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THESIS

LOW SIDELOBE REFLECTOR ANTENNA DESIGN
FOR COMMUNICATIONS

by

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An existing computer code based on the the method of moments was used to compute the gain and the radiation pattern. Circular parabolic reflectors of 36 inches and 48 inches were analyzed. The results show that the 36 inch reflector cannot satisfy the conditions over the entire frequency band (1350 to 1850 MHz) simultaneously. The 48 inch reflector came very close to satisfying all the conditions, although the sidelobe level is off by approximately 2 dB at wide angles in the H-plane.

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LOW SIDELOBE REFLECTOR ANTENNA DESIGN FOR COMMUNICATIONS

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of the requirements for the degree of

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I. INTRODUCTION

A. BACKGROUND

An antenna is the transducer that intercepts propagating electromagnetic waves and directs them into guided waves in a transmission line. In the case of a transmitting antenna, guided electromagnetic energy in a transmission line is converted into radiated electromagnetic waves. In short, the antenna couples the system to the environment [Ref. 1].

Almost all radar, communication, and electronic warfare (EW) systems require some form of antenna. Even for highly directive antennas, all of the energy is not concentrated into the main beam; there is always radiation in directions other than the intended one. These *sidelobes*, as they are called, are of particular importance in electronic warfare, since they represent a major limitation to the system's effectiveness. Jamming signals or false targets received through a sidelobe can cause confusion and failure of a mission more easily than false signals detected by the main beam. The reduction and control of the position and magnitude of sidelobes is extremely important when attempting to localize target azimuths in a hostile electronic environment.

Antenna sidelobe control is one of the most basic methods of defeating jammers and avoiding detection. Low sidelobes also reduce multipath signals, which can cause signal fading in communications systems and tracking errors in radars. The methods of sidelobe suppression for passive antennas are well known, and the technology is low risk. However, low sidelobes are accompanied by a reduction in gain, and generally require a more complicated antenna design. Consequently, there are tradeoffs in the antenna design that impact the overall system performance and cost.

B. OBJECTIVE

This thesis investigates the feasibility of reducing antenna sidelobes for the Marine Radio MRC-142. This system provides medium-range ultra high frequency (UHF) line-of-sight multi-channel radio communications over a distance of up to 35 miles. The AN/MRC-142 radio terminal set is installed in the M-998 variant of the High Mobility Multipurpose Wheeled Vehicle (HMMWV) and when deployed appears as in Figure 1.

This unit can be configured as a repeater to extend the communications range between two other systems or to overcome terrain conditions that prevent a direct line-of-sight path between the other two pieces of equipment. The AN/MRC-142 interfaces with a distant end AN/MRC-142 over a 1350 to 1850 MHz UHF radio link using parabolic antennas that are mounted on masts which can be extended up to 50 feet. The current design uses a parabolic reflector with a focal-point feed and has a first sidelobe requirement of -10 dB relative to the mainbeam. A reduction of another 10 dB is desired for the new design, with a minimum impact on the system upgrade cost.

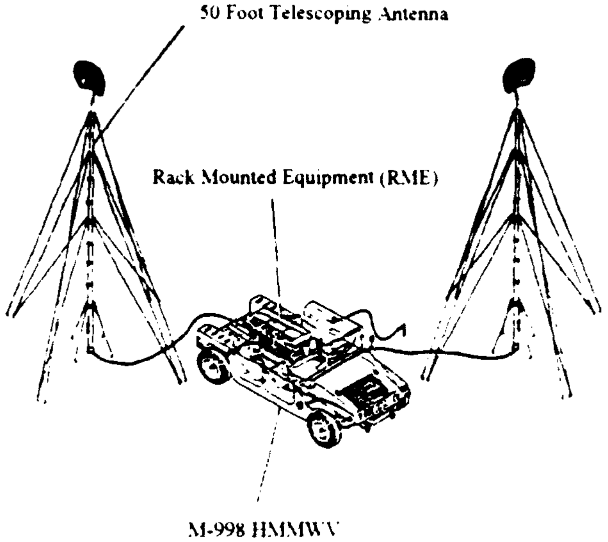


Figure 1. Deployed AN/MRC-142 Radio Terminal Set [Ref. 2].

C. METHOD OF SOLUTION

Possible options for the low sidelobe antenna include:

1. an array antenna;
2. a completely redesigned reflector and feed, or;
3. an improved feed used in conjunction with the current reflector.

The complete antenna specifications are given in the Appendix. Options 1 and 2 could satisfy the specifications in their entirety, but the cost of design and development would be significant. The third option is the one pursued here. Even though all of the antenna specifications are not achieved simultaneously with the new feed, there is significant improvement in all areas. Most importantly, the cost of the new feed is minimal because of its simplicity.

The proposed feed design consists of a fed dipole in the vicinity of a parasitic ring and disk as shown in Figure 2 [Ref. 3]. Essentially the disk acts as a ground plane for the dipole and the ring narrows the beamwidth, resulting in a stronger edge taper on the reflector. The dimensions are chosen to minimize the sidelobes. This "tuning" approach is narrow band and, as discussed in Chapter III, does not allow an optimum feed design for both the transmit and receive frequencies.

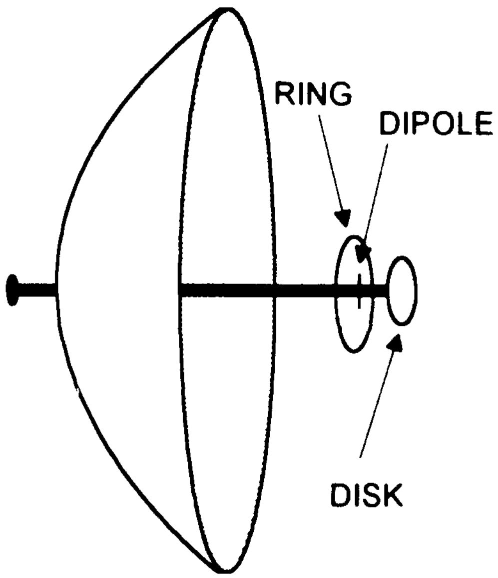


Figure 2. Dipole-Disk Antenna with Ring Used as a Feed in Paraboidal Reflector.

D. SCOPE OF THESIS

In Chapter II the method of analysis is discussed in detail. All of the gain and pattern data presented are generated using the method of moments. Chapter III discusses the tradeoffs involved in the antenna design. As mentioned earlier, the greatest challenge was selecting the geometrical parameters to provide acceptable performance at both frequencies (1350 MHz and 1850 MHz). Finally, Chapter IV presents a summary of the work performed along with some conclusions.

II. THEORETICAL BACKGROUND

A. E-FIELD INTEGRAL EQUATION AND THE METHOD OF MOMENTS

To determine the pattern and gain of a reflector antenna, it is first necessary to find the current on the reflector surfaces. This is accomplished by solving an integral or differential equation for the current which is derived from Maxwell's equations and the boundary conditions. For wire and surface geometries of arbitrary complexity, the integral or differential equation must be solved numerically on a high speed digital computer. The method of moments (MM) is such a technique which reduces the E-field integral equation (EFIE) to a matrix equation which is then solved on a computer [Ref. 4]. The following paragraphs summarize the method of moments technique. Phaser notation is used throughout and $e^{j\omega t}$ time convention is assumed and suppressed.

If the current on a body is known, then the scattered (or radiated) field can be determined from [Ref. 5]

$$\bar{E} = -\nabla\phi - j\omega\bar{A} = -j\omega\bar{A} - j\frac{1}{\omega\mu\varepsilon}\nabla(\nabla\bullet\bar{A}), \qquad (1)$$

where $\omega = 2\pi f$ is the radian frequency, and μ and ε are the permeability and permittivity of free space. $\bar{A}$ is the magnetic vector potential, which can be represented as

$$\bar{A} = \frac{\mu}{4\pi}\iint_s \bar{J}_s(x',y',z')\frac{e^{-jkR}}{R}ds' \qquad (2)$$

where $\bar{J}_s$ is the surface current and S refers to the surface of the conductor.

The electric field integral equation is based on the boundary condition that the total tangential electric field on a perfectly electric conducting (PEC) surface of an antenna or scatterer is zero. This can be expressed as

$$\bar{E}_t^t(\bar{r}=\bar{r}_s) = \bar{E}_t^i(\bar{r}=\bar{r}_s) + \bar{E}_t^s(\bar{r}=\bar{r}_s) = 0 \text{ on } S \qquad (3)$$

where S is the conducting surface of the antenna or scatterer, as stated before, and $\bar{r}=\bar{r}_s$ is the distance from the origin to any point on the surface of the antenna or scatterer. The subscript "t" indicates tangential components.

Referring to Figure 3, Equations (1) and (2) can be combined and expressed as

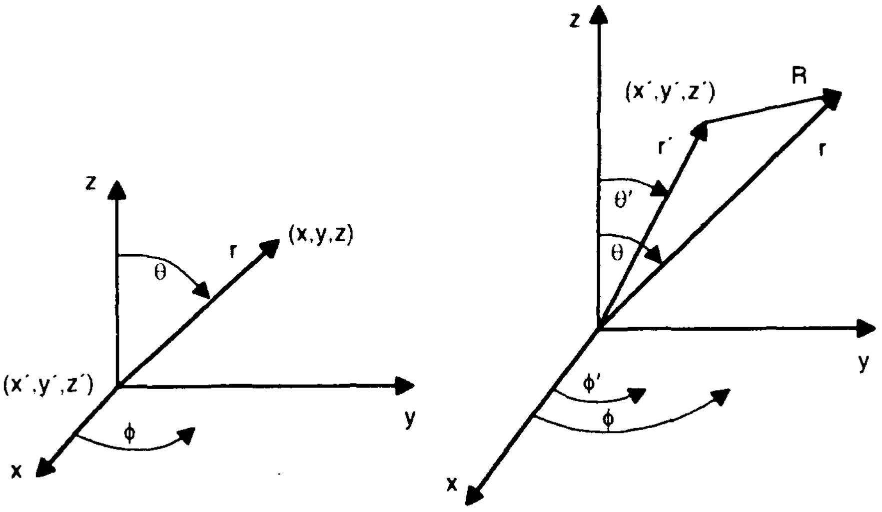


Figure 3. Coordinate Systems for Computing Radiation Fields.

$$\bar{E}^s(\bar{r}) = -j\frac{\eta}{\beta}[\beta^2\iint_s \bar{J}_s(\bar{r}')G(\bar{r},\bar{r}')ds' + \nabla\iint_s \nabla' \bullet \bar{J}_s(\bar{r}')G(\bar{r},\bar{r}')ds'], \tag{4}$$

where

$$G(\bar{r},\bar{r}') = \frac{e^{-jkR}}{4\pi R}, \tag{5}$$

and

$$\bar{R} = |\bar{r} - \bar{r}'|. \tag{6}$$

Now, applying the boundary condition of Equation (3) gives

$$\bar{E}^s(\bar{r}) = E_t^s(\bar{r}_s) = \frac{j\eta}{\beta}[\beta^2\iint_s \bar{J}_s(\bar{r}')G(\bar{r},\bar{r}')ds' + \nabla\iint_s \nabla' \bullet \bar{J}_s(\bar{r}')G(\bar{r},\bar{r}')ds']. \tag{7}$$

This is an integral equation with $\bar{J}_s$ as the unknown. Equation (7) is referred to as the electric-field integral equation. In Equation (7), ∇ and ∇' are the gradients with respect to the observation (unprimed) and source (primed) coordinates, respectively, and

$$G(\bar{r},\bar{r}')$$

is the Green's function for a three dimensional radiator or scatterer.

For convenience, an operator L can be defined which will operate on $\bar{J}_s$

$$L(\bar{J}_s) = j\omega\mu\iint_s \bar{J}_s G;\ ds' + \frac{j\varepsilon}{\omega}\nabla\Big[\nabla\iint_s \bar{J}_s G;\ ds' + \iint_s \bar{J}_s \bullet \nabla G;\ ds' \tag{8}$$

where unknown current $\bar{J}_s$ depends only on the primed quantities. G is a scalar quantity that depends on both the primed and unprimed quantities. It is desirable to have all the differential operations in terms of the primed variables of integration. Equation (8) can therefore be written as

$$L(\bar{J}_s) = j\omega\mu\iint_s \bar{J}_s G;\ ds' + \frac{j\varepsilon}{\omega}\nabla\Big[\iint_s G;\ \nabla \bullet \bar{J}_s ds' + \iint_s \bar{J}_s \bullet \nabla;\ G;\ ds', \tag{9}$$

where the vector identity

$$\nabla(\bar{J}_s \bullet \nabla G) = (\bar{J}_s \bullet \nabla)\nabla G + (\nabla G \bullet \nabla)\bar{J}_s + \bar{J}_s \times (\nabla \times \nabla G) + \nabla G \times (\nabla \times \bar{J}_s). \qquad (10)$$

has been used.

The gradient of G in terms of the two sets of coordinates is related by

$$\nabla G = -(jk + \tfrac{1}{r})\tfrac{e^{-jkr}}{4\pi r}\hat{r} = -\nabla' G. \qquad (11)$$

Using the surface divergence theorem developed by Mautz and Harrington [Ref. 5], it can be shown that

$$\iint_s \nabla' \bullet (\bar{J}_s G)ds' = 0. \qquad (12)$$

Finally, Equation (7) can be written as

$$L(\bar{J}_s) = \iint_s [j\omega\eta\bar{J}_s G - \tfrac{j\varepsilon}{\omega}\nabla[(\nabla' \bullet \bar{J}_s)G]]ds'. \qquad (13)$$

Now the electric field integral equation can be represented as

$$\bar{E}^i_t(r_s) = L(\bar{J}_s). \qquad (14)$$

Equation (14) can be solved numerically using the method of moments. The current on the antennas is expanded in terms of a finite series of known basis functions with unknown amplitudes. The antenna under consideration consists of surfaces and thin wires, so basis functions must be defined on each. On a surface two orthogonal components are required. The coordinate system for the reflector is shown in Figure 4 and the following basis functions defined on the surface [Ref. 6]:

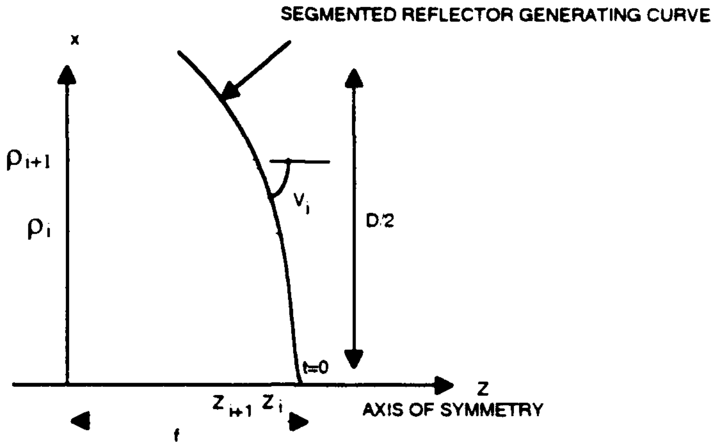


Figure 4. A Reflector Geometry for Method of Moments.

$$\begin{aligned} \bar{J}^{t}_{ni} &= \hat{t}\frac{T_i(t)}{\rho}e^{-jn\phi}, & n &= 0, \pm 1, \ldots \pm \infty, \quad i = 1, 2, \ldots, N_s - 2 \\ \bar{J}^{\phi}_{ni} &= \hat{\phi}\frac{P_i(t)}{\rho}e^{-jn\phi}, & n &= 0, \pm 1, \ldots \pm \infty, \quad i = 1, 2, \ldots, N_s - 1 \end{aligned} \qquad (15)$$

$T_i(t)$ is the triangle function (which extends over two segments, i and i + 1) and $P_i(t)$ is the pulse function. A point on the surface of the antenna is specified by the coordinates (t, ϕ), where t is an arclength variable along the reflector generating curve. The distance of a point from the axis of symmetry (z-axis) is given by ρ and N_s is the number of surface generating points. A discussion leading to the choice of these basis functions is given by Mautz and Harrington [Ref. 5].

For thin wires the radius "a" is much less than a wavelength and the current will only have an axial component. Thus the operator ∇ becomes $\hat{t}(\partial/\partial t)$, where t is the arc length along the wire. Furthermore, the current is constant around the wire and $\iint_s ds'$

reduces to $2\pi a\int_L dt'$, as shown in Figure 5. Thus appropriate basis functions on the wire are [Ref. 7]:

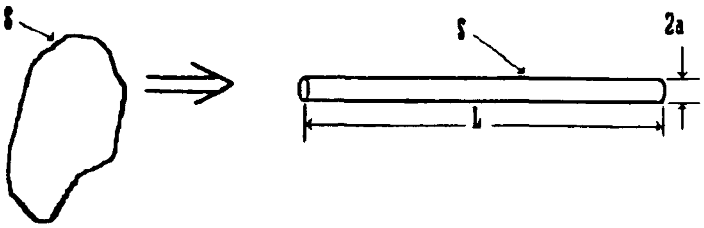


Figure 5. Thin Wire Approximation.

$$\bar{J}_i = \hat{t}\frac{T_i(t)}{2\pi a}, \qquad i=1,2\ldots,N_w. \tag{16}$$

In this case $\hat{t}$ is a unit vector along the wire axis and N_w is the number of wire generating points. The total current is the sum over all expansion functions

$$\bar{J}_s = \sum_{m=1}^{N_w-2} I_m^w \bar{J}_m^w + \sum_{n=-\infty}^{\infty}\left[\sum_{p=1}^{N_s-2} I_{pn}^t \bar{J}_{pn}^t + \sum_{q=1}^{N_s-1} I_{qn}^\phi \bar{J}_{qn}^\phi\right]. \tag{17}$$

The coefficients I are the unknowns which need to be determined.

From the linearity of L, Equation (14) can be combined with Equation (17) as follows

$$\bar{E}_t^i = \sum_{i=1}^{N_b} I_i L(\bar{J}_i). \tag{18}$$

where N_b is the total number of basis functions of both types. N_b equations need to be provided to enable a solution for the unknown constants I_i. Galerkin's method is used to reduce Equation (18) to a matrix equation, and weighting functions are defined such that $\bar{W}_k = \bar{J}_k^*$ (Ref. 8, 9]. Each side is multiplied by each of the basis functions and then each side integrated. The result is N_b equations of the form

$$\iint_{s_{k1}} \bar{E}^i \bullet \bar{W}_k ds = [\iint_{s_{k1}} \bar{W}_k \bullet I_1 L(\bar{J}_1) + \iint_{s_{k2}} \bar{W}_k \bullet I_2 L(\bar{J}_2) + \ldots + \iint_{s_{kN}} \bar{W}_k \bullet I_N L(\bar{J}_N)]ds$$

$$k=1,2,\ldots N_b \qquad (19)$$

which can be written as

$$\iint_{s_k} \bar{E}^i \bullet \bar{W}_k ds = \iint_{s_{ki}} [\bar{W}_k \bullet \sum_{i=1}^{N_b} I_i L(\bar{J}_i) ds]. \qquad (20)$$

Interchanging summation and integration,

$$\iint_{s_k} \bar{E}^i \bullet \bar{W}_k ds = \sum_{i=1}^{N_b} I_i \iint \bar{W}_k \bullet L(\bar{J}_i) ds. \qquad (21)$$

Equation (21) can be cast in the form

$$V_k = \sum_{i=1}^{N_b} Z_{ik} I_i. \qquad (22)$$

for k = 1, 2, ...,N_b, where the impedance elements are given by

$$Z_{ik} = \iint_s ds \iint_s \left[j\omega\mu \bar{W}_k \bullet \bar{J}_i - \tfrac{j}{\omega\varepsilon}(\nabla' \bullet \bar{J}_i)(\nabla \bullet \bar{W}_k) \right] G ds'. \qquad (23)$$

The excitation elements are defined by

$$V_k = \iint_s \bar{W}_k \bullet \bar{E}^i ds, \qquad (24)$$

In matrix notation Equation (22) becomes

$$[V] = [Z][I], \tag{25}$$

and the unknown coefficients are determined by solving the matrix equation

$$[I] = [Z]^{-1}[V]. \tag{26}$$

Submatrices in Equation (25) associated with the $\hat{t}$ and $\hat{\phi}$ surface components can be identified as follows

$$\begin{bmatrix} [V_n^t] \\ [V_n^\phi] \end{bmatrix} = \begin{bmatrix} [Z_n^{tt}][Z_n^{t\phi}] \\ [Z_n^{\phi t}][Z_n^{\phi\phi}] \end{bmatrix} \begin{bmatrix} I_n^t \\ I_n^\phi \end{bmatrix}. \tag{27}$$

The impedance matrix will have the following block structure when all of the surface and wire basis functions are considered

$$\begin{bmatrix} Z_{-M}^{ss} & \cdots & \cdots & \cdots & \cdots & Z_{-M}^{sw} \\ \vdots & \ddots & & & & \vdots \\ \vdots & & Z_0^{ss} & & & Z_0^{sw} \\ \vdots & & & \ddots & & \vdots \\ \vdots & & & & \ddots & Z_M^{sw} \\ Z_{-M}^{ws} & \cdots & Z_0^{ws} & \cdots & Z_M^{ws} & Z_{-M}^{ww} \end{bmatrix} \begin{bmatrix} I_{-M}^s \\ \vdots \\ I_0^s \\ \vdots \\ I_M^s \\ I^w \end{bmatrix} = \begin{bmatrix} V_{-M}^s \\ \\ V_0^s \\ \\ V_M^s \\ V^w \end{bmatrix}. \tag{28}$$

The superscripts s and w refer to surface and wire, respectively. Although n in Equation (17) can take on values between $\pm\infty$, it has been truncated at $\pm$ M in the above matrix. In practice, when the feed is on the reflector axis of symmetry, a converged solution can be obtained with M = 1. If the pattern is calculated for the antenna transmitting, the excitation vector will have only one non-zero value corresponding to the dipole feed point.

