/)

COMPOSITE DISCAGE ANTENNA DEVELOPED
FOR 2-TO-30-MC/S BAND

Provides omnidirectional coverage in horizontal plane with VSWR of 3 to 1 or better

S.E. Parker, L.G. Robbins, and W.J.E. Edwards   **Research and Development Report**   **8 August 1967**

49

THIS DOCUMENT HAS BEEN APPROVED FOR PUBLIC RELEASE AND SALE;
ITS DISTRIBUTION IS UNLIMITED.

PROBLEM

Develop a 2-to-30-Mc's antenna with impedance and pattern characteristics that are satisfactory for general ship and shore applications.

RESULTS

1. A composite discone-cage vertically polari ed antenna has been developed. It provides a VSWR of 3 to 1 or better throughout the 2-to-30-Mc/s band. Its coverage in the horizontal plane is omnidirectional.

2. Scale-model measurements demonstrate that low-angle radiation is provided by the cage section at most frequencies from 2 to 8 Mc/s. The discone section, owing to its elevated feed point, gives multilobed vertical patterns with a major lobe at relatively low angles from 8 to 30 Mc's and higher.

3. Auxiliary low-pass and high-pass networks can be used to isolate the antenna sections and to obtain favorable impedance transformations. These networks insure that impedance and pattern characteristics will remain stable and predictable.

RECOMMENDATIONS

1. Utilize the general-purpose DISCAGE antenna for ship and shore applications requiring an extremely versatile broadband antenna with omnidirectional characteristics.

2. Employ auxiliary low-pass and high-pass networks to obtain highly stable impedance and pattern characteristics, particularly when simultaneous operation of the cage and discone sections is required.

3. Employ highly selective multicoupling equipment to accommodate a large number of radio equipments with a single DISCAGE antenna installation.

ADMINISTRATIVE INFORMATION

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

4

INTRODUCTION

The idea of combining a cage monopole with a discone to form a compact antenna structure originated at this Laboratory in August 1954.[1] The well known discone was invented by Kandoian over 20 years ago,[2] and the practice of using a cage of wires to form a broadband monopole is much older. The basic discone structure "consists of a disc and a cone whose apex approaches and becomes common with the outer conductor of the coaxial feeder at its extremity."[3] Along with several related antenna forms, the discone evolved from the biconical antenna, or electromagnetic horn.[4]

The first discone-cage. or DISCAGE, antenna was developed for shipboard installation on a 5-inch, 54-calibre gun turret.[5] As shown in figure 1, a simulated gun and turret were installed at the Laboratory's Model Range to facilitate this development. Pattern and impedance characteristics of an antenna with the dimensions shown in the insert were considered generally satisfactory from 5 to 30 Mc/s.

Various DISCAGE antennas have been developed for both ship and shore applications during the past decade. Different sizes and shapes have been used to satisfy stringent space limitations. and several different feed techniques have evolved. The rather thin DISCAGE antenna of figure 2, for example, provides a VSWR of 3 to 1 from 5 to 15 Mc/s with the cage section and from 15 to 30 Mc/s with the discone section.[6] A shunt-feed technique is employed with both cage and discone. This affords important structural advantages and facilitates installation of a uhf antenna above the disc. During recent years special provisions have been made to accommodate large antenna structures aboard ships such as the CC and AGMR classes which have major command and control functions. Figure 3 shows a DISCAGE developed at the Laboratory for USS WRIGHT (CC 2).[7] Note that a uhf antenna is mounted above the disc.

Apart from these shipboard requirements, there has been a long-standing need for a highly versatile, onmidirectional hf antenna at many military shore facilities. Available real estate is becoming so scarce and so costly that it is often difficult to provide enough space for several large structures with separate ground planes. This problem is illustrated by an antenna requirement that occurred at the Laboratory around 1960 when it became necessary to provide a complete hf antenna installation to evaluate a special communications system. Expensive grading and filling operations would have been required to provide space for several conical monopoles or sleeve antennas in the vicinity of the main Communications Facility, and the required transmission lines would have been excessively long and costly. As shown in figure 4, this requirement was effectively satisfied by designing and installing a 2-to-30-Mc/s DISCAGE antenna on a nearby parking lot. The parking area was in need of resurfacing, and a system of ground radials was laid before new asphalt topping was applied. Although the size and shape of the ground plane were somewhat less than optimum, the measured VSWR of the antenna was better than 3 to 1 throughout 90 percent of the 2-to-30-Mc/s band.

---

1 See references at end of report
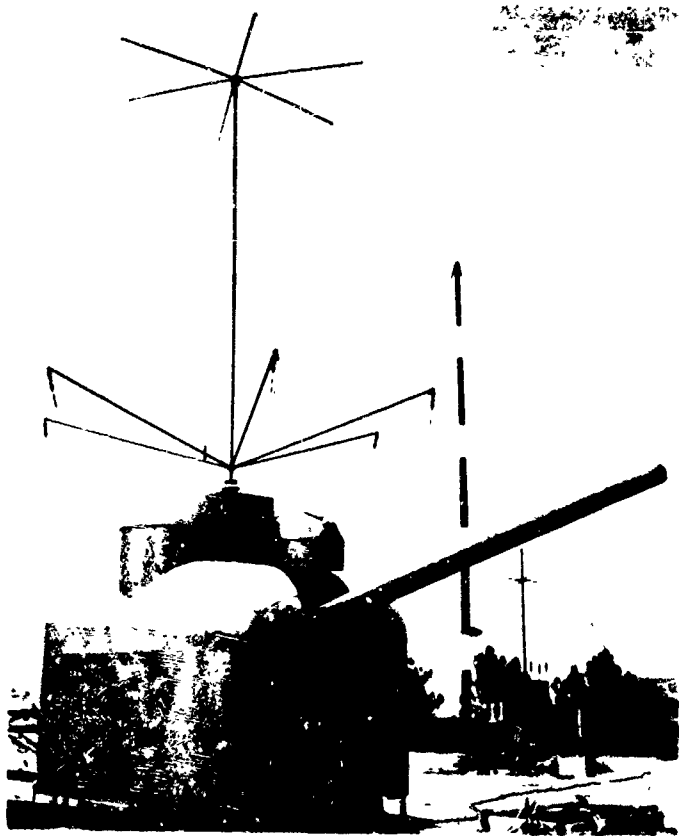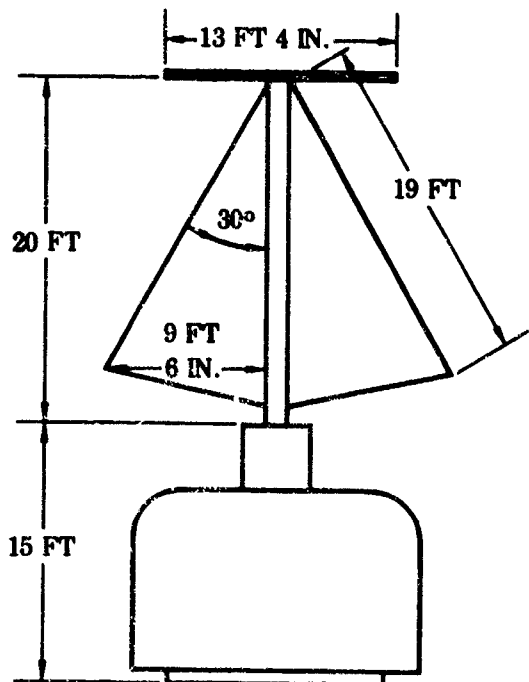
Figure 1. DISCAGE antenna on 5-inch, 54-calibre gun turret.

9 FT

18 FT 9 IN.

19 FT 6.6 IN.

20°

32 FT

13 FT 6 IN.

13 FT 3 IN.

6 FT

BARREL FEED RING

INSULATOR

1 FT 6 IN.

DISC FEED LINE

CAGE FEED INSULATOR
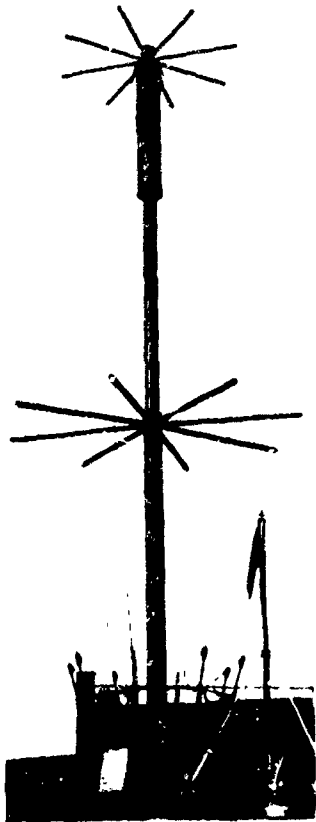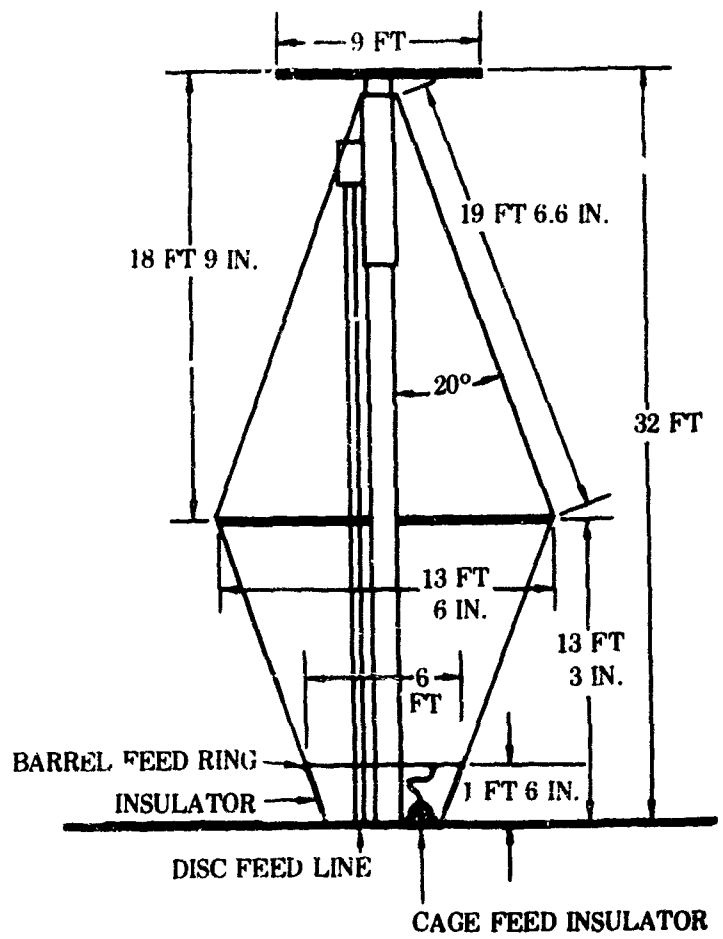
Figure 2. DISCAGE antenna (5 to 30 Mc/s) for shipboard use.

MATCHING
NETWORK BOX
CABLE ENTRANCE

AS-1018 ANTENNA

3.25 IN.

2 FT 3 IN.

FIBER GLASS
INSULATOR

13 FT

SLANT HEIGHT
= 25 FT 0.6 IN.

22 FT

10 FT 3 IN.

SHORTING
PLATE

WIRES 22.5 IN.
APART

62.5°

52.5°

12 FT

1 FT 3 IN.

2 FT

2 FT

FOUNDATION
STRUCTURE

Figure 3. DISCAGE antenna (4 to 30 Mc/s) used on USS WRIGHT (CC 2).
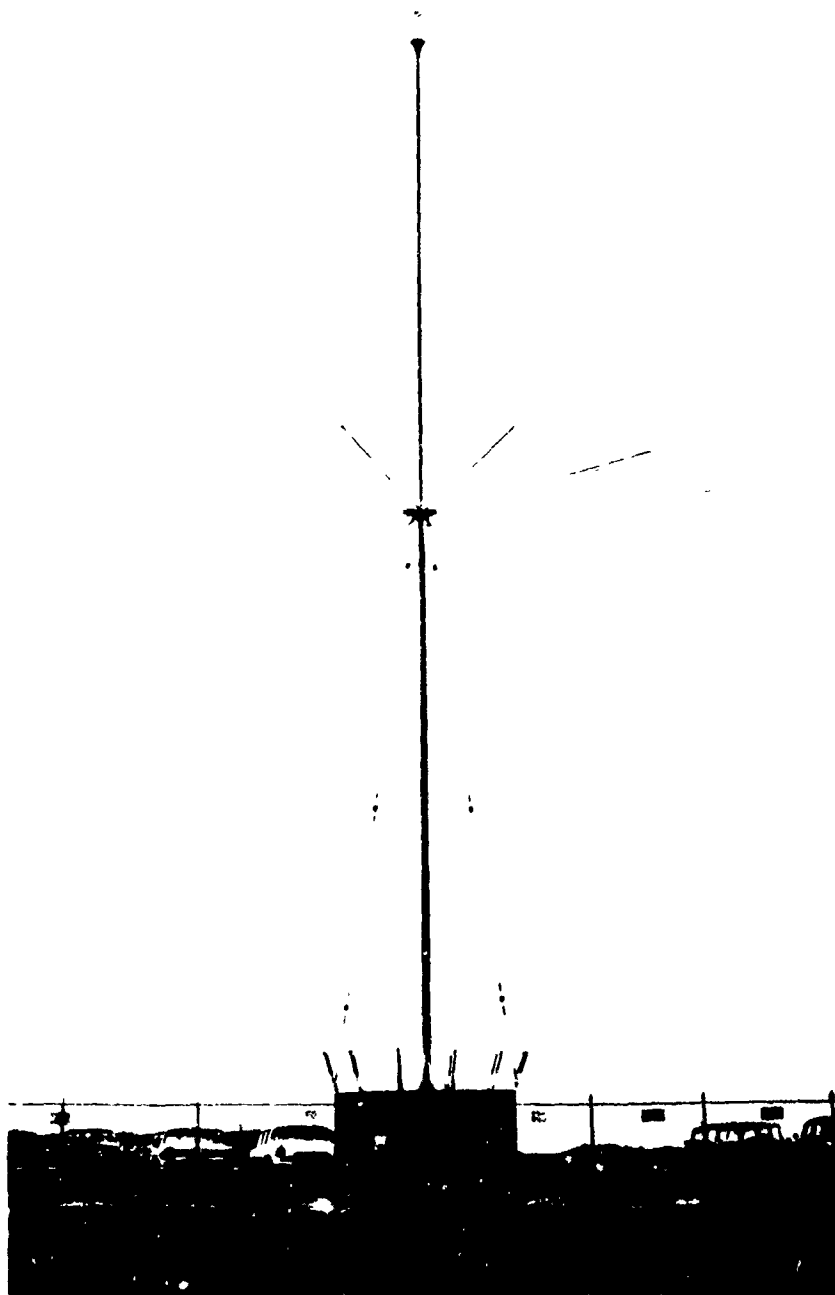
Figure 4. DISCAGE antenna (2 to 30 Mc/s) used at NELC Communications Facility.

In 1964 another need for a general-purpose, broadband hf antenna arose at the Laboratory. For testing and evaluating a new series of hf power-amplifier/coupler (PAC) equipment under development at the Model Range, an extremely broadband antenna was needed to provide a highly stable complex load impedance and to facilitate open-field measurements of harmonics and other spurious radiation products. (In high-power testing of this nature, considerable difficulty has been experienced in attempting to simulate actual antennas without introducing troublesome instability or unwanted nonlinear products.)

