Investigation of VHF Nonoptical Propagation Between Sardinia and Minorca

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INTRODUCTION

ANNOUNCEMENTS that vhf and uhf transmission had been found possible over distances considerably greater than classical diffraction theory had predicted, aroused considerable interest in Europe. It was felt that if such transmission proved to be reliable, there would be numerous cases where it could provide circuits more conveniently and, perhaps, more economically, than could conventional transmission systems. One such case would be the provision of telephone circuits between Italy and Spain, via Sardinia and Minorca (see map, Fig. 1). Accordingly, the Italian and Spanish Administrations decided to set up an experimental link over the longest section of the route, namely, between Sardinia and Minorca. With the collaboration of I.T. & T. associates in Italy, Spain, and Great Britain, special equipment was manufactured and installed, and a test program was decided upon.

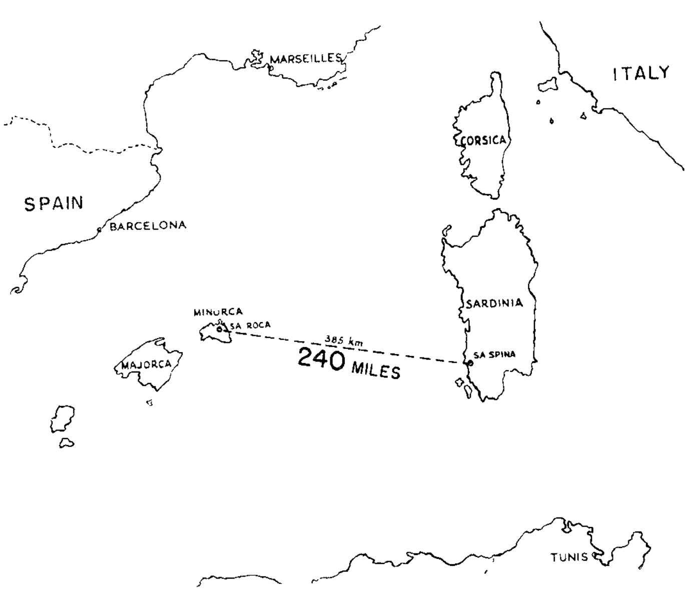

Fig. 1

In view of the small amount of information published on the depth of fading and the available bandwidth of "beyond-the-horizon" transmission, it was felt that the object of the experiment should be to collect as much basic data as possible, and not to attempt, at this stage, to provide an operational telephone link. After consideration of the factors involved, a radio frequency of about 300 mc was chosen, as it was felt that this frequency afforded the best combination of readily available transmitter power and antenna gain. In this connection it should be remembered that the development of high-power klystrons for frequencies of 800–1,000 mc has not proceeded so rapidly in Europe as it has in the United States, where this development had the apparent incentive of uhf television broadcasting.

In order to explore the possibilities of wide-band transmission it was decided to modulate the transmitter with a constant frequency and to provide separate narrow-band receivers for the resulting carrier and first sidebands. Means were then provided to record the amplitude of each sideband, so that any differential fading could be observed. In addition, the two equal frequencies obtained by mixing each received sideband with the carrier were compared in a phase discriminator, so that some idea could be obtained of the group delay distortion over a frequency band.

The equipment was designed so that either 238 or 297 mc could be transmitted, and results could be obtained at more than one frequency. Similarly, the antenna dipole feed were designed so that either horizontal or vertical polarization could be used. The test program was arranged so as to change the frequency or the polarization at weekly intervals. For example:

1st week, 238-mc horizontal polarization
2nd week, 297-mc horizontal polarization
3rd week, 297-mc vertical polarization
4th week, 238-mc vertical polarization.

DESCRIPTION

Sites

The transmitter is located near the center of the island of Minorca. The site is 200 meters above sea level, and the ground slopes away from the site, giving a clear view of the sea.

The receiving site is at Campo Spina near the southwest coast of Sardinia. The site is nearly 1,000 meters above sea level, and there is again a clear horizon to the sea. Profile of the radio path is in Fig. 2 (next page).

Antennas

Both receiver and transmitter employ paraboloids of 10-meter diameter. They consist of angle-iron framing covered with a wire mesh. The transmitting antenna was manufactured in Spain and its supporting structure differs from the receiving antenna made in Italy.

