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OVER-WATER TROPOSPHERIC SCATTER PROPAGATION INVESTIGATIONS SUMMER CONDITIONS [U]

[~~CONFIDENTIAL TITLE~~]

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Communication Branch
Radio Division

August 9, ~~1955~~ 1956

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ABSTRACT

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During July 1955, studies of tropospheric forward scatter propagation over an all-seawater path were conducted. The receiving installation for these studies was aboard the USS ACHERNAR (AKA-53). It consisted of a steerable paraboloid antenna 17 feet in diameter, a suitable high-sensitivity receiver, and a signal level recorder. For the first two weeks of operation, transmissions on 385.5 Mc, originating at the Lincoln Laboratory field station at Round Hill, Mass., were employed. The transmissions were from a 10-kw transmitter feeding a 28-foot paraboloid antenna. The signal levels of these transmissions were recorded on the ship while traveling away from and toward the transmitting site at Round Hill on a bearing of 199 degrees true. Because of operating time limitations, the maximum range was confined to 400 nautical miles.

During the second two-week period of operation, transmissions on 220 Mc, originating at the Air Force Cambridge Research Center field station near Scituate, Mass., were used. These were pulse transmissions (PRF = 60) of approximately 0.3 Mw peak power into a 28-db gain "billboard" type of antenna. The ship traversed a course on a bearing of 084 degrees true from the transmitting site, following a procedure similar to that of the first two-week period.

For what appeared to be true scatter propagation conditions, the average signal level at the antenna terminals of the 385.5-Mc transmissions was approximately 75 db below one milliwatt at 200 nautical miles. For the same conditions, the average peak signal level of the 220-Mc transmission was 50 db below one milliwatt. The scatter signals had an average attenuation of about 0.18 db per nautical mile for both transmissions and the received signal level followed the Rayleigh probability distribution law. Periodic voice and music modulation tests on the Round Hill transmissions were of excellent quality out to distances of 300 miles. At the greater distances, the quality remained good, but short-period outages occurred during deep fades in the signal.

PROBLEM STATUS

This is an interim report on one phase of this problem. Work is continuing on this and other phases.

AUTHORIZATION

NRL Problem R01-18
Project No. NR 681-180

Manuscript submitted June 27, 1956

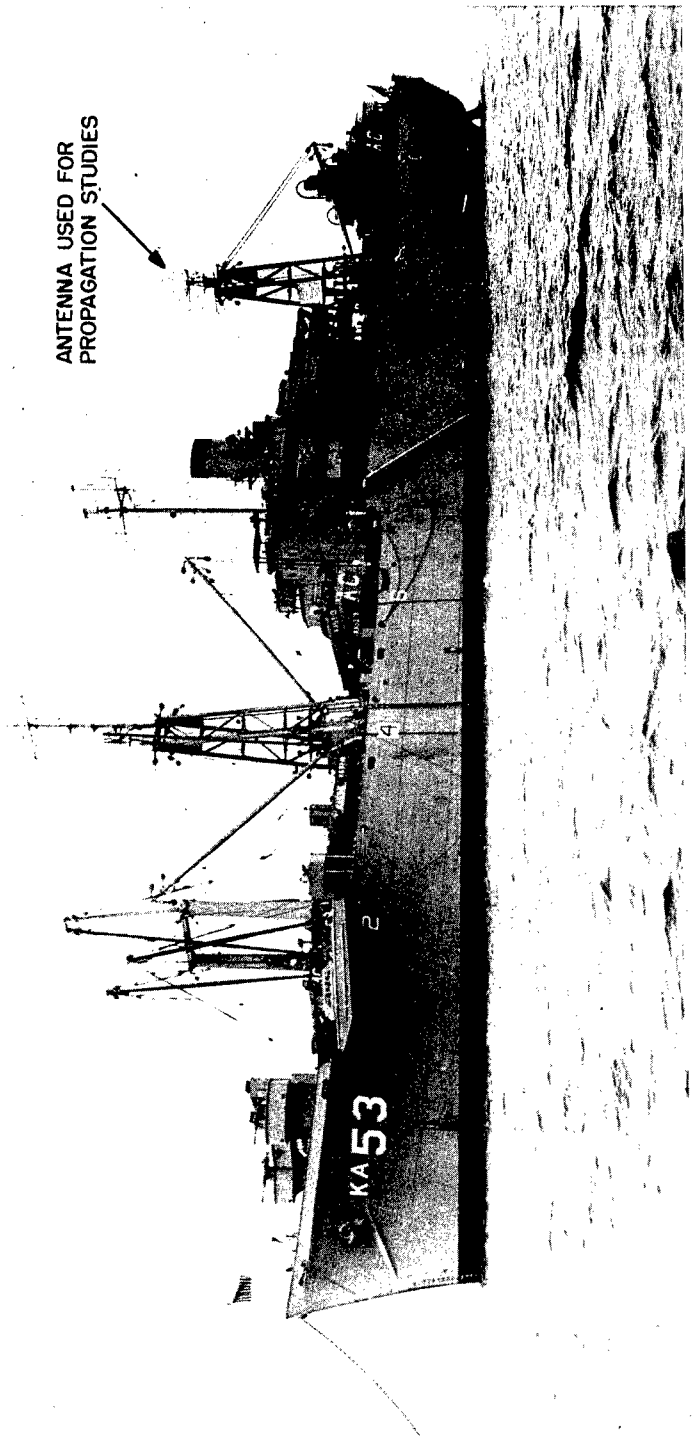

Fig. 1 - USS ACHERNAR (AKA-53) as equipped for propagation studies

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OVER-WATER TROPOSPHERIC SCATTER PROPAGATION INVESTIGATIONS SUMMER CONDITIONS
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INTRODUCTION

Considerable success has been obtained and reported by various workers using vhf-uhf tropospheric forward scatter transmission. Most of the available scientific and engineering information on this mode of propagation, however, has been obtained between fixed points with all over-land, or mixed over-land and over-water paths. The Navy has an interest in determining whether this mode of propagation can be successfully utilized for communication and data transmission between naval vessels at ranges out to 150 or 200 nautical miles.*

The Naval Research Laboratory[1] conducted some preliminary investigations in the Chesapeake Bay area, using frequencies in the neighborhood of 200 Mc during 1953 and 1954. The results and experience obtained from these limited investigations indicated the desirability of more extensive work. Plans were therefore formulated for experiments using a naval vessel as the receiving end of an all over-water transmission link, the originating point being located on the Atlantic coast.

Suitable transmitting facilities were located at the Round Hill Point (Massachusetts) site of the Lincoln Laboratory and the Scituate (Massachusetts) site of the Air Force Cambridge Research Center. The Round Hill transmitter operated on cw at a frequency of 385.5 Mc and the Scituate transmitter was pulsed at a repetition rate of 60 per second on a frequency of 220 Mc. Both organizations agreed to cooperate with NRL in the experiments. The USS ACHERNAR (AKA-53) was assigned to the project for a period of approximately one month (July 1955). During the first two-week period at sea, the ship was used for measurements on the Round Hill transmission; during the second two-week period the Scituate transmissions were utilized. Brief progress reports [2, 3] were issued immediately following the collection of data.

SHIPBOARD INSTALLATION

The receiving antenna aboard the USS ACHERNAR was a modified Model SK-3 radar antenna with its accompanying pedestal mount and controls. The antenna was mounted on the after quadrapost (Fig. 1) with its center 95 feet above the water. The antenna beam was unobstructed by the ship's superstructure except when directed within a small sector (about 10 degrees) over the ship's bow. During the recording of signal levels, the ship was always so oriented with respect to the transmitting site that the receiving antenna was directed either over the bow or over the stern. When directed over the bow, the ship's superstructure caused a reduction in the indicated signal level of 2 db at 385.5 Mc and 5 db at 220 Mc. These losses were taken into account in determining the true signal level. Because of the difference in frequency of the two transmitters used, the dipole elements of the receiving antenna were changed at the end of the two-week period of Round Hill transmissions. As stated in Table 1, the receiving antenna gain was 19 db at 385.5 Mc and 15 db at 220 Mc. The antenna was coupled to the receiving equipment through

*Nautical miles will be used throughout this report.

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approximately 90 feet of low-loss (Styraflex) transmission line. A more detailed discussion of the antenna and transmission line appears in Appendix A.

TABLE 1
System Parameters

ROUND HILL:			
	Frequency	385.5	Mc
	Transmitter Power	10	kw
	Transmitting Antenna Gain	26	db
SCITUATE:			
	Frequency	220	Mc
	Transmitter Power	0.3	Mw
	Transmitting Antenna Gain	28	db
USS ACHERNAR:			
	385.5-Mc Receiving Antenna Gain	19	db
	220-Mc Receiving Antenna Gain	15	db
	Transmission Line Loss Approx.	1	db

The Round Hill transmissions were received and recorded on two separate recording installations—one supplied by Lincoln Laboratory and the other by NRL (Figs. 2 and 3). The two equipments were operated in parallel except at great distances when very weak signals were obtained. At these times, the Lincoln equipment was used alone to avoid the additional loss. The narrow-band (16-kc) Lincoln equipment had a greater sensitivity and therefore permitted signal recording out to a greater range than the wider-band (200-kc) NRL equipment.

The Lincoln equipment consisted of a very sensitive receiver with dc amplifiers driving an Esterline-Angus and an Edin strip recorder. An input to the receiver of -133 dbm (26 db below one microvolt, 50-ohm input) could be detected on the recorder chart. The input to the Esterline-Angus recorder had a 12-second time constant and a chart speed of three inches per hour. The speed of the Edin recorder together with the associated circuit time constants enabled fading rates of 60 per second or more to be observed. The Lincoln receiver was also used to receive the FM voice and music transmissions which were sent approximately once every four hours and recorded on magnetic tape aboard ship.

The NRL receiving equipment was basically the same for the entire four weeks of the investigation. A TS-587/U Noise and Field Intensity Meter was employed in conjunction with a dc amplifier which drove an Esterline-Angus recorder, a Brush strip recorder, and a signal level time totalizer. The TS-587/U was altered so that while recording the cw transmissions from Round Hill, the circuit time constants were approximately two milliseconds charge and discharge. An input voltage to the receiver of -113 dbm could be observed on the recorder charts. During the pulsed transmissions from Scituate, the time constants were changed to approximately two milliseconds charge and 600 milliseconds discharge. Also, during this phase of the investigation, a preamplifier, supplied by the Cambridge Research Center, was used ahead of the TS-587/U to increase the sensitivity. An input to the preamplifier of -127 dbm was then observable on the recorder charts. The Esterline-Angus recorder used with the NRL equipment was operated at a chart speed of three fourths of an inch per minute. The Brush recorder was used only during the cw portion of the investigation. The time totalizer (discussed in more detail in Appendix B) consisted of ten signal-level channels, each of which was adjusted to trigger at a signal

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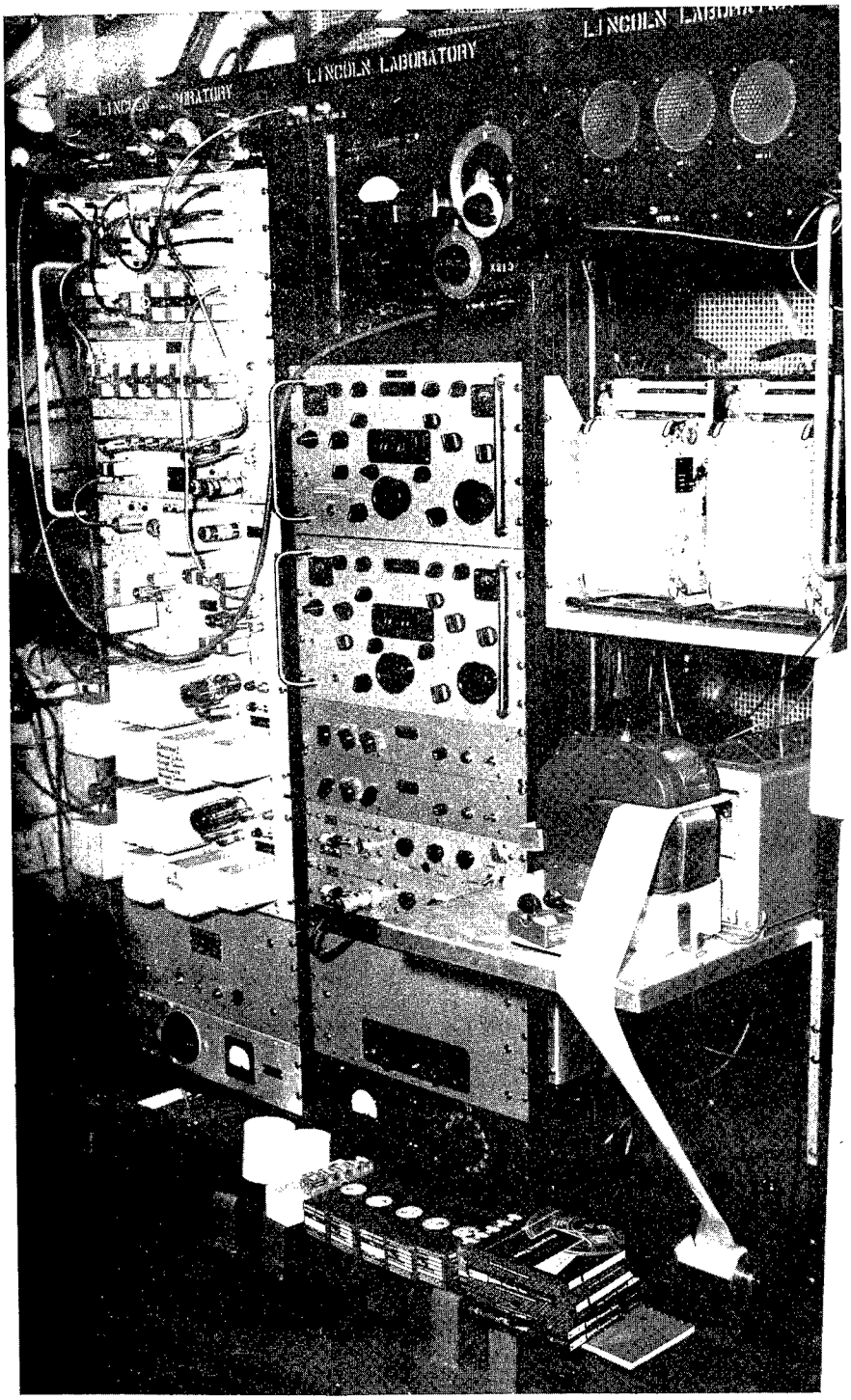

Fig. 2 - Lincoln Laboratory equipment installed aboard the USS ACHERNAR for recording signal levels on 385.5 Mc

