NRL REPORT NO. R-3234

COMPARISON OF AM AND NARROW-BAND FM UHF COMMUNICATION SYSTEMS

APPENDIX E

SHIPBOARD STUDIES AND INVESTIGATIONS

D. McClenon

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Approved by:

T. McL. Davis, Head, Radio Techniques Section
L. A. Gebhard, Superintendent, Radio Division II

NAVAL RESEARCH LABORATORY

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ABSTRACT

Shipboard comparisons were made between amplitude modulation reaching 100 percent modulation on peaks and frequency modulation deviating plus and minus 7 kc. Model TDZ transmitters were employed for both fm and am, with necessary modifications to the fm version. Model RDZ receivers were employed for both fm and am, with the usual am second detector replaced by a ratio detector for fm.

On range trials, a crossover point was obtained at which the signal-to-noise ratio was equal for both f-m and a-m systems. For signals weaker than crossover value, am provided better signal-to-noise ratios, and vice-versa for stronger signals. The crossover point varied from +15 db to +23 db signal-to-noise ratio for various combinations of equipment.

Neither cross-modulation on am nor the corresponding signal-to-noise ratio depression on fm due to near-channel interference appeared appreciable with well-engineered shipboard antenna arrangements. With very close-spaced antennas, the two effects were comparable in magnitude.

Capture effect data obtained were obscured by too many variables to be conclusive, and laboratory trial results obtained under better controlled conditions should be relied on instead.

No noise interference was experienced on either system from radar or ships' electrical or radio equipment.

PROBLEM STATUS

This report completes the shipboard trials on this phase of Problem R01-12.

AUTHORIZATION

NRL Problem No. R01-12 (BuShips Problem S-1388).

COMPARISON OF AM AND NARROW-BAND FM UHF COMMUNICATION SYSTEMS
APPENDIX E
SHIPBOARD STUDIES AND INVESTIGATIONS

INTRODUCTION

The AM vs FM sea trials described herein were conducted to determine the comparative performance of the two types of modulation under practical shipboard operating conditions. The investigation was intended to check the laboratory studies and to uncover any factors of importance which might not have been apparent in the laboratory trials.

Comparison of the two systems on the basis of range, capture effect, cross-modulation or output signal-to-noise ratio depression, and susceptibility to noise interference was desired. All these comparisons appeared possible by the use of three ships. The Operational Development Force furnished the communication ship USS ADIRONDACK, the tank landing ship USS LST 506, and the minesweeper USS PEREGRINE for the trials. These ships were operated out of the Norfolk Naval Station by Operational Development Force personnel. Most of the tests were conducted out of sight of land and in good weather, so that the results represent about the best environmental conditions obtainable for shipboard operation.

Standard crystal-controlled Model TDZ shipboard transmitters were employed to produce the amplitude-modulated signals for the trials. This equipment was operated to deliver about a 16-watt unmodulated carrier to the 52-ohm transmission line, in the 225- to 400-Mc frequency range. (This level dropped about 30 percent with 100 percent modulation; however, no such correction was made for this as was made in the laboratory measurements described in the Laboratory Trials report). This power output is below the rated output of the TDZ, but was kept low to reduce the possibility of transmitter failure. Several TDZ transmitters were modified for the trials to provide a narrow-band frequency modulated carrier and were operated to produce about the same level as the unmodulated AM carrier into the same line. These FM transmitters were designated as Model X-TDZ-2.

Standard crystal-controlled Model RDZ shipboard receivers were employed for amplitude-modulated reception. These receivers utilize a superheterodyne circuit with one r-f amplifier stage and five 15.1-Mc i-f amplifier stages. They can operate on signal frequencies from 200 to 400 Mc. A few RDZ's were modified for FM reception by substituting a ratio-type detector for the usual diode second-detector. These receivers were designated as Model X-RDZ-2. Since the ratio type of FM detector does not have to be preceded by special limiters, the r-f, i-f, and audio systems of the f-m and a-m receivers were identical, and the comparison could be made on the basis of system performance, with a minimum of differences in equipment. Complete descriptions of the equipment with performance data are given in another report. Prior to the trials, the noise-factor was measured on all the operating and spare f-m and a-m receivers employed. This was done (and is more fully described in another report) with a crystal diode and a d-c micro-ammeter connected across the output of the stage immediately preceding the second detector. The transformer involved was retrimmed to correct for the small change in capacity due to the added components. With AVC off and no signal input, the r-f gain was adjusted to produce a convenient noise indication on the micro-ammeter scale. Unmodulated resonant signals of several values close to 1, 2, 3, and 10 microvolts were then applied to the antenna input terminal of the receiver from a standard signal generator, and the micro-ammeter indication was recorded for each signal level. F-m and a-m receivers giving about the same Noise Factor characteristics were used in pairs for the trials. It was found that a pair of receivers perfectly matched on this basis were within 3 db of the same sensitivity when a 20-db signal-to-noise ratio was taken at the audio output and the input was deviated $\pm$ 7 kc at 1000 cps on f m or was modulated 100 percent at 1000 cps on a m Because of this correlation and the much greater ease of making the overall audio or standard sensitivity measurements, only the overall measurements were used for matching receivers on shipboard. Pairs of receivers (one f-m and one a-m) within a 2-db sensitivity limit were selected for use on each ship.

Each ship was fitted with a complete f-m and an a-m RDZ receiver and a complete f-m and an a-m TDZ transmitter, plus spares for each. Each had at least two Type 66147(TDZ/RDZ) antennas - one for receiving, and one for transmitting, with a coaxial line to a suitable coaxial switch so that a quick shift could be made from f m to a m and vice-versa at both transmitter and receiver.

TRANSMITTER INSTALLATION

A block diagram of the transmitter room connections employed on each of the three ships is shown in Figure 1. All the equipment was fed from a 115-volt 60-cps power line through a 2.5 kva variable autotransformer. This transformer, in conjunction with a power line voltmeter, enabled the input to be held constant at 115 volts throughout the trials. Both the f-m and a-m transmitters were equipped with power line filters to reduce the amount of r-f energy which might be fed back into the line and thereby affect some of the measuring equipment. The audio input to the transmitters consisted of either a tone from an audio oscillator or the output from a Brush Model BK-401 magnetic reproducer playing previously prepared tapes. This signal was monitored on an oscilloscope and a vacuum-tube voltmeter to check its quality and level, and it was fed to both transmitters simultaneously.

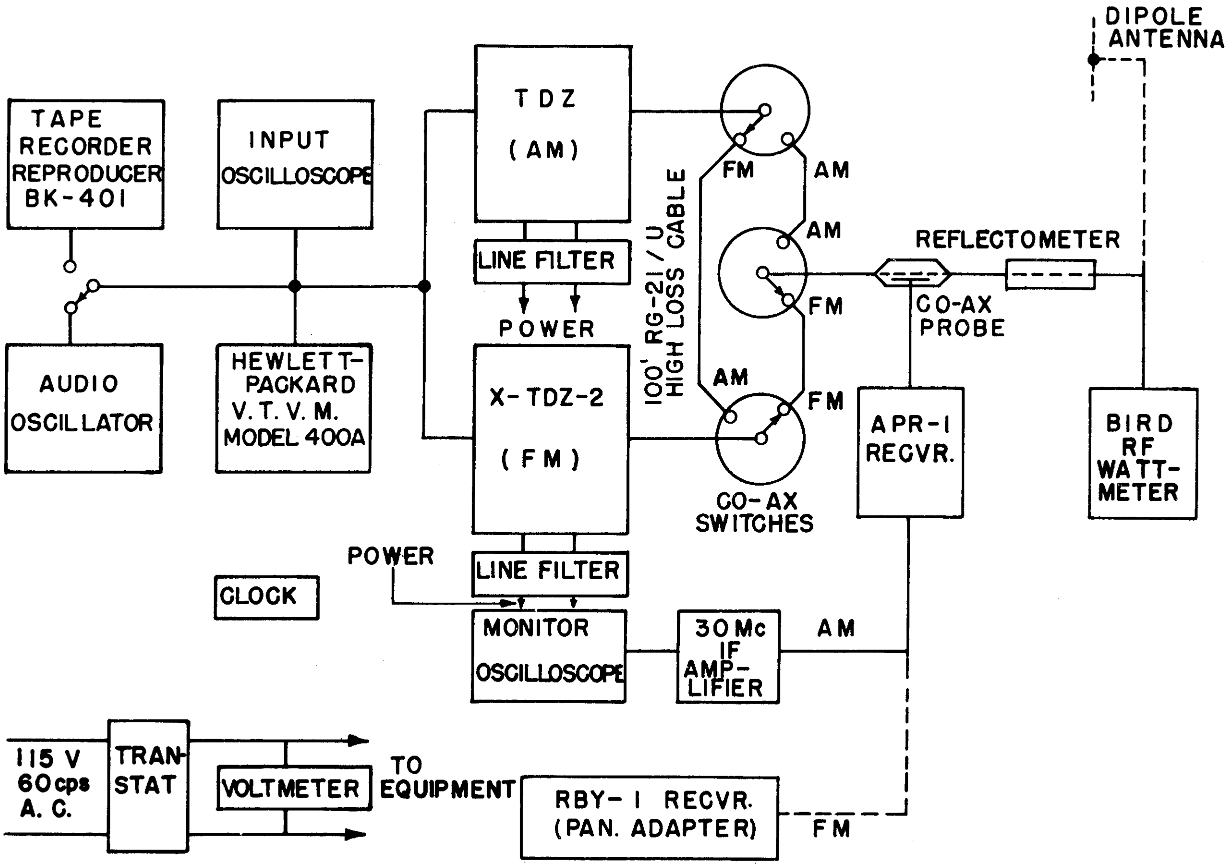

Fig. 1 TRANSMITTER ROOM INSTALLATION - *In Addition to the Facilities Indicated, the Following Communication Arrangements were Provided: (a) Radiophone to the Other Two Ships, (b) Contact with Receiver Room, (c) Contact with Bridge, (d) Contact with Radar Indicator for Range Data.*

It was found that the TDZ transmitter power output level changed excessively just after applying power following a " stand-by " period. The transmitter antenna switching arrangement therefore incorporated a provision for energizing both transmitters, feeding one into the antenna or the Bird r-f wattmeter, while the other fed a lossy-line dummy load of similar characteristics. The transmitters could be interchanged rapidly by throwing three coaxial switches. A reflectometer was installed in the antenna cable to check the standing-wave ratio. A coaxial probe was also installed in this line to permit a sample of the output signal to be taken and fed to the aligning and calibrating equipment. This sample was first fed to a Model AN/APR-1 search receiver incorporating the proper preselector unit for the transmitter frequency. The 30-Mc i-f output from the APR-1 receiver was fed through a 30-Mc amplifier to a monitoring oscilloscope used for a-m adjustments. The same 30-Mc i-f output was also fed to a Model RBY-1 panoramic receiver sharp enough to indicate carrier drop-out for adjusting the f-m deviation.

Communication facilities were available to the bridge of each ship, to the receiving room, and to a radar indicator for range data. The facilities employed varied somewhat from one ship to another. In addition, a medium-frequency radio-telephone link between all three ships was provided. A large clock was mounted within easy view of the operators for operations where synchronization was required.

RECEIVER INSTALLATION

The basic receiver-room installation plan employed on each of the three ships is shown in the block diagram of Figure 2. The same arrangement for controlling the line voltage was used as was employed in the transmitter room, except that a variable autotransformer with a 500-VA rating was found to be large enough. The antenna could be switched to the input of either receiver by a coaxial switch. The antenna cables from the switch to each receiver were of the same length. The audio output of either receiver could be switched to a line feeding a Ballantine Model 300 electronic voltmeter, a Brush Model BK-401 magnetic tape recorder, and a pair of monitoring headphones. A microphone on the recorder enabled local voice announcements describing the conditions of the tests to be incorporated on the records. The communication facilities and the clock were similar to the arrangement in the transmitter room. An RCA Voltohmyst Jr., a cathode-ray oscilloscope, a Measurements Model 80 or a Model LAF signal generator, a modified Boonton f-m signal generator, and a Model LP-5 signal generator with appropriate dummy antennas were employed in aligning and calibrating the receivers, although they were not used during the actual trials. At least one spare f-m and one a-m receiver in good alignment were usually available in each receiver room.

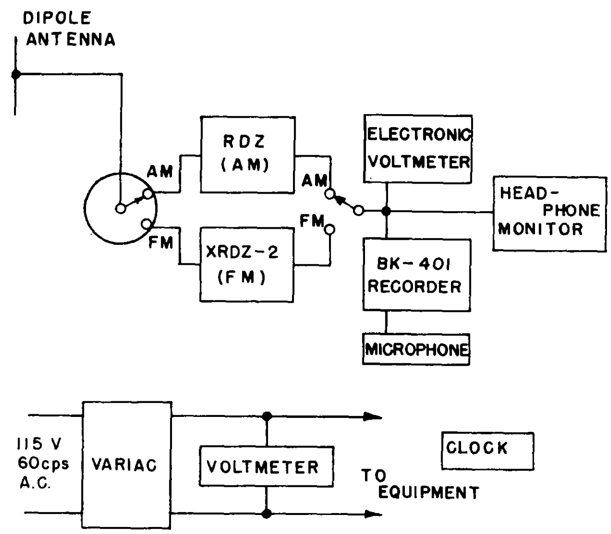

Fig. 2 RECEIVER ROOM INSTALLATION
In Addition to the facilities Indicated, the Following Communication Arrangements were Provided: (a) Radiophone to the Other Two Ships, (b) Contact with Transmitter Room, (c) Contact with Bridge, (d) Contact with Radar Indicator for Range Data.

PRELIMINARY CALIBRATION

A-M Transmitter: - The TDZ was tuned for an unmodulated power output of about 20 watts at 328.2 Mc, using the r-f wattmeter. A one-volt 1000-cps modulating tone from the audio oscillator was applied to the TDZ audio input terminals. The APR-1 receiver was tuned to 328.2 Mc and a signal indication was obtained on the monitor oscilloscope. While the scope was watched, the 1000-cps tone level was adjusted for 100 percent modulation with transmitter AGC off. The fully modulated r-f power output was recorded, as well as the unmodulated value. There was usually a decrease of power output with modulation. The input monitoring scope pattern was adjusted to a convenient amplitude, such as two inches.

F-M transmitter: - The X-TDZ-2 was tuned for an unmodulated power output of about 20 watts at 328.2 Mc. The Model RBY-1 receiver input was connected to the APR-1 receiver's "panoramic" terminal, and the resulting 30-Mc i-f signal was tuned to give a trace on the RBY-1 screen. With the X-TDZ-2's AGC off, the same 1000-cps tone voltage was applied as was used to produce 100 percent amplitude modulation on the TDZ. The modulating frequency was then changed to 2910 cps with the tone voltage held constant and the deviation control was adjusted for the first carrier drop-out as shown on the RBY-1. This drop-out condition corresponds to a deviation of ± 7.0 kc for 2910 cps modulation. The f-m output power was assumed to be the same as it was without modulation. The antenna was connected in place of the r-f wattmeter and the reflection coefficient was measured. The tape reproducer, employing one of the prepared tapes, was started, and the tape reference tone output was adjusted to give the same transmitter input as was used for the initial adjustments.

The r-f and i-f systems of all the f-m and a-m RDZ receivers were carefully aligned after a long warmup period. Use was made of the Model LAF or Measurements Model 80 signal generators and a vacuum-tube d-c voltmeter connected across the diode load to align the r-f section. The Model LP-5 signal generator and an electronic voltmeter connected across the audio output terminals were employed to align the i-f circuits. The signal generator frequencies were accurately set by beating against a Model LM frequency meter at the three critical i-f alignment points.

The sensitivity of all receivers (including all spares for each ship) was measured after alignment. By selection, it was found possible to obtain one f-m and one a-m receiver for each ship. These receivers were within about 2 db of the same sensitivity at the desired operation frequency of 328.2 Mc. The input meter of each receiver was calibrated using the Model 80 or Model LAF signal generator. This calibration was checked at the beginning and end of each run, and if it differed appreciably, the receiver alignment was rechecked.

ANTENNA PATTERNS

Before the disposition of the ships in an operating plan could be decided, it was necessary to know the configurations of the antenna pattern for each antenna used, at the frequencies to be employed in the trials.

The patterns of all antennas on all three ships were measured at the Chesapeake Bay Annex of the Naval Research Laboratory on June 2, 1947. The patterns were measured one ship at a time. Two antennas could be checked simultaneously on different frequencies. The antennas to be checked were excited at a constant level with TDZ transmitters. In some cases, this required an extra length of cable for the receiving antennas. The ship having its patterns checked turned in a tight circle about an anchored buoy approximately 4.5 miles from CBA. The ship's pelorus was used to read relative bearings to CBA. As the CBA tower approached the pelorus cross hair, "standby" was called over the medium-frequency radio link to the CBA operator. When the tower was centered, "mark" was called, followed by "20 degrees", or whatever the proper relative bearing was at that time. The pelorus was then set up 10 degrees, and the process repeated. Two circles were made for each antenna to check the data.

