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A COMMUNICATION ANTENNA SYSTEM FOR CLASS SS-487 GUPPY SUBMARINE

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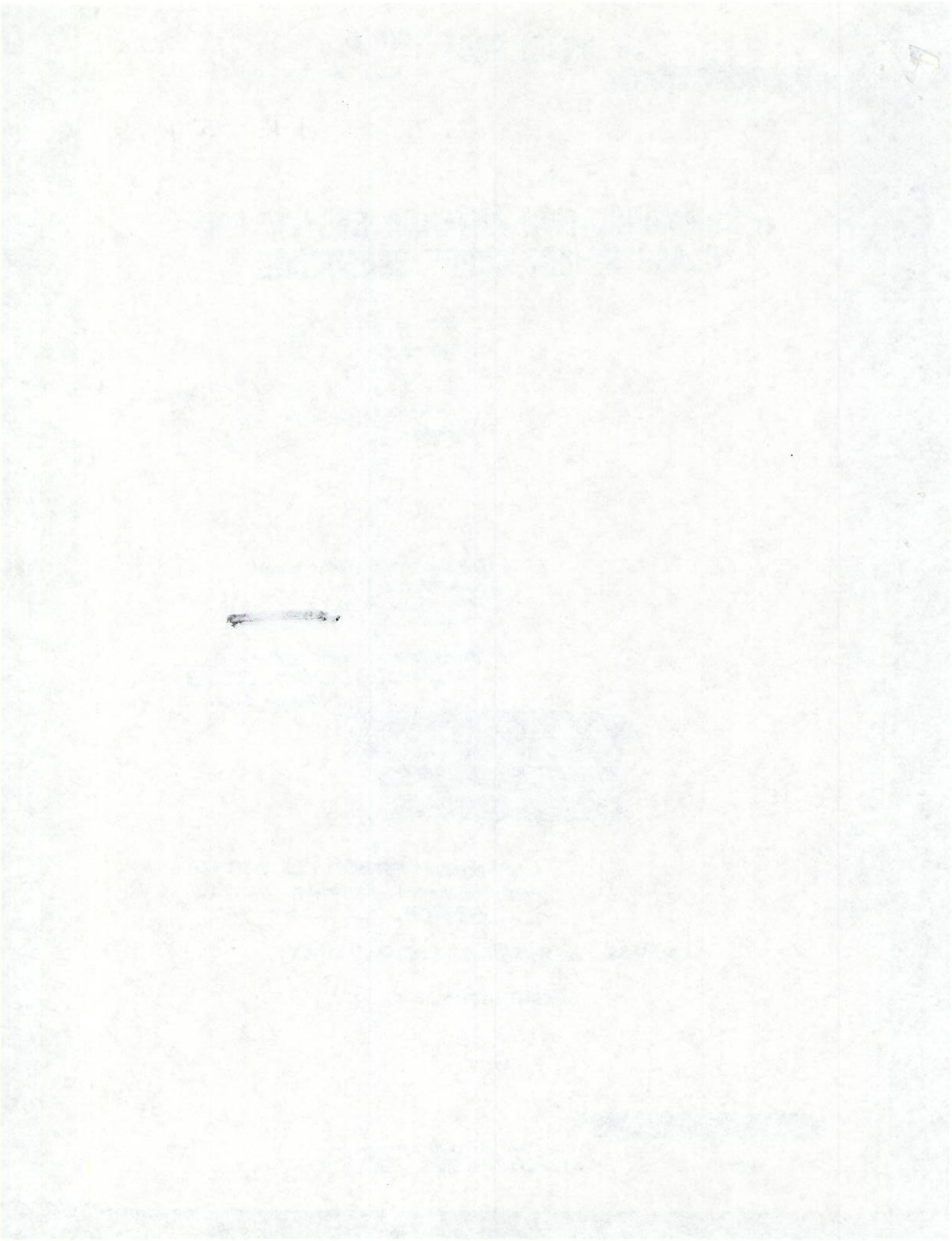
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A COMMUNICATION ANTENNA SYSTEM FOR CLASS SS-487 GUPPY SUBMARINE

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August 23, 1949

Approved by:

R. B. Meyer, Head, Communication Branch
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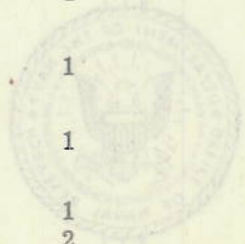
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This report contains one phase of the general problem
 on high-power antenna development. Work is continuing on
 related phases.

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ABSTRACT

A high-frequency antenna system adapted to the Class 487 Guppy submarine is presented. The broad-band sleeve antenna for this system uses the superstructure of the submarine at the conning tower location as the sleeve element, while the upper radiator section is formed by a whip. The range of usable upper radiator dimensions is indicated and three representative whips are studied in detail. Impedance characteristics are improved by using a suitable transformer. One of the transformed antennas maintains a SWR of better than 0.3 over the frequency range 5.2 to 15.2 Mc, and better than 0.5 from 5.7 to 10.0 Mc. Radiation patterns in the vertical plane are shown for this antenna.

The availability of an effective broad-band antenna makes it possible to consider the design of a comprehensive communication system for submarines. A tentative system employing Common Antenna Working units and a specialized filter, permitting simultaneous medium- and high-frequency transmission and reception, is outlined.

PROBLEM STATUS

This report completes one phase of the general problem on shipboard antenna development. Work is continuing on related phases.

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A COMMUNICATION ANTENNA SYSTEM FOR CLASS SS-487 GUPPY SUBMARINE

INTRODUCTION

The distinctive limitations of submarines make it essential that communication requirements be fulfilled with an absolute minimum number of antennas. The physical design of the antennas should be such as to produce negligible effects upon the streamlined characteristics of the hull. Electrically, the antennas should provide broad-band operation, possess good impedance characteristics and produce radiation patterns suitable for long range transmissions. When these important factors are realized, multiplex operation permitting simultaneous transmission and reception on multiple frequencies becomes possible.

With these requirements in mind the Class SS-487 submarine was studied with a view of applying the principle of broad-band sleeve-antenna design. The sleeve-type antennas possess characteristics that are peculiarly adaptable to the problem in hand. Effective broad-band performance is obtained with little increase in topside weight since it is possible to adapt the conning tower structure for use as the sleeve section of the antenna.^{1*} The broad-band characteristic is important as it permits use of the "Common Antenna Working" principle making it possible to operate several equipments simultaneously with a single antenna. Even at frequencies where an antenna is a considerable portion of a wavelength, the radiation patterns of sleeve antennas are inherently advantageous, in that the radiation is near the maximum along the horizon. The importance of low-angle radiation in long distance communication is well recognized and general references can be found in the literature. The achievement of a good radiation pattern in the horizontal plane is also enhanced because the conning tower structure which might normally distort the pattern, now forms an integral part of the antenna. Previous work¹ has demonstrated that the superstructure of a modern submarine is well adapted for incorporation into a sleeve antenna, while the top radiating section can be provided by means of a properly proportioned retractable whip mounted on top of the superstructure.

FACTORS LIMITING THE CHOICE OF A TOP RADIATING SECTION

Since the superstructure of the submarine is to serve as the sleeve section of the antenna, the problem is reduced to selecting a top radiating section which will give near-optimum results. The maximum length considered feasible was 35 feet, which is the length of the longest self-supporting whip available for Navy use. In view of previous investigations,¹ the minimum usable length was considered to be equal to the approximate over-all

* References appear at the end of this report.