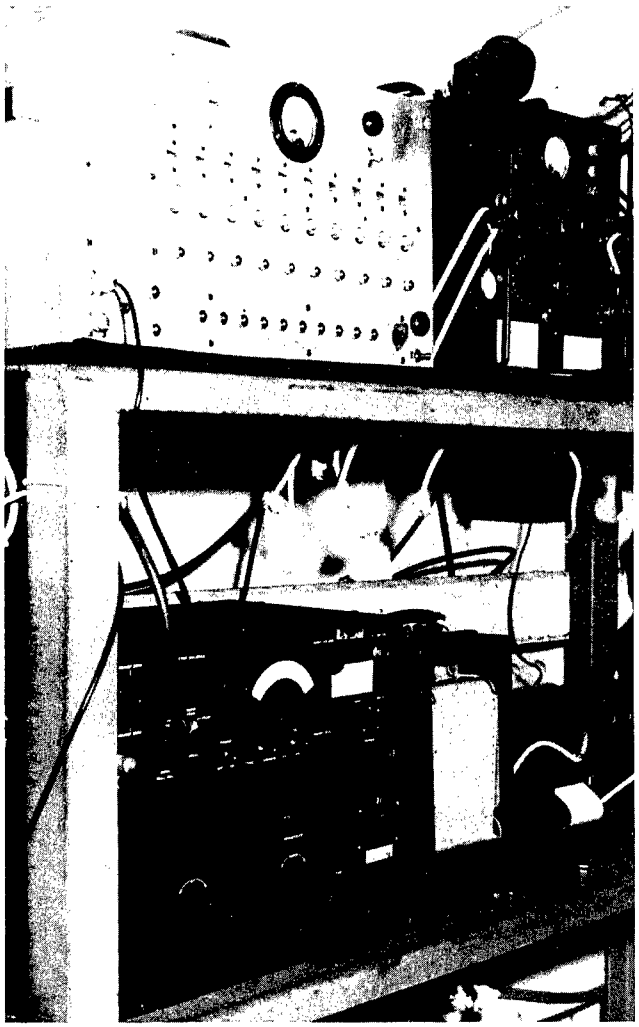

Fig. 3 - NRL equipment installed aboard the USS ACHERNAR for signal level recording on 385.5 and 220 Mc

level 4 db higher than the preceding channel. The clock associated with each channel recorded the total time that the trigger level of that channel was exceeded. Median values and fading ranges were thus obtained more rapidly than from the recorder charts.

TRANSMITTING FACILITIES

The transmitting facilities of the Lincoln Laboratory were located at Round Hill Point, on the southern coast of Massachusetts. A 10-kw transmitter, capable of being frequency modulated, was connected through a duplexer to a 28-foot paraboloid antenna having a gain of 26 db and a beamwidth of 6 degrees. The effective radiated power was approximately 4 Mw. The antenna was mounted 95 feet above mean sea level and normally directed on a bearing of 199 degrees true for these experiments. The 6-degree beam had an unobstructed over-water path.

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The Scituate transmitter produced 50-μsec pulses at a rate of 60 per second and a peak power of 0.3 Mw. It was connected to a "billboard" type antenna, having a gain of 28 db, a horizontal beamwidth of 4 degrees, a vertical beamwidth of 8 degrees, and a height of 80 feet above mean sea level. The effective peak radiated power was approximately 189 Mw. The beam was directed on a bearing of 084 degrees true for these experiments.

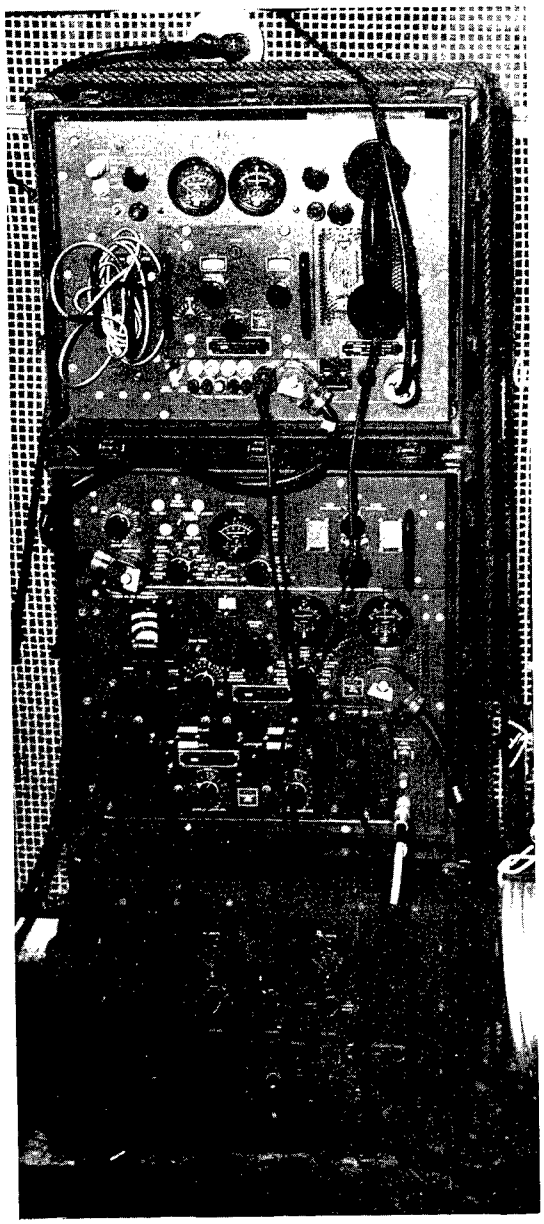

Fig. 4 - AN/TRC-24 transmitter installed aboard the USS ACHERNAR

All transmissions were horizontally polarized. The gains of all antennas are given relative to a half-wave dipole and the beamwidths are with reference to the 3-db points.

An AN/TRC-24 FM transmitter (Fig. 4), furnished by Lincoln Laboratory, was also installed aboard ship for certain two-way voice communication trials. This transmitter operated on a frequency of 399.5 Mc and had an output power of approximately 80 watts. When used, it was connected into the modified SK-3 antenna through a duplexer.

A regular high-frequency communication transmitter was also available at both shore-base sites for communication with the ship.

OPERATIONAL PROCEDURE

The USS ACHERNAR left Norfolk, Virginia, on the morning of 5 July 1955 and proceeded directly toward Round Hill. At a point approximately 12 miles from the transmitting site, and at a bearing of 199 degrees true, horizontal antenna patterns were checked. The horizontal pattern of the receiving antenna was recorded and the magnitude of the effect of the ship's superstructure on the received signal level was determined. The transmitting antenna was rotated back and forth through the 199-degree bearing and then fixed at that bearing. The ship then made several runs across the beam to determine that the midpoint was at 199 degrees true. During the balance of the two-week period, the ship made several runs out and back on this bearing (Table 2). The ship returned to Norfolk for the weekend of 16-17 July so that the dipole elements of the receiving antenna could be changed to the frequency to be used during the next phase of the investigation. Figure 5, a map of the east coast area, shows the relative position of the transmission beams employed.

TABLE 2
Ship Operation Schedule

Transmitter Location	Date/Time (July 1955/GMT)		Distance (nautical miles)		Bearing from Transmitter (degrees true)
	From	To	From	To	
Round Hill	07/0100	07/1900	65	297	199
	07/1900	08/1300	297	63	199
	11/1600	12/2100	27	400	199
	12/2100	14/0300	400	12	199
	14/0500	15/0100	30	208	216
Scituate	20/0400	21/0800	38	400	084
	21/0800	22/2200	400	45	084
	25/1600	26/1600	25	222	084
	26/1600	27/0200	222	100	084
	27/0200	27/1300	100	242	084
	27/1300	28/0200	242	80	084

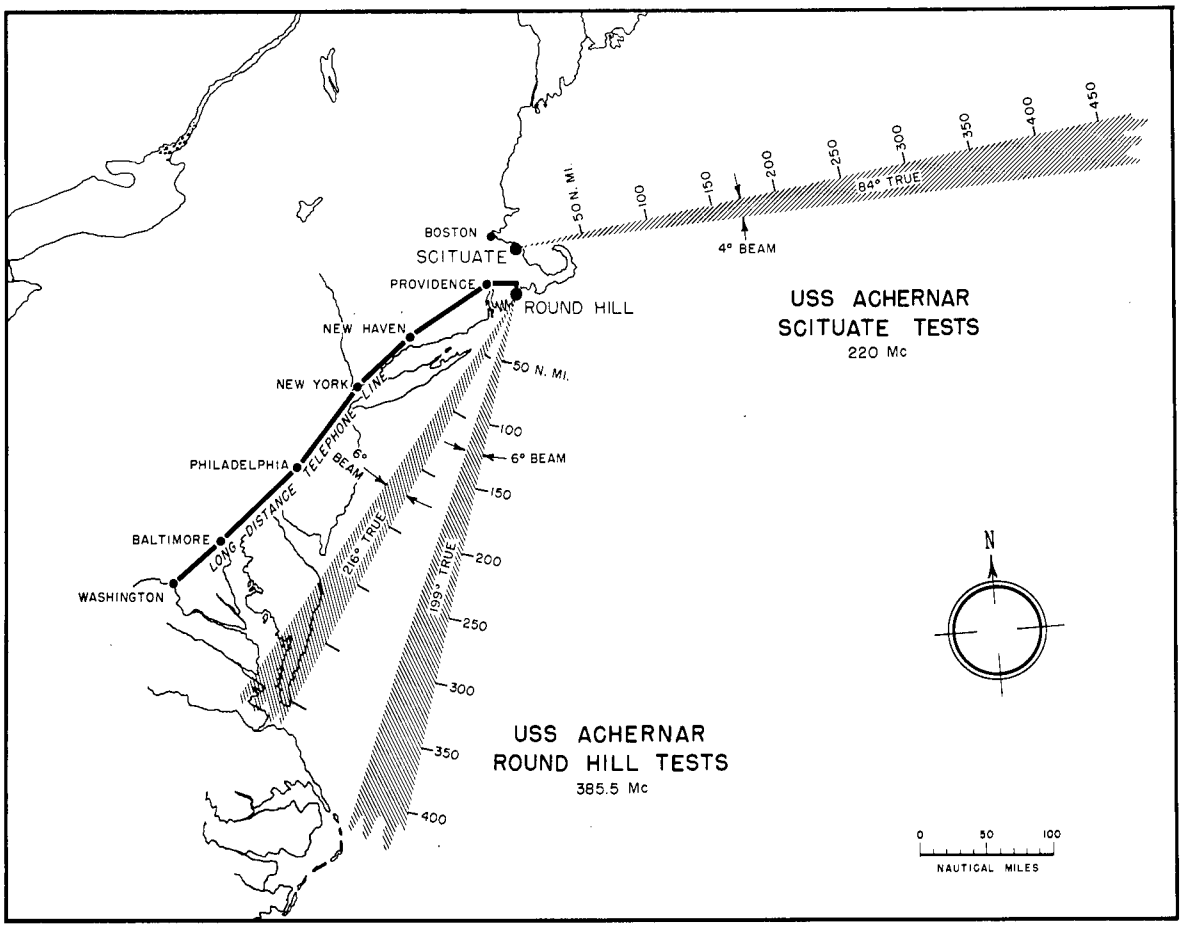

Fig. 5 - Transmission beams used during Scituate and Round Hill tests

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On the morning of 18 July the ship again left Norfolk and headed for the Scituate site. Antenna pattern and transmission beam checks were made at a point approximately 12 miles from this site, and at a bearing of 084 degrees true. During the balance of this two-week period, the ship made runs back and forth on this bearing (Table 2).

RESULTS

Esterline-Angus chart recorders were operated continuously during both phases of the investigation. The Edin and/or Brush high-speed recorders were operated intermittently to determine the fading rates encountered. The time totalizer was operated the majority of the time during the first two weeks, but not continuously. In general, it was used for sampling periods of approximately one hour; however, many of the sampling periods were of shorter duration because of large changes in signal level or changes in the fading characteristic. It was desirable to have the individual sampling periods represent only one type of fading.

Fading Characteristics

For the purposes of this report, the fading characteristics have been divided into three groups: fast, slow, and relatively steady. Portions of the Esterline-Angus charts showing recordings of the received signal level with each type of fade are shown in Fig. 6. The fast fluctuation type (Fig. 6a) represents the more pure scatter propagation condition, while the relatively steady type (Fig. 6c) is indicative of ducting conditions. The slow fluctuation characteristic (Fig. 6b) appears to be a semi or unsteady ducting condition. These three groups are naturally somewhat arbitrary and the recordings often showed characteristics intermediate to the three groupings; however, for simplicity in reporting, all data have been catagorized into one of the three general groups. It was found that the signal occasionally changed from one type to another very rapidly. An example of this can be seen in Fig. 7.

The Round Hill transmissions were recorded for a total of 120 hours and the Scituate transmissions for 122 hours. Of these total times, the ship was at distances greater than 75 miles for 93 and 95 hours, respectively. At distances greater than 75 miles the signal from Round Hill was of the rapid fluctuation type 38 percent of the time, the slow fluctuation type 41 percent, and the relatively steady type 21 percent. For the same conditions, the Scituate signal was of the rapid fluctuation type 28 percent, slow fluctuation type 50 percent, and relatively steady 22 percent of the time.

