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DESIGN OF SHIPBOARD HF ANTENNAS FOR BROADBAND CHARACTERISTICS.(U)

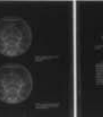
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document provides guidance in design of broadband hf antennas on ships. It will be useful to engineers not familiar with Navy shipboard hf antenna systems. It will also be useful to shipyard engineers in the determination of antenna construction techniques.

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FOREWORD

This report is based on research and development completed in 1965 to develop principles and techniques for the design of high frequency (2-30 MHz) broadband antennas for complex environments such as the topside of a ship. An informal report was submitted in January 1966 to Bureau of Ships, but no report available in the general literature was ever published on this work, nor has any other research been published in the intervening years which adequately discusses the subject. All the ships modeled for this study are, or soon will be, out of service, but the concepts, principles, and techniques discussed are as valid today as they were in 1965.

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INTRODUCTION

Shipboard environments are electrically complex. A ship's topside is designed and shaped to satisfy many, often competing, functions. Among these functions is to provide a means of radiating and receiving hf signals. But because of the many competing functions, the topside of a ship cannot be shaped to be optimum as an hf antenna site.

When electromagnetic energy is radiated or received in the ship's topside, rf currents are induced on all the complex conducting shapes on the structure (masts, yardarms, antenna platforms, deck houses, boat davits, ladders, gun mounts, missile launchers, etc.). The ship's topside in effect acts as a complex antenna and has some highly undesirable shapes from the point of view of the antenna designer. Prominent ship features such as corners (the bow, deck edges), masts, and yardarms have a strong effect on hf antenna characteristics.

Typical US Navy ships have 5 to 19 (more on command ships) hf transmitters and 6 to 24 or more hf receivers which must all be capable of operating simultaneously without mutual interference. The antenna designer must be sophisticated, therefore, in the use of rf filters, and in the careful placement and control of hf antennas and rf conductors in the ship's topside.

This document provides guidance in design of broadband hf antennas on ships. The information provided will be especially useful for engineers not yet familiar with Navy shipboard hf antenna systems and could also be used as a guide by shipyard engineers in the determination of construction techniques for antennas.

Subsequent to the 1965 work published here, additional work on resistively loading antennas to improve their impedance and radiation pattern characteristics has been published (reference 1). The reference also describes the use of resistively loaded conductors to change the electrical shape, and to reduce the electrical Q, of parasitic structures (masts, yardarms, platforms). Clever use of this technique can greatly improve ship hf antenna impedance and radiation characteristics while having negligible effect on system efficiency.

BROADBAND ANTENNA DESIGN CONCEPTS

For Navy shipboard application, hf broadband transmitting antennas are required to be within a 3:1 Voltage Standing Wave Ratio (VSWR) referred to $50\ \Omega$ over a 3:1 bandwidth. These bands are usually 2-6, 4-12, and 10-30 MHz. The 3:1 VSWR limit is set to satisfy multicoupler requirements. Scale models are used to obtain most of the antenna impedance data and, provided the ship's structure is accurately modeled, there is good correlation.

In designing these antennas, the low frequency cutoff is determined by the available height of the ship's structure and antenna length. Above this cutoff the antenna impedance characteristic is determined mainly by the shape of the feed zone and secondarily by discontinuities such as sharp bends farther out on the antenna and by coupling to other structures. An antenna with a matched feed and only very small discontinuities along its length can be considered to be a highpass network. Figure 1 shows the effect of feedpoint configuration on a broadband antenna. The reflection coefficient becomes significant with a small deviation from a matched feed and the highpass characteristic is lost. Figure 2 shows the effect of antenna shape on the reflections. It shows that with a matched feed and smooth antenna configuration there is a considerable range of acceptable antenna shapes. Mainly, the

1. RL Goodbody, U.S. Patent 3,803,615, "Resistive Loading Technique for Antennas"

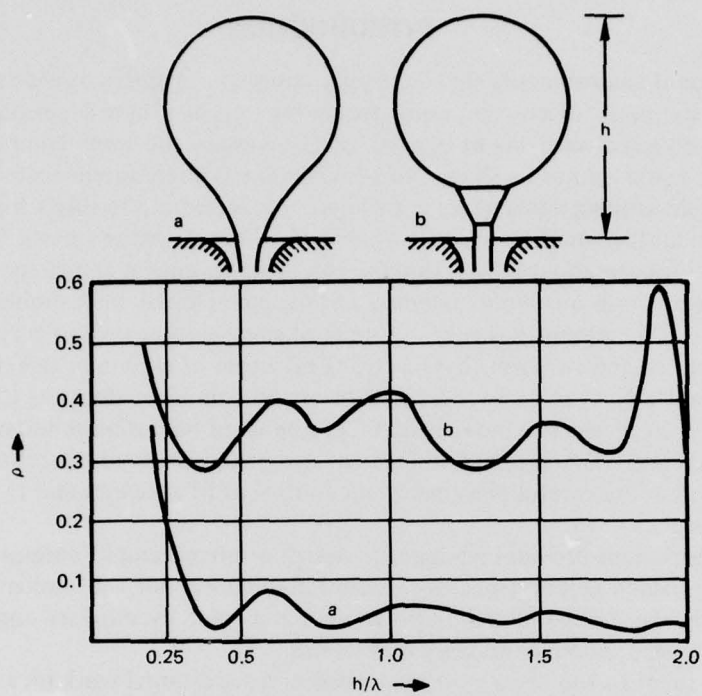


Figure 1. Reflection coefficient ρ of radiators with different feed zones.
(From WADD TR 60-356, Part I, Omnidirectional Broadband Antennas,
HH Meinke, Technische Hochschule, Munich, Germany)

