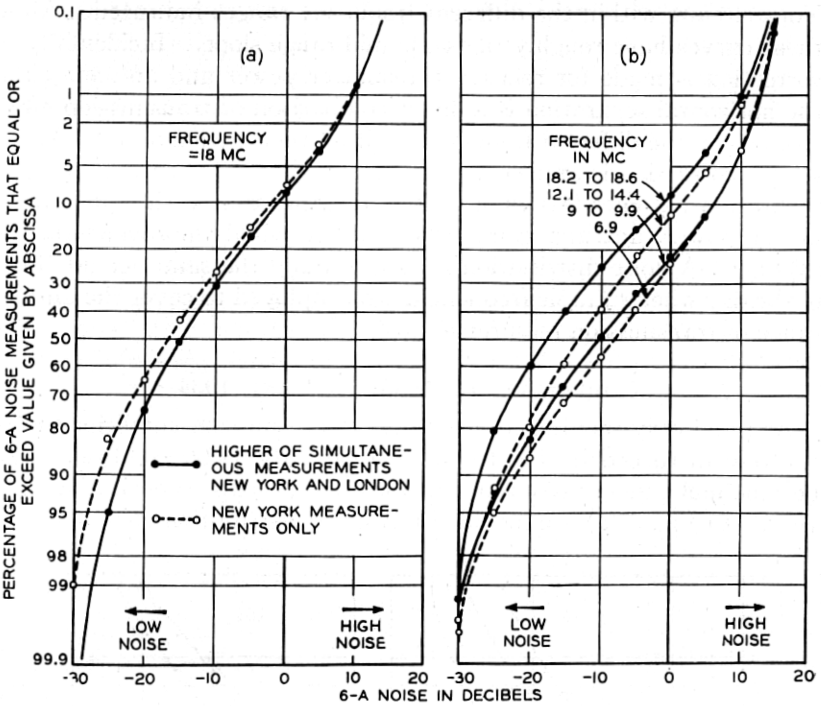

FIG. 2—Percentage distribution of 6-A noise measurements made on London to New York short-wave circuits during 1930 on (*a*) one 18-megacycle circuit and in (*b*) each of four frequency ranges.

type of distribution. The bend at the low noise end is apparently due to noise transmitted from the distant terminal and that introduced by the local receiver. These sources of noise are approximately constant and, when the atmospheric noise is very low, become the limiting factors. The bend at the high noise end of the curve is probably due to the action of the automatic volume control in the receiver. This control normally holds the speech volume approximately constant, but when noise is exceedingly high the noise in itself reduces the receiver gain and depresses both the noise and signal output. Since at such times speech volume cannot be accurately checked, the measurement is no longer an accurate indication of noise-to-signal ratio and the curve reaches a limiting value. Evidence confirming the inaccuracy of the 6-A noise readings at the high and low noise extremes will be discussed later in connection with the observed distribution of high-frequency signal intensity values.

In Fig. 2 (b) are shown distribution curves for 6-A noise values measured at New York during 1930 on several of the London to New

York circuits within the different frequency ranges indicated. All of these curves have roughly the same mid-range slope. Incidentally, if correction is made for relative transmitter power and antenna gains the horizontal separation is a direct comparison of transmission effectiveness on the different frequencies within their period of use. When such a correction is applied to the curves of Fig. 2 (b) the mid-range separation becomes less than 3 db, indicating that with equal transmitter power, antenna gains and other terminal improvements the average 6-A noise distribution is substantially the same for all times of the day when suitable frequencies are employed to cover the diurna range of transmission requirements.

COMPARISON OF 1930, 1932 AND 1934

As previously mentioned, short-wave transmission conditions were severely disturbed during the year 1930. By 1932, conditions had become much more favorable and 1934 was perhaps typical of a quiet year. In Fig. 3 (a) are included 6-A noise distribution curves for the