The paraboloids are fed from normal dipoles and it is possible to vary within limits the position of the dipole

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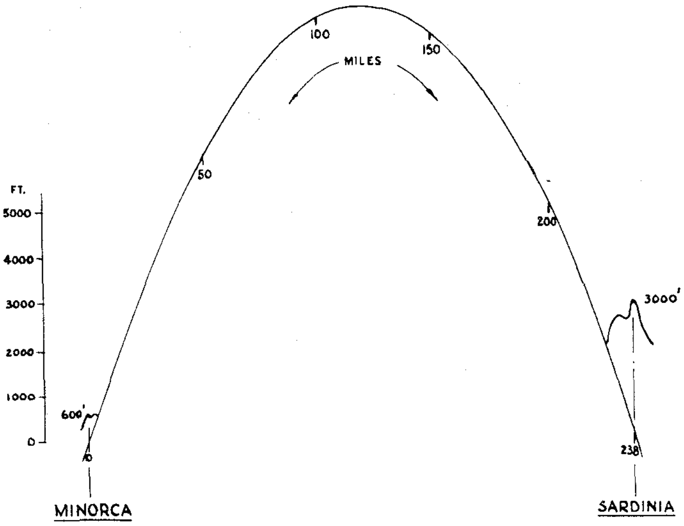

Fig. 2

in the focal plane of the paraboloid, which enables fine adjustments of the radio beam. In addition, both paraboloids have a limited movement in the horizontal and vertical plane.

Radio Equipment

Transmitter (*Fig. 3*): The transmitter has a carrier output of approximately 1 kw at the frequencies of operation, namely, 238 mc and 297 mc. The carrier is phase-modulated with a modulation index which produces maximum amplitude of the first sidebands. With this optimum value of modulation index, the rate of change of sideband amplitude with modulation is a minimum, and is thus the most stable condition of operation.

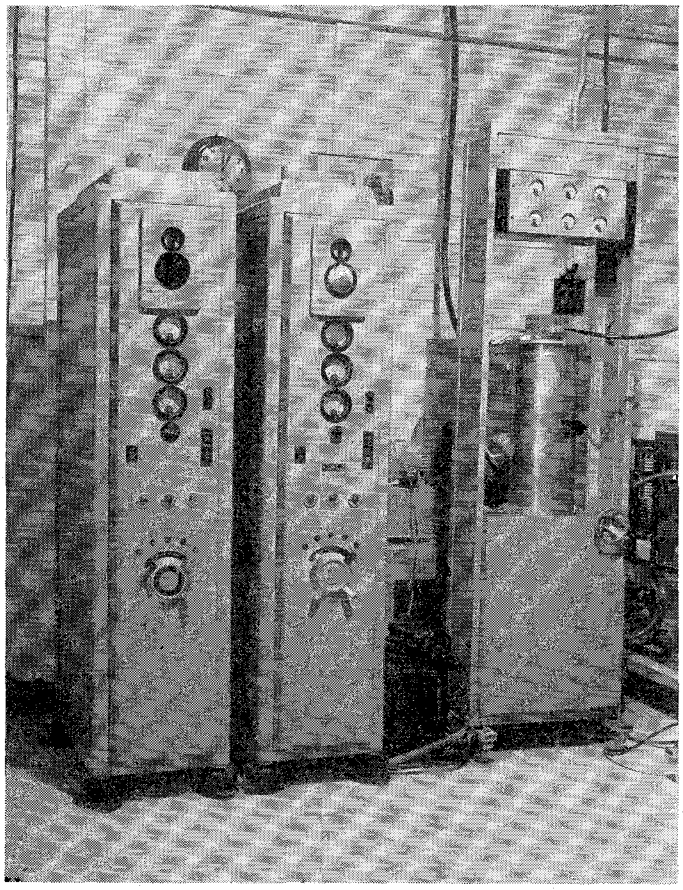

Fig. 3

The radio frequency of the transmitter is governed by a temperature-controlled crystal oscillator of frequency 124 kc, of the type used in a coaxial cable system, which has a frequency stability of 2 parts in 10^7. The oscillator is followed by two stages of multiplication which produces a frequency of 2.48 mc. This frequency is then multiplied by 4, when the final frequency required is 238 mc, and by 5, when the final frequency is 297 mc.