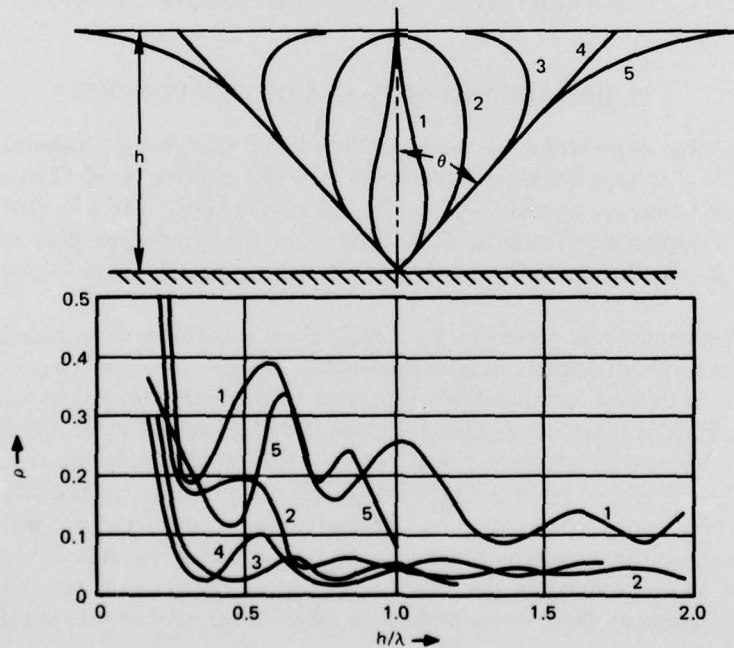


Figure 2. Reflection coefficient of radiators with different shapes.

antenna should be reasonably fat. The characteristic impedance for these antennas is determined by the half-angle, θ , of the cone, which for $50\ \Omega$ is 45° , approximately. Shape 3 gives the lowest reflection coefficient above the cutoff. The data on figures 1 and 2 were taken from reference (2). A flat fan or planar type antenna as shown in figure 3 should have an angle $\theta = 80^\circ$ for a characteristic impedance of $50\ \Omega$ over a ground plane. See reference (3) for additional description of this antenna.

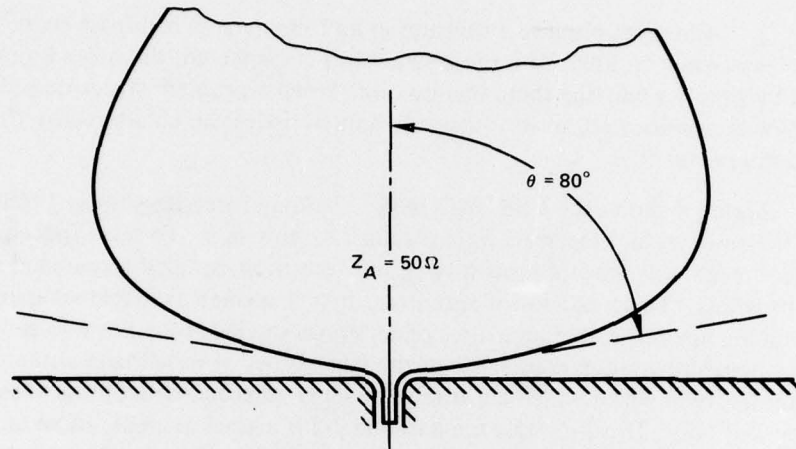


Figure 3. Planar broadband antenna on ground plane.
(From Annual Summary Report 3, contract
AF61(052)-506, Research on Antennas, HH Meinke,
Technische Hochschule, Munich, Germany)

APPLICATION OF ANTENNA DESIGN CONCEPTS TO SHIP HF ANTENNAS

In general, the antenna can be viewed as an extension of the coaxial cable. The characteristic of the coax is determined by the dimensions, which give it characteristic L and C per unit length and a characteristic impedance Z . As the antenna extends from the coax, a shape is maintained such as to minimize rapid changes in L or C per unit distance. A gradual shift from the $50\text{-}\Omega$ characteristic Z of the coax to the $377\text{-}\Omega$ characteristic Z of free space is thus achieved. If this tapering of the shape is done over a long enough distance, and no perturbing resonant shapes are in the near field of the antenna, then an almost perfect impedance transformation is achieved so that no reflected wave results.

Actual shipboard installations limit the bandwidth and VSWR attainable. There are two limiting factors:

1. Inability to attain an optimum matched feed zone and/or smooth antenna configurations. The feed zone configuration can be improved by using shorting wires to change the shape of the existing structure and by using multiwire feeds. Proper termination of the

2. WADD Technical Report 60-350, contract AF61(052)41, Omnidirectional Broadband Antennas
3. Annual Summary Report 3 Contract AF61(052)506, Research on Antennas

feeding coax is especially important. The outer conductor must be grounded at its very end; grounding must be accomplished with very short, fat, solid conducting material, and the termination should be immediately adjacent to the antenna feedpoint (or to the matching network when a matching network is required) to attain the shortest possible lead length from the center conductor. Use of long feed leads and standoff insulators should be avoided, because they introduce series inductance and parallel capacity that usually cannot be tolerated with a broadband antenna. Ideally, the feed should approach that shown in figures 1 and 3.