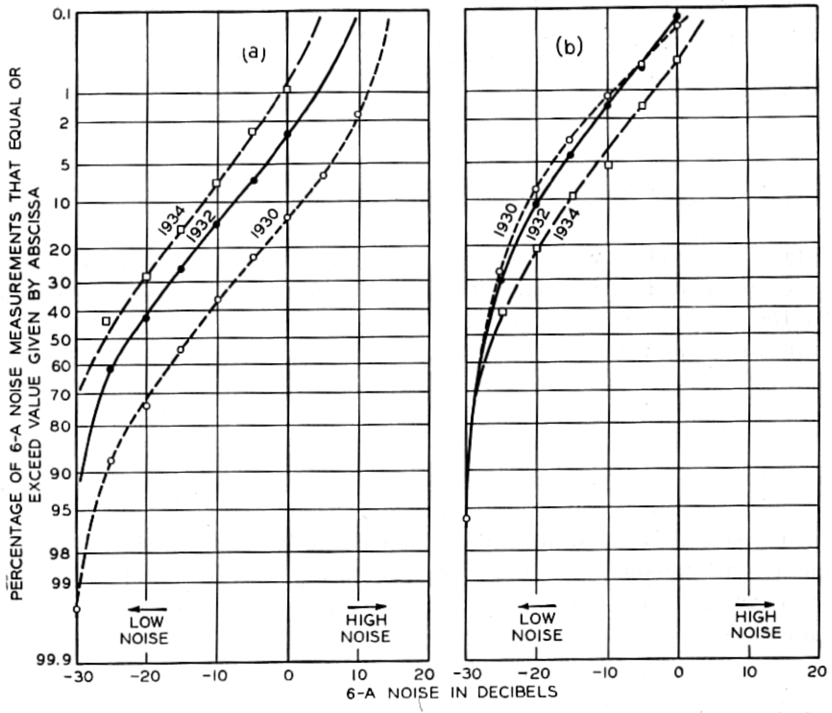

FIG. 3—Percentage distribution curves of 6-A noise measurements made during 1930, 1932 and 1934 on (*a*) all London to New York short-wave circuits and on (*b*) all Buenos Aires to New York circuits.

London-New York short-wave telephone circuits during 1930, 1932 and 1934. These three curves have very nearly the same mid-range slope, showing that the general character of the distribution was the same over the wide range of transmission conditions experienced within this interval. To those familiar with transatlantic short-wave transmission during 1930, the year 1934 would rate as comparatively undisturbed, and yet these curves indicate that for an equal percentage of measurements or, as will be apparent later, for equal lost circuit time during these two years the difference in required transmission effectiveness would be only 13 or 14 db.

Fig. 3 (b) shows that there was relatively small db separation between the 6-A noise distributions for 1930, 1932 and 1934 on the low latitude South American circuits but that the position of the curves is reversed, 1930 being better than 1934. An examination of field intensity data for these years indicates that this is due to a change in noise rather than to a change in signal transmission.