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height of the superstructure, or about 23 feet. Therefore this investigation was confined to examining antennas whose top radiating sections would have full-scale lengths within the limits of 35 and 23 feet.

Previous investigations also indicated that the minimum frequencies for broad-band operation would be about 4.0 and 6.0 Mc for the longest and shortest usable antennas, respectively. The expected frequency range of operation for this type of antenna is about 3 to 1, with a standing wave ratio of better than 0.3. Thus it would appear possible to construct broad-band antennas for this type of submarine to operate between approximately 4 and 12 Mc, and between 6 and 15 Mc.

MEASUREMENT DETAILS

The physical arrangement for making measurements and the details of construction of the model antennas are shown in Figures 1 and 2. Briefly, the model antenna was placed on the ground screen as shown in Figure 1. At each measuring frequency, the position of the current minimum and the ratio of the current maximum to current minimum were recorded. These quantities, together with the position of the current minimum when the line is shorted at the antenna terminals, and the impedance of the measuring line, determine the antenna impedance.

The impedance-measuring system used for obtaining these experimental data is essentially that in common usage with the probe-slotted line technique. It differs only in that the ground plane has been mounted on the side of a building with the center at a second-floor level. This arrangement provided sufficient clearance from surrounding objects and permits the use of an unusually short section of dielectric feed cable between the antenna and the end of the slotted line. Moreover, this method of feed provides numerous other advantages over a system employing a long solid dielectric or air dielectric feed line.

A sketch of the system for measuring the vertical patterns is shown in Figure 3. With the model antenna inserted into the system, R. F. power was applied at the selected measuring frequencies by means of a Model LAF signal generator. Radio frequency power received by the loop antenna was amplified, rectified and applied to a polar recorder which rotated in synchronism with the loop antenna. Thus a continuous recording of field strength in a vertical plane was obtained from 0 to 180 degrees. The system sensitivity was limited to about 25 db in the average case, and system errors in general were less than ± 2 db.

Since the measuring system operates most satisfactorily in the frequency range 90 to 390 Mc, and since the anticipated frequency range of the full-scale modified sleeve antennas is approximately 4 to 15 Mc, scaled models were constructed using a factor of 1/23. An exact model of the submarine superstructure was made of wood and sprayed with copper. It should be noted that the top of the superstructure on the SS-487 is open, and this air space was simulated in the scaled model by leaving the wood unsprayed on the top surface of the superstructure. After careful study, it was decided that the most suitable location for the whip would be at the after portion of the superstructure. Therefore, the air dielectric feed line was terminated at that point, as illustrated in Figure 2. The inner conductor of the feed line was threaded and extended about 1/2 inch above the top surface, to facilitate mounting the various whip top radiating sections.

EXPERIMENTAL RESULTS

Three scaled-model top radiating sections were investigated, all having a diameter of 0.095 inch and having lengths of 18.3, 14.1, and 12.0 inches. These correspond to full-scale whips having an average diameter of 2.2 inches and lengths of 35, 27, and 24 feet, respectively. The measured values of resistance and reactance for these three scaled-model

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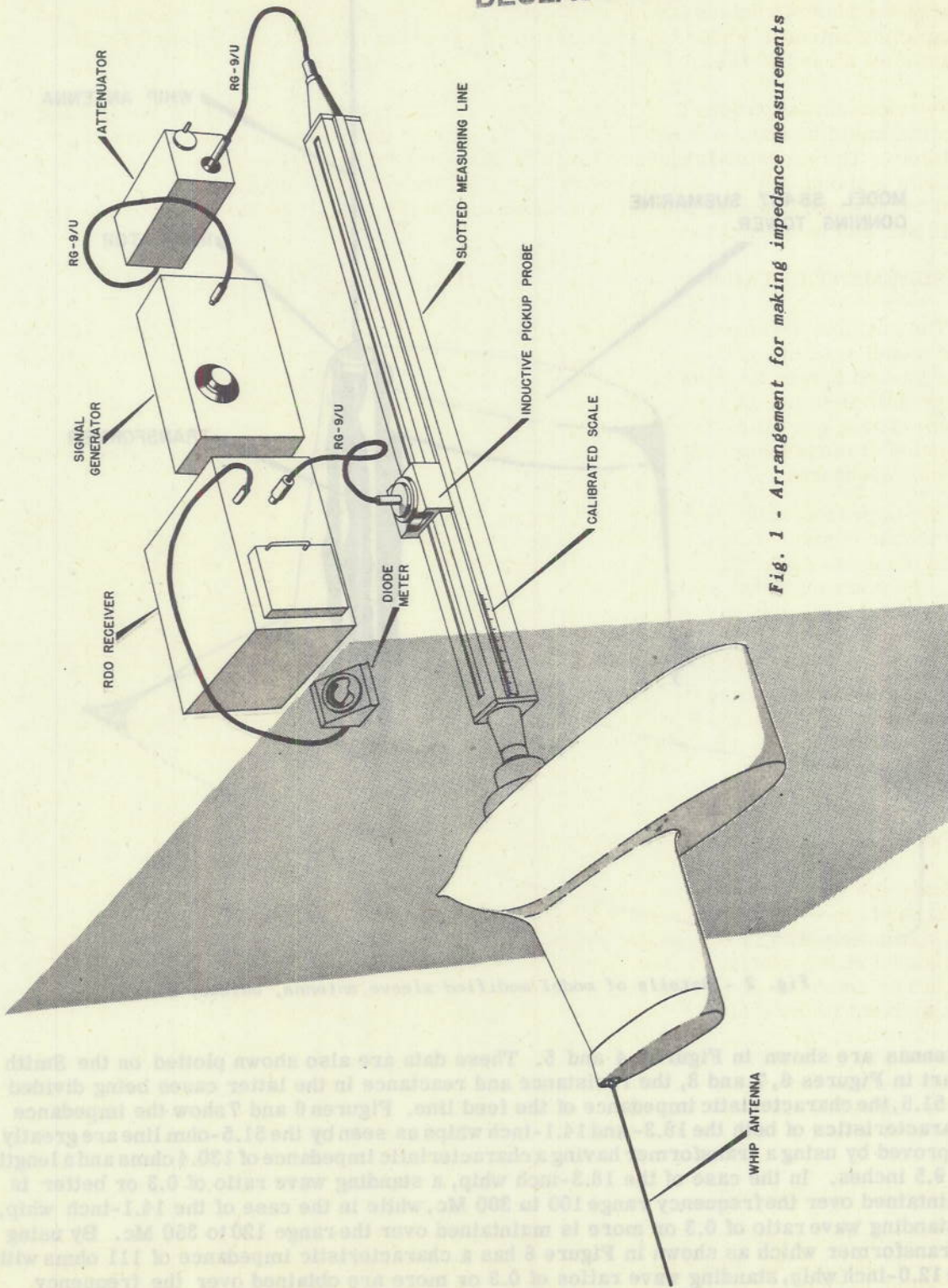


Fig. 1 - Arrangement for making impedance measurements

Antennas are shown in Figure 5. These data are also shown plotted on the Smith chart in Figure 6 and 7. The standing wave ratio in the latter cases being divided by 2.2, the characteristic impedance of the test line. Figure 8 and 9 show the impedance characteristics of the 12.0-inch whip as seen by the 51.5-cm line and the 14.1-inch whip as seen by the 14.1-inch line. The standing wave ratio of 0.3 or better is improved by using a transformer having characteristic impedance of 136 ohms and a length of 9.5 inches. In the case of the 18.3-inch whip a standing wave ratio of 0.3 or better is maintained over the frequency range 100 to 300 Mc, while in the case of the 14.1-inch whip a standing wave ratio of 0.3 or more is maintained over the range 100 to 300 Mc. By using a transformer which is shown in Figure 5 has a characteristic impedance of 111 ohms with the 12.0-inch whip, standing wave ratios of 0.3 or more are obtained over the frequency range 100 to 300 Mc.