Fading Rate

The Round Hill transmissions were periodically recorded on either a Brush or an Edin recorder. These recorders and their input circuits were capable of showing fading rates as high as 60 per second or more. Figure 8 shows a photograph of a sample recording made on the Edin recorder when the ship was at a distance of approximately 400 miles from Round Hill. This sample is representative of the fastest fading rates observed during the two-week period except for some examples of airplane "flutter." For purposes of this report, fading rate is defined as the number of times per second that the slope of the envelope of the received signal level changes from positive to negative. The maximum fading rate that was observed was between 2 and 3 per second. However, when the fades were in excess of approximately 10 db, the maximum fading rate that was observed was

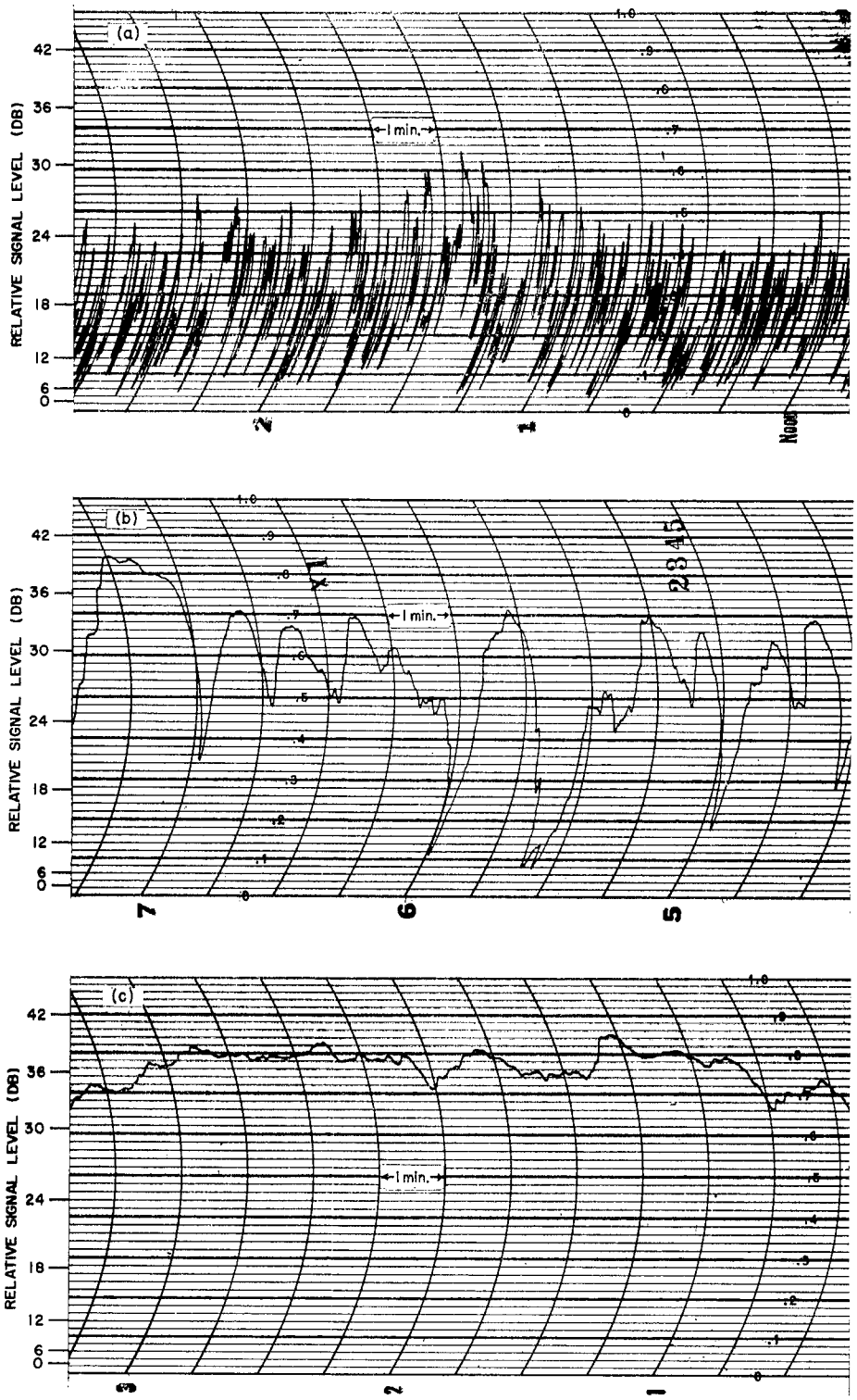


Fig. 6 - Esterline-Angus recordings showing fading characteristics of received signal. (a) Fast fading, (b) slow fading, (c) relatively steady.

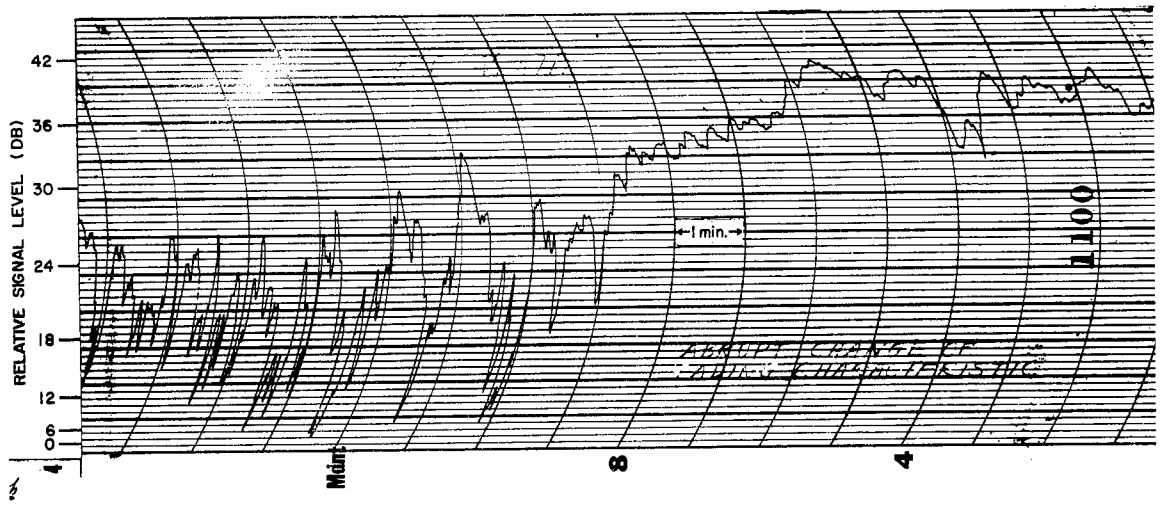


Fig. 7 - Esterline-Angus recording showing sudden change in fading characteristic of received signal

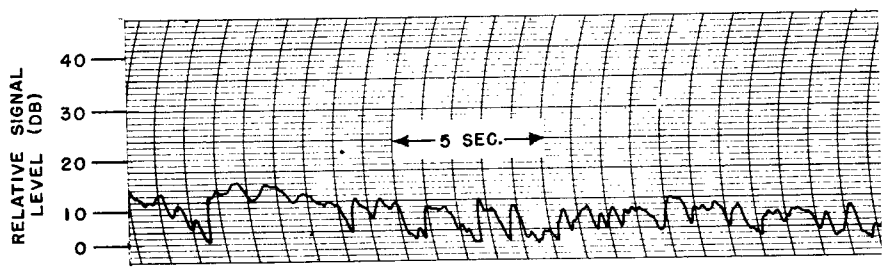


Fig. 8 - Edin recording showing sample of fastest signal fading observed

less than one per second. The magnitude of the slower fades was often much greater than 10 db as can be seen in Fig. 6.

Signal Level Measurements

The median signal levels measured during the four weeks of operation have been plotted against distance in Fig. 9. The signal levels are plotted in db above one milliwatt (dbm) output of the receiving antenna. (One microvolt into a 50-ohm load is equal to -107 dbm. Also, for the antenna and transmission line used, the field strength in db above one microvolt per meter is equal to the signal level in dbm plus 106 db for either transmission frequency.) The data recorded while the receiving antenna was directed over the bow of the ship (ship heading toward transmitting site) have been corrected to allow for the effect of the ship's superstructure on the received signal level. Most of the data were taken from the time totalizer readings. However, for periods when the totalizer was not in operation, the median values have been estimated from the Esterline-Angus chart records. The Esterline-Angus charts were also used to determine the fading characteristics of the received signal. It was found that with experienced personnel analyzing the

records, the estimated median from the charts agreed within 1 or 2 db with the value obtained from the totalizer. Each point plotted represents the median over a period of one hour or less. The shorter periods were used when the median or the fading characteristics changed significantly. The different symbols used in plotting the signal levels denote the fading characteristic.

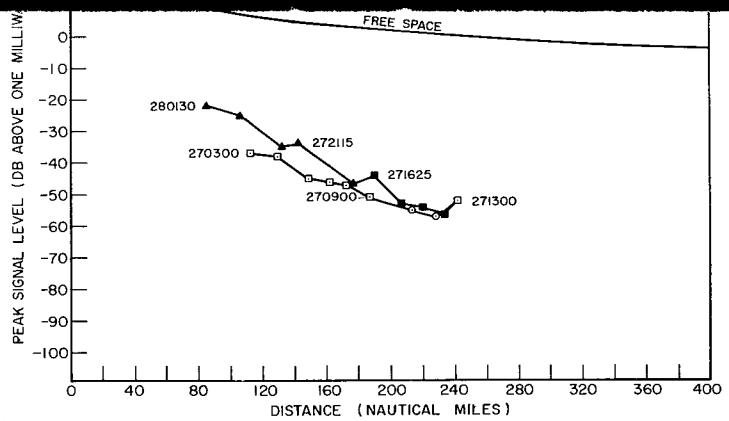
The data plotted in Figs. 9a and 9b were obtained during two round-trip runs on the 199-degree bearing from Round Hill. Figure 9c presents data obtained while the ship was on a bearing of 216 degrees from Round Hill. During this run the transmitting antenna was directed on this bearing, but did not have an unobstructed path to the horizon. Therefore, the signal levels given in Fig. 9c may have been influenced somewhat by the land and other obstacles within the beam. Figures 9e, 9f, and 9g show the results of measurements made during three round-trip runs within the transmission beam on a bearing of 084 degrees from Scituate. The signal levels indicated for the Scituate transmissions are the medians of the peaks of the received pulses. Appropriate factors for the duty cycle employed were applied to the recorded signal levels to convert the measurements to peak values. During the Scituate transmissions, the ship made only one run out to distances greater than 250 miles. During this run, a transmitter failure accounts for the sparseness of the data at the greater distances.

Since the transmission paths involved were normally all over-water, the paths can be considered to be over a smooth spherical earth; therefore, the angular distance (θ) is one degree at a distance of about 120 miles for the antenna heights involved. (The angular distance is the angle formed by the lines drawn between the transmitting and receiving antennas and their respective horizons, in the great circle plane.) It is generally considered that when the angular distance exceeds a value of about one degree, the predominant part of the signal is received as a result of some mode of propagation often termed <u>scatter</u>, except during periods of ducting.

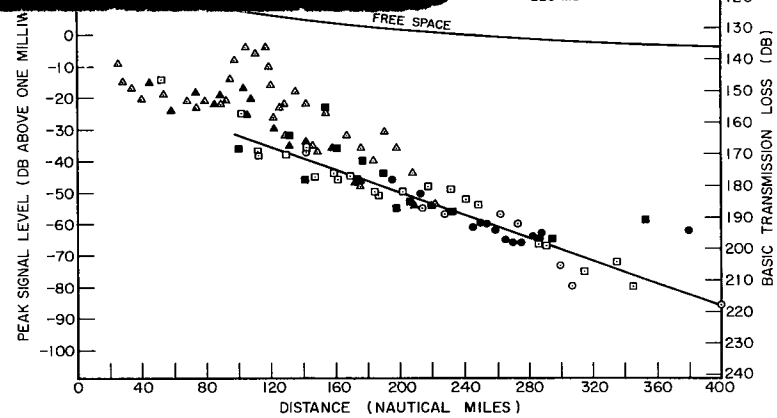
The numbers appearing beside some of the points on the curves shown in Fig. 9 represent the mean GMT date/time group when that particular series of values was recorded. The first two digits refer to the date during July 1955 and the last four digits give the time. These times indicate the approximate speed of the ship and also give some indication of the change in signal level and fading characteristic with time.

The data presented in Figs. 9a and 9b have been replotted in Fig. 9d to show the composite of all data obtained with the ship in the transmission beam on a bearing of 199 degrees true from Round Hill. The data in Fig. 9c were not included in this composite for reasons previously discussed. Figure 9h shows the composite of all data given in Figs. 9e, 9f, and 9g. A straight line with a slope of 0.18 db per nautical mile has been included in Figs. 9d and 9h. These straight lines are not intended to represent the average signal level versus distance for all the data presented. The authors believe that it is important in this study to differentiate the more truly scatter-type signals from those enhanced by ducting or partial ducting conditions. This is particularly true for relatively short-time investigations such as reported here; therefore, the straight lines in Figs. 9d and 9h are intended to represent the average of the data recorded at distances greater than 100 miles, and which were observed to have a fast fading characteristic. If the curves had been drawn to represent the average of all the data beyond 100 miles, the slope would have been greater. It can be seen that for the Scituate transmissions (Fig. 9h) none of the data recorded at distances less than 195 miles had a fast fading characteristic.

A comparison of the average signal levels with the calculated free-space levels shows that the Scituate signal was about 9 db higher than the Round Hill signal. Some of this



(g) 220 Mc, 084° True, Scituate, July 27-28, 1955



(h) Composite of Figs. 9e, 9f, and 9g

Fig. 9 - Median signal levels versus distance

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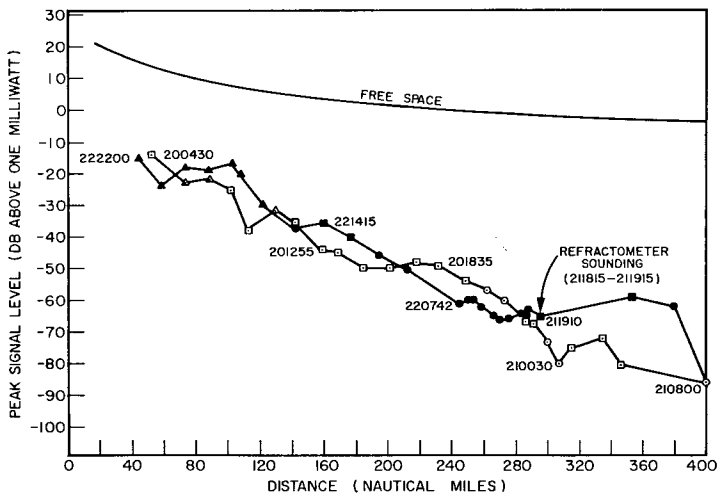
DISTANCE (NAUTICAL MILES)

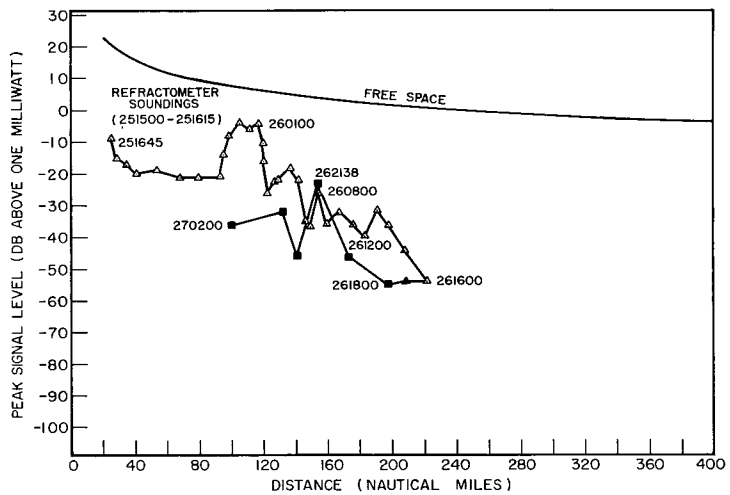
(c) 385.5 Mc, 216° True, Round Hill, July 14-15, 1955