The multiplied frequency of 9.92 mc or 12.4 mc is phase-modulated by the crystal-controlled 124 kc to produce two sidebands of maximum amplitude. This phase-modulated output is then fed to a multiplier (×24) which produces the final frequencies of 238 mc and 297 mc.

The final frequency is amplified in three stages to produce an output of a little over 1 kw. The power in each sideband is approximately $\frac{1}{2}$ kw.

Receiver (*Fig. 4*): The receiver employs three stages of frequency conversion and the first two local oscillators' frequencies are derived from the same type of master oscillator used in the transmitter, thus preserving the same degree of frequency stability in both transmitter and receiver. The received frequency after amplification is first converted to an IF frequency of 56.544 mc and subjected to further amplification. The second converter produces the second IF frequency of

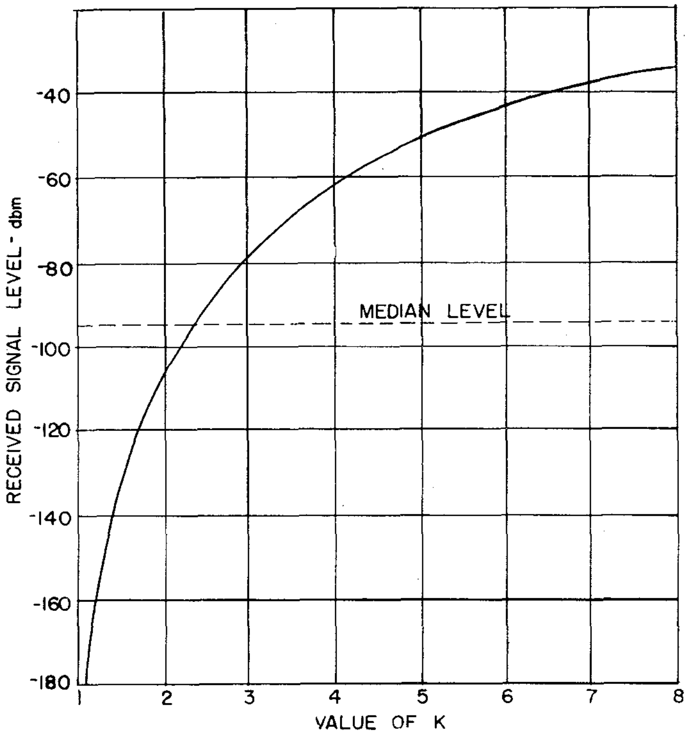

Fig. 4

2.976 mc which is amplified in a narrow-band amplifier, and then mixed with a frequency of 2.676 mc, produced by a separate crystal oscillator.

The resulting carrier of 300 kc, with sidebands of 424 and 176 kc, are then separated by means of band-pass filters and amplified by separate amplifiers. The outputs of the sideband amplifiers are rectified and fed to two movements of a three-pen continuous recorder.

The 300 kc carrier, after limiting, is mixed with the two sideband frequencies in a phase discriminator, the output of which gives a direct indication on the third pen of the three-pen recorder of the phase difference between the two received sidebands.

The three-pen recorder normally has a paper speed of 6 inches per hour, but it is possible to increase this speed 60 times for short periods. The time constant of the recorder movement is approximately one second, which is much longer than any time constant associated with the receiving equipment.

RESULTS

The tests have now been in operation for some months, having commenced last November, but the results so far analyzed relate to winter months only. The results should thus be interpreted with some reservation, as they may not be representative of yearly distribution of signal level. However, it is possible to make some observations on the general characteristics of the received signal.

It was soon realized that at times the signal was below the noise level of the receiver (−125 dbm), whereas it could also be of the order of −60 dbm, a range of level of over 60 db. The recording circuits of the receiver can accept a variation in signal level of only 40 db, but it is possible to center this variation at any particular level by means of an attenuator in the input circuit to the receiver. The normal setting of the attenuator was based on the signal-to-noise ratio required to operate the phase measuring circuits, and with this in view it was decided to set the receiver to operate between −75 and −115 dbm. This range enables a fairly accurate analysis of the distribution of low-signal levels, which are obviously of the greatest importance in assessing the performance of a possible future radio link, over the same radio path.