The unknown expansion coefficients are determined by solving the matrix in Equation (27) for [I]. To compute the electric field, the coefficients are used in Equation (17), which in turn is used in Equations (1) and (2). Define a measurement vector,

$$R_m = \int\int_s \bar{E}_r \bullet \bar{J}_s ds, \tag{29}$$

where $\bar{E}_r$ denotes a unit radiated plane wave weighted by the current on S. In general $\bar{J}_s$ will give rise to both θ and ϕ components in the far field. The radiated θ component is of the form

$$\bar{E}_r = \hat{\theta} e^{-jk\bullet r} = \hat{\theta} e^{-jk[xu+yv+zw]}, \tag{30}$$

where $u = \sin\theta\cos\phi$, $v = \sin\theta\sin\phi$, and $w = \cos\theta$. By substituting Equation (30) into Equation (29), there results

$$R_m^{\theta} = \int\int_s e^{-jk[xu+yv+zw]}(\hat{\theta} \bullet \bar{J}_s)ds'. \tag{31}$$

The total θ component of the electric field is the superposition of all surface current contributions

$$E_\theta = \frac{-jk\eta}{4\pi r} e^{-jkr} \sum_m R_m^{\theta} I_m. \tag{32}$$

The analysis holds true for the ϕ component. The measurement elements are

$$R_m^{\phi} = \int\int_s e^{-jk[xu+yv+zw]}(\hat{\phi} \bullet \bar{J}_s)ds', \tag{33}$$

and the electric field is then defined by

$$E_\phi = \frac{-jk\eta}{4\pi r} e^{-jkr} \sum_m R_m^\phi I_m . \tag{34}$$

B. GAIN CALCULATION

The degree to which any particular antenna pattern is concentrated into a beam is known as *directivity* which is defined by

$$D = \frac{P_{max}}{P_{ave}} , \tag{35}$$

where P_{max} is the maximum power flux radiated, and P_{ave} is the average power flux radiated. Since the average power flux radiated is equal to the total power radiated (P_{tot}) divided by 4π steradians,

$$D = 4\pi \frac{P_{max}}{P_{tot}} . \tag{36}$$

Directivity, as defined above, is a function of the antenna pattern only, and does not take into account the antenna efficiency or losses. In order to compare the relative performance of antennas in any electronic-warfare system, it is necessary to consider antenna efficiency. The pertinent quantity is gain G which is defined as

$$G = KD , \tag{37}$$

where K is the efficiency factor ($0 \leq K \leq 1$). Thus it is seen that for a 100% efficient antenna ($K = 1$), the gain would be equal to the directivity. For all practical antennas $K < 1$. Gain is frequently expressed as a decibel ratio

$$G, \mathrm{db} = 10 \log_{10} G. \tag{38}$$

A very important relationship exists between gain, physical antenna dimensions, and electrical wavelength, expressed by

$$G = 4\pi \frac{KA}{\lambda^2}, \tag{39}$$

where A is the "effective" area of the antenna and λ is the wavelength. The effective area of the antenna and the wavelength must be expressed in the same units (meters, inches, feet, etc.). The total radiated power required in Equation (36) can be obtained by integrating the electric field over a sphere

$$P_{tot} = \int_0^{2\pi} \int_0^{\pi} \{ |E_\theta|^2 + |E_\phi|^2 \} r^2 \sin\theta \, d\theta \, d\phi \tag{40}$$

where E_θ and E_ϕ are known from Equations (32) and (34).

III. LOW SIDELOBE ANTENNA DESIGN STUDY

A. SUMMARY OF TRADEOFFS IN THE ANTENNA DESIGN

The purpose of this thesis is to achieve a reduction in the antenna sidelobes for the Marine radio AN/MRC-142. The approach will be to upgrade the existing reflector in Figure 6 by implementing a feed design similar to that of Kildal and Skyttemyr [Ref. 3] shown in Figure 2 of Chapter I.

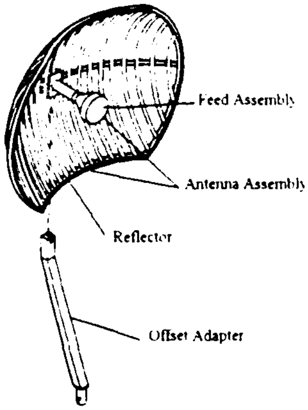


Figure 6. AN/MRC-142 Antenna Assembly and Offset Adapter [Ref. 2.].

The size of the reflector aperture is 36 x 48 inches as shown in Figure 7. The projected aperture is not circular, but has two circular segments removed. The method of moments code that was used to compute the gain and radiation pattern can only handle rotationally symmetric reflectors. In the design of the antenna, circular parabolic reflectors of 36 and 48 inches were analyzed. Additionally, the structure supports only vertical currents, whereas the method of moments code assumes radial and azimuthal currents (solid surface). The actual AN/MRC-142 performance will lie somewhere between the two. The pattern will resemble the 48 inch reflector in the plane of the wide dimension, and the 36 inch reflector in the plane of the narrow dimension. The effect on gain can be accurately estimated based on the area reduction from the 48 inch diameter circular antenna due to removal of the circular segments.

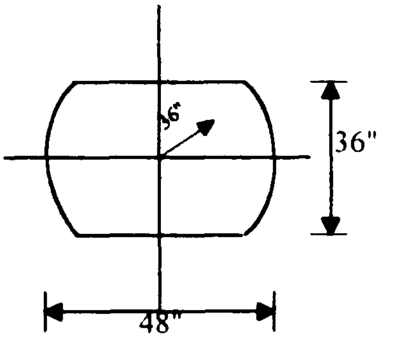


Figure 7. Antenna Radius Determination.

The reflector surface is a section of a parabaloid and is fed from the front. Four factors affect the efficiency of this type of antenna:

1. Spillover efficiency;

2. Illumination efficiency;

3. Blockage by the feed;

4 Cable and line losses from the antenna input to the feed

Taking into consideration all these factors, most of the burden in maximizing the efficiency is placed upon the antenna feed. The dipole-disk antenna, which essentially consists of a halfwave dipole over a circular plane reflector, is widely used as feed for paraboloidal reflector antennas at VHF and UHF. A method of improving this feed consists in incorporating a circular conducting beam-forming ring (BFR) over the dipole in a plane parallel to the disk. The beam-forming ring compresses the H-plane pattern of the dipole-disk feed, whereas it has no significant effect on the E-plane pattern. When this antenna is used as feed for paraboloidal reflectors, it exhibits near-identical principal plane aperture illumination and reduces H-plane spillover lobes.

The diameter of the disk should be as small as possible in order to reduce blockage loss. However a small disk and ring result is a broad feed radiation pattern which does not provide sufficient edge taper for a low sidelobe pattern. To obtain the best performance a parametric study was performed for the geometrical quantities shown in Figure 8 and listed in Table 1. The parameters and their effect in antenna radiation pattern and gain discussed in the following sections. All dimensions used by the computer code are in wavelengths.

1. Reflector Size

The size of the reflector is 36 x 48 inches as shown in Figure 7. Two different designs were obtained for each frequency: one for 36 inches and the other one for 48 inches. At 1350 MHz, the wavelength is 8.75 inches and at 1850 MHz the wavelegth is

6.38 inches. Thus 36 inches corresponds to 4.1λ and 5.6λ, while 48 inches corresponds to 5.5λ and 7.5λ at these two frequencies.

The focal-length-to-diameter ratio (f/D) of the existing reflector antenna could not be determined from AN/MRC-142 technical manuals. Typical values are in the range of 0.3 to 0.55. Smaller values are preferable to reduce spillover loss and increase edge taper. A value of 0.4 was chosen for f/D. This parameter could be varied slightly without significant modification of the antenna's gain and pattern.

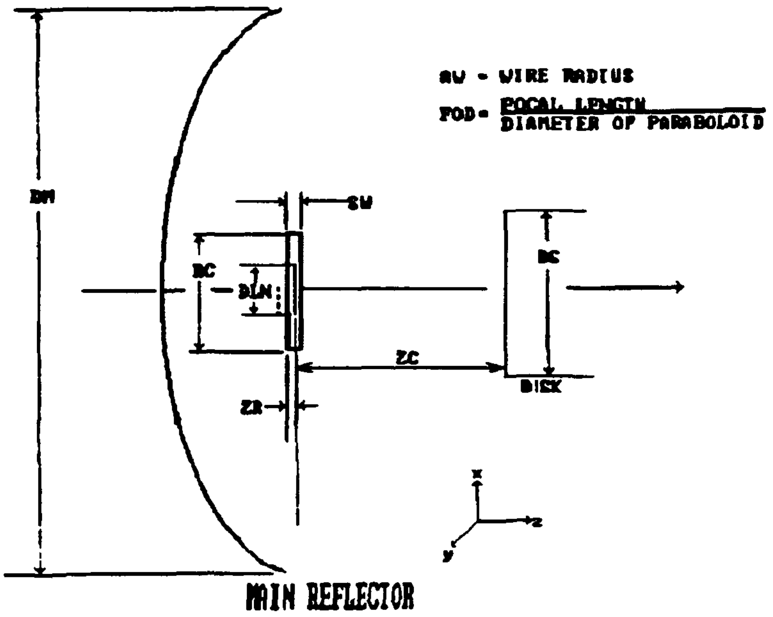


Figure 8. Program Parameters

TABLE 1. DESIGN PARAMETERS

DM = diameter of paraboloid
DS = diameter of disk
ZC = distance of dipole to ground plane
FOD = focal length to diameter ratio of the parabolid
ZR = distance of ring from fed dipole along the z axis
RC = radius of ring
SW = ring width (modeled as a thin strip)
DLN = fed dipole length
PLN = parasitic director dipole length
DDIP = distance between DLN and PLN along the z axis
AW = radius of dipoles
HLGTH = parasitic (H plane) dipole length (not used)
DHP = H plane dipole distance from feed along the y axis (not used)

2. Gain Calculation

Gain estimates for the reflector and feed were obtained by first integrating the total electric field to find the total radiated power P_{tot}. The result is then used in Equation [36] to determine the directivities shown in Table 2. These numbers include spillover and aperture efficiency because the total field is integrated (that is, feed plus scattered fields).

Losses that are not accounted for and thus determine the value of K in Equation [37] include:

1. Transmission line losses for the cable that feeds the dipole. Assuming 0.5 dB/ft and 3 ft of cable yields 1.5 dB of loss.

2. Reflection loss from the reflector surface. This is due to the fact that the surface is a grid rather than a solid. A conservative estimate is 0.5 dB.

3. Any impedence mismatch loss. A VSWR of 2:1 results is approximately 0.5 dB of loss.

Based on the above numbers the total loss is about 2.5 dB. The corresponding gains are shown in Table 3.

TABLE 2. CALCULATED DIRECTIVITIES.

	48 inches	36 inches
1350 MHz	24.75 dB	22.19 dB
1850 MHz	27.44 dB	24.90 dB

TABLE 3. CALCULATED GAINS WITH LOSS.

	48 inches	36 inches
1350 MHz	22.25 dB	19.19 dB
1850 MHz	23.94 dB	21.90 dB

B. MODIFICATIONS TO ANTENNA DESIGN

Each of the parameters of the feed and reflector were varied in small increments and their effect on the antenna pattern and gain was evaluated. The results are summarized below.

1. Baseline Feed Design

The dimensions of the baseline feed design are listed in Table 4. The disk serves as a ground plane for the dipole. The phase center of the feed will vary with frequency and angle. If the disk is an effective ground plane the phase center of the dipole and its image will be approximately at the midpoint of the two. However in the following discussion the dipole is considered to be the center of the feed.

Low sidelobes require a strong amplitude taper across the reflector, which in turn requires a narrow feed beamwidth. Generally a narrow feed beamwidth is associated with a feed aperture which results in increased blockage. Thus there is a tradeoff between sidelobe taper and blockage loss.

The geometrical parameters in Table 4 were the starting point for the parametric study, which is summarized in the following sections. The baseline antenna performance is shown in Figure 10. The solid line is the E-plane (ϕ=0°) pattern and the dashed line the H-plane (ϕ=90°) pattern.

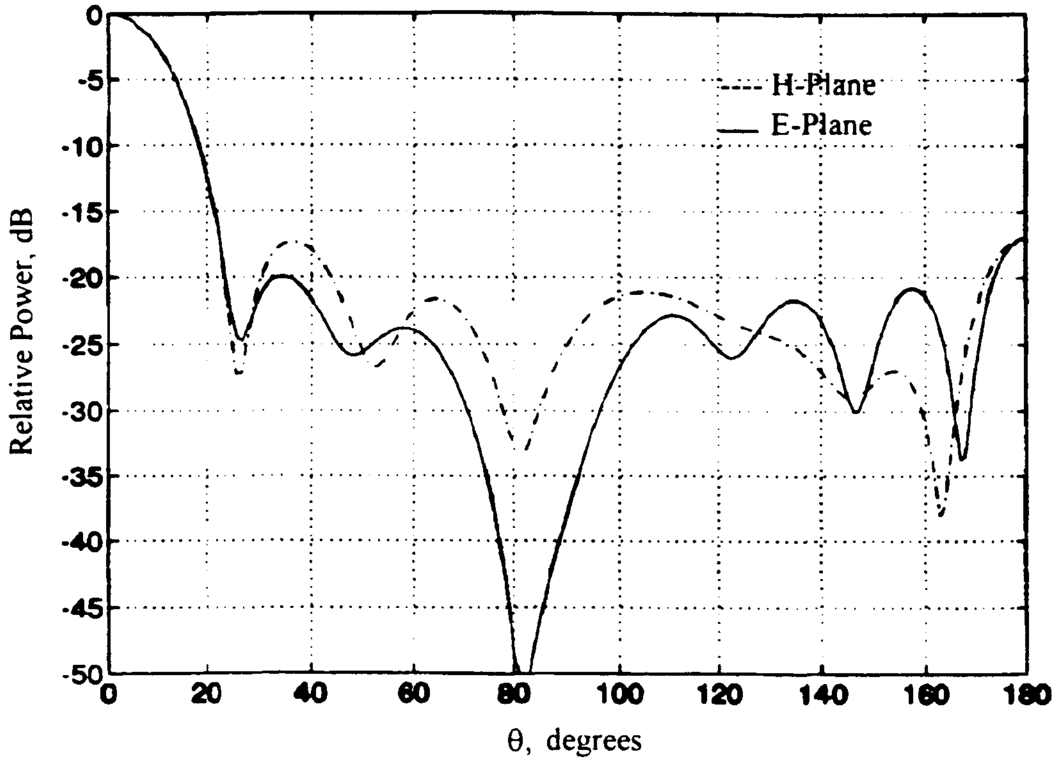


Figure 10. Baseline Antenna Pattern.

TABLE 4. BASELINE FEED GEOMETRY

Variable	Value	Z distance or coordinate[1]
disk diameter	4.1	Zc = .25
ring diameter	0.7	Zr = 0.0
fed dipole length	0.5	Zd = -0.25
parasitic dipole length	not part of baseline design	
fed dipole height above disk	0.5	Zc-Zd
ring heigth above disk	0.25	Zc-Zr
wire radius	.001λ	-

[1] The fed dipole is located at Z = 0; positive Z is away from the reflector

2. Disk Size and Location

The disk must be large enough to serve as an effective ground plane for the dipole. Generally the dipole height must be significantly less than the diameter of the disk. For the dipole and its image to add constructively in the direction of the reflector, the spacing should be approximately .25λ. The patterns for disk locations of Z = +.1λ, and -.1λ are shown in Figures 11 and 12. All other feed parameters are held constant (values given in Table 4). The reflector diameter is 4.1λ and f/D = 0.5 in all cases. The high levels in the H plane patterns for 80° ≤ θ ≤ 120° are due to feed spillover. A comparison of the figures shows that there is a tradeoff between spillover levels in the rear hemisphere (90 ≤ θ ≤ 180) and sidelobe levels in the forward hemisphere (θ ≤ 90°). The impact of changing the disk radius by .1λ is illustrated in Figures 13 and 14.

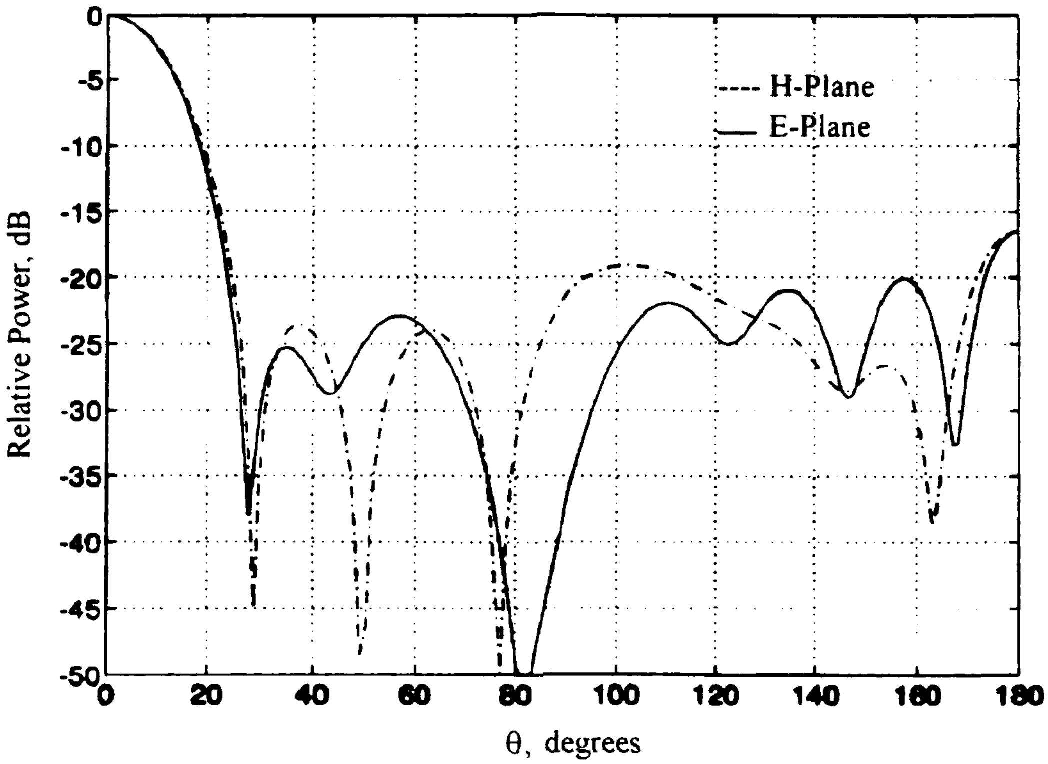


Figure 11. Radiation Pattern with Disk Shift of +0.1λ.

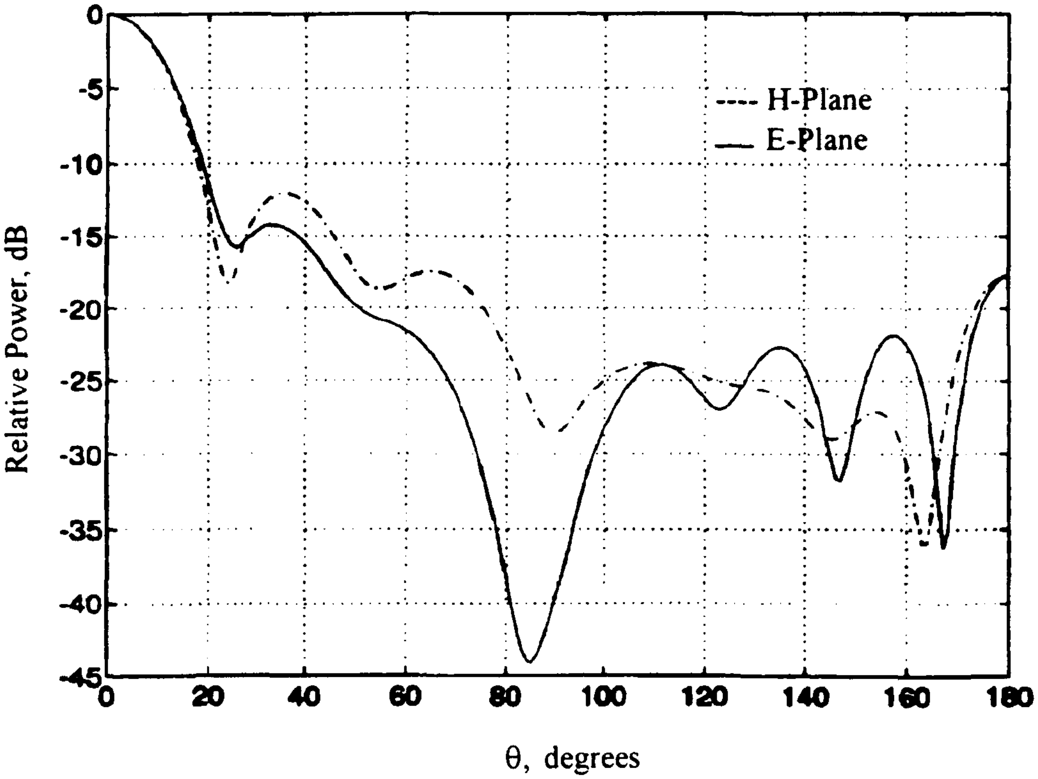


Figure 12. Radiation Pattern with Disk Shift of -0.1λ.