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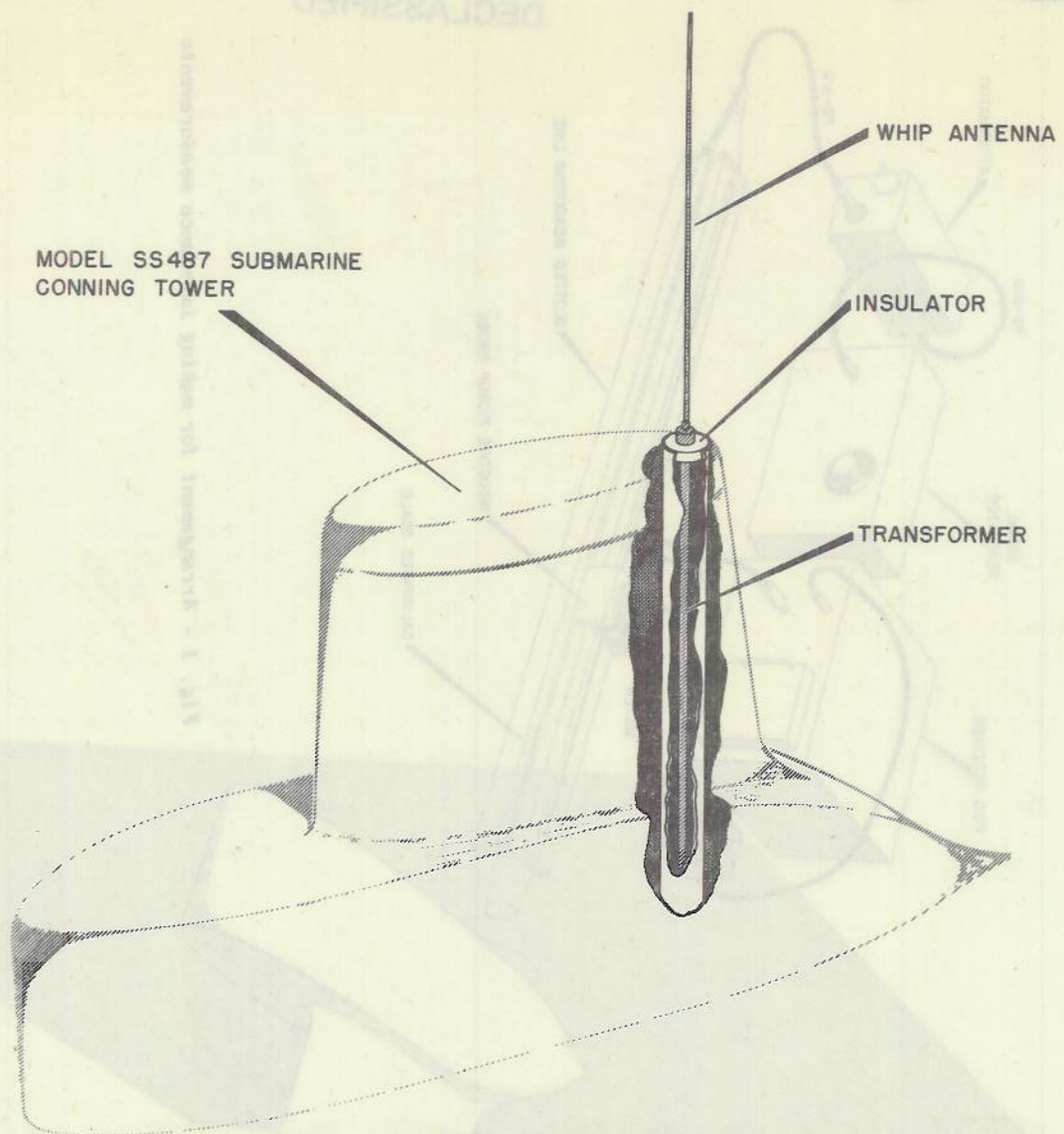


Fig. 2 - Details of model modified sleeve antenna, cutaway view

antennas are shown in Figures 4 and 5. These data are also shown plotted on the Smith chart in Figures 6, 7, and 8, the resistance and reactance in the latter cases being divided by 51.5, the characteristic impedance of the feed line. Figures 6 and 7 show the impedance characteristics of both the 18.3- and 14.1-inch whips as seen by the 51.5-ohm line are greatly improved by using a transformer having a characteristic impedance of 130.4 ohms and a length of 9.5 inches. In the case of the 18.3-inch whip, a standing wave ratio of 0.3 or better is maintained over the frequency range 100 to 300 Mc, while in the case of the 14.1-inch whip, a standing wave ratio of 0.3 or more is maintained over the range 120 to 350 Mc. By using a transformer which as shown in Figure 8 has a characteristic impedance of 111 ohms with the 12.0-inch whip, standing wave ratios of 0.3 or more are obtained over the frequency range 130 to 340 Mc.