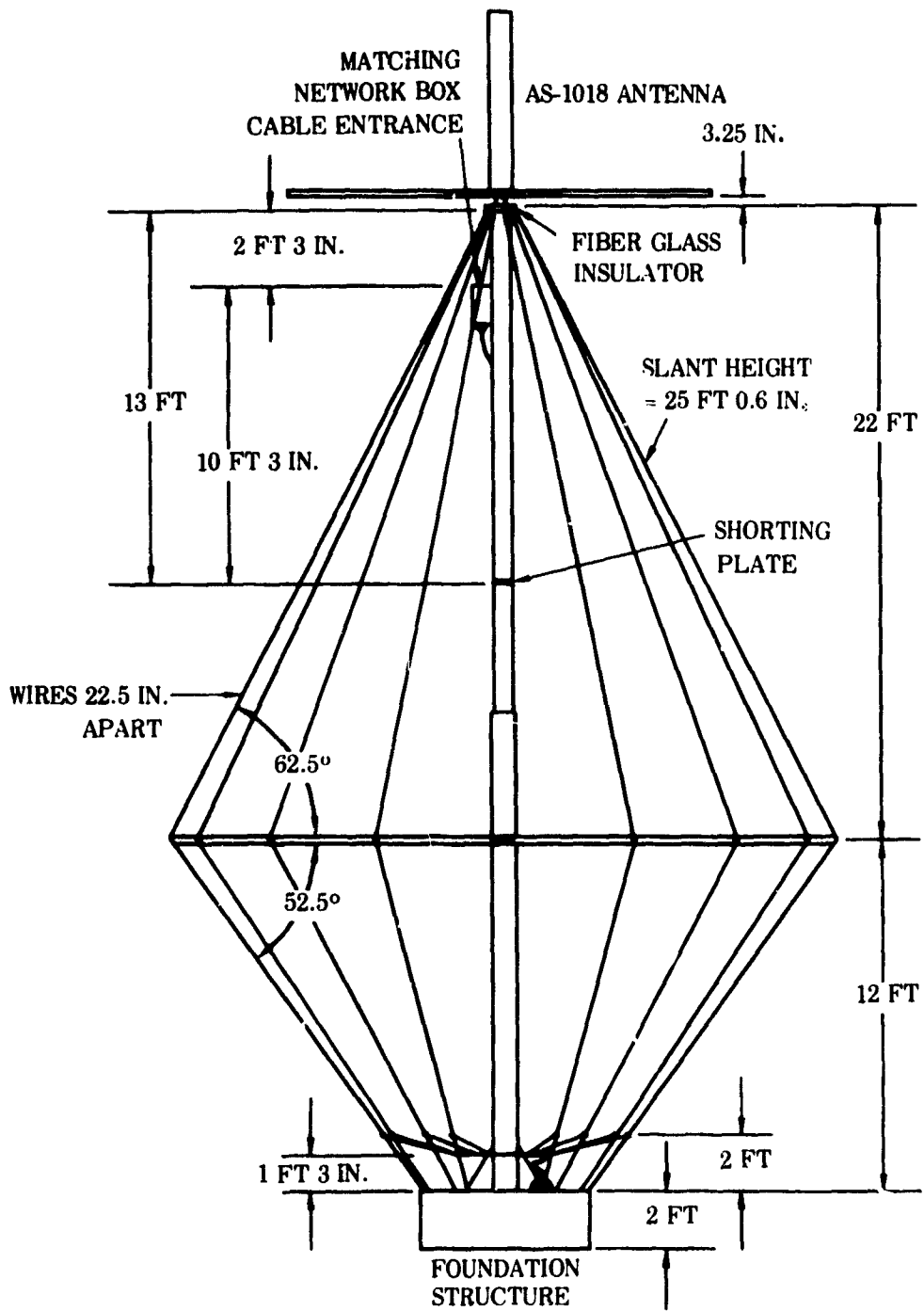This report is largely concerned with the series of studies performed during the development of a 2-to-30-Mc/s DISCAGE antenna to satisfy the foregoing antenna requirements. The resulting full-scale structure, installed about 500 feet west of building 382, is shown in figure 5. The antenna satisfies the immediate requirements, as we shall see, and should prove to be a valuable addition to NELC Model Range facilities for many future studies. Above all, it is hoped that information derived from this developmental effort will facilitate wider application of the general-purpose DISCAGE antenna throughout the Navy.

Figure 5. DISCAGE antenna (2 to 30 Mc/s) installed in the NELC Model Range
1965-1966. (Three of the lower wires of the cage have been removed to facilitate
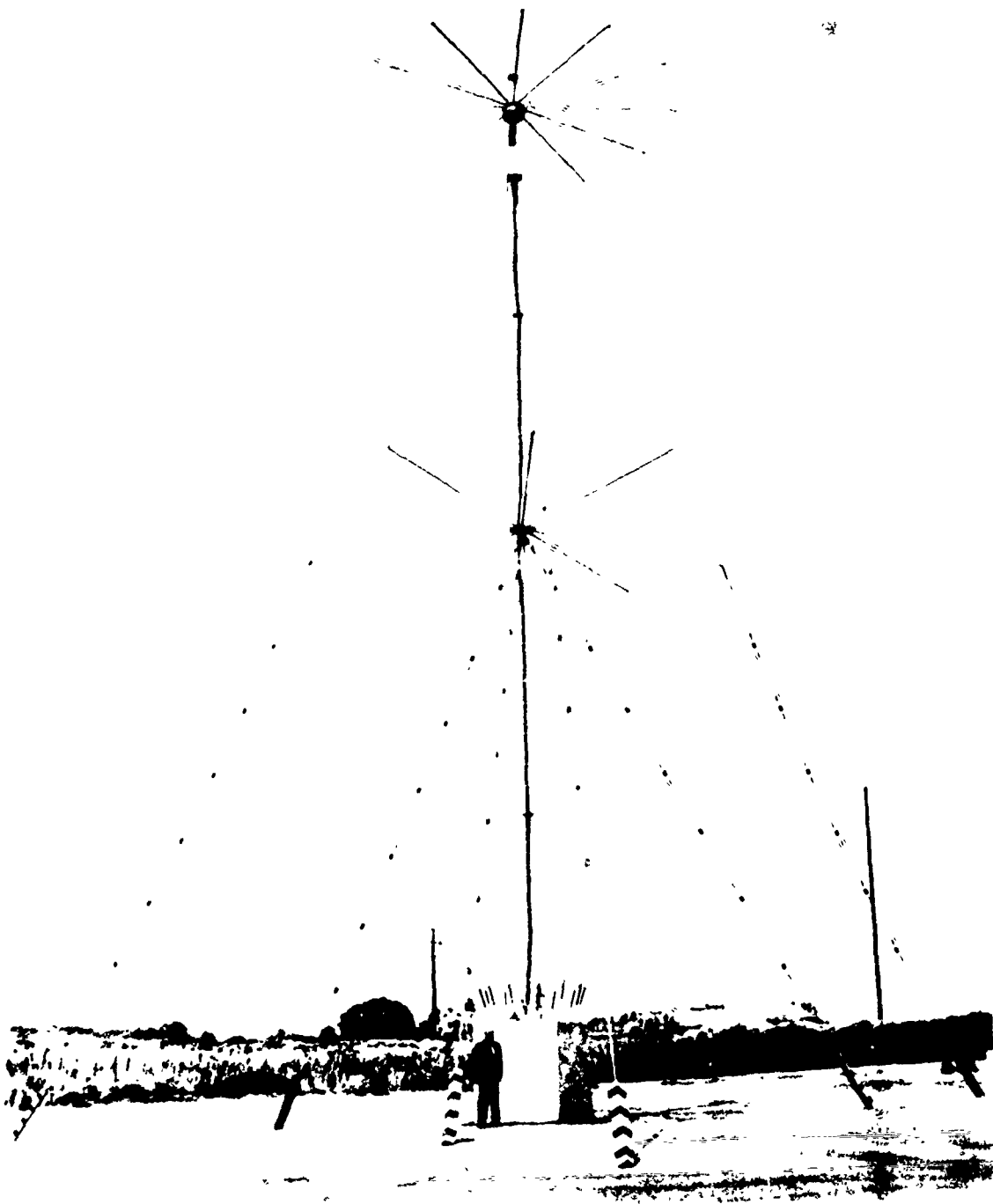guying near the midpoint of the main mast.)

THE DISCAGE ANTENNA

General Features

The DISCAGE antenna consists of a thick top-loaded monopole and a discone integrated into one compact radiating structure. Its general features are illustrated by the simplified diagram in figure 6. Being base driven, the cage requires an adequate ground plane. The disc can provide top-loading and increase the electrical height of the cage under certain terminating conditions at the discone's feed point. This top-loading is desirable at the lower frequencies from an impedance standpoint, but is undesirable at the cage's higher operating frequencies from a pattern standpoint. If the most favorable impedance and pattern characteristics are to be obtained from the cage section, therefore, the terminating conditions of the discone must be controlled. As explained later, a high-pass filter or a suitable switching scheme may be used for this purpose, the selection depending upon the application.

Owing to certain high-pass properties inherent in the discone, the impedance and pattern characteristics of the discone are not particularly sensitive to the cage's terminations. Since the cone is an integral part of the cage, however, the resulting isolation at the cage's operating frequencies is not considered adequate for general applications. This situation is illustrated in figure 7. (Note that full-scale frequencies are shown on graphs giving results of scale-model studies.)

An additional and perhaps more important reason for using an auxiliary low-pass network with the cage stems from impedance (or VSWR) requirements. Subsequent discussion will show that one or more significant perturbations are introduced in the impedance characteristic of the cage when a suitable high-pass network is inserted in the feed line to the discone. Means will be described for empirically optimizing this impedance characteristic by means of the same low-pass network that isolates the cage from the discone.
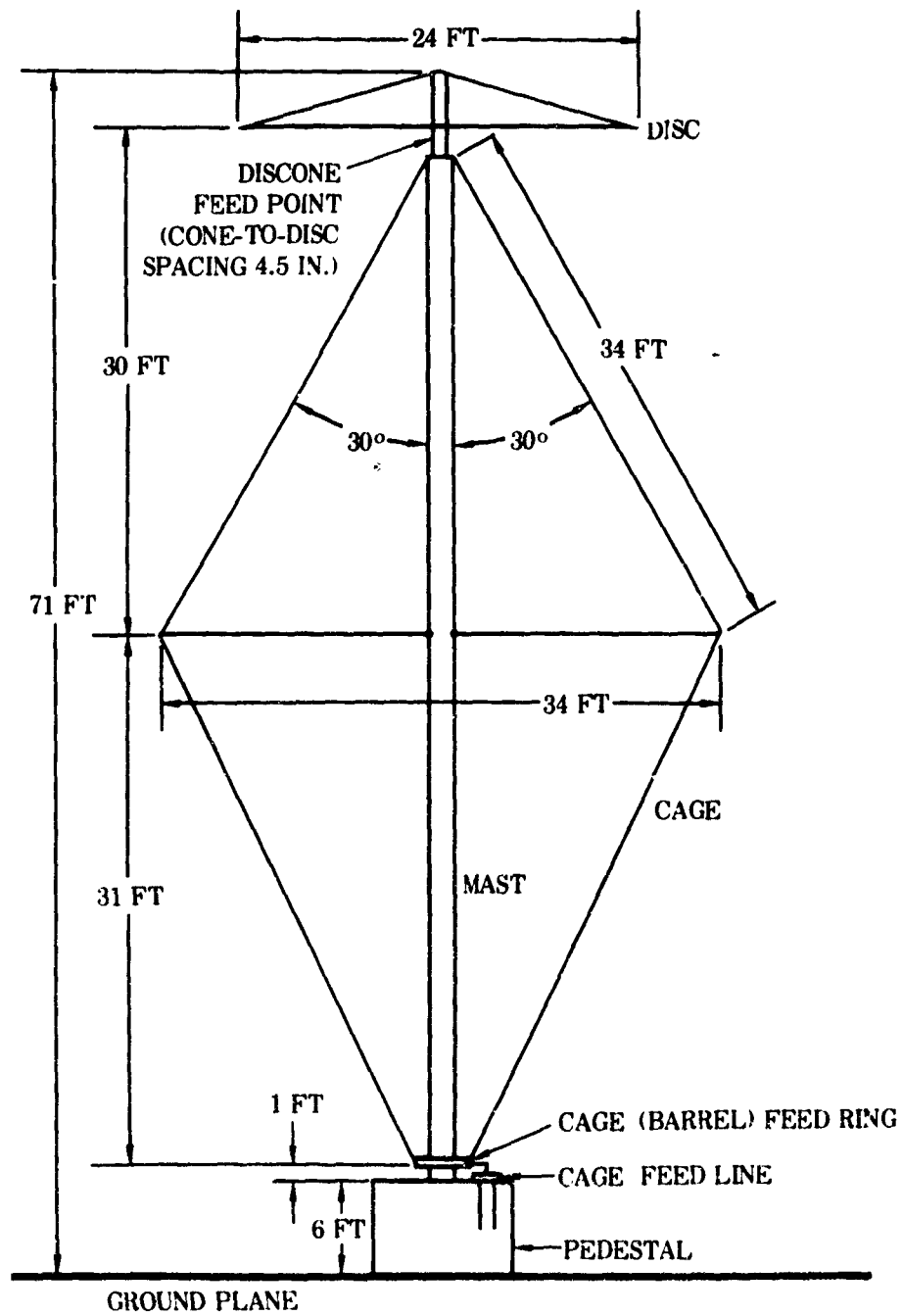
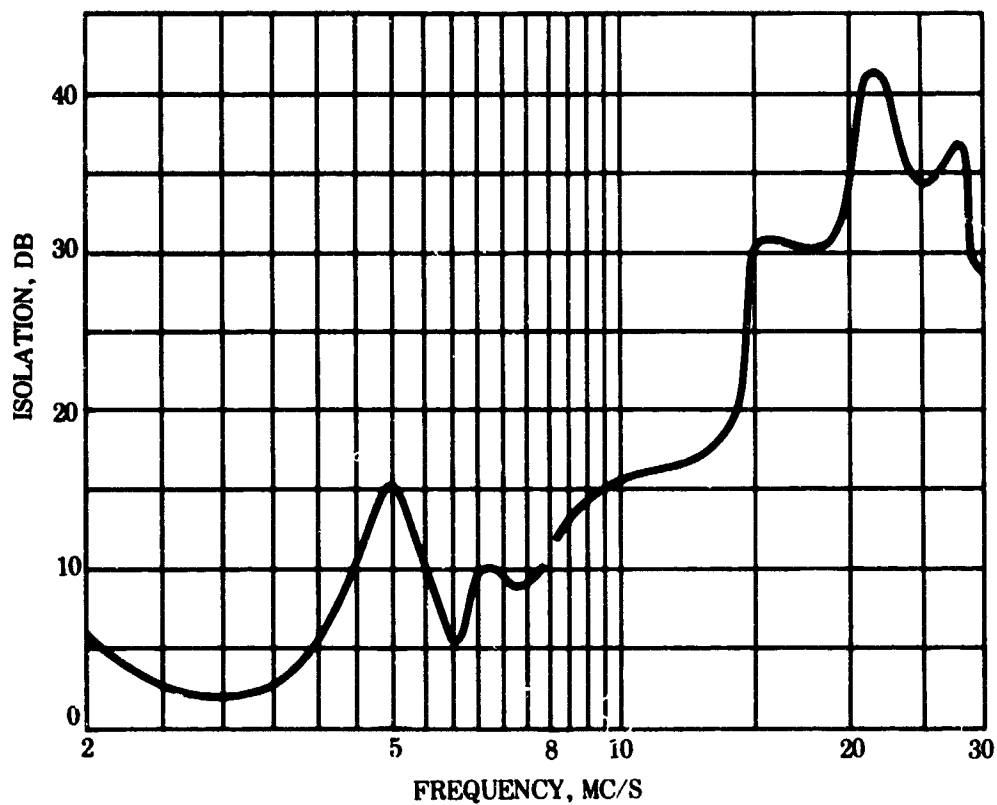Figure 6. DISCAGE antenna (2 to 30 Mc/s), schematic.

Figure 7. Measured isolation between feed points of cage and discone. (1:12 scale model DISCAGE antenna was used, frequencies employed were 12 times those shown on the abscissa.)

14

Antenna Design Considerations

Design of a general-purpose DISCAGE antenna requires careful considera-
tion of the dimensions and angles that establish the integrated discone and cage.
General criteria for designing a discone for operation with a 50-ohm coaxial line
have been reported.[8] The flare angle of the cone should be about 60 degrees,
the disc-to-cone spacing should be about 0.3 the diameter of the cone at its apex,
and the diameter of the disc should be at least 0.7 the maximum diameter of the
cone. The slant height should be approximately 1/4 wavelength at the discone's
lowest operating frequency.

The choice of frequency at which the transition is made between the op-
erating bands of cage and discone is especially important in DISCAGE antenna
design. This transition frequency simultaneously determines the overall dimen-
sions of the discone and the maximum diameter of the cage. The antenna height
is chosen on the basis of the cage's lowest operating frequency. Top-loading
effects of the disc are taken into account. Electrical height should be less than
3/4 wavelength at the transition frequency to avoid undue vertical lobing from the
cage. In addition to these technical matters, proper consideration must be given
to a logical subdivision of frequencies commonly used by the military, to special
factors that influence the design of ancillary equipment such as multicouplers, and
to overall system requirements of typical Navy applications.