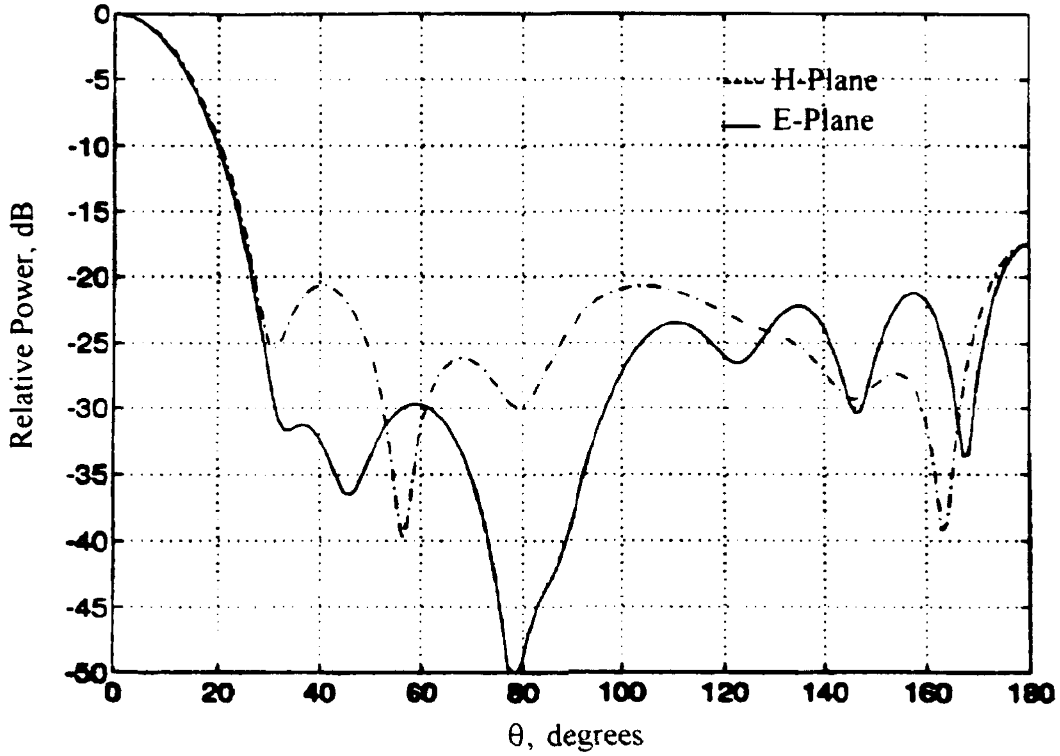


Figure 13. Radiation Pattern with Disk Size .1λ.

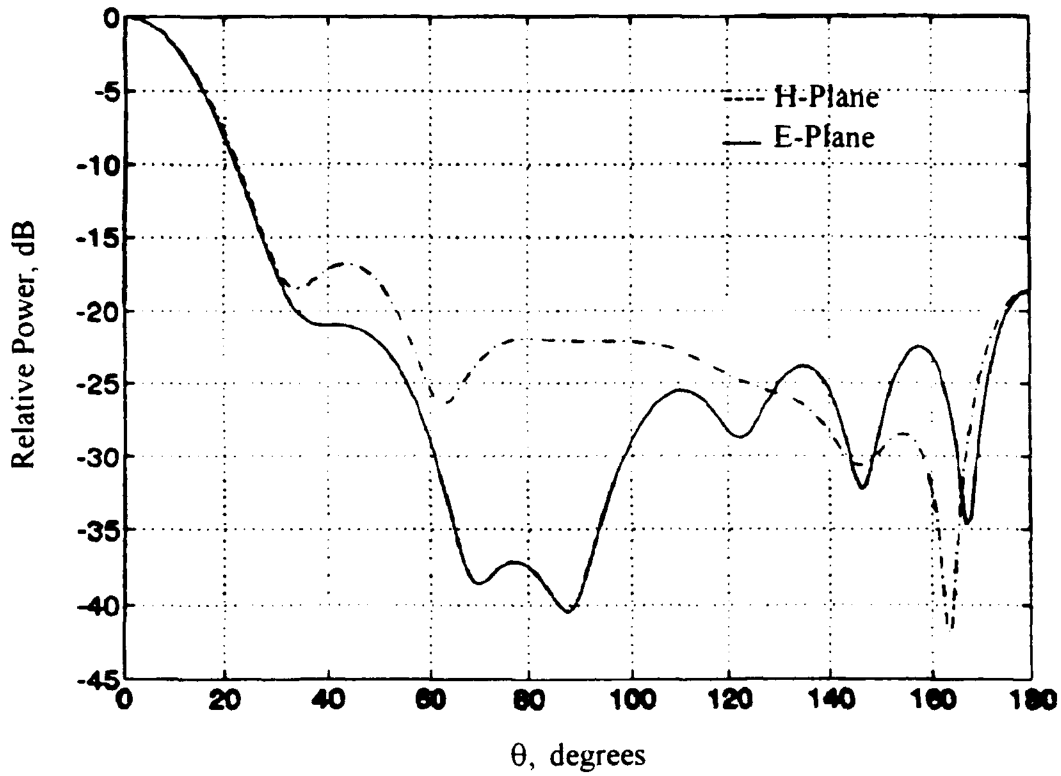


Figure 14. Radiation Pattern with Disk Reduced -.1λ.

3. Ring Size and Position

The beam-forming ring (BFR) compresses the H-plane beamwidth but leaves the E-plane beamwidth essentially unaffected. Thus the ring size and location can be used to equalize the feed beamwidth. Patterns for two ring radii are shown in Figures 15 and 16.

The ring acts somewhat like a director in a Yagi array when it is located in front of the dipole (towards the reflector) [Ref. 6]. When the ring is located behind the dipole it has little effect on the reflector scattered field. As illustrated in Figure 17 and 18, a shift of $.1\lambda$ results in about a 1 dB difference in the first sidelobe level.

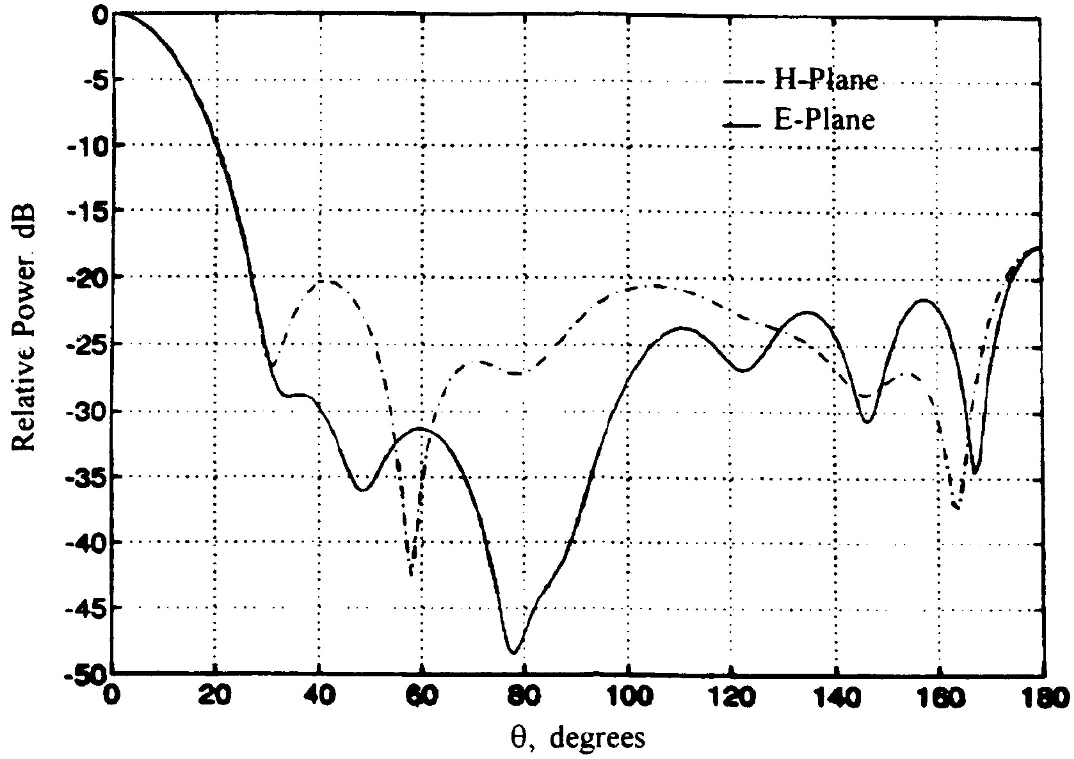


Figure 15. Radiation Pattern with Ring Size of 0.6λ.

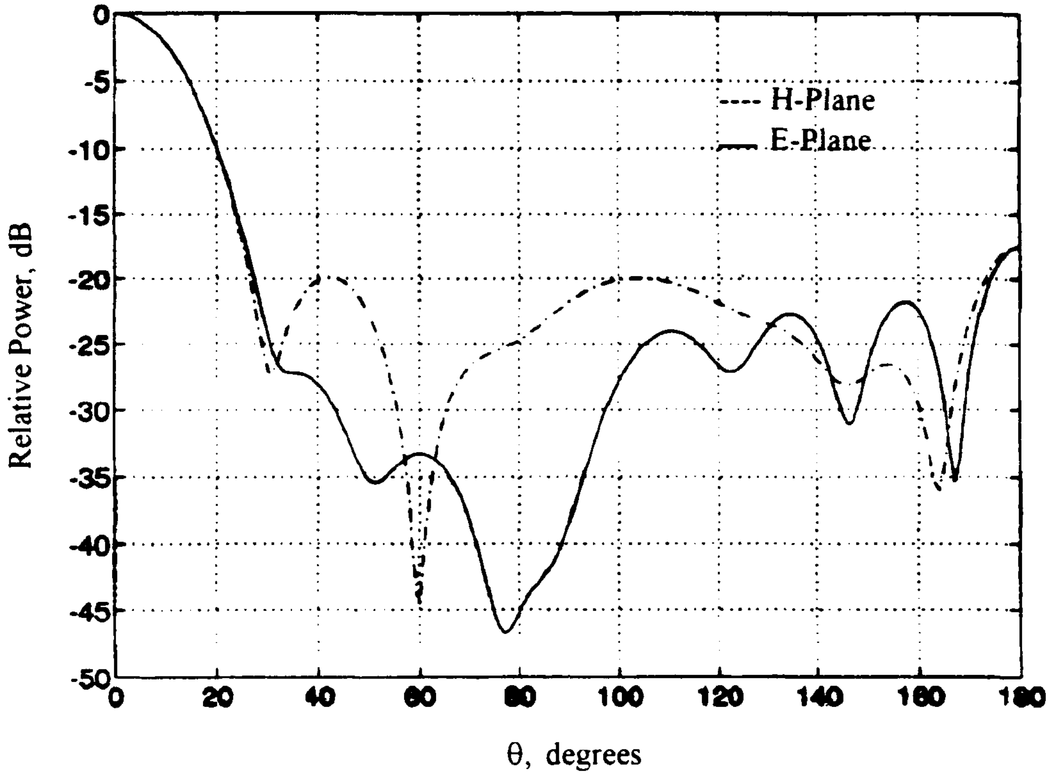


Figure 16. Radiation Pattern with Ring Size of 0.5λ.

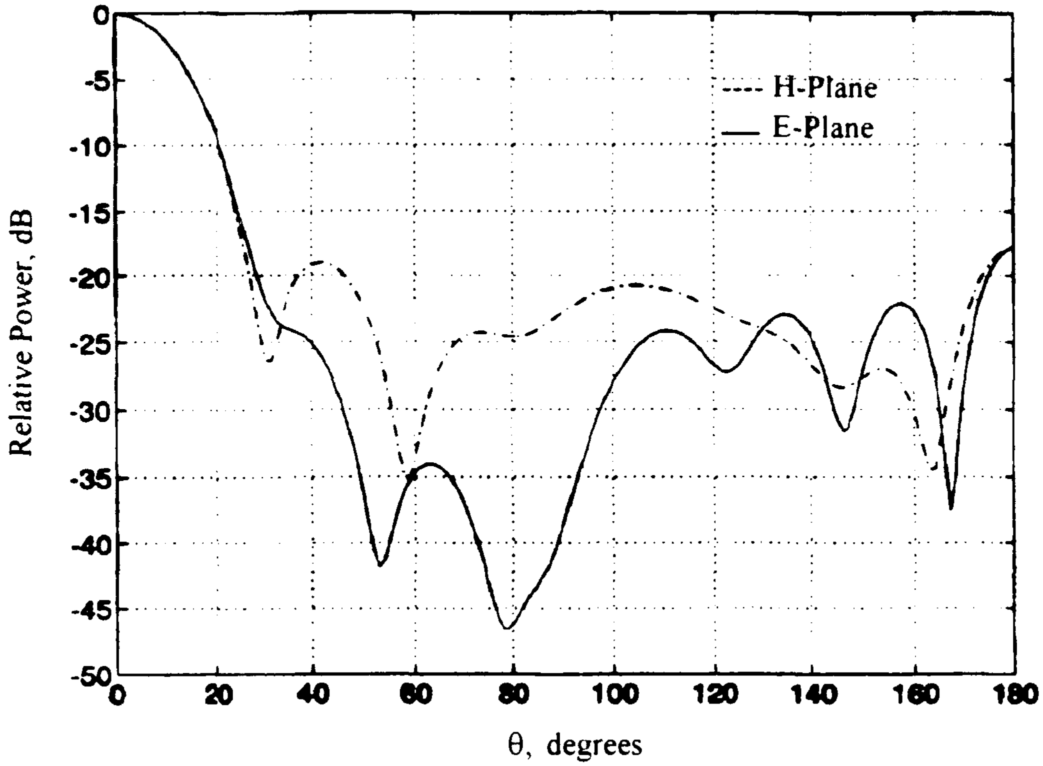


Figure 17. Radiation Pattern with Ring at Z = -0.2λ.

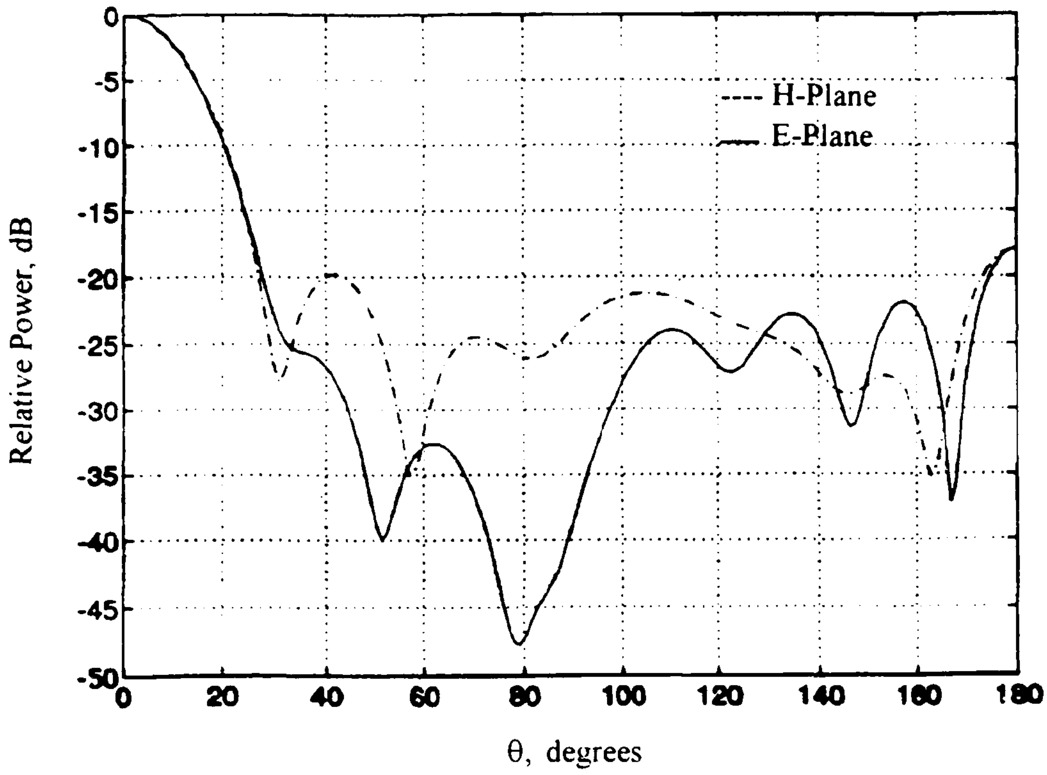


Figure 18. Radiation Pattern with Ring at Z = -0.1λ.

4. Adding a Parasitic Dipole

A parasitic dipole was added as a director in order to improve the directivity of the feed and therefore increase the reflector edge taper. This method is effective in narrowing the beamwidth of cavity-backed dipole antennas. In this case it was found that changing the size and position of the parasitic element has no significant effect on the performance of the antenna and does not offer any advantage. This is probably because the parasitic dipole is not located within a cavity. Adding a second ring around the parasitic dipole could improve the performance. In an effort to keep the feed as simple as possible, the parasitic element was not considered further.

5. Defocusing the Feed

The phase center of the feed varies with frequency and angle, but is generally located between the fed dipole and disk. The antenna bandwidth can be increased by slightly displacing the feed from the reflector focus. Defocusing can cause a degradation at one frequency but an improvement at the other. Relative to an optimum pattern, defocusing will result in a spoiled beam; that is, null filling and change in beam slope. An example is shown in Figure 19. Defocusing also affects pattern levels in the rear hemisphere.

C. OPTIMUM DESIGNS

1. Single Frequency (1850 MHz)

After making all the comparisons mentioned earlier, an optimum configuration was identified for the 36 inch parabolic reflector operating at 1850 MHz. The patterns are shown in Figure 20, and the configuration parameters shown in Table 5.

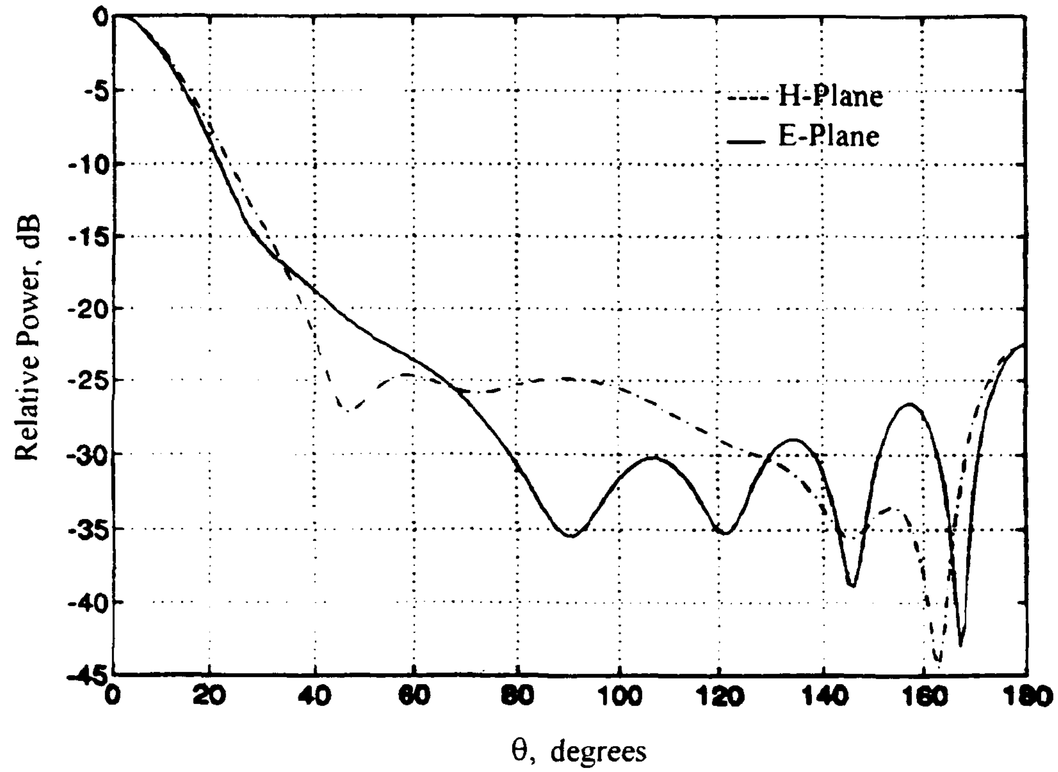


Figure 19. Radiation Pattern with Reflector Shifted 0.2λ in the Positive Direction To Defocus the Feed.

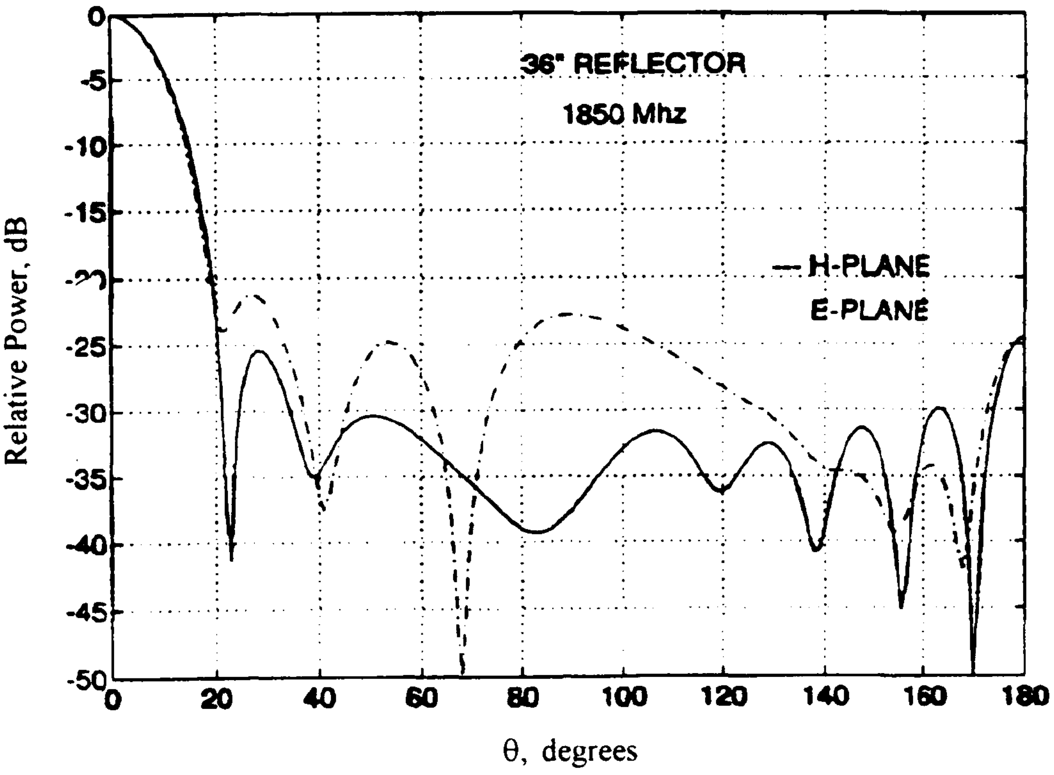


Figure 20. Radiation Pattern of Optimum Single Frequency Design for 36 inch Reflector (The Dimensions are given in Table 6).

