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An Experimental Investigation of Signal Strength in the Area Around a Transmitter's Antipode

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Observations were made of signal strength as a function of distance from the antipode of an HF transmitter. A 15.9 Mc/s, 5 kw beacon transmitter was located at Perth, Western Australia, whose antipode is within 90 km of St. George, Bermuda. In December of 1961, an airborne receiving system was used to record signal strength to a range of 1600 km in each of the four cardinal compass directions from Bermuda. The airborne measurements were normalized with similar measurements recorded at a fixed receiving site at Bermuda.

An empirical fifth degree equation is derived which fits the data in a least square sense. Although considerable variation exists in the results obtained on the four flights, the area of antipodal reception was found to be approximately 500 km in radius with a minimum of signal strength at a radius of 1050 km. Some evidence was obtained which indicates that these results vary as a function of local time. The measured size of the antipodal area agrees with that deduced by previous investigations.

1. Introduction

Recently several studies have been undertaken to investigate the general characteristics of antipodal propagation [Furutsu, 1951; Harnischmacher, 1960; Gerson, Nardozza, and Hengen, 1962]. These studies have utilized stationary transmitter and receiver sites located at approximately antipodal points on the earth's surface. In addition to the main receiver site, a limited number of other receiver sites have been used in at least two of these experiments [Furutsu, 1951; Gerson, Nardozza, and Hengen, 1962]. With these additional receiver sites it was possible to compare normal long distance propagation with antipodal propagation. Information gathered from these studies indicate that reception at the antipode of the transmitter is considerably better than is normal for long distance propagation.

Little is known about the size of the antipodal area in which enhanced reception may be expected. A study was therefore undertaken to measure the variation in signal strength as a function of distance from the antipode of the transmitter. This study was part of an antipodal experiment which was being conducted between Perth, Western Australia, and St. George, Bermuda. The beacon transmitter located at Perth was operated continuously from December 1959 through December 1961. Continuous signal strength recordings were made at the receiving site at Bermuda.

In December of 1961, an aircraft was equipped with a receiving and recording system identical to that at the ground station at Bermuda. Utilizing the beacon transmissions from Perth, continuous recordings of the signal strength were made in the aircraft as it flew approximately 1600 km in each of the four cardinal compass directions from Bermuda. By comparing the data thus obtained on the aircraft with the data recorded at Bermuda, it was possible to obtain plots of signal strength as a function of the distance from the antipode.

2. Equipment and Location Details

The beacon transmitter for this experiment was located at Perth, Western Australia and operated on a frequency of 15.9 Mc/s with a power of 5 kw. The antenna was an omnidirectional vertically polarized folded monopole. The transmitting cycle consisted of an hourly pattern divided in the following manner: a slowly keyed Morse identification code during the first 5 min of the hour followed by 25 min of steady unmodulated carrier. There was no transmission from 30 to 35 min past the hour followed by another 25 min of steady carrier.

The location of the ground receiver site was St. George, Bermuda which is located about 90 km northwest of the exact geographic antipode of Perth. The Bermuda receiving antenna was a quarter wavelength vertical. The receiver used was a military R390A and was operated with an IF bandwidth of 1 kc/s. Signal strength records were obtained by integrating and amplifying the diode load output of the receiver and recording this level on a milliammeter. This recorder provided a permanent strip chart record of signal strength. The time constant of the integrating and recording system was approximately 10 sec. Calibration of the receiving system was accomplished by feeding the output of a radiofrequency signal generator into the antenna terminals of the receiver. The resultant percent deflection was annotated on the strip chart.

The aircraft receiving and recording equipment was installed in a DC–4 aircraft. This system was

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identical to the ground system with the exception of the antenna. The aircraft antenna consisted of a horizontal long wire with an associated matching network which was adjusted to maintain minimum VSWR at 15.9 Mc/s. Calibration was performed in the same manner in the aircraft as on the ground. The accuracy of the calibration on the aircraft was somewhat limited by the fact that the equipment had a warm up time of less than 1 hr before each flight. Also, the vibration of the aircraft increased the drift in the signal generator which made calibration difficult at times.