Many of these considerations lead to the selection of a transition frequency
in the vicinity of 8 Mc/s. Being near the geometric mean of the 2-to-30-Mc/s band,
this transition permits operation of both sections throughout subbands of 4 to 1
(two octaves) and, as we shall see, facilitates design of a versatile system for
operating a rather large number of transmitters or receivers with this composite
antenna structure.

Although the physical and structural details of the antenna in figure 5 are
based on the foregoing criteria, no pretense is made that optimum solutions have
been found to all the problems involved. Rather, the design details should be
considered tentative--reflecting compromises necessitated by limitations on the
time available.

The number and size of conductors forming the cage and disc structures
were determined empirically from the 1:12 scale model in figure 8 (A). The
simulation of a solid cage or disc improves, of course, as the number of conductors
and their diameters are increased, within practical limits. Early studies, performed
in developing the gun-mounted DISCAGE antenna of figure 1, indicated that a
cage of 11 wires and a disc of six radials were about minimal for this application.
The more recent scale-model studies showed that worthwhile improvements in
impedance characteristics resulted from increasing the wires forming the cage to
24 and the radials forming the disc to 36. These details are reflected in figure 5.

A large dielectric cylinder, specially fabricated of silicone fiber glass, is
used to support the relatively heavy disc structure. Details of the discone feed,
with dimensions of this fiber glass cylinder, are shown in figure 9. An effort was
made to improve the mechanical form of the disc structure by designing it in the
shape of a bicycle wheel. This approach was rejected when the relatively small
increase in angle between the cone and the "disc" was found to adversely affect
the discone's impedance characteristics.
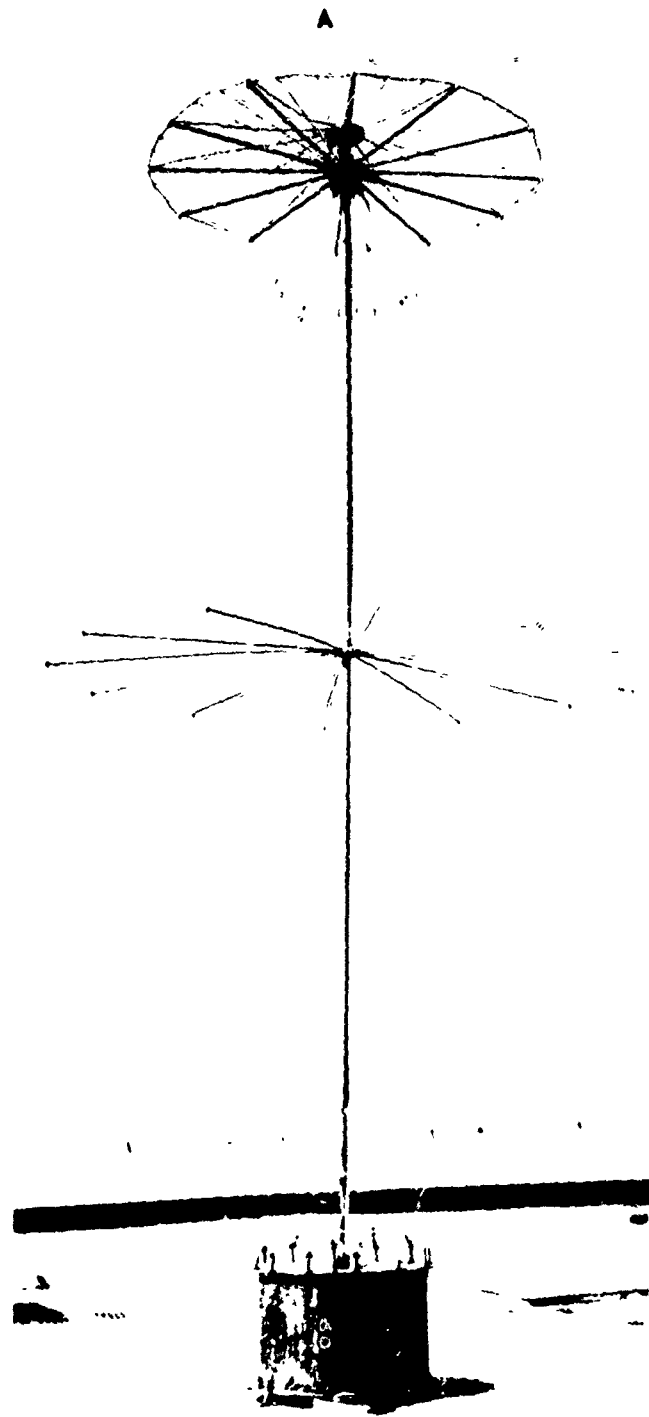
Figure 8. Scale models of DISCAGE antennas, 1:12 for 24-to-96-Mc/s and 96-to-360-Mc/s ranges (A) and 1 24 for 48-to-192-Mc/s and 192-to-720-Mc/s ranges (B). 1:24 antenna has bicycle-wheel-type disc.

16

B
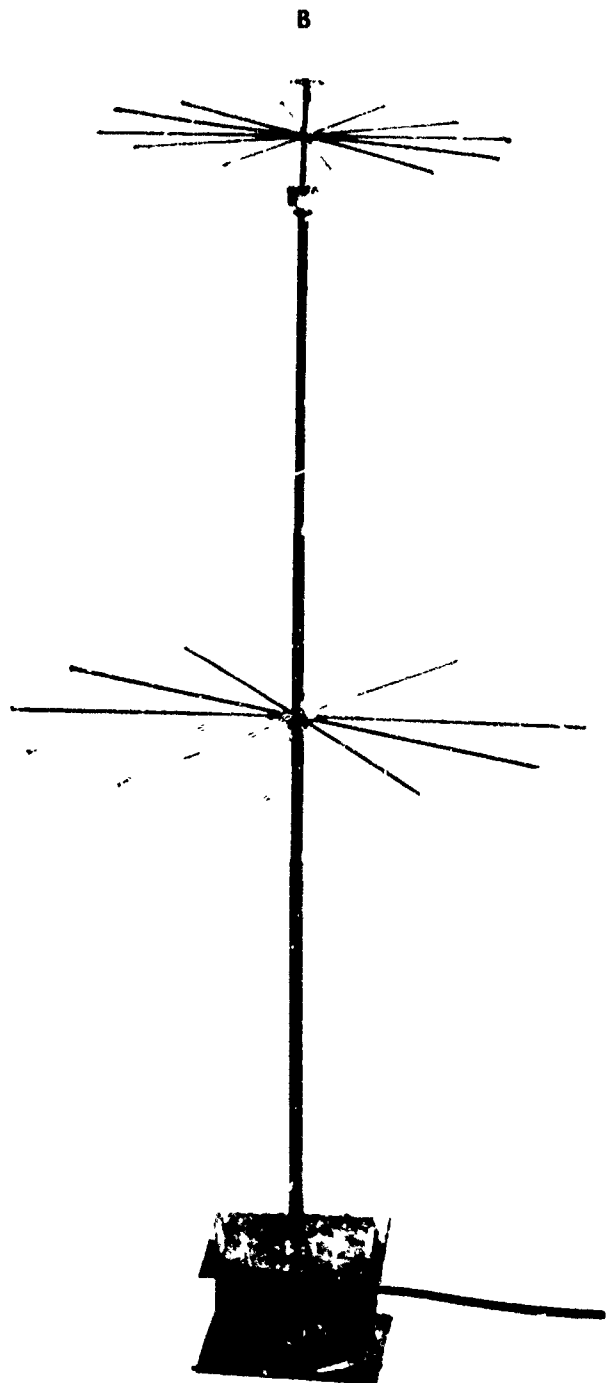
Figure 8 (Continued)

Figure 9. Discone feed assembly.

DISC SPREADER (1-IN. CRS TUBING; TWO STRANDED CONDUCTORS BETWEEN TUBING PAIRS FOR TOTAL OF 36 CONDUCTORS)

DISC MAST

DISC HUB FLANGE

DISCONE-FEED CONNECTOR

DISCONE-FEED INSULATOR

5 IN.

DISC-TO-CONE SPACER (SILICONE RESIN BONDED FIBER GLASS)

CONE APEX FLANGE ASSEMBLY

14 IN.

CONE-CAGE CONDUCTORS (24)

DISCONE FEED LINE

CAGE MAST

HIGH-PASS FILTER

18

Several studies were conducted with the 1:12 scale model in establishing the details of the cage's shunt-feed system. Relatively little change in input impedance was observed as the cage wires were alternately terminated in 15-inch-diameter and 30-inch-diameter copper rings. Moreover, only minor impeda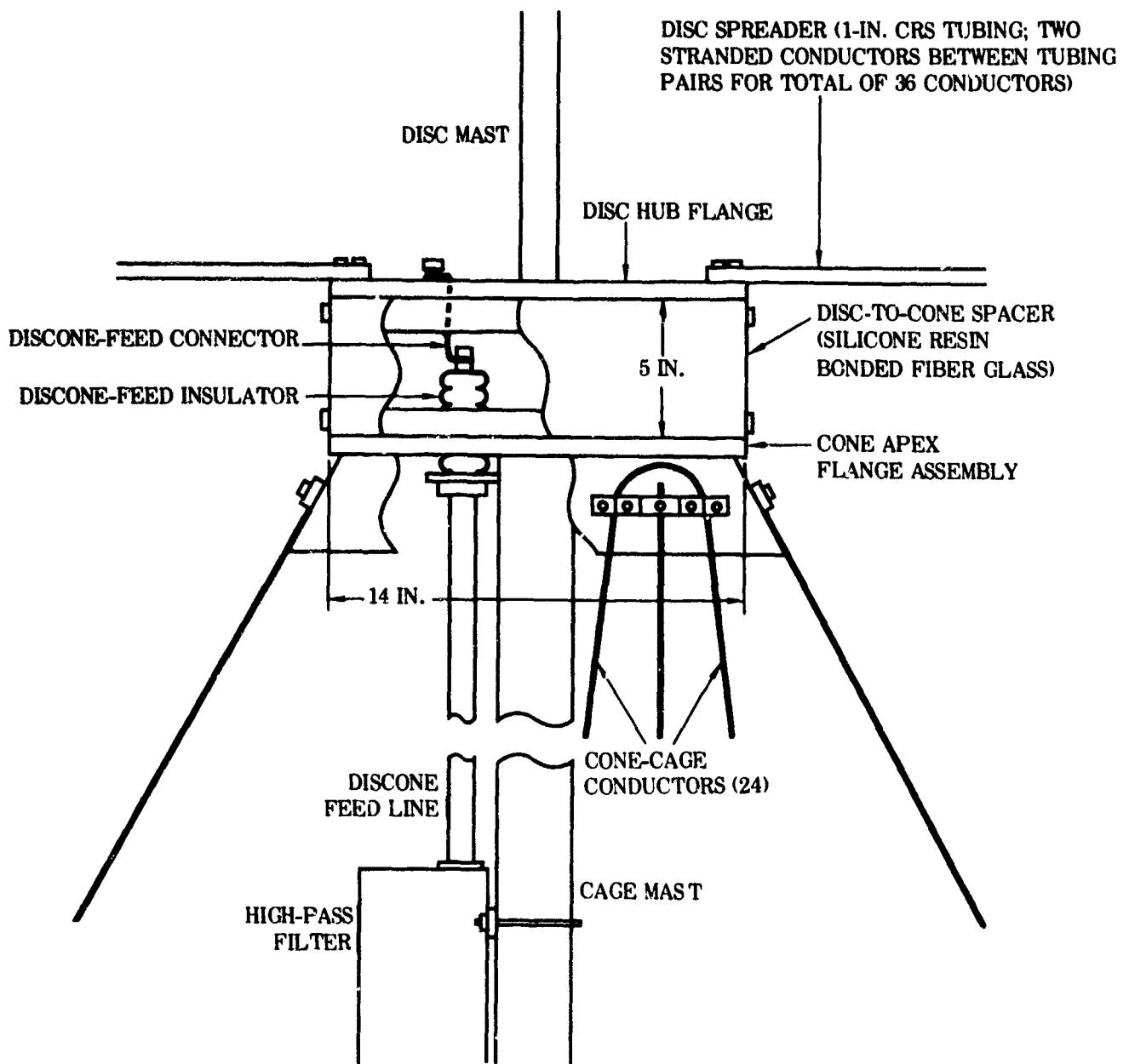nce changes were observed as the base pedestal was changed from a 10-foot cylinder (fig. 4) to a 6-foot cube (fig. 5). Thus, owing to the cage's relatively large base capacity and low characteristic impedance, the input-impedance characteristic of the cage is not particularly sensitive to modest changes in these feed details.

Another aspect of this feed technique warrants special consideration, however. In a general sense, the cage's feed point is shunted by a form of tapered coaxial transmission line that is short-circuited by the central support arms, or spreader assembly, of the cage. It is apparent that the effective length of this short-circuited "line" must remain sufficiently less than $\lambda/2$ to avoid excessive shunting effects on the cage's input-impedance characteristic. Full-scale measurements on the antenna pictured in figure 5 show that the input impedance of the cage becomes quite low around 16 Mc/s, indicating that this shunt line approaches the half-wave region near this frequency. Other effects of this shunt-line section were demonstrated on the 1:12 scale model. It was shown, for example, that this line section can be somewhat lengthened or shortened by raising or lowering the support point of the spreader arms and changing the length of the arms as required to keep the diameter of the cage constant. The model studies also demonstrated that the shunt-line section can be lengthened by inserting inductors in each of the spreader arms. (The spreaders are convenient for changing the line length in this manner without altering the physical or electrical properties of the cage in the process.)

The ground plane is conventional, consisting of 120 copper radials 125 feet long. As shown in figure 5, the radials are protected by a thin asphalt coating which also prevents erosion--except for a small sector on the side nearest the ocean, where the terrain slopes considerably.

AUXILIARY ISOLATION AND IMPEDANCE-MATCHING NETWORKS

System Design Considerations

For general DISCAGE applications, auxiliary networks are desirable to adequately isolate the two feed points, to provide proper terminating conditions, and to effect favorable impedance transformations. The interrelationships between these requirements lead to rather complex and challenging design problems. The situation is further complicated by a strong dependence upon system requirements that are difficult to specify in the general case.

In the past, most DISCAGE installations have involved multiple operation of a number of radio transmitters or receivers. Various multicoupling systems have been developed for installations of this type, and further advances in this field can be expected from current development and procurement programs. Apart from features designed to give greatly improved reliability and operational characteristics, major advances are expected in the isolation properties of the new multicouplers. In consequence, modern multicoupling installations can be expected to provide adequate isolation between circuits and it should be unnecessary to provide auxiliary filters for this purpose with the DISCAGE or any other combination of antennas. In multicoupled installations, therefore, auxiliary networks would be used primarily to stabilize the pattern characteristics of the cage and to correct for impedance perturbations that appear to be unavoidable in the process. The added isolation that is afforded between circuit groups by these networks is advantageous, but not necessary.

Several important applications of the general-purpose DISCAGE antenna do not entail simultaneous operation of both sections. A requirement may exist, for instance, to scan the 2-to-30-Mc/s band with a single transmitter or receiver. An ionospheric sounder might be involved. In installations of this type, auxiliary isolation networks may perhaps be replaced with appropriate switching schemes. For transmission from the cage, for example, the discone's feed might be short-circuited at the lower frequencies and open-circuited at the higher frequencies. The termination of the cage might be controlled in a similar manner for transmission from the discone. (These various possibilities will become apparent after specific impedance and pattern characteristics have been presented.)