TABLE 5. OPTIMUM GEOMETRY FOR 36 INCH REFLECTOR AT LOW FREQUENCY

DM	=	4.1	DNL	=	0.48
DS	=	0.5	PLN	=	0.4
ZC	=	0.3	DDIP	=	-0.25
FOD	=	0.4	ROT	=	0
RC	=	0.5	AW	=	0.001
ZR	=	0	ZSHIFT	=	0.2
SW	=	0.05			

This radiation pattern meets almost all the requirements listed in the Appendix A. The calculated total gain is G = 20.7775, which is sufficient, but the far out sidelobes are about 2 dB too high. Unfortunately this is a narrow band design and has poor performance at the lower frequency (1350 MHz) This design illustrates that achieving the specifications at a single frequency is relatively easy. However, broadbanding the antenna proves to be much more difficult.

2. Dual Frequency (1350 and 1850 MHz)

Starting from the configuration described in Table 4, attempts have been made to obtain a broadband design for the frequency range from 1350 to 1850 MHz. Figures 21 and 22 present the radiation patterns obtained for the 36 inch antenna which achieves most of the specifications given in the Appendix A. The gains are marginal at both frequencies and the beamwidth at the low frequency in too wide. Table 6 describes the configuration of this reflector.

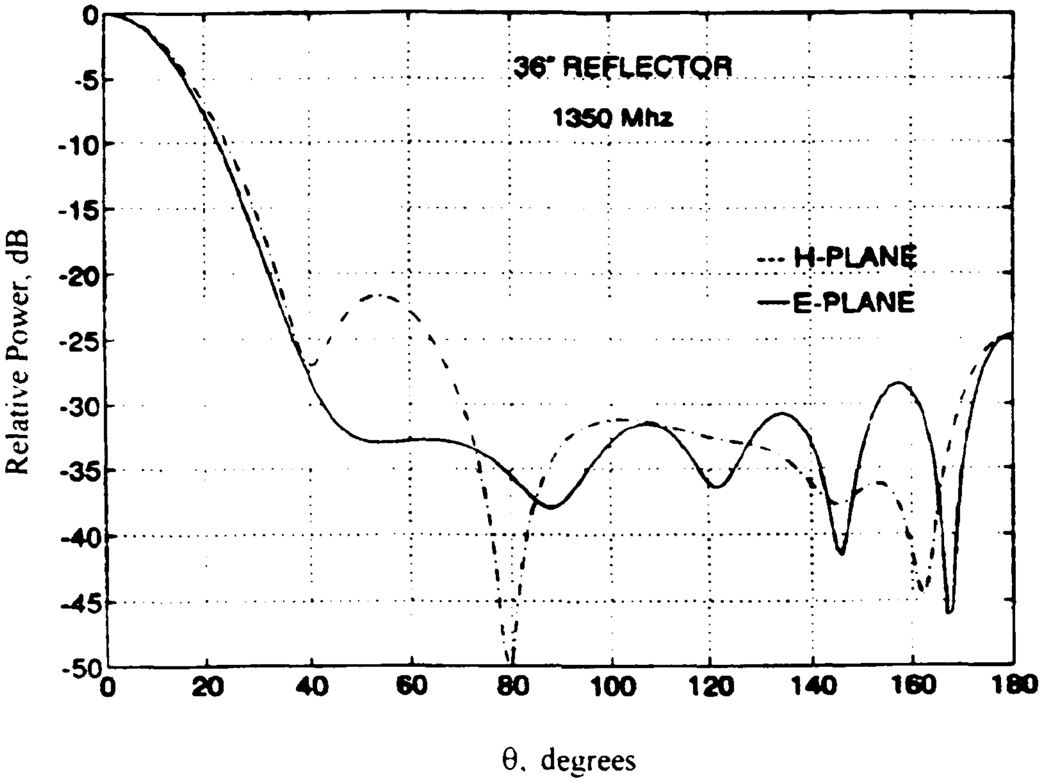


Figure 21. Radiation Pattern of 36 inch Reflector for Lower Frequency (1350 MHz). Dimensions are given in Table 6.

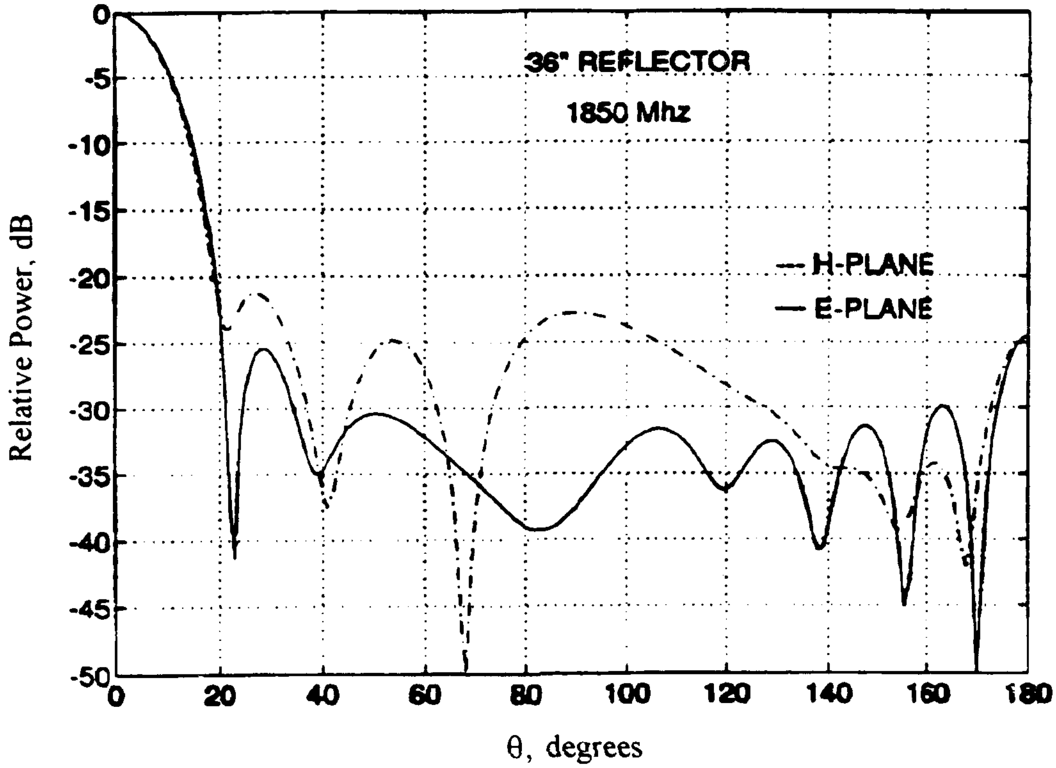


Figure 22. Radiation Pattern of 36 inch Reflector for Higher Frequency (1850 MHz).

TABLE 6. OPTIMUM GEOMETRY FOR 36 INCH REFLECTOR FOR THE LOW FREQUENCY

DM	=	4.1	DNL	=	0.5
DS	=	0.6	PLN	=	0.4
ZC	=	0.3	DDIP	=	-0.25
FOD	=	0.4	ROT	=	0
RC	=	0.6	AW	=	0
ZR	=	0.1	ZSHIFT	=	0.25
SW	=	0.05			

For the 48 inch antenna, Figures 23 and 24 show the radiation patterns for the optimum configuration whose dimensions are listed in Table 7.

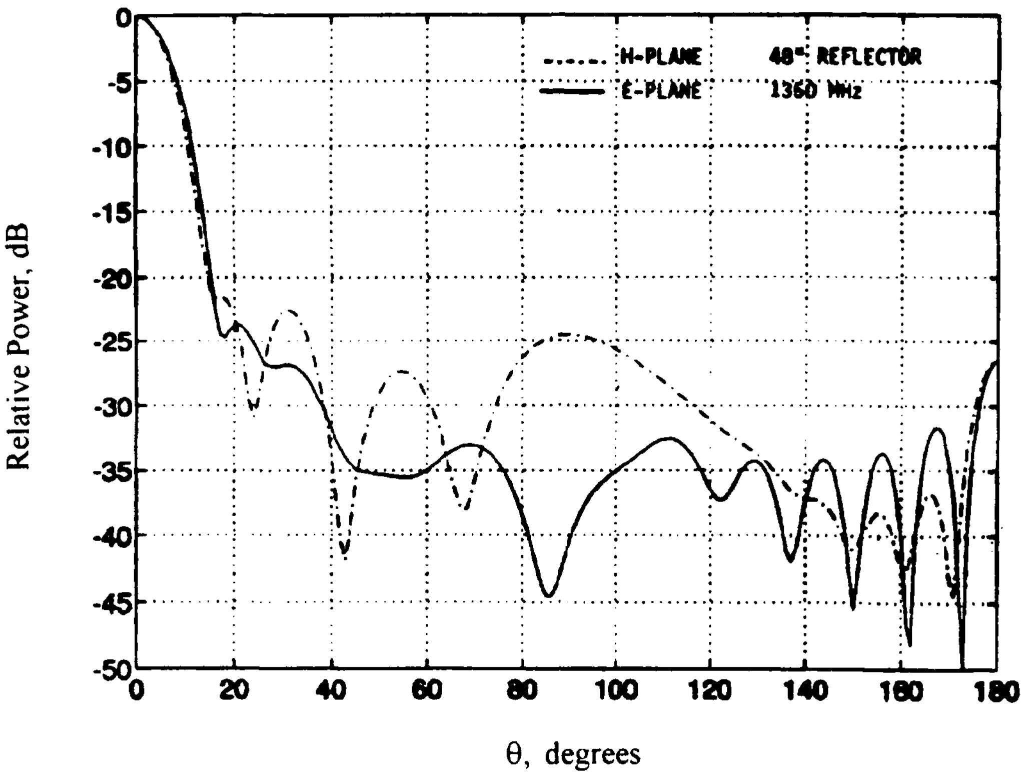


Figure 23. Radiation Pattern of 48 inch Reflector for Lower Frequency (1350 MHz).

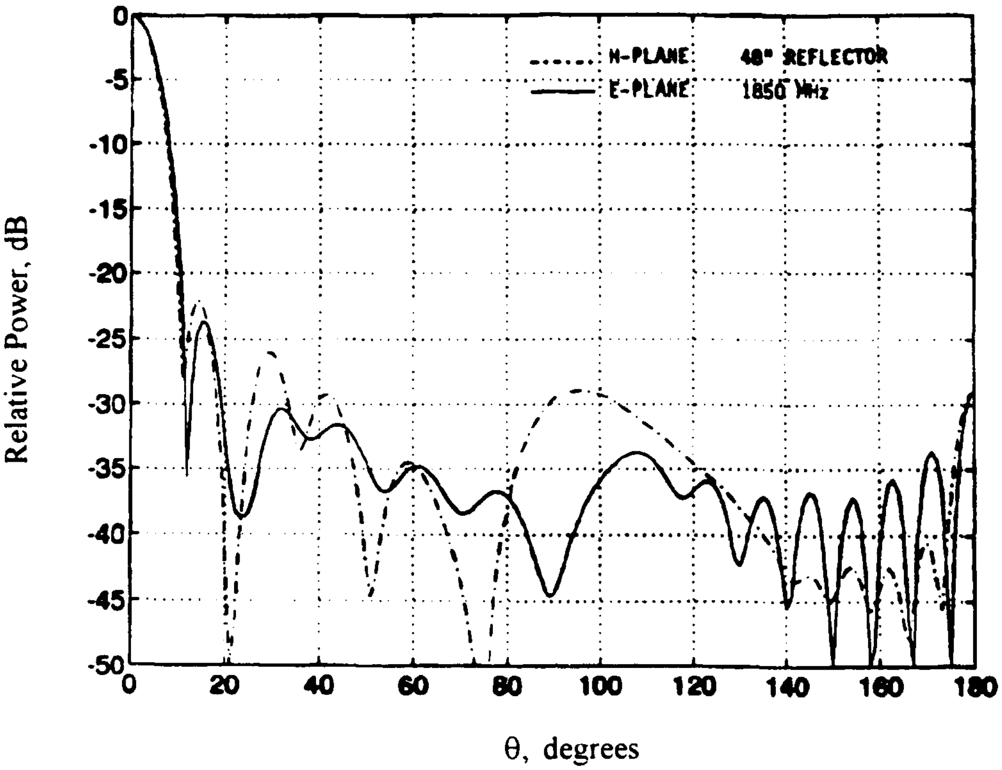


Figure 24. Radiation Pattern of 48 inch Reflector for Higher Frequency (1850 MHz).

TABLE 7. OPTIMUM GEOMETRY FOR 48 INCH REFLECTOR FOR HIGH FREQUENCY

DM	=	7.5	DNL	=	0.48
DS	=	0.8	PLN	=	0.4
ZC	=	0.3	DDIP	=	-0.25
FOD	=	0.4	ROT	=	0
RC	=	0.5	AW	=	0.001
ZR	=	0	ZSHIFT	=	0.2
SW	=	0.05			

It is worth noting that there is no feed configuration that can be used for both frequencies and simultaneously meet the specifications.

IV. CONCLUSIONS AND RECOMMENDATIONS

The objective of this thesis was to find the optimum combination of the feed and reflector geometry over the frequency band 1350 to 1850 MHz. The current antenna size is 36 x 48 inches. Since the computer code only accepts circular reflector apertures, two separate circular antennas were analyzed. One was 36 inches and the second was 48 inches. The proposed feed design, which consists of a fed dipole in the vicinity of a parasitic ring and disk, was a good approach to achieve a significant improvement compared with the original geometry of the Marine radio AN/MRC-142. Because of its simplicity, the cost of the new feed represents a minimum impact on the system upgrade.

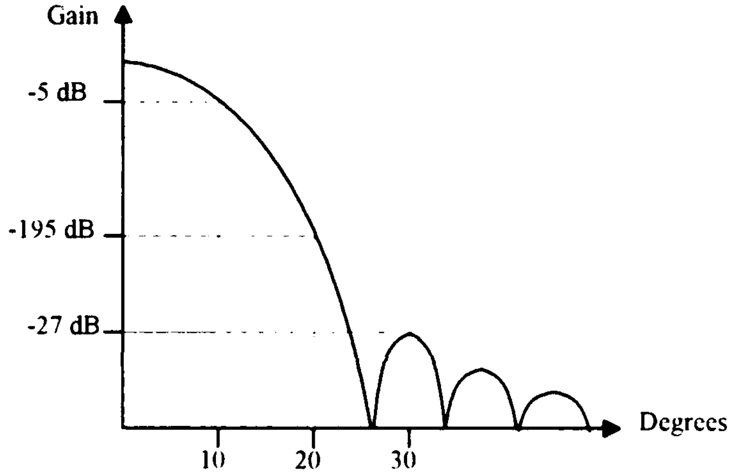
Calculations for both sizes were made separately and, as it is shown in Chapter III, the 36 inch reflector could not satisfy the requirements at both frequencies simultaneously, but it gave the best result for the high frequency (1850 MHz). The results obtained with the 48 inch reflector come very close to satisfying all the requirements, although the sidelobe level (SLL) is off by approximately 2 dB at wide angles in the H-plane.

An assumption with regard to the transmission line losses was made, which affect the total gain of the antenna. In the field calculations, solid surface reflection characteristics were assumed. In fact, the surface is a grid, and consequently the reflection coefficients for the θ and ϕ components of the electric field will vary with the angle of incidence. This effect will be small if the wire spacing is small compared to λ. Achieving the required gain was not a problem for the 48 inch design, and small adjustments in the antenna feed geometry did not have a significant negative impact on the antenna performance. It was also determined that if there was an improvement due to an additional parasitic dipole, the increase in complexity did not merit its use

To summarize, a low sidelobe reflector antenna has been designed which fulfilled most of the requirements for the Marine radio. The dipole disk feed with beam-forming ring is electrically and mechanically simple. It can be supported by means of a stiff coaxial cable aligned along the axis of the paraboloid, and held by a center support which offers minimum blockage when compared with the usual strut supports, as was stated by Kildal and Skyttemyer [Ref. 3].

APPENDIX A. ANTENNA SPECIFICATIONS

Over the frequency range of 1350-1850 MHz, the antenna must have gains as described in Figure A.



Azimuth Relative to Boresight (degrees)	Gain (dBi)
At 0	A - see note A
At ± 10	At least 5 dB lower than A
At ± 20	At least 19.5 dB lower than A
At ± 30 to 180	At least 27 dB lower than A

Shall satisfy the relationship $17.5 \leq A \leq 21$ dB

Figure A. Gain Requirements.

TABLE A. ANTENNA/MAST REFERENCE DATA

Antennna	Lightweight, open grid, reflector
Frequency Range	1350 to 1850 MHz
Gain	
Frequency	
1350 MHz	18 dBi minimum
1850 MHz	20 dBi minimum
Breamwidth	+7.5°
Horizontal	
7½ ± 1° from boresight	3 dB half power
15 ± 1° from boresight	15 dB down
Sidelobes	10 dB min
Antennna	
Vertical	
7½ ± 1°, -2° from boresight	3 dB half power
15 ± 1°, -2° from boresight	15 dB down
Sidelobes	10 dB min
Polarization	Horizontal or vertical polarization
Weigth	17.5 lbs
Maximum Input Power	15 W
Maximum Output Power	2320 W Effective Radiated Power (ERP)
Reflector Dimensions	45 in X 35 in. Depth: 16 in
Mast	Telescoping mast, consists of eleven carbon-fiber tubular sections
Height	Continously adjustable from 5 ft 8 in to 50 ft
Length (for storage and transit)	5 ft 8 in
Maximum Height (deployed)	50 ft
Headload	37 lbs maximum
Maximum Wind (50 ft. erection)	60 mph (without ice) 40 mph (with ½ in ice loading)
Weight	35 lbs
2-Man Deployment Time	15 minutes
Mast Accessories Time	Stowage of mast accessories
	Total accessory bag weight: 44 lbs

APPENDIX B. PROGRAM CODE*

```
Gain2f

C PROGRAM mrcint.f
C
C FAR FIELD PATTERN INTEGRATION FOR GAIN
CALCULATIONS.
C  *** general wire/bor geometries can be handled ***
C
C  >>>> INPUT FILE IS pcurrent - SPECIALIZED FOR
PROGRAM mrc.f
C  >>>> HAS A GAIN NORMALIZATION LOOP
INCORPORATED
C  >>>> WIRE DOES NOT HAVE TO LIE IN THE Z=0
PLANE
C
      DIMENSION
RH(1000),ZH(1000),AG(100),XG(100),XT(10),AT(10)
      DIMENSION
Q(30),S(30),nw1(2),nw2(2),pha(1000),xh(1000),yh(1000)
      COMPLEX
RS(1800),ETW,EPW,U,CNT(1500),ET1,EP1,ET2,EP2
      COMPLEX
CONJG,CMPLX,EXP1,EXP2,RW(2000),ET,EP,UC
      DATA pi/3.14159/
      data nt/2/,xt(1),at(1)/.5773503,1./
c     data
nt/4/,xt(1),xt(10),at(1),at(10)/.33998104,.8611363115,
c     * .6521451548,.3478548451/
      RAD=PI/180.
      BK=2.*PI
      U=(0.,1.)
      UC=-U/4./PI
      OPEN(1,FILE='outgaus')
      READ(1,*) NPHI
      NT2=NT/2
      DO 1 K=1,NT2
      K1=NT-K+1
      AT(K1)=AT(K)
      XT(K1)=XT(K)
    1 XT(K)=-XT(K)
      DO 3 K=1,NPHI
    3 READ(1,*) XG(K),AG(K)
      OPEN(3,file='pcurrent',STATUS='old')
       READ(3,*)
DM,AW,ZC,RC,DS,NP1,NP2,NBLOCK,NWIRES,FFAC
       READ(3,*)
NP,MT1,MP1,N,MT2,NSURF,NROW,MHI,MODES
       write(6,*) 'NP1,NP2,N,MODES,NROW,NWIRES,NP='

       write(6,*) NP1,NP2,N,MODES,NROW,NWIRES,NP

       READ(3,*) (xh(i),i=1,np)
       READ(3,*) (yh(i),i=1,np)
       READ(3,*) (zh(i),i=1,np)
       READ(3,*) (rh(i),i=1,np)
       READ(3,*) (pha(i),i=1,np)
       READ(3,*) (nw1(i),i=1,nwires)
       READ(3,*) (nw2(i),i=1,nwires)
       READ(3,*) (cnt(i),i=1,nrow)
      CLOSE(3)
      NS=NBLOCK*N
      OPEN(8,FILE='outint')
      WRITE(8,8000) NP1,NP2,NBLOCK
 8000 FORMAT(//,10X,'** WIRE/BOR ANTENNA GAIN
CALCULATION **',
     *//,10X,'NUMBER OF BOR POINTS (NP1)=',i4,/,10x,
     *'NUMBER OF DIPOLE POINTS (NP2)=',I4,/,10X,
     *'NUMBER OF MODE BLOCKS (2*M+1)=',I2)
      NDIVT=2
      NDIVP=2
      WRITE(6,*) 'ENTER NDIVT AND NDIVP'
      READ(5,*) NDIVT,NDIVP
      S1=0.
      S2=180.
      Q1=0.
      Q2=180.
      WRITE(6,*) 'THETA START AND STOP ANGLES
(DEGREES)'
      READ(5,*) S1,S2
      WRITE(6,*) 'THETA START AND STOP ANGLES
(DEGREES)'
      READ(5,*) Q1,Q2
C
C DEFINE STANDARD BOR INDICES
C
      MT1=NP1-2
      MP1=NP1-1
      MT2=NP2-2
C NWIRES=1 SINCE DUMMY SEGS WILL HAVE ZERO
CURRENT
      NWIRES=1
      NW1(1)=NP1+1
      NW2(1)=NP
C
C GAIN NORMALIZATION LOOP (USE THETA=PHI=0)
C
      ET1=(0.,0.)
      ET2=(0.,0.)
      ETW=(0.,0.)
      CALL
PLANEW(NWIRES,NW1,NW2,NP1,NP2,xh,yh,zh,0.,0.,RW)
      DO 610 L=1,MT2
610   ETW=ETW+RW(L)*CNT(L+NS)
      EXP1=(1.,0.)
      EXP2=CONJG(EXP1)
      DO 611 M=1,MHI
      NM=M-1
      CALL PLANES(NM,NP1,0,NT,RH,ZH,XT,AT,0.,RS)
      NTOP1=MODES-NM
      NTOP2=NBLOCK-(NTOP1+1)
      NS2=NTOP1*N
      NS1=NTOP2*N
      DO 612 L=1,MT1
      ET1=ET1+RS(L)*CNT(L+NS1)*EXP1
      IF(NM.EQ.0) GO TO 612
      ET1=ET1+RS(L)*CNT(L+NS2)*EXP2
```