3. Data Collection

Since the length of the time the aircraft could stay airborne was limited, it was necessary to schedule the flight times to coincide with the times of most probable antipodal reception. The data which were collected during October and November 1961 at Bermuda showed that the antipodal signal would most probably be received during the period from 1100 through 1400 GMT. At approximately 1400 GMT a strong interfering station usually began transmitting on the same frequency as the beacon signal. The strength of the interfering signal was usually sufficient to overpower the wanted beacon signal. This limitation of about 3 hr per day of data collection at first appeared to be a rather serious handicap. In actuality however, it turned out to be advantageous in that it made it necessary to record the signal strength measurements during essentially the same time of day on succeeding days.

The distance covered in both the north and south legs was greater than could be flown during a 3 hr period. Therefore the data collection for each of these legs was broken into two phases. On the outbound southern flight from Bermuda, data was collected for the first 800 km, at which time the presence of the interfering signal terminated collection, although the flight continued to Puerto Rico. The next day, during the return flight to Bermuda, data collection began at a point 1600 km south of Bermuda and continued to approximately the 800 km point. By combining the data obtained on these two successive flights, signal strength measurements for the entire south leg were obtained. A similar plan of attack was used to obtain the data for the north leg.

The east leg was flown on a day when the interfering station was not scheduled to transmit. Signal strength measurements were obtained during the entire outbound and inbound portions of the leg. The range for the east leg was limited to 1500 km by the range of the aircraft.

On the flight from Charleston to Bermuda no data were obtained due to equipment failures. Therefore all data for this leg were obtained on the return flight from Bermuda to Charleston. On the particular day of the flight the strength of the interfering signal was somewhat below that of the antipodal signal at both the aircraft and Bermuda which enabled data collection during the greater portion of the flight. It should be noted that signal measurements made during the last portion of this flight, along with those made during the inbound portion of the eastern leg, were the only ones made outside the period of 1100 GMT thru 1400 GMT. The time of each flight is given in table 1.

Table 1

Date	Radial distance covered	Time of flights in GMT	Leg
	Kilometers		
13 Dec 61	50–817	1055–1325	South
14 Dec 61	1711–869	1100–1340	South
15 Dec 61	50–914	1045–1340	North
16 Dec 61	1813–876	1125–1355	North
17 Dec 61	50–1493	1120–1540	East (out)
17 Dec 61	1493–50	1540–2110	East (in)
19 Dec 61	58–1463	1150–1700	West

An experimentally obtained pattern of the aircraft antenna compared satisfactorily with published patterns [Moore, 1953; Ohio State Antenna Laboratory, 1953]. Since the recorded signal strength was dependent upon the relative azimuth of arrival of the signal, the following method was used to obtain an hourly correction factor. Once each hour the aircraft was flown in a rectangular pattern as shown in figure 5. If the signal strength recorded on any of the four legs of the rectangle was greater than the level recorded either immediately before or after the pattern, the difference was a correction factor which was later added to the recorded data. This flight pattern does not completely eliminate the antenna's pattern effect. No compensation is made for vertical directivity.

All data on the ground were automatically recorded on strip charts and the equipment was left on continuously. The system was calibrated and held this calibration for many days without appreciable change.

4. Data Reduction

The continuous signal strength records obtained at Bermuda and on the aircraft were quantized into 5 min segments. The hourly aircraft antenna correction factor was then added to the aircraft signal strength. The quantized data points along with the associated radial distance from Bermuda were then transferred to punched cards. Using a digital computer, the signal strength data points for each leg were fitted to a fifth degree polynomial which was calculated by a least squared method.