The type of signal received can be roughly classified into four categories (see Figs. 5–8 following page):

Type 1. A high median level of signal of the order of 30 db above the median expected, from the information published by K. Bullington,[1] with occasional short duration fades sometimes reaching the noise level (−125 dbm). The high-level signal is most likely due to super-refraction, and, referring to Fig. 4, it will be seen that a value of K greater than 3.5 could produce a signal which is greater than −70 dbm. The curve assumes diffraction over a smooth sphere.

If the value of K is greater than 6, the path becomes an optical path and the occasional deep fades could be the result of reflection from the sea, especially as the receiver is nearly 1,000 meters above sea-level.

Type 2. A fairly rapidly fluctuating signal with a median level somewhat lower than expected. The duration of the fades is approximately equal to the period between fades, both being about 1 minute. The peak-to-peak amplitude is of the order of 25–30 db.

Type 3. A rapidly fluctuating signal with very short deep fades extending to the noise level of the receiver. The median value is approximately that expected from scatter propagation.

Type 4. Very rapid fluctuating signals, the characteristics of which cannot be resolved by the normal recorder paper speed of 6 inches per hour. Increasing the paper speed to 6 inches per minute has shown fading duration of 1 second, which is the limiting time constant of the recorder, but even shorter fades may well be present which are masked by the present system of recording.

The median value is that expected from scattering considerations.

The tests have been operating on two frequencies and both types of polarization have been used. There does not appear to be any appreciable difference in receiving level between the two frequencies used; neither is there a more favorable polarization. Short period tests have been carried out with the transmitting antenna horizontally polarized and with the receiving antenna vertically polarized, and at all times the signal has been at least 20 db lower than normal. The plane of the transmitted polarization thus appears to be well maintained, even when subjected to scattering from the troposphere.

ANALYSIS OF RESULTS

The first broad analysis of the results concerned the probability of occurrence of the four types of signal already noted. This was, very approximately:

Type 1, 10 per cent of the time.
Type 2, 10 per cent of the time.
Type 3, 55 per cent of the time.
Type 4, 25 per cent of the time.

Type 1 appears to be typical of fine still weather conditions and may be expected to occur more frequently during the summer months. Types 2, 3, and 4 occurred during turbulent weather.

We have devoted most of our attention to the Type 3 signal, because of its predominance and because it is not too rapidly fluctuating to be dealt with by normal methods of analysis. With the normal recorder speed, Type 4 defies analysis and we have not yet sufficient samples of high-speed recording to produce any reliable data.

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[1] K. Bullington, "Radio transmission beyond the horizon in the 40- to 4,000-Mc band," PROC. IRE, vol. 41, pp. 132–135; January, 1953.