---

* Although this is FORTRAN code, the column conventions are not observed for this listing so that space can be conserved.

```
612  CONTINUE
     DO 613 L=1,MP1
     ET2=ET2+RS(L+MT1)*CNT(L+NS1+MT1)*EXP1
     IF(NM.EQ.0) GO TO 613
     ET2=ET2-RS(L+MT1)*CNT(L+NS2+MT1)*EXP2
613  CONTINUE
611  CONTINUE
     ET=UC*(ET1+ET2+ETW)
     EMAX=CABS(ET)
     WRITE(6,*) 'EMAX=',EMAX
     WRITE(8,8008) NT,NPHI,NDIVP,NDIVT,S1,S2,Q1,Q2
 8008 FORMAT(//,10X,'NT=',I3,/,10x,'NPHI=',I4,/,10X,
    * 'NUMBER OF INTEGRATION INTERVALS IN
PHI=',i3,/,10x,
    * 'NUMBER OF INTEGRATION INTERVALS IN
THETA=',i3,/,10x,
    * 'THETA LIMITS: START,STOP=',F7.2,2X,F7.2,/,10X,
    * 'PHI LIMITS: START,STOP=',F7.2,2X,F7.2)
c
c theta integration intervals
c
     S1=S1*RAD
     S2=S2*RAD
     Q1=Q1*RAD
     Q2=Q2*RAD
     DS=(S2-S1)/FLOAT(NDIVT)
     DO 502 I=1,NDIVT+1
     S(I)=(I-1)*DS
     WRITE(6,*) "I,S(I)=",I,S(I)
  502 CONTINUE
c
c phi integration intervals
c
     DQ=(Q2-Q1)/FLOAT(NDIVP)
     DO 503 I=1,NDIVP+1
     Q(I)=(I-1)*DQ
     WRITE(6,*) "I,Q(I)=",I,Q(I)
  503 CONTINUE
     SUM=0.
     do 2000 JJ=1,NDIVP
     P1=DQ/2.
     P2=(Q(JJ+1)+Q(JJ))/2.
     DO 2000 J=1,NPHI
     PHR=p1*xg(j)+p2
     DO 1000 II=1,NDIVT
     T1=DS/2.
     T2=(S(II+1)+S(II))/2.
     DO 1000 I=1,NPHI
     THR=T1*XG(I)+T2
     IF(THR.LT.PI) GO TO 510
     THR=(BK-THR)
     PHR=PHR+PI
  510 CONTINUE
     STRA=SIN(THR)*AG(I)*ag(j)
     ET1=(0.,0.)
     EP1=(0.,0.)
     ET2=(0.,0.)
     EP2=(0.,0.)
     ETW=(0.,0.)
     EPW=(0.,0.)
C
C WIRE CONTRIBUTION TO THE RADIATED FIELD
C
     CALL
PLANEW(NWIRES,NW1,NW2,NP1,NP2,XH,YH,ZH,THR,P
HR,RW)
     DO 210 L=1,MT2
     ETW=ETW+RW(L)*CNT(L+NS)
  210 EPW=EPW+RW(L+MT2)*CNT(L+NS)
c
c BOR SURFACE CONTRIBUTION TO THE RADIATED
FIELD
c
     DO 300 M=1,MHI
     NM=M-1
     EXP1=CEXP(CMPLX(0.,FLOAT(NM)*PHR))
     EXP2=CONJG(EXP1)
     CALL PLANES(NM,NP1,0,NT,RH,ZH,XT,AT,THR,RS)
     NTOP1=MODES-NM
     NTOP2=NBLOCK-(NTOP1+1)
     NS2=NTOP1*N
     NS1=NTOP2*N
     DO 250 L=1,MT1
     ET1=ET1+RS(L)*CNT(L+NS1)*EXP1
     EP1=EP1+RS(L+N)*CNT(L+NS1)*EXP1
     IF(NM.EQ.0) GO TO 250
     ET1=ET1+RS(L)*CNT(L+NS2)*EXP2
     EP1=EP1-RS(L+N)*CNT(L+NS2)*EXP2
  250 CONTINUE
     DO 260 L=1,MP1
     ET2=ET2+RS(L+MT1)*CNT(L+NS1+MT1)*EXP1
     EP2=EP2+RS(L+MT1+N)*CNT(L+NS1+MT1)*EXP1
     IF(NM.EQ.0) GO TO 260
     ET2=ET2-RS(L+MT1)*CNT(L+NS2+MT1)*EXP2
     EP2=EP2+RS(L+MT1+N)*CNT(L+NS2+MT1)*EXP2
  260 CONTINUE
  300 CONTINUE
     ET=UC*(ET1+ET2+ETW)
     EP=UC*(EP1+EP2+EPW)
     SUM=SUM+(CABS(ET)**2+CABS(EP)**2)*STRA
 1000 CONTINUE
 2000 CONTINUE
     PRAD=T1*P1*SUM
     GAIN=4.*PI*EMAX**2/PRAD
     GDB=10.*alog10(GAIN)
     WRITE(8,8010) PRAD,EMAX,GAIN,GDB
 8010 FORMAT(//,10X,'TOTAL RADIATED
POWER=',E15.8,/,10X,
    * 'MAXIMUM FIELD VALUE (V/M)=',E15.8,/,10X,
    * 'GAIN=',E15.8,/,10x,'(dB)=',f8.2)
     WRITE(6,*) "PRAD,GAIN,dB=",PRAD,GAIN,GDB
 9999 STOP
     END
     SUBROUTINE
PLANES(M1,NP1,NP2,NT,RH,ZH,XT,AT,THR,R)
C
C PLANE WAVE EXCITATION VECTOR FOR BOR
ELEMENTS.
C NO CHANGE FROM HARRINGTON'S ORIGINAL
PROGRAM OTHER THAN
C ** ONLY ONE MODE PER CALL **
C
     COMPLEX
R(1800),U,U1,UA,UB,FA(50),FB(50),F2A,F2B,F1A,F1B
     COMPLEX U2,U3,U4,U5,CMPLX
     DIMENSION RH(1000),ZH(1000),XT(10),AT(10)
     DIMENSION R2(10),Z2(10),BJ(5000)
     U=(0.,1.)
```

```
   U1=3.141593*U**M1
   NF=1
   M2=M1
   NP=NP1+NP2
   MP=NP-1
   MT=MP-1
   N=MT+MP
   N2=2*N
   CC=COS(THR)
   SS=SIN(THR)
   M3=M1+1
   M4=M2+3
   IF(M1.EQ.0) M3=2
   M5=M1+2
   M6=M2+2
   DO 12 IP=1,MP
   K2=IP
   I=IP+1
   DR=.5*(RH(I)-RH(IP))
   DZ=.5*(ZH(I)-ZH(IP))
   D1=SQRT(DR*DR+DZ*DZ)
   R1=.25*(RH(I)+RH(IP))
   IF(ABS(R1).LT.1.E-5) R1=1.
   Z1=.5*(ZH(I)+ZH(IP))
   DR=.5*DR
   D2=DR/R1
   DO 13 L=1,NT
   R2(L)=R1+DR*XT(L)
   Z2(L)=Z1+DZ*XT(L)
13 CONTINUE
   D3=DR*CC
   D4=-DZ*SS
   D5=D1*CC
   DO 23 M=M3,M4
   FA(M)=0.
   FB(M)=0.
23 CONTINUE
   DO 15 L=1,NT
   X=SS*R2(L)
   IF(X.GT..5E-7) GO TO 19
   DO 20 M=M3,M4
   BJ(M)=0.
20 CONTINUE
   BJ(2)=1.
   S=1.
   GO TO 18
19 M=2.8*X+14.-2./X
   IF(X.LT..5) M=11.8+ALOG10(X)
   IF(M.LT.M4) M=M4
   BJ(M)=0.
   JM=M-1
   BJ(JM)=1.
   DO 16 J=4,M
   J2=JM
   JM=JM-1
   J1=JM-1
   BJ(JM)=J1/X*BJ(J2)-BJ(JM+2)
16 CONTINUE
   S=0.
   IF(M.LE.4) GO TO 24
   DO 17 J=4,M,2
   S=S+BJ(J)
17 CONTINUE
24 S=BJ(2)+2.*S
18 ARG=Z2(L)*CC
```

```
     UA=AT(L)/S*CMPLX(COS(ARG).SIN(ARG))
     UB=XT(L)*UA
     DO 25 M=M3,M4
     FA(M)=BJ(M)*UA+FA(M)
     FB(M)=BJ(M)*UB+FB(M)
  25 CONTINUE
  15 CONTINUE
     IF(M1.NE.0) GO TO 26
     FA(1)=- FA(3)
     FB(1)=- FB(3)
  26 UA=U1
     DO 27 M=M5,M6
     M7=M-1
     M8=M+1
     F2A=UA*(FA(M8)+FA(M7))
     F2B=UA*(FB(M8)+FB(M7))
     UB=U*UA
     F1A=UB*(FA(M8)-FA(M7))
     F1B=UB*(FB(M8)-FB(M7))
     U4=D4*UA
     U2=D3*F1A+U4*FA(M)
     U3=D3*F1B+U4*FB(M)
     U4=DR*F2A
     U5=DR*F2B
     K1=K2-1
     K4=K1+N
     K5=K2+N
     R(K2+MT)=-D5*(F2A+D2*F2B)
     R(K5+MT)=D1*(F1A+D2*F1B)
     IF(IP.EQ.1) GO TO 21
     R(K1)=R(K1)+U2-U3
     R(K4)=R(K4)+U4-U5
     IF(IP.EQ.MP) GO TO 22
  21 R(K2)=U2+U3
     R(K5)=U4+U5
  22 K2=K2+N2
     UA=UB
  27 CONTINUE
  12 CONTINUE
     RETURN
     END
     SUBROUTINE
PLANEW(NWIRES,NW1.NW2.NP1.NP2.XH.YH.ZH,
    * THR.PHR.R)
C
C  PLANE WAVE EXCITATION VECTOR ELEMENTS FOR
WIRE AND
C  ATTACHMENT SEGMENT. INCIDENCE DIRECTION IS
(THR.PHR).
C   - ONLY ONE INCIDENCE ANGLE PER CALL
C   - WIRE DOES NOT HAVE TO LIE IN THE Z=0 PLANE
C
     COMPLEX
U0,AA.BB,C,R(400).CEXP,EXP,FI1,FI2.SI,DI.CMPLX
     DIMENSION
ZH(400).NS(2),NW1(2).NW2(2),XH(400),YH(400)
     MP2=NP2-1
     MT2=NP2-2
     MT22=2*MT2
     DO 5 L=1,NWIRES
   5 NS(L)=NW2(L)-NW1(L)+1
     U0=(0.,0.)
     CC=COS(THR)
     SS=SIN(THR)
     CP=COS(PHR)
```

```
      SP=SIN(PHR)
      UP=SS*CP
      VP=SS*SP
      WP=CC
      DO 12 IP=1,MP2
      II=IP+NP1
      I=II+1
      ZS=.5*(ZH(I)+ZH(II))
      XS=.5*(XH(I)+XH(II))
      YS=.5*(YH(I)+YH(II))
      DX=XH(I)-XH(II)
      DY=YH(I)-YH(II)
      D1=SQRT(DX**2+DY**2)
      SU=DY/D1
      CU=DX/D1
C FOR WIRES IN PERPENDICULAR TO Z SIN(V)=1 AND
COS(V)=0
      SV=1.0
      CV=0.0
C
C WIRE SEGMENT CALCULATIONS
C
      A=UP*CU+VP*SU
      B=UP*XS+VP*YS+WP*ZS
      C=CMPLX(0.,A)
      EXP=CEXP(CMPLX(0.,B))
      AA=CC*(CU*CP+SU*SP)
      BB=SU*CP-SP*CU
      PSI=D1*A/2.
      IF(PSI.NE.0.) GO TO 60
      SINC=1.
      GO TO 61
   60 SINC=SIN(PSI)/PSI
   61 COSP=COS(PSI)
      FI1=SINC*D1*EXP/2.
      FI2=(0.,0.)
      IF(ABS(A).LT.1.E-4) GO TO 62
      CSP=COSP-SINC
      IF(ABS(CSP).LT.1.E-4) GO TO 62
      FI2=EXP/C*CSP
   62 CONTINUE
      SI=FI1+FI2
      DI=FI1-FI2
C
C R-WIRE-THETA
C
      IF(IP.EQ.MP2) GO TO 10
      R(IP)=AA*SI
      R(IP+MT2)=BB*SI
   10 CONTINUE
C
C R-WIRE-PHI
C
   14 IF(IP.EQ.1) GO TO 12
      R(IP-1)=R(IP-1)+AA*DI
      R(IP-1+MT2)=R(IP-1+MT2)+BB*DI
   12 CONTINUE
      RETURN
      END
```