The USS PEREGRINE had only two vertically-mounted RDZ/TDZ antennas installed; one at each end of the sweeping-light yardarm, 71 feet above the water. These antennas were an estimated 20 feet apart horizontally. A 116-foot length of RG-10/U coaxial transmission line ran to the receiver coaxial switch. The same type of line, about 130 feet long, ran to the transmitter switch. This line has a loss of 0.0385 db per foot at 328 Mc.

The polar antenna patterns discussed below are plots of field strength in microvolts per meter against azimuth bearings relative to the ship's head. The pattern of the PEREGRINE'S port antenna (designated No. 1), normally used only for transmitting, is shown in Figure 3. This pattern resembles a four-leaf clover with nulls at the sides, and fore and aft. The presence of these nulls frequently complicated the operating plan, since they required a 20- to 30-degree relative bearing from the PEREGRINE for a good signal. The absolute value of field strength was low for this antenna, even in its best direction, for the amount of power fed to the transmission line. This may have been due to excessive absorption by rigging or other local objects.

The pattern of the starboard PEREGRINE antenna (designated as No. 2), used normally for reception, is shown in Figure 4. This pattern is even poorer than that of the port antenna, being effective over, roughly, only the stern half. This meant that the PEREGRINE could work only off the stern on this antenna, at about a 20- to 30-degree angle. Actual attempts to receive on the "dead" forward portions of this pattern confirmed its shape.

The USS LST 506 installation was similar to that on the PEREGRINE, with the antennas an estimated 35 feet apart and 64 feet above the water. The transmission line from each antenna to its coaxial switch consisted of 78 feet of RG-10/U coaxial cable, with a loss of 0.0385 db per foot at 328 Mc.

The pattern of the starboard LST 506 antenna (designated as No. 2) used normally for transmitting, is shown in Figure 5. There is a null where the mast bearing is located, and the pattern is too sharp and weak directly ahead or astern for reliable use. A minimum use was made of this antenna.

The corresponding No. 1 port receiving antenna pattern is shown in Figure 6. This is fairly good ahead and astern with a null in the direction of the mast. It was used for receiving on most of the range runs.

The antenna installation on the USS ADIRONDACK (E-AGC 15) was considerably more elaborate. There were several MAR, RDR, RDZ, and TDZ equipments aboard, with their associated antennas. Patterns were measured on some of these, and on some installed especially for these trials.

A pair of antennas were mounted 138 feet above the water and 10 feet apart horizontally on outriggers from the forward SG-3 radar platform. A 90-foot length of RG-10/U cable ran from each of these antennas to a radar enclosure designated as the "Top House". From this point, an additional pair of 34-foot lengths of RG-10/U cables could be spliced on, to bring either of these antenna terminations to the coaxial switch of the receiving location in the Flag Communications Room. A TDZ transmitter was located in the "Top House" and was used to excite the receiving antennas for pattern measurements and for certain portions of the tests.

The starboard "Top House" antenna was designated as No. 1 for these trials. Its pattern is shown in Figure 7. The SG-3 radar antenna and the mast shadow nearly a whole quadrant, but the rest of the pattern is fairly good. The port "Top House" antenna was designated as No. 2 for these trials. Its pattern is quite similar to that of No. 1, as shown in Figure 8, except that a different quadrant is shadowed out. Considerable use was made of both these antennas for reception during the trials.

The antenna designated as No. 3 was mounted 121 feet above the water on an outrigger from the YG platform on the after mast. A 132-foot length of RG-18/U cable with a loss of 0.0185 db per foot at 328.2 Mc was installed between this antenna and the coaxial switch in the Radio IV transmitter room. There was a horizontal spacing of 100 feet between the No. 1 or No. 2 antennas and the No. 3 antenna. The pattern of No. 3 antenna is shown in Figure 9. It is unusually smooth for this frequency range aboard ship, and has about a 70-degree dead sector due to shadowing by the Model YG antenna. This antenna radiated more power for the same input than any of the others measured, probably because of its relatively clear location and the somewhat lower losses in its transmission line. It was used for transmitting in most of the range runs.

The antenna designated as No. 4 was mounted about 107 feet above the water at the end of the upper starboard yardarm of the after mast. It was fed with RG-10/U cable from the Radio IV transmitter room. Its pattern, shown in Figure 10, was so irregular compared to that of Figure 9 that antenna No. 4 was not used during the trials.

The No. 5 antenna was mounted about 100 feet above the water on the end of the lower port yardarm of the after mast. It was fed with RG-10/U cable from the Radio IV transmitter room. Measurements were made of its patterns at several frequencies other than the 328.2-Mc trials frequency to determine the extent to which a typical pattern might vary with frequency. The 250.6-Mc pattern is shown in Figure 11, that at 285 Mc is shown in Figure 12, and that at 387.4 Mc is shown in Figure 13. There are wider variations in these patterns than between several different antennas at the same frequency, in some cases. The No. 5 antenna was not used during these trials.

ATTENUATION BETWEEN ANTENNAS

In order to correlate the shipboard data on cross-modulation and signal-to-noise ratio depression with that taken in the Laboratory, it was desirable to determine the attenuation due to spacing between the various transmitting and receiving antennas on the same ship.

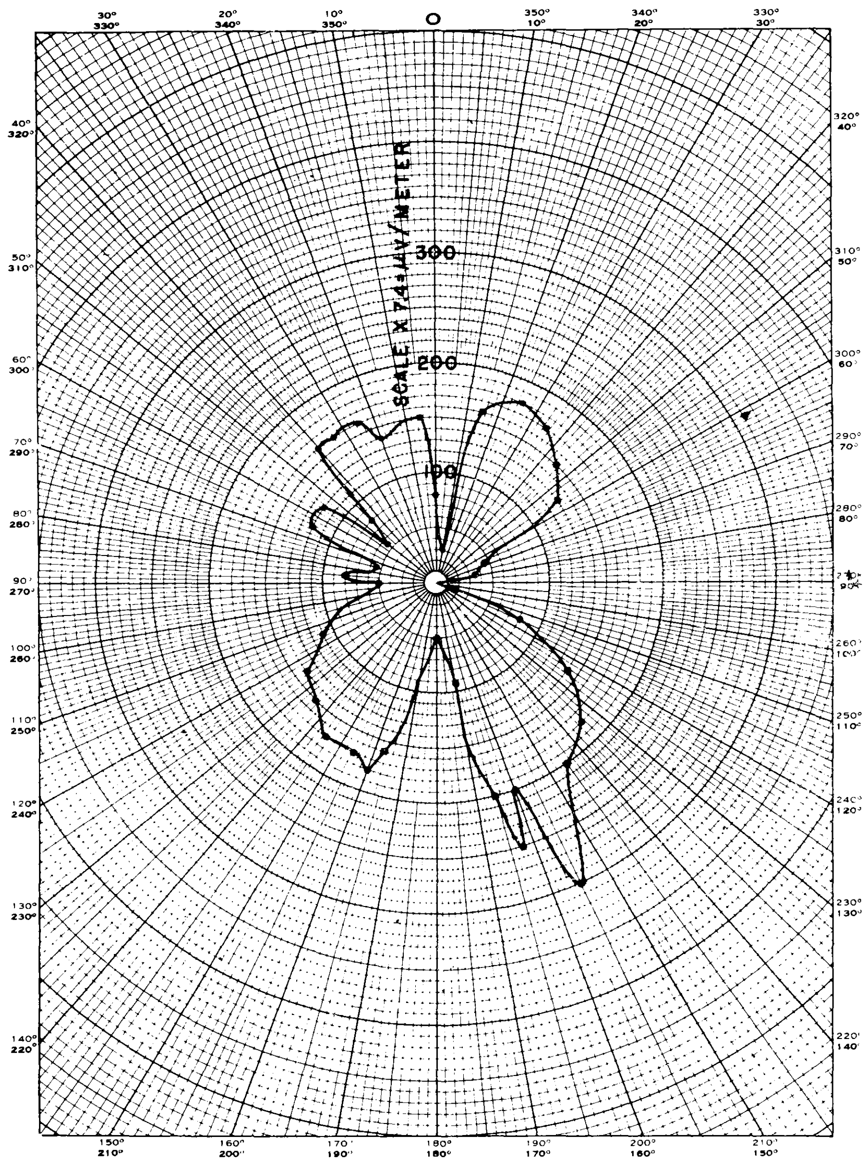

Fig. 3 PATTERN OF USS PEREGRINE PORT NO. 1 ANTENNA AT 328.2 Mc

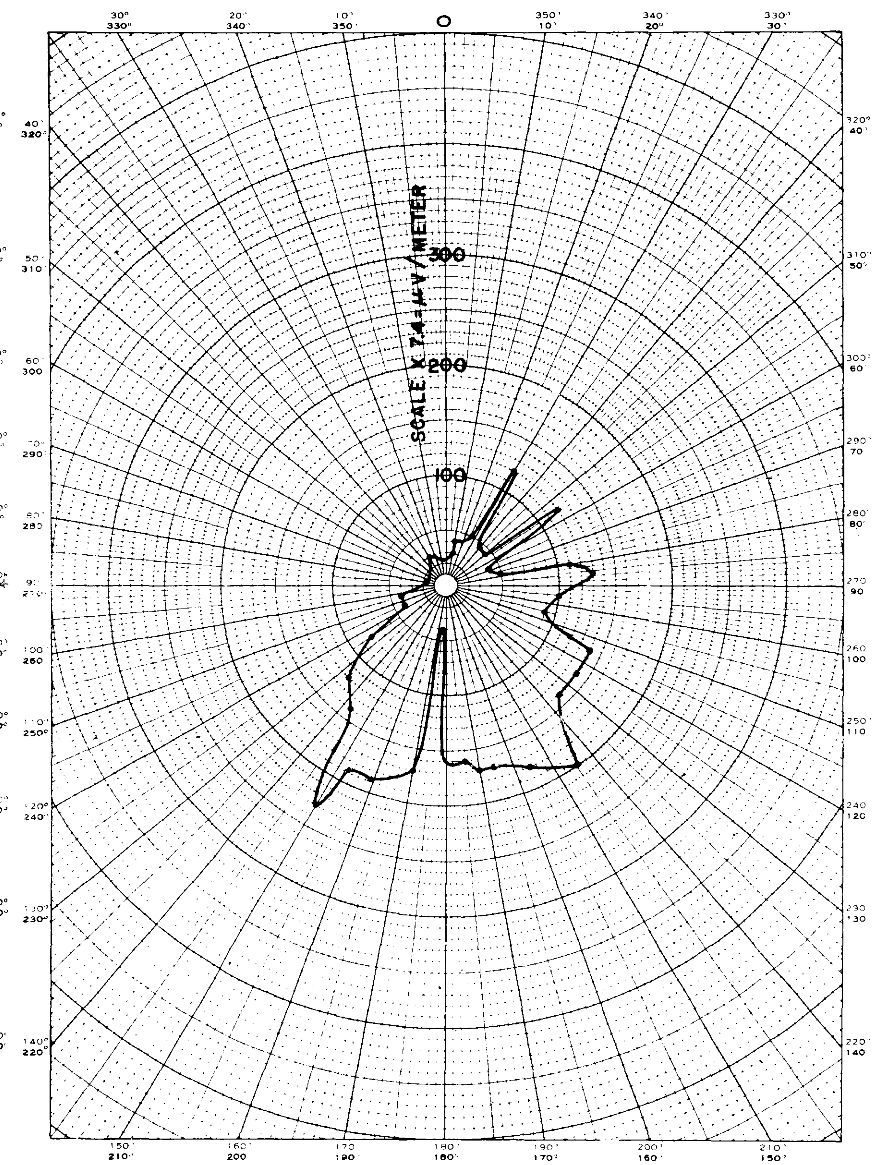

Fig. 4 PATTERN OF USS PEREGRINE STARBOARD NO. 2 ANTENNA AT 328.2 Mc

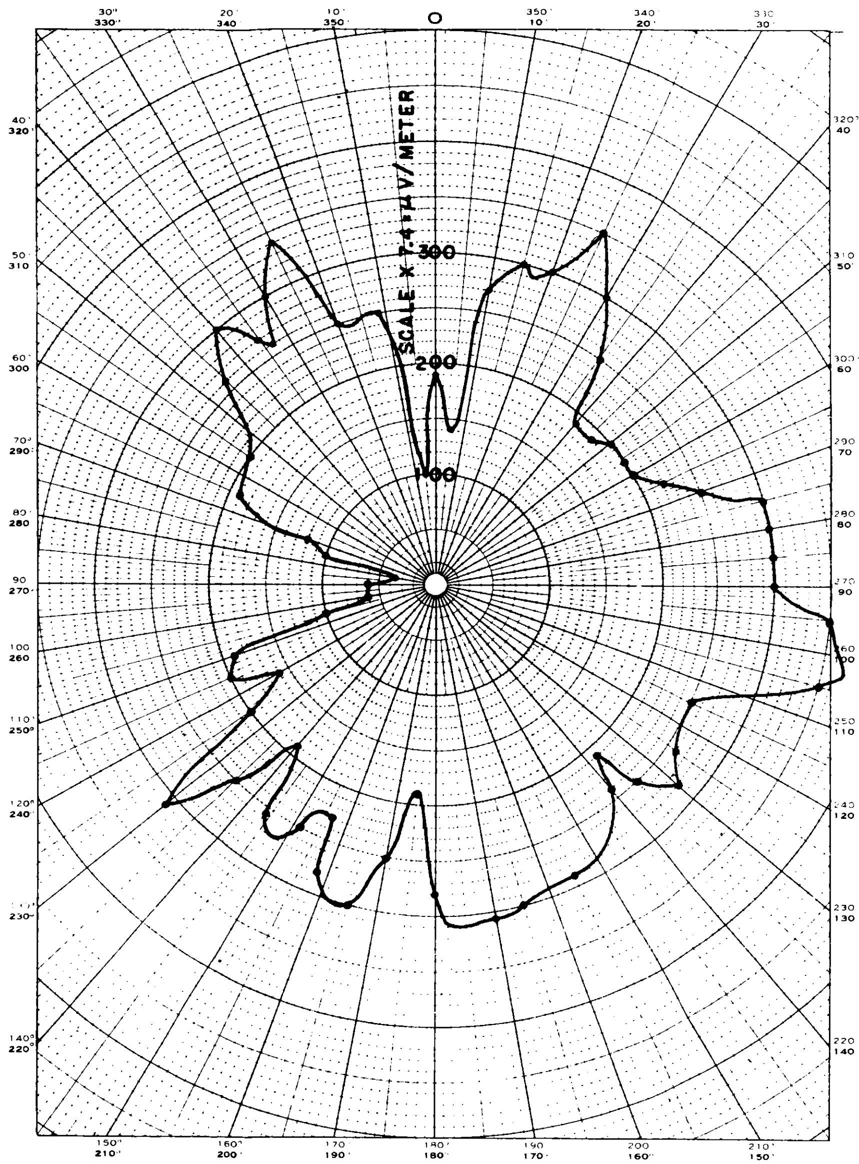

Fig. 5 PATTERN OF USS LST 506 STARBOARD NO. 2 ANTENNA AT 328.2 MC.