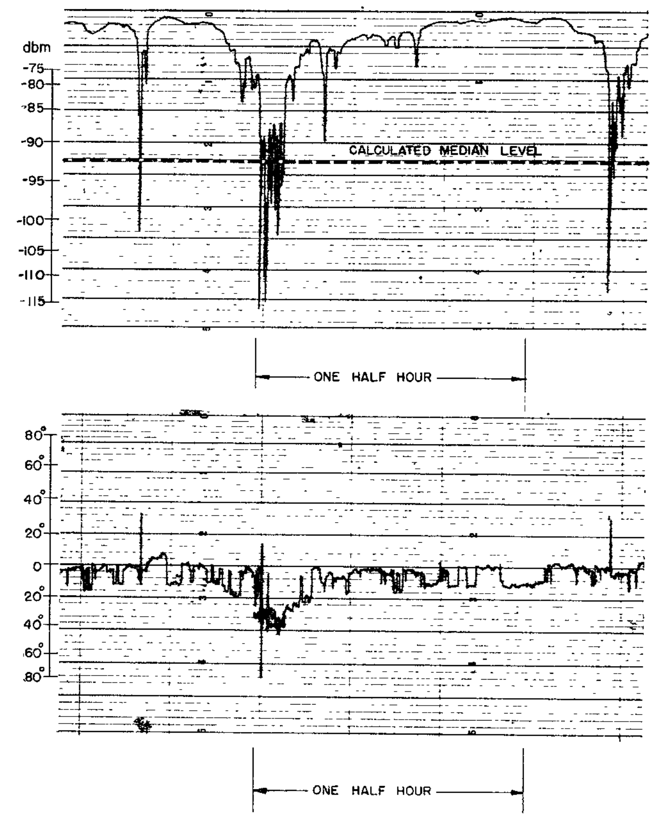

Fig. 5

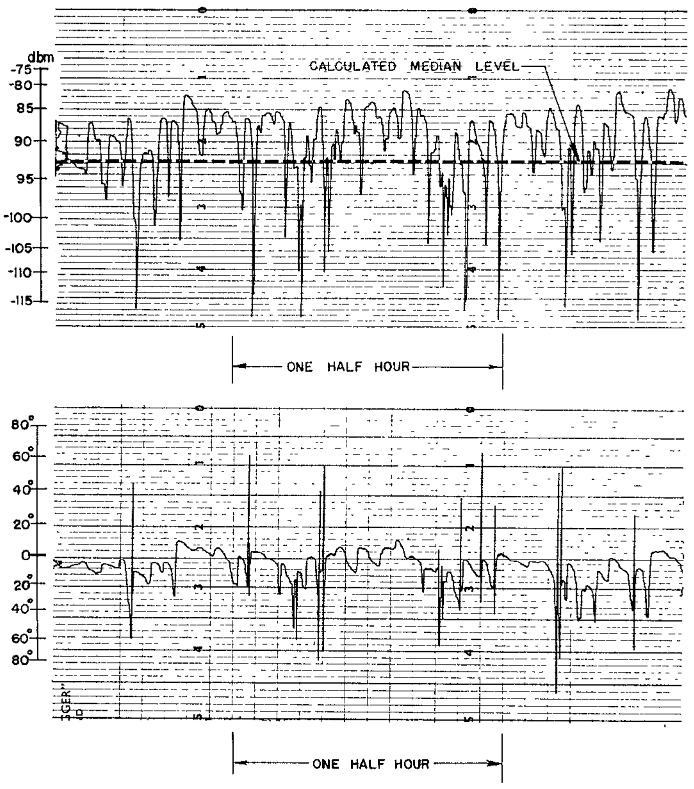

Fig. 6

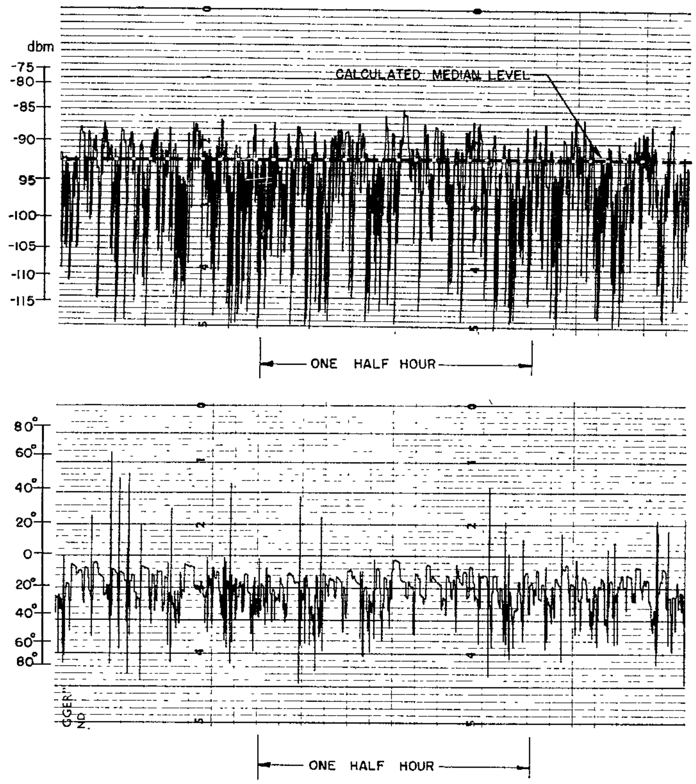

Fig. 7

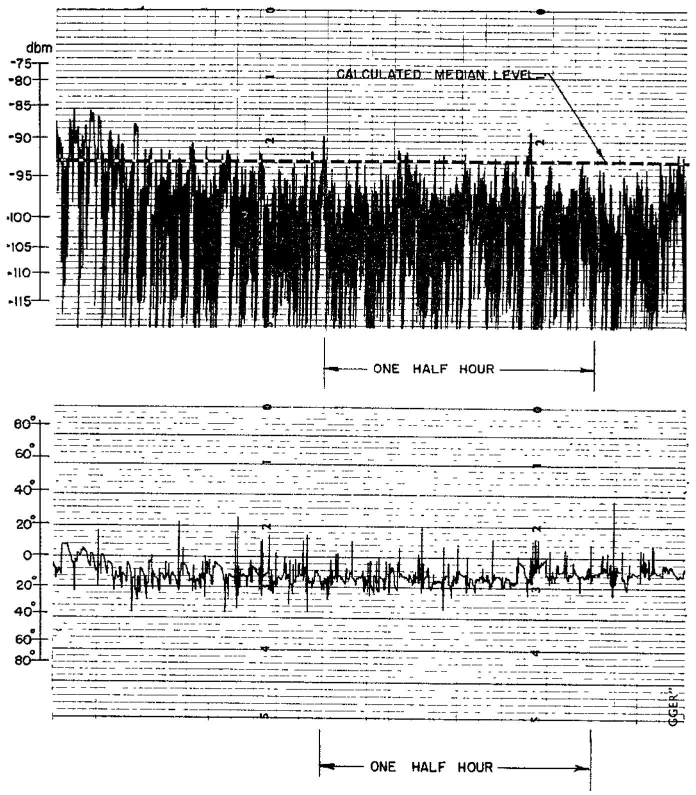

Fig. 8

Fig. 9 shows the distribution of the estimated hourly median signal (of all types) for the period for which results are available. As an indication of the variability of the transmission, we also show curves for a good week and a bad week.

It will be seen that the median value of the total distribution is within 2 db of that expected from the application of the curves published by Bullington. In