Isolation Criteria

From classic image-parameter filter theory, it is known that the difference between the open-circuit and short-circuit impedances is related to the characteristic impedance Z_I and the image attenuation constant α by the expression

$$\Delta Z = \frac{2 Z_I}{\sinh (2\alpha)}$$

For nominal values of Z_I, it is clear that ΔZ becomes relatively small and insensitive to the terminating conditions when α is some 3 nepers (26 dB) or more. This suggests that filter networks of two sections, including one or more m-derived terminating half-sections, will satisfy this isolation criterion except, of course, in the immediate vicinity of cutoff. The filters shown by the schematics in figure 10 were designed on this basis; certain impedance transformations described later were taken into account.
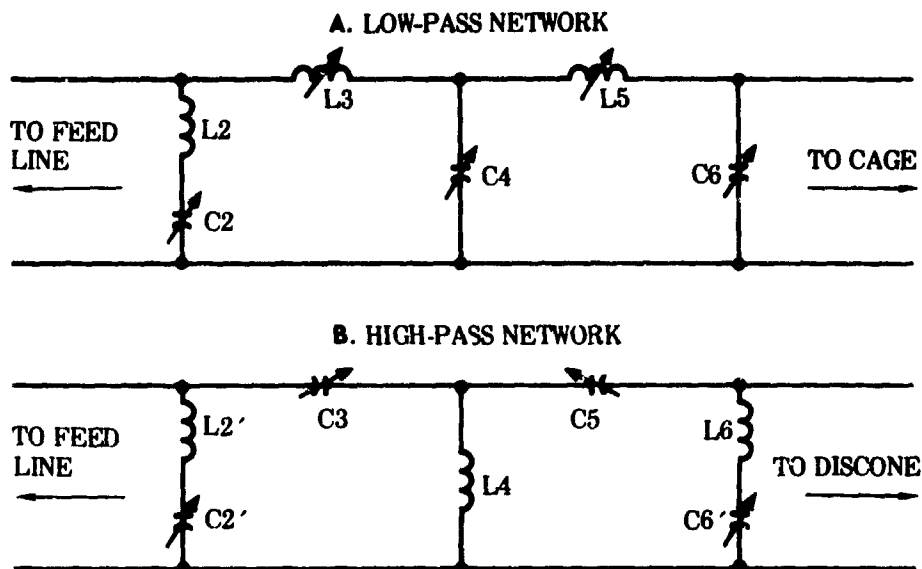

Figure 10. Filter assemblies designed to give increased isolation between the cage and the discone and to provide desirable terminating conditions.

The open-circuit and short-circuit impedance characteristics of these networks are shown in figures 11 and 12. The results were obtained from the well known continued fraction expansion of these ladder networks on a digital computer, with lossless elements assumed. Whereas the values of X_{oc} and X_{sc} alternate in sign across the respective passbands, they are seen to be practically coincident throughout the stop bands. The data in figure 11 show that, with the filter in figure 10A installed near the feed point of the cage, this section will be terminated in capacitive reactance from 8 to 11 Mc/s (the value of f_∞) and in inductive reactance at the discone's operating frequencies above this point. Likewise, with the filter in figure 10B installed near the discone's feed point, this section will be terminated in capacitive reactance from 2 to 5.577 Mc/s (the value of f_∞ in this network) and in inductive reactance from this point to cutoff. Note that the cutoff frequencies of the low-pass and high-pass filters are set some 10 percent above and below 8 Mc/s, respectively. Thus with some sacrifice in isolation, pass-band losses are minimized by making transmission bands overlap.
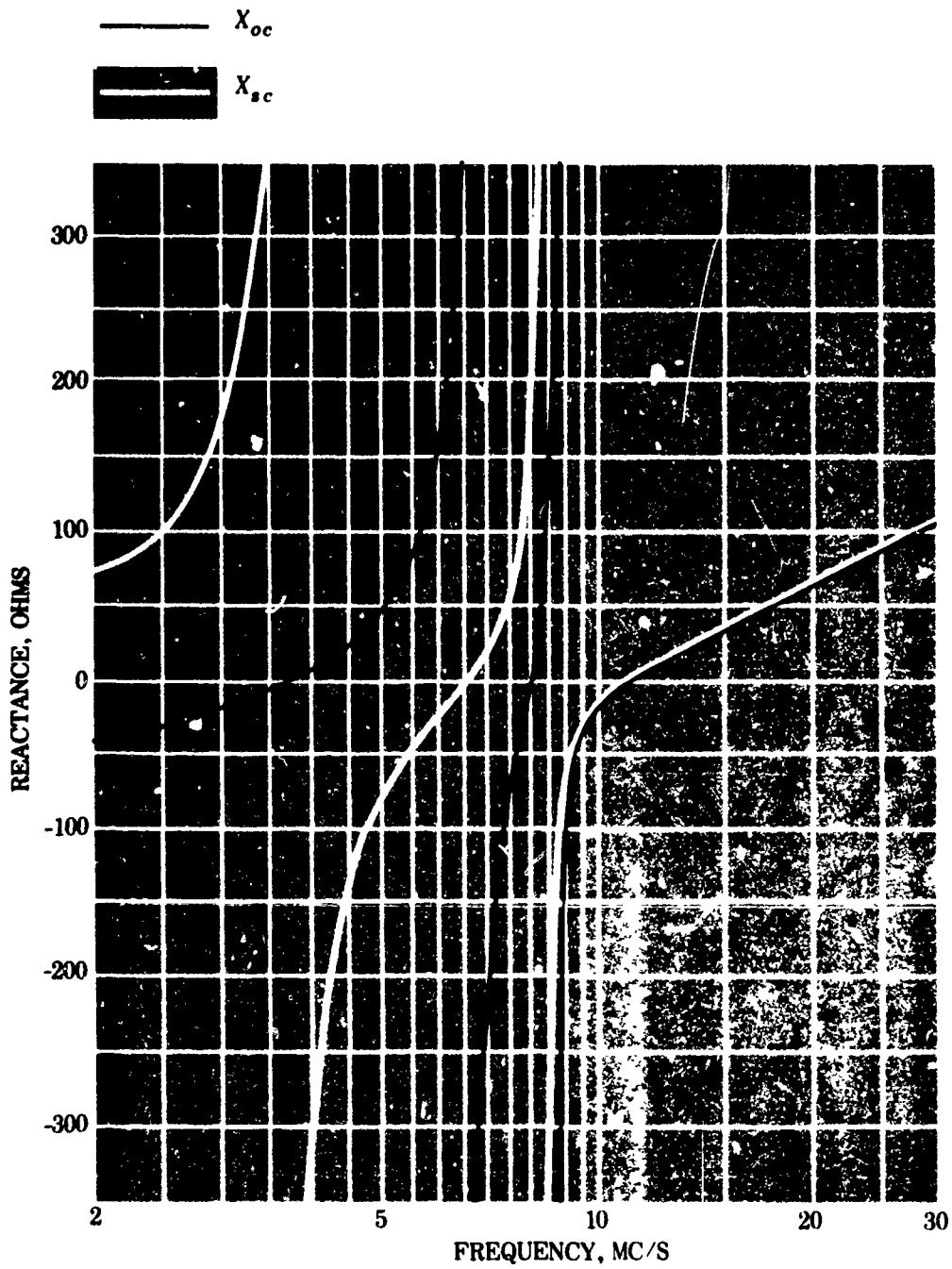
Figure 11. Computed values of input reactance of the filter shown in figure 10A with output terminals open and shorted. Dissipation is neglected.
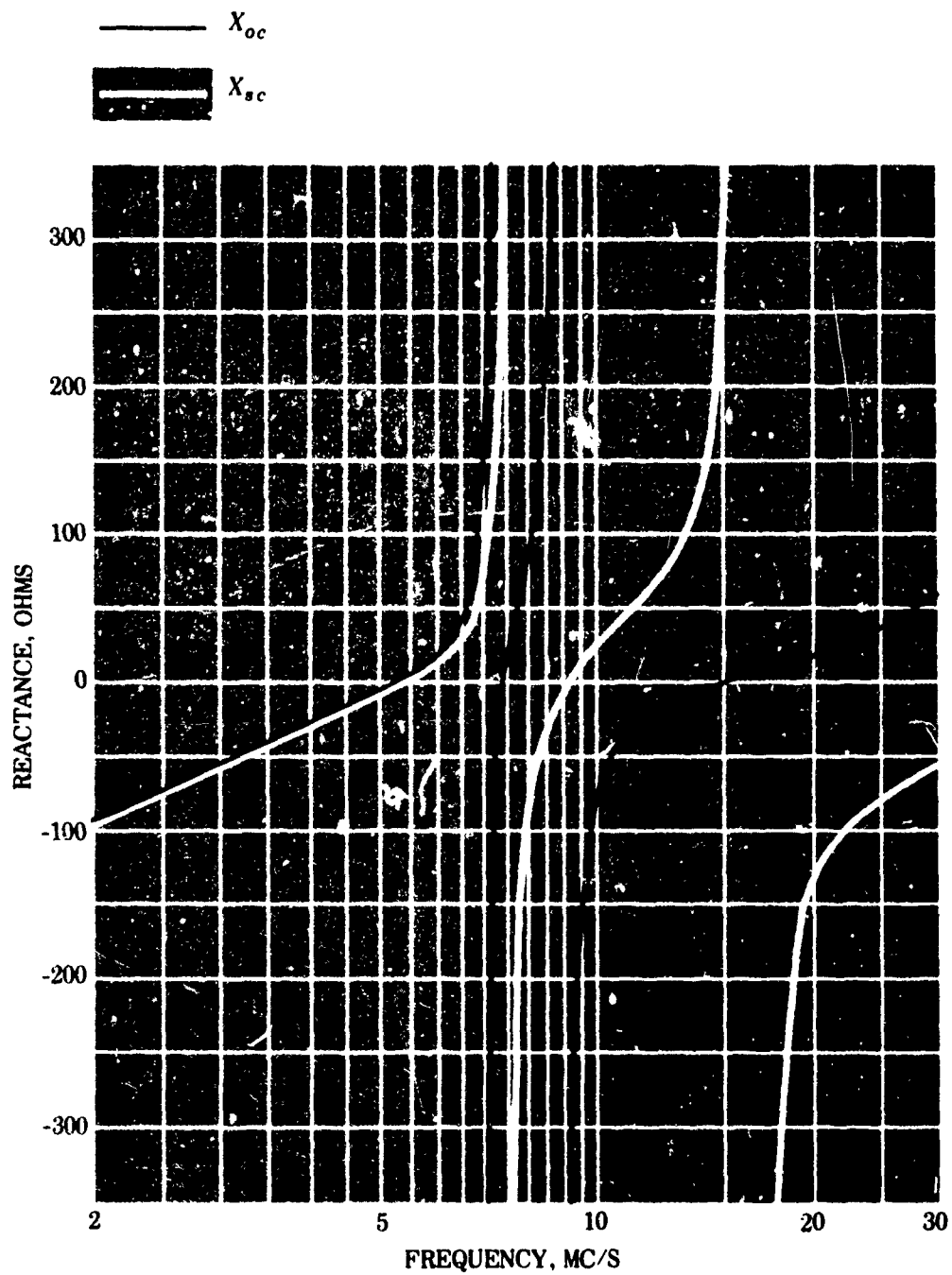
22

Figure 12. Computed values of input reactance of the filter shown in figure 10B with output terminals open and shorted. Dissipation is neglected.

IMPEDANCE CHARACTERISTICS

Because of its influence on the design of the low-pass filter, the develop-
ment of the high-pass filter will be described first. Input-impedance characteristics
of the discone were initially measured on the 1:12 scale model. For these meas-
urements the cage was terminated in coaxial stubs that had been specially cut to
simulate stop-band-impedance characteristics of a two-section low-pass filter with
m-derived terminating half-sections. These data gave a VSWR of about 2 to 1 rela-
tive to 60 ohms. With these measured values of load impedance and a variety of
uniform and tapered impedance levels, input-impedance characteristics of several
high-pass networks of the form shown in figure 10B were computed. From these
limited computer analyses, best results were obtained from a filter with impedance
levels of 50, 55, and 60 ohms, increasing toward the antenna load. With this
experimental filter assembly installed about 4 feet from the discone's feed point,
the VSWR characteristic is as shown in figure 13. The cage was terminated by a
low-pass filter. It is seen that the VSWR is generally less than 2.5 to 1 relative to
50 ohms from 8 to 30 Mc/s.

The essential reasons for mounting the high-pass filter in close proximity to
the discone's feed point will be briefly explained. The inconvenience of mounting
and servicing this equipment near the top of a 70-foot mast must obviously be
justified by superior performance or operating characteristics. Available information
appears to provide this justification. Measurements show that both the pattern and
impedance characteristics of the cage are adversely affected at some frequencies
when the discage is terminated in certain low-loss inductive loads. It appears that
these inductive terminations cause a form of resonance with the disc, thereby alter-
ing the current distribution on the top-loaded cage. With the high-pass filter in-
stalled in the base pedestal some 65 feet from the discone's feed point, a marked
perturbation was observed in the cage's input-impedance curve in the vicinity of
3.5 Mc/s. The filter termination is capacitive at this frequency (fig. 12) and be-
comes inductive when transformed through 65 feet of Foam Heliax having a rated
velocity factor of 79 percent. This phenomenon was explored further by substituting
a variable capacitor for the high-pass filter. The input-resistance component of a
low-pass filter connected to the cage was varied from about 12 to 200 ohms at
3.5 Mc/s by varying this capacitor. While this phenomenon may afford a convenient
means for impedance and pattern control in certain special installations, it is clearly
undesirable in broadband applications. Figure 12 shows that inductive terminations
are avoided by mounting the high-pass filter close to the discone's feed, except at
the high end of the cage's operating band. This effect can be moved somewhat
higher in the band by moving f_c closer to 8 Mc/s and by using a smaller value of m
(thus raising f_∞). These changes might degrade the transmission or isolation charac-
teristics of the network. These changes and alternative designs are proper subjects
for future investigation.

With the discone terminated by the high-pass filter, the measured impedance
characteristic of the cage section is shown by the Smith chart (fig. 14). The
unsatisfactory VSWR at 2 Mc/s could be corrected by making the antenna some
10 percent taller, but no means are readily available for correcting the perturba-
tion around 6.635 by antenna design changes. In consequence, correction of these
input-impedance characteristics of the cage is a major design consideration of the
low-pass network in figure 10A. The problem has been approached by a combina-
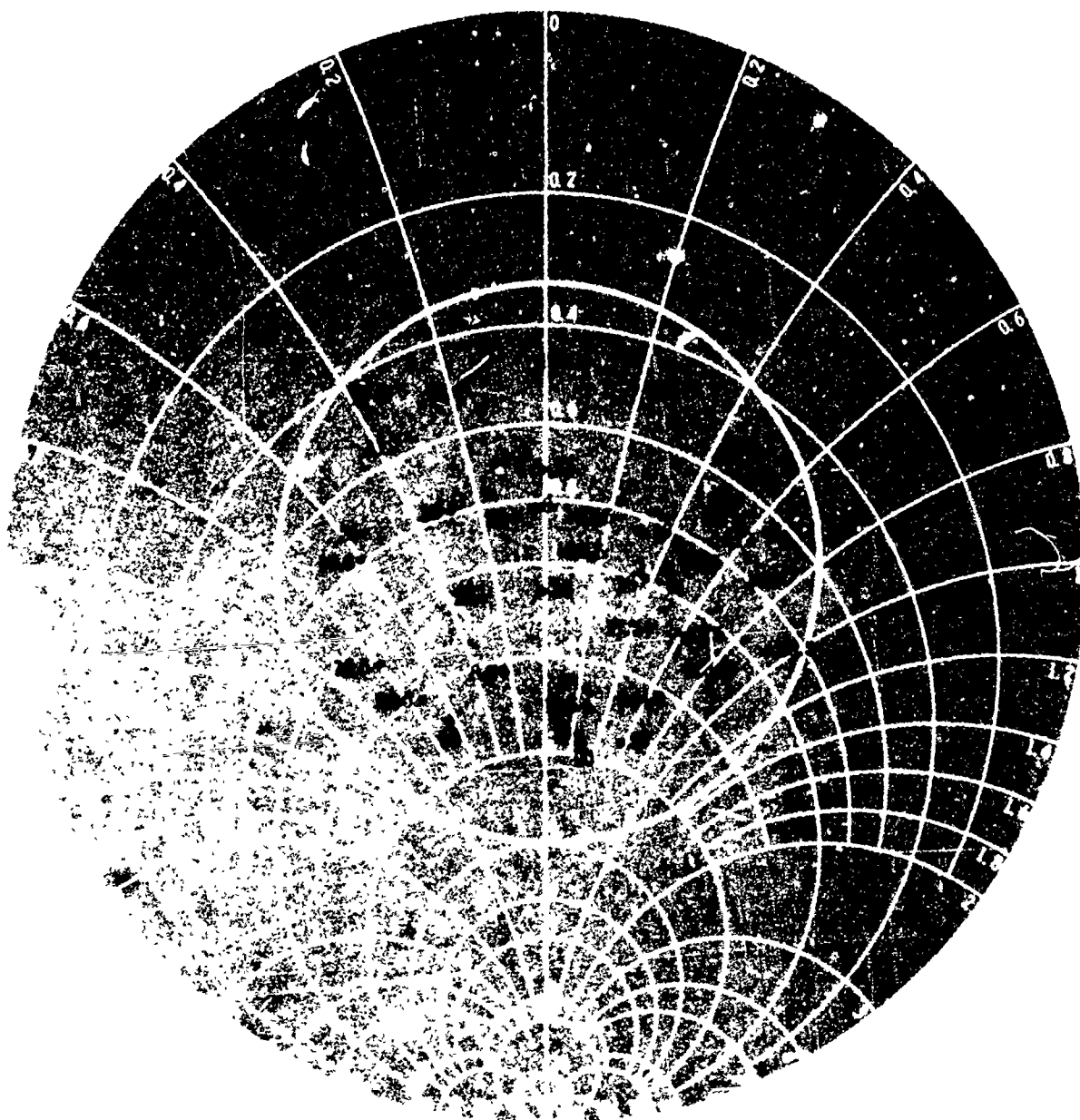tion of analytical and empirical methods.

Figure 13. Measured VSWR characteristic at input to high-pass filter installed 4 feet from discone feed point. Cage terminated by low-pass filter.
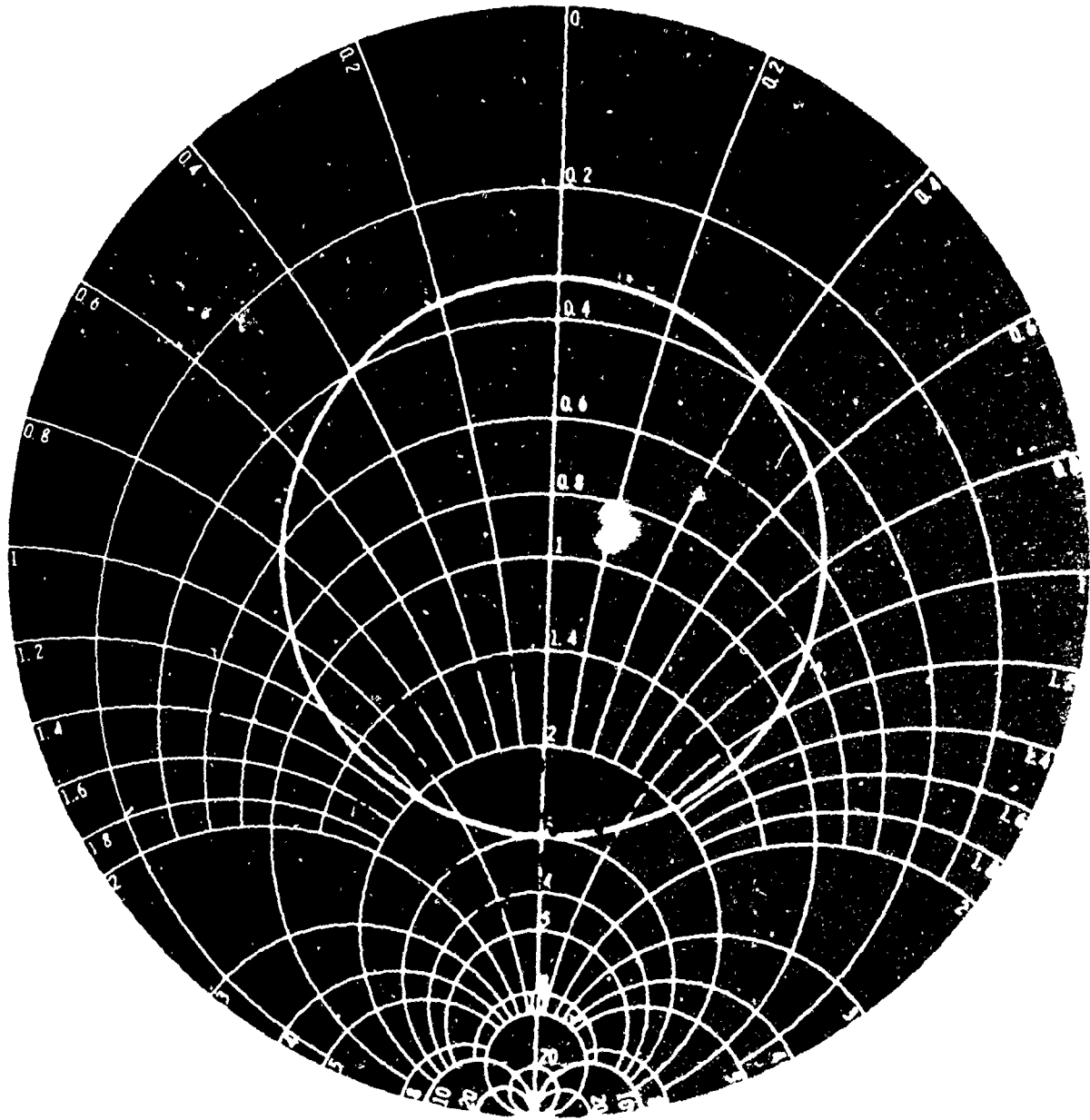
25

Figure 14. Measured VSWR characteristic of the cage section with the discone terminated in the high-pass filter.

Both scale-model and full-scale measurements show that the input resistance of the cage exhibits a gradually rising characteristic. As illustrated in figure 15, this variation agrees in a general way with a well known characteristic of a low-pass constant-k π-section filter whose image impedance is given by the expression

$$R_{\pi k} - \frac{R_o}{\sqrt{1 - w^2}}$$

where R_o denotes characteristic resistance and w relates the operating frequency to the cutoff frequency ($w - f/f_c$). The dashed curves in figure 15 show variations in $R_{\pi k}$ for R_o of 50 and 60 ohms. Digital computer analyses using scale-model measurements showed an impedance level of 60 ohms to be approximately optimum for the network in figure 10A and the filter was designed on this basis. The cutoff frequency was set almost 10 percent above 8 Mc/s (at 8.772 Mc/s) to insure low-loss transmission from 2 to 8 Mc/s and an m of 0.6 was used for the input half-section.

The measured values of input resistance in figure 15 coincide well except for the region around 6 to 7 Mc/s. These major deviations are attributed largely to difficulties in accurately simulating the terminating effects of the high-pass filter. Note that a small shift in the frequency of this resonance effect can cause a relatively large change in resistance between 6 and 7 Mc/s and that minor shifts of this nature can be expected in practice, since no two DISCAGE installations will be exactly alike. It seems desirable to utilize variable elements in the low-pass network and to make provision for adjusting or trimming them to realize optimum VSWR characteristics at each installation.

The data in figure 16 illustrate the improved VSWR characteristic on the cage's feed line obtained with the network shown in the insert. The network component values were measured after adjustment had been made to minimize the overall VSWR characteristic across the band. The solid circles in figure 16 identify values of input impedance computed from measured values of network components and measured values of the cage's input impedance. At most frequencies, the computed and measured values of the input impedance to the network are seen to agree reasonably well, considering that dissipation and distributed parameters were neglected in the digital computations. Also, it is seen that the design objective of a 3-to-1 VSWR characteristic is practically realized throughout the cage's operating band.
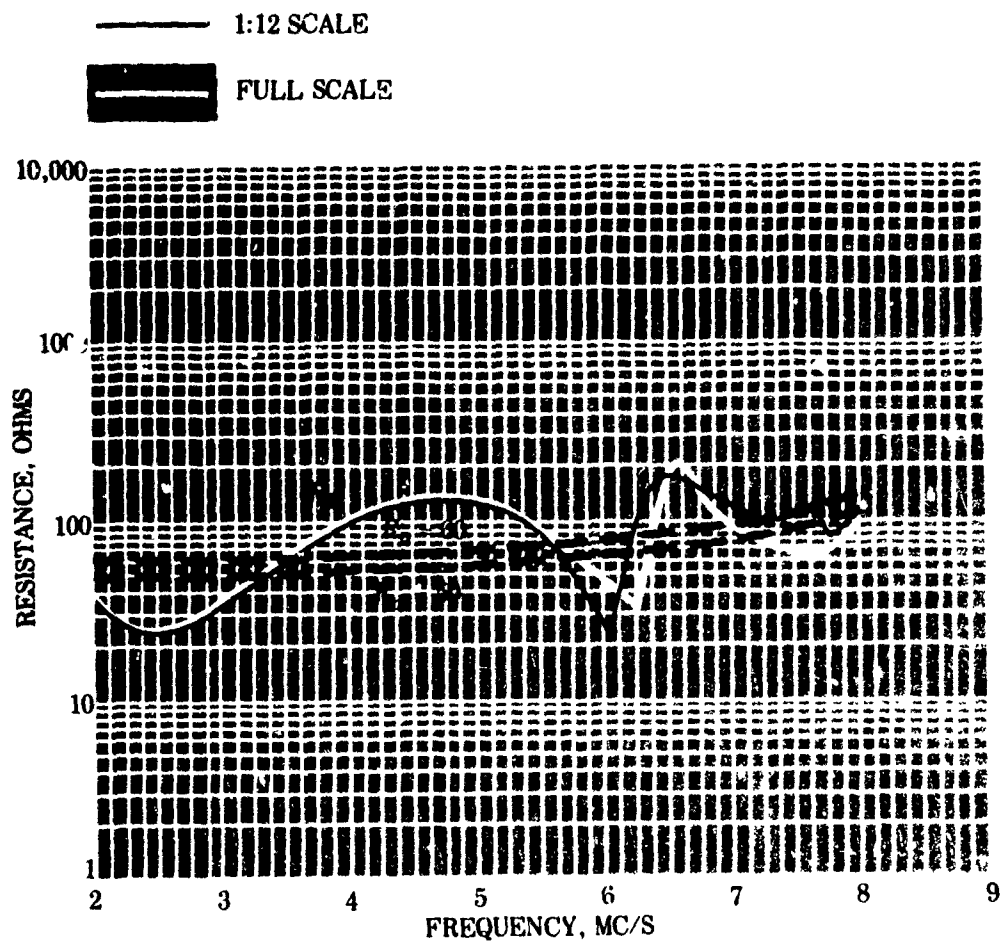
Figure 15. Measured input resistance of the cage section with the discone terminated in the high-pass filter (termination effects simulated by coaxial stubs during model studies). Dashed curves show variations of $R_{\pi k}$ for two values of R_0.
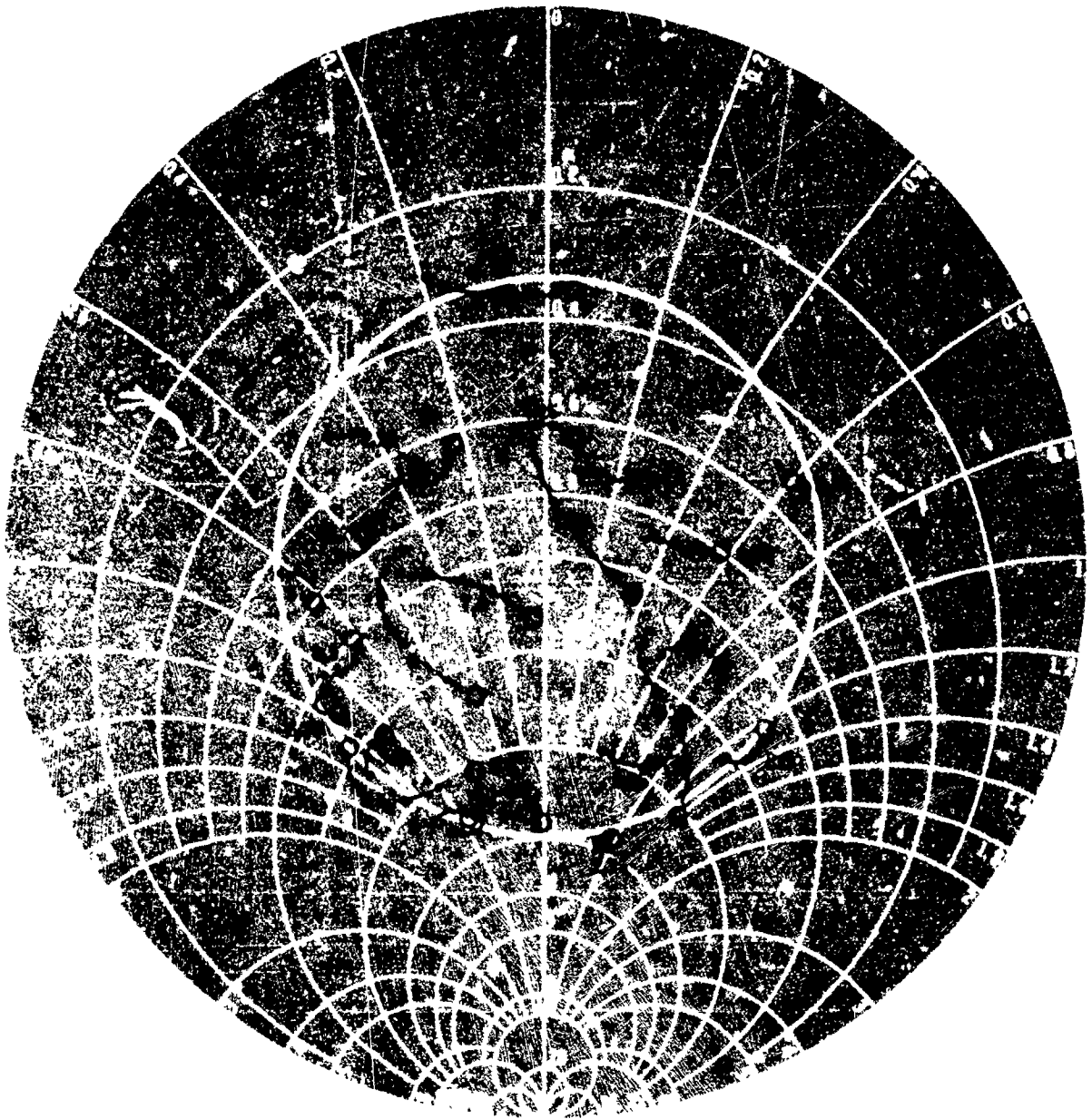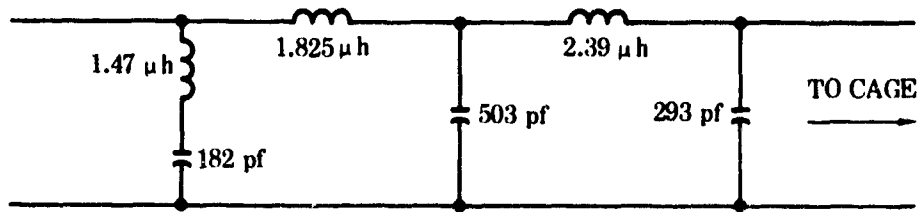
28

Figure 16. Measured input impedance (open circles) and computed values (solid points) obtained with the low-pass filter shown in the insert terminated in the cage section.

TRANSMISSION AND ISOLATION MEASUREMENTS

A brief account of recent experience with experimental models of the impedance-transforming and isolation networks will be given to assist with future development and procurement of this equipment. Methods used in adjusting and testing the networks in the laboratory and system tests at the antenna site will be described.

Network components were initially selected and adjusted in a simulated enclosure to approximate design values. General Radio Type 1606-A and Type 821-A impedance-measuring equipment was used. The Type 1606-A rf bridge was also used to make minor component adjustments to take into account interconnecting leads and stray parameters after the coils and capacitors were mounted in a copper box. Based on experience to date, the general arrangement of components in figure 17 is suggested. Note that all variable components in both networks are oriented so that they may be conveniently adjusted through holes in the sides or ends of the enclosures (indicated by solid arrows). Each enclosure includes three compartments with provisions for 1-5/8-inch coaxial connections at opposite ends.

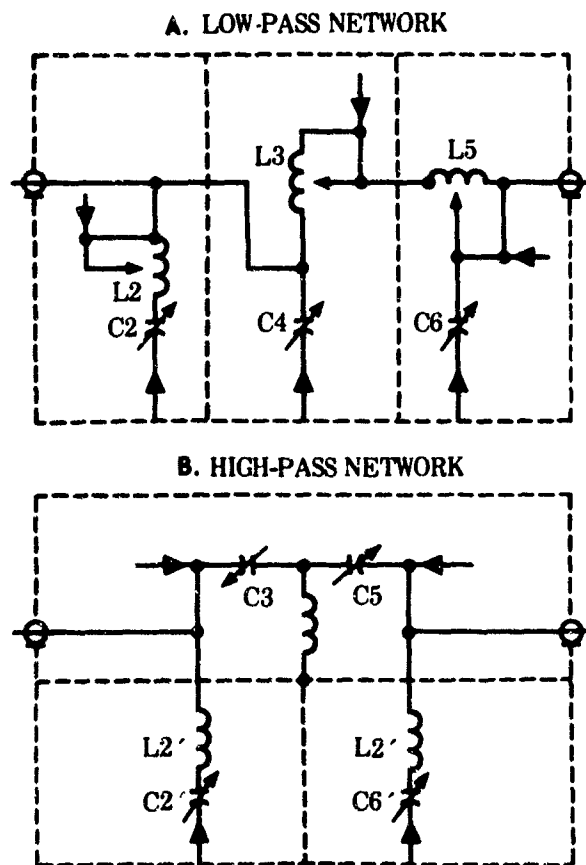## A. LOW-PASS NETWORK

B. HIGH-PASS NETWORK

Figure 17. Suggested arrangement of network components in shielding enclosures (dashed lines).

After various coil-capacitor combinations had been adjusted to give series resonance at the desired frequencies, the distribution of zeros and poles of the open-circuit and short-circuit impedances of the networks was obtained with a Hewlett Packard Type 4815A Vector Impedance Meter (fig. 18). Typical results of these measurements are given in figure 19. The data compare well with the critical frequencies in figures 11 and 12, the major differences being observed at the higher frequencies in figure 19B. Limited evidence indicates that the differences result primarily from lead inductance between the input and output terminals.
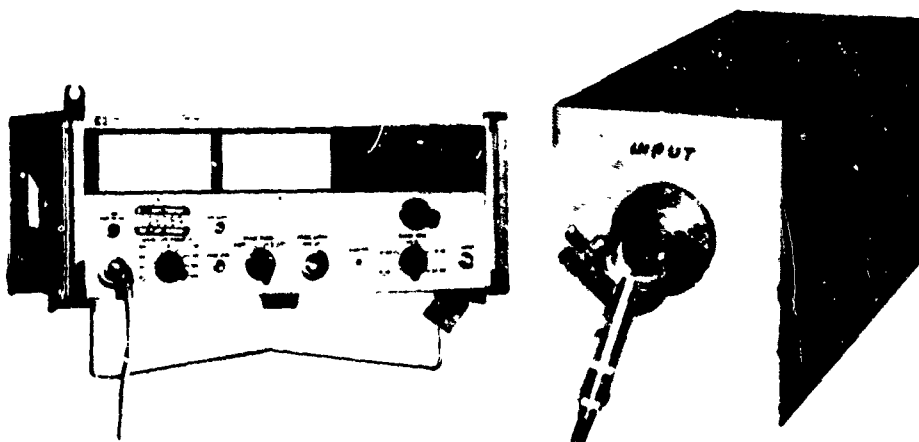

Figure 18. Instrumentation used in determining the zeros and poles of two terminal-pair networks.

In figure 19B, the zero at 28.33 and the pole at 32.30, for example, occurred at 24.92 and at 40.7 Mc/s, respectively, before small lengths of coaxial cable were added, as shown in figure 20, thereby effectively reducing the separation between the (coaxial) input and output terminals. With excessive lead inductance, the insertion loss increased somewhat at the higher frequencies. The compact arrangement of capacitors in the series arms of the high-pass network, indicated in figure 17B, is recommended to minimize this effect.

While the high-pass unit required no further adjustment, it was necessary to trim various components of the low-pass unit to minimize the VSWR characteristic of the cage section. An AN/WRC-1 transmitter was used as the signal source and an hf reflectometer as the indicator. The results shown in figure 16 are typical of those obtained on two separate occasions, on which somewhat different forms of high-pass and low-pass networks with different instrumentation were used. Since these adjustments must be performed on a not-to-interfere basis, with minimum radiated power, the automatic control features of the AN/WRC-1 equipment are desirable. Means for indicating incident and reflected power simultaneously are helpful, permitting rapid indication that the VSWR is 3 to 1 or less, as shown by the fact that the reflected power does not exceed one-fourth of the incident power. The necessity for working at moderate power levels stems from the fact that noise and strong spurious signals are sometimes experienced. These have been observed on sensitive reflectometers rated at 50 watts or less.
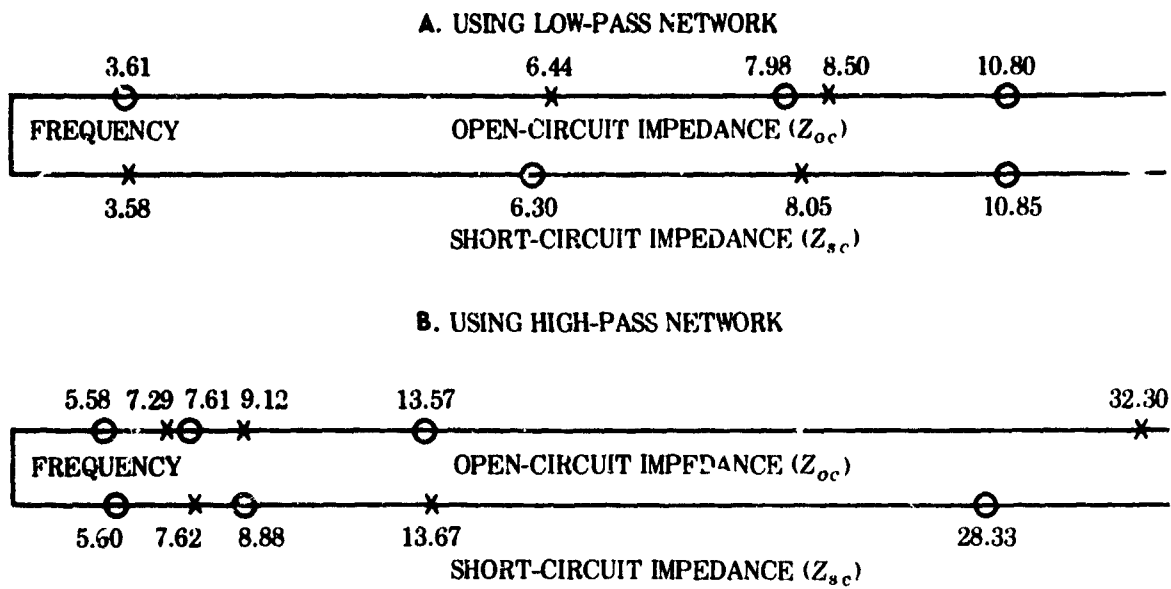
31

A. USING LOW-PASS NETWORK

| 3.61 | | 6.44 | | 7.98 8.50 | | 10.80 |

FREQUENCY — OPEN-CIRCUIT IMPEDANCE (Z_{oc})

| 3.58 | | 6.30 | | 8.05 | | 10.85 |

SHORT-CIRCUIT IMPEDANCE (Z_{sc})

B. USING HIGH-PASS NETWORK

| 5.58 7.29 7.61 9.12 | 13.57 | | 32.30 |

FREQUENCY — OPEN-CIRCUIT IMPEDANCE (Z_{oc})

| 5.60 7.62 8.88 | 13.67 | | 28.33 |

SHORT-CIRCUIT IMPEDANCE (Z_{sc})

Figure 19. Distribution of zeros and poles at input terminals of networks. Frequencies are in Mc/s.
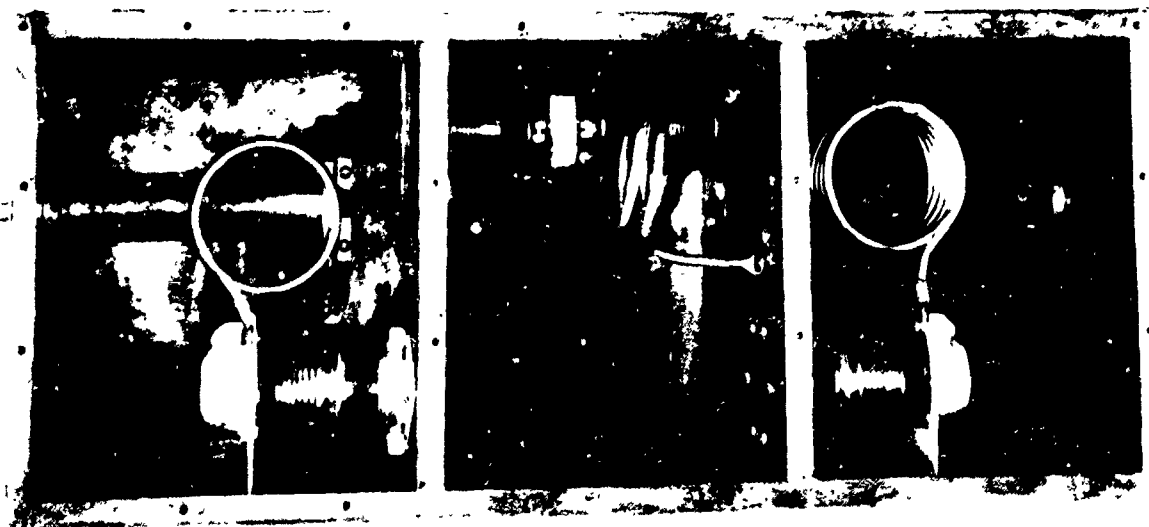
Figure 20. Short lengths of coaxial line added to reduce lead inductance effects in high-pass network.

The insertion-loss characteristics of the networks were measured after final adjustments were made. Instrumentation and results are give in figure 21. (The test setup is similar to that shown in figure 3 on page 3 of MIL-STD-220A of 15 December 1959.) These measurements in a 50-ohm system do not accurately reflect the transmission characteristics that will be obtained with complex load impedances; but they indicate that losses will be small (less than 1 dB) throughout the operating bands and that attenuation will be adequate at most frequencies in the stop bands. The lower attenuation peak of the low-pass network results from the fact that this circuit has one m-derived half-section while the high-pass network has two.

TEST SETUP
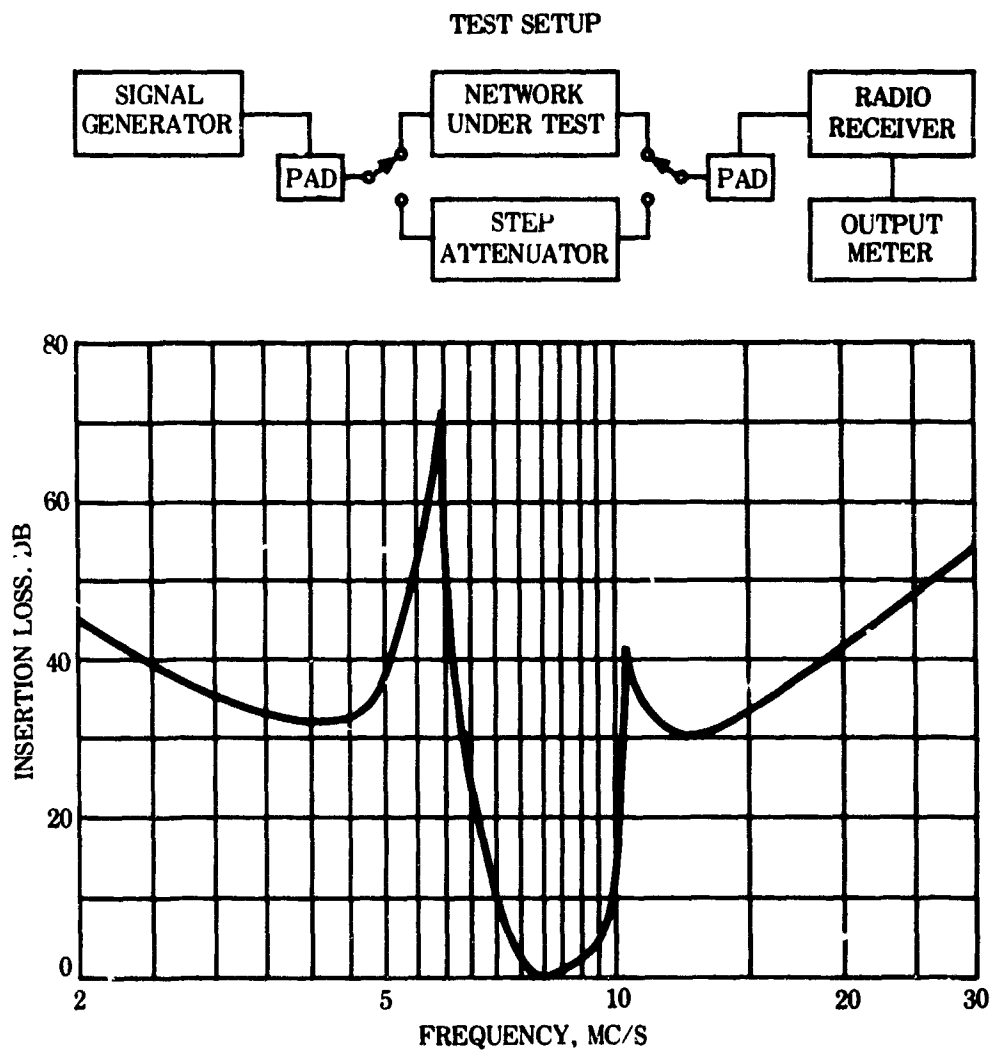
Figure 21. Measured insertion-loss characteristics of networks.

Isolation between the cage and discone sections was measured after the networks had been installed. Results are given in figure 22. Instrumentation is shown in the insert. From isolation criteria given earlier, these results indicate that impedance and pattern characteristics of both sections will be practically independent of the design details and operation of associated radio equipment—especially with the additional isolation afforded by modern multicoupling techniques.
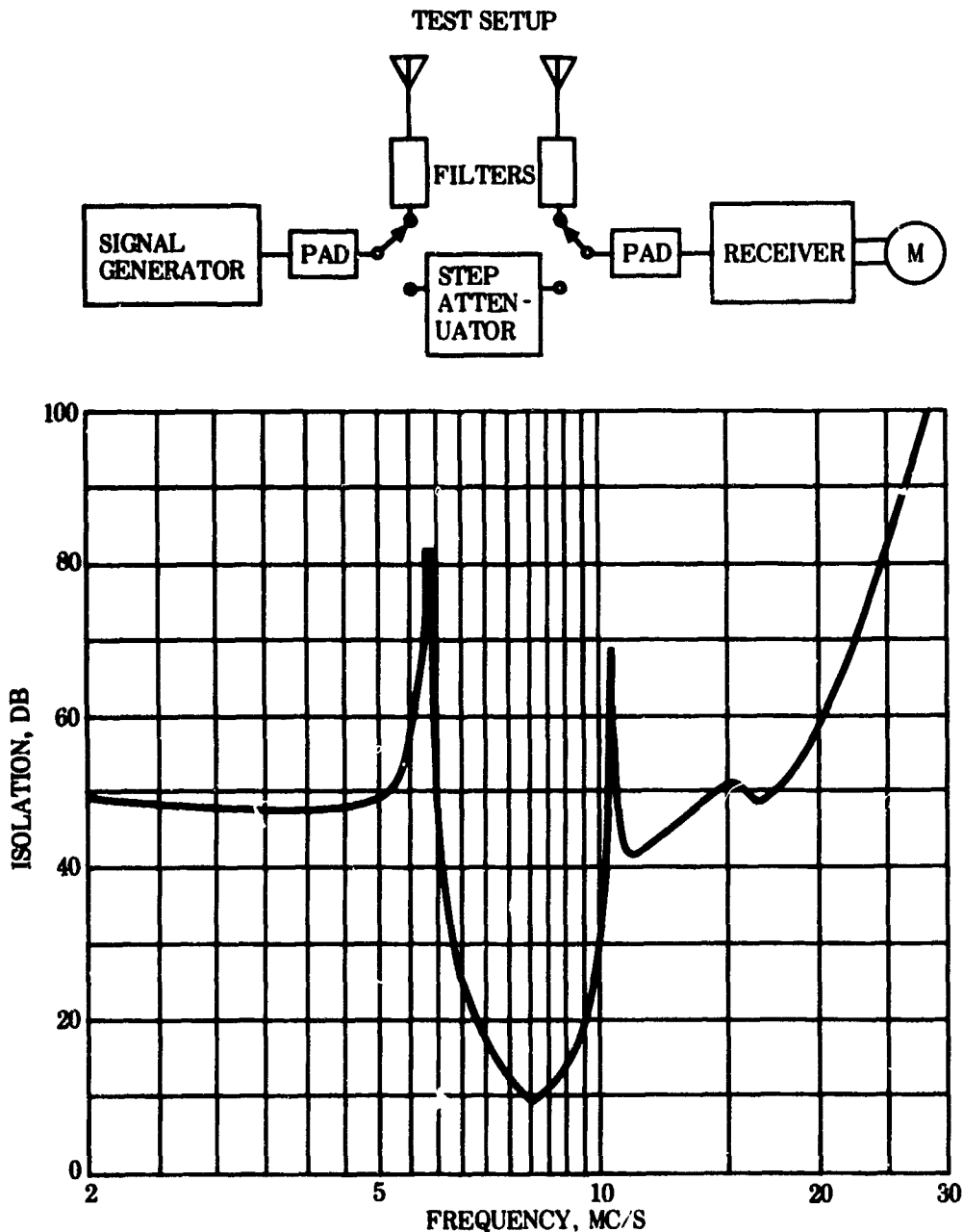
TEST SETUP

Figure 22. Measured isolation between cage and discone sections with auxiliary filters installed.