2. Close coupling to structures exhibiting narrow bandpass characteristics may be a problem. When trouble from these structures is suspected, the offending structures can be found by simply removing them one by one. When a problem structure is discovered, it can be removed or relocated, or its electrical characteristics can be altered by the addition of conducting wires.*

Figure 4 shows the USS TACONIC, a landing force flagship in 1965. A large number of hf transmitters and receivers were installed on this ship. To serve this equipment, seven multicoupled** broadband transmitting and four multicoupled broadband receiving antennas were provided. This was a lot of antennas for such a small available area, and obtaining acceptable impedance characteristics on antennas so close together was quite a task. The arrangement shown illustrates some of the basic types of broadband antennas used — trussed monopoles, twin whips which are tiltable to clear guns and helicopters, discone cage antennas, and fans. The 2–6-MHz fan antenna 2-2 is a good example of an antenna design problem. A 1/48th scale ship model was used to obtain the impedance data. At first the antenna was tried with the feedpoint at the SPS-30 radar platform (no log periodic (LP) antenna installed — LP shown on figures 4 and 8A). Another fan antenna had been located on the stack. The changes made to improve the impedance of antenna 2-2 were to remove the antenna on the stack, raise the feedpoint to reduce the size of conducting structure above it, and modify the feed zone by using shorting wires. The mast on which the antenna feedpoint is mounted is, of course, part of the antenna and is therefore as important a consideration as the wire fan in determining the antenna characteristics. Figures 5 and 6 show impedance plots indicating the progress made. Figure 5 was the first measurement and shows a very poor impedance with VSWR as high as 20:1. After the 4–12-MHz fan antenna was removed from the stack, there was a marked improvement, as shown in figure 6. Figure 7 shows a view of the feed zone as it was for the plots of figures 5 and 6. When the feedpoint was raised and the feed zone modified, as shown in figures 8A and 8B, an acceptable impedance characteristic was obtained as shown in figure 9. The impedance attained so far, however, is without the LP installed. Note the use of grounded wires to shape the feed zone and reduce the electrical discontinuities in its vicinity. After the LP was installed on a normal metal support mast, the antenna again was unusable. The solution was to isolate the LP by winding the LP feed cable on a 3-foot-diameter by 10-foot-long fiber glass support, shown on figure 8A, in place of the metal support mast to form a choke inductance. Figure 10 shows the impedance of the antenna without, and figure 11 with, the isolating choke installed. Figure 12 shows the antenna impedance after matching with lumped elements.

*The conducting wires can also be loaded with an appropriate resistor (chosen to minimize hf energy losses) or in some cases an appropriate combination of L, C, R. For ship construction, however, a guiding principle should be "Keep it simple."

**The term "multicoupled" means that several transmitters or receivers are simultaneously coupled to one antenna via a multicoupling device.