The signal strength received at the ground station varied as a function of time of day over a range of from −110 db below a milliwatt (DBM) to −90 DBM. In the data obtained in the aircraft, the variations caused by the change in location were superimposed on the time variations. By taking the ratio of the signal strength as received on the aircraft to the signal strength received at the same time at the antipode, a ratio was obtained which is a measure of the variation in the signal strength as a function of the distance from the antipode. The time variation is thus minimized.

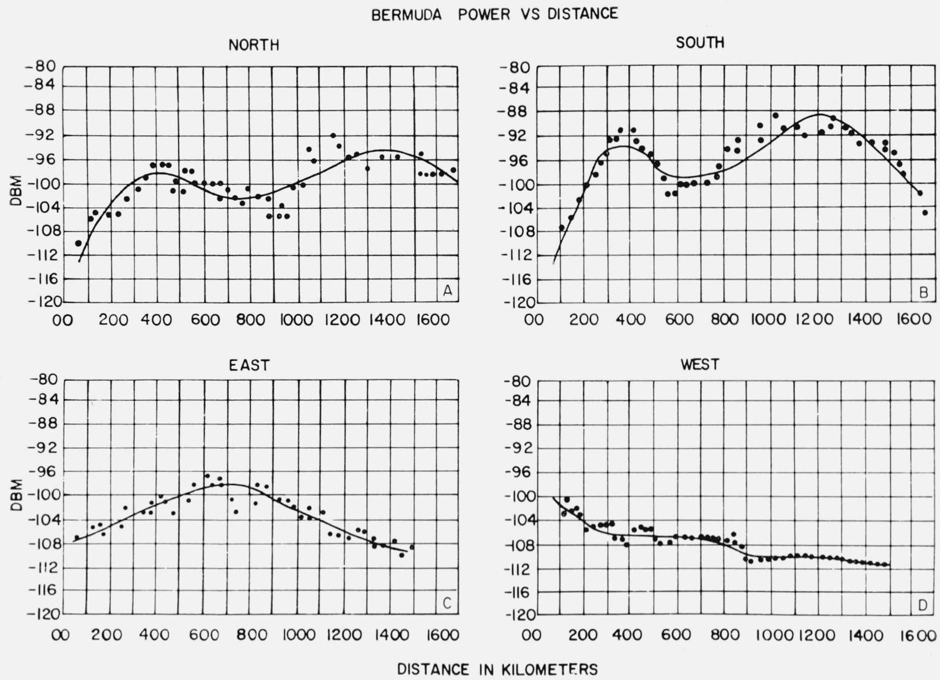

FIGURE 1. *Bermuda signal power in db versus the aircraft radius from Bermuda in km.*