Reflector

```
C  PROGRAM  mrc.f  (Marine Radio Antenna Program)
C
c  Modified from ORDONEZ.f -- hyperboloid becomes a disc
C  Paraboloie WITH A PARASITIC RING DIPOLE FEED
Fed dipole is at z=0.
C  This program uses a parasitic dipole and two h-plane
C  parasitic dipoles and the subreflector. This system also
contains
C  a cavity ring.
C
C   ICALC=0 CALC CURRENTS AND FIELD
C        =1 CALC FIELDS ONLY (READ CURRENTS)
C    IMP=0 PEREECTLY CONDUCTING SURFACES
C        =1 SOME NONZERO SURFACE RESISTANCE
C   ICWRT=0 WRITE CURRENT COEFFICIENCTS TO
FILE pcurrent
C    IRES=0 READ RESISTIVE CORRECTIONS
C
      COMPLEX
EP,ET,Z(500000),RS(1000),RW(400),E(700),C(700),U,UC
      COMPLEX ZL0(400),ZL(1500),EC,EX,ZSS(50000)
      COMPLEX EXP1,EXP2,ZSW(50000),ZWW(10000)
      COMPLEX
CEXP,CONJG,CMPLX,ET1,ET2,EP1,EP2,ETW,EPW
      DIMENSION
RH(400),ZH(400),XT(4),AT(4),IPS(700),NW1(4),NW2(4)
      DIMENSION
A(400),X(400),EXP(800),ANG(800),ECP(800)
      DIMENSION ECV(800),EXV(800),PHC(800),PHX(800)
      DIMENSION
XX(41),YY(41),XH(400),YH(400),PHA(400)
      DATA
PI,START,STOP,DT/3.14159,0.,180.,1./,ICWRT/0/,IRES 1
      DATA ICALC/0/,IPRINT/0/,IMP/0/,ITEST/1/
      DATA nt/2/,xt(1),at(1)/.5773503,1./
c     data nt/4/,xt(1),xt(2),at(1),at(2)/.33998104,.8611363115,
c     * .6521451548,.3478548451/
      OPEN(1,FILE='outgaus',status='old')
      OPEN(30,FILE='rh.m')
      OPEN(31,FILE='zh.m')
      READ(1,*) NPHI
      DO 3 K=1,NPHI
      READ(1,*) X(K),A(K)
    3 CONTINUE
      RAD=PI/180.
      BK=2.*PI
      U=(0.,1.)
      U0=(0.,0.)
      UC=-U/4./PI
      NT2=NT/2
      DO 1 K=1,NT2
      K1=NT-K+1
      AT(K1)=AT(K)
      XT(K1)=XT(K)
    1 XT(K)=-XT(K)
C
C NP10 = NUMBER OF PARABOLOID POINTS
C NP11 = NUMBER OF DISC POINTS
C NP12 = NUMBER OF RING POINTS
C
      MODES=1
      MHI=MODES+1
      NBLOCK=2*MODES+1
      NWIRES=1
      WRITE(6,*) 'ENTER START,STOP,DT'
      READ(5,*) START,STOP,DT
      NP10=61
      NP11=31
```

```
      NP12=3
      WRITE(6,*) 'ENTER PARA (NP10), DISC (NP11) AND
RING (NP12) PTS'
      READ(5,*) NP10,NP11,NP12
      NP1=NP10+NP11+NP12
C
C DM=MAIN REFLECTOR DIAMETER
C DS=DISC (SUBREFLECTOR) DIAMETER
C ZC=DISC LOCATION ALONG Z AXIS
C FOD=f/DM RATIO
C RC=RADIUS OF THE RING
C SW=RING (STRIP) WIDTH
C
      DM=5.0
      R0=DM/2.
      DS=1.1
      ZC=.25
      FOD=.3
      RC=0.5
      SW=.05
      WRITE(6,*) 'ENTER DM, DS, ZC (>0), FOD, RC, ZR
AND SW'
      READ(5,*) DM,DS,ZC,FOD,RC,ZR,SW
      FM=FOD*DM
      WRITE(6,*) 'ENTER ZSHIFT FOR PARABOLOID'
      READ(5,*) ZSHIFT
C
C GENERATE PARABOLOID CONTOUR
C
      PHIV=2.*ATAN(1./4./FOD)
      FNM=FLOAT(NP10-1)
      DO 50 I=1,NP10
      TH=FLOAT(I-1)*PHIV/FNM
      RM=2.*FM/(1.+COS(TH))
      XH(I)=0.
      YH(I)=0.
      ZH(I)=-RM*COS(TH)*BK+ZSHIFT*BK
      RH(I)=RM*SIN(TH)*BK
      PHA(II)=0.
   50 CONTINUE
C
C DISC LOCATED A Z=ZC
C
      DSK=DS/2./FLOAT(NP11-1)
      DO 5 I=1,NP11
      II=I+NP10
      XH(II)=0.
      YH(II)=0.
      ZH(II)=ZC*BK
      RH(II)=FLOAT(I-1)*DSK*BK
      PHA(II)=0.
5     CONTINUE
C
C NEXT THE SIDEWALLS
C
      DSW=SW/FLOAT(NP12-1)
      ZRBK=ZR*BK
      IF(NP12.NE.0) THEN
      DO 7 I=1,NP12
      II=NP11+NP10+I
      XH(II)=0.
      YH(II)=0.
      RH(II)=RC*BK
      ZH(II)=FLOAT(I-1)*DSW*BK+ZRBK
7     PHA(II)=0.
```

```
      ENDIF
      NP1=NP10+NP11+NP12
C
C DIPOLE ANTENNA POINTS IN WAVELENGTHS: AW=
RADIUS; NP2= NUMBER
C OF POINTS (=NP21+NP22; NP21 MUST BE ODD);
DLGTH= LENGTH;
C PLGTH IS PARASITIC ELEMENT LENGTH.
C
      AW=.001
      DLGTH=.45
      PLGTH=.44
      WRITE(6,*) 'ENTER DLN, PLN, DDIP, ROT AND AW'
      WRITE(6,*) '(DDIP<0 IS TOWARD PARABOLOID)'
      READ(5,*) DLGTH,PLGTH,DDIP,ROT,AW
      CENT=DLGTH/2.
      AK=AW*BK
      NP21=11
      NP22=0
      WRITE(6,*) 'ENTER NP21 AND NP22 (ONLY 1 DIP IF
NP22=0)'
      READ(5,*) NP21,NP22
      NW1(1)=NP1+1
      NW2(1)=NP1+NP21
      NP2=NP21+NP22
      DEL=DLGTH/FLOAT(NP21-1)
      DO 10 I=1,NP21
      II=NP1+I
      YH(II)=0.
      ZH(II)=0.
      XH(II)=BK*(FLOAT(I-1)*DEL-CENT)
      RH(II)=SQRT(XH(II)**2+YH(II)**2)
      PHA(II)=ATAN2(YH(II),XH(II)+1.E-6)
10    CONTINUE
      IF(NP22.NE.0) THEN
      NWIRES=2
      NW1(2)=NP1+NP21+1
      NW2(2)=NP1+NP21+NP22
      DEL=PLGTH/FLOAT(NP22-1)
      CENT=PLGTH/2.
      DO 11 I=1,NP22
      II=NP1+NP21+I
      ZH(II)=DDIP*BK
      XH(II)=BK*(FLOAT(I-1)*DEL-CENT)*COS(ROT*RAD)
      YH(II)=BK*(FLOAT(I-1)*DEL-CENT)*SIN(ROT*RAD)
      RH(II)=SQRT(XH(II)**2+YH(II)**2)
      PHA(II)=ATAN2(YH(II),XH(II)+1.E-6)
11    CONTINUE
      ENDIF
C NP23=NUMBER OF H-PLANE DIPOLE POINTS
C HLGTH=H-PLANE DIPOLE LENGTH
C DHP=H-PLANE DIPOLE DISTANCE FROM FEED
C ZHP=H-PLANE DIPOLE Z COORDINATE
C NP24=NUMBER OF POINTS FOR THE OTHER
H-PLANE DIPOLE
      NP23=7
      NP24=7
      HLGTH=.2
      DHP=.2
      ZHP=.001
      WRITE(6,*) 'ENTER NUMBER OF POINTS PER
H-PLANE DIPOLE'
      WRITE(6,*) '(0 FOR NO H-PLANE PARASITIC
DIPOLES)'
      READ(5,*) NP23
```

```
      IF(NP23.NE.0) THEN
      WRITE(6.*) 'H-PLANE DIPOLE LENGTH. DISTANCE
AND LOCATION'
      READ(5.*) HLGTH DHP,ZHP
      NWIRES=NWIRES+2
      NP24=NP23
      NP2=NP21+NP22+NP23+NP24
      NW1(3)=NP1+NP21+NP22+1
      NW2(3)=NP1+NP21+NP22+NP23
      NW1(4)=NP1+NP21+NP22+NP23+1
      NW2(4)=NP1+NP21+NP22+NP23+NP24
      DEL=HLGTH/FLOAT(NP23-1)
      CENT=HLGTH/2.
      DO 12 I=1,NP23
      I1=NP1+NP21+NP22+I
      ZH(I1)=ZHP*BK
      YH(I1)=DHP*BK
      XH(I1)=BK*(FLOAT(I-1)*DEL-CENT)
      RH(I1)=SQRT(XH(I1)**2+YH(I1)**2)
      PHA(I1)=ATAN2(YH(I1),XH(I1)+1.E-6)
      I2=I1+NP23
      ZH(I2)=ZHP*BK
      YH(I2)=-DHP*BK
      XH(I2)=BK*(FLOAT(I-1)*DEL-CENT)
      RH(I2)=SQRT(XH(I2)**2+YH(I2)**2)
      PHA(I2)=ATAN2(YH(I2),XH(I2)+1.E-6)
12   CONTINUE
      ENDIF
      CLOSE(1)
      NP=NP1+NP2
      WRITE(6.*) 'ENTER FREQUENCY FACTOR'
      READ(5.*) FFAC
      OPEN(8,file='outmrc')
      WRITE(8,8000)
DM,DS,FOD,PHIV/RAD,NP10,NP11,RC,SW,
     *
NP12,ZSHIFT,DLGTH,PLGTH,DDIP,NP2,AW,MODES,NT,
NPHI,FFAC
      IF(NP23.NE.0) WRITE(8,8001) HLGTH,DHP,ZHP,NP23
 8000 FORMAT(//,5X,'*** MARINE RADIO REFLECTOR
ANTENNA ***',//,5X,
     *'REFLECTOR PARAMETERS (LENGTHS IN
WAVELENGTHS):',/,5X,
     *'MAIN REFL DIA=',F8.3,/,5X,'DISC
DIA=',F8.3,/,5X,'F/D=',F8.4,
     * /,5X,'PHIV (DEG)=',F8.2,/,5X,'MAIN REFL POINTS
(NP11)=',I4,/,
     * 5X,'SUB REFL POINTS (NP12)=',I4,/,5X,/,5X,
     * 'RING RADIUS=',F8.3,/,5X,'SIDEWALL
LENGTH=',F8.3,/,5X,
     * 'NUMBER OF RING POINTS (NP12)=',I4,//,5X,
     * 'PARABOLOID SHIFT DISTANCE,
ZSHIFT=',F8.3,/,5X,
     * 'DIPOLE PARAMETERS:',/,5X,'FED DIPOLE
LENGTH=',F8.3,/,5X,
     * 'PARASITIC DIPOLE
LENGTH=',F8.3,/,5X,'SPACING=',F8.3,/,5X,
     * 'NUMBER OF DIPOLE POINTS =',I4,/,5X,'RADIUS OF
DIPOLE=',
     * F8.4,//,5X,'NUMBER OF AZIMUTHAL
MODES=',I3,/,5X,'NT=',I3,
     * /,5X,'NPHI=',I3,/,5X,'FREQ. SCALE FACTOR=',F8.4)
 8001 FORMAT(/,5X,'H-PLANE DIPOLE
LENGTH=',F8.3,/,5X,
     * 'H-PLANE DIPOLE DISTANCE FROM
AXIS=',F8.3,/,5X,
     * 'Z POSITION OF H-FIELD
DIPOLE=',F8.3,/,5X,'NUMBER OF H-FIELD
     * DIPOLE POINTS=',I3)
      IF(ISEG.EQ.0) WRITE(8,1300)
 1300
FORMAT(/,5X,'INDEX',8X,'Z(I)',10X,'RHO(I)',8x,'ZSURF')
C
C FILE difdat CONTAINS RESISTIVE CORRECTIONS IF
IRES.NE.0
C
      IF((IMP.EQ.0).OR.(IRES.NE.0)) GO TO 70
      OPEN(9,FILE='difdat')
      READ(9,*) ID
      WRITE(6,*) 'ID=',ID
      DO 75 I=1,ID
      READ(9,*) II,RI,YY(I),DUM
      IF(YY(I).LT.0.) YY(I)=0.
75   CONTINUE
      XXI=1./FLOAT(ID-1)
      DO 15 II=1,ID
      XX(II)=XXI*FLOAT(II-1)
15   CONTINUE
      WRITE(6,*) 'SURFACE IMPEDANCE VALUES READ'
70   CONTINUE
      DO 52 I=1,NP1
      IF(ABS(ZH(I)).LT..001) ZH(I)=0.
      IF(ABS(RH(I)).LT..001) RH(I)=0.
      ZL0(I)=(0.,0.)
      XH(I)=XH(I)*FFAC
      YH(I)=YH(I)*FFAC
      ZH(I)=ZH(I)*FFAC
      RH(I)=RH(I)*FFAC
      ZHB=ZH(I)/BK
      RHB=RH(I)/BK
      WRITE(30.5019) RHB
      WRITE(31,5019) ZHB
c     if(rhb.ge.10.) zl0(i)=(.2,0.)
C
C NONZERO SURFACE IMPEDANCES IF IMP > 0
C
      IF((IMP.EQ.0).OR.(IRES.NE.0)) GO TO 51
      IF(I.GT.NP10) GO TO 51
C
C USE THE EXACT RESISTIVE CORRECTIONS --
INTERPOLATE BETWEEN
C DATA POINTS.
C
      UU=RHB/R0
      CALL INTERP(UU,VV,XX,YY,ID)
      ZL0(I)=VV
   51 CONTINUE
      WRITE(8,8004) I,ZHB,RHB,ZL0(I)
   52 CONTINUE
 8004 FORMAT(6X,I4,4X,F8.3,8X,F8.3,6X,2F8.4)
      WRITE(8,1310)
 1310 FORMAT(/,5X,'DIPOLE COORDINATES:',//,
     * 5X,'INDEX',8X,'Z(I)',10X,'RHO(I)',10X,'PHI PLN')
      DO 53 I=NP1+1,NP
      IF(ABS(ZH(I)).LT..001) ZH(I)=0.
      IF(ABS(RH(I)).LT..001) RH(I)=0.
      XH(I)=XH(I)*FFAC
      YH(I)=YH(I)*FFAC
      ZH(I)=ZH(I)*FFAC
```

```
    RH(I)=RH(I)*FFAC
    PHB=PHA(I)/RAD
    ZHB=ZH(I)/BK
    RHB=RH(I)/BK
    WRITE(30,5019) RHB
    WRITE(31,5019) ZHB
  53 WRITE(8,8005) I,ZHB,RHB,PHB
 8005 FORMAT(6X,I4,4X,F8.3,8X,F8.3,9X,F8.2)
  799 CONTINUE
    IF(ITEST.EQ.0) GO TO 9998
    write(6,*) 'geometry defined'
C
C DEFINE DIMENSIONS OF THE IMPEDANCE MATRIX
BLOCKS
C
    MT1=NP1-2
    MP1=NP1-1
    N=MP1+MT1
    MT2=NP2-2
    NSURF=NBLOCK*N
    NSW=NSURF+MT2
    NROW=NSW
    WRITE(6,*)
'NP1,NP2,NSURF,NROW=',NP1,NP2,NSURF,NROW
    WRITE(6,*) 'MT2 SHOULD BE ODD -- MT2=',MT2
    IF(ITEST.EQ.0) GO TO 9998
    IF(ICALC.EQ.0) THEN
C
C COMPUTE IMPEDANCE MATRIX ELEMENTS
C
    CALL
ZMATWW(NWIRES,NW1,NW2,XH,YH,RH,ZH,NT,XT,AT,A
K,ZWW)
    CALL ZASMB0(NP1,NP2,MODES,Z,ZWW)
    write(6,*) 'wire impedance computed'
    IF(IMP.NE.0) THEN
    CALL ZLOAD(NP1,RH,ZH,ZL0,ZL)
    WRITE(6,*) 'RESISTIVE SURFACE IMPEDANCE
MATRIX COMPUTED'
    ENDIF
    DO 400 M=1,MHI
    NM=M-1
    CALL
ZMATSS(NM,NM,NP10,NP11,NP12,NPHI,NT,RH,ZH,X,A,X
T,AT,ZSS)
    IF(IMP.NE.0) CALL ZTOT(MT1,MP1,ZL,ZSS)
    CALL
ZMATSW(NWIRES,NW1,NW2,NP10,NP11,NP12,XH,YH,R
H,ZH,
   * NT,XT,AT,NPHI,X,A,NM,AK,ZSW)
    CALL ZASMBN(NP1,NP2,MODES,NM,Z,ZSS,ZSW)
    IF(NM.EQ.0) GO TO 400
    NMN=-NM
    CALL
ZMATSW(NWIRES,NW1,NW2,NP10,NP11,NP12,XH,YH,R
H,ZH,
   * NT,XT,AT,NPHI,X,A,NMN,AK,ZSW)
    CALL ZASMBN(NP1,NP2,MODES,NMN,Z,ZSS,ZSW)
  400 CONTINUE
    write(6,*) 'z filled'
    CALL DECOMP(NROW,IPS,Z)
    write(6,*) 'z decomposed'
C
C EXCITATION ELEMENTS (NONZERO FOR THE
DIPOLE ONLY)
C
    DO 40 I=1,NROW
  40 B(I)=(0.,0.)
    I0=NSURF+(NP21-1)/2
    B(I0)=(1.,0.)
    CALL SOLVE(NROW,IPS,Z,B,C)
    write(6,*) 'current coefficients computed'
c    do 665 ii=1,nrow
c665  write(6,*) ii,c(ii)
    IF((ICWRT.EQ.0).AND.(ICALC.EQ.0)) THEN
C
C WRITE CURRENTS ON DISC FOR PATTERN
INTEGRATION
c (program 'cavarchint.f')
C
     OPEN(3,file='pcurrent')
     WRITE(3,*)
DM,AW,ZC,RC,DS,NP1,NP2,NBLOCK,NWIRES,FFAC
     WRITE(3,*)
NP,MT1,MP1,N,MT2,NSURF,NROW,MHI,MODES
     WRITE(3,*) (XH(I),I=1,NP)
     WRITE(3,*) (YH(I),I=1,NP)
     WRITE(3,*) (ZH(I),I=1,NP)
     WRITE(3,*) (RH(I),I=1,NP)
     WRITE(3,*) (PHA(I),I=1,NP)
     WRITE(3,*) (NW1(I),I=1,NWIRES)
     WRITE(3,*) (NW2(I),I=1,NWIRES)
     WRITE(3,*) (C(I),I=1,NROW)
    ENDIF
    ENDIF
C
C IF ICALC.NE.0 THEN READ CURRENT COEFFICIENTS
FROM DISK FILE
C
    IF(ICALC.NE.0) THEN
    OPEN(3,file='pcurrent',STATUS='OLD')
     READ(3,*)
DMX,AWX,ZCX,RCX,DSX,NP1X,NP2X,NBLX,NWX
     READ(3,*)
NPX,MT1X,MP1X,NX,MT2X,NSX,NRX,MHIX,MODESX
     READ(3,*) (xh(i),i=1,np)
     READ(3,*) (yh(i),i=1,np)
     READ(3,*) (zh(i),i=1,np)
     READ(3,*) (rh(i),i=1,np)
     READ(3,*) (pha(i),i=1,np)
     READ(3,*) (nw1(i),i=1,nwires)
     READ(3,*) (nw2(i),i=1,nwires)
     READ(3,*) (c(i),i=1,nrow)
    CLOSE(3)
    write(6,*) 'data read from pcurrent'
    do 909 i=1,np
909   write(6,*) 'i,rh,zh=',i,rh(i)/bk,zh(i)/bk
    ENDIF
    IT=INT((STOP-START)/DT)+1
C
C RECEIVER PHI CUTS: DO 0 AND 90 (E- AND H-
PLANES)
C
    DO 501 IP=1,2
    ECX=1.e-10
    PHR0=0.
    IF(IP.EQ.2) PHR0=RAD*90.
    DO 500 I=1,IT
    THETA=FLOAT(I-1)*DT+START
    THR=THETA*RAD
```

```
      PHR=PHR0
      IF(THETA.LE.180.) GO TO 99
      THR=(360.-THETA)*RAD
      PHR=PHR0+PI
   99 CONTINUE
c      write(6,*) 'theta,phi=',theta,phr/rad
      ET1=U0
      ET2=U0
      EP1=U0
      EP2=U0
      ETW=U0
      EPW=U0
C
C DIPOLE FIELD
C
      CALL
PLANEW(NWIRES,NW1,NW2,NP1,NP2,XH,YH,ZH,THR,P
HR,RW)
      DO 210 L=1,MT2
      ETW=ETW+RW(L)*C(L+NSURF)
  210 EPW=EPW+RW(L+MT2)*C(L+NSURF)
C
C REFLECTOR AND CAVITY FIELD CONTRIBUTIONS
C
      DO 300 M=1,MHI
      NM=M-1
      EXP1=CEXP(CMPLX(0.,FLOAT(NM)*PHR))
      EXP2=CONJG(EXP1)
      CALL
PLANES(NM,NP10,NP11,NP12,NT,RH,ZH,XT,AT,THR,RS)
      NTOP1=MODES-NM
      NTOP2=NBLOCK-(NTOP1+1)
      NS2=NTOP1*N
      NS1=NTOP2*N
      DO 250 L=1,MT1
      ET1=ET1+RS(L)*C(L+NS1)*EXP1
      EP1=EP1+RS(L+N)*C(L+NS1)*EXP1
      IF(NM.EQ.0) GO TO 250
      ET1=ET1+RS(L)*C(L+NS2)*EXP2
      EP1=EP1-RS(L+N)*C(L+NS2)*EXP2
  250 CONTINUE
      DO 260 L=1,MP1
      ET2=ET2+RS(L+MT1)*C(L+NS1+MT1)*EXP1
      EP2=EP2+RS(L+MT1+N)*C(L+NS1+MT1)*EXP1
      IF(NM.EQ.0) GO TO 260
      ET2=ET2-RS(L+MT1)*C(L+NS2+MT1)*EXP2
      EP2=EP2+RS(L+MT1+N)*C(L+NS2+MT1)*EXP2
  260 CONTINUE
  300 CONTINUE
      ET=UC*(ET1+ET2+ETW)
      EP=UC*(EP1+EP2+EPW)
      EC=ET
      EX=EP
      ECV(I)=CABS(EC)
      EXV(I)=CABS(EX)
      ECR=REAL(EC)
      ECI=AIMAG(EC)
      EXR=REAL(EX)
      EXI=AIMAG(EX)
      PHC(I)=ATAN2(ECI,ECR+1.e-10)/RAD
      PHX(I)=ATAN2(EXI,EXR+1.e-10)/RAD
      ANG(I)=THETA
      ECX=AMAX1(ECX,ECV(I),EXV(I))
  500 CONTINUE
      WRITE(8,103) PHR/RAD,ECX
```

```
  103 FORMAT(/,5X, 'PHI OF RECEIVER
(DEG)=',F8.2,/,5X,
     * 'MAXIMUM FIELD VALUE (V/M)=',E15.5)