VERTICAL-PATTERN MEASUREMENTS

Vertical radiation characteristics of the DISCAGE antenna were measured with the facilities shown in figure 23. The 1:24 scale model in figure 8B was mounted on the 22-foot rotating turntable at the center of the 160-foot ground plane. The zenith arch permits patterns to be recorded at angles between 5 and 65 degrees.

At first, a few horizontal patterns were measured with both the cage and the discone sections. Since these were invariably circular and free from significant perturbations, none of these patterns are included in this report.

The DISCAGE antenna vertical radiation depends on the termination of the parasitic section, as do its impedance properties. This is especially true of the discone whose terminations influence the current distribution on the top-loaded cage. As expected, these effects are most noticeable at the high end of the cage's operating band. Figures 24 through 27 show linear voltage plots.

Figure 23. NELC Model Range with zenith arch.

35

The patterns in figures 24 and 25 show typical radiation characteristics of the cage with the discone's driving point alternately shorted and open-circuited. (On these and subsequent pattern recordings, full-scale frequencies are indicated, the test frequencies being 24 times higher.) The patterns in figure 24 are representative of those obtained below 6 Mc/s under both of these extreme conditions of termination at the discone's feed point. Consequently, in figure 25, recordings at the lower frequencies are omitted and emphasis is given to the higher operating frequencies of the cage section. Considered together, therefore, figures 24 and 25 illustrate the vertical radiation characteristics of the cage that would be obtained, in general, as the discone's feed points were shorted or open-circuited by a coaxial switch. Whereas low-angle radiation could be expected below about 6 Mc/s, considerable high-angle radiation would occur at most frequencies above this point. With an effective ground, however, the overall radiation characteristics of the cage should be generally satisfactory from 2 to 8 Mc/s with appropriate switching at the discone's feed terminals.

Figure 26 shows vertical-pattern characteristics to be expected from the cage with the discone terminated in the auxiliary high-pass network. Note that a high-angle lobe is forming at 6 Mc/s, and that the patterns at lower frequencies are comparable with those in figure 24. Above 6 Mc/s, the vertical-lobe structure changes rapidly with frequency, doubtless because of the rather rapid changes in the terminating impedance presented by the high-pass network at these frequencies. If an effective ground is again assumed, the overall pattern characteristics in figure 26 would seem to be satisfactory for general applications involving this wide frequency band.

The discone section, as do other vertically polarized antennas with elevated feed points, has a multilobed vertical radiation characteristic. The position and number of the lobes depend on the height of the feed point, the operating wavelength, and the relationship between the currents in the antenna and its image.[9] When the overall length of the antenna is an odd multiple of $\lambda/2$, its image is positive. In this case, maximum radiation occurs along the ground (high conductivity is assumed) as well as at higher lobes which equal in number the height of the feed point expressed in half wavelengths. When the length of the antenna is an even multiple of $\lambda/2$, its image is negative and a null occurs at zero elevation.

Figure 27 shows vertical patterns of the DISCAGE antenna with the feed points of the cage alternately open-circuited (black lines) and shorted (white lines). Since the frequencies in the range of the discone are primarily used for medium-to-long-distance propagation, radiation at relatively low angles is particularly desirable.[10] The patterns in figure 27 do not indicate a generally preferable type of termination for the cage section except perhaps in the vicinity of 9 Mc/s, where a low-impedance termination appears to be desirable. The low-pass filter seems to satisfy this general criterion, as indicated in figure 11. Since the discone's feed is some 68 feet above ground, the occurrence of a positive image probably explains the relatively strong low-angle lobes at 9, 22, and 24 Mc/s. Conversely, a negative image occurs near 16 and 28 Mc/s, explaining the rather weak low-angle radiation at these frequencies. Considered as a whole, however, the vertical radiation characteristics of the DISCONE antenna are considered satisfactory for omnidirectional applications involving operations throughout this wide frequency band.
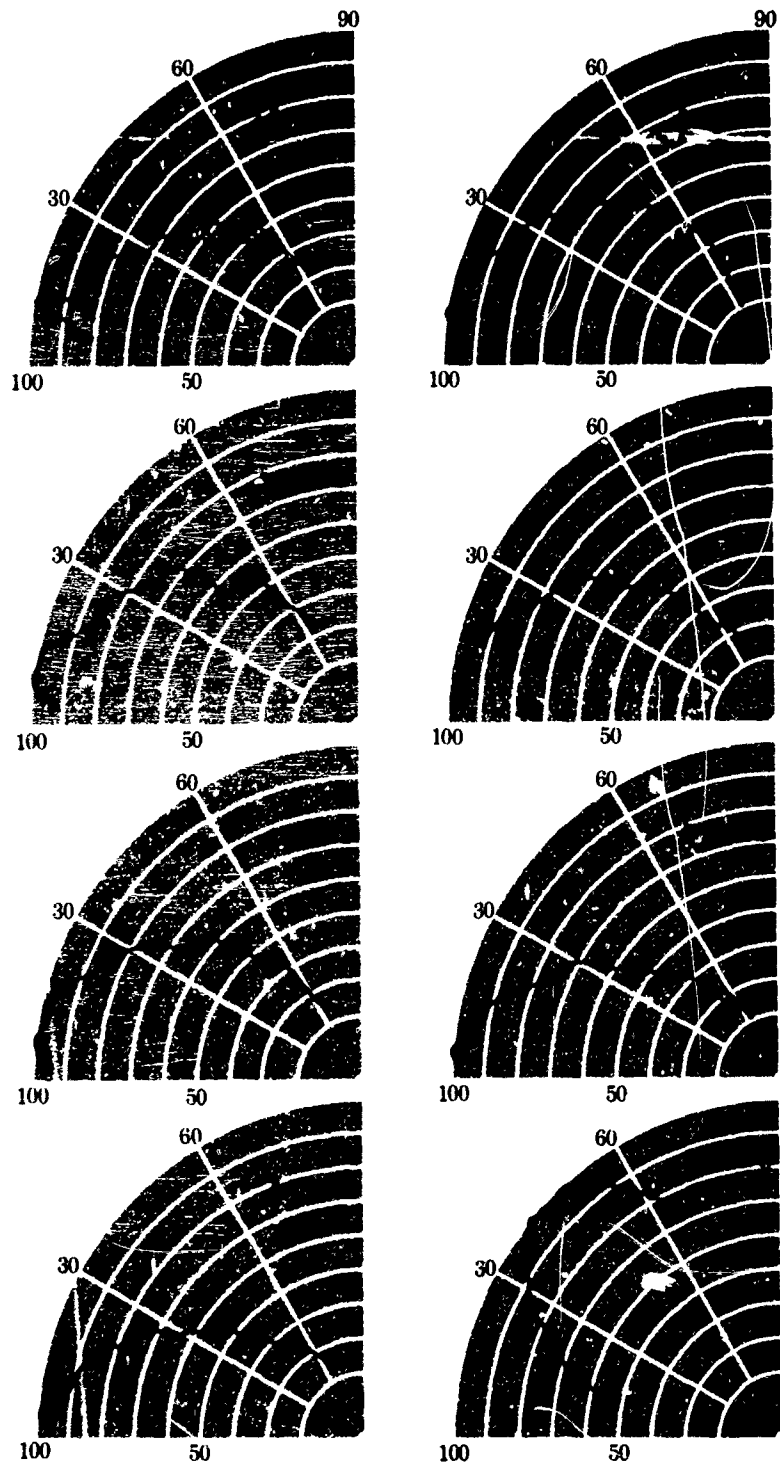
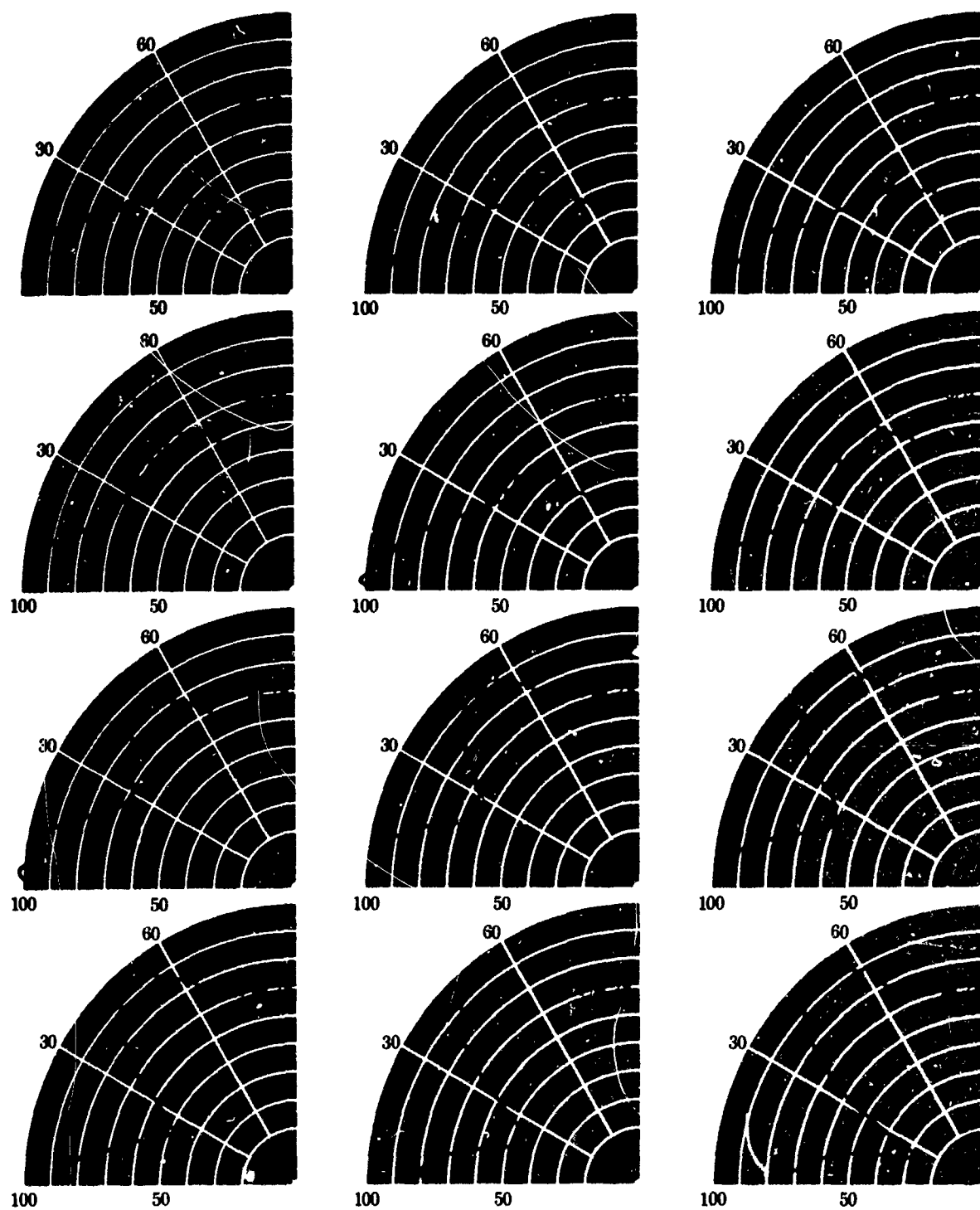Figure 24. Vertical patterns of cage with discone feed short-circuited
(1:24 model).

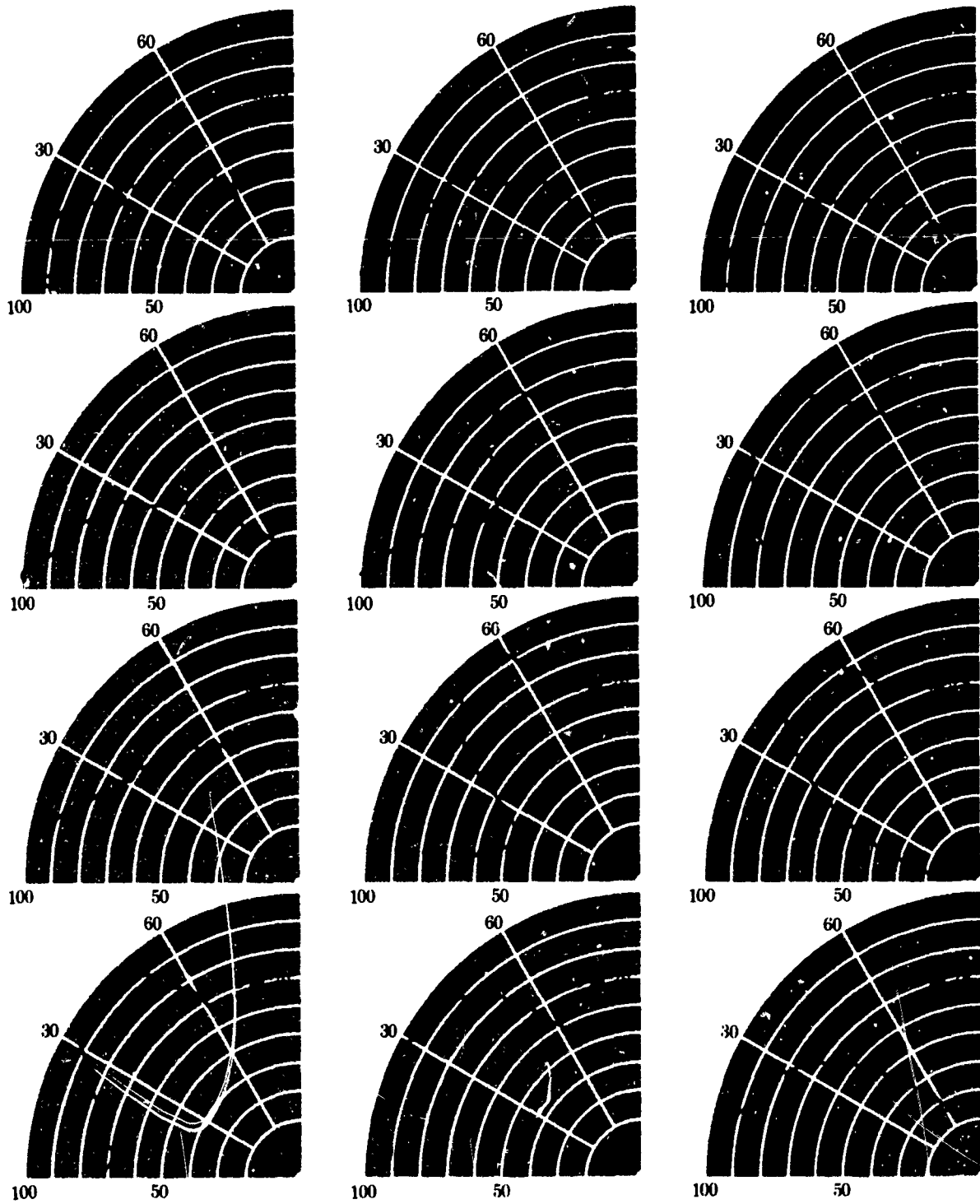Figure 25. Vertical patterns of cage at high end of operating band with discone feed open (1:24 model).