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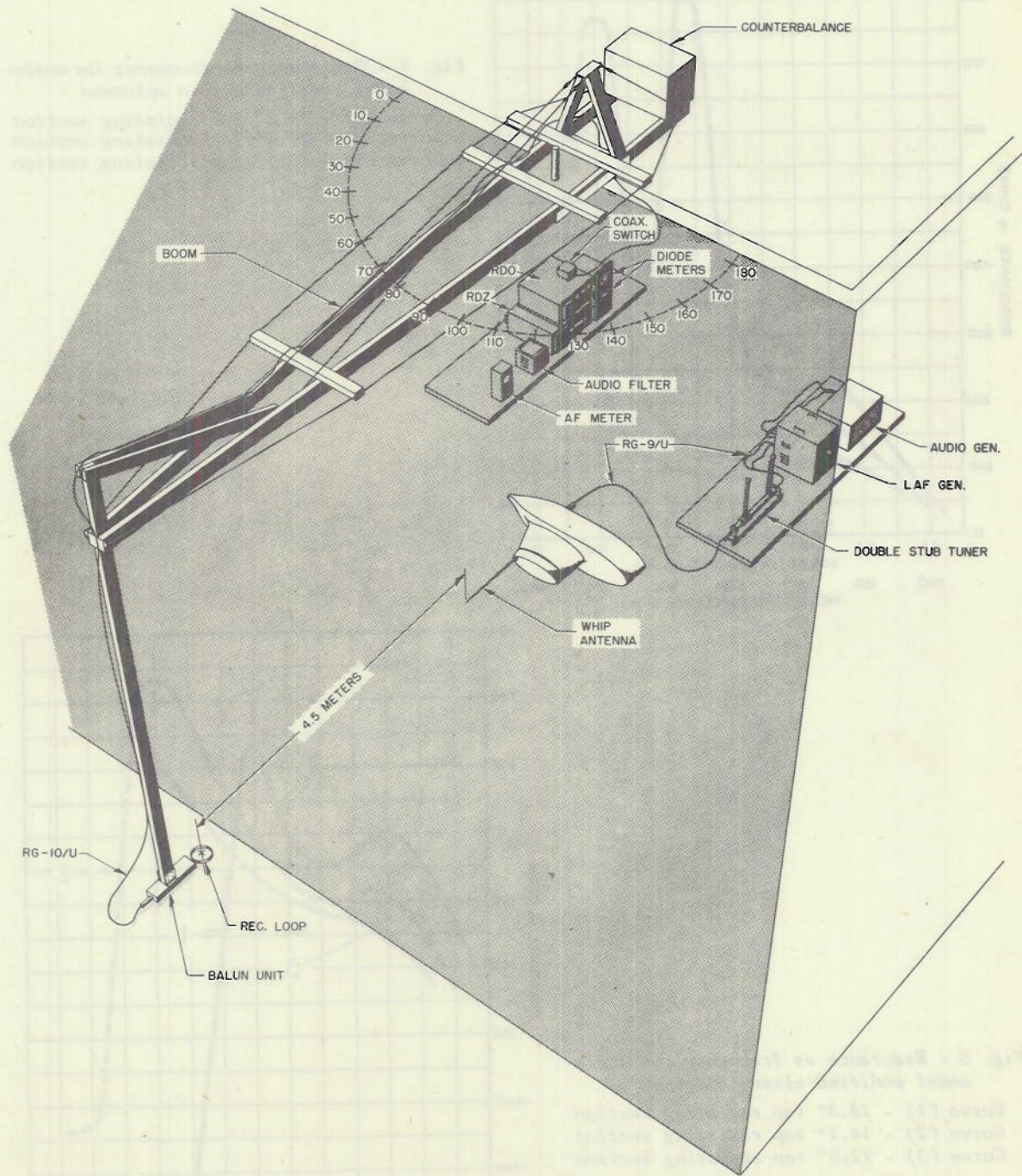


Fig. 3 - Arrangement for making pattern measurements

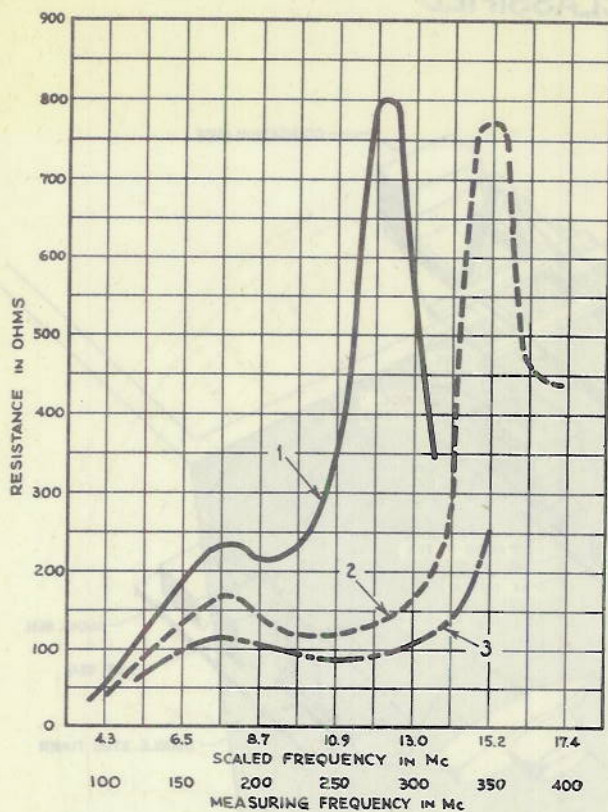
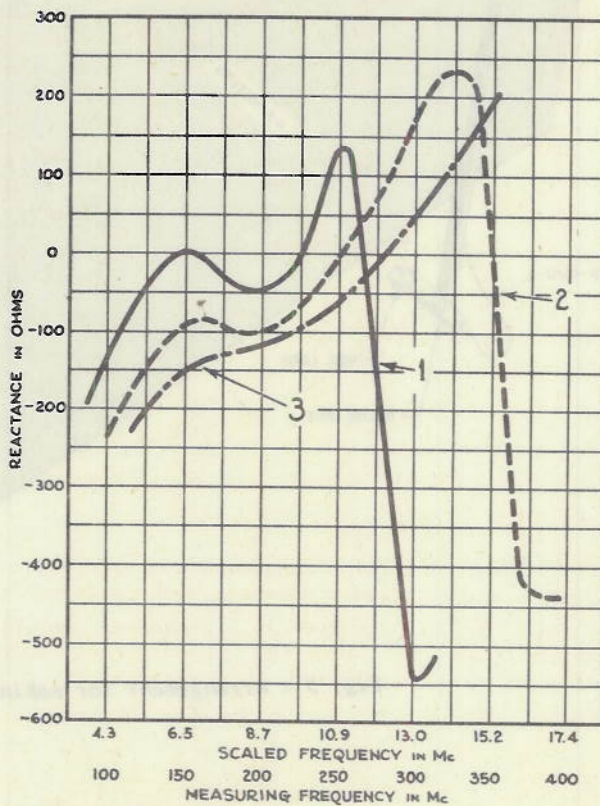


Fig. 4 - Resistance vs frequency for scale-model modified sleeve antennas

Curve (1) - 18.3" top radiating section
 Curve (2) - 14.1" top radiating section
 Curve (3) - 12.0" top radiating section

Fig. 5 - Reactance vs frequency for scale-model modified sleeve antennas

Curve (1) - 18.3" top radiating section
 Curve (2) - 14.1" top radiating section
 Curve (3) - 12.0" top radiating section