view of the wide spread of the weekly median, however, this agreement should be treated with caution.

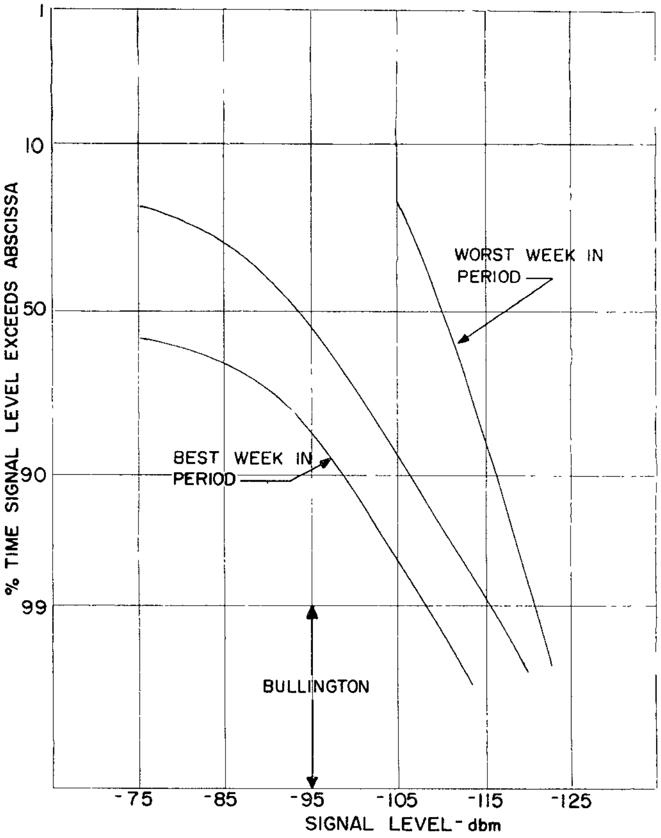

Fig. 9

An analysis has also been made of the distribution of instantaneous values of signal. Such a distribution is shown in Fig. 10. This is for a period of 8 hours and is fairly typical of Type 3 signals. This curve is probably in error at the low-signal and because of the difficulty of determining, from the somewhat-slow recording, the duration of short deep fades. However, median value agrees well with that of long term distribution.