Fig. 4 (a) compares the distributions for the circuits Buenos Aires–

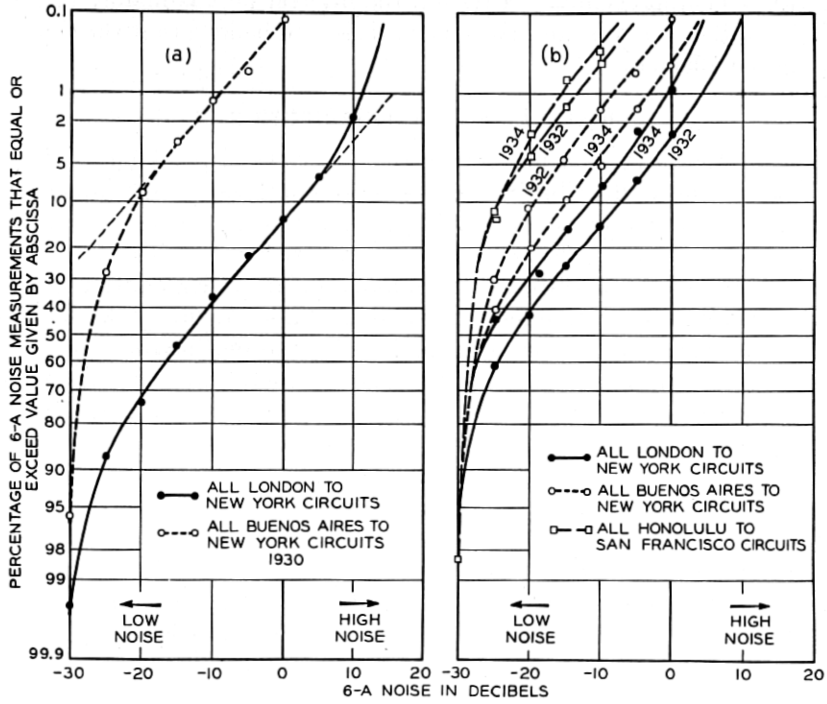

FIG. 4—Percentage distribution curves of 6-A noise measurements made on (*a*) all London to New York, and Buenos Aires to New York short-wave circuits during 1930 and on (*b*) all London to New York, Buenos Aires to New York, and Honolulu to San Francisco short-wave circuits during 1932 and 1934.

New York and London–New York for the year 1930. Again the mid-range slope as shown by the extended broken lines is about the same. The horizontal separation of roughly 25 db illustrates the much more favorable noise-to-signal conditions on the low latitude circuit, since the transmitter power and antenna gains were substantially the same in the two cases.

In Fig. 4 (b) are shown 6-A noise distribution curves for the Honolulu–San Francisco, Buenos Aires–New York and London–New York circuits representing conditions during 1932 and 1934. The mid-range slope is remarkably similar for all six curves. A comparison of these curves illustrates the high degree of reliability obtained on the circuit to Honolulu.

In Figs. 4 (a) and (b) the data for the low latitude paths cover about 9 hours of daylight operation as compared with 24-hour full time operation for the transatlantic case. Although data are not available for a 24-hour comparison some available experience indicates that such a comparison would not have altered the separation between the curves shown very appreciably. After all, the interest here is mainly in the slopes of these curves, and there is no reason to believe that the slopes would be affected.

Field Intensity Distribution

So far the discussion has shown that over the dependable portion of the 6-A noise distribution curves representative of both different circuits and different years the slopes appear to be nearly the same. If this is the case one curve may be constructed to represent approximately the effect of transmission improvement or degradation upon the performance of any long range short-wave circuit. The useful range of this curve is, however, limited by the dependable range of the 6-A noise measurements. To extend the useful range of the curve in order to estimate the effect of large changes in transmission improvement it is necessary to resort to a correction for the bend at the high noise end. Correction at the low noise end would concern the less important case of transmission degradation. Although it is possible to apply an approximate correction for the above-mentioned effect of the automatic gain control upon the bend at the high noise end it is probably more accurate to consider the distribution of field intensity data at these times of high noise-to-signal ratio.

The limiting conditions on short waves are predominantly those accompanying magnetic disturbances when the signal fields drop to very low values. The indications are that the atmospheric noise fields also decrease to a less noticeable extent during these disturbances,[3] so that if this were the only effect to be considered the 6-A noise which is dependent upon the noise-to-signal ratio would increase slowly. But first circuit and tube noise in the receiver are probably the real limitation during times of disturbance. If this high-frequency first circuit noise remains constant and the field intensity decreases the 6-A noise will increase in opposite proportion. Therefore it may be assumed that the slopes of the corrected 6-A noise curves in the high noise region will correspond to the slopes of the field intensity distribution curves. In a conservative estimate it is reasonable to assume that this is the case and that although the field intensity falls during times of magnetic disturbance the high-frequency noise will not decrease.

In correcting the less important low noise ends of the 6-A noise curves, use of the field intensity distribution is not so easily justified. It may be reasoned, however, that here atmospheric noise is again low compared to receiver noise but due in this case to a scarcity of electrical storms within favorable transmission distance from the point of reception. Then the corrected 6-A noise distribution at the low noise end would also correspond in shape to the field intensity distribution. For these reasons it is assumed in the absence of better data that the field intensity distribution may be used to correct for the bends that occur at both ends of the 6-A noise distribution curves. Fairly dependable field intensity data are available over a much wider decibel range than is accurately covered by the 6-A noise measurement.