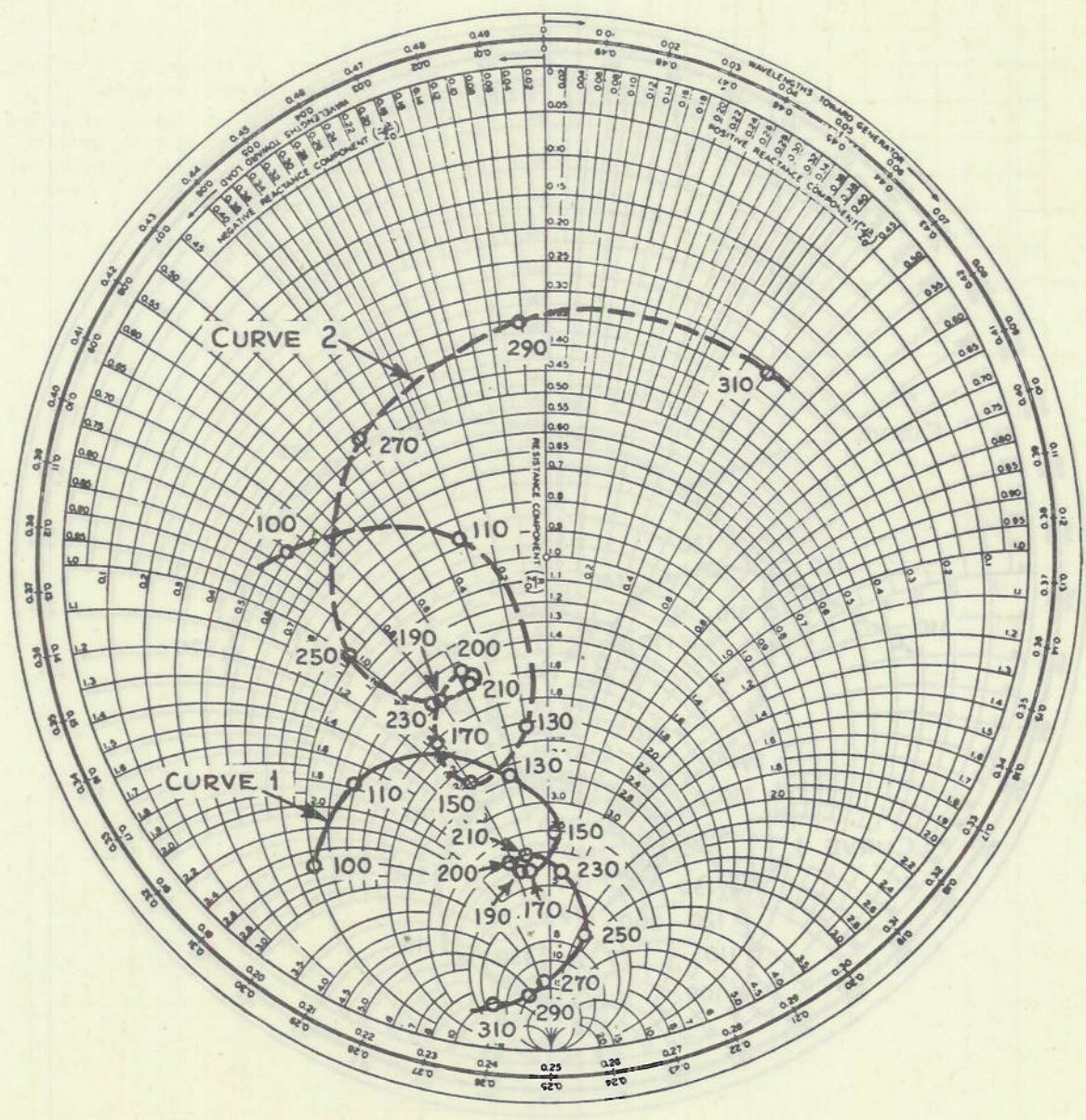


Fig. 6 - Impedance characteristic for scale-model modified sleeve antennas with 18.3 inch top radiating section
 Curve (1) - Impedance characteristic
 Curve (2) - Transformed impedance characteristic

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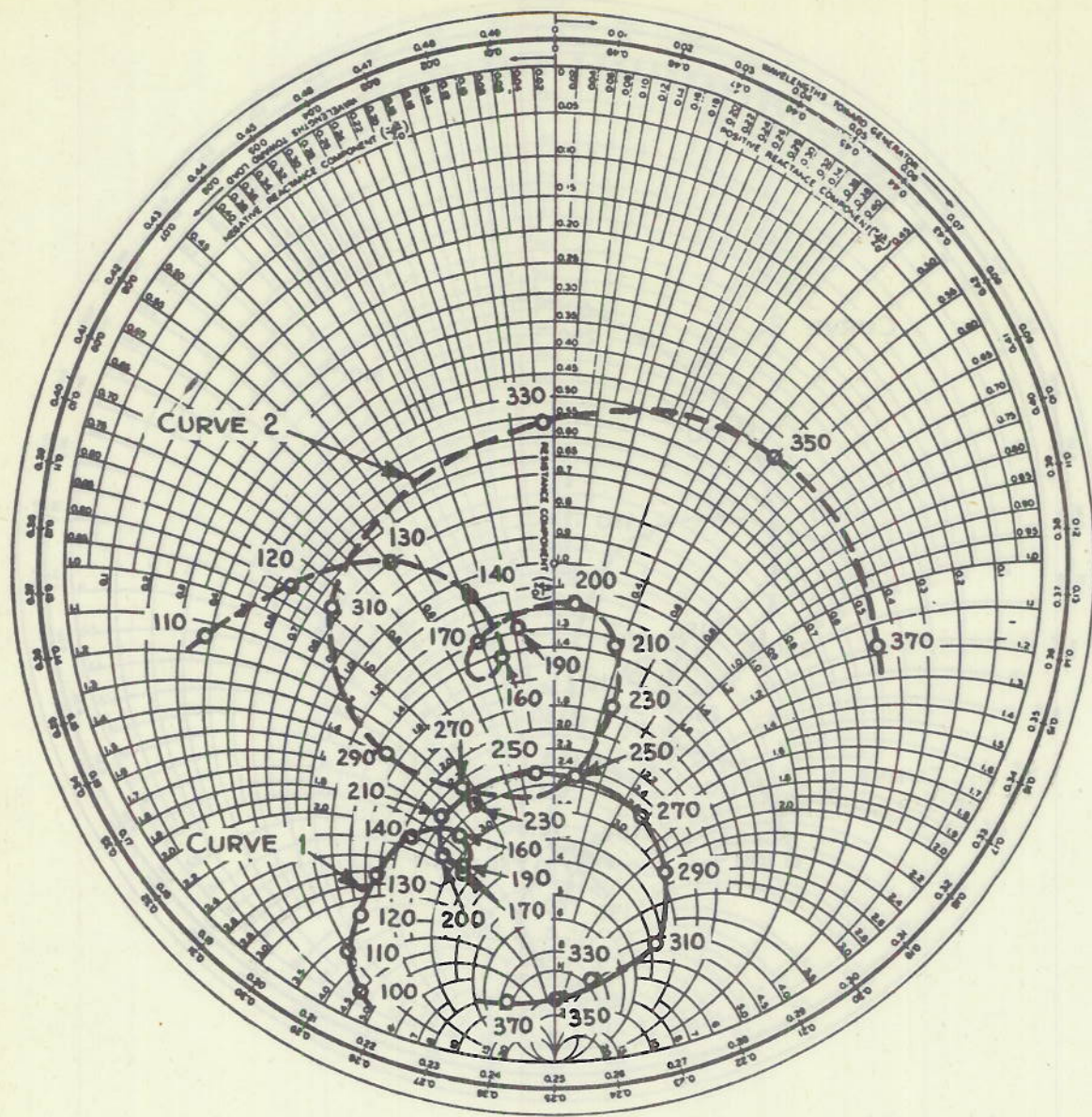


Fig. 7 - Impedance characteristic for scale-model modified sleeve antenna with 14.1 inch top radiating section
 Curve (1) - Impedance characteristic
 Curve (2) - Transformed impedance characteristic