      DO 600 I=1,IT
      ECP(I)=(ECV(I)/ECX)**2
      EXP(I)=(EXV(I)/ECX)**2
      ECP(I)=AMAX1(ECP(I),.00001)
      EXP(I)=AMAX1(EXP(I),.00001)
      ECP(I)=10.*ALOG10(ECP(I))
      EXP(I)=10.*ALOG10(EXP(I))
  600 CONTINUE
      IF(IPRINT.NE.0) GO TO 310
      WRITE(8,5015)
 5015
FORMAT(///,7X,'ANGLE',15X,'CO-POL',25X,'X-POL',/,7X,
     *'(DEG)',4X,2('(VOLTS)',4X,'(DEG)',3X,'(DB-REL)',4X))
      DO 9000 L=1,IT
      WRITE(8,5016)
ANG(L),ECV(L),PHC(L),ECP(L),EXV(L),PHX(L)
     *,EXP(L)
 5016 FORMAT(5X,F6.1,3X,2(F8.4,3X,F7.1,3X,F7.2,3X))
 9000 CONTINUE
  310 CONTINUE
C
C WRITE MATLAB FILES ( .m FILES)
C
      IF(IP.EQ.1) THEN
      OPEN(2,file='ang.m')
      OPEN(3,file='cpole.m')
      OPEN(4,file='xpole.m')
      DO 9097 I=1,IT
      WRITE(2,5019) ANG(I)
      WRITE(3,5019) ECP(I)
 9097 WRITE(4,5019) EXP(I)
      CLOSE(2)
      CLOSE(3)
      CLOSE(4)
      ENDIF
      IF(IP.EQ.2) THEN
      OPEN(3,file='cpolh.m')
      OPEN(4,file='xpolh.m')
      DO 9098 I=1,IT
      WRITE(3,5019) ECP(I)
 9098 WRITE(4,5019) EXP(I)
      CLOSE(3)
      CLOSE(4)
      ENDIF
501   CONTINUE
5019  FORMAT(F8.3)
9998  STOP
      END
      SUBROUTINE SOLVE(N,IPS,UL,B,X)
      COMPLEX UL(500000),B(700),X(700),SUM
      DIMENSION IPS(700)
      NP1=N+1
      IP=IPS(1)
      X(1)=B(IP)
      DO 2 I=2,N
      IP=IPS(I)
      IPB=IP
      IM1=I-1
      SUM=(0.,0.)
      DO 1 J=1,IM1
      SUM=SUM+UL(IP)*X(J)
    1 IP=IP+N
```

```
 2 X(I)=B(IPB)-SUM
   K2=N*(N-1)
   IP=IPS(N)+K2
   X(N)=X(N)/UL(IP)
   DO 4 IBACK=2,N
   I=NP1-IBACK
   K2=K2-N
   IPI=IPS(I)+K2
   IP1=I+1
   SUM=(0.,0.)
   IP=IPI
   DO 3 J=IP1,N
   IP=IP+N
 3 SUM=SUM+UL(IP)*X(J)
 4 X(I)=(X(I)-SUM)/UL(IPI)
   RETURN
   END
   SUBROUTINE DECOMP(N,IPS,UL)
   COMPLEX UL(500000),PIVOT,EM
   DIMENSION SCL(700),IPS(700)
   DO 5 I=1,N
   IPS(I)=I
   RN=0.
   J1=I
   DO 2 J=1,N
   ULM=ABS(REAL(UL(J1)))+ABS(AIMAG(UL(J1)))
   J1=J1+N
   IF(RN-ULM) 1,2,2
 1 RN=ULM
 2 CONTINUE
   SCL(I)=1./RN
 5 CONTINUE
   NM1=N-1
   K2=0
   DO 17 K=1,NM1
   BIG=0.
   DO 11 I=K,N
   IP=IPS(I)
   IPK=IP+K2

SIZE=(ABS(REAL(UL(IPK)))+ABS(AIMAG(UL(IPK))))*SCL(
IP)
   IF(SIZE-BIG) 11,11,10
 10 BIG=SIZE
   IPV=I
 11 CONTINUE
   IF(IPV-K) 14,15,14
 14 J=IPS(K)
   IPS(K)=IPS(IPV)
   IPS(IPV)=J
 15 KPP=IPS(K)+K2
   PIVOT=UL(KPP)
   KP1=K+1
   DO 16 I=KP1,N
   KP=KPP
   IP=IPS(I)+K2
   EM=-UL(IP)/PIVOT
 18 UL(IP)=-EM
   DO 16 J=KP1,N
   IP=IP+N
   KP=KP+N
   UL(IP)=UL(IP)+EM*UL(KP)
 16 CONTINUE
   K2=K2+N
 17 CONTINUE
```

```
    RETURN
    END
    FUNCTION BLOG(X)
    IF(X.GT..1) GO TO 1
    X2=X*X
    BLOG=((.075*X2-.1666667)*X2+1.)*X
    RETURN
  1 BLOG=ALOG(X+SQRT(1.+X*X))
    RETURN
    END
    SUBROUTINE ZLOAD(NP,RH,ZH,Z0,Z)
C
C COMPUTES IMPEDANCE MATRIX ELEMENTS FOR
LOADED BODIES OF REV
C Z0(I) IS THE SURF IMPEDANCE OF THE ITH
SEGMENT (NP-1 SEGMENTS)
C Z(.) ARE THE IMPEDANCE MATRIX TERMS
(TRIDIAGONAL FOR T-T
C SUBMATRIX; DIAGONAL FOR P-P SUBMATRIX).
STORED IN COL VECTOR.
C
    COMPLEX
C1,C2,Z0(400),Z(1500),X1,X2,X3,Y1,Y2,Y3,FN(400)
    COMPLEX U1,U2,U3,XI,YI
    DIMENSION RH(400),ZH(400),RS(400),D(400),SV(400)
    PI=3.14159
    MT=NP-2
    MP=NP-1
    N=MT+MP
    DO 10 IP=2,NP
    II=IP-1
    DR=RH(IP)-RH(II)
    DZ=ZH(IP)-ZH(II)
    D(II)=SQRT(DR*DR+DZ*DZ)
    SV(II)=DR/D(II)
    RS(II)=.5*(RH(IP)+RH(II))
    DS=D(II)*SV(II)/2.
    Q1=RS(II)+DS
    Q2=RS(II)-DS
    FN(II)=1.
    IF((ABS(Q2).GT.1.E-6).AND.(ABS(Q1).GT.1.E-6))
   * FN(II)=ALOG(Q1/Q2)
 10 CONTINUE
    L0=MT*3-2
    DO 20 I=1,MP
    C1=PI*Z0(I)
    IF(I.EQ.MP) GO TO 80
    KI=2
    IF(I.EQ.1) KI=1
    IF(I.EQ.MT) KI=3
    II=I+1
    C2=PI*Z0(II)
    A=SV(I)
    IF(ABS(A).LT.1.E-6) GO TO 41
    X1=C1*FN(I)/2./A
    X2=C1*2./A*(1.-RS(I)*FN(I)/D(I)/A)
    X3=-X2*RS(I)/D(I)/A
    GO TO 42
 41 CONTINUE
    X1=C1/2./RS(I)*D(I)
    X2=(0.,0.)
    X3=C1*D(I)/6./RS(I)
 42 CONTINUE
    A=SV(II)
    IF(ABS(A).LT.1.E-6) GO TO 45
```

```
    Y1=C2*FN(II)/2./A
    Y2=C2*2./A*(1.-RS(II)*FN(II)/D(II)/A)
    Y3=-Y2*RS(II)/D(II)/A
    GO TO 40
  45 CONTINUE
    Y1=C2/2./RS(II)*D(II)
    Y2=(0.,0.)
    Y3=C2*D(II)/6./RS(II)
  40 CONTINUE
C
C DEFINE TRIDIAGONAL ELEMENTS FOR T-T
SUBMATRIX (STORED IN COLS)
C (U1- DIAG; U2- LOWER; U3- UPPER)
C
    XI=X1+X2+X3
    YI=Y1-Y2+Y3
    IF(KI.EQ.1) XI=C1/SV(I)
C    IF(KI.EQ.3) YI=C2/SV(II)
    U1=XI+YI
    U2=X1-X3
    U3=Y1-Y3
    L=2+(I-2)*3
    IF(KI.EQ.1) L=0
    L1=L+1
    L2=L+2
    L3=L+3
    go to (50,60,70),ki
  50 Z(L1)=U1
    Z(L2)=U2
    GO TO 80
  60 Z(L1)=U3
    Z(L2)=U1
    Z(L3)=U2
    GO TO 80
  70 Z(L1)=U3
    Z(L2)=U1
  80 Z(L0+I)=2.*C1*D(I)/RS(I)
  20 CONTINUE
    RETURN
    END
    SUBROUTINE ZTOT(MT,MP,ZL,Z)
C
C ADDS THE SURF IMPEDANCE TERMS TO THE
TRIDIAGONAL ELEMENTS OF
C THE BOR IMPEDANCE MATRIX Z.
C
    COMPLEX ZL(700),Z(50000)
    N=MT+MP
    M0=MT*3-2
    DO 100 I=1,MP
    L0=MT*N+(I-1)*N+MT
    IF(I.EQ.MP) GO TO 80
    KI=2
    IF(I.EQ.1) KI=1
    IF(I.EQ.MT) KI=3
    L2=(I-1)*N+I
    L1=L2-1
    L3=L2+1
    M=2+3*(I-2)
    IF(KI.EQ.1) M=0
    M1=M+1
    M2=M+2
    M3=M+3
    go to (50,60,70),ki
  50 Z(L2)=Z(L2)+ZL(M1)
    Z(L3)=Z(L3)+ZL(M2)
    GO TO 80
  60 Z(L1)=Z(L1)+ZL(M1)
    Z(L2)=Z(L2)+ZL(M2)
    Z(L3)=Z(L3)+ZL(M3)
    GO TO 80
  70 Z(L1)=Z(L1)+ZL(M1)
    Z(L2)=Z(L2)+ZL(M2)
  80 Z(L0+I)=Z(L0+I)+ZL(M0+I)
 100 CONTINUE
    RETURN
    END
    subroutine interp(u,v,x,y,nn)
c program to interpolate linearly between arrays of x and y
c values (with dimensions nn).  u is specified and v is
returned
c uniform sampling in x (the ordinate) is assumed.
    dimension x(nn),y(nn)
    delx=x(2)-x(1)
    n1=int(u/delx)+1
    n2=n1+1
    dely=y(n2)-y(n1)
    sgn=sign(1.,dely)
    dely=abs(dely)
    alpha=u-x(n1)
    zeta=dely*alpha/delx
    v=y(n1)+sgn*zeta
    return
    end
    SUBROUTINE
PLANEW(NWIRES,NW1,NW2,NP1,NP2,XH,YH,ZH,
   * THR,PHR,R)
C
C  PLANE WAVE EXCITATION VECTOR ELEMENTS FOR
WIRE AND
C  ATTACHMENT SEGMENT. INCIDENCE DIRECTION IS
(THR,PHR).
C   - ONLY ONE INCIDENCE ANGLE PER CALL
C   - WIRE DOES NOT HAVE TO LIE IN THE Z=0 PLANE
C
    COMPLEX
U0,AA,BB,C,R(400),CEXP,EXP,FI1,FI2,SI,DI,CMPLX
    DIMENSION
ZH(400),NS(4),NW1(4),NW2(4),XH(400),YH(400)
    MP2=NP2-1
    MT2=NP2-2
    MT22=2*MT2
    DO 5 L=1,NWIRES
   5 NS(L)=NW2(L)-NW1(L)+1
    U0=(0.,0.)
    CC=COS(THR)
    SS=SIN(THR)
    CP=COS(PHR)
    SP=SIN(PHR)
    UP=SS*CP
    VP=SS*SP
    WP=CC
    DO 12 IP=1,MP2
    II=IP+NP1
    I=II+1
    ZS=.5*(ZH(I)+ZH(II))
    XS=.5*(XH(I)+XH(II))
    YS=.5*(YH(I)+YH(II))
    DX=XH(I)-XH(II)
    DY=YH(I)-YH(II)
```

```
      D1=SQRT(DX**2+DY**2)
      SU=DY/D1
      CU=DX/D1
C FOR WIRES IN PERPENDICULAR TO Z SIN(V)=1 AND
COS(V)=0
      SV=1.0
      CV=0.0
C
C WIRE SEGMENT CALCULATIONS
C
      A=UP*CU+VP*SU
      B=UP*XS+VP*YS+WP*ZS
      C=CMPLX(0.,A)
      EXP=CEXP(CMPLX(0.,3))
      AA=CC*(CU*CP+SU*SP)
      BB=SU*CP-SP*CU
      PSI=D1*A/2.
      IF(PSI.NE.0.) GO TO 60
      SINC=1.
      GO TO 61
   60 SINC=SIN(PSI)/PSI
   61 COSP=COS(PSI)
      FI1=SINC*D1*EXP/2.
      FI2=(0.,0.)
      IF(ABS(A).LT.1.E-4) GO TO 62
      CSP=COSP-SINC
      IF(ABS(CSP).LT.1.E-4) GO TO 62
      FI2=EXP/C*CSP
   62 CONTINUE
      SI=FI1+FI2
      DI=FI1-FI2
C
C R-WIRE-THETA
C
      IF(IP.EQ.MP2) GO TO 10
      R(IP)=AA*SI
      R(IP+MT2)=BB*SI
   10 CONTINUE
C
C R-WIRE-PHI
C
   14 IF(IP.EQ.1) GO TO 12
      R(IP-1)=R(IP-1)+AA*DI
      R(IP-1+MT2)=R(IP-1+MT2)+BB*DI
   12 CONTINUE
C
C WRITE OVER DUMMY WIRE SEGMENTS
C
c     IF(NWIRES.EQ.1) GO TO 210
c     NSPTS=0
c     DO 209 L=1,NWIRES-1
c     NSPTS=NSPTS+NS(L)
c     IN=NSPTS-2
c     R(IN+1)=U0
c     R(IN+2)=U0
c     IN=IN+MT2
c     R(IN+1)=U0
c     R(IN+2)=U0
c 209 CONTINUE
  210 RETURN
      END
      SUBROUTINE
PLANES(M1,NP0,NP1,NP2,NT,RH,ZH,XT,AT,THR,R)
C
C PLANE WAVE EXCITATION VECTOR FOR BOR
ELEMENTS.
C NO CHANGE FROM HARRINGTON'S ORIGINAL
PROGRAM OTHER THAN
C
C ** ONLY ONE MODE PER CALL **
C
      COMPLEX
R(1000),U,U1,UA,UB,FA(50),FB(50),F2A,F2B,F1A,F1B
      COMPLEX U2,U3,U4,U5,CMPLX
      DIMENSION RH(400),ZH(400),XT(4),AT(4)
      DIMENSION R2(4),Z2(4),BJ(5000)
      U=(0.,1.)
      U1=3.141593*U**M1
      NF=1
      M2=M1
      NP=NP0+NP1+NP2
      NRF=NP0+NP1
      MP=NP-1
      MT=MP-1
      N=MT+MP
      N2=2*N
      CC=COS(THR)
      SS=SIN(THR)
      M3=M1+1
      M4=M2+3
      IF(M1.EQ.0) M3=2
      M5=M1+2
      M6=M2+2
      DO 12 IP=1,MP
      K2=IP
      I=IP+1
      DR=.5*(RH(I)-RH(IP))
      DZ=.5*(ZH(I)-ZH(IP))
      D1=SQRT(DR*DR+DZ*DZ)
      R1=.25*(RH(I)+RH(IP))
      IF(ABS(R1).LT.1.E-5) R1=1.
      Z1=.5*(ZH(I)+ZH(IP))
      DR=.5*DR
      D2=DR/R1
      DO 13 L=1,NT
      R2(L)=R1+DR*XT(L)
      Z2(L)=Z1+DZ*XT(L)
   13 CONTINUE
      D3=DR*CC
      D4=-DZ*SS
      D5=D1*CC
      DO 23 M=M3,M4
      FA(M)=0.
      FB(M)=0.
   23 CONTINUE
      DO 15 L=1,NT
      X=SS*R2(L)
      IF(X.GT..5E-7) GO TO 19
      DO 20 M=M3,M4
      BJ(M)=0.
   20 CONTINUE
      BJ(2)=1.
      S=1.
      GO TO 18
   19 M=2.8*X+14.-2./X
      IF(X.LT..5) M=11.8+ALOG10(X)
      IF(M.LT.M4) M=M4
      BJ(M)=0.
      JM=M-1
```

```
   BJ(JM)=1.
   DO 16 J=4,M
   J2=JM
   JM=JM-1
   J1=JM-1
   BJ(JM)=J1/X*BJ(J2)-BJ(JM+2)
  16 CONTINUE
   S=0.
   IF(M.LE.4) GO TO 24
   DO 17 J=4,M,2
   S=S+BJ(J)
  17 CONTINUE
  24 S=BJ(2)+2.*S
  18 ARG=Z2(L)*CC
   UA=AT(L)/S*CMPLX(COS(ARG).SIN(ARG))
   UB=XT(L)*UA
   DO 25 M=M3,M4
   FA(M)=BJ(M)*UA+FA(M)
   FB(M)=BJ(M)*UB+FB(M)
  25 CONTINUE
  15 CONTINUE
   IF(M1.NE.0) GO TO 26
   FA(1)=- FA(3)
   FB(1)=- FB(3)
  26 UA=U1
   DO 27 M=M5,M6
   M7=M-1
   M8=M+1
   F2A=UA*(FA(M8)+FA(M7))
   F2B=UA*(FB(M8)+FB(M7))
   UB=U*UA
   F1A=UB*(FA(M8)-FA(M7))
   F1B=UB*(FB(M8)-FB(M7))
   U4=D4*UA
   U2=D3*F1A+U4*FA(M)
   U3=D3*F1B+U4*FB(M)
   U4=DR*F2A
   U5=DR*F2B
   K1=K2-1
   K4=K1+N
   K5=K2+N
   R(K2+MT)=-D5*(F2A+D2*F2B)
   R(K5+MT)=D1*(F1A+D2*F1B)
   IF(IP.EQ.1) GO TO 21
   R(K1)=R(K1)+U2-U3
   R(K4)=R(K4)+U4-U5
   IF(IP.EQ.MP) GO TO 22
  21 R(K2)=U2+U3
   R(K5)=U4+U5
  22 K2=K2+N2
   UA=UB
  27 CONTINUE
  12 CONTINUE
c    R(NP0-1)=(0.,0.)
c    R(NP0)=(0.,0.)
c    R(NP0+MT)=(0.,0.)
c    R(NRF-1)=(0.,0.)
c    R(NRF)=(0.,0.)
c    R(NRF+MT)=(0.,0.)
  99 RETURN
   END
   SUBROUTINE
ZMATSS(M1,M2,NP0,NP1,NP2,NPHI,NT,RH,ZH,X,A,XT,A
T,Z)
C
C ******** THREE DETACHED SURFACES ***********
C SURFACE-SURFACE IMPEDANCE ELEMENTS
REMAINS UNCHANGED FROM HARRINGTON
C EXCEPT MULTIPLE SURFACES ARE PERMITTED.
THE FIRST SURFACE HAS NP0
C POINTS. THE SECOND NP1 POINTS AND THE THIRD
NP2.
C NP0 PARABOLOID PTS; NP1 HYPERBOLOID PTS;
NP2 CAVITY PTS.
C
   COMPLEX
Z(50000),U1,U2,U3,U4,U5,U6,U7,U8,U9,UA,UB,G4A(4),G5
A(4)
   COMPLEX
G6A(4),G4B(4),G5B(4),G6B(4),H4A,H5A,H6A,H4B,H5B
   COMPLEX CMPLX,H6B,UC,UD,GA(400),GB(400)
   DIMENSION
RH(400),ZH(400),X(400),A(400),AT(4),RS(400),ZS(400)
   DIMENSION
D(400),DR(400),DZ(400),DM(400),C2(400),C3(400),R2(4)
   DIMENSION
C4(400),C5(400),C6(400),Z7(4),R7(4),Z8(4),R8(4)
   DIMENSION XT(4),Z2(4)
   CT=2.
   CP=.1
   NP=NP0+NP1+NP2
   NRF=NP0+NP1
   DO 10 I=2,NP
   I2=I-1
   RS(I2)=.5*(RH(I)+RH(I2))
   ZS(I2)=.5*(ZH(I)+ZH(I2))
   D1=.5*(RH(I)-RH(I2))
   D2=.5*(ZH(I)-ZH(I2))
   D(I2)=SQRT(D1*D1+D2*D2)
   DR(I2)=D1
   DZ(I2)=D2
   DM(I2)=D(I2)/RS(I2)
  10 CONTINUE
   M3=M2-M1+1
   M4=M1-1
   PI2=1.570796
   DO 11 K=1,NPHI
   PH=PI2*(X(K)+1.)
   C2(K)=PH*PH
   SN=SIN(.5*PH)
   C3(K)=4.*SN*SN
   A1=PI2*A(K)
   D4=.5*A1*C3(K)
   D5=A1*COS(PH)
   D6=A1*SIN(PH)
   M5=K
   DO 29 M=1,M3
   PHM=(M4+M)*PH
   A2=COS(PHM)
   C4(M5)=D4*A2
   C5(M5)=D5*A2
   C6(M5)=D6*SIN(PHM)
   M5=M5+NPHI
  29 CONTINUE
  11 CONTINUE
   MP=NP-1
   MT=MP-1
   N=MT+MP
   N2N=MT*N
   N2=N*N
```

```
  U1=(0.,.5)
  U2=(0.,2.)
  JN=-1-N
  DO 15 JQ=1,MP
  KQ=2
  IF(JQ.EQ.1) KQ=1
  IF(JQ.EQ.MP) KQ=3
  R1=RS(JQ)
  Z1=ZS(JQ)
  D1=D(JQ)
  D2=DR(JQ)
  D3=DZ(JQ)
  D4=D2/R1
  D5=DM(JQ)
  SV=D2/D1
  CV=D3/D1
  T6=CT*D1
  T62=T6+D1
  T62=T62*T62
  R6=CP*R1
  R62=R6*R6
  DO 12 L=1,NT
  R2(L)=R1+D2*XT(L)
  Z2(L)=Z1+D3*XT(L)
12 CONTINUE
  U3=D2*U1
  U4=D3*U1
  DO 16 IP=1,MP
  R3=RS(IP)
  Z3=ZS(IP)
  R4=R1-R3
  Z4=Z1-Z3
  FM=R4*SV+Z4*CV
  PHM=ABS(FM)
  PH=ABS(R4*CV-Z4*SV)
  D6=PH
  IF(PHM.LE.D1) GO TO 26
  D6=PHM-D1
  D6=SQRT(D6*D6+PH*PH)
26 IF(IP.EQ.JQ) GO TO 27
  KP=1
  IF(T6.GT.D6) KP=2
  IF(R6.GT.D6) KP=3
  GO TO 28
27 KP=4
28 GO TO (41,42,41,42),KP
42 DO 40 L=1,NT
  D7=R2(L)-R3
  D8=Z2(L)-Z3
  Z7(L)=D7*D7+D8*D8
  R7(L)=R3*R2(L)
  Z8(L)=.25*Z7(L)
  R8(L)=.25*R7(L)
40 CONTINUE
  Z4=R4*R4+Z4*Z4
  R4=R3*R1
  R5=.5*R3*SV
  DO 33 K=1,NPHI
  A1=C3(K)
  RR=Z4+R4*A1
  UA=0.
  UB=0.
  IF(RR.LT.T62) GO TO 34
  DO 35 L=1,NT
  R=SQRT(Z7(L)+R7(L)*A1)
  SN=-SIN(R)
  CS=COS(R)
  UC=AT(L)/R*CMPLX(CS,SN)
  UA=UA+UC
  UB=XT(L)*UC+UB
35 CONTINUE
  GO TO 36
34 DO 37 L=1,NT
  R=SQRT(Z8(L)+R8(L)*A1)
  SN=-SIN(R)
  CS=COS(R)
  UC=AT(L)/R*SN*CMPLX(-SN,CS)
  UA=UA+UC
  UB=XT(L)*UC+UB
37 CONTINUE
  A2=FM+R5*A1
  D9=RR-A2*A2
  R=ABS(A2)
  D7=R-D1
  D8=R+D1
  D6=SQRT(D8*D8+D9)
  R=SQRT(D7*D7+D9)
  IF(D7.GE.0.) GO TO 38
  A1=ALOG((D8+D6)*(-D7+R)/D9)/D1
  GO TO 39
38 A1=ALOG((D8+D6)/(D7+R))/D1
39 UA=A1+UA
  UB=A2*(4./(D6+R)-A1)/D1+UB
36 GA(K)=UA
  GB(K)=UB
33 CONTINUE
  K1=0
  DO 45 M=1,M3
  H4A=0.
  H5A=0.
  H6A=0.
  H4B=0.
  H5B=0.
  H6B=0.
  DO 46 K=1,NPHI
  K1=K1+1
  D6=C4(K1)
  D7=C5(K1)
  D8=C6(K1)
  UA=GA(K)
  UB=GB(K)
  H4A=D6*UA+H4A
  H5A=D7*UA+H5A
  H6A=D8*UA+H6A
  H4B=D6*UB+H4B
  H5B=D7*UB+H5B
  H6B=D8*UB+H6B
46 CONTINUE
  G4A(M)=H4A
  G5A(M)=H5A
  G6A(M)=H6A