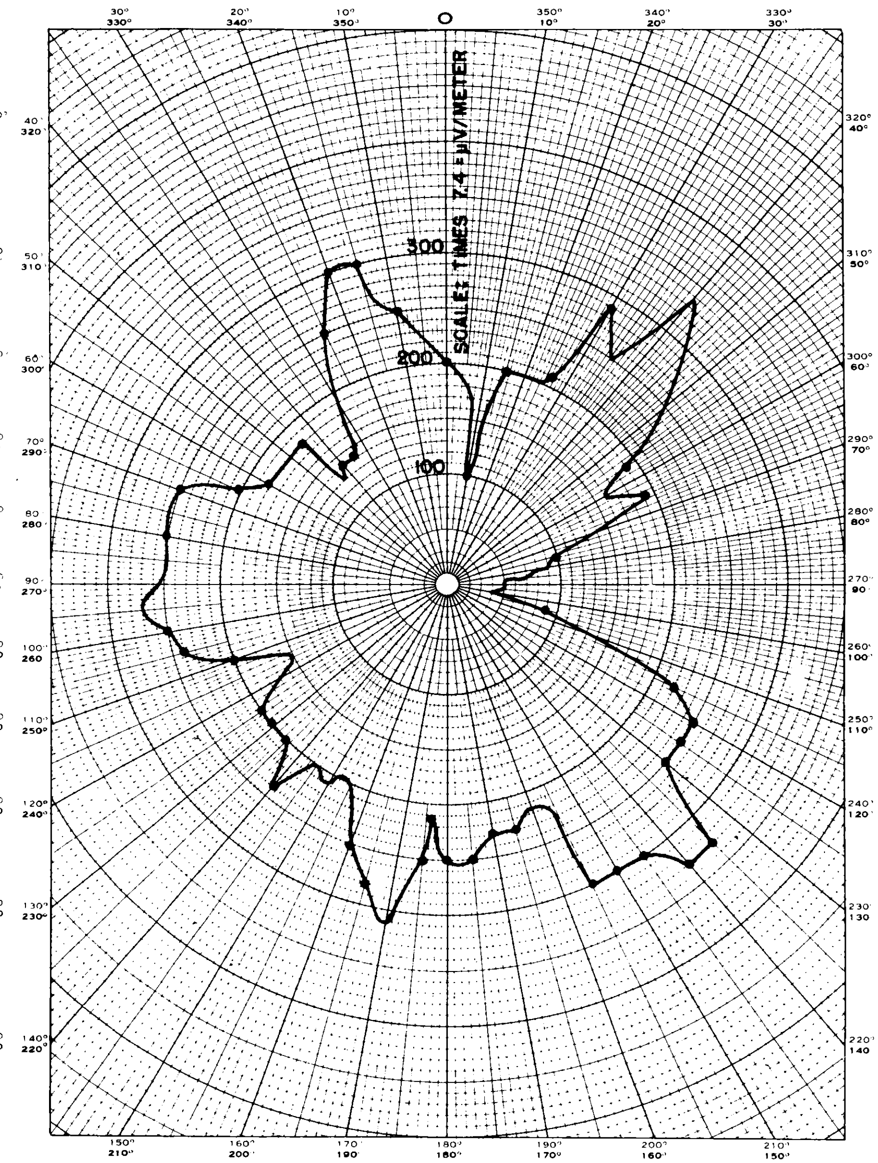

Fig. 6 PATTERN OF USS LST 506 PORT NO. 1 ANTENNA AT 328.2 MC.

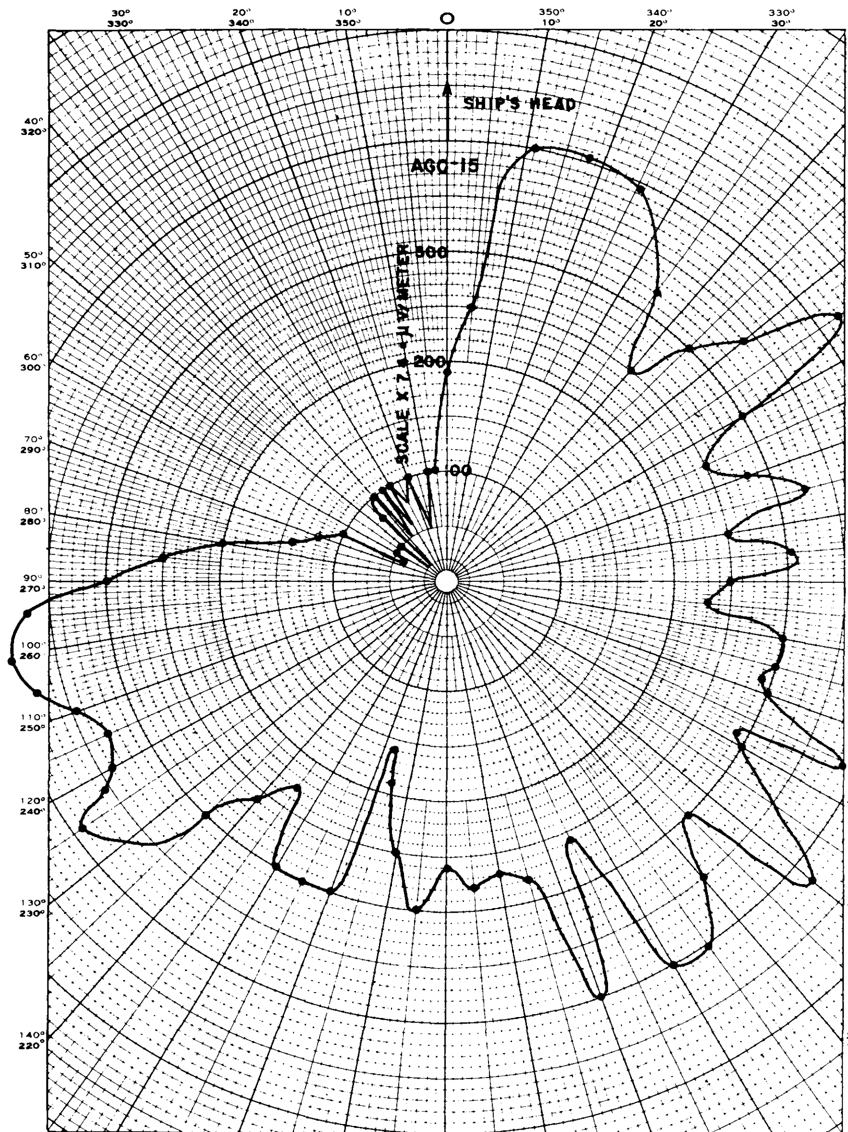

Fig. 7 PATTERN OF USS ADIRONDACK STARBOARD "TOP HOUSE" ANTENNA NO. 1 AT 328.2 MC

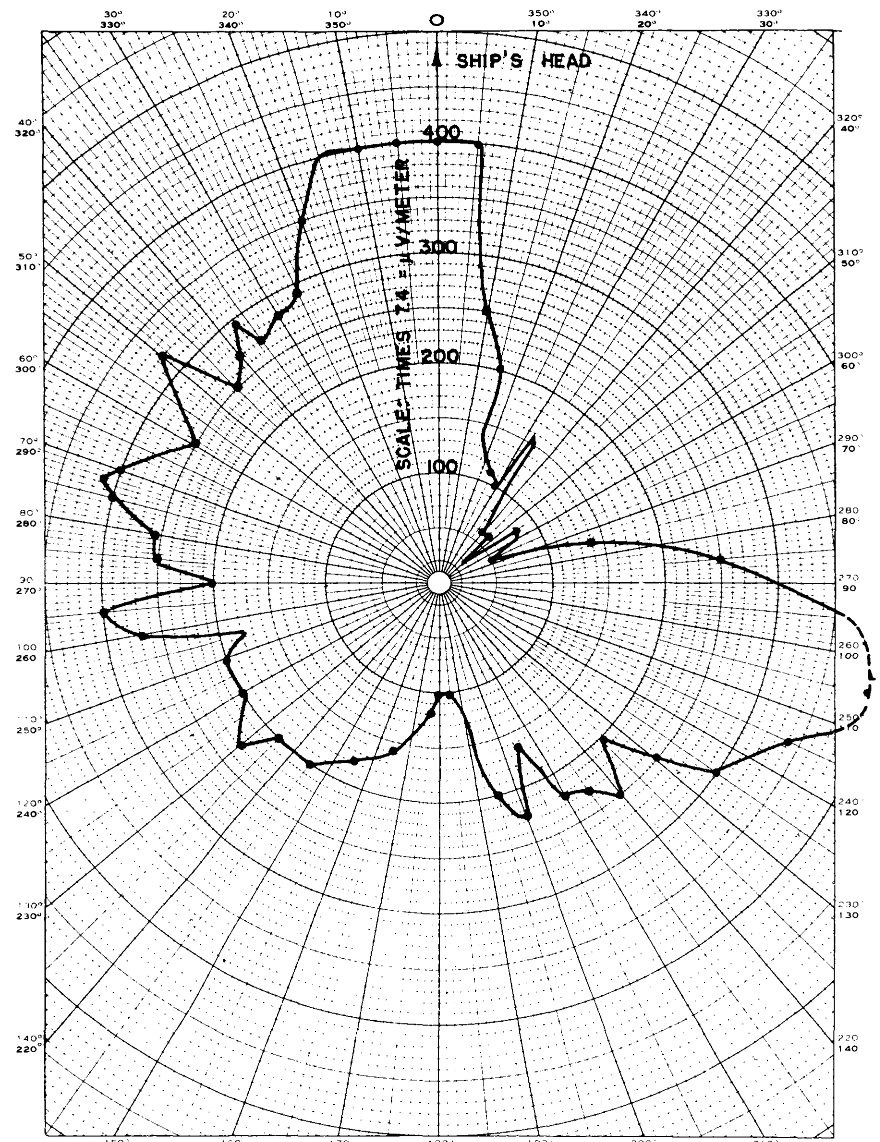

Fig. 8 PATTERN OF USS ADIRONDACK PORT "TOP HOUSE" NO. 2 ANTENNA AT 328.2 MC.

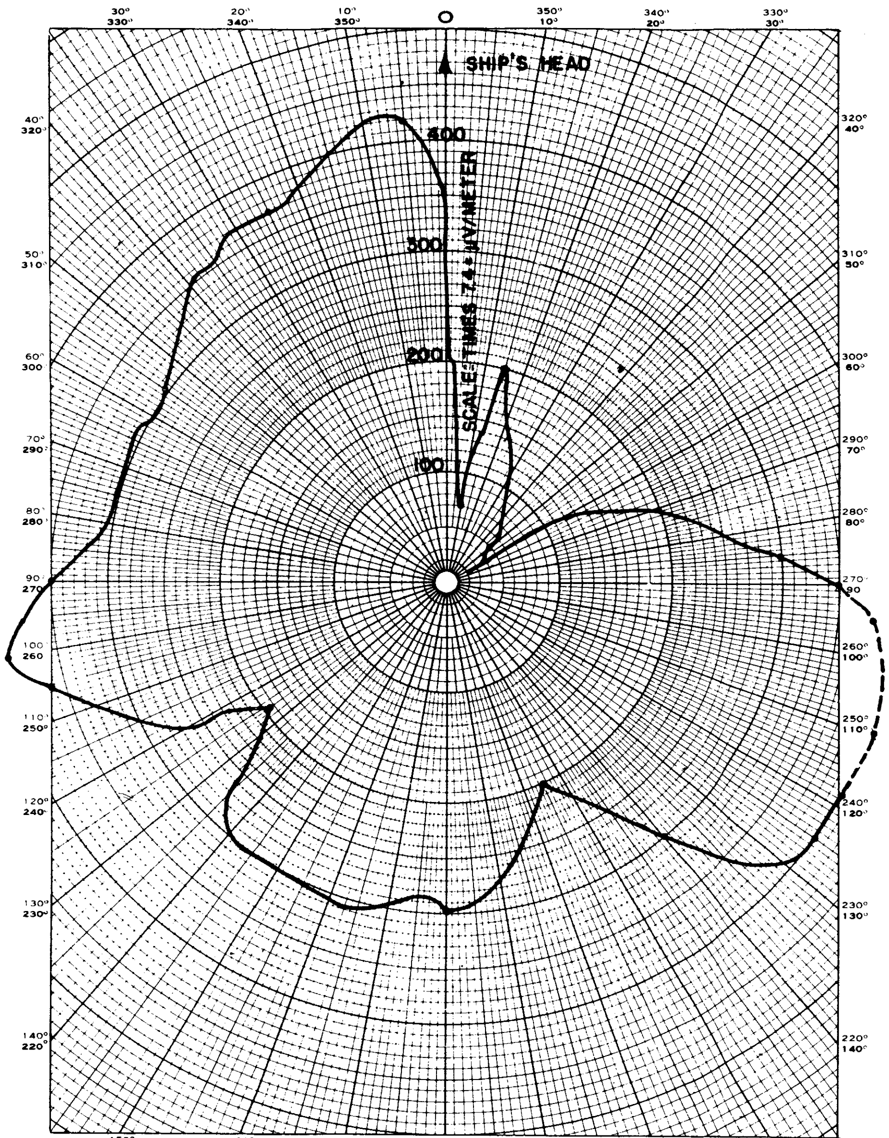

Fig. 9 PATTERN OF USS ADIRONDACK ANTENNA NO. 3 ON YG PLATFORM RAILING AT 328.2 MC.

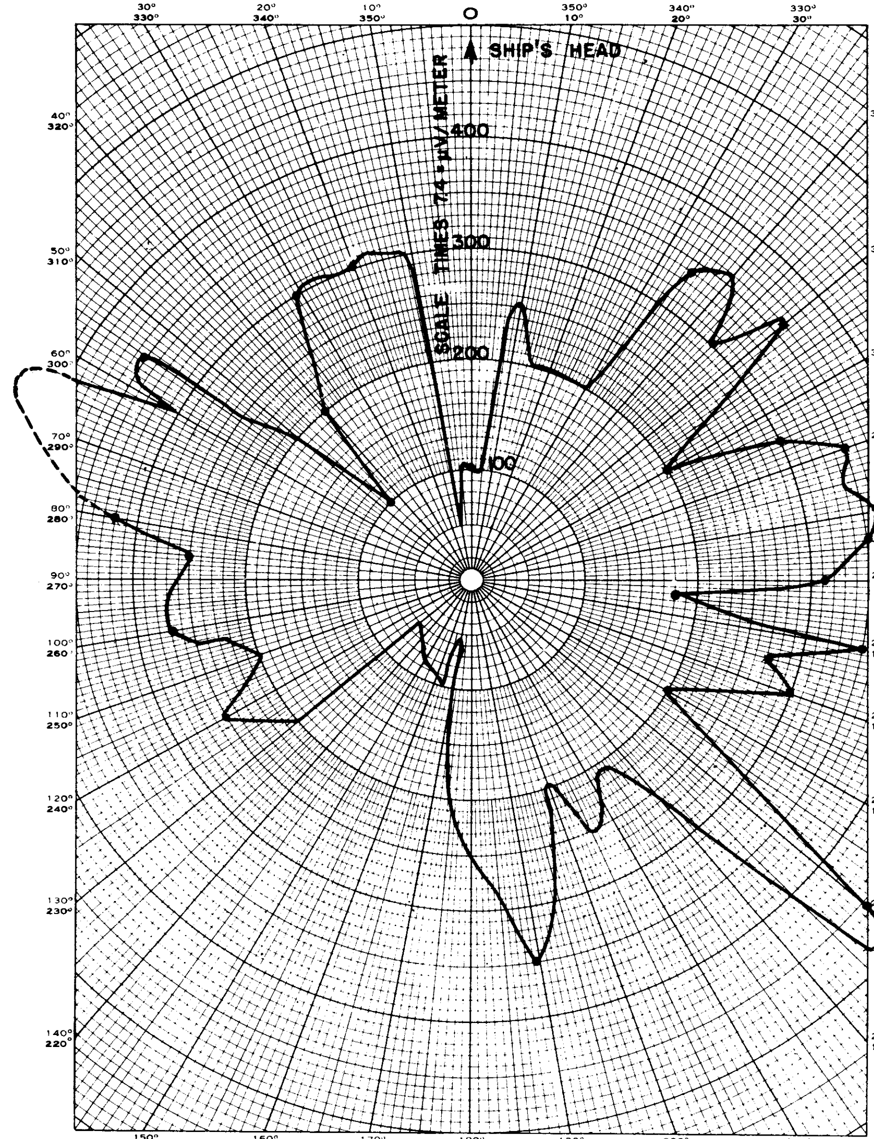

Fig. 10 PATTERN OF USS ADIRONDACK ANTENNA NO. 4 (STARBOARD RDZ FROM RADIO IV) AT 328.2 MC.

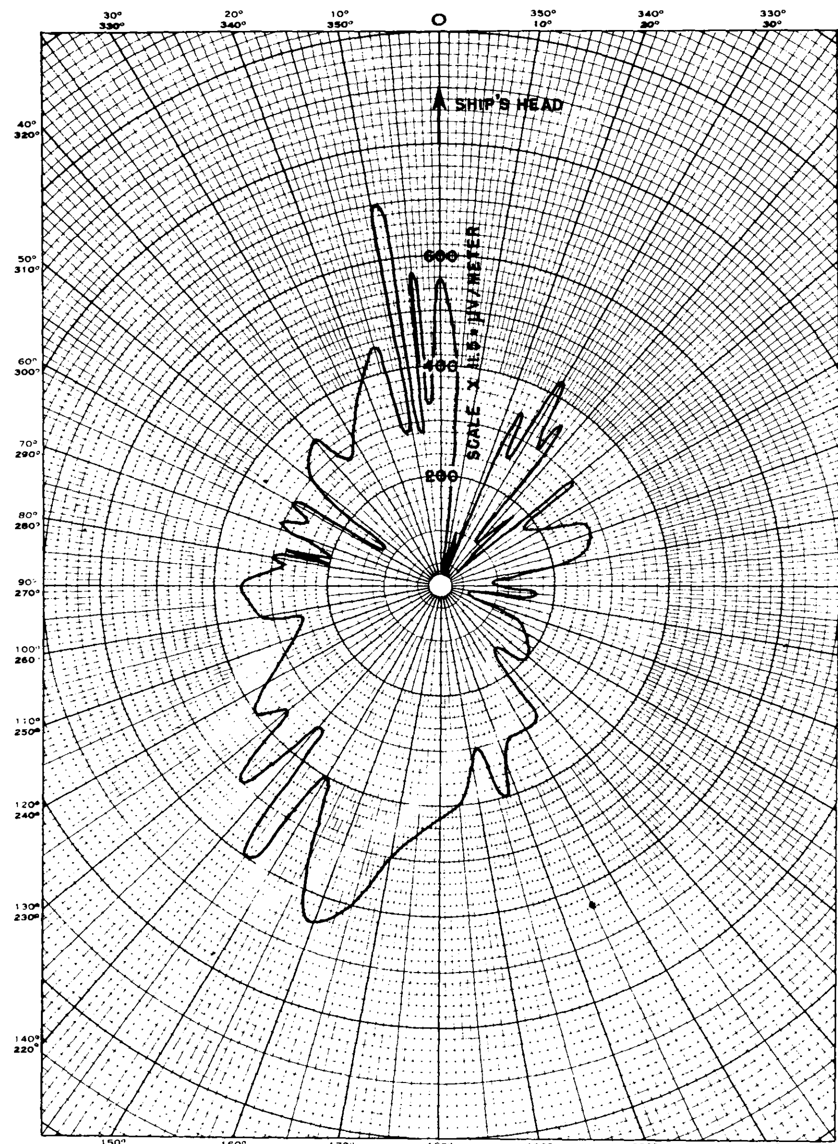

Fig. 11 PATTERN OF USS ADIRONDACK ANTENNA NO. 5 (PORT TDZ FROM RADIO IV) AT 250.6 MC.

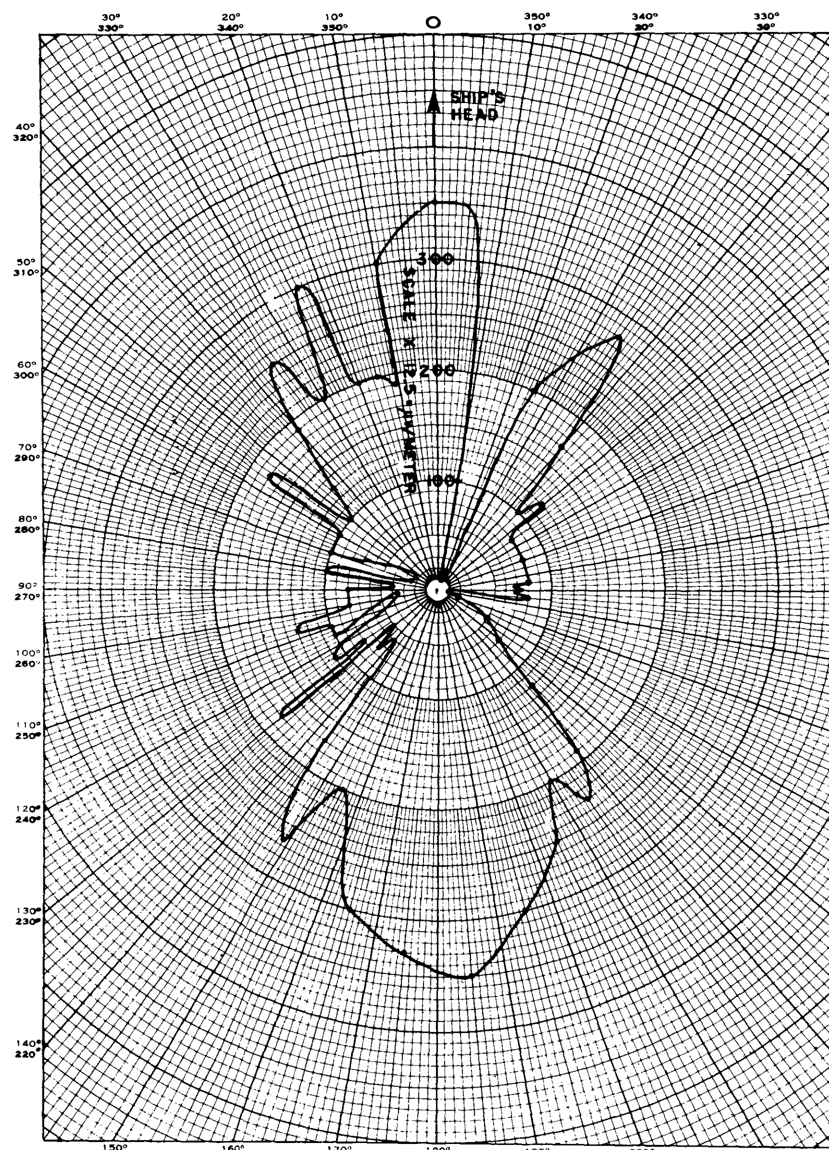

Fig. 12 PATTERN OF USS ADIRONDACK ANTENNA NO. 5 (PORT TDZ FROM RADIO IV) AT 285.0 MC.

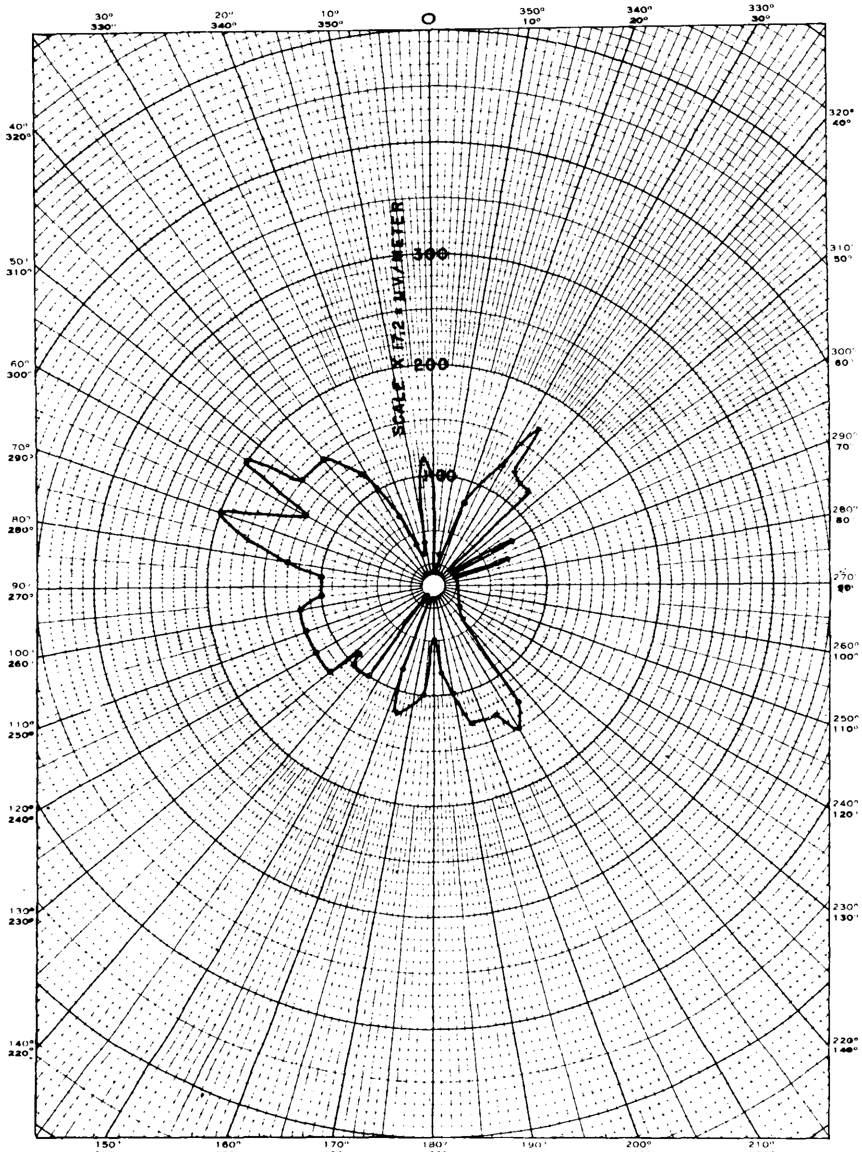

Fig. 13 PATTERN OF USS ADIRONDACK NO. 5 ANTENNA (PORT TDZ FROM RADIO IV) AT 387.4 MC.

This was done by using the unmodulated signal from a TDZ transmitter to feed an RDZ receiver, either by radiation from the TDZ to RDZ antennas, or directly through a calibrated Model LAF signal-generator attenuator specially modified for the purpose. The block diagram of connections is shown in Figure 14. A 26-db "lossy" line was connected on each side of the LAF attenuator so that it could not upset the standing-wave ratio on the line. The attenuator was set at minimum, and the RDZ receiver's AVC was switched "on". With both TDZ and RDZ operating on 328.2 Mc, the RDZ input meter reading was noted. Both antenna cables were then removed and the output lossy line was directly connected to the RDZ receiver's antenna terminal. This was possible, even though the RDZ was on a different deck, by feeding the lossy line down ladders, through stuffing tubes, etc., as it had considerable physical length. The LAF attenuator was then adjusted until the previous RDZ input meter reading was obtained, and the attenuation was determined from the attenuator calibration. This total attenuation included the individual attenuations due to both the transmitting and receiving antenna cables normally present in the system. From the previously given cable lengths and the cable attenuation figures available, cable losses could be subtracted to determine the space attenuation between antennas alone, assuming proper line termination.

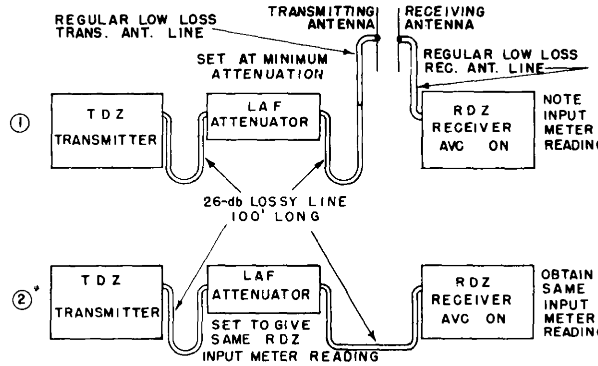

Fig. 14 MEASUREMENT OF ATTENUATION BETWEEN TRANSMITTING AND RECEIVING ANTENNAS PLUS BOTH TRANSMISSION LINE LOSSES.

RANGE TRIALS

The general procedure employed for the shipboard range trials was to have one ship transmit while traveling just fast enough on a constant line and heading to maintain steerageway, while another ship received the signal as it traveled on the same line and heading ahead of the first ship at a greater speed to open the range. Range data was usually obtained directly by radar but sometimes by adding radar range data from a third ship stationed between the two engaged in the range run. When radar range was exceeded, dead reckoning had to be employed.

The transmitters were fed a program from the magnetic reproducer, consisting of 30 "cycles" of one-minute duration each. A cycle consisted of the voice announcement of the cycle identification number (Cycle 1, Cycle 2, etc.), followed by several seconds of 1000-cps tone, and then eight one-syllable words taken from the Harvard Psychoacoustic Laboratory's "P.B." word lists. On every odd cycle (1, 3, 5, etc.), the f-m transmitter was switched into the radiating antenna, and the f-m receiver was switched to the antenna on the receiving ship. A-M equipment was employed at both ends of the system on the even cycles (2, 4, 6, etc.). The recorded tone level had been previously related to the voice level so that if the transmitter was adjusted for full f-m deviation or 100 percent amplitude modulation on the tone, the voice peaks would just reach this value of deviation or modulation.

On the receiving ship, the audio output was set to the standard value of 6 milliwatts by adjusting the audio gain control while the reference 1000-cps tone was being transmitted. The receiver conditions were AVC "on", silencer "off" (zero position), output meter "on", i-f "narrow", and audio "narrow", for both f-m and a-m systems. Readings were taken, during each cycle, of the cycle number, the time, range, relative bearing, noise level with unmodulated carrier, and the input meter indication. Occasionally the noise level without carrier was checked to see if the receiver gain was holding constant. The entire program was recorded on magnetic tape. At the end of cycle 30, a new blank tape was put on the receiving recorder. The date, reel number, and approximate range were recorded on each tape by voice announcement, using the local microphone. The transmitting ships each had a supply of identical program tapes, all made from the same master. At the end of a half-hour program, the record could either be rewound and used over, or removed and replaced with a duplicate record while being rewound or repaired.

From the data taken, the bearing variation could be checked to insure that excessive changes in antenna pattern lobes had not been allowed to occur. The output signal-to-noise ratio was determined, and the input signal strength was separately established from the input meter calibration of each receiver.

It was believed that the results could be most usefully presented as plots of signal-to-noise ratio vs range in nautical miles. To establish the correlation between signal-to-noise ratio and signal strength, comparisons were made in much of the recorded data, and although individual points were found to be slightly off the general trend, the correlation as a whole appeared to be remarkably good in all cases. A typical example is a portion of the a-m data taken on the June 9, 1947 range run and shown in Figure 15. A minimum signal of 1 microvolt could be detected on the input meter, and this was arbitrarily called zero-db level for signal strength. Over a 21-db spread of signal level, the correlation can be seen to be good, even for relatively fast drop-outs. All the following range data is therefore given in terms of signal-to-noise ratio vs nautical miles range, and the signal strength at any point may be estimated from the data in Figure 15. Exact figures were taken in all cases, but inclusion in this report did not appear pertinent to the object of the trials.

Plots of S/N ratio vs microvolts input showing all points taken on several LST-506 runs are shown in Figure 16 for a.m. and in Figure 17 for f-m. These show that the spread of data or the degree of control in the tests, on the average is within about 7 db. Plots for the other ship installations are similar, but are displaced in position, due to differences in signal generator calibrations.

Several range runs were made in which equipment trouble developed, or alignment or calibration changed excessively during the run. Since these data have no value in comparing the systems, except possibly on a reliability basis, which reflects on the equipment used rather than the system, they are not included in this report.

The signal-to-noise ratios at various ranges for both fm and am obtained during a short daytime range run, with the ADIRONDACK transmitting and the PEREGRINE receiving, are shown in Figure 18. The run was started with a little less than 15 nautical miles spacing. From here out to about 16.5 miles, the f-m signal had a higher signal-to-noise (S/N) ratio. They became equal at a 22-db S/N ratio. For the rest of the run out to over 21.5 miles, the a-m signal had the higher S/N ratio. At 19.85 miles, the f-m signal had dropped so low that it was not discernible, and it was not heard thereafter. At 21.35 miles, the a-m signal was still giving voice signals which produced perfect copy of plain language newspaper stories by about seven out of ten of the engineers and ship's personnel present.

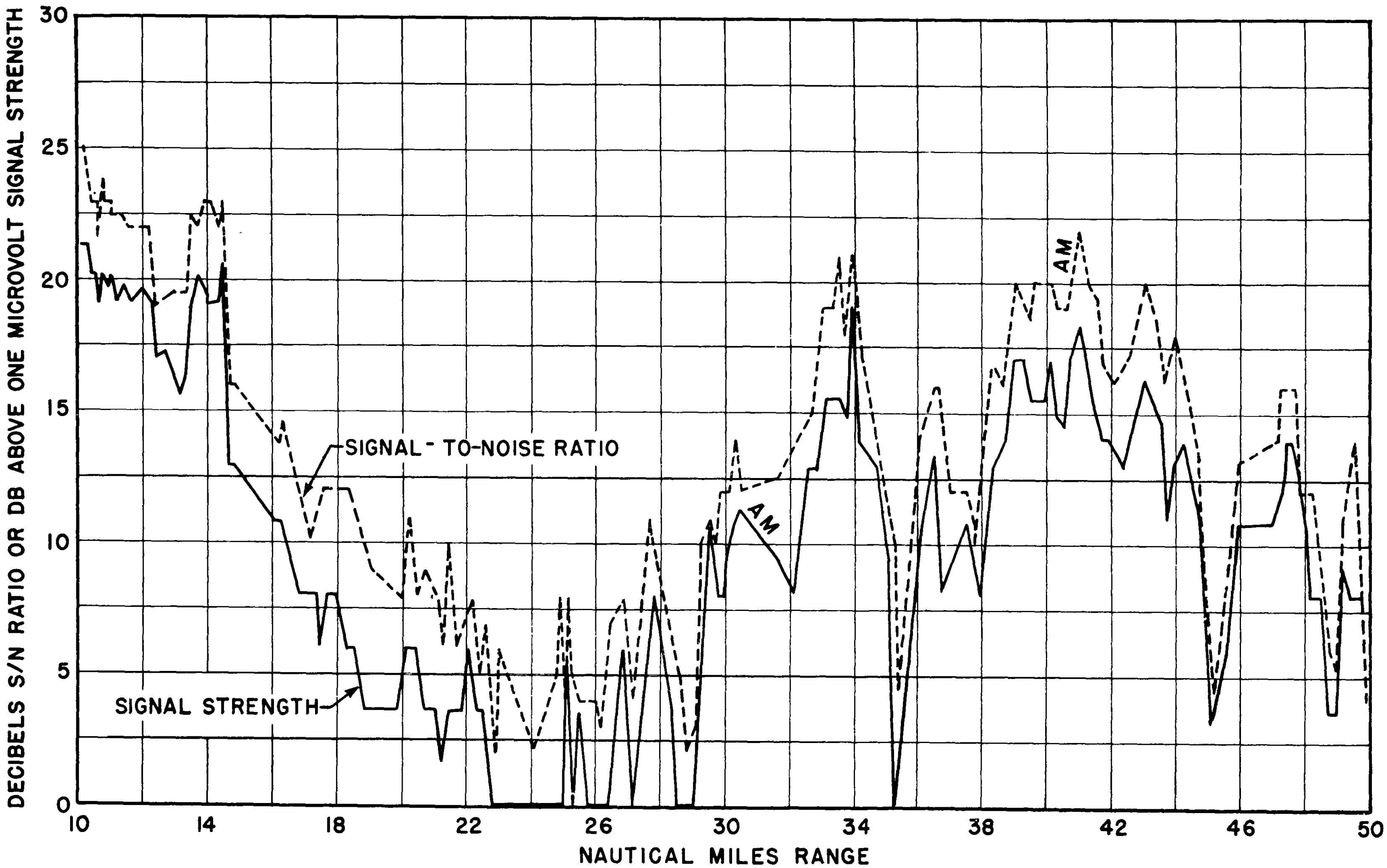

Fig. 15 SIGNAL STRENGTH COMPARED WITH SIGNAL-TO-NOISE RATIO FOR AM ONLY, TAKEN FROM RANGE RUN OF JUNE 9, 1947 - *The USS ADIRONDACK was Transmitting 11 Watts Carrier into Transmission Line at 100 Percent 1000 cps Modulation. Transmitting Antenna No. 3 was 121 Feet Above Water, and the USS LST 506 was Receiving on the Port No. 1 Antenna, 64 Feet Above Water.*

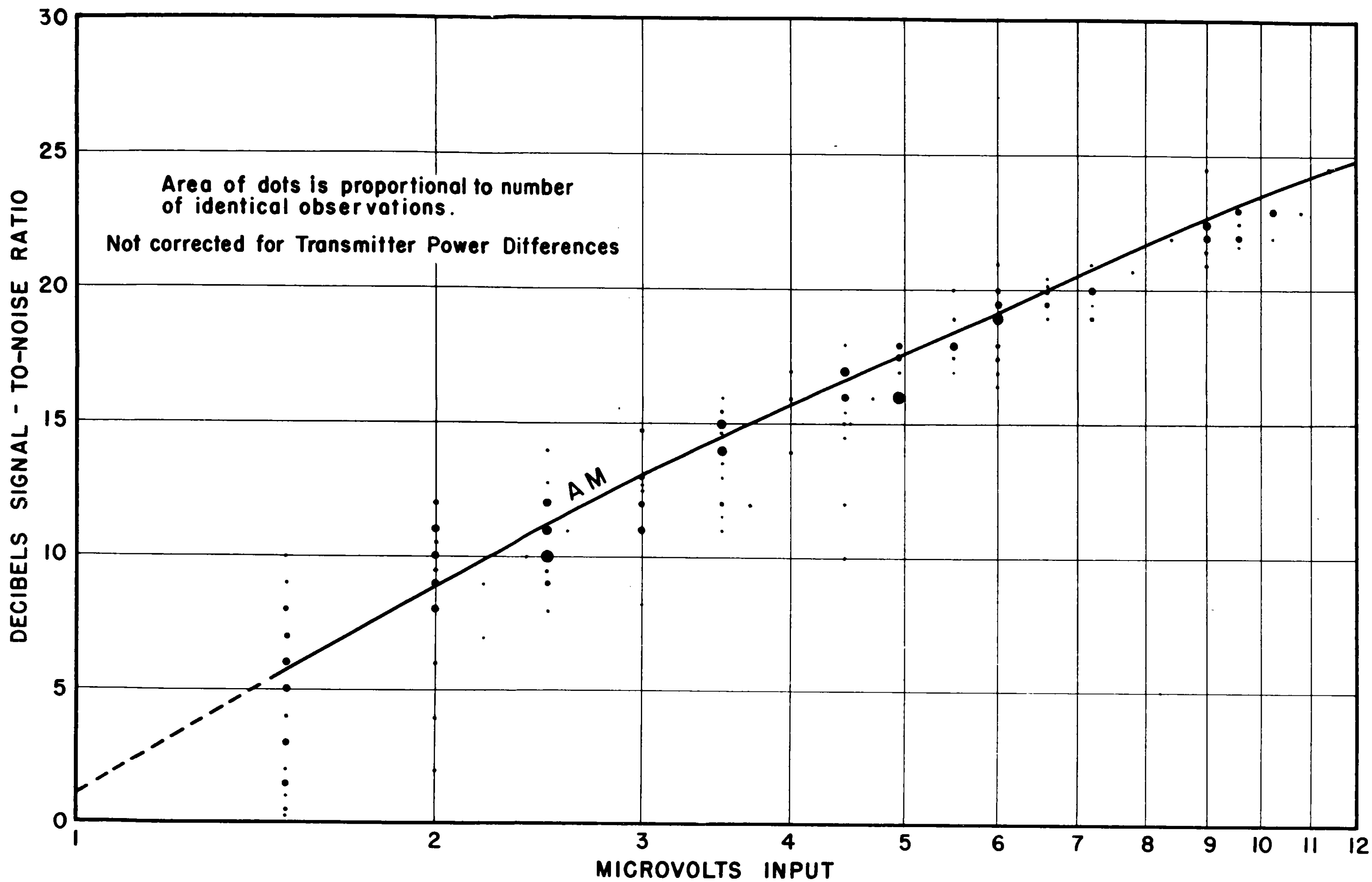

Fig. 16 COMPOSITE PLOT OF A-M S/N RATIO VS MICROVOLTS INPUT, TAKEN FROM RANGE RUNS OF JUNE 6 THROUGH 12, 1947, USING RDZ RECEIVER ON USS LST 506

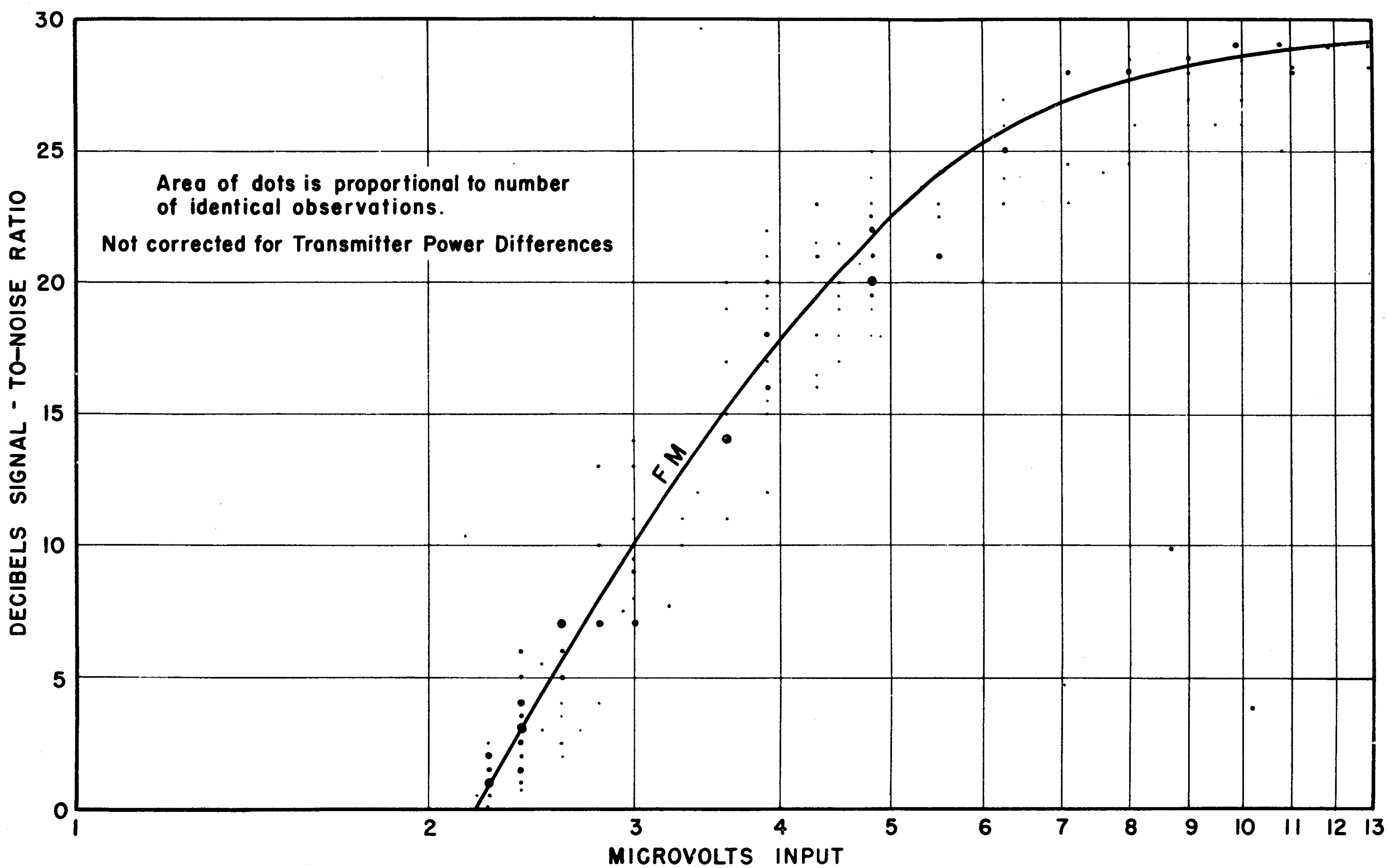

Fig. 17 COMPOSITE PLOT OF F-M S/N RATIO VS MICROVOLTS INPUT, TAKEN FROM RANGE RUNS OF JUNE 6 THROUGH 12, 1947, USING X-RDZ-2 RECEIVER ON USS LST 506

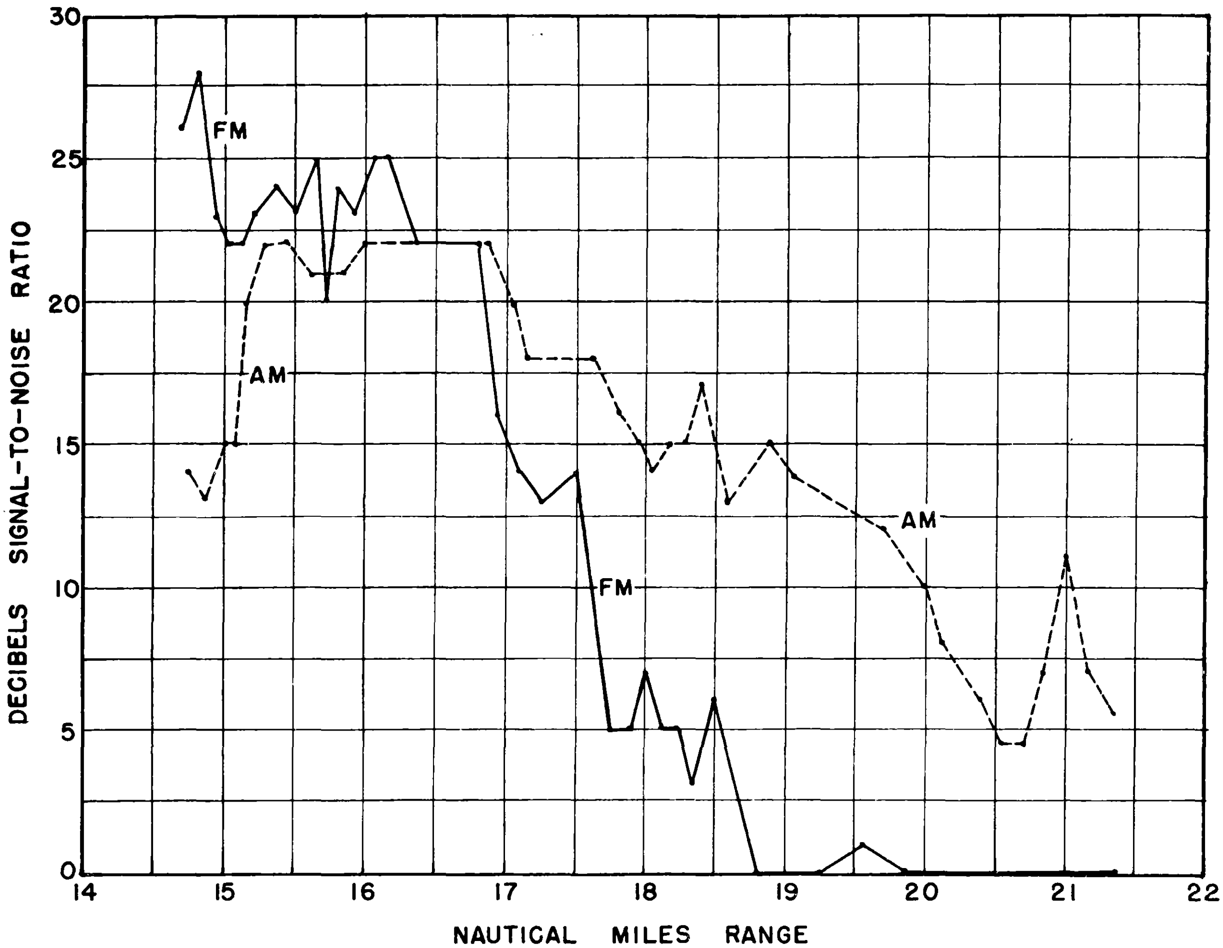

Fig. 18 DAY RANGE RUN OF JUNE 6, 1947, WITH USS PEREGRINE RECEIVING – *The USS ADIRONDACK was Transmitting 11 Watts Carrier into Transmission Line at 100 Percent 1000-cps Modulation on am and 16 Watts Carrier into Transmission Line at ±7.0 kc Deviation at 1000-cps Modulation on fm; Transmitting Antenna No. 3 was 121 Feet Above Water.*

There was fairly good agreement among all personnel participating in the trials (about 15 persons), that a 4-db S/N output ratio was about the limit to which the signal could drop (based on a 1000-cps tone modulated 100 percent on am or ±7 kc on fm) and still give an 80 to 90 percent perfect copy on plain language voice signals.

A similar day range run made with the same transmitting setup on the ADIRONDACK, but with the LST 506 receiving, provided the data shown in Figure 19. The test started at about 18 miles, where both signals were equal at a 15-db S/N ratio. Throughout the remainder of the run, the a-m signal always provided the higher S/N ratio. The increase in absolute range over that obtained with the PEREGRINE is ascribed to the superior antenna location and pattern on the LST 506.

To illustrate how propagation conditions change, another day run, made with the two ships and antennas just described, is shown in Figure 20. This run commenced at a 13.5-mile spacing with about a 23-db S/N ratio for both fm and am, but with fm averaging slightly better. At the 18.2-mile range where the two were equal previously, they were again equal at a 19-db S/N ratio. Then a series of violent "fades" took place, which gave opportunity to check the cross-over point several times. Both signals faded completely out briefly at 21 miles, and then built up to even higher levels than at the start of the run. Cross-overs varied from about 14 to 23-db S/N ratios, but the suddenness of

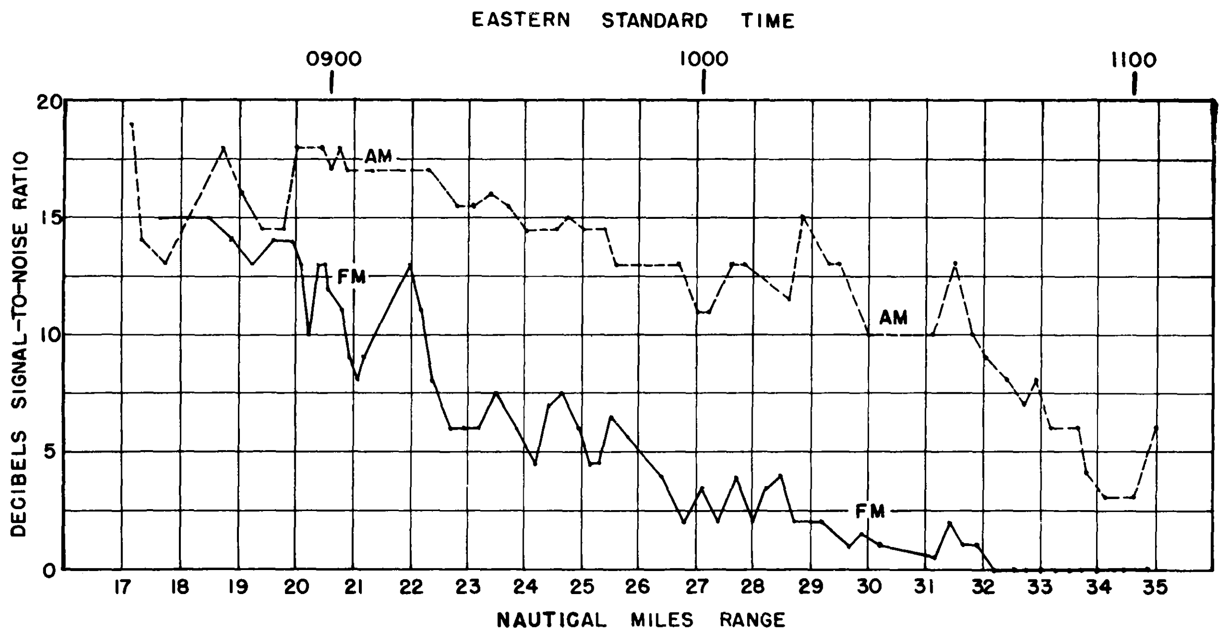

Fig. 19 DAY RANGE RUN OF JUNE 6, 1947, WITH USS LST 506 RECEIVING- *The USS ADIRONDACK was Transmitting 11 Watts Carrier into Transmission Line at 100 Percent 1000-cps Modulation on am and 16 Watts Carrier into Transmission Line at ±7.0 kc Deviation at 1000-cps Modulation on fm; Transmitting Antenna No. 3 was 121 Feet Above Water. USS LST 506 was Receiving Over Bow on Port No. 1 Antenna, 64 Feet Above Water.*

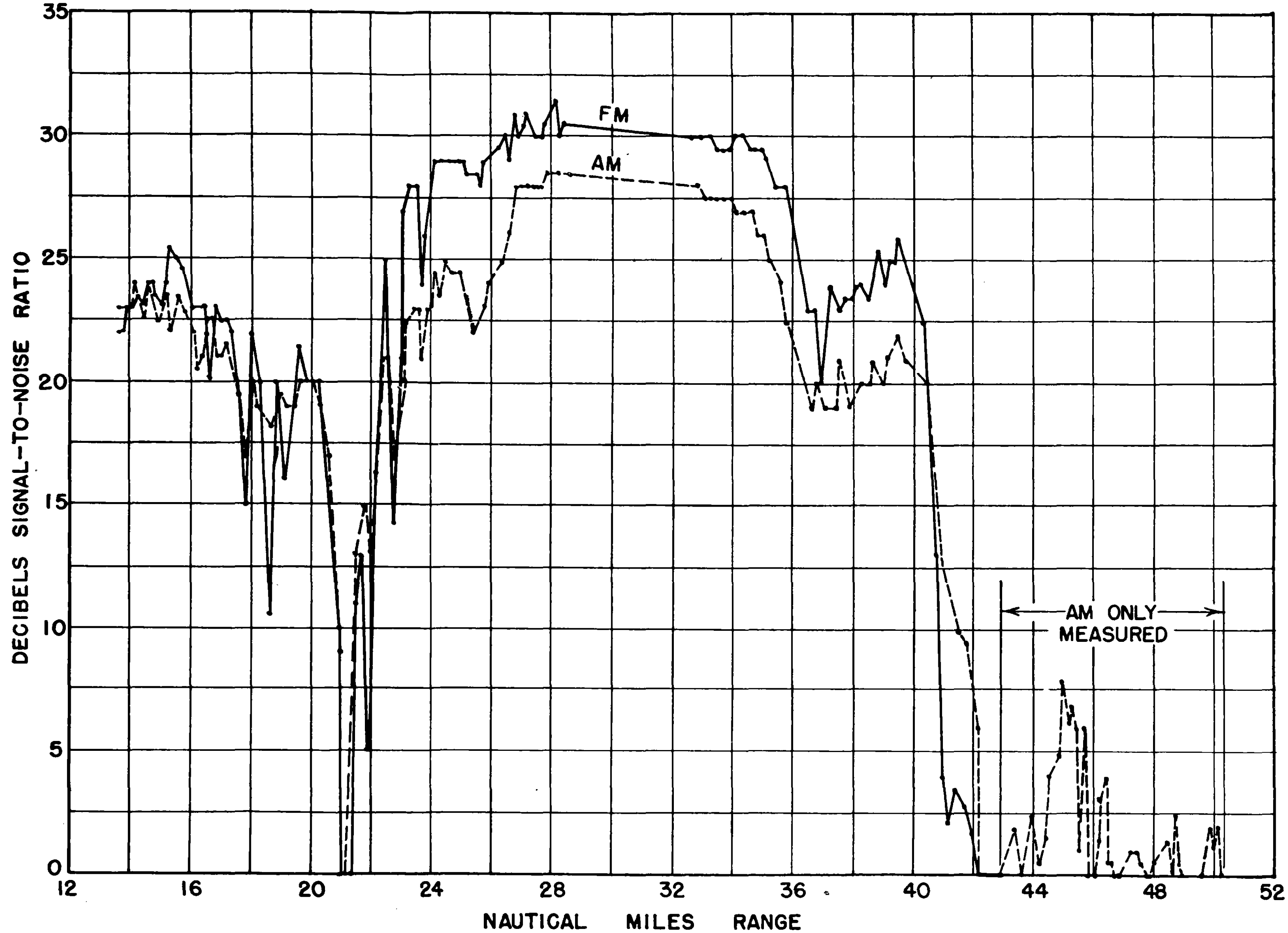

Fig. 20 DAY RANGE RUN OF JUNE 10, 1947, (IN FULL DAYLIGHT) - *The USS ADIRONDACK was Transmitting 11 Watts Carrier into Transmission Line at 100 Percent 1000-cps Modulation on am and 16 Watts Carrier into Transmission Line at ±7.0 kc Deviation at 1000-cps Modulation on fm; Transmitting Antenna No. 3 was 121 Feet Above Water. The USS LST 506 was Receiving on Port No. 1 Antenna, 64 Feet Above Water.*

changes made their exact location doubtful in some cases. From 23 to 40.5 miles range the f-m signal had a higher S/N ratio, and at one time reached a value of 32.5 db. The 40.5-mile cross-over was at 19.5 db. At 42.2 miles, both signals were undetectable. The run was continued using a-m tone only, out to 50.2 miles. The signal came in and dropped out, but seldom reached a strength usable for voice communication. Under these conditions, the f-m measurement did not appear worth attempting. There were variations in range up to 50 percent on different days, with the same setup. Only a small percentage of them could be attributed to the transmitting, receiving, or antenna equipment, which left the rest to propagation conditions.

A night range run was made on June 11, 1947, using the same ships and antennas as in the last two runs described. The data is shown in Figure 21. In this case, when the signals became too weak to be usable, the leading ship slowed to steerageway speed, and the following ship speeded up to close the range and get repeat data. The run began at a 38-mile range with a just usable a-m signal and the f-m signal out. The a-m signal also dropped out at 38.2 miles. Both signals came up, with fm superior, and then both were again gone at 39.6 miles. At 40 miles am was useful again, and fm was just discernible. At this point, relative ship speeds were changed to produce a reduction in range, making 40 miles the greatest range for this run. As can be seen, the data taken at the same range in closing range do not agree with that taken opening. The signals shown are both much stronger at all ranges. The relative bearings of the ships, the transmitted power, and the receiver sensitivities were the same, but the time was different. The average overall relative speed was about 6 knots (including changing time) so that there was approximately a one-hour interval between the two 37-mile range points. There was a cross-over at approximately 20-db S/N ratio at 34 miles, followed by a drop-out and am remained superior until another cross-over at 23-db S/N ratio at 31.5 miles. The test was discontinued shortly after this cross-over for navigational reasons.

The data shown in Figure 22 is for the June 9 range run employing the same ADIRONDACK transmitting antenna and LST 506 receiving antenna. The run, lasting about 8.5 hours, commenced in daylight and continued well after complete darkness. At initial separation of 10 miles, the f-m signal was better by about 1 db. At about 14.6 miles, there was a cross-over at 16-db S/N ratio. Am then remained superior up to a 15-db cross-over at 32.5 miles. Fm dropped out several times between 23 and 29 miles, but am usually stayed at least at the minimum usable level at these times. As dusk approached, both signals built up to nearly the starting levels, with fm superior. There was a rapid drop to a just usable a-m and unusable f-m level, followed by a building-up of both signals to a good level as complete darkness set in. Fm was generally better up to 45 miles. There was rapid fading and even am dropped to unusable levels, but not for nearly as long a time as the f-m signals. Between 52 and 56 miles, both signals were very strong, and then both sank rapidly to unusable levels.

Another run of this same type was made on the night of June 10-11, 1947. The data is shown in Figure 23.

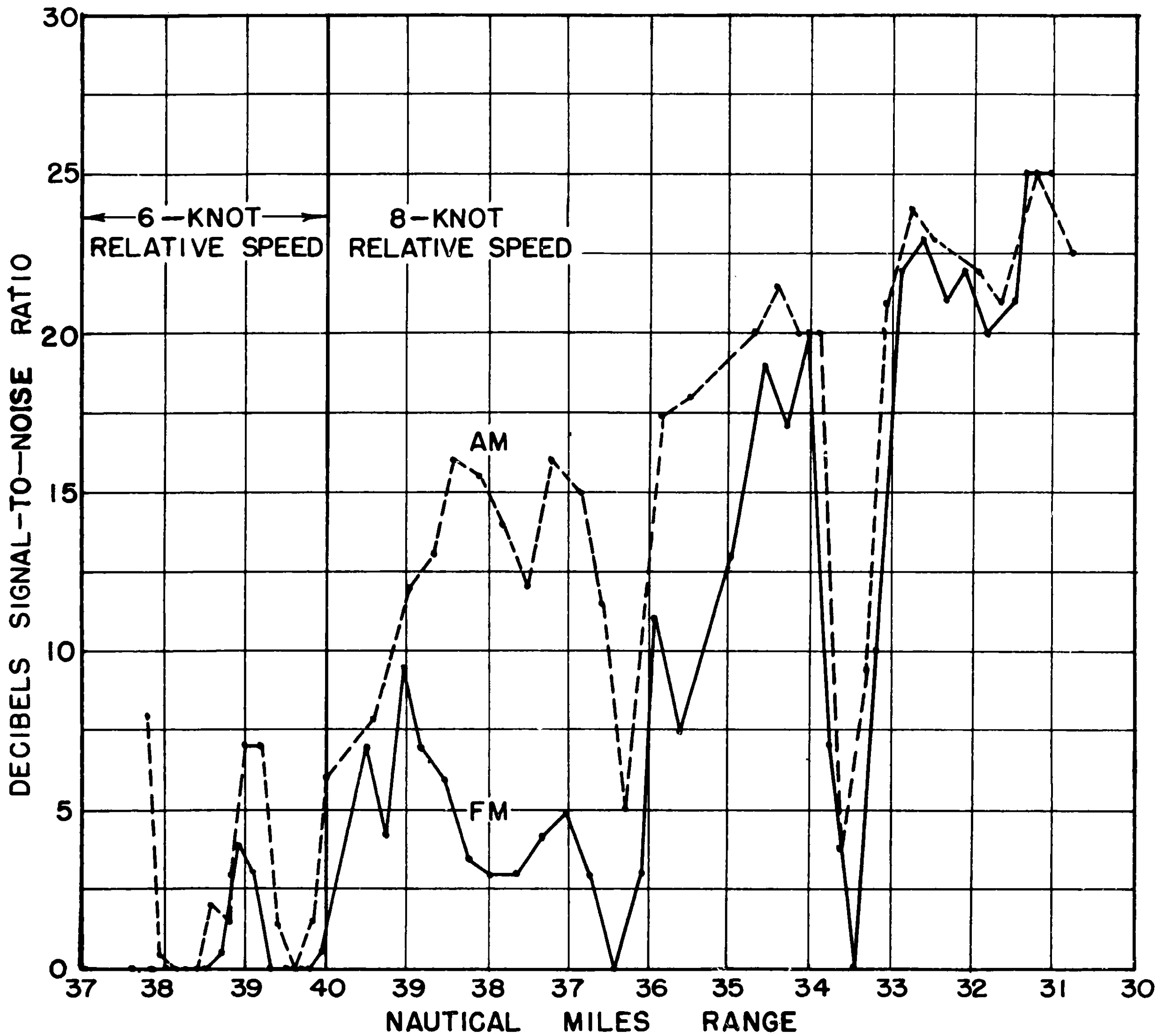

Fig. 21 NIGHT RANGE RUN OF JUNE 11, 1947, IN TOTAL DARKNESS - *The USS ADIRONDACK was Transmitting 11 Watts Carrier into Transmission Line at 100 Percent 1000-cps Modulation on am and 16 Watts Carrier into Transmission Line at ±7.0 kc Deviation at 1000-cps Modulation on fm; Transmitting Antenna No. 3 was 121 Feet Above Water. The USS LST 506 was Receiving on Port No. 1 Antenna, 64 Feet Above Water.*

This run began before dark and lasted until dawn. At the initial 22-mile range, only a-m S/N data was taken to check conditions until it became completely dark, because this was a night range run. The a-m S/N ratio varied from a 14-db maximum at 25 miles down to a 4-db level as the run commenced at 28.6 miles with the f-m signal out. A peak was recorded, with fm just discernible at 29.5 miles, and then a drop-out occurred. An equipment failure resulted in a little over three miles of no data, after which the run was resumed. This run was characterized by rapid fades, with am generally providing higher S/N ratios than fm. At 73.5 miles, the signals were stronger than at

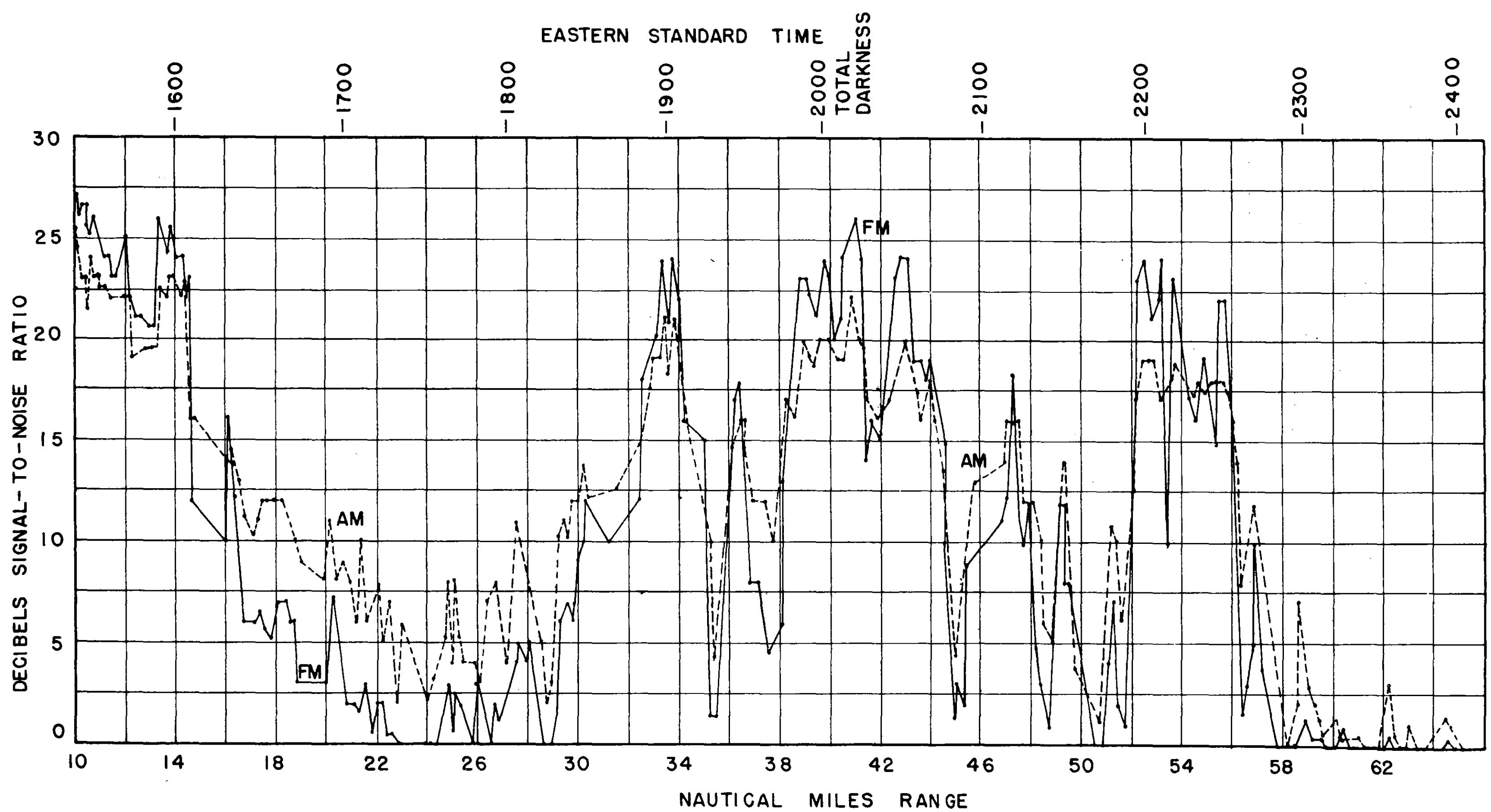

Fig. 22 RANGE RUN OF JUNE 9, 1947, BEGINNING IN DAYLIGHT AND CONTINUING UNTIL AFTER DARK - *The USS ADIRONDACK was Transmitting 11 Watts Carrier into Transmission Line at 100 Percent 1000-cps Modulation on am and 16 Watts Carrier into Transmission Line at ±7.0 kc Deviation at 1000-cps Modulation on fm; Transmitting Antenna No. 3 was 121 Feet Above Water. The USS LST 506 was Receiving on Port No. 1 Antenna, 64 Feet Above Water.*

22 miles, when the run was started. The signals dropped rapidly after dawn, and am only was monitored for a few more miles, still giving occasional peaks of just usable signals out to 77 miles. These ranges far exceed the daytime results, and show interesting propagation effects which could not be studied in any detail during these trials.