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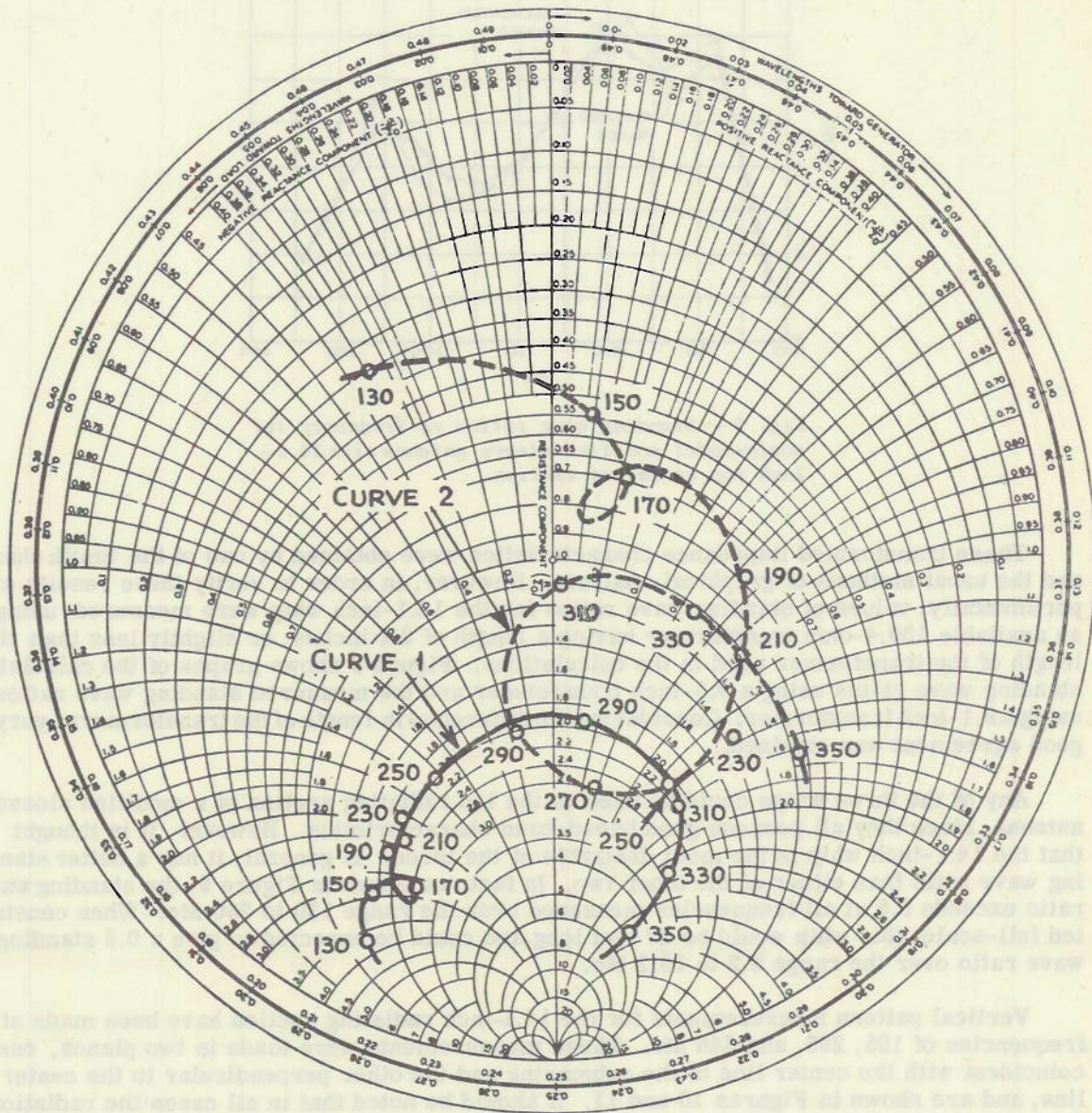


Fig. 8 - Impedance characteristic for scale-model modified sleeve antenna with 12.0 inch top radiating section
 Curve (1) - Impedance characteristic
 Curve (2) - Transformed impedance characteristic

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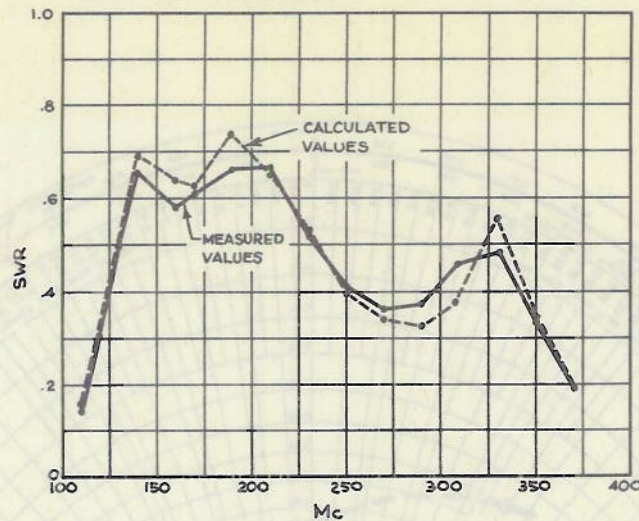


Fig. 9 - Standing wave ratios vs frequency for scale-model modified sleeve antenna with 14.1-inch top radiating section

These transformed impedance characteristics were obtained by use of the Smith chart and the usual methods of graphical analysis. However, in order to verify these results experimentally, values of standing wave ratios for the 14.1-inch whip were measured, using an available 130.4-ohm transformer having a length of 9.1 inches, or slightly less than the length of the transformer used in the calculations. Figure 9 shows graphs of the calculated standing wave ratios using a 9.5-inch transformer and the measured standing wave ratios using a 9.1-inch transformer. Considering the difference in length of the transformers, very good agreement was obtained.

Any of the three whips could be used as the top radiating section of a modified sleeve antenna, since they all possess good broad-band characteristics. However, it is thought that the 14.1-inch whip is the most desirable of the three. In general, it has a better standing wave ratio than either of the other two. In fact, as shown in Figure 9, the standing wave ratio exceeds 0.5 at all frequencies measured over the range 130 to 230 Mc. When constructed full-scale, this whip would be 27 feet long and could be expected to give a 0.3 standing wave ratio over the range 5.2 to 15.2 Mc.

Vertical pattern measurements for the 14.1-inch radiating section have been made at frequencies of 195, 295, and 346 Mc. These measurements were made in two planes, one coincident with the center line of the submarine and the other perpendicular to the center line, and are shown in Figures 10 and 11. It should be noted that in all cases the radiation is at the maximum or nearly the maximum at the horizon, and that in no case does a minimum occur within 10 degrees of the horizon. The relative importance of low angle radiation is indicated in Figure 12 in which the single reflection radiation angle is plotted against great circle distance for various ionosphere layer heights.²

COMMON ANTENNA WORKING

As was pointed out earlier, an antenna with broad-band characteristics was desired for the purpose of permitting the simultaneous operation of communication equipments at different frequencies in conjunction with a single antenna. A tentative communication