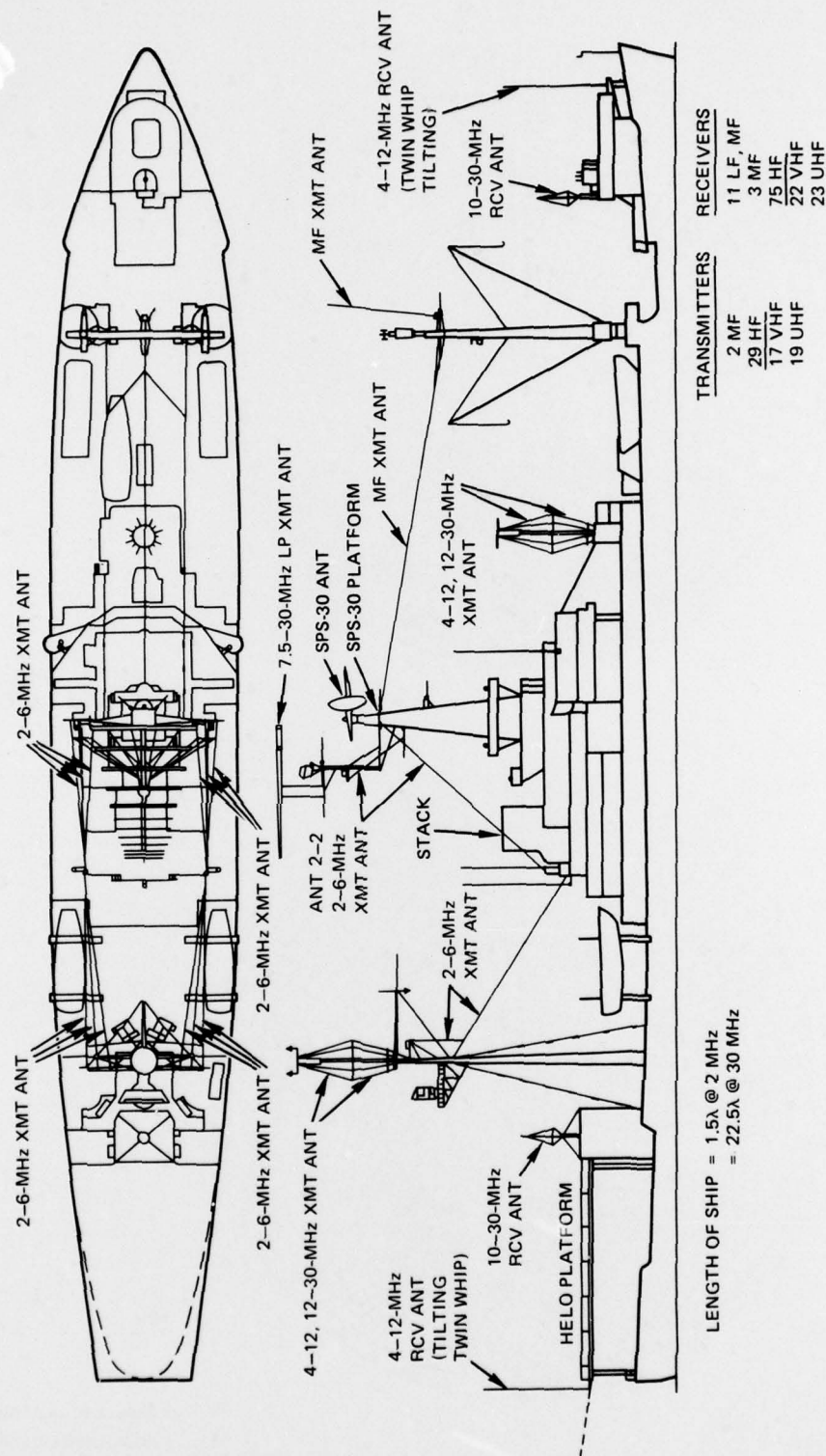
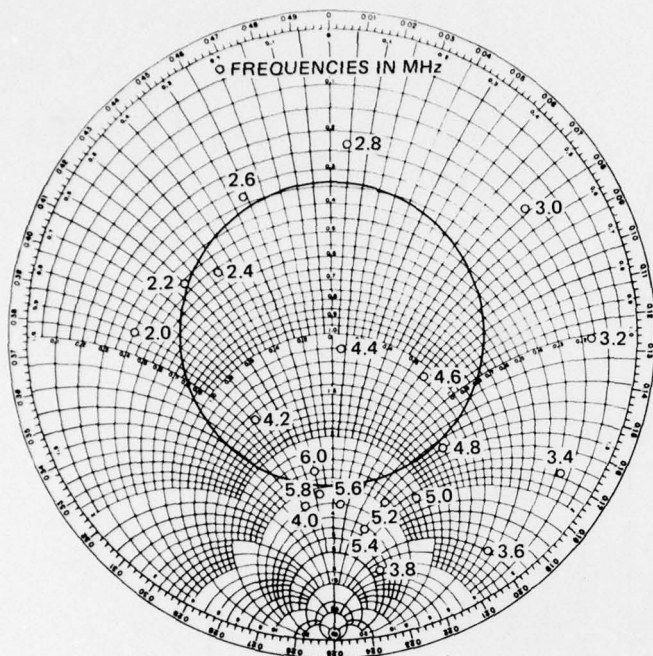


Figure 4. Topside configuration, landing force flagship, USS TACONIC (AGC 17).



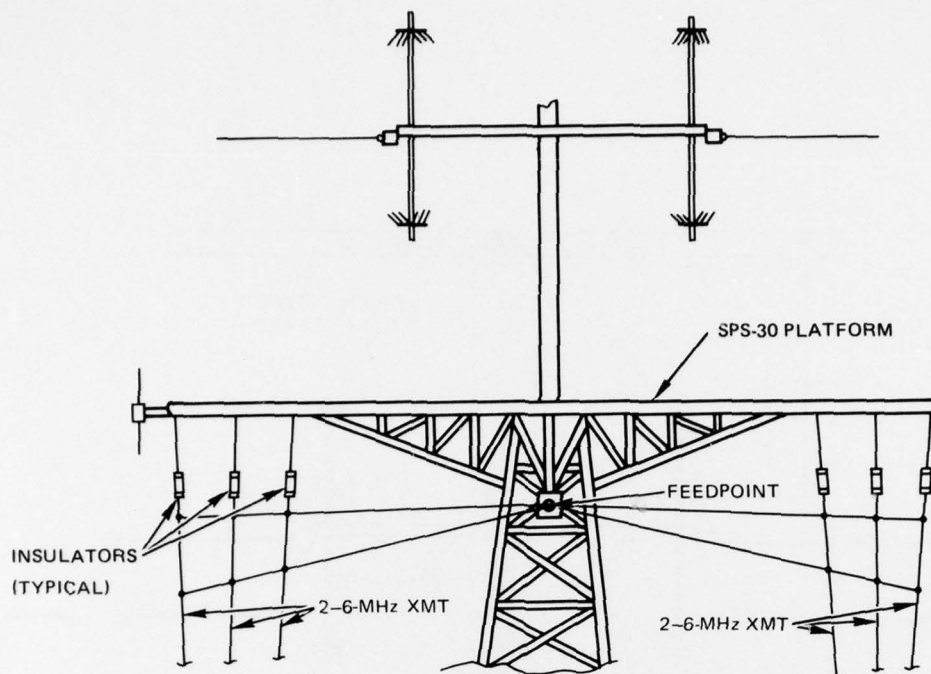


Figure 7. Antenna 2-2, looking forward, first configuration (for plots shown in figures 5 and 6).

The following are two examples of solutions to the problems caused by coupling of an antenna with another structure. Figure 13 is an example, on the old heavy cruiser, USS NEWPORT NEWS (CA 148), of the use of a shorting wire to modify structure for improving the impedance of an antenna. The impedance of the 2-6-MHz antenna 3-1 on this ship was not acceptable. Removal of the SPS-12 radar antenna and platform which caused the difficulty would have solved the problem. However, since relocation of the radar antenna would be impractical and expensive, shorting wires were used to change the electrical characteristics of the platform. This resulted in an acceptable impedance characteristic on the antenna. Figure 14 shows an antenna on USS ALBANY (CG 10) the feedpoint of which was changed from the forward end to the after end to decouple it from an mf antenna which caused impedance problems. The shaping of the feed zone on this antenna should also be noted.