In Fig. 5 is shown by the full line *e–c–d–f* a form of noise-to-signal distribution which is conservatively representative of that experienced on several short-wave radio telephone circuits as described above. The horizontal decibel scale in this figure is arbitrarily referred to the midpoint of the distribution curve. The broken line extension *d–b* represents the decibel distribution of the lowest 15 per cent of the field intensity values as experienced during the years 1930 and 1932. The broken line extension *a–c* similarly represents the distribution of the highest 30 per cent. The reason for using the transatlantic data is that there are many more measurements available in the low field region than there are for transmission over less disturbed paths. The available data indicate that if suitable frequencies are used at all times of the day the distribution of field intensities within the lowest 15 per cent and the highest 30 per cent has roughly the same average slope during different years and on different circuits.

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[3] R. K. Potter, "High Frequency Atmospheric Noise," *Proc. I.R.E.*, Vol. 19, pp. 1731–1765, October, 1931.

Circuit Reliability Curve

The corrected form of the noise-to-signal distribution curve represented by the line *a–c–d–b* in Fig. 5 may by a simple translation be put in terms of percentage lost circuit time versus transmission improvement in decibels where noise rather than quality degradation or equipment failures interrupts continuity of service. To start this translation, take, for example, the point at which 50 per cent of the noise-to-signal values are greater and 50 per cent are less than a value given on the horizontal scale. This is 0 db and the value in itself has

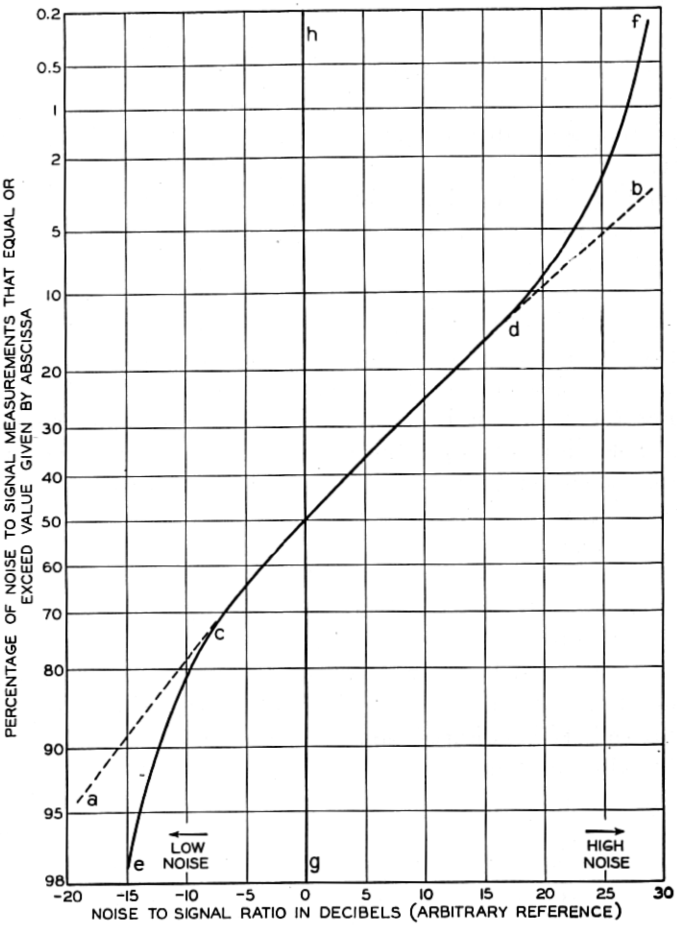

Fig. 5—Correction of assumed 6-A noise distribution curve where it is influenced by terminal equipment effects.

no significance except as an arbitrary reference point on this scale. A vertical line is erected through this point as shown by *g–h*. If, on a certain short-wave circuit, conditions are unsatisfactory 50 per cent of the time, the effect of 10 db improvement upon this percentage may be determined by shifting the curve *a–c–d–b* of Fig. 5 ten db to the left and reading the percentage value on the vertical scale opposite the intersection of the vertical reference line. It will be remembered from previous discussion that such a shift of the 6-A noise curve toward lower values accompanies a corresponding db transmission improvement. If 50 per cent of the time conditions were unsatisfactory in the former case, they would be unsatisfactory only some 25 per cent of the time for the same tolerable noise condition and 10 db improvement. That is, the lost circuit time has been reduced from 50 to 25 per cent by 10 db transmission improvement.