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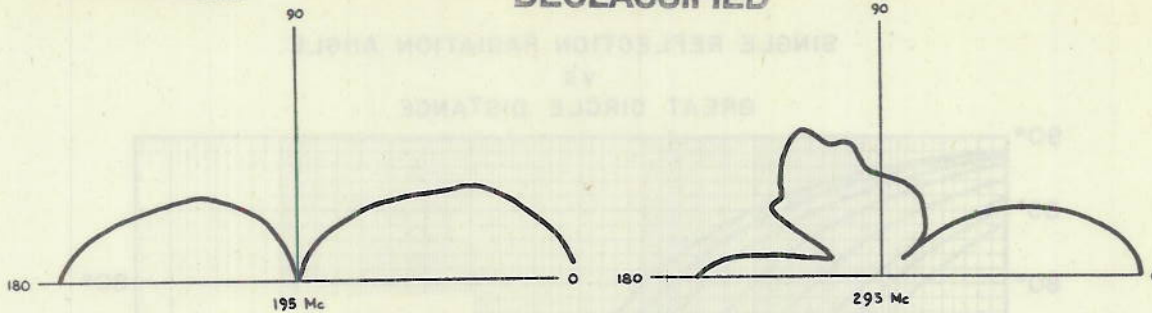


Fig. 10 - Relative field strength vs angles in a vertical plane coincident with center line of the submarine for scale-model modified sleeve antenna using a 14.1-inch top radiating section at the frequencies shown

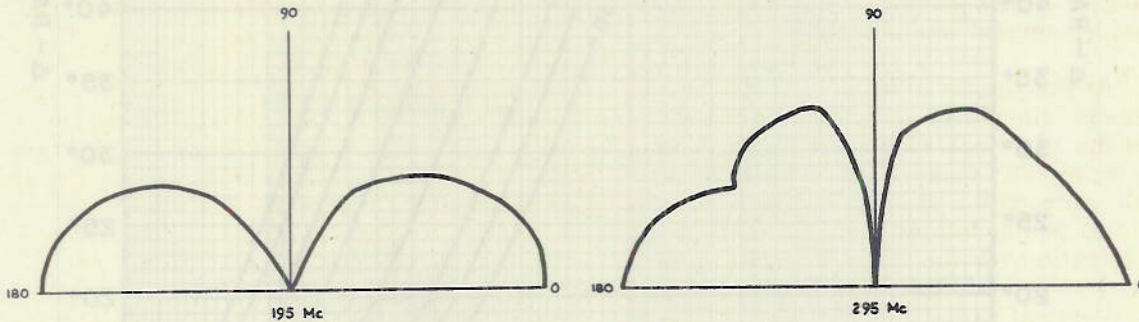
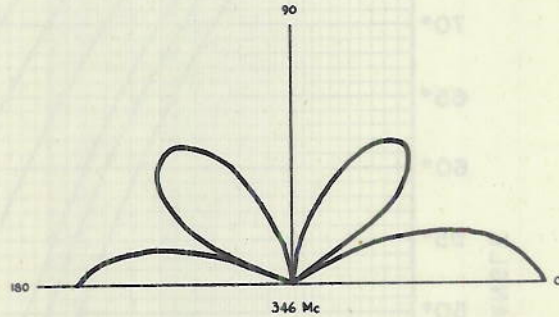
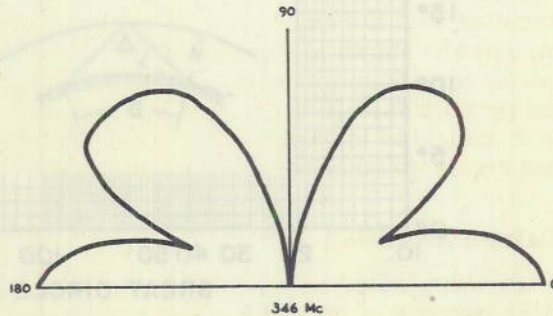


Fig. 11 - Relative field strength vs angles in a vertical plane perpendicular to the center line of the submarine and in the plane of the top radiating section for the scale-model modified sleeve antenna using a 14.1-inch top radiating section at the frequencies shown



SINGLE REFLECTION RADIATION ANGLE
VS
GREAT CIRCLE DISTANCE

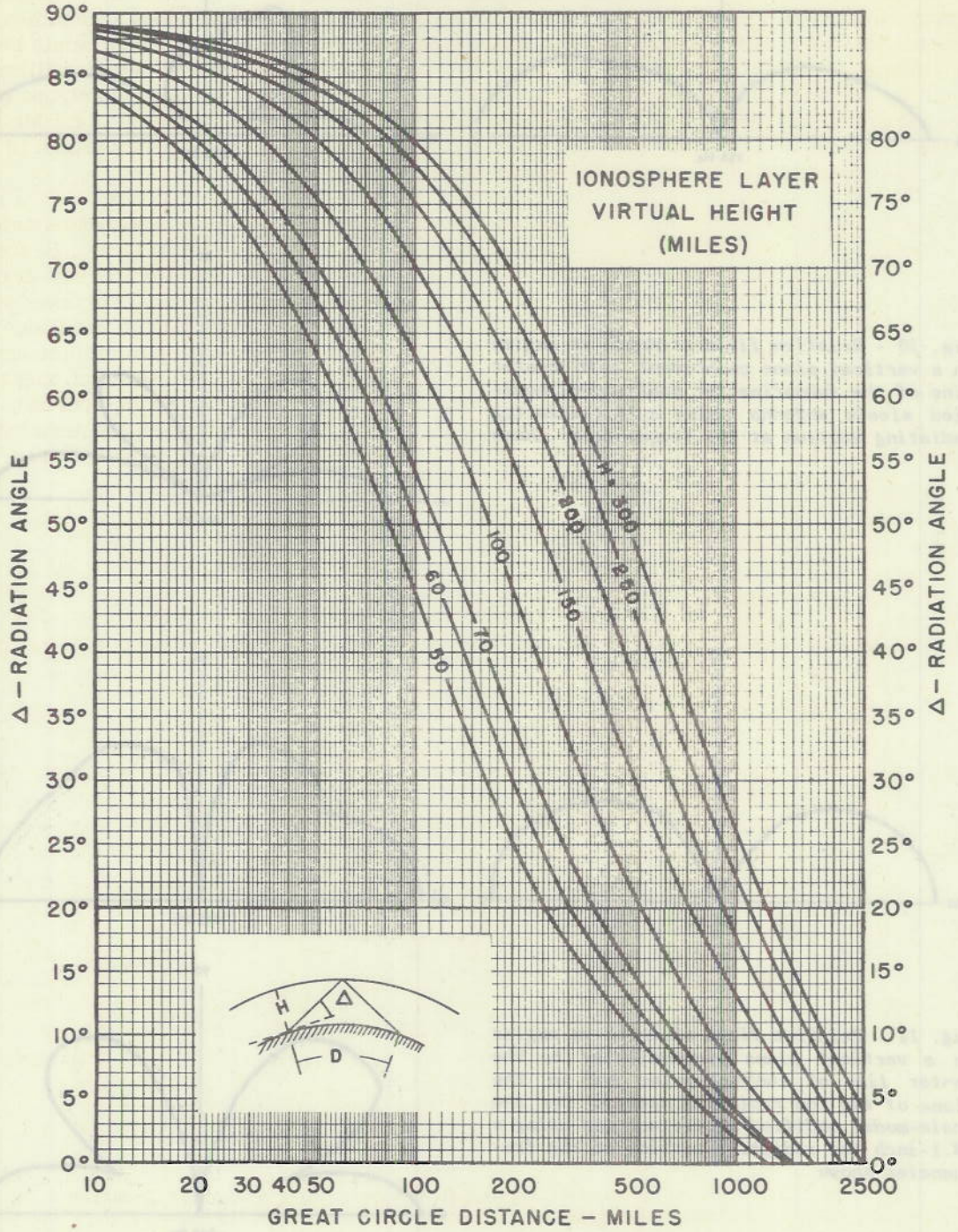


Figure 12

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his principle is illustrated graphically by a block diagram, Fig-
trical relationships between the component parts of the system.

block diagram it is envisioned that two transmitter-receiver
-ked in simplex operation each in conjunction with a "Common
-AW) unit.^{3,4,5,6} For these equipments the frequency range would be
4.5 to 15 Mc. For reception at frequencies of 4.0 Mc and below, a filter
provided having the proper characteristics to pass energy from the antenna at
se frequencies and to permit the satisfactory operation of the CAW units at 4.5 Mc and
above. (The filter should present in the 4.5 to 15 Mc range nearly zero impedance to the
CAW-antenna circuit for correct CAW operation.)