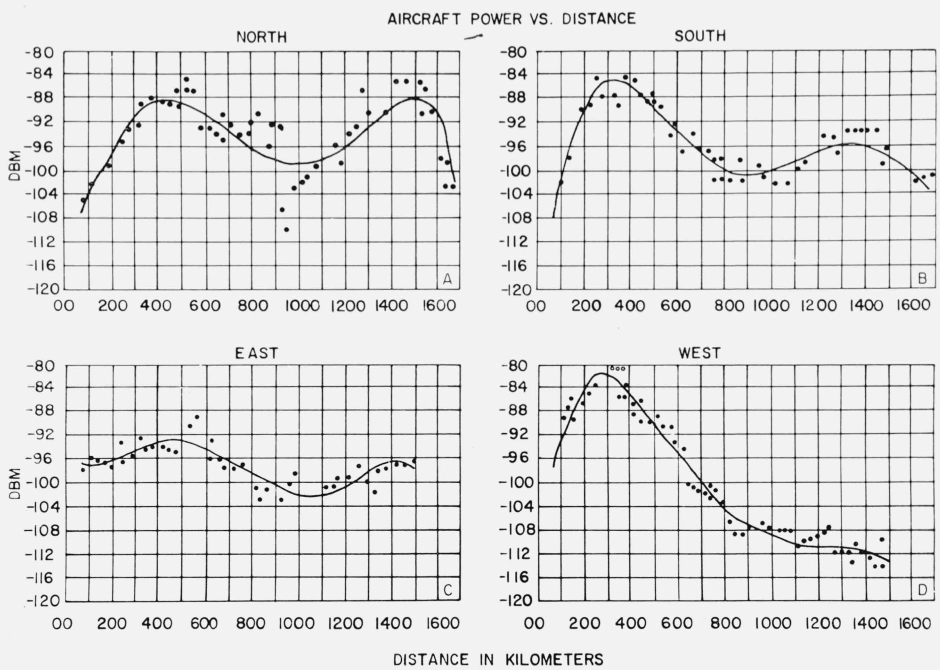

FIGURE 2. *Aircraft signal power in db versus the aircraft radius from Bermuda in km.*

Path loss calculations utilizing NBS prediction procedures [Lucas and Haydon, 1962] were made for the shortest great circle path from Perth to

(A) Bermuda (bearing 321° receiver to transmitter).

(B) Five representative points along each of the four aircraft flight paths.

The diurnal curves of Bermuda signal strength thus predicted agree very closely with the monthly median values for the period 1100 GMT through 1400 GMT. The predictions are significantly different from the measured values for the rest of the day. The predicted signal strengths for the various aircraft locations were extracted for the actual time the aircraft was at the location. These data points were processed, with the corresponding values predicted for Bermuda, in the manner described above for the measured values.

5. Discussion of Results

An examination of the power ratio versus distance curves, figure 3A, shows remarkable similarity in the north, east, and south legs. They indicate an annular area of 500 km radius in which the signal strength was relatively constant; followed by a decrease in signal strength which reached a minimum at a range of about 1050 km. The west leg shows a large increase at a range of 300 km. This hump was produced by the fact that the Bermuda signal was lower than normal on this day while the aircraft signal was stronger than received on the other flights at this radius. The combination of these two facts results in the high power ratio. This indicates that the area of enhanced reception was displaced from the geographical antipode on the day of this flight. The composite power ratio curve, figure 3B, was obtained by combining all the data points and utilizing the same curve fitting process previously discussed for the individual legs. Since the data obtained on the north, east, and south legs are self-consistent, it is felt that this composite curve best represents the results obtained on this experiment.

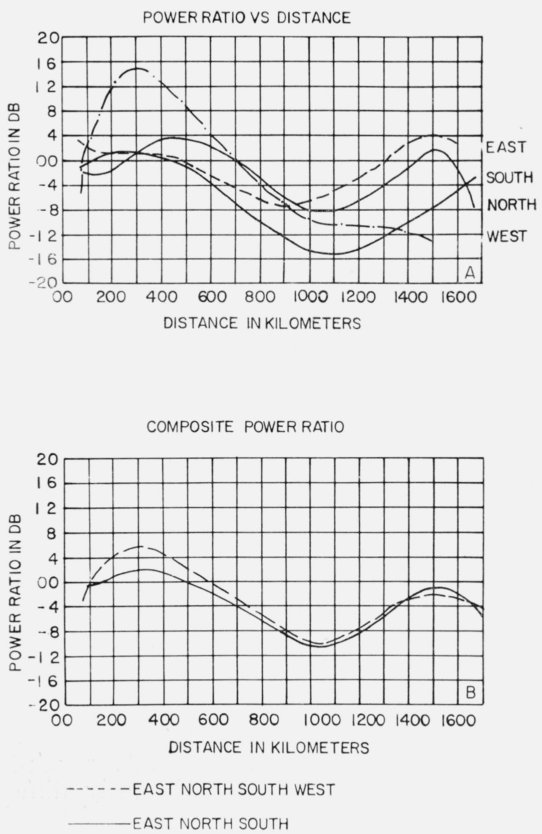

FIGURE 3. *(A) The power ratio curves obtained by subtracting the curves shown in figure 1 from their respective curves shown in figure 2; (B) the power ratio curves for the combined data of respective legs. These curves were obtained by the same process as used in figure 3A.*

The fifth degree equation which describes the composite north, east, and south power ratio curve is given in (1).

$$DB = +0.477 - 2.07R + 1.6R^2 - 0.37R^3 + 0.0299R^4 - 0.786 \times 10^{-3}R^5 \quad (1)$$

where DB = signal strength in decibels above the signal strength at the antipode.