Figure 26. Vertical patterns of cage with discone feed terminated in reactances that
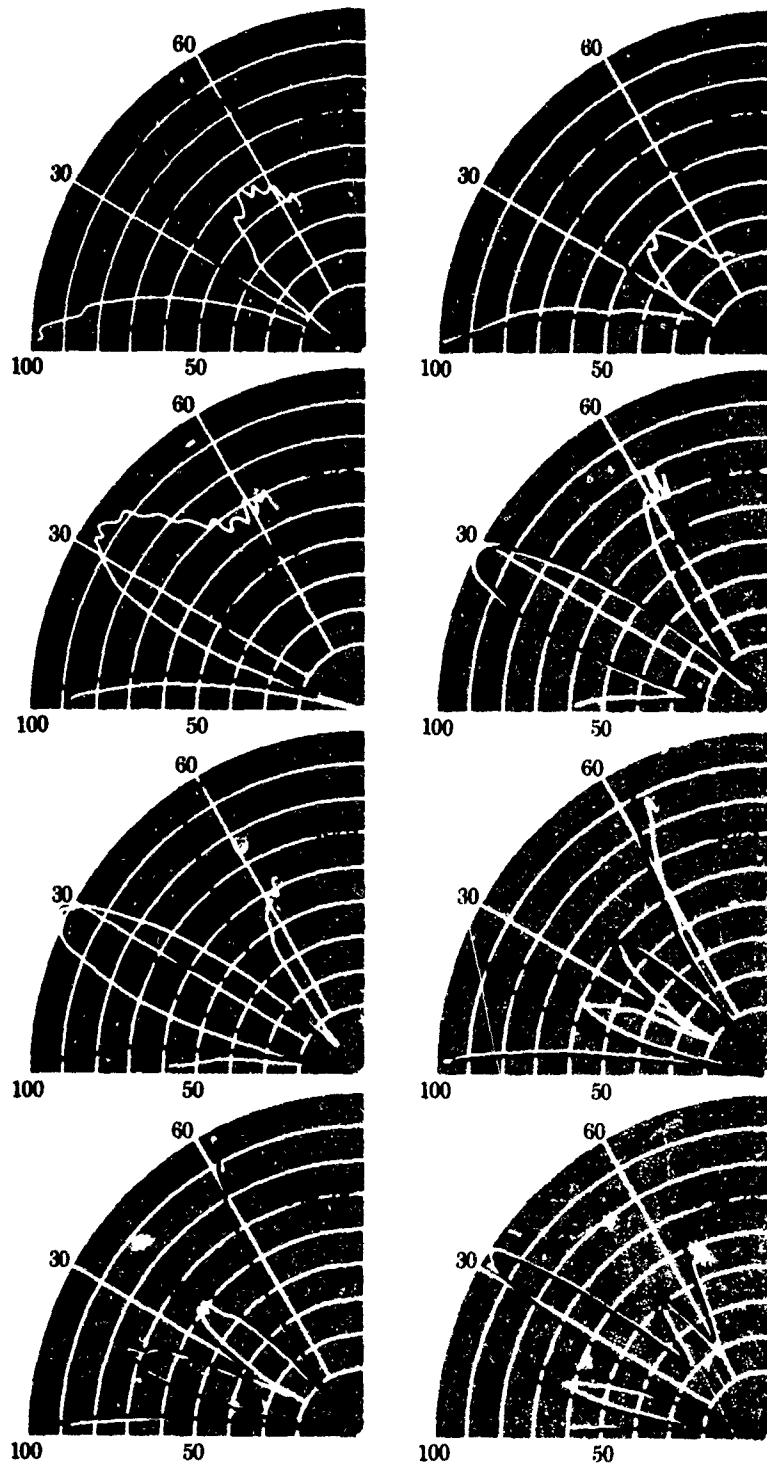simulate the stop-band-reactance values of the high-pass filter.

Figure 27. Vertical patterns of cage with cage feed open (solid) and short-circuited (dashed).

POTENTIAL MULTICOUPLING APPLICATIONS

The potential advantages afforded by the general-purpose DISCAGE antenna with modern multicoupling techniques will be briefly described. Applications of the antenna with single radio equipments are self-evident and need no elaboration.

The Navy is currently developing and procuring a variety of multicoupling equipments for transmitting and receiving applications. Special emphasis is being given to urgent shipboard requirements under the Naval Ships Advanced Communication System (NSACS) project. In addition to these advanced developments, a series of multicouplers of improved design is being procured by NAVSHIPS.

Figure 28 illustrates the potential circuit capabilities afforded by the 2-to-30-Mc/s DISCAGE antenna through the application of advanced multicoupling techniques. The illustration utilizes power-amplifier/coupler (PAC) equipment being developed under the NSACS project.[11, 12] Twenty transmitting circuits are shown--12 with the 2-to-8-Mc/s cage section and eight with the 8-to-30-Mc/s discone section. Complementary band-pass distribution lines (D-lines) permit two groups of PAC assemblies to be operated in each of the 4-to-1 frequency bands of the antenna. While the maximum circuit possibilities of the D-lines remain to be determined, the D-lines are modularized to permit different numbers of circuits and single groups to be utilized, as required by system considerations. Plans call for PAC equipment that is either automatically or manually controlled. Although each PAC assembly can be operated throughout a band of 2.5 to 1, operation of each unit in figure 28 would be limited to a 2-to-1 band by the complementary D-line arrangement.
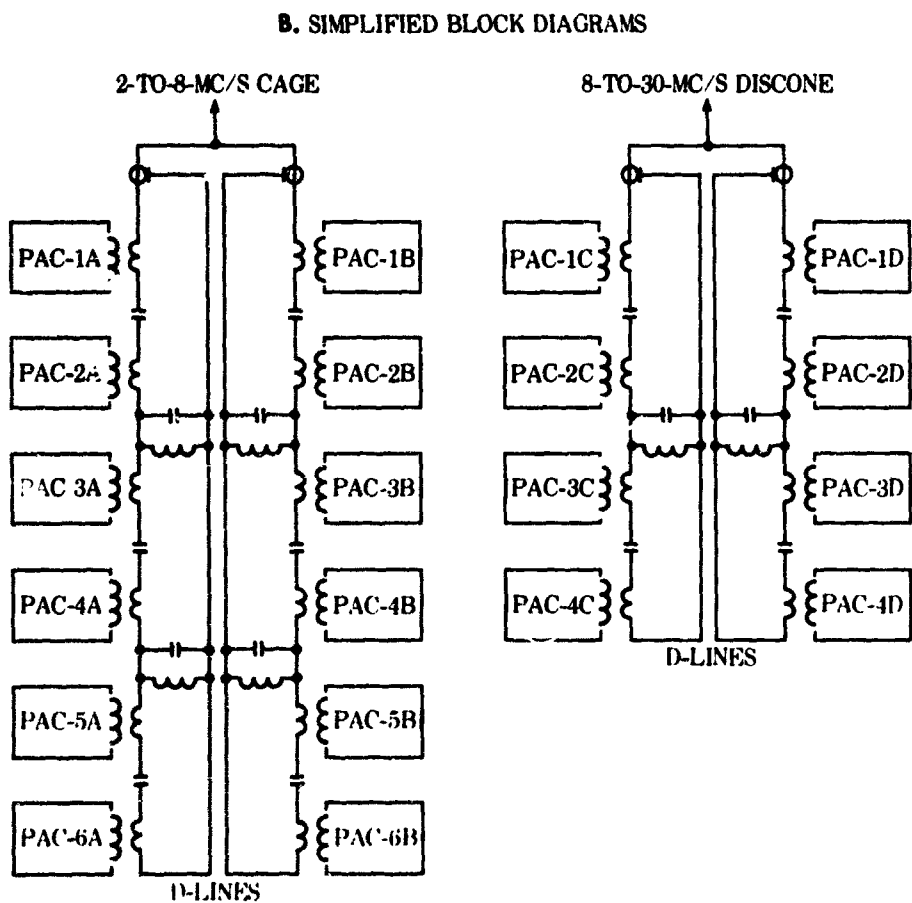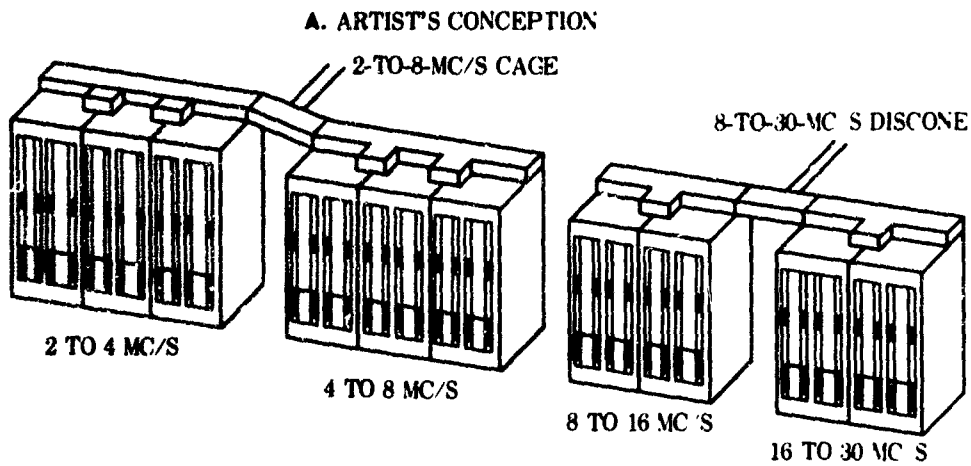
A. ARTIST'S CONCEPTION

2-TO-8-MC/S CAGE

8-TO-30-MC S DISCONE

2 TO 4 MC/S

4 TO 8 MC/S

8 TO 16 MC 'S

16 TO 30 MC S

B. SIMPLIFIED BLOCK DIAGRAMS

2-TO-8-MC/S CAGE

8-TO-30-MC/S DISCONE

PAC-1A   PAC-1B   PAC-1C   PAC-1D

PAC-2A   PAC-2B   PAC-2C   PAC-2D

PAC 3A   PAC-3B   PAC-3C   PAC-3D

PAC-4A   PAC-4B   PAC-4C   PAC-4D

PAC-5A   PAC-5B   D-LINES

PAC-6A   PAC-6B

D-LINES

Figure 28. Typical combinations of integrated power-amplifier/coupler (PAC) assemblies
with band-pass distribution lines (D-lines), showing potential transmitting circuit
capabilities of the DISCAGE antenna.

42

CONCLUSIONS

1. The composite discone-cage, or DISCAGE, antenna can provide a VSWR in the order of 3 to 1 or better relative to 50 ohms from 2 to 30 Mc/s and higher.

2. This vertically polarized antenna gives omnidirectional radiation in the horizontal plane.

3. Scale-model measurements demonstrate that the cage section gives low-angle radiation at most frequencies from 2 to 8 Mc/s.

4. Owing to its elevated feed point, the discone section gives a multilobed vertical pattern. A fairly strong major lobe occurs at relatively low angles at most frequencies from 8 to 30 Mc/s and higher.

5. In applications involving simultaneous operation of both antenna sections, auxiliary low-pass and high-pass networks provide desirable isolation and impedance transformations. This insures that pattern and impedance characteristics will remain stable and predictable.

6. The extremely broadband characteristics of the DISCAGE antenna permit an unusually large number of transmitting or receiving circuits to be accommodated at ship and shore installations by means of advanced multicoupling techniques.

RECOMMENDATIONS

1. Utilize the general-purpose DISCAGE antenna for ship and shore applications requiring an extremely versatile broadband antenna with omnidirectional characteristics.

2. Employ auxiliary low-pass and high-pass networks to obtain highly stable impedance and pattern characteristics, particularly when simultaneous operation of the cage and discone sections is required.

3. Employ highly selective multicoupling equipment to accommodate a large number of radio equipments with a single DISCAGE antenna installation.

REFERENCES

1. Edwards, W.J.E. and Parker, S.E., Broadband Discage Antenna, U.S. Patent 2,987,721, 6 June 1961

2. Kandoian, A.G., Broad Band Antenna, U.S. Patent 2,368,663, 6 February 1945

3. Kandoian, A.G. "Three New Antenna Types and Their Application," Institute of Radio Engineers. Proceedings, v.34, p.70W-77W, February 1946

4. Alford, A., "Ultrashort Electromagnetic Waves -- V Radiation," Electronic Engineering, v.62, p.303-312, July 1943

5. Navy Electronics Laboratory Report 635, Experimentally Determined Characteristics of a Broadband Discage Antenna, by C.I. Warner, 7 October 1955

6. Navy Electronics Laboratory Report 882, A Broadband Discone/Cage Antenna For 5 30 Mc, by R.T. Brackett and W.E. Schaeffer, 30 December 1958

7. Navy Electronics Laboratory Technical Memorandum 602, Model Study of a Communications System Arrangement For USS Wright (CC-2), by M.V. Eddy, Figure 47, 18 April 1963

8. Nail, J.J., "Designing Discone Antennas," Electronics, v.26, p.167-169, August 1953

9. Terman, F.E., Electronic and Radio Engineering. 4th ed., p.882-886, McGraw-Hill, 1955

10. Utlaut, W.F., "Effect of Antenna Radiation Angles Upon HF Radio Signals Propagated Over Long Distances," Journal of Research of the National Bureau of Standards, Section D: Radio Propagation, v.65D, p.167-174, March-April 1965

11. Navy Electronics Laboratory Report 1279, Predesign of a High-Power HF Transmitting Multicoupler System for Southern Cross, by S.E. Parker, 30 March 1965

12. Navy Electronics Laboratory Report 1311, HF Transmitter Couplers Compared With Integrated Power Amplifier-Couplers by Computer Analysis, by S.E. Parker, 5 October 1965

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
NAVAL ELECTRONICS LABORATORY CENTER	UNCLASSIFIED
For Command Control and Communications	2b. GROUP
San Diego, California 92152	

3 REPORT TITLE

COMPOSITE DISCAGE ANTENNA DEVELOPED FOR 2-TO-30-MC/S BAND

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)
Research and Development Report, July 1964 - July 1967

5 AUTHOR(S) (First name, middle initial, last name)

S. E. Parker, L. G. Robbins, and W. J. E. Edwards

6 REPORT DATE	7a. TOTAL NO. OF PAGES	7b NO OF REFS
8 August 1967	44	12
8a CONTRACT OR GRANT NO	9a ORIGINATOR'S REPORT NUMBER(S)	
b PROJECT NO SF 006 03 04	1504	
Task 7046		
c (NELC B12771)	9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d		

10 DISTRIBUTION STATEMENT

This document has been approved for public release and sale;
its distribution is unlimited.

11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY
	Naval Ship Systems Command
	Department of the Navy

13 ABSTRACT

. . Vertically polarized antenna has VSWR of 3 to 1 or better throughout band,
and provides omnidirectional coverage in horizontal plane. Low-angle radiation
is provided by the cage section at most frequencies from 2 to 8 Mc/s. Vertical
patterns -- with a major lobe at relatively low angles -- are provided by the discone
section from 8 to 30 Mc/s and higher. Auxiliary networks insure stability of
impedance and pattern characteristics.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Discone Antennas						
Antennas - Development						

DD FORM 1473 (BACK)
(PAGE 2)

Naval Electronics Lab. Center, San Diego, Calif.
Report 1504

COMPOSITE DISCAGE ANTENNA DEVELOPED FOR 2-TO-30-MC/S
BAND, by S. E. Parker, L. G. Robbins, and W. J.E. Edwards,
44 p., 8 Aug 67.

UNCLASSIFIED

Vertically polarized antenna has VSWR of 3 to 1 or better
throughout band, and provides omnidirectional coverage in
horizontal plane. Low-angle radiation is provided by the cage
section at most frequencies from 2 to 8 Mc/s. Vertical
patterns -- with a major lobe at relatively low angles -- are
provided by the discone section from 8 to 30 Mc/s and higher.
Auxiliary networks insure stability of impedance and pattern
characteristics.

1. Discone Antennas
2. Antennas - Development
I. Parker, S.E.
II. Robbins, L.G.
III. Edwards, W.J.E.

SF 006 03 04, Task 7046
(NELC B12771)

This card is UNCLASSIFIED