As has been indicated, the experimental work for the design of the broad-band antenna
has been completed and it is felt that a method previously reported by G. W. Dexter⁷
for simultaneous operation of the low-frequency receivers beyond the filter is satisfactory.
Work on the design of the other essential components of the above system is proceeding.
Preliminary results indicate that the CAW units will operate in the 4.5 to 15 Mc range pro-
viding 20 to 25 db isolation between communication equipments operating simultaneously
with a 10 percent frequency separation. Under these conditions the efficiency of operation
of the CAW units would be 70 percent or higher. A filter has been built which permits sat-
isfactory operation of CAW units in the 4.5 to 15 Mc range and simultaneously permits
either reception at 4 Mc and below, or low power transmission in the 2 to 4 Mc range.

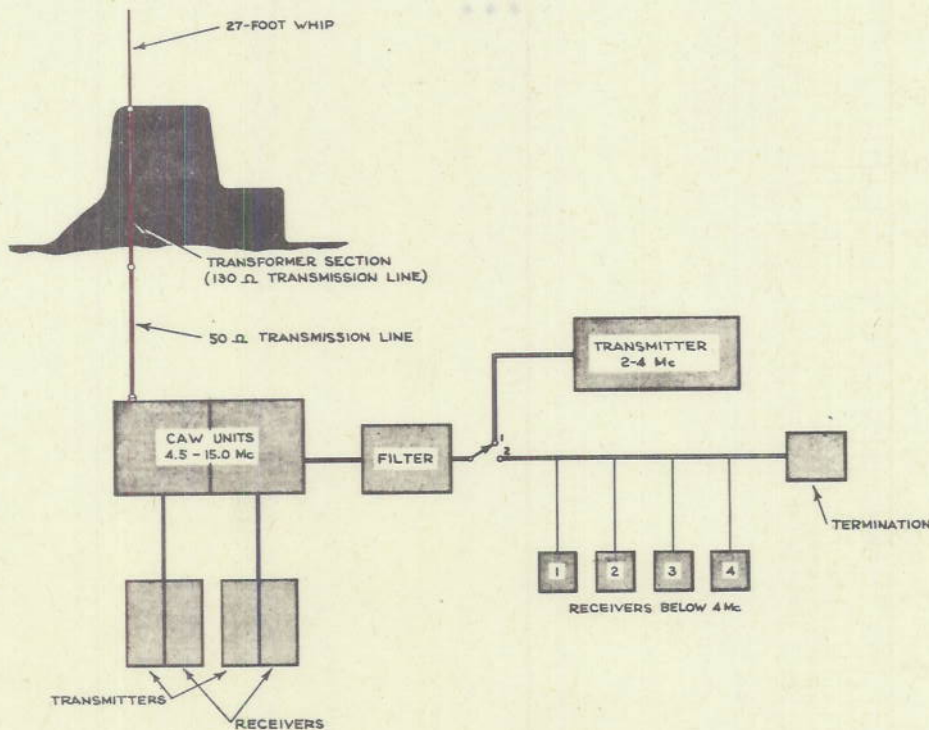


Fig. 13 - View of submarine installation indicating equipment location
and block diagram of tentative antenna installation

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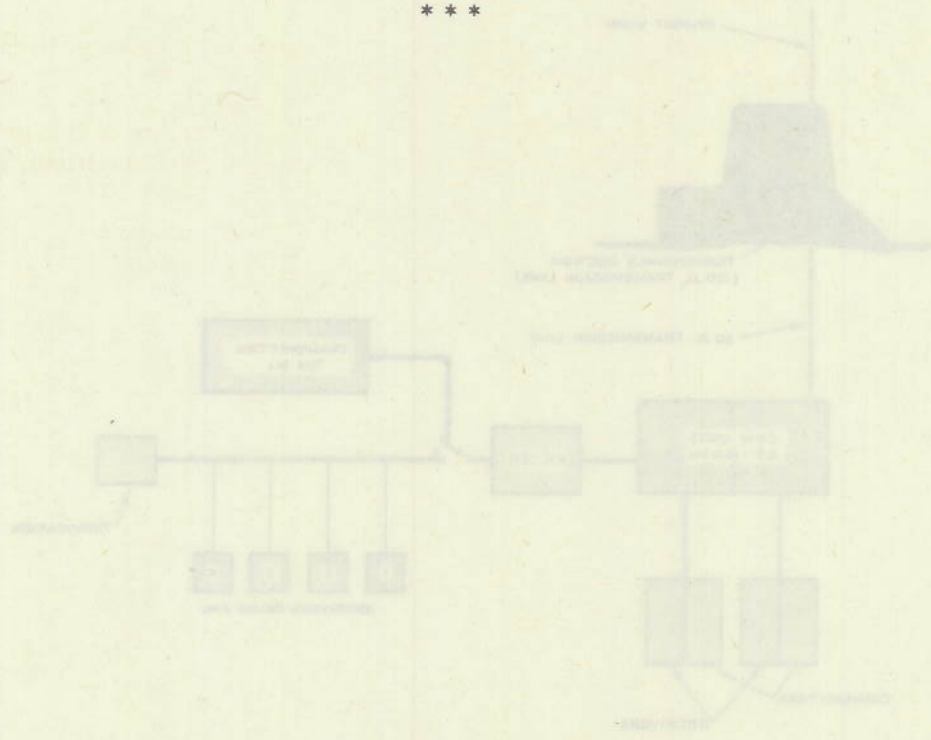
Work is proceeding on the design of a filter which will transmit powers of the order of magnitude required for normal communication activities.

CONCLUSIONS

Three modified sleeve antennas, employing the conning tower structure as the sleeve element, have been designed for the Class SS-487 submarine. These antennas when constructed on a full-scale basis can be expected to maintain values of standing wave ratio of 0.3 or better over bandwidths ranging from 2.6/1 to 3/1 in the high-frequency band. If operated outside their stipulated frequency range, the antennas should give results comparable with those obtained with a simple monopole or whip antenna.

The results secured on the model antennas were obtained under near-optimum conditions, a situation which is unlikely to exist in full-scale shipboard installations. Other nearby structures, such as radar hoists and periscopes, will influence the radiation patterns and impedance characteristics to some extent.

The combination of a broad-band antenna in conjunction with common antenna working units and a properly designed filter provides simplex operation on at least two circuits in the 4.5 to 15.0 Mc range and the operation of either a transmitter or multiple receiving equipments at frequencies below this range.



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