R = radius from antipode in km.

Figure 4 presents the data collected on the east

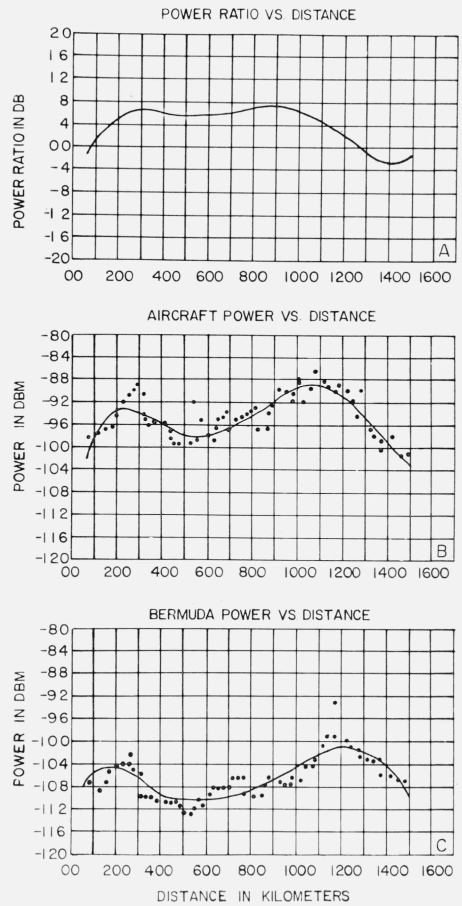

FIGURE 4. *Data for east inbound flight.*

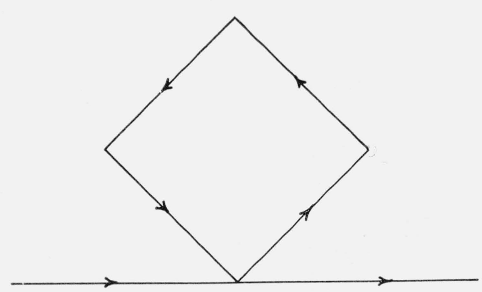

FIGURE 5. *Aircraft flight pattern to minimize aircraft antenna effects.*

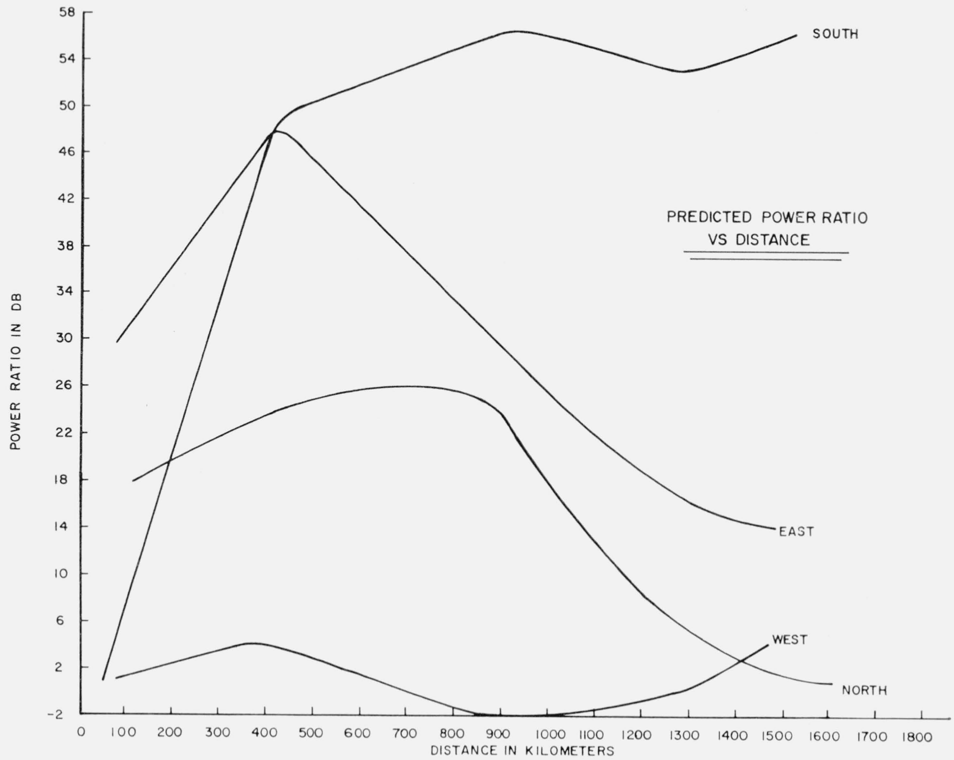

FIGURE 6. *Power ratio curves obtained from predicted signal strengths.*

inbound flight. Recall that these data were taken from 2 to 8 hrs later than any other data in this experiment. It may be deduced from the appearance of the power ratio curve, figure 4A, that the area of antipodal reception has shifted east by 400 km. Since only one day's data were taken at this time, it is also possible that the area of antipodal reception is still centered about the antipode and has become enlarged. Further research is required to determine the nature of this change.

The power ratio curves, figure 6, which resulted from the predicted values do not exhibit the self consistency which is evident in the measured data. The fact that each point used for the aircraft signal calculation is based on a different great circle path may mask the variation measured.

The conclusion that the area of antipodal reception has a 500 km radius is in very close agreement with the 550 km radius deduced by [Whale 1956]. H. A. Whales' conclusions result from measurements of the azimuth and elevation angle of arrival of an antipodal 14.9 Mc/s signal. This independent verification of the results is significant due to the limited nature of the data collected in this experiment.

6. Conclusions