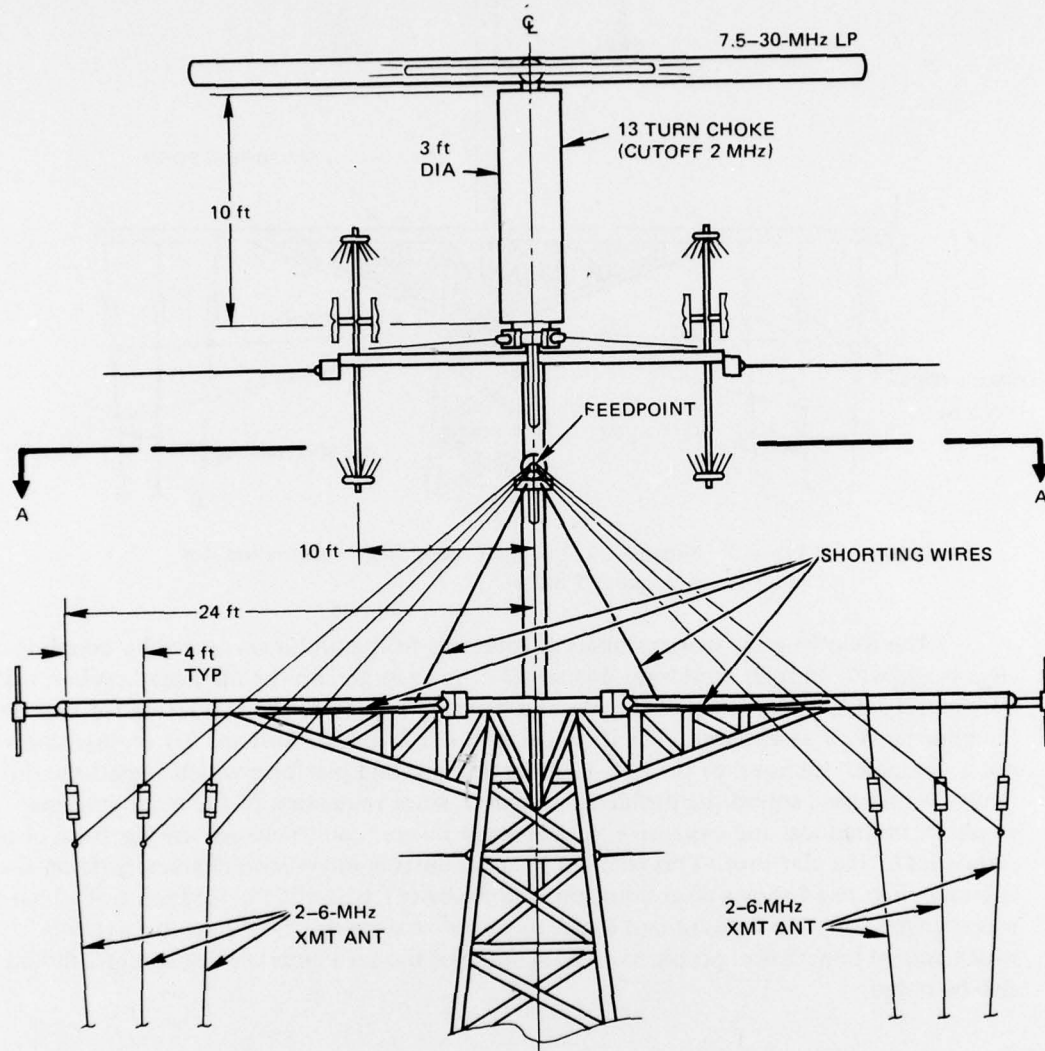


Figure 8A. Antenna 2-2, looking forward, final configuration (for plot shown in figure 9).

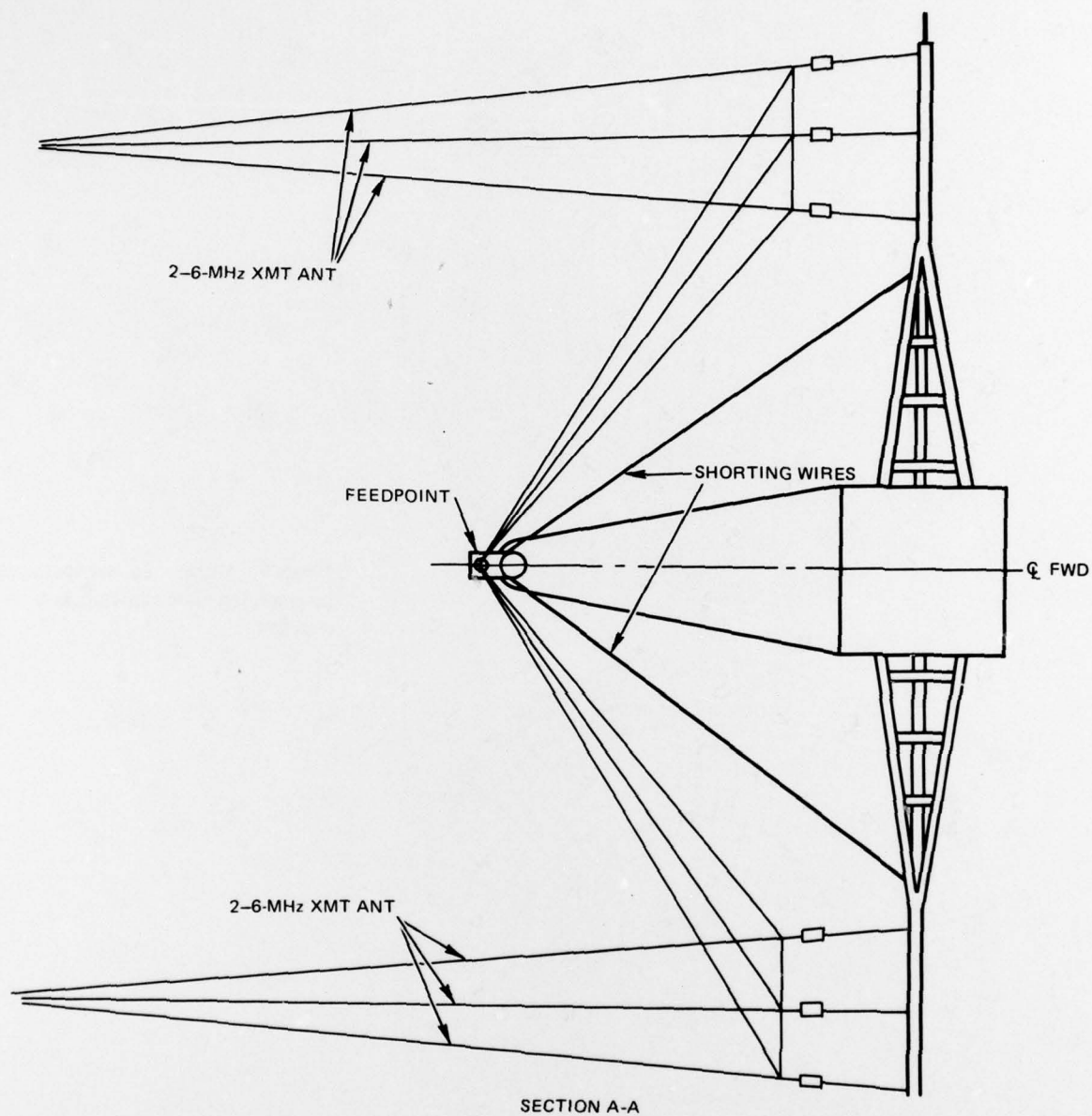


Figure 8B. Antenna 2-2, top view, final configuration (for plot shown in figure 9).

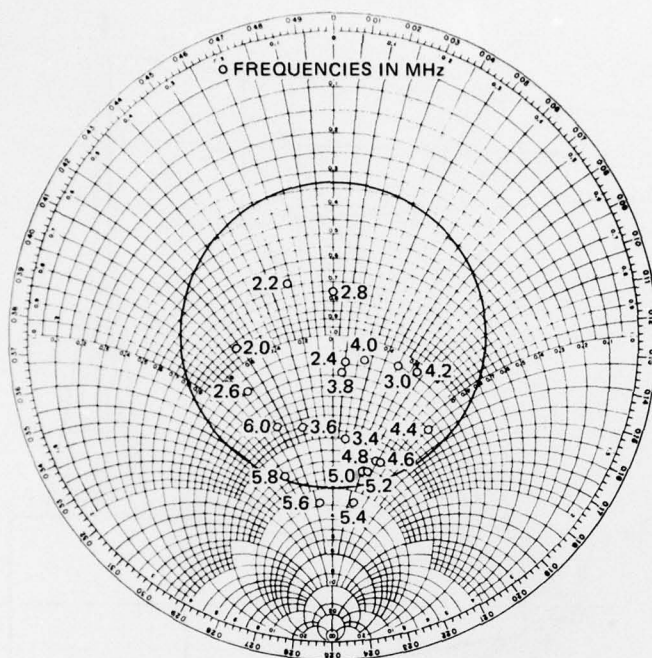


Figure 9. Antenna 2-2 feedpoint impedance, log period antenna not installed.

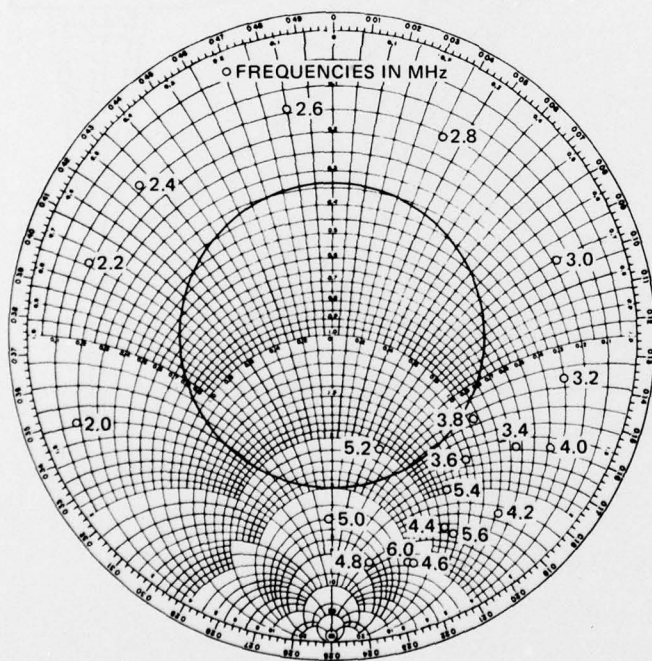


Figure 10. Antenna 2-2 feedpoint impedance, log periodic antenna installed, no isolating choke.