No detailed analysis of the phase recording has yet been undertaken. As it will be seen from the example shown, the deviation from zero phase shift is not usually very large, except during deep fades. Unfortunately, the phase measuring circuit does not function correctly when the signal-to-noise ratio is low, and most of the apparent large deviations of phase can be neglected as false indications.

Similarly, there are no signs of differential fading of the two sidebands, but until the phase measurements are examined in greater detail it is not possible to predict what bandwidth may be transmitted: however, it would appear that it will be greater than the 250 kc explored in the present experiments.

Operational Possibilities

It is, of course, very early to attempt to draw any very definite conclusions from the small amount of data available at present, but nevertheless it is of interest to consider the possibilities of operational telephony over this route in the light of the test results. Various authorities have stated that path loss is likely to be at its greatest during the winter months, so that, in using

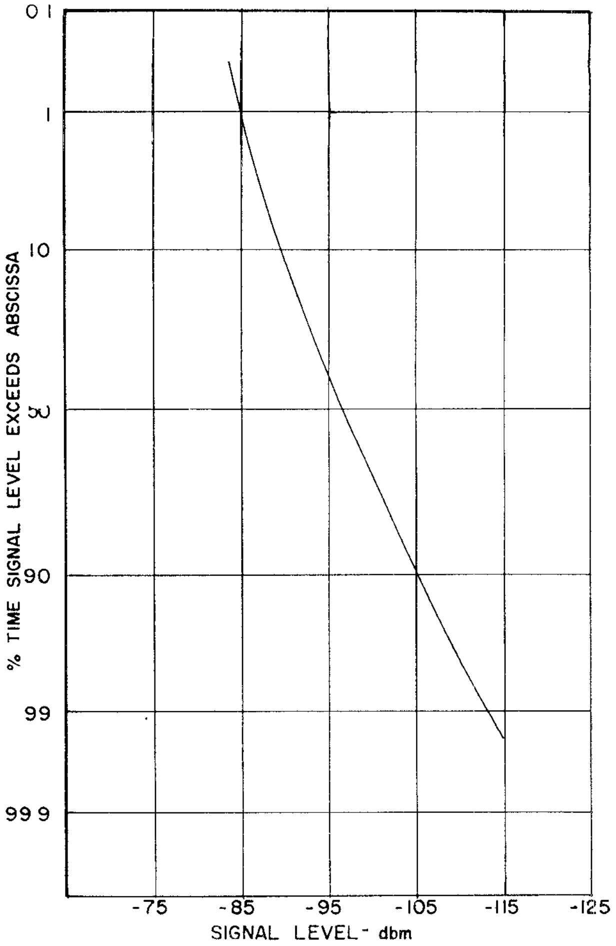

Fig. 10

results obtained during that period, our estimates of possible performance should not be over-optimistic.

It is immediately apparent that the present experimental link cannot be expected to provide any worthwhile communication facilities. Let us, therefore, assume that we have 10 kw at 1,000 mc but that we retain the 10-m dishes. Diversity reception may also be assumed, although it seems probable that the main advantage thereby obtained would be a reduction in the depth of short period fading, with little or no effect on the longer term median levels.

From the distribution curve of hourly median levels we find that the level exceeded 99 per cent of the time is −118 db. Increasing the transmitter power from 0.5 kw to 10 kw would give a gain of 13 db, and increasing the frequency to 1,000 mc would reduce the path loss by 10 db. Thus a total gain of 23 db might be expected. However, it is known that for small signals the full plane-wave gain of a large antenna may not be realized. We have no data on the magnitude of this effect but we will allow 5 db, thereby reducing the improvement to 18 db. Hence the hourly median signal level exceeded 99 per cent of the time would be −100 db. It is of interest to note that a similar performance could be obtained at 300 mc by using 10 kw and dishes of at least double the area of those now in service. This solution might be more attractive in Europe, owing to the relative scarcity of high power tubes operating in the 800–1,000-mc band.