The results of this experiment indicate that the effective antipodal area in which enhanced high frequency signal reception can be expected to occur extends to approximately a radius of 500 km from the geographic antipode. At distances beyond 500 km the signal strength decreases until it reaches a minimum at about 1000 km. This minimum signal strength was measured to be about 10 db below that received at the same time at the antipode. Additional experimental and theoretical work is necessary to obtain a more complete knowledge on this subject.

7. References

Furutsu, K. (1951), Calculation of field intensity about the antipode of the transmitting station, Report of Ionosphere Research in Japan, **V,** No. 4, 159–165.

Gerson, Nardozza, and Hengen (1962), High-frequency propagation over long paths, J. Geophys. Res. **67,** No. 10, 4080–4085.

Harnischmacher, E. (1960), A calculation method of ionospheric propagation conditions for very high and antipode distance. Electromagnetic wave propagation, Ed. M. Desirant and J. L. Michiels (Academic Press Inc., London, S. W. 1).

Lucas, D. L. and Haydon, G. W. (1962), Predicting the performance of band 7 communication systems using electronic computers (private communications).

Moore, E. J. (1953), Performance specification and evaluation of liaison antenna, Final Report SRI Project 606 Task III, Wright Air Development Center, Contract AF33(616)–83.

Ohio State Antenna Laboratory (1953), Pattern measurements of long wire antenna mounted on C–54 aircraft model, Dept. of Electrical Engineering, Ohio State University, Contract AF18(600)–160.

Whale, H. A. (1956), An estimate of the size of the antipodal area in short wave radio propagation, J. Atmospheric Terrest. Phys. **9,** No. 2/3, 159–161.

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