DISTANCE (NAUTICAL MILES)

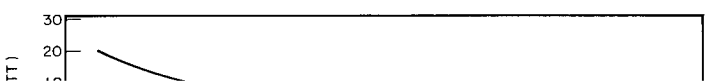
(d) Composite of Figs. 9a and 9b

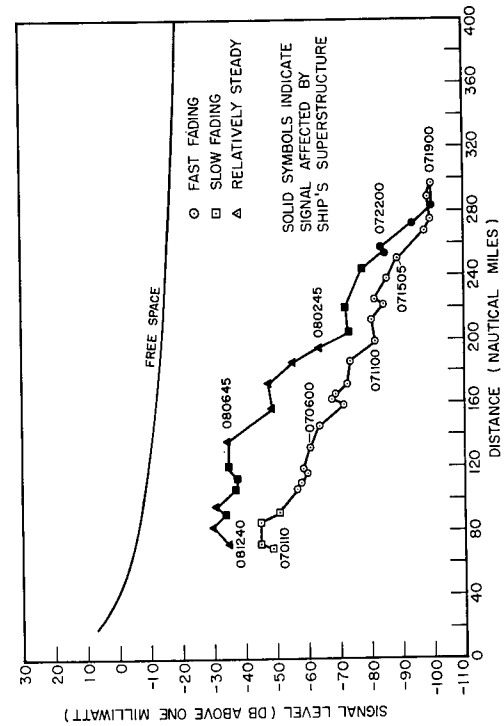


(e) 220 Mc, 084° True, Scituate, July 20-22, 1955

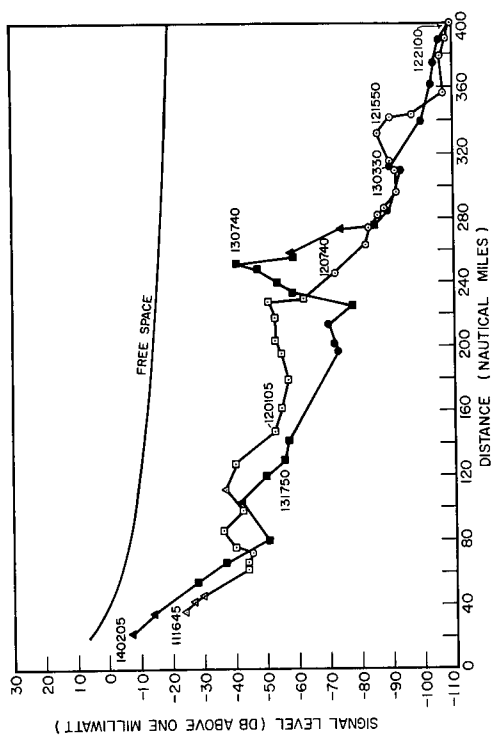


(f) 220 Mc, 084° True, Scituate, July 25-27, 1955

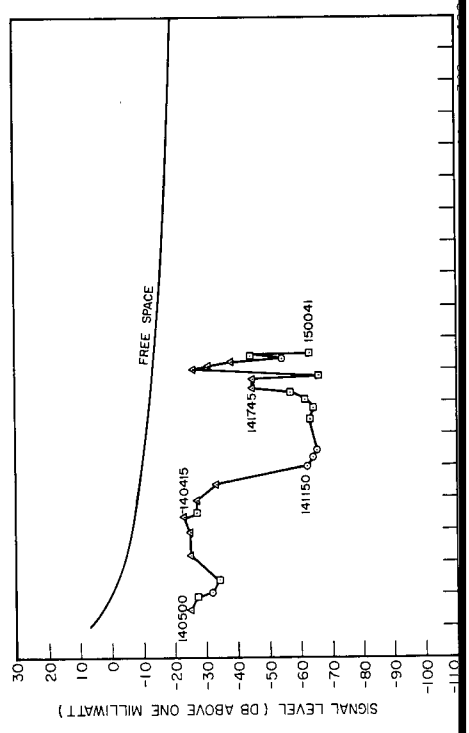


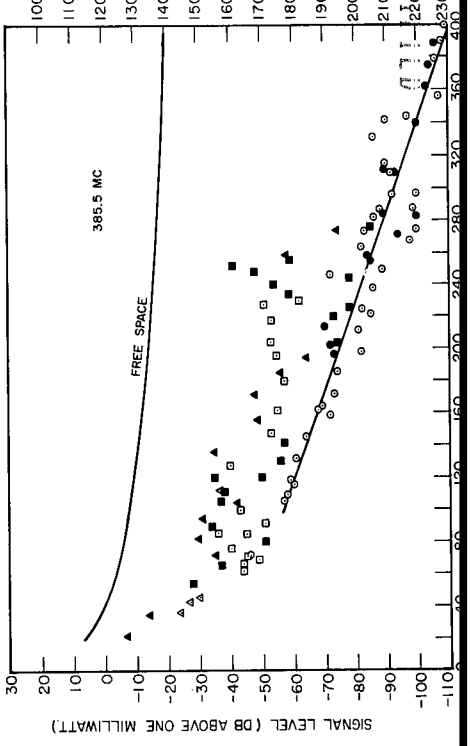


(a) 385.5 Mc, 199° True, Round Hill, July 7-8, 1955



(b) 385.5 Mc, 199° True, Round Hill, July 11-14, 1955





difference may be due to the characteristics of the two transmission paths; however, this is not conclusive due to insufficient data. The difference may be due to the particular meteorological conditions prevelant during the period of investigation. Fog was present over the path a very high percentage of the time that the 220-Mc signal was being recorded. Other investigators[4] have reported signal enhancements of 6 to 10 db during foggy conditions.

Also included in Figs. 9d and 9h are ordinates giving the basic transmission loss[5] in db. These ordinates give the transmission loss that would be expected if isotropic transmitting and receiving antennas were used. In this form the propagation data are reduced to basic terms so that the results can be easily applied to any transmitting and receiving system. The received signal level, P_a, expressed in dbm, can be calculated from

$$P_a = P_r + G_t + G_r - L_b \tag{1}$$

where

P_r = power in dbm available for radiation from the transmitting antenna

G_t = transmitting antenna gain in db

G_r = receiving antenna gain in db

L_b = basic transmission loss in db

The antenna gains, G_t and G_r, are expressed in db relative to an isotropic antenna. The gain of an antenna over an isotropic antenna is equal to its gain over a half-wave dipole plus 2.15 db. In Eq. (1) the "effective gains" of the antennas should actually be used, but in most instances this is not known; therefore, the free-space gains of the antennas can be used to give a good approximation. The combined effective gain will be equal to or less than the free-space value. Most of the literature states that when using a higher gain antenna its calculated gain over one of less gain will not be realized when the propagation mode is predominently "scatter." Recent investigations indicate that this conclusion may be incorrect and that at times a gain greater than that calculated is realized. The relative gains of the antennas vary with time and possibly the length of the propagation path. A more extensive study of this phenomenon is needed.*

Although the data obtained are not to be regarded as complete and applicable to all climatic areas and meteorological conditions, it is believed that they are representative of the conditions existing a very large portion of the time for the true scatter mode of propagation. The transition from line of sight to diffraction to scatter modes has been found to be smooth and it is believed that very little difference exists between over land and over water for the scatter mode.

Probability Distribution

The signal-level data recorded on the time totalizer were plotted as cumulative probability distribution curves. The signal-level data in db for each sampling period were

*An NRL report (in preparation) covering a recent study of a winter month of forward scatter propagation data will include results obtained using transmitting antennas of different gains.

plotted using two types of distribution coordinates, Rayleigh and Gaussian. These coordinates are such that a plot of a Rayleigh or Gaussian distribution would be a straight line when using the respective coordinates. The Rayleigh distribution is characterized not only by being a straight line, but, unlike the Gaussian, it also has a particular slope. This slope is such that there is a 13.4-db difference between the ordinate values exceeded 10 and 90 percent of the time. The distribution curves showed that the ship's superstructure not only affected the magnitude of the received signal when the receiving antenna was directed over the bow of the ship, but also affected the distribution of the fading at distances greater than about 100 miles. The received signal under these circumstances would be the resultant of the direct wave and the wave reflected from the superstructure. The result can probably be explained as being a space diversity effect. By the same principle as space diversity reception, there would be little or no correlation between the fading of the direct wave and the wave reflected from some portions of the superstructure. The totalizer data recorded while the receiving antenna was directed over the bow of the ship (the ship heading toward the transmitting site) plotted as a straight line on Rayleigh coordinate graph paper but had a different slope than that for a true Rayleigh distribution given by the equation

$$P(E) = 100 \exp\left[-0.693(E/E_m)^2\right]. \qquad (2)$$

In this equation, P(E) is the percentage of time that the signal level E is exceeded, and E_m is the median signal level. When Eq. (2) is plotted on Rayleigh coordinate graph paper, it results in a straight line with a slope such that the ratio of the signal levels exceeded 10 percent and 90 percent of the sampling period is 13.4 db. The equation for the distribution of the experimentally obtained data as affected by reflections from the superstructure would be similar to that of Eq. (2) except that the constant in the exponential would assume a different value depending upon the particular sampling period. That is, the slope of the curve was not the same for all sampling periods. Therefore, all distribution data included in this report were obtained when the receiving antenna was directed over the stern of the ship (an unobstructed path).

The cumulative probability distributions of data for nine sampling periods when the receiving antenna was unobstructed by the ship's superstructure are shown in Figs. 10, 11, and 12. Those presented in Fig. 10 are of data recorded during periods when, by observing the Esterline-Angus charts, the received signal had a fast fading characteristic such as shown in Fig. 6a. The data in Fig. 11 are of the slow fading types shown in Fig. 6b, while those in Fig. 12 are of the relatively steady type shown in Fig. 6c. The average length of the transmission path for each period is shown in the graphs. In all cases the angular distance was nearly equal to or greater than one degree.

In the four examples presented in Fig. 10, the best fitting straight line with the proper slope was drawn through the points on the Rayleigh coordinates, and the best fitting straight line on the Gaussian coordinates. It appears that the data are better represented by the Rayleigh distribution. The sampling period for the data in Figs. 10a and 10b was 15 minutes, while for Figs. 10c and 10d the period was one hour. It may be noted that the data for the two 15-minute samples deviate from the log-normal distribution in about the same manner. Likewise, the deviation from the log-normal for the data of the one-hour samples is similar, but it differs from that for the shorter sampling periods. This may be significant but some other data, not presented here, do not follow this pattern. The four examples presented in Fig. 11, data taken while the received signal had a slow fading characteristic, also appear to be Rayleigh distributed.

The scatter propagation signals were of primary interest in this investigation, and, during most of the periods of suspected ducting conditions, the time totalizer was not

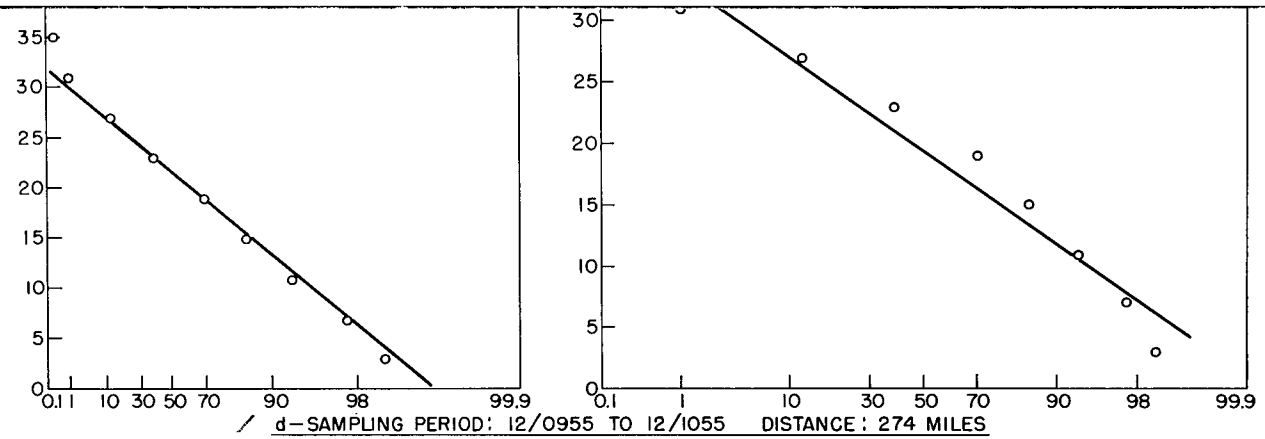


Fig. 10 - Probability distribution of received signal level having a fast fading characteristic

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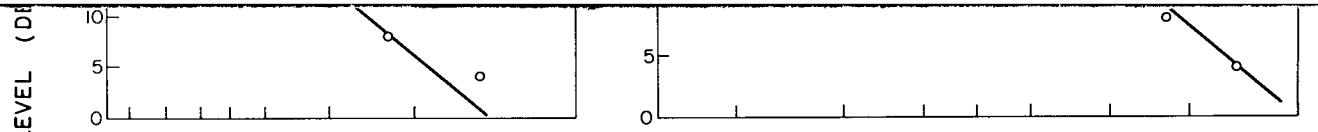
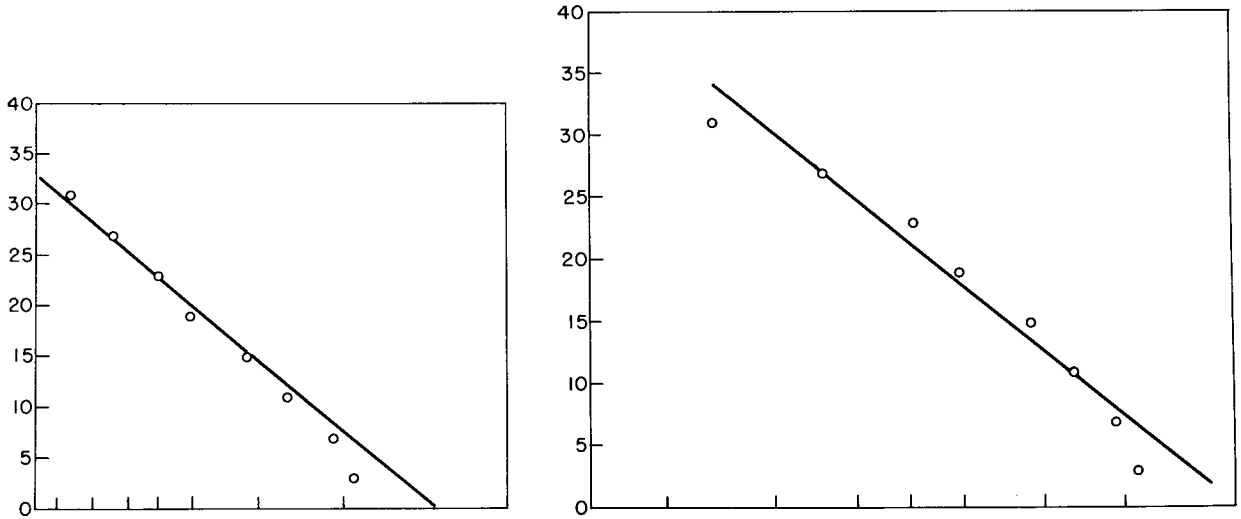
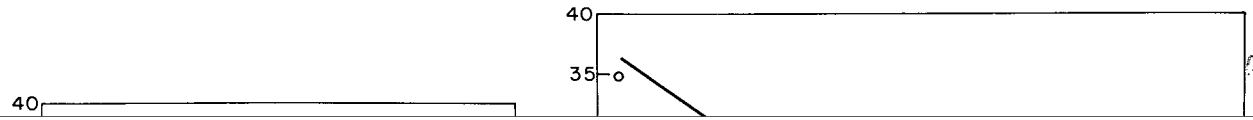


b-SAMPLING PERIOD: 07/0825 TO 07/0840 DISTANCE: 165 MILES



c-SAMPLING PERIOD: 12/0850 TO 12/0950 DISTANCE: 264 MILES



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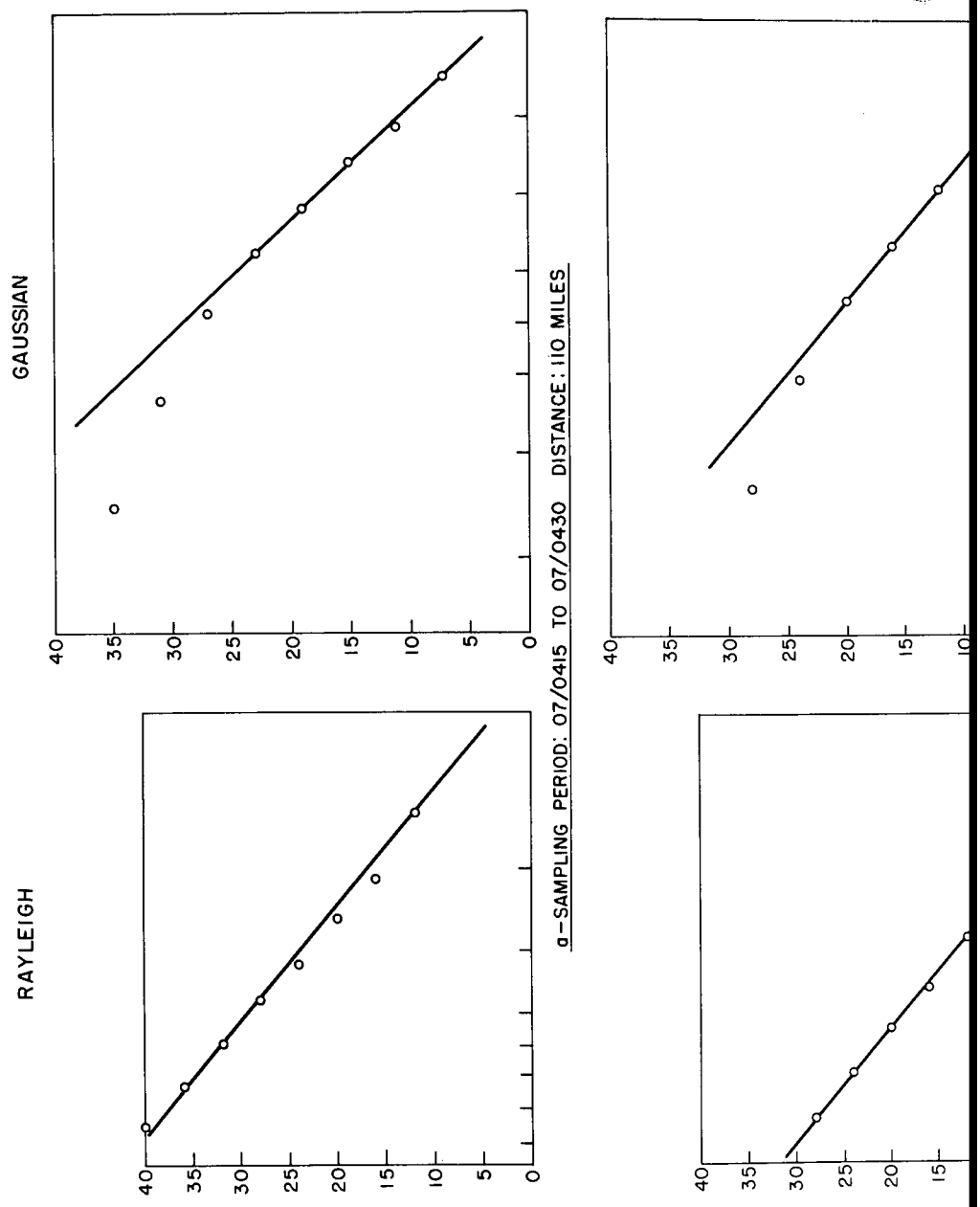
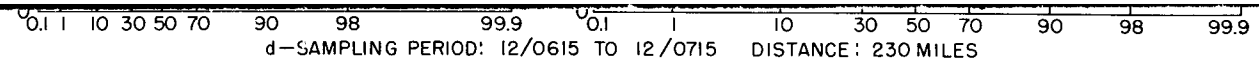
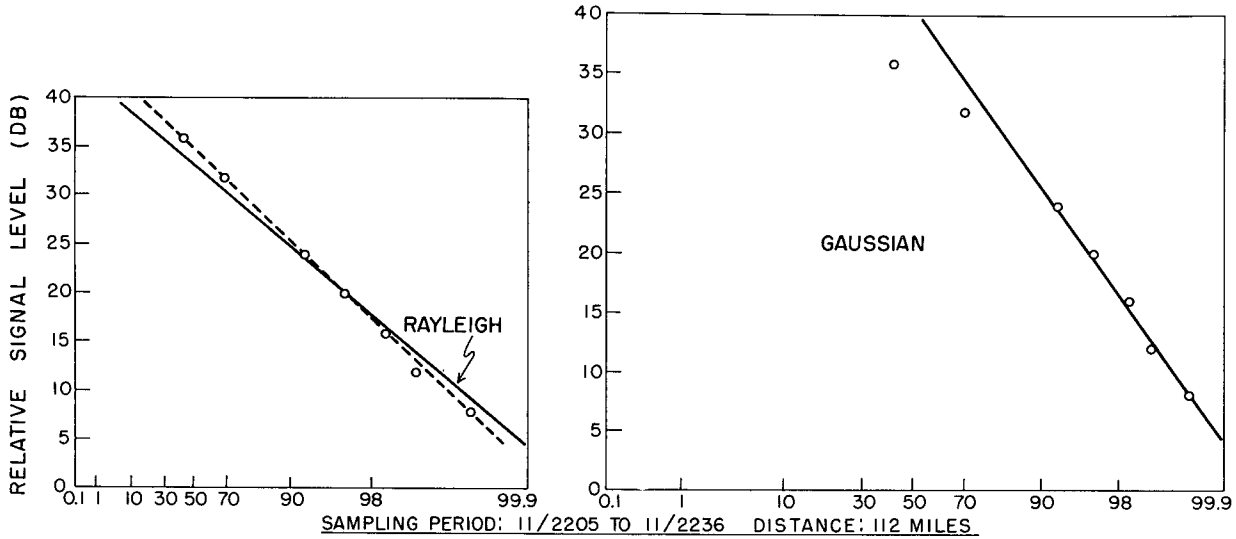


a–SAMPLING PERIOD: 07/0415 TO 07/0430 DISTANCE: 110 MILES



PERCENTAGE OF TIME THE VALUES EXCEED THE ORDINATE

Fig. 11 - Probability distribution of received signal level having a slow fading characteristic



PERCENTAGE OF TIME THE VALUES EXCEED THE ORDINATE

Fig. 12 - Probability distribution of received signal level having a relatively steady characteristic

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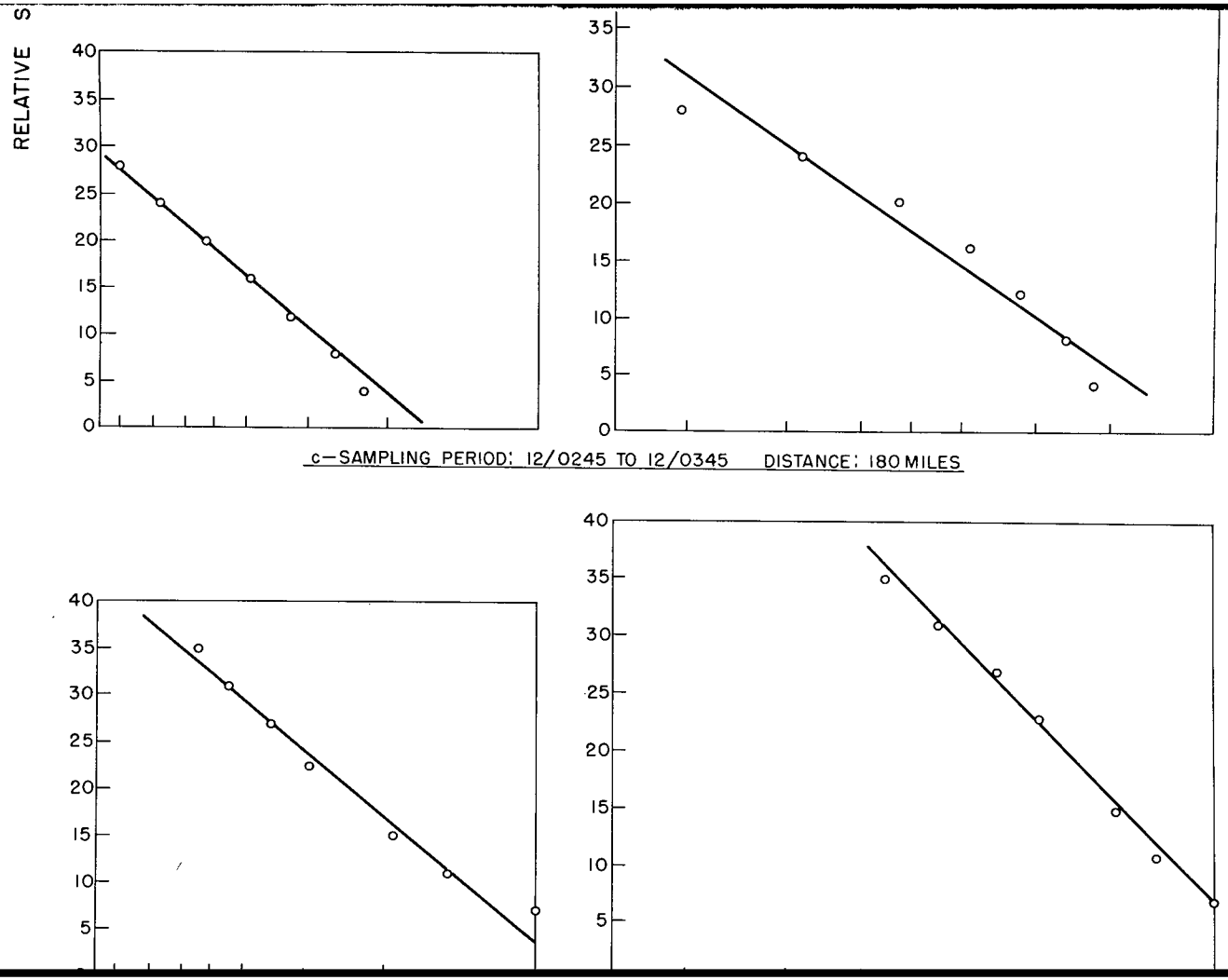

c—SAMPLING PERIOD: 12/0245 TO 12/0345 DISTANCE: 180 MILES

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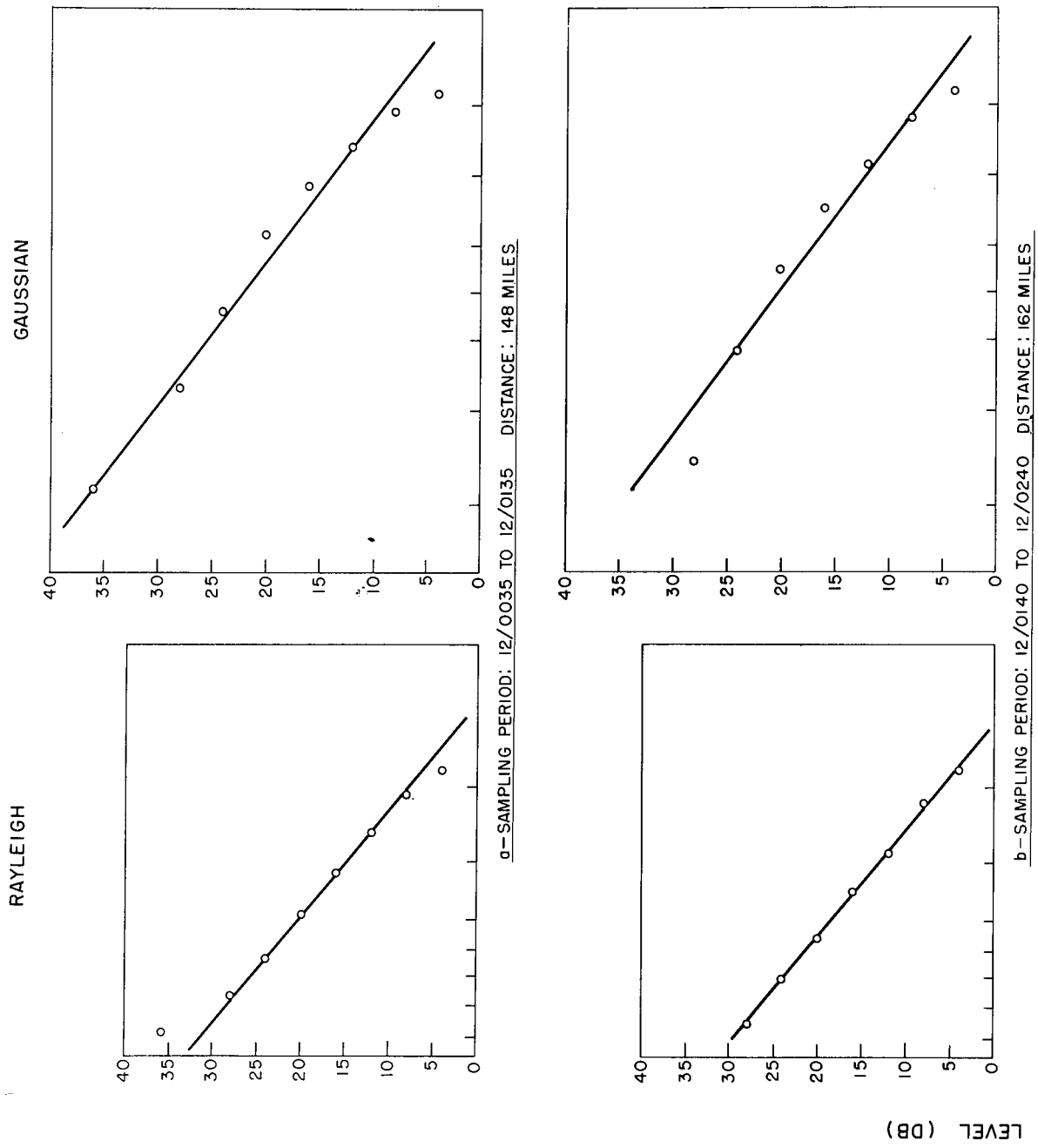

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operated; the data were recorded on the Esterline-Angus charts only. As previously stated, ducting conditions were considered to exist when the received signal had the relatively steady type of fading characteristic and was of generally higher level. This refers, of course, to signals received at angular distances greater than about one degree. During much of the time that the signal was of this type, the level varied no more than about 6 db for periods of 10 minutes or more. However, for some periods of an hour or more, the level would slowly vary over a range of 20 or 30 db. The time totalizer data recorded during one such period are presented in Fig. 12. The data plot as a straight line on Rayleigh coordinates but with a different slope. No conclusions were formulated since not enough distribution data were recorded during ducting conditions. Figure 12 is included for information only.

All data shown in the distribution curves were obtained from the Round Hill transmissions. Data obtained on the pulse transmissions from Scituate have not been included because the time totalizer, as used, was inherently less accurate for pulses with a repetition rate of 60 per second.

The distribution curves give information concerning the fading range. Fading range is defined as the ratio in decibels of the signal levels exceeded 10 percent and 90 percent of the sampling period. Since the scatter propagated signals are better represented by the Rayleigh distribution, then, by definition, the fading range of the scatter signals is 13.4 db. From Eq. (2) it can be determined that if the fading characteristics of the received signal follow a Rayleigh distribution the signal level exceeded 90 percent of the time is 8.17 db below the median level. Also, the level exceeded 99 percent of the time is 18.41 db below the median. Curves drawn in Figs. 9d and 9h represent the average of the median levels of data which follow the Rayleigh distribution. Therefore, if it is desired to know the average signal levels exceeded 90 and 99 percent of the time, they can be obtained by drawing lines parallel to the lines in Fig. 9d or 9h and displaced by -8.17 and -18.41 db, respectively.

Communication Intelligibility Transmissions

The Round Hill transmissions were periodically modulated (narrow-band FM) with a previously recorded voice and music magnetic-tape test sample. These transmissions were tape recorded aboard ship at various distances from Round Hill. Excellent quality recordings were consistently obtained at distances out to about 300 miles. Beyond 300 miles the quality was still excellent, but there were some short-period outages at times when the signal was in a deep fade.

Two-Way Communication Trials

The AN/TRC-24 FM transmitter was used aboard ship for frequent two-way voice communication checks. Good results were obtained out to distances of about 250 miles on scatter mode signals. During ducting conditions, good communication was had to much greater distances. Although these transmissions were not previously arranged as part of the planned project, they yielded some practical qualitative information useful for future planning.

On 14 July, when the ship was at a bearing of 216 degrees true and approximately 200 miles from Round Hill, a two-way circuit was set up between the ship and Round Hill using this transmitter, and between Round Hill and NRL using commercial telephone line. This communication circuit can be seen in Fig. 5. For a period of approximately one hour very successful two-way communication was maintained between personnel aboard ship and at NRL.

Although ducting conditions prevailed during this period, information obtained at other periods indicates that successful communication would have been obtained under scatter conditions at this distance.

Refractometer Soundings

While planning this project, the possibility of having an appropriately equipped aircraft make some simultaneous refractometer soundings over the transmission path was considered. It was found that such a plane would not be available because of other commitments. However, while the investigation was in progress, the operation schedule of the plane was changed, and it was made available to this project for several runs during the last two-week period. There was little time to plan the coordinated operation of the plane with the movement of the ship, and adverse weather conditions altered the operation schedule of the ship. Therefore only a very limited amount of information was obtained.

The plane made two groups of soundings while the ship was in the transmission beam. Each group of soundings consisted of index of refraction recordings aboard the plane while spiraling down from an altitude of 10,000 feet to about 500 feet at two or three locations in the transmission beam. The first group of soundings was made while the ship was approximately 300 miles from Scituate. The plane made two spiral runs—over the transmitting site and 100 miles away. This group of profiles with the GMT date/time at each sounding is given in Fig. 13. The signal level and fading characteristic recorded aboard the ship while the soundings were being made can be seen in Fig. 9e. The other group of soundings was made when the ship was at a distance of only 20 miles from Scituate and the test transmission was not being recorded. However, the signal recording started very soon after the soundings and the ship began heading away from Scituate in the transmission beam. The plane made three spiral runs in this group—over Scituate, 100 miles away, and 200 miles away. The signal level and fading characteristic recorded soon after the soundings can be seen in Fig. 9f. This group of index of refraction profiles is shown in Fig. 14.

FUTURE PLANS

A similar series of measuremnts was conducted during February 1956 in order to determine the seasonal effect on the tropospheric scatter mode of propagation over water. After analysis and evaluation, these data will be reported separately. These particular investigations have been confined to a rather limited area of the sea, and it is realized that additional studies must be made before conclusions can be drawn as to results that would be obtained in other areas, particularly the polar regions. Plans are also being considered to investigate tropospheric scatter-mode propagation at S-band frequencies using error-counting techniques.

ACKNOWLEDGMENTS

In a cooperative project of a magnitude such as the one reported here, it is very difficult to give proper credit to all who participated. The authors would be remiss, however, if they did not mention certain organizations and personnel that made the project possible.

NRL liaison officers provided a valuable service in handling numerous arrangements and details concerning the naval operations involved. CNO assigned a suitable ship for the

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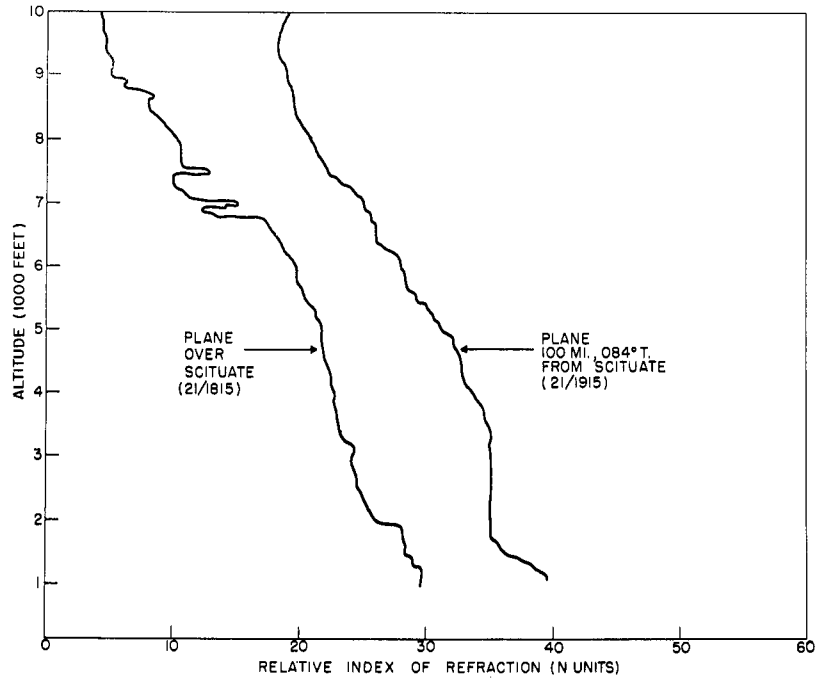

Fig. 13 - Index of refraction profiles. Soundings made while ship was 300 miles from Scituate

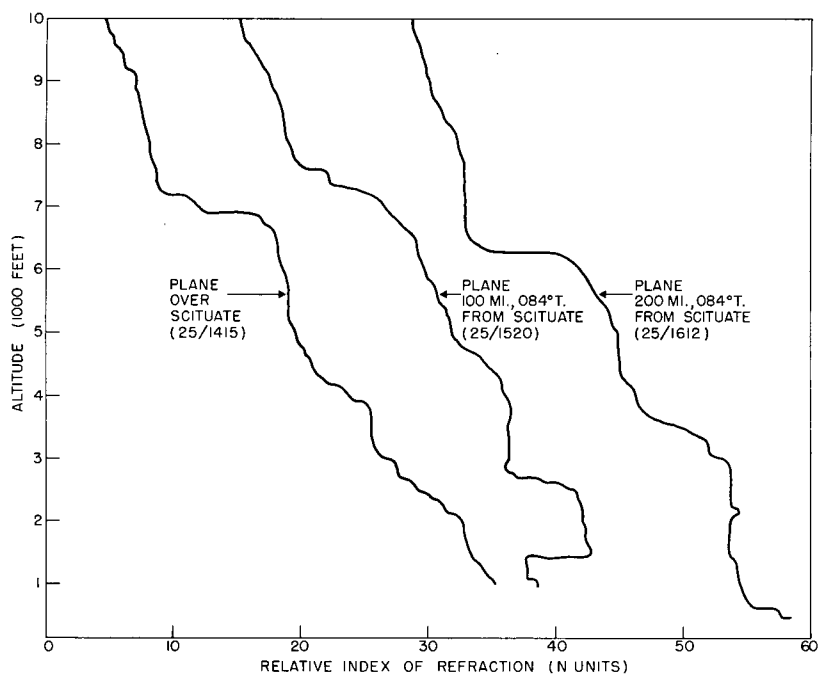

Fig. 14 - Index of refraction profiles. Soundings made while ship was 20 miles from Scituate.

period covered by the investigation. The Industrial Manager of the Fifth Naval District gave valuable services with respect to the installation of equipment aboard ship. Captain Ensey together with the other officers and the crew of the USS ACHERNAR were extremely cooperative in providing excellent arrangements and operational facilities aboard ship.

The Lincoln Laboratory and the Cambridge Research Center provided transmitting facilities without which the project could not have been pursued with the desired scope and thoroughness. In addition, Lincoln Laboratory contributed materially to the operation aboard ship by supplying valuable equipment and assigning well-qualified personnel to assist in the shipboard part of the first phase of the project.

The over-all program was coordinated by Mr. J. D. Wallace of NRL. Other NRL personnel who contributed materially were: J. E. Raudenbush, F. C. Kahler, H. R. Johannessen, J. R. Gouge, and L. A. Knavish.

REFERENCES

1. Dinger, H. E., Garner, W. E., and Raudenbush, J. E., "200-Mc Propagation Measurements Beyond the Radio Horizon," NRL Report 4449, November 1954

2. Wallace, J. D., "Communication System," Report of NRL Progress (Confidential), pp. 45-46, August 1955

3. Garner, W. E., "Communication System," Report of NRL Progress (Confidential), p. 43, September 1955

4. Bullington, K., Inkster, W. J., and Durkee, A. L., "Results of Propagation Tests at 505 Mc and 4,090 Mc on Beyond-Horizon Paths," Proc. IRE, 43:1306-1316, October 1955

5. Norton, K. A., Rice, P. L., and Vogler, L. E., "The Use of Angular Distance in Estimating Transmission Loss and Fading Range for Propagation Through a Turbulent Atmosphere over Irregular Terrain," Proc. IRE, 43:1488-1526, October 1955

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APPENDIX A
The Directive Receiving Antenna
[Confidential]

Hans R. Johannessen

The directive receiving antenna employed aboard the USS ACHERNAR during the forward scatter investigations was a modified SK-3 radar antenna (Navy Type CG 66 AFR).

Modification consisted mainly of providing two four-element arrays, one operating at 220 Mc (Figs. A1 and A2) and the other at 385.5 Mc (Figs. A3 and A4), which could be substituted individually on the cone in place of the SK-3 exciter and reflector. The arrays were positioned for reception of horizontally polarized waves.

These four-element arrays consist of two exciter-reflector combinations spaced one-half wavelength apart. The two halves of each array are connected to a common 1-5/8-inch transmission line by two elbows and a tee. Construction of one half of an array is shown in Fig. A5. The reflector element is rigidly attached to the end of the transmission line. This point is at zero potential since the inner and outer conductors are shorted. The exciting element is located one-quarter wavelength down the line from the reflector and attached to the outer conductor of the line. A one-half wavelength slot cut along the line forms a quarter wavelength impedance between the exciter and the end of the line. Also the length of the inner conductor to the end of the line is one-quarter wavelength. The net result is that no energy can flow beyond the exciter; therefore, the outer conductor feeds one half of the exciter and the inner conductor feeds the other half. Note that this half of the exciter passes through the outer conductor and is grounded to it. Continuation of the slot another quarter wavelength down the line insures that the r-f energy flows into the exciter rather than back along the outside of the outer conductor. A slot one-quarter inch wide in the 1-5/8-inch tubing is sufficient to form the quarter wavelength impedances without changing the 50-ohm line impedance up to the exciter. In order to maintain strength and air tightness of the line along the slot a covering of polyester glass laminate, a low-loss material, was wrapped around the line to cover the slot. A 10 percent reduction in slot length was required to compensate for the change in dielectric constant resulting from use of the glass laminate.

The length of the exciter and reflector elements of the arrays as well as the distance of the arrays from the paraboloidal reflector at each operating frequency were determined by adjusting lengths and spacing step by step until the sharpest beam pattern was obtained. Dimensions of the array for the two frequencies employed are given in Fig. A5. The distance of the exciter from the paraboloidal reflector at 220 Mc is 50 inches and at 385.5 Mc is 42.5 inches.

The beam pattern obtained at 220 Mc is shown in Fig. A6. To obtain the pattern, horizontally polarized waves were transmitted from a distance of 440 feet. Received voltage was measured at the output of the transmission line as the SK-3 paraboloidal reflector was rotated clockwise through 90 degrees either side of peak reception. In Fig. A6 the rotational scale is plotted in degrees and the intensity scale in db below the peak value. At the half-power point the beam is 23.5 degrees wide. Side lobes are down by at least 28 db.

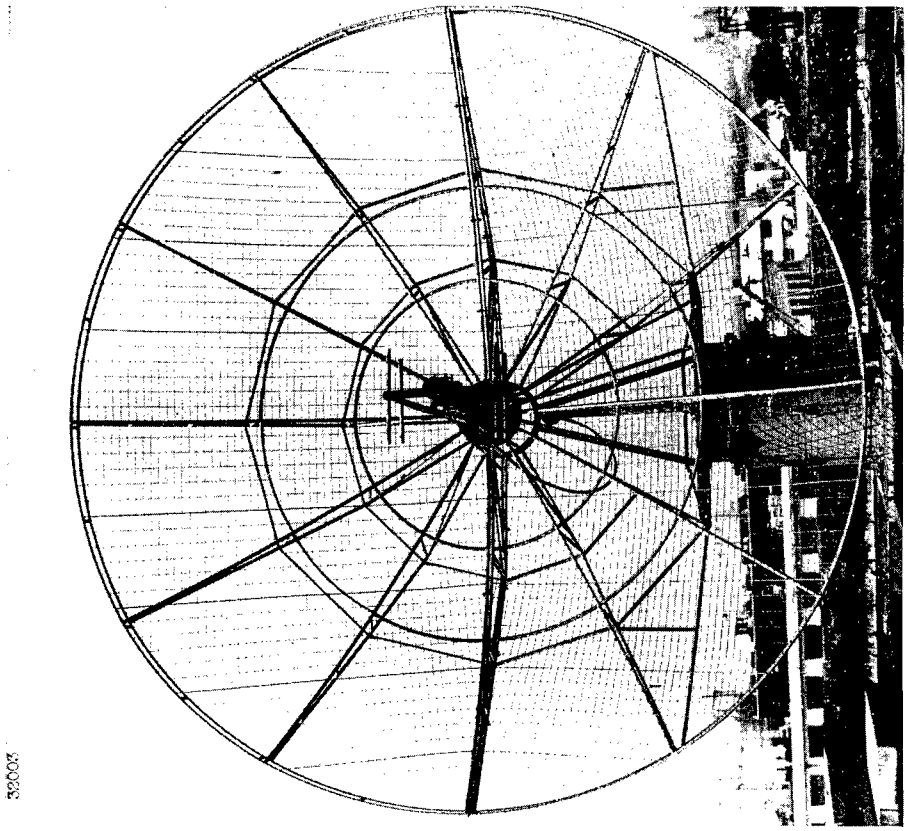

Fig. A2 - Front view of 220-Mc directive antenna

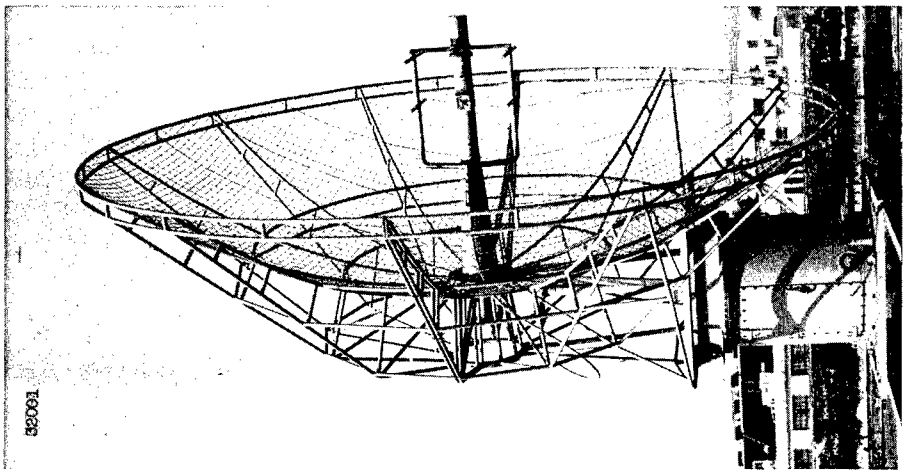

Fig. A1 - Side view of 220-Mc directive antenna

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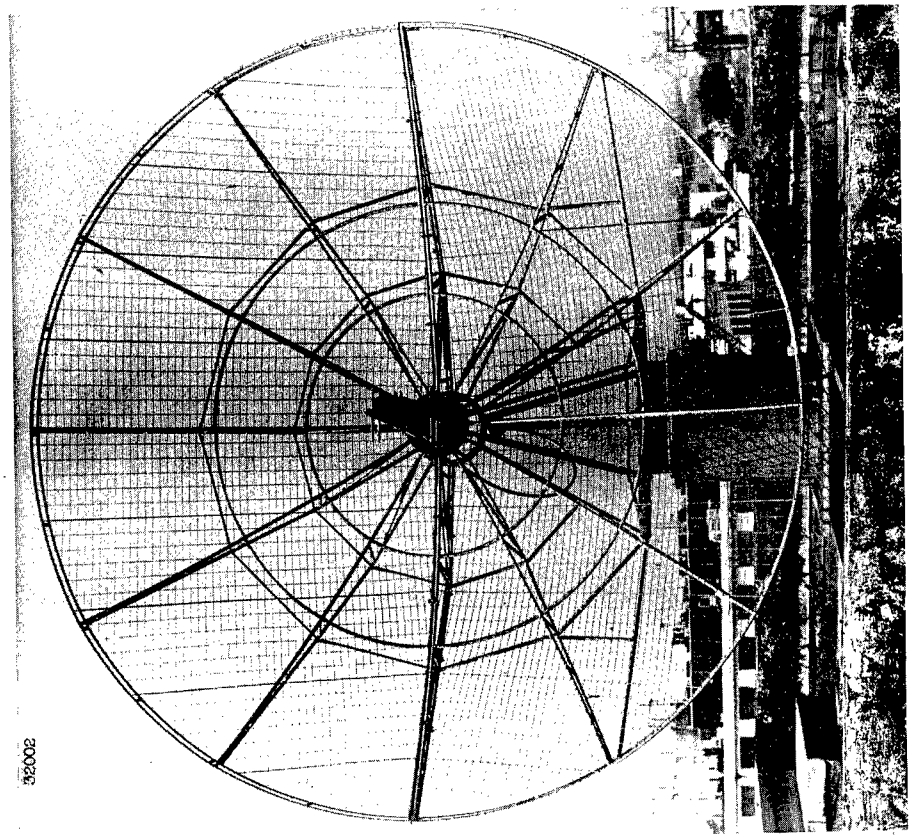

Fig. A4 - Front view of 385.5-Mc directive antenna

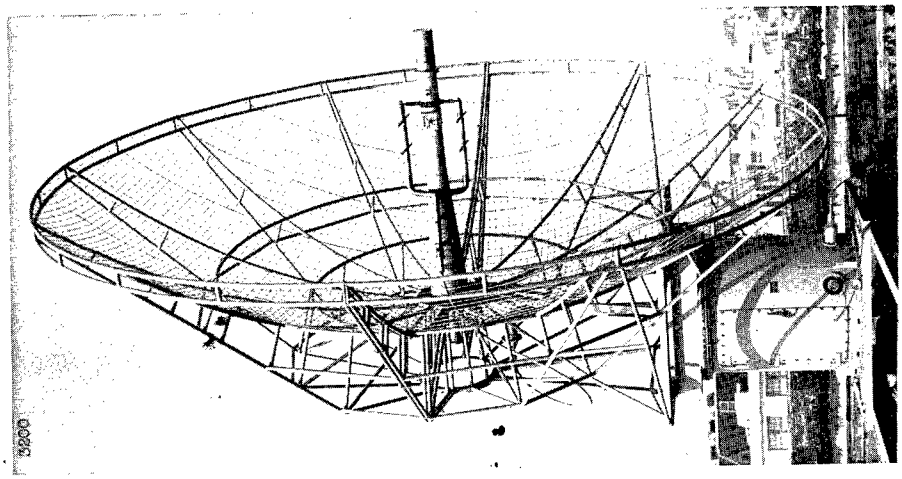

Fig. A3 - Side view of 385.5-Mc directive antenna

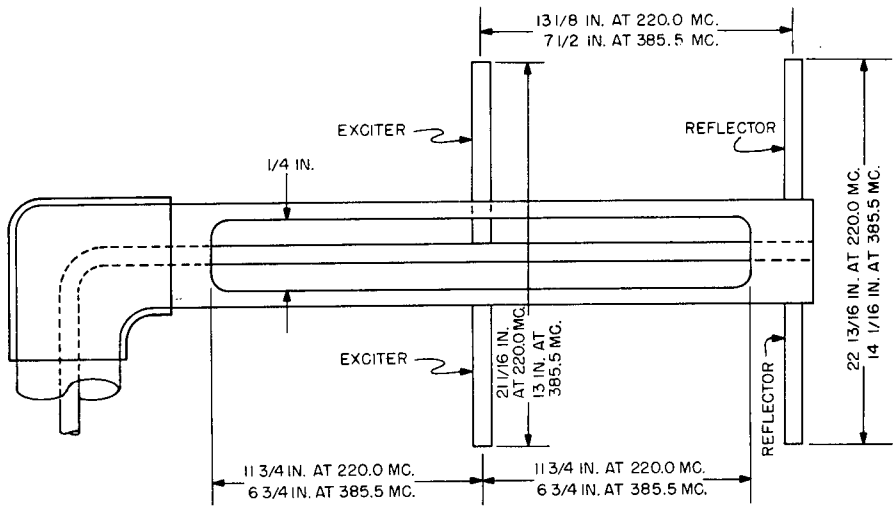

Fig. A5 - Construction of one half of array

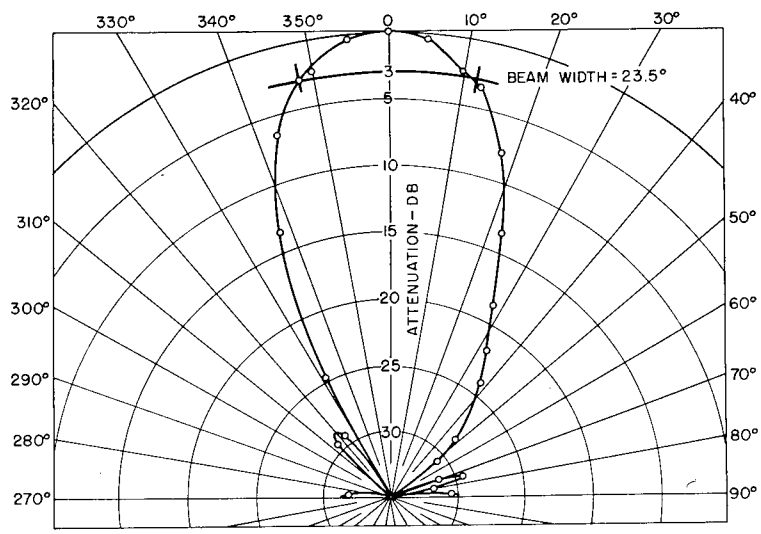

Fig. A6 - 220-Mc receiving antenna horizontal directivity pattern measured at NRL

In order to obtain an approximate picture of the vertical pattern, the array was turned 90 degrees on the cone. Array elements were then vertical. A pattern was obtained while receiving vertically polarized waves. Although the pattern obtained by this method is not free of reflections from the earth's surface it is considered a good approximation of the vertical directivity of the antenna system. The pattern is shown in Fig. A7. Half-power beamwidth is 24.5 degrees. From a study of the two patterns it is evident that the depreciation of the received signal is no greater than 0.5 db at 4 degrees either side of the peak value in either plane. Therefore, reception should suffer but little from normal roll and pitch of the ship employed.

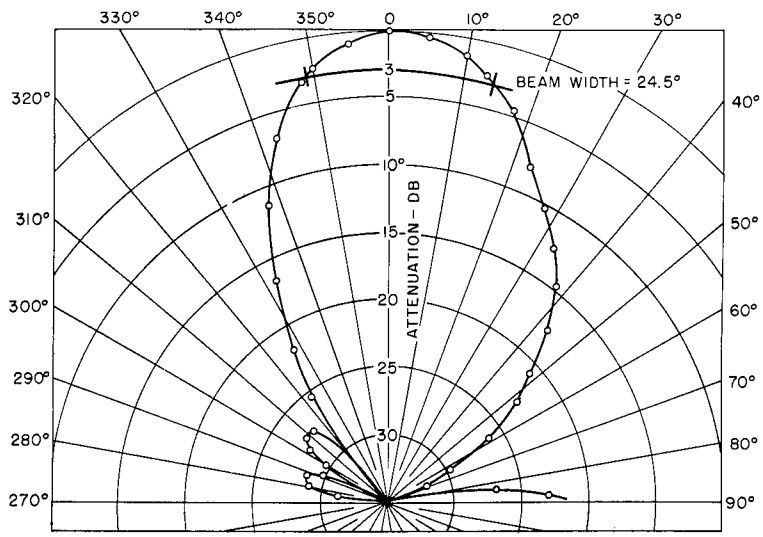

Fig. A7 - 220-Mc receiving antenna vertical directivity pattern measured at NRL

Approximate power gain of a directive antenna over an isotropic radiator may be computed from

$$G = \frac{30,000}{W_V W_H}$$

where

W_V = Vertical plane half-power width in degrees

W_H = Horizontal plane half-power width in degrees

For the antenna under consideration G is 17.2 db; therefore, the gain over a half-wave dipole is

$$17.2 - 2.2 = 15 \text{ db}$$

The horizontal directivity of the 385.5-Mc system for reception of horizontally polarized waves is shown in Fig. A8. Side lobes merging into the main lobe appear at angles of 335 and 30 degrees. However, these lobes are at least 17 db down from the peak of the main lobe. Half-power beamwidth is approximately 13.6 degrees. Vertical directivity at 385.5 Mc is shown in Fig. A9. The pattern shows a trace of a side lobe at 45 degrees. Half-power beamwidth is 15.6 degrees. Gain of this antenna calculates to 19.3 db over a half-wave dipole. Signal depreciation indicated on the horizontal and vertical patterns at the ±4-degree angle is not in excess of 1.5 db. Thus, the signal should not be depreciated too greatly during normal roll and pitch of the ship employed.

Immediately before starting the Round Hill runs a directivity pattern was obtained. The same was done before the Scituate runs. In making the patterns the ship stood out at a distance of approximately 12 miles from the transmitting site and the received signal strength was measured as the antenna was rotated clockwise a full 360 degrees. The pattern obtained at 220 Mc is shown in Fig. A10 and that at 385.5 Mc in Fig. A11.