By shifting the curve *a–c–d–b* of Fig. 5 various amounts to the right and left and tabulating the percentages obtained as described above, a generalized "reliability" curve may be plotted which shows the transmission improvement required to reduce the lost circuit time by any desired amount. Similarly, if we know the percentage lost time on two circuits their transmission performance may be compared on a decibel basis by determining the horizontal db separation between these two lost time values on the "reliability" curve.

A "reliability" curve of the kind described above is shown in Fig. 6. Although it is obviously unsafe to conclude on the basis of the data presented that this curve is accurately representative of all long-range short-wave circuits and circuit conditions, it serves to indicate the order of service improvement that will be afforded within the practical range of transmission improvement. For example, to reduce the lost or unsatisfactory circuit time from 50 per cent to 25 per cent appears to require about 10 db transmission improvement on any long-range short-wave circuit. Starting with a 50 per cent lost time condition and applying improvements in 10 db steps the successive percentages of lost circuit time would be roughly 25, 10, 2.5, 0.7 and 0.1.

Changes in the standards of tolerable service may be treated as equivalent to a change in the effectiveness of transmission as described earlier. Thus in terms of a high grade service the lost circuit time might for example be 50 per cent. For a grade of service 10 db lower than this the lost circuit time would be reduced to 25 per cent. The effect is equivalent to improving the transmission 10 db for the same standard of service.

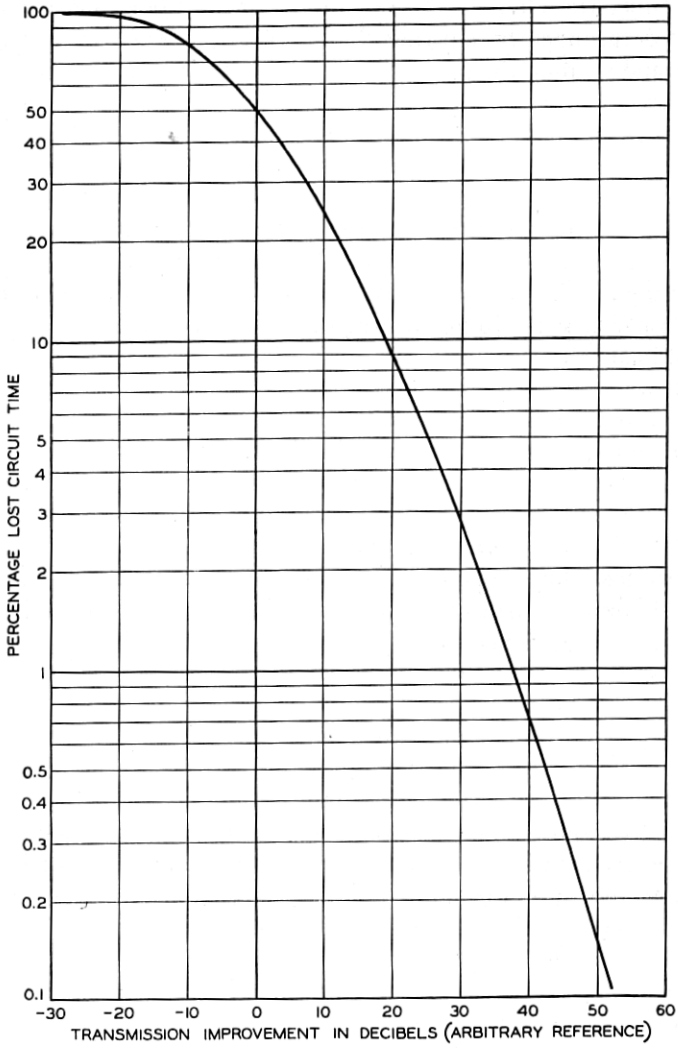

Fig. 6—Approximate relation between transmission improvement and percentage lost circuit time.

DURATION OF INTERRUPTIONS

In the traffic operation of radio telephone circuits we are concerned in a practical way with the effect of transmission improvement upon the duration of intervals when circuits are unsatisfactory as well as upon the percentage lost or unsatisfactory circuit time. Obviously, the reduction of lost time must be accompanied by a reduction of the length of unsatisfactory intervals, or what may be termed interruptions to service. It is of interest to know how the distribution of interruptions of various lengths may be expected to vary with improvement of a circuit.