The range runs employing the USS ADIRONDACK as the transmitting ship were run using its no. 3 antenna, as this gave the most uniform pattern. A photograph of this antenna is shown in Figure 24.

Requests for temperature inversion data for these night-run dates from the Norfolk fleet weather station were answered with reports that isothermal conditions existed in the area where the trials were being run. The weather was generally clear and the sea calm, with light winds.

AM CROSS-MODULATION

Cross-modulation is an effect in which the modulation on a strong, interfering, off-resonant carrier is transferred to a weaker on-resonant carrier. If the weak, desired carrier is modulated, the receiver output contains a mixture of the modulations of both signals. It requires the presence of both signals to produce cross-modulation, and, if removing the on-resonance carrier does not cause the interfering modulation from the off-resonance carrier to disappear, the interference is breaking through the weak-signal selectivity of the receiver and is not due to cross-modulation.

On shipboard, cross-modulation is likely to occur only if a transmitter aboard or near the ship is operating on a channel near that on which a desired weak signal is being received. For these trials, a desired 328.2-Mc unmodulated carrier was radiated by one ship at a distance from the receiving ship which provided about a 25-microvolt input signal in an a-m RDZ receiver tuned to this frequency and connected to the receiving antenna. The a-m TDZ transmitter on the receiving ship was adjusted to give normal output in the transmitting antenna, thereby producing an interfering signal, which was modulated 100 percent at 1000 cps. The frequency of this local interfering transmitter was varied in as many steps on each side of 328.2 Mc as the supply of special crystals available permitted. At each frequency, readings were taken of the frequency, the equivalent input to the receiver from each transmitter alone, the noise level with only the desired signal on, the output with both carriers on (local "interfering" one modulated as described), and the output with only the "interfering" modulated carrier on. The decibels of tone output above the "weak-carrier-only on" noise output of the receiver was indicated as cross-modulation, if there was no trace of tone output present when the weak carrier was turned off. Considerable use of interior communication and voice radio between ships was necessary to accomplish the desired switching. The weak-carrier ship maintained a constant relative bearing and range to the receiving ship throughout the test.

The attenuation between antennas was measured as previously described. It was not practicable to do this for the 100-foot spacing of several antennas on the ADIRONDACK. There were only two TDZ antennas on the PEREGRINE and two on the LST 506.

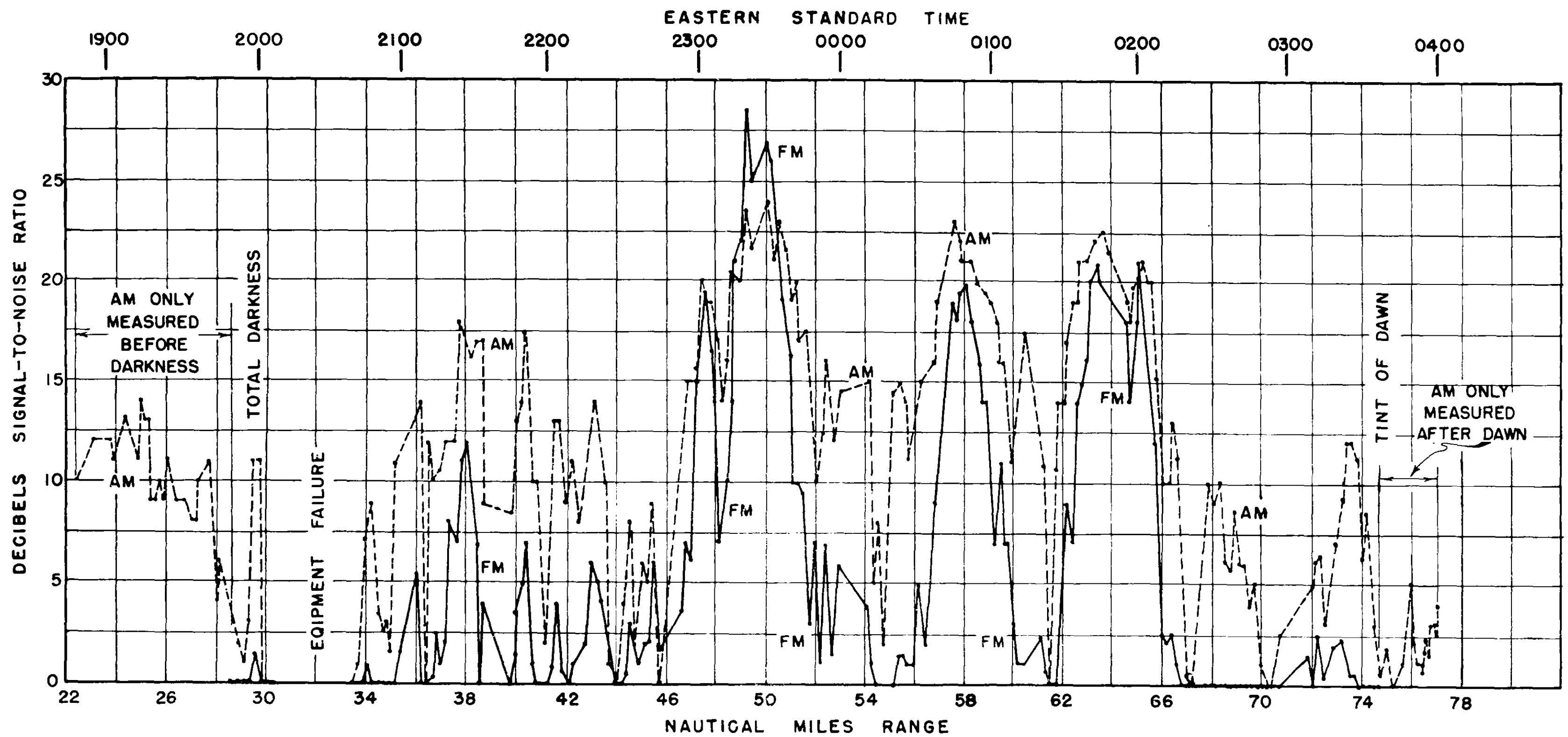

Fig. 23 NIGHT RANGE RUN OF JUNE 10-11, 1947 - *The USS ADIRONDACK was Transmitting 11 Watts Carrier into Transmission Line at 100 Percent 1000-cps Modulation on am and 16 Watts Carrier into Transmission Line at ±7.0 kc Deviation at 1000-cps Modulation on fm; Transmitting Antenna No. 3, 121 Feet Above Water. The USS LST 506 was Receiving on Port No. 1 Antenna, 64 Feet Above Water.*

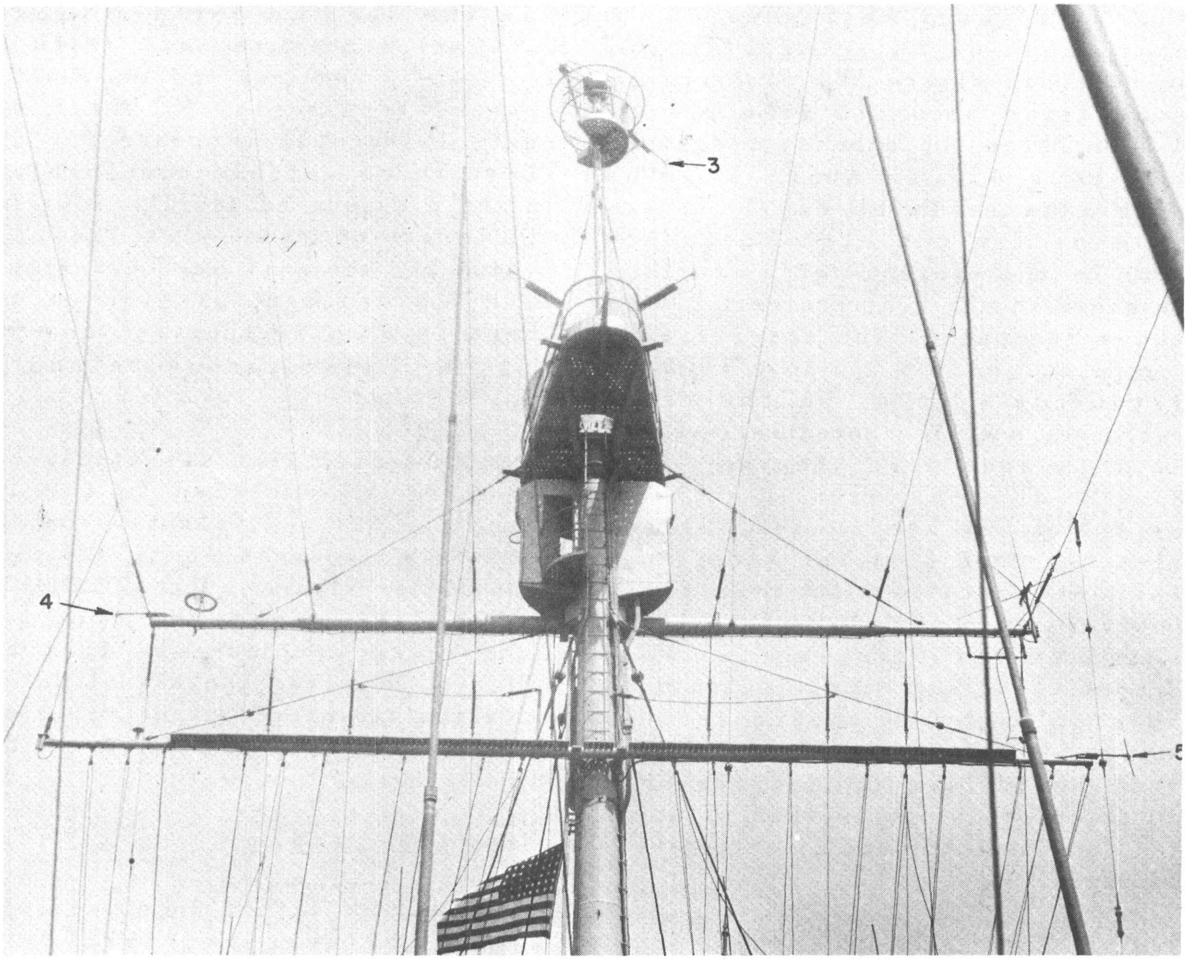

Fig. 24 USS ADIRONDACK E-AGC-15 TRANSMITTING ANTENNAS (LOOKING AFT)

The attenuation measurement results, including both transmission lines, were as follows:

TABLE 1

ATTENUATION MEASURED BETWEEN ANTENNAS

Ship	Spacing Between Antennas (Ft)	Attenuation (Db)
ADIRONDACK	100	Not Measured
PEREGRINE	20	49.5
LST 506	35	45.0
ADIRONDACK	10	36.1

No cross-modulation was detected with the first three combinations of antennas, and no other interference of any kind was obtained at frequencies more than 400 kc away from resonance. The cross-modulation obtained with the close spacing of 10 feet (36.1-db attenuation) is shown in Figure 25. A photograph of this installation is shown in Figure 26. Some cross-modulation occurred from nearly 1.6 Mc below the channel frequency to about 4.3 Mc above it. The interference frequency band was extended on the high-frequency side by the presence of a spurious response in the RDZ receiver, 0.8 Mc above resonance. The interference "rode in" on this spurious response frequency just as on the true-resonance one. The antennas involved in this case were the two "Top House" dipoles. Normally only one or the other was in use, at any time and then only for receiving; The data obtained in this test, however, then is believed to be of interest for cases where close transmitting and receiving antenna spacing might be considered. In any event, the worst cross-modulation that could be produced was only 10 db before a combination of overload and breakthrough of selectivity occurred.

F-M NOISE INCREASE OR SIGNAL-TO-NOISE RATIO DEPRESSION

When an off-channel interference measurement is attempted on fm, employing the techniques just described, there is usually no tone output until direct breakthrough occurs, but the background noise level increases. This decreases the signal-to-noise ratio of the desired signal, "depressing", or, in extreme cases, obliterating it. Up to the breakthrough point, it makes no apparent difference weather the off-resonance interfering carrier is modulated or not. In these trials, it was always modulated ± 7.0 kc at 1000 cps to determine when breakthrough had occurred. The appearance of a 5-db tone output above the noise was considered breakthrough. The procedure otherwise was the same as for a-m cross-modulation measurements, with an f-m X-RDZ-2 receiver and two X-TDZ-2 transmitters employed. There was negligible noise increase for the first three antenna combinations in the previous table. The data for the fourth condition is shown in Figure 25, where it may be compared with the cross-modulation on am. There is a noise increase down to 3.25 Mc below resonance and up to 1.6 Mc above.

A special test was also made, in which, in addition to the on-resonance 328.2-Mc signal from the PEREGRINE, and the local 328.6-Mc transmitter signal on the ADIRONDACK, a 327.8-Mc signal of about 50 microvolts was received from the LST 506. No effect on signal output or signal-to-noise output ratio was produced by the presence of the third signal.

CAPTURE EFFECT

Capture effect in a receiving system is characterized by an increase in the ratio of stronger-to-weaker signal in the output of the system as compared to the input, when both signals appear simultaneously within the pass-band of the receiver. This effect is present in both a-m and f-m receivers. From a naval shipboard operating standpoint, capture is desirable if two contacts widely separated geographically are to be held simultaneously without interference. It is undesirable for a local contact to lock out a more distant member of the task force who may have urgent traffic to deliver.