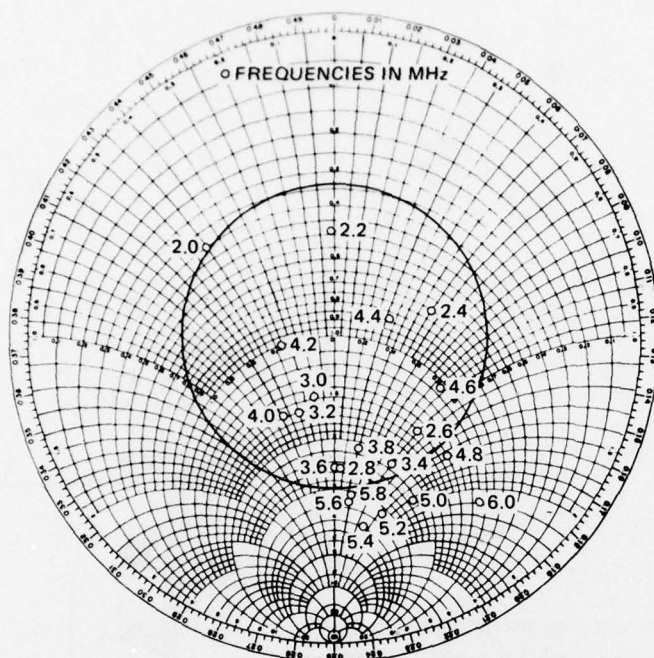


Figure 11. Antenna 2-2 feedpoint impedance, isolating choke installed.

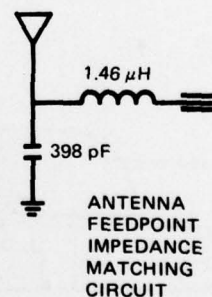
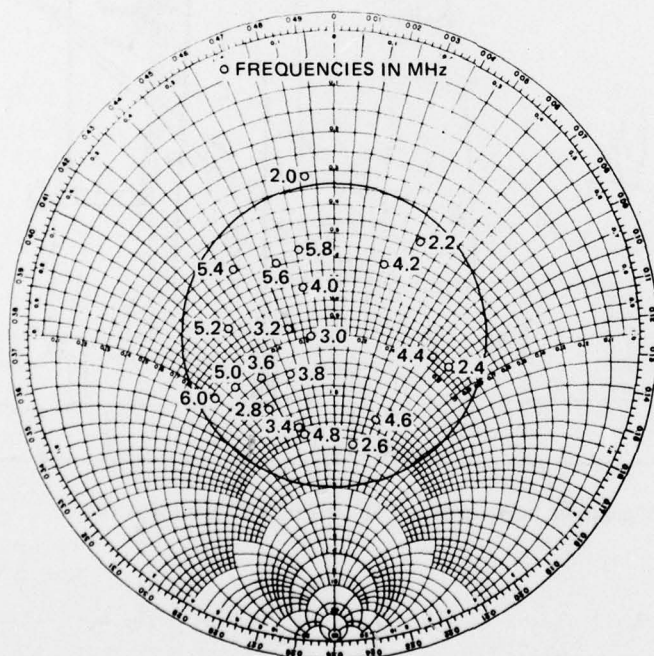


Figure 12. Antenna 2-2 matched impedance, log periodic antenna and isolating choke installed.