  G4B(M)=H4B
  G5B(M)=H5B
  G6B(M)=H6B
45 CONTINUE
  IF(KP.NE.4) GO TO 47
  A2=D1/(PI2*R1)
  D6=2./D1
  D8=0.
  DO 63 K=1,NPHI
```

```
  A1=R4*C2(K)
  R=R4*C3(K)
  IF(R.LT.T62) GO TO 64
  D7=0.
  DO 65 L=1,NT
  D7=D7+AT(L)/SQRT(Z7(L)+A1)
65 CONTINUE
  GO TO 66
64 A1=A2/(X(K)+1.)
  D7=D6*ALOG(A1+SQRT(1.+A1*A1))
66 D8=D8+A(K)*D7
63 CONTINUE
  A1=.5*A2
  A2=1./A1
  D8=-PI2*D8+2./R1*(BLOG(A2)+A2*BLOG(A1))
  DO 67 M=1,M3
  G5A(M)=D8+G5A(M)
67 CONTINUE
  GO TO 47
41 DO 25 M=1,M3
  G4A(M)=0.
  G5A(M)=0.
  G6A(M)=0.
  G4B(M)=0.
  G5B(M)=0.
  G6B(M)=0.
25 CONTINUE
  DO 13 L=1,NT
  A1=R2(L)
  R4=A1-R3
  Z4=Z2(L)-Z3
  Z4=R4*R4+Z4*Z4
  R4=R3*A1
  DO 17 K=1,NPHI
  R=SQRT(Z4+R4*C3(K))
  SN=-SIN(R)
  CS=COS(R)
  GA(K)=CMPLX(CS.SN)/R
17 CONTINUE
  D6=0.
  IF(R62.LE.Z4) GO TO 51
  DO 62 K=1,NPHI
  D6=D6+A(K)/SQRT(Z4+R4*C2(K))
62 CONTINUE
  Z4=3.141593/SQRT(Z4/R4)
  D6=-PI2*D6+ALOG(Z4+SQRT(1.+Z4*Z4))/SQRT(R4)
51 A1=AT(L)
  A2=XT(L)*A1
  K1=0
  DO 30 M=1,M3
  U5=0.
  U6=0.
  U7=0.
  DO 32 K=1,NPHI
  UA=GA(K)
  K1=K1+1
  U5=C4(K1)*UA+U5
  U6=C5(K1)*UA+U6
  U7=C6(K1)*UA+U7
32 CONTINUE
  U6=D6+U6
  G4A(M)=A1*U5+G4A(M)
  G5A(M)=A1*U6+G5A(M)
  G6A(M)=A1*U7+G6A(M)
  G4B(M)=A2*U5+G4B(M)
```

```
  G5B(M)=A2*U6+G5B(M)
  G6B(M)=A2*U7+G6B(M)
30 CONTINUE
13 CONTINUE
47 A1=DR(IP)
  UA=A1*U3
  UB=DZ(IP)*U4
  A2=D(IP)
  D6=-A2*D2
  D7=D1*A1
  D8=D1*A2
  JM=JN
  DO 31 M=1,M3
  FM=M4+M
  A1=FM*DM(IP)
  H5A=G5A(M)
  H5B=G5B(M)
  H4A=G4A(M)+H5A
  H4B=G4B(M)+H5B
  H6A=G6A(M)
  H6B=G6B(M)
  U7=UA*H5A+UB*H4A
  U8=UA*H5B+UB*H4B
  U5=U7-U8
  U6=U7+U8
  U7=-U1*H4A
  U8=D6*H6A
  U9=D6*H6B-A1*H4A
  UC=D7*(H6A+D4*H6B)
  UD=FM*D5*H4A
  K1=IP+JM
  K2=K1+1
  K3=K1+N
  K4=K2+N
  K5=K2+MT
  K6=K4+MT
  K7=K3+N2N
  K8=K4+N2N
  GO TO (18,20,19).KQ
18 Z(K6)=U8+U9
  IF(IP.EQ.1) GO TO 21
  Z(K3)=Z(K3)+U6-U7
  Z(K7)=Z(K7)+UC-UD
  IF(IP.EQ.MP) GO TO 22
21 Z(K4)=U6+U7
  Z(K8)=UC+UD
  GO TO 22
19 Z(K5)=Z(K5)+U8-U9
  IF(IP.EQ.1) GO TO 23
  Z(K1)=Z(K1)+U5+U7
  Z(K7)=Z(K7)+UC-UD
  IF(IP.EQ.MP) GO TO 22
23 Z(K2)=Z(K2)+U5-U7
  Z(K8)=UC+UD
  GO TO 22
20 Z(K5)=Z(K5)+U8-U9
  Z(K6)=U8+U9
  IF(IP.EQ.1) GO TO 24
  Z(K1)=Z(K1)+U5+U7
  Z(K3)=Z(K3)+U6-U7
  Z(K7)=Z(K7)+UC-UD
  IF(IP.EQ.MP) GO TO 22
24 Z(K2)=Z(K2)+U5-U7
  Z(K4)=U6+U7
  Z(K8)=UC+UD
```

```
  22 Z(K8+MT)=U2*(D8*(H5A+D4*H5B)-A1*UD)
     JM=JM+N2
  31 CONTINUE
  16 CONTINUE
     JN=JN+N
  15 CONTINUE
C
C THREE MULTIPLE BODIES USING THE SIMPLIFIED APPROACH
C NULL OUT ROWS AND COLS FOR THE FIRST DUMMY SEGMENT
C
     DO 100 LSS=1,N
     LS=LSS-1
     Z(LS*N+NP0)=(0.,0.)
     Z(LS*N+NP0-1)=(0.,0.)
 100 Z(LS*N+NP0+MT)=(0.,0.)
     DO 101 LS=1,N
     Z((NP0-2)*N+LS)=(0.,0.)
     Z((NP0-1)*N+LS)=(0.,0.)
 101 Z((NP0-1+MT)*N+LS)=(0.,0.)
     Z((NP0-2)*N+NP0-1)=(1.,0.)
     Z((NP0-1)*N+NP0)=(1.,0.)
     Z((MT+NP0-1)*N+NP0+MT)=(1.,0.)
C
C NULL OUT ROWS AND COLS FOR THE SECOND DUMMY SEGMENT
C
     DO 200 LSS=1,N
     LS=LSS-1
     Z(LS*N+NRF)=(0.,0.)
     Z(LS*N+NRF-1)=(0.,0.)
 200 Z(LS*N+NRF+MT)=(0.,0.)
     DO 201 LS=1,N
     Z((NRF-2)*N+LS)=(0.,0.)
     Z((NRF-1)*N+LS)=(0.,0.)
 201 Z((NRF-1+MT)*N+LS)=(0.,0.)
     Z((NRF-2)*N+NRF-1)=(1.,0.)
     Z((NRF-1)*N+NRF)=(1.,0.)
     Z((MT+NRF-1)*N+NRF+MT)=(1.,0.)
 999 RETURN
     END
     SUBROUTINE ZASMB0(NP1,NP2,MODES,Z,ZWW)
C
C ASSEMBLES MODE INDEPENDENT BLOCKS OF Z
C
     COMPLEX Z(500000),ZWW(10000)
     MT1=NP1-2
     MP1=NP1-1
     N=MT1+MP1
     MT2=NP2-2
     NBLOCK=2*MODES+1
     NS=NBLOCK*N
     NR=NS+MT2
     NS2=NS*NR
     NWW=NS2+NS
     DO 10 IC=1,MT2
     IC1=IC-1
     DO 10 IR=1,MT2
     K=NWW+IC1*NR+IR
     IW=IC1*MT2+IR
10   Z(K)=ZWW(IW)
     RETURN
     END
```

```
     SUBROUTINE ZASMBN(NP1,NP2,MODES,NM,Z,ZSS,ZSW)
C
C ASSEMBLES MODE DEPENDENT BLOCKS IN Z. MODES=TL # OF MODES;
C NM IS THE MODE # OF THE BLOCKS ZSS,ZSW,ZSJ. (IF NM<0 THEN
C ZSS IS OMITTED - ONLY FILLED FOR POSITIVE NM)
C
     COMPLEX ZSS(50000),Z(500000),ZSW(50000)
     MT1=NP1-2
     MP1=NP1-1
     MT2=NP2-2
     N=MP1+MT1
     NBLOCK=2*MODES+1
     NS=NBLOCK*N
     NR=NS+MT2
     MT=MT1+MT2
     MTN=MT*N
     IF(NM.LT.0) GO TO 225
C
C ZSS BLOCKS FOR MODE NM (+ AND - FILLED IN 1 LOOP)
C
     NTOP1=MODES-NM
     NTOP2=NBLOCK-(NTOP1+1)
     NSS2=NTOP1*(N+NR*N)
     NSS1=NTOP2*(N+NR*N)
     DO 200 IC=1,MP1
     IC1=IC-1
     DO 200 IR=1,MP1
     IF(IC.GT.MT1) GO TO 100
     IF(IR.GT.MT1) GO TO 50
     I0=IC1*N+IR
     ITT=IC1*NR+IR
     Z(ITT+NSS1)=ZSS(I0)
     IF(NM.NE.0) Z(ITT+NSS2)=ZSS(I0)
50    I0=MT1+IC1*N+IR
     IPT=IC1*NR+MT1+IR
     Z(IPT+NSS1)= ZSS(I0)
     IF(NM.NE.0) Z(IPT+NSS2)=-ZSS(I0)
100   IF(IR.GT.MT1) GO TO 150
     I0=N*MT1+IC1*N+IR
     ITP=MT1*NR+IC1*NR+IR
     Z(ITP+NSS1)= ZSS(I0)
     IF(NM.NE.0) Z(ITP+NSS2)=-ZSS(I0)
150   I0=N*MT1+MT1+IC1*N+IR
     IPP=IC1*NR+MT1+MT1*NR+IR
     Z(IPP+NSS1)=ZSS(I0)
     IF(NM.NE.0) Z(IPP+NSS2)=ZSS(I0)
200   CONTINUE
225   CONTINUE
C
C ZSW AND ZWS BLOCKS
C
     NTOP1=MODES+NM
     NTOP2=NBLOCK-(NTOP1+1)
     NSW=NTOP1*N+NS*NR
     NWS=NTOP2*NR*N+NS
     DO 250 IC=1,MT2
     IC1=IC-1
     DO 250 IR=1,N
     ISW=IR+IC1*NR+NSW
     IWS=(IR-1)*NR+IC+NWS
     I0=IC1*N+IR
```

```
    Z(ISW)=ZSW(I0)
    Z(IWS)=ZSW(I0)
250  CONTINUE
    RETURN
    END
    SUBROUTINE
ZMATSW(NWIRES,NW1,NW2,NP11,NP12,NP13,
   * XH,YH,RH,ZH,NT,XT,AT,NG,XG,AG,MODE,A,Z)
C
c >>>>>>>>>>> revised version <<<<<<<<<<
c
C CALCULATION OF THE SURFACE-WIRE MATRIX
ELEMENTS. ATTACHMENT
C POINT NOT AT A SURFACE EDGE, BUT CAN BE ON Z
AXIS (IC#1). SURFACE
C START INDEX IS 1.  TWO BORS OF LENGTHS NP11,
NP12 AND NP13. WIRE
C START AND STOP POINTS ARE NW1 AND NW2.
C
    COMPLEX
CEXP,EXP,Z(50000),G5,G6,G7,CONH,F5,F6,F7
    COMPLEX
U,U0,PSI,T0,T1,T2,T3,ST1,ST2,ST3,CON,SP1,SP2,SP3
    COMPLEX U5,U6,U7,U8,U9,CMPLX,T4,T5,T6,T7
    DIMENSION
RS1(400),RH(400),ZH(400),XG(400),AG(400),XT(4),AT(4)
    DIMENSION
ZS1(400),D1(400),D(400),S(400),C(400),RS(400)
    DIMENSION
ZS(400),S1(400),C1(400),NW1(4),NW2(4),NS(4)
    DIMENSION
XH(400),YH(400),XS1(400),YS1(400),CU(400),SU(400)
    PI=3.14159
    PI2=2.*PI
    NP1=NP11+NP12+NP13
    NRF=NP11+NP12
    DO 1 L=1,NWIRES
  1 NS(L)=NW2(L)-NW1(L)+1
    U0=(0.,0.)
    U=(0.,1.)
C
C DEFINE SURFACE GEOMETRY TERMS
C
    MP=NP1-1
    MT=MP-1
    NROW=MP+MT
    DO 5 I=2,NP1
    I2=I-1
    RS(I2)=.5*(RH(I)+RH(I2))
    ZS(I2)=.5*(ZH(I)+ZH(I2))
    DR=RH(I)-RH(I2)
    DZ=ZH(I)-ZH(I2)
    D(I2)=SQRT(DR**2+DZ**2)
    S(I2)=DR/D(I2)
  5 C(I2)=DZ/D(I2)
C
C DEFINE WIRE GEOMETRY TERMS
C
    NW=NW2(NWIRES)-NW1(1)
    NWP=NW+1
    MT2=NWP-2
    DO 10 N=2,NWP
    N0=N-1
    I=NP1+N
    I2=I-1
    RS1(N0)=.5*(RH(I)+RH(I2))
    ZS1(N0)=.5*(ZH(I)+ZH(I2))
    XS1(N0)=.5*(XH(I)+XH(I2))
    YS1(N0)=.5*(YH(I)+YH(I2))
    DX=XH(I)-XH(I2)
    DY=YH(I)-YH(I2)
    D1(N0)=SQRT(DX**2+DY**2)
C FOR WIRES PARALLEL TO THE XY PLANE SIN(V)=1
AND COS(V)=0
    S1(N0)=1.
    C1(N0)=0.
    CU(N0)=DX/D1(N0)
    SU(N0)=DY/D1(N0)
  10 CONTINUE
    CON=U/PI2/2.
C INTEGRATING FROM 0 TO 2*PI
    O1=PI
    O2=PI
    JN=-1-NROW
C
C SEGMENT LOOPS: q=WIRE, p=SURFACE
C
    DO 100 JQ=1,NW
    KQ=2
    IF(JQ.EQ.1) KQ=1
    IF(JQ.EQ.NW) KQ=3
    H1=D1(JQ)/2.
    ZW=ZS1(JQ)
    DO 22 IP=1,MP
    ST1=U0
    ST2=U0
    ST3=U0
    SP1=U0
    SP2=U0
    SP3=U0
    AA=S(IP)*CU(JQ)
    BB=S(IP)*SU(JQ)
    RD=RS(IP)*D1(JQ)
    DD=D(IP)*D1(JQ)
    CONH=CON*D(IP)
C
C FIRST TERM (H-INTEGRATION)
C
    DO 30 I=1,NT
    H=H1*XT(I)
    HHD=2.*H/D1(JQ)
    XW=XS1(JQ)+H*CU(JQ)
    YW=YS1(JQ)+H*SU(JQ)
C
C PHI INTEGRATIONS FOR G-HAT FUNCTIONS
C
    G7=U0
    G5=U0
    G6=U0
    DO 32 K=1,NG
    PH=O1*XG(K)+O2
    PHM=PH*FLOAT(MODE)
    XS=RS(IP)*COS(PH)
    YS=RS(IP)*SIN(PH)
    EXP=CEXP(CMPLX(0.,-PHM))
    RP=SQRT((XS-XW)**2+(YS-YW)**2+(ZS(IP)-ZW)**2)
    PSI=CEXP(CMPLX(0.,-RP))/RP
    F5=EXP*COS(PH)*PSI
    F6=EXP*SIN(PH)*PSI
    F7=EXP*PSI
```

```
      G7=G7+F7*AG(K)
      G5=G5+F5*AG(K)
   32 G6=G6+F6*AG(K)
      G7=O1*G7
      G5=O1*G5
      G6=O1*G6
      T0=G5*AA/4.
      T1=T0*HHD
      T2=G6*BB/4.
      T3=T2*HHD
      T4=G5*SU(JQ)/2.
      T5=T4*HHD
      T6=-G6*CU(JQ)/2.
      T7=T6*HHD
      ST1=ST1+AT(I)*(T0+T2)
      ST2=ST2+AT(I)*(T1+T3)
      ST3=ST3+AT(I)*G7/DD
      SP1=SP1+AT(I)*(T4+T6)
      SP2=SP2+AT(I)*(T5+T7)
      SP3=SP3+AT(I)*U*G7*FLOAT(MODE)/RD
   30 CONTINUE
C
C ZSW-t TERMS (K1,K2,K3,K4)
C
      U5=(ST1-ST2)*CONH*H1
      U6=(ST1+ST2)*CONH*H1
      U7=-ST3*CONH*H1
C
C ZSW-p TERMS (K5,K6)
C
      U8=SP1*CONH*H1
      U9=(SP2+SP3)*CONH*H1
      K1=IP+JN
      K2=K1+1
      K3=K1+NROW
      K4=K2+NROW
      K5=K2+MT
      K6=K4+MT
      GO TO (18,20,19),KQ
   18 Z(K6)=U8+U9
      IF(IP.EQ.1) GO TO 21
      Z(K3)=Z(K3)+U6-U7
      IF(IP.EQ.MP) GO TO 22
   21 Z(K4)=U6+U7
      GO TO 22
   19 Z(K5)=Z(K5)+U8-U9
      IF(IP.EQ.1) GO TO 23
      Z(K1)=Z(K1)+U5+U7
      IF(IP.EQ.MP) GO TO 22
   23 Z(K2)=Z(K2)+U5-U7
      GO TO 22
   20 Z(K5)=Z(K5)+U8-U9
      Z(K6)=U8+U9
      IF(IP.EQ.1) GO TO 24
      Z(K1)=Z(K1)+U5+U7
      Z(K3)=Z(K3)+U6-U7
      IF(IP.EQ.MP) GO TO 22
   24 Z(K2)=Z(K2)+U5-U7
      Z(K4)=U6+U7
   22 CONTINUE
      JN=JN+NROW
  100 CONTINUE
C
C FOR MULTIPLE BORS WRITE OVER DUMMY
SEGMENT ROWS
C WRITE OVER ROWS AND COLS FOR FIRST DUMMY
SEG.
C
      DO 101 LSS=1,MT2
      LS=LSS-1
      Z(LS*NROW+NP11)=(0.,0.)
      Z(LS*NROW+NP11-1)=(0.,0.)
  101 Z(LS*NROW+NP11+MT)=(0.,0.)
C
C WRITE OVER ROWS AND COLS FOR SECOND
DUMMY SEG.
C
      DO 201 LSS=1,MT2
      LS=LSS-1
      Z(LS*NROW+NRF)=(0.,0.)
      Z(LS*NROW+NRF-1)=(0.,0.)
  201 Z(LS*NROW+NRF+MT)=(0.,0.)
C
C WRITE OVER DUMMY SEGMENTS IN THE CASE OF
MULTIPE WIRES
C
      IF(NWIRES.EQ.1) GO TO 292
      NSPTS=0
      DO 291 L=1,NWIRES-1
      NSPTS=NSPTS+NS(L)
      DO 291 I=1,NROW
C
C SET COLS TO ZERO FOR STRIPS
C
      IN=(NSPTS-2)*NROW
      Z(IN+I)=U0
      Z(IN+I+NROW)=U0
  291 CONTINUE
  292 RETURN
      END
      SUBROUTINE
ZMATWW(NWIRES,NW1,NW2,XH,YH,RH,ZH,NT,XT,AT,A,
Z)
C
C *** MODS FOR DIPOLE -- RECTANGULAR
COORDINATES ARE SENT OVER ***
C COMPUTE MATRIX ELEMENTS FOR MULTIPLE
WIRES USING GLISSON METHOD
C NWIRES= # OF WIRES; NW1(I),NW2(I) ARE START
AND STOP POINTS.
C &&&&& WIRES NEED NOT BE IN THE Z=0 PLANE
&&&&&
C
      COMPLEX CEXP,Z(10000),CON,CMPLX
      COMPLEX U,U0,PSI,SUM1,SUM2,SUM3,U5,U6,U7
      DIMENSION
RH(400),ZH(400),XT(4),AT(4),XH(400),YH(400)
      DIMENSION D1(400),S1(400),C1(400)
      DIMENSION
NW1(4),NW2(4),NS(4),XS1(400),YS1(400),ZS1(400)
      DIMENSION CU(400),SU(400)
      PI=3.141592
      PI2=2.*PI
      PD2=PI/2.
      U0=(0.,0.)
      U=(0.,1.)
C
C DEFINE GEOMETRY TERMS FOR THE WIRE.
XH,YH,RH,ZH ARE ALL KNOWNS.
C
```

```
      DO 5 L=1,NWIRES
    5 NS(L)=NW2(L)-NW1(L)+1
      NS1=NW2(NWIRES)-NW1(1)
      NPS=NS1+1
      DO 10 N=2,NPS
      N0=N-1
      I=NW1(1)+N-1
      I2=I-1
      XS1(N0)=.5*(XH(I)+XH(I2))
      YS1(N0)=.5*(YH(I)+YH(I2))
      ZS1(N0)=.5*(ZH(I)+ZH(I2))
      DX=XH(I)-XH(I2)
      DY=YH(I)-YH(I2)
      D1(N0)=SQRT(DX**2+DY**2)
      CU(N0)=DX/D1(N0)
      SU(N0)=DY/D1(N0)
      S1(N0)=1.0
      C1(N0)=0.0
   10 CONTINUE
      NROW=NS1-1
      JN=-1-NROW
      DO 500 JQ=1,NS1
      KQ=2
      IF(JQ.EQ.1) KQ=1
      IF(JQ.EQ.NS1) KQ=3
      Q1=D1(JQ)/2.
      DO 22 IP=1,NS1
      LQ=0
      IF(IP.EQ.JQ) LQ=1
      CON=D1(IP)/4./PI*U
      SUM1=U0
      SUM2=U0
      SUM3=U0
      AA=CU(IP)*CU(JQ)+SU(IP)*SU(JQ)
C
C H INTEGRATION -- SUBTRACT OUT SINGULARITY IF
JQ=IP
C AND SAME SEGMENT (N11=N21): DESIGNATED LQ=1
C
      DO 100 I=1,NT
      H=Q1*XT(I)
      IF(LQ.NE.1) GO TO 40
      RP=SQRT(H**2+A*A)
      GO TO 50
   40 XP=XS1(JQ)+H*CU(JQ)*S1(JQ)
      YP=YS1(JQ)+H*SU(JQ)*S1(JQ)

RP=SQRT((XS1(IP)-XP)**2+(YS1(IP)-YP)**2+(ZS1(JQ)-ZS
1(IP))**2)
   50 PSI=CEXP(CMPLX(0.,-RP))
c     IF(LQ.NE.1) GO TO 60
c     PSI=PSI-(1.,0.)
   60 PSI=PSI/RP
      SUM1=SUM1+PSI*AA*AT(I)/4.
      SUM2=SUM2+PSI*AA*AT(I)/2./D1(JQ)*H
      SUM3=SUM3+PSI*AT(I)/D1(IP)/D1(JQ)
  100 CONTINUE
      X1=0.
      X2=0.
      X3=0.
c     IF(LQ.NE.1) GO TO 200
c     DQ=D1(JQ)/2.
c     SDQ=SQRT(DQ**2+A**2)
c     X10=ALOG(SDQ+DQ)-ALOG(SDQ-DQ)
c     X1=X10*AA/4.
c     X3=X10/D1(IP)/D1(JQ)
c 200 CONTINUE
      SUM1=(SUM1*Q1+X1)*CON
      SUM2=(SUM2*Q1+X2)*CON
      SUM3=(SUM3*Q1+X3)*CON
      U5=SUM1-SUM2
      U6=SUM1+SUM2
      U7=-SUM3
      K1=IP+JN
      K2=K1+1
      K3=K1+NROW
      K4=K2+NROW
      GO TO (18,20,19),KQ
   18 CONTINUE
      IF(IP.EQ.1) GO TO 21
      Z(K3)=Z(K3)+U6-U7
      IF(IP.EQ.NS1) GO TO 22
   21 Z(K4)=U6+U7
      GO TO 22
   19 CONTINUE
      IF(IP.EQ.1) GO TO 23
      Z(K1)=Z(K1)+U5+U7
      IF(IP.EQ.NS1) GO TO 22
   23 Z(K2)=Z(K2)+U5-U7
      GO TO 22
   20 CONTINUE
      IF(IP.EQ.1) GO TO 24
      Z(K1)=Z(K1)+U5+U7
      Z(K3)=Z(K3)+U6-U7
      IF(IP.EQ.NS1) GO TO 22
   24 Z(K2)=Z(K2)+U5-U7
      Z(K4)=U6+U7
   22 CONTINUE
      JN=JN+NROW
  500 CONTINUE
      IF(NWIRES.EQ.1) GO TO 297
      NSPTS=0
      DO 291 L=1,NWIRES-1
      NSPTS=NSPTS+NS(L)
      DO 291 I=1,NROW
C
C USE THE SIMPLIFIED METHOD OF HANDLING
MULTIPLE WIRES
C SET COLS TO ZERO FOR STRIPS
C
      IN=(NSPTS-2)*NROW
      Z(IN+I)=U0
      Z(IN+I+NROW)=U0
C
C SET ROWS TO ZERO FOR STRIPS
C
      IN=NSPTS-2+(I-1)*NROW
      Z(IN+1)=U0
      Z(IN+2)=U0
  291 CONTINUE
C
C SET DIAGONALS TO 1 FOR STRIPS
C
      NSPTS=0
      DO 296 L=1,NWIRES-1
      NSPTS=NSPTS+NS(L)
      I0=NSPTS-2
      I1=I0*NROW+NSPTS-2
      Z(I1+1)=(1.,0.)
      Z(I1+NROW+2)=(1.,0.)
```

```
296 CONTINUE
297 RETURN
   END
```

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