The procedure employed to measure capture effect during these trials involved two ships traveling on parallel courses at a constant speed in order to keep their spacing

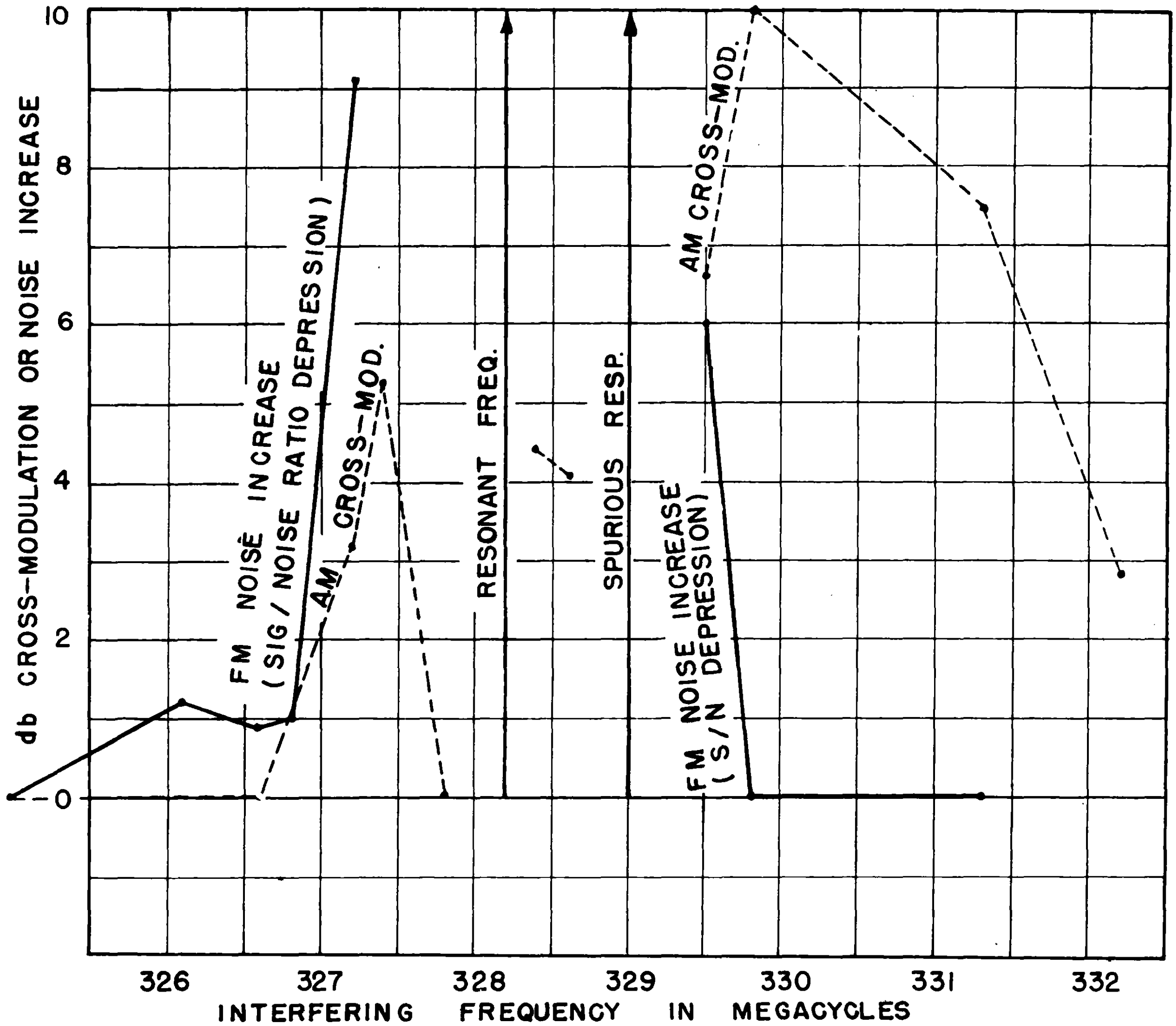

Fig. 25 A-M CROSS MODULATION AND F-M NOISE INCREASE (S/N RATIO DEPRESSION) - *Resonant Unmodulated Signal at 328.2 Mc with 25 μv am and 50-μv fm. F-M and a-m Receivers were Operated from USS ADIRONDACK No. 1 Starboard " Top House " Antenna. Local Interfering Transmitter put 13.3 Watts Carrier into Transmission Line at 100 Percent 1000-cps Modulation on am and 20 Watts Carrier into Transmission Line at ±7.0 kc Deviation at 1000-cps Modulation on fm. Transmitting on No. 2 Port " Top House " Antenna, 10 Feet Horizontally away from No. 1. A-M Cross Modulation Output Dropped to Zero when Resonant Weak Signal was Removed. F-M Noise Increase was due to Introduction of Local Transmitter with Resonant Weak Signal Already on. Attenuation Between No. 1 and No. 2 Antennas Measured 36.1 db.*

constant. A third ship stayed on the line between the first two, and occasionally maneuvered to get closer to one end ship and farther from the other to vary the relative signal strength received from each.

At each set of spacings, one end ship transmitted a continuous recorded word list on am, while the other transmitted a recorded newspaper story also on am, spoken by the same person. One signal was

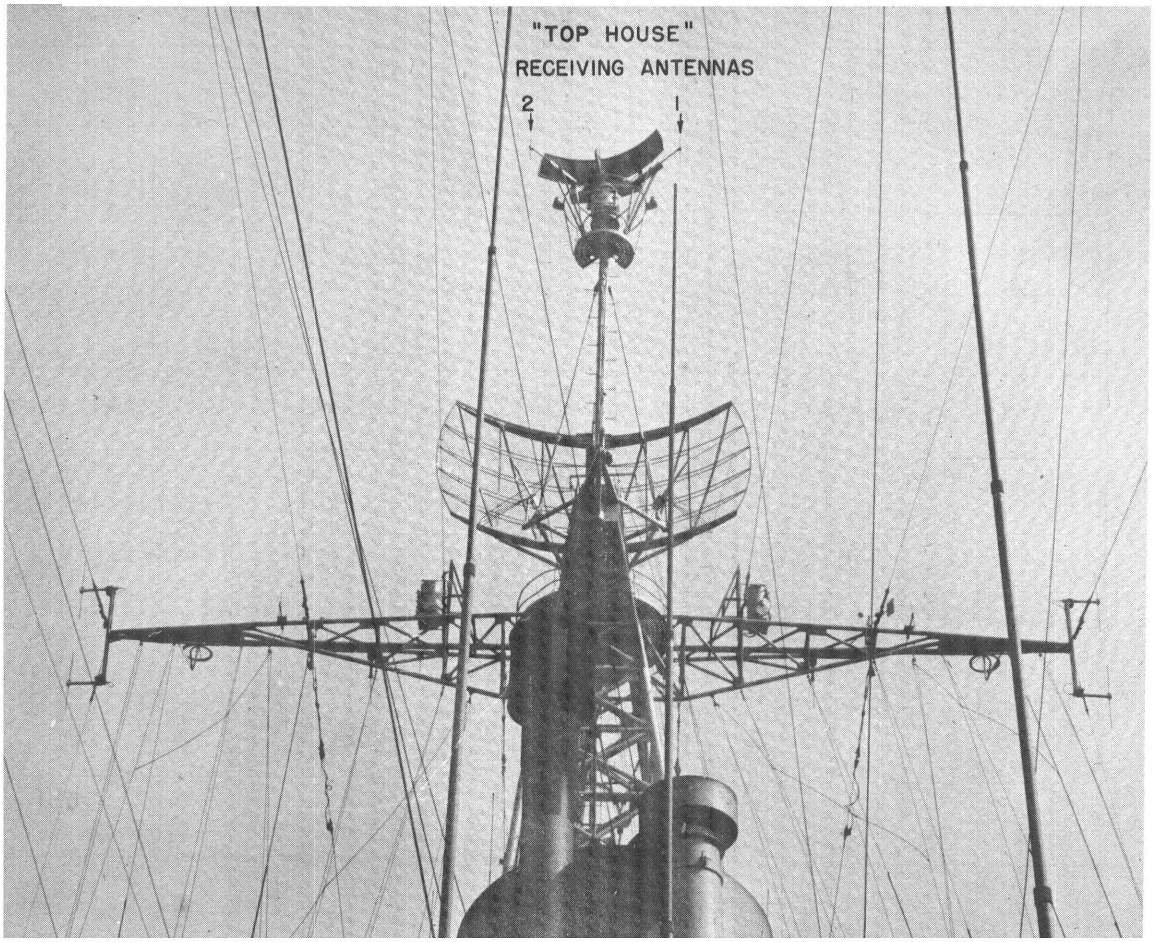

Fig. 26 USS ADIRONDACK E-AGC-15 RECEIVING ANTENNAS (LOOKING FORWARD)

shut off while tone was put on the other to determine its carrier level and the S/N output ratio at the receiving ship. This signal was then shut off and the carrier level and S/N ratio of the other signal was determined. The range to each of the two ships was determined. The entire program was recorded, with suitable explanatory voice announcements inserted on the record. The whole procedure was repeated with both transmitters and the receiver on fm. The ADIRONDACK was the receiving ship, and the line of ships was at a 20-degree relative bearing off the stern to allow optimum use of the PEREGRINE'S antenna pattern.

The first trial was at a 20-mile separation between outside ships, and complete capture was not secured on am at reasonable spacings between the inside ship and either outside ship. A second trial was made with a 40-mile outside-ship spacing. This run was not completed, due to navigational difficulties, but most of the important data was obtained prior to stopping the run. The laboratory ''capture'' results have been presented in terms of the decrease of one signal due to the presence of the other. Audible heterodyne beats between carriers were usually above 2500 cps and a wave analyzer was used to pick out the desired modulation frequency. In these shipboard trials, however, heterodynes of about 1000-cps pitch on am and 3500-cps pitch on fm were always present to obscure the signal and noise data when both carriers were on. For this reason, data comparable with that taken in the laboratory capture tests could not be obtained, and opinions of observers or auditors of the test records had to be employed. The 1000-cps beat on am was at optimum receiver audio response, causing maximum annoyance. The 3500-cps beat on fm was at the upper limit and was more attenuated, causing much less annoyance. These beat frequencies have a major effect on the results of the capture tests.

There was no interference, even of beats, when the ADIRONDACK was 3.6 miles from the LST 506 and 36.5 miles from the PEREGRINE. Only the LST 506 signal was heard on fm or am at the ADIRONDACK. When the LST was 8.2 miles away and the PEREGRINE was 31.8 miles, a weak beat was heard on am or when speech pauses coincided on fm, but there was little degradation of the stronger program on either system. When the LST 506 range was opened to 10.3 miles with the PEREGRINE at 29.7, the a-m signal was still good, but the f-m signal was much better, having no trace of noise or heterodyne beat, except on pauses of speech, while there was a constant weak heterodyne background on am. When the LST range was increased to 12.5 miles to the PEREGRINE'S 27.5, the f-m signal remained about the same. The a-m signal was still perfectly understandable, but the heterodyne was becoming strong enough to be annoying. With the LST range increased to 14 miles to the PEREGRINE'S 26, the LST f-m signal was slightly better than the a-m signal had been at 10.3 miles. The a-m signal was still intelligible but the tone was strong. With the LST range 16 miles from the ADIRONDACK to the PEREGRINE'S 24, the LST f-m signal was readable but was becoming quite " swishy " with the PEREGRINE program breaking through. The a-m heterodyne was so strong that no intelligibility was obtained from either program. When the LST range was made 18 miles to the PEREGRINE'S 22, the f-m signals were quite " swishy " with both programs readable. The a-m signals were unintelligible, but an extra " squawk " was added to the output whenever another word was spoken on the PEREGRINE program, indicating that it was beginning to break through the the heterodyne. The test results beyond this point are questionable, but the LST signal apparently would have been replaced by the PEREGRINE signal had the procedure been continued in the same manner. This data with corresponding S/N ratios is summarized in Table II on the opposite page.

It appears likely that crystal frequency and drift tolerances will be decreased rather than increased in the future, so the presence of an audible heterodyne as obtained in these trials is more normal than its absence. The fact that the a-m beat was centered at optimum receiver and ear response while the f-m beat was down on both makes the preceding test favor fm. Interpretation of the shipboard test results is further complicated by the lack of coincidence between the f-m and a-m data in regard to signal-to-noise output ratio for most of the ship spacings, as shown in Table II.

NOISE INTERFERENCE

It was originally planned to conduct an extensive series of tests

TABLE II

CAPTURE EFFECT AT VARIOUS RELATIVE SHIP SEPARATIONS

Ratio of Desired Signal Miles, to Interfering Signal Miles	AM		FM	
	S/N Ratio (db)	Remarks	S/N Ratio (db)	Remarks
3.5/36.5	48	No interference; good intelligibility.	43.3	No interference; good intelligibility.
8.2/31.8	37.3	Weak steady beat; good intelligibility.	34.7	Intermittent beat; good intelligibility.
10.3/29.7	34.2	Stronger beat; good intelligibility.	42.0	Intermittent beat; good intelligibility.
12.5/27.5	27.8	Annoying beat; understandable.	37.6	Intermittent beat; good intelligibility.
14.0/26.0	27.7	Strong beat; intelligible.	32.5	Better than am at 10.3/29.7 miles.
16.0/24.0	23.3	Obliterated by beat.	32.1	Readable but " swishy ".
18.0/22.0	21.0	Unintelligible; other signal modulation detectable.	23.3	Readable but quite " swishy ".

to determine the relative effects of various radar, beacon, IFF, teletype, and other shipboard equipment in regard to noise on the f-m and a-m systems. After the completion of the laboratory noise tests described in detail in another report, most of this work appeared to be unnecessary, since it was found that the RDZ antenna had to be inside the radar dish and within inches of a radiator before any interference could be detected on either fm or am with noise limiter on.

During the shipboard tests, all the radars aboard were turned off and on and rotated through all angles on all three ships with no sign of interference on fm, or on am with noise limiter off. Radar could thus be employed to obtain ranges without fear of affecting test results. At no time did any ship's machinery or other equipment appear to produce any increase in receiver noise.

CONCLUSIONS

There were several aspects of the shipboard f-m vs a-m trials in which conditions were idealized to a much greater extent than could be expected in normal shipboard service with the type of operation and maintenance usually available. The equipment was carefully matched in performance prior to the trials, and was kept in an excellent state of alignment. Experienced engineers were present to detect and correct any slight decrease in equipment performance. Antenna patterns were known for all antennas for the frequency employed, which is usually not the case, and the optimum portions of the patterns were used. This was not done to see how much range could be obtained, because only relative differences were of interest, but rather to utilize smooth portions of the patterns, so that slight range and bearing errors in ship handling would produce negligible effects on the measurement results. It had been determined in the laboratory results reported elsewhere that slight frequency drifts of transmitter relative to receiver, or small changes in receiver alignment have a much more serious degrading effect on fm than on am. By insuring that these drifts were not present during these trials (mainly by frequent receiver alignment checks), the f-m system has thus been allowed an advantage that it would not receive with the present state of stability of the best available equipment. The f-m system has been allowed to employ over twice the modulation spectrum of am (14 kc plus higher modulation products, as against 7 kc). The a-m transmitter power usually decreased under heavy modulation while the f-m power did not. The unmodulated power was made the same for comparison purposes, and no correction has been applied for the "downward" modulation performance of the a-m transmitter in the shipboard test data.

There was fairly good agreement among the ship and scientific personnel engaged in the trials that a voice-modulated signal-to-noise ratio corresponding to about +4-db based on complete modulation of the transmitter (i.e., 100 percent or ± 7.0 kc) with a 1000-cps tone was close to the minimum useful value for intelligible voice communication. For this condition, all personnel could get 80 percent copy of plain language speech and 100 percent copy on one repeat. About 70 percent of the personnel could get 100 percent copy the first time. This figure was the same for fm and am.

There is a cross-over point at which the signal-to-noise ratio is equal for both the f-m and a-m systems with equal transmitter unmodulated carrier power and equal receiver sensitivity, as previously described. In these trials, this cross-over point varied from about 15 db S/N output ratio up to about 23 db. For signal strengths below the cross-over point, am always gave the superior S/N ratios, often providing signals which the previously mentioned group of engineers and ship's personnel agreed were intelligible when the f-m signal was undetectable. For signal strengths above the cross-over point, fm always provided the superior S/N ratios. The differences in range between the systems encountered in the shipboard tests may be taken from the range curves in Figures 18 through 23, for any desired value of S/N ratio, in terms of nautical miles. F-m range will be greater above the cross-over value, and a-m range will be greater below it.

Some of the absolute range values obtained in these tests were so far in excess of the predicted line-of-sight ranges as to excite comment from many who have seen the data. The daytime range may be nearly doubled at night. These effects were only incidental to the object of the f-m vs a-m trials, since the range of both systems was extended in this manner, but these results may indicate the desirability of further propagation studies in this frequency range with different seasons and conditions of sea surface.

From an operational viewpoint, the cross-modulation effect on am is considered to be about comparable with the signal-to-noise ratio depression or noise-increase effect on fm, with cross-modulation objectionable over a slightly greater bandwidth in these tests. With the equipment used in these tests, neither of these effects were observed except with close antenna placement on the ship and they are consequently considered to be minor factors in comparing the two types of modulation until the time when much higher transmitter power is utilized for u-h-f communication.

The capture effect data obtained in these trials is obscured by too many variables to be conclusive. The beat note on am was centered in the receiver audio pass-band, and in the optimum frequency response region of the human ear, making it of maximum annoyance, while the f-m beat was at the outside edge of the pass-band, reducing its annoyance factor. It was not possible to separate overload effects from capture effects with the equipment at hand. The fact that one signal increased as the other decreased made comparison with laboratory data difficult. These factors combine to give S/N ratios which, while carefully measured, do not appear logical from other standpoints. Those participating in the tests agree that capture effect test conclusions cannot be drawn from this data and must be based on laboratory data taken where conditions were under much better control.

Noise interference with proper power-line filtering and coaxial antenna leads appears to be negligible with either system from usual shipboard equipment.

During the trials, the major sources of equipment failure were two instances of RDZ receiver switch contact trouble and several transmitter tube failures, mostly of Type 2C39 tubes. In general, the equipment performed well and the results obtained are believed to represent good shipboard performance of the systems.

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Mr. H. C. Peterson of BuShips, Navy Department, was in charge of procurement of equipment for the trials, and acted as coordinator of the various aspects of the work, and also served as an observer during actual runs.

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