In Fig. 7 the upper curve shows how the number of circuit interruptions for the year as indicated by the ordinate value varied with hours duration on the transatlantic short-wave radio telephone circuits during 1930.[4] This upper curve was obtained from traffic data. In determining the points shown it was necessary to exclude all interruptions of uncertain length that occurred at the beginning or end of the periods when circuits were in use so that only the slope of this curve is significant.

From the field intensity measurements obtained regularly on the transatlantic circuits it is possible to obtain a useful check on the traffic experience. For example, the interruptions may be defined as the intervals of time during which no signal could be heard by beating in the carrier received on a short-wave measuring set to an audible tone with a local oscillation. By this means signals 30 db or more below those required for a barely satisfactory radio telephone circuit can be heard. In Fig. 7 the lower curve shows the distribution of interruptions based upon such a standard. This curve has substantially the same logarithmic slope as the one obtained from traffic experience. That is, the slope remains the same when the conditions defining the point of interruption are shifted by perhaps 30 or 40 db.

The summation of all interruptions shown by curves such as those in Fig. 7 should agree with the observed lost circuit time. If it is assumed, as the rather meager evidence cited above appears to indicate, that the logarithmic distribution of the interruptions remains constant for different circuit conditions, it is possible to show how the probable number of interruptions of various lengths will vary with transmission improvement. With the slope shown the position of curves corresponding to different db improvements is established by the reliability curve of Fig. 6 and the requirement that the summation of interruptions equal the lost time. Curves obtained in this manner are shown

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[4] Interruptions during other years have been too infrequent to provide dependable data.