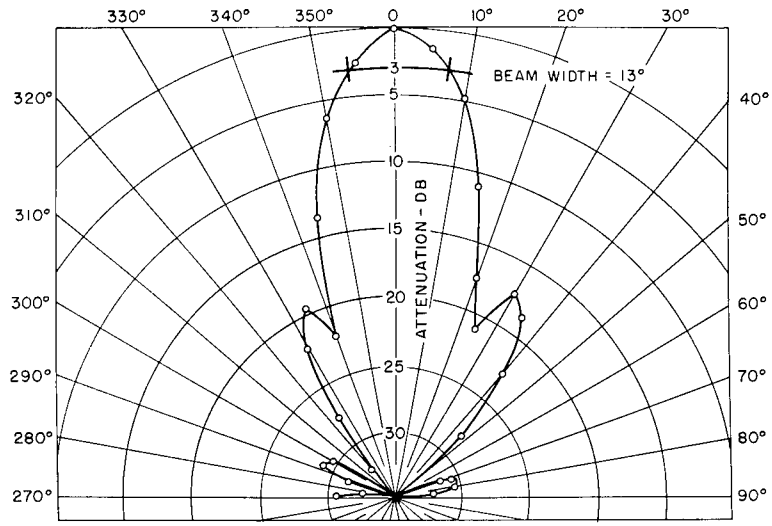

Fig. A8 - 385.5-Mc receiving antenna horizontal directivity pattern measured at NRL

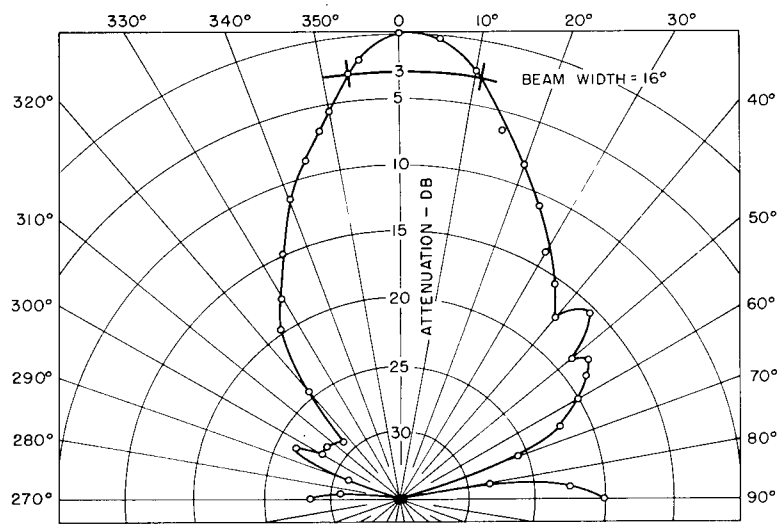

Fig. A9 - 385.5-Mc receiving antenna vertical directivity pattern measured at NRL

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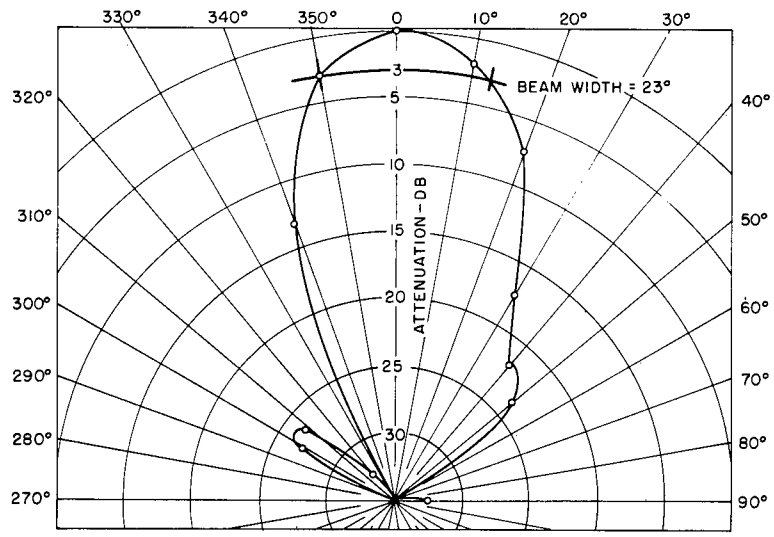

Fig. A10 - 220-Mc receiving antenna horizontal directivity pattern measured aboard ship

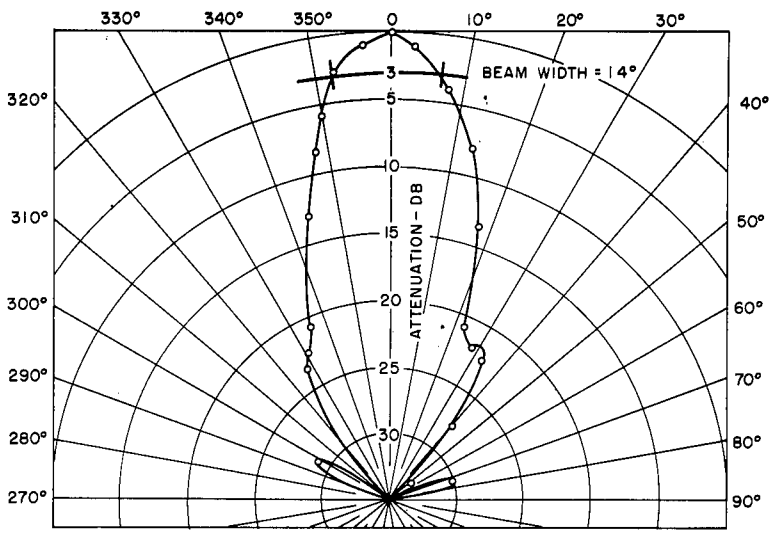

Fig. A11 - 385.5-Mc receiving antenna horizontal directivity pattern measured aboard ship

Laboratory impedance measurements made just beyond the tee in the array piping showed considerable mismatch to the feed line at both operating frequencies. It was necessary, therefore, to insert a matching transformer in the transmission line just behind the tee in each case. At 220 Mc it was possible to reduce an adverse VSWR to 1.12 to 1 looking into the transformer toward the array. At 385.5 Mc the transformer provided produced a VSWR of 1.16 to 1. These measurements were made at the transformer terminals.

VSWR measurements made at the transformer were somewhat different from the VSWR measured at the transmission line terminals in the SK-3 pedestal. Here the VSWR at 220 Mc was found to be 1.29:1 and at 385.5 Mc 1.03:1. These ratios depended to a considerable degree upon the tuning of the "transmission line separator," a quarter-wave impedance transformer associated with separation of the IFF and radar signals when the SK-3 antenna is used in its normal function. In the present instance the transformer tuning was adjusted in each case to the value which gave the best VSWR at the pedestal terminals for 220 and 385.5 Mc. In order to obtain optimum transformer tuning at 385.5 Mc it was necessary to construct a considerably shortened tuning cylinder for the transformer. The optimum transformer setting found experimentally at the Laboratory was employed as the operating frequency required during the sea trials. Shipboard VSWR measurements at the end of the 80-foot run of 1-5/8-inch Styroflex from the pedestal to the receiver room plus the 15-foot run of 3/8-inch Styroflex in the room gave a ratio of 1.6:1 at 220 Mc and 1.12:1 at 385.5 Mc. Published data on the Styroflex indicate an approximate line loss of 0.5 db for the lengths involved.

During the sea runs it was required that the directive antenna remain beamed on the transmitting source even though the ship veered somewhat from the course. By employing a Train Indicator control unit and its associated equipment, automatic positioning of the antenna was maintained after it had been set manually while the ship was on course. Thus, if the ship were to stray considerably off the course, the antenna would no longer be directed toward the transmitting site but along a line parallel to the course. All that the control unit does is to maintain the direction of the antenna fixed with respect to the earth. During the sea runs the ship was able to hold course very accurately.

In order to maintain the low-loss characteristic of the Styroflex line and the line associated with the antenna system both were carefully dehydrated with dry nitrogen immediately after installation. The dry condition of the line was maintained throughout the investigation by use of a dehydrator unit which pumped dry air into the system at 5 pounds per square inch as air was lost from the line through minor leaks in the assembly.

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APPENDIX B
Signal Level Time Totalizer

~~[Unclassified]~~ UNCLASSIFIED

William E. Garner

In the study of vhf-uhf forward scatter propagation it was desired to record signal levels in such a manner that the final data could be presented in the form of a probability distribution. Extracting data from strip-chart recorders for this purpose is much too laborious. Signal level time totalizers have been built to record the total time that the input exceeded certain pre-set levels, and these data could be reduced to a probability distribution very simply. Such totalizers consisted of about ten time-recording channels, each being set to a different input triggering level. The input of the totalizer was generally connected to the agc voltage of a receiver, and thereby recorded the total times that the signal level to the receiver exceeded the various pre-set triggering levels.

The accuracy of the totalizers available for this project was found to be very poor if the input fluctuated at rates of one cycle per second or greater. Some had large errors even at much slower fluctuation rates. These equipments used individual synchronous clock motors driving mechanical counters in each channel. This was satisfactory for very slow cycling; however, for fast cycling (2 to 10 cycles per second) the friction of the motors, being variable among the different units, introduced large errors in the indicated elapsed time. To eliminate this source of error, the design and construction of a totalizer using one continuously running synchronous motor to drive mechanical counters through magnetic clutches was undertaken. It was desired that this totalizer be capable of recording the distribution data for signals fading at maximum rates of 10 per second.

A ten-channel totalizer (Fig. B1) employing magnetic clutches was developed. Each channel consisted of a single stage, dc amplifier driving a thyratron which actuated a magnetic clutch. Four-digit mechanical counters were used in each channel, and all counters were driven from one synchronous motor through the individual clutches. The drive for the counters was so geared that the running time of each channel was recorded in minutes and tenths of minutes. Another counter, driven by a separate synchronous clock motor, recorded the total time of the sampling period. The drive mechanism with the magnetic clutches and a general view of the chassis can be seen in Fig. B2. Each channel was also equipped with a pilot light which indicated when that particular channel was triggered. This was particularly useful when adjusting the trigger levels of the individual channels. Power for the totalizer was obtained from an external, regulated power supply.

The totalizer was tested by adjusting all channels to trigger at the same level and then feeding a 50-percent duty cycle, square-wave voltage to the input. The voltage was sufficient to trigger all channels. The total running time of the test was recorded along with the running times of the ten channels. If the error were zero, then all channel counters would indicate the same elapsed time, which would be one half of the total test period. This test was performed using square-wave repetition rates of 2 and 10 cps consecutively. The maximum error for all channels was ±3 percent for the 2-cps rate and about 20 percent for the 10-cps rate. It is believed that this error could have been reduced if better magnetic clutches were used. This totalizer has proved to be reliable and accurate for recording signals with fading rates up to 5 per second.

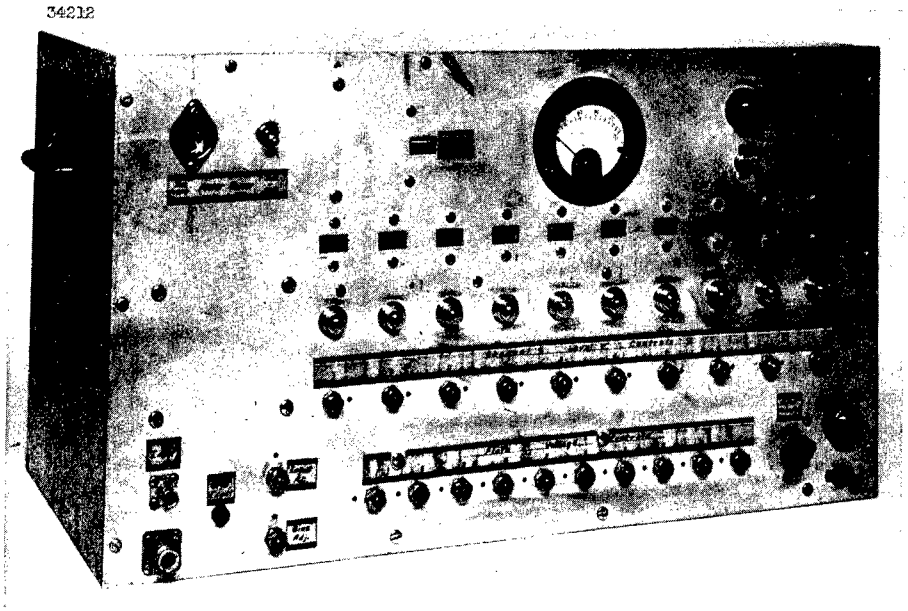

Fig. B1 - Signal level time totalizer

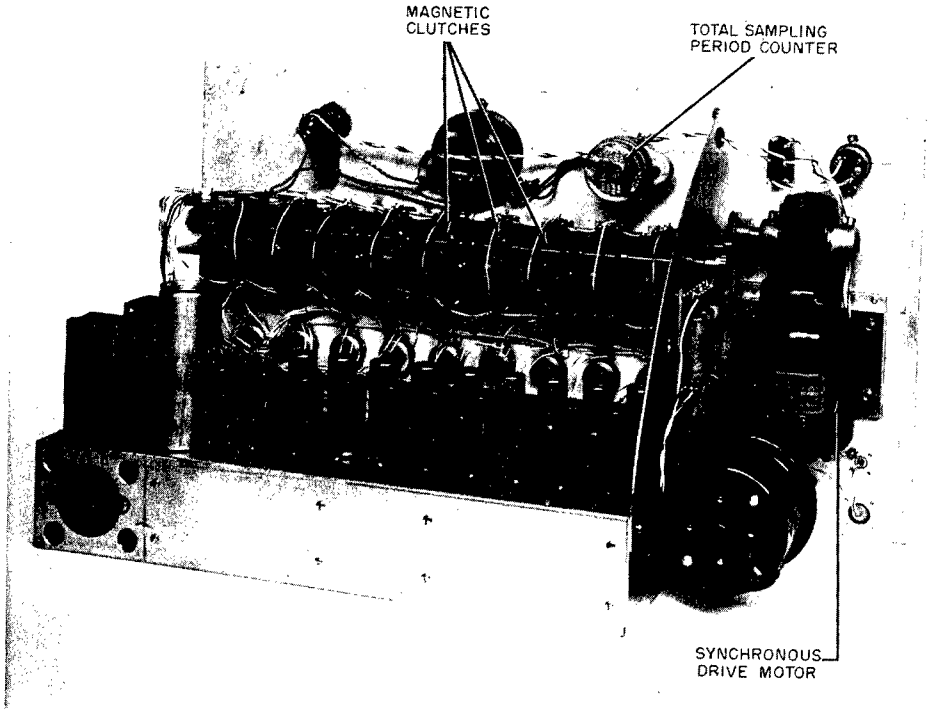

Fig. B2 - Internal view of signal level time totalizer

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