We now assume that under these conditions the predetector signal-to-noise ratio is 5 db and that the receiver noise factor is 10 db, which implies that the IF bandwidth will be 1 mc. Let us now consider a 12-channel frequency-division multiplex system, with a baseband of 12–60 kc. Using straightforward frequency modulation such a system could be accommodated in the 1-mc band with a peak frequency deviation of about ±400 kc. Thus an fm advantage of 20 log 400/60, *i.e.*, 16 db can be expected, giving a signal-to-noise ratio of 21 db in the baseband. Holbrook and Dixon give the peak power of a 12-channel signal as 17.5 dbm at a point of zero relative level, but we will use a figure of 16 dbm. Hence, considering a 3-kc channel, the unweighted noise level will be $21-16+10 \log 1{,}000/6=27$ db below a milliwatt at a point of zero relative level. This corresponds to a noise meter reading of 46 dba at −9-db relative level. The over-all median path loss is 23 db less than the 99 per cent value, so that the yearly median noise level in a telephone channel would be 23 dba at −9-db relative level. This last figure may be pessimistic since under median signal conditions the full antenna gain may be realized, resulting in a 5-db improvement.

At first sight these performance figures seem quite practical, but it must be remembered that they apply to a link of only 240 miles, and that for 1 per cent of the hours of a year, *i.e.*, 88 hours, the performance will be worse than 46 dba. It may be very much worse in fact, because under the 99 per cent conditions the pre-detector signal-to-noise ratio is must about at the threshold value and any further deterioration will result in a disproportionate increase in channel noise level. Diversity reception should reduce fading range below 99 per cent signal level; there is little doubt complete outage will sometimes occur. Remember also that no allowance for intermodulation distortion has been made.

Admittedly, the performance calculation just carried out is based on insufficient data and a certain amount of estimate, but it is thought that the discrepancy between these performance figures and those expected of a link in a main toll route is too great to permit the use of this type of transmission at present, except under most difficult circumstances, where physical or financial obstacles preclude the use of more conventional means of transmission. There is, however, a strong probability that future improvements in technique will modify this rather pessimistic view, and we are therefore continuing the tests. It is hoped to add diversity reception to determine what advantages can be gained, and, in order to save time and labor, an automatic signal-strength analyzer will be incorporated in the equipment.

ACKNOWLEDGMENT

Several parties have collaborated in these tests. The equipment design was suggested by Standard Telecommunication Laboratories of London, England; the detailed design and manufacture were carried out by Fabbrica Apparecchiature Per Comunicazioni Elettriche, of Milan, Italy. The sites were provided by the Italian and Spanish Administrations, who were also responsible for power supplies and other facilities. Installation was carried out by F.A.C.E., with the assistance of Società Italiana Reti Telefoniche Interurbane, of Milan, and Standard Electrica, of Madrid, Spain. The Transmitter site is staffed by Standard Electrica, of Madrid, while the receiver site is staffed by S.I.R.T.I., who are also analyzing the records obtained. The coordination of the tests is the responsibility of Standard Telecommunication Laboratories Ltd., to whom we are indebted for much of the information in this paper.

Data on the Temperature Dependence of X-Band Fluorescent Lamp Noise Sources*

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Summary—**This paper is concerned primarily with the performance of fluorescent lamps as microwave noise sources at 9,000 mc. In particular, it deals with the temperature dependence of the excess noise ratio of an 8-watt lamp running at a lamp current of 150 ma in a 10° *E*-plane holder. It was found that 1) the bulb temperature is much higher than that with a lamp current of 75 ma encountered in the 90° *H*-plane circuit investigated previously at 4,000 mc, hence the temperature coefficient of excess noise versus waveguide temperature obtained in the 4,000 mc circuit does not apply, 2) anomalous and unreproducible inversions in the temperature coefficient at these higher bulb temperatures have been observed, 3) these anomalies can be avoided by operating the bulb at lower temperatures, 40°C to 50°C, where the lamps appear to be just as uniform and stable and probably just as noisy as they are at 4,000 mc.**

During the last five years, fluorescent lamps have been used more and more as microwave noise sources for measuring the noise figures of microwave receivers. When these lamps are operated at or near their normal bulb temperature, 40°C, their available microwave noise power is stable with respect

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