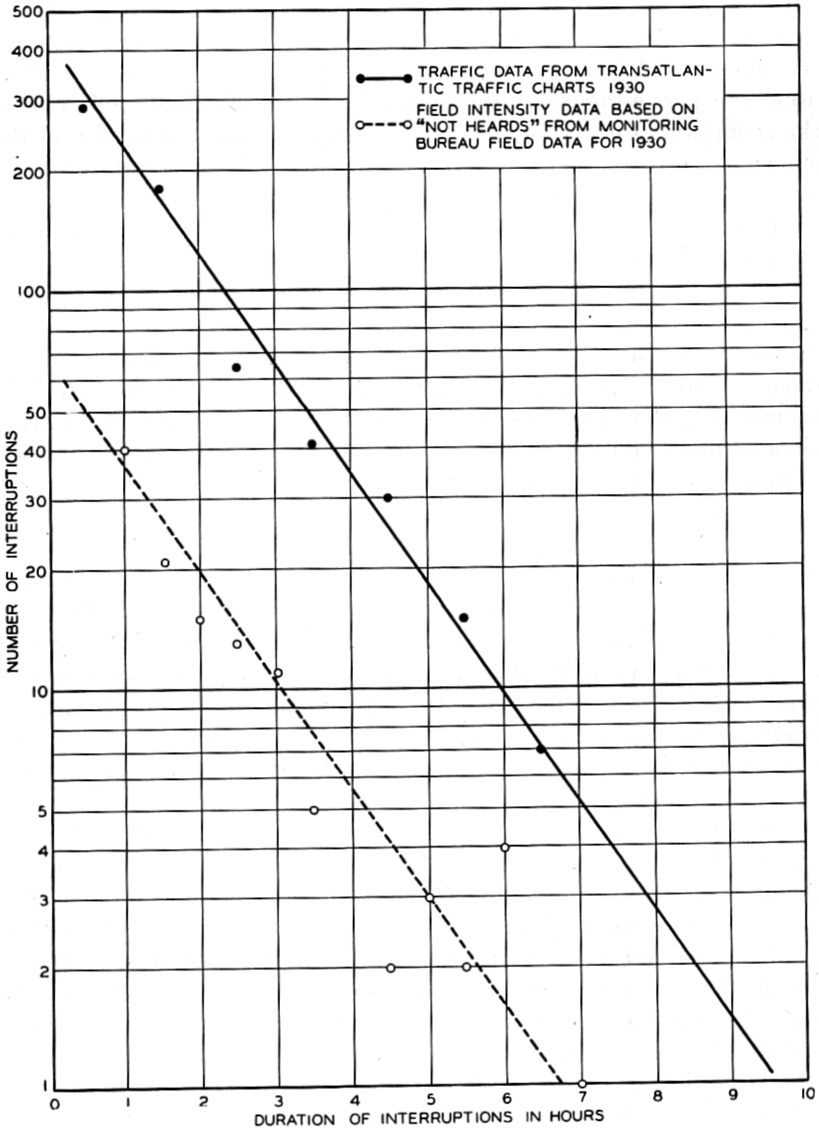

FIG. 7—Observed relation between number and duration of transatlantic short-wave radio telephone circuit interruptions during part of 1930.

in Fig. 8. As for the generalized reliability curve of Fig. 6, the reference point adopted is 50 per cent lost circuit time. Consequently the curve of Fig. 8 marked "50 per cent lost circuit time" is also designated as "0 db Transmission Improvement." Knowing the percentage lost time experienced on a certain circuit the position of the corresponding interruption curve in Fig. 8 may be determined by interpolation. The effect of, say, 10 db transmission improvement

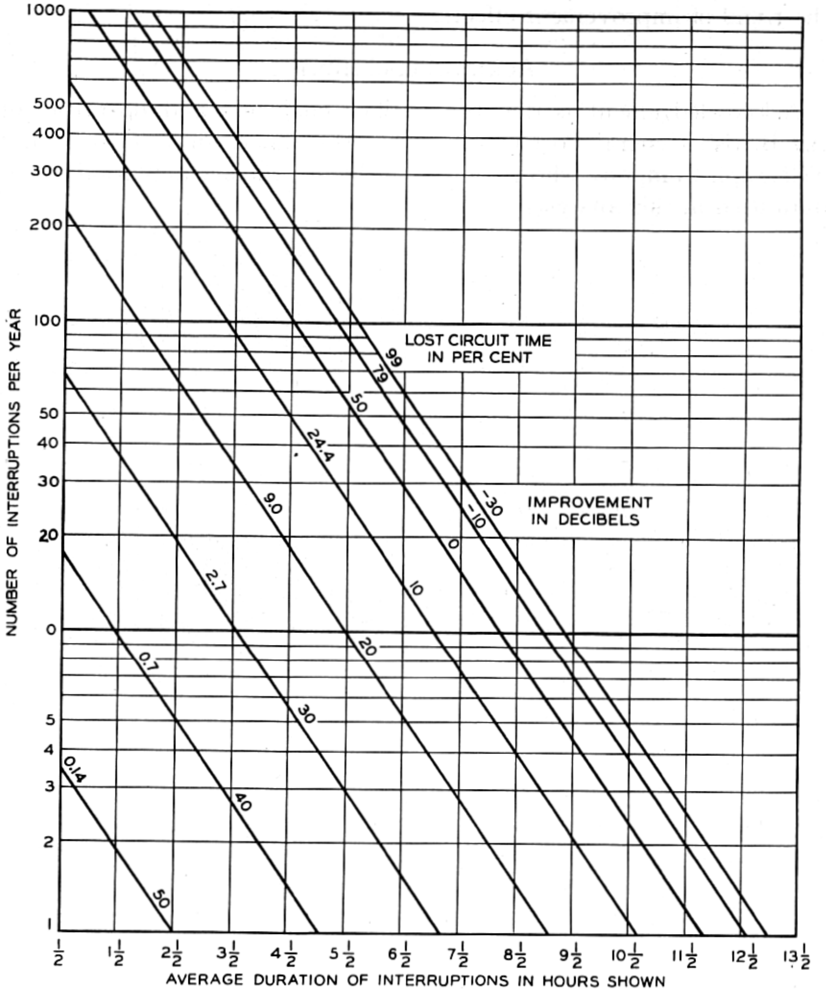

FIG. 8—An estimate of probable duration versus number of interruptions for full time operation.

upon the probable interruptions, is determined by shifting this curve 10 db to the left as measured by the indicated db spacing between curves.

It should be remembered that estimates based upon Fig. 8 are probably very approximate but the curves will at least serve to indicate the trend of improvement effects.

ACKNOWLEDGEMENT

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