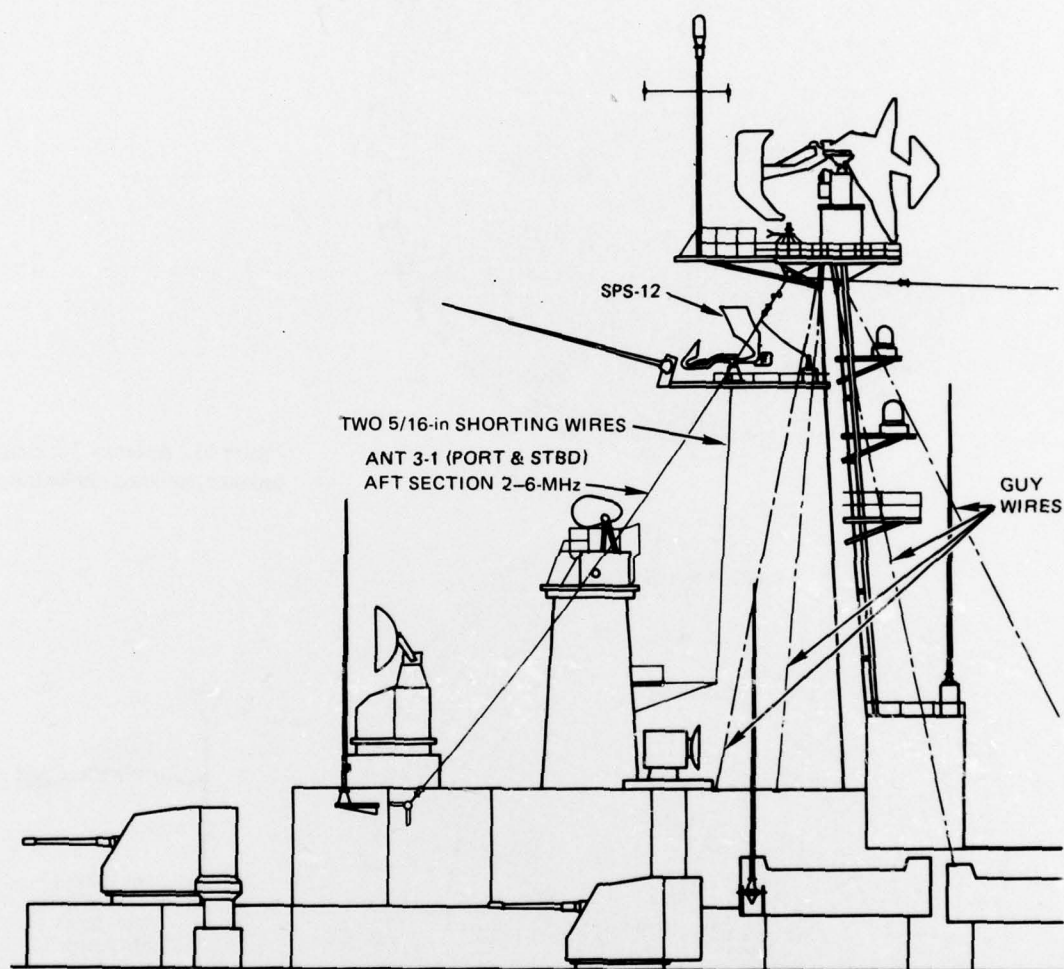


Figure 13. Topside configuration, heavy cruiser, USS NEWPORT NEWS (CA 148).

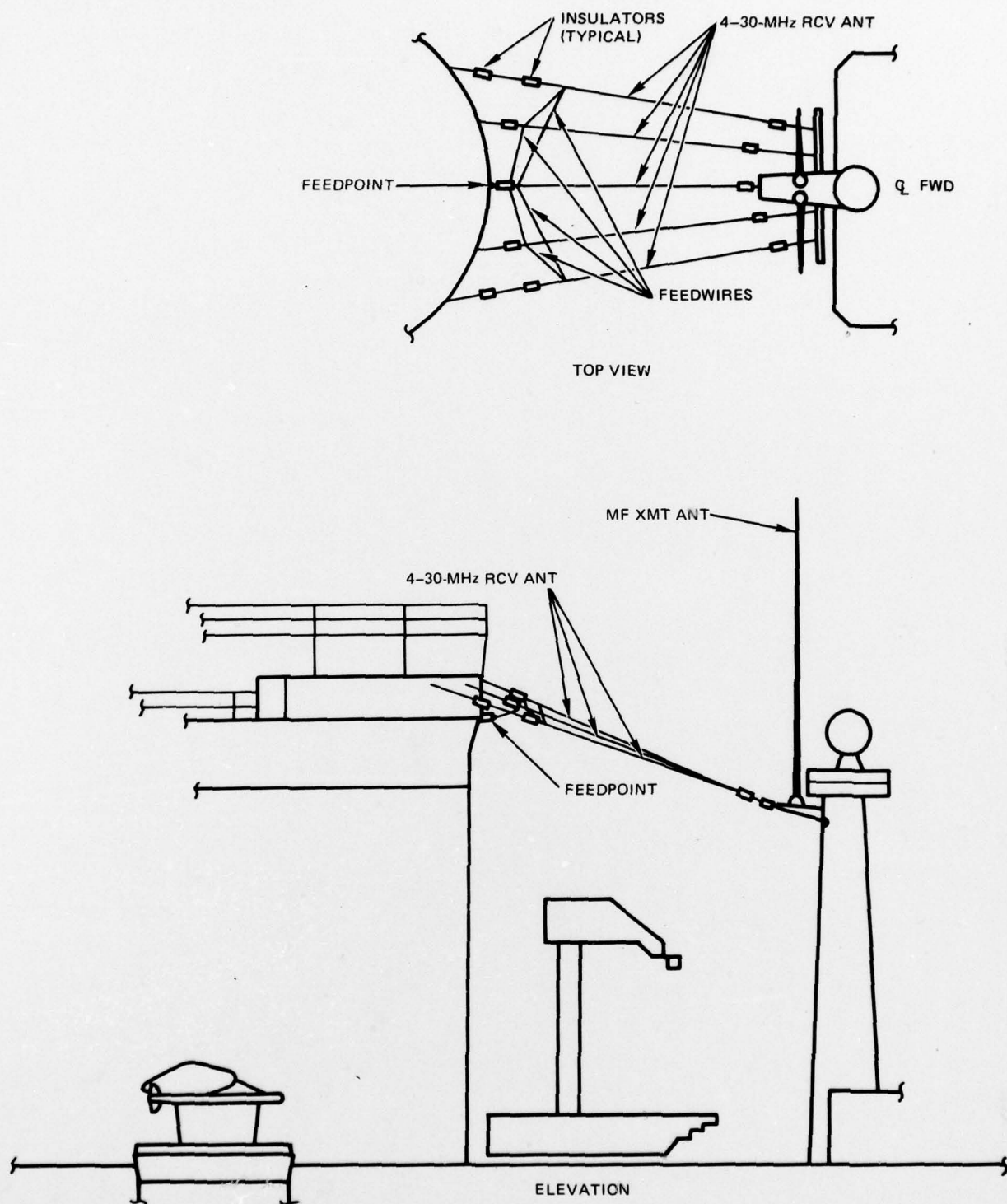


Figure 14. Topside configuration, guided missile cruiser, USS ALBANY (CG 10).