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EDL-G220
VOLUME 2

DA 36-039 AMC-00088(E)

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# Noncommunication Expendable Jammer Investigations

VOLUME 2

## Omnidirectional Antennas

CHARLES F. HUMMEL

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EDL-G220
Volume 2


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3 April 1964

# NONCOMMUNICATIONS EXPENDABLE JAMMER INVESTIGATIONS
## VOLUME 2
## OMNIDIRECTIONAL ANTENNAS


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SYLVANIA ELECTRIC PRODUCTS INC.

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NONCOMMUNICATION EXPENDABLE JAMMER INVESTIGATIONS
VOLUME 2 - OMNIDIRECTIONAL ANTENNAS

Charles F Hummel

## 1 INTRODUCTION.

Adequate electromagnetic coupling between antennas is essential to the successful tactical operation of a microwave jammer against a target. In an idealized case, where reflecting surfaces are very remote from the antennas (or where the surfaces are near but have reflection coefficients which are negligible at microwave frequencies), electromagnetic coupling between antennas can be readily established from free-space radiation patterns and the distance between antennas. Complications arise, however, when the antennas are in relatively close proximity to a large reflecting surface whose reflection coefficient is not negligible. Such is the situation usually encountered in various practical applications and, in particular, in the case of tactical deployment of an expendable microwave jammer whose antenna is in relatively close proximity to the earth's surface and the target is near the horizon (i.e., at a very low elevation angle).

The type of reflecting surface, such as irregular terrain, its moisture content, snow cover, etc., add further complications to the general electromagnetic coupling problem particularly when various types of obstructions and vegetation are involved. The heart of the antenna coupling problem, however, centers around one important antenna-system parameters: antenna height above ground

The following discussion has a two-fold purpose.

(a) to present engineering data related to the development of an 8-db (relative to isotropic) omnidirectional (in the azimuth plane) antenna breadboard model and its measured free-space radiation-pattern characteristics,

(b) to present data in graphical form, based upon theoretical ground-effect considerations, which show the important effect that height above ground has upon the antenna's effective radiated power at low elevation angles

The data presented herein do not include effects due to irregular terrain, obstructions, or vegetation. Only flat terrain is assumed and the data should be considered representative only of the idealized terrain condition. This was done in order to explore the magnitude of the ground effect without undue complication Actual conditions encountered in the field can be expected to cause quite wide variations.

## 2 PRELIMINARY INVESTIGATIONS.

Early in the program it appeared desirable to consider an azimuth omnidirectional microwave antenna configuration which could be an integral part of the structure of the expendable-jammer vehicle (such as a cavity-backed slotted array, or as a portion of the tail structure) For a description of the expendable jammer the reader is referred to EDL-M622.[1] It soon became apparent that the expendable jammer's microwave antenna performance would be quite dependent upon the vehicle's vertical attitude and the antenna height after impact. The vehicle's inability to control its penetration depth (over wide variations in type of terrain such as hard soil to loosely packed sand) means that a relatively large variation in antenna-to-ground height must be considered.

Another problem pertaining to environment presented itself during the preliminary investigations Under typical field conditions, the orientation angle, off vertical, that the longitudinal axis of the vehicle and antenna can be expected to assume after impact could not be predicted or controlled. A realistic solution to this problem was deemed important since a relatively large off-vertical angle of incidence could seriously reduce the effective radiated power by a directive antenna whose beam is narrow in the elevation pattern.

Also considered in the preliminary investigations were various types of azimuth omnidirectional antennas which could be developed, separate from the vehicular structure, that would lend themselves to being elevated from the aft portion of the vehicle after impact Briefly considered was the possibility of utilizing a gimbal-type assembly to maintain vertical or near-vertical antenna orientation regardless of the vehicle's orientation with respect to the terrain; for the case where the vehicle might impact on the side of a hill, however, the gimbal assembly could not be expected to orient the beam of the antenna toward the target

The need for a suitable microwave elevation direction-finding device to solve elevation orientation problems when using a high-gain antenna became apparent The only simple and practical alternative was to consider an antenna which had a broader beamwidth and then to compensate for the corresponding reduction in antenna gain by increasing the antenna height above ground A solution to the latter approach was deemed less complex and possibly more reliable in operation so breadboard developmental work was initiated

1 See list of references in Section 7

## 3. OMNIDIRECTIONAL ANTENNA TYPES CONSIDERED.

Initial electrical design effort centered around various types of omnidirectional in azimuth, vertically polarized, S-band antennas which would provide free-space directive gains of at least 6 db over the frequency range of 2.7 to 2.85 Gc with antenna power handling capabilities of 2-kilowatt peak (20 watts average)

The first antenna type considered was a curved-surface radiator of the tapered monopole variety with a dielectric-ring type of lens above a metallic ground plane.[2] Preliminary tests of this type of omnidirectional antenna configuration disclosed, however, that the dielectric ring's beam-shaping effect in elevation was not as pronounced as was expected.

The next antenna type considered was a simple series-fed collinear array of four dipoles.[3] Seemingly identical breadboard models exhibited rather pronounced variations in electrical characteristics; the relatively small cylindrical configuration was found to be critical with regard to alignment, spacing, tolerances, etc. In addition, test results at these microwave frequencies could not be repeated readily with routine handling of the breadboard models. A parallel-fed collinear dipole array with a coaxial-within-coaxial feed offered hope of improvement over the series-feed arrangement, but proved to be quite complex in feed arrangement.

The last antenna type considered was an individually fed stacked-discone array consisting of four radiating elements connected via spiraling coaxial cable routings to a power divider.[4,5,6] When this configuration was breadboarded and tested electrically, it was found to be much less critical to physical misalignments and other nonuniformities than the other antenna types investigated.

The last configuration, the stacked-discone array, appeared to satisfy the need for a relatively simple, mechanically reliable structure which could lend itself to modular construction (the radiating elements are individually fed from separate ports of the power divider). The modular aspect was considered desirable for various reasons. For instance, in later radiation measurements, patterns could be obtained for a single element as well as for the array of four elements and comparisons could be made conveniently between wide-beam and relatively narrow-beam effects over terrain at different orientation angles. Consequently, a breadboard model was designed and constructed in the modular configuration for system testing within the laboratory.

It should be noted that the antenna breadboard effort centered around electrical characteristics physical requirements relating to size, weight, vibration, shock, and other environmental factors were not stressed in the breadboard

2. [illegible] Continued

eff[illegible]rts reported here. After performing preliminary system tests and deciding upon either the single-element or multi-element (more directive) array for further testing, [illegible] commercial [illegible] could be introduced into the further development of a lightweight prototype [illegible] capable of surviving shock and vibration during field use.

## 4. DEVELOPMENT OF THE STACKED-DISCONE ARRAY ANTENNA.

The radiation pattern of a discone element is similar to that of a dipole; the energy is radiated in patterns which form a solid of revolution with a figure-eight cross section. The operational frequency range of a discone, however, exceeds that of a dipole. With the discone's axis oriented vertically, the radiating element provides vertically polarized patterns which are, for the idealized case, perfectly omnidirectional in azimuth. (Slight deviations in the omnidirectional characteristic were encountered in this application, due to slight aperture blocking by feed lines. This is discussed later.)

### 4.1 Discone Geometry.

The discone consists of a cone (i.e., a conducting conical surface) and a coaxial feed line that is coincident with the axis of the cone. The outer conductor of the coaxial is connected to the cone and the inner conductor of the coaxial is permitted to pass through the slightly truncated apex of the cone and connect to the center of a relatively small conducting disk. The disk is positioned perpendicular to the cone's axis and at a predetermined spacing.

The cone's flare angle and slant height are based upon electrical requirements (relating to such characteristics as bandwidth, impedance, and desired radiation pattern characteristics) in addition to physical requirements which relate to maximum over all size. Disk size and disk-to-cone spacing are chosen for optimum impedance match to the coaxial-line feed.

With reference to Figure 1, the geometry of a discone can be expressed thus:

$$\frac{\psi}{2} = \tan^{-1} \frac{(r_1 - r_o)}{h_c} ,$$

where $\psi$ = total flare angle (as measured from the truncated apex of the cone),

$r_1$ = maximum radius of the cone,

$r_o$ = minimum radius at the slightly truncated apex,

$h_c$ = height of the cone (as measured from the truncated apex).

Optimum values for disk size and disk-to-cone spacing were established experimentally; disk radius ($r_d$) was set at 70 percent of the maximum cone radius ($r_1$), and disk-to-cone spacing(s) was selected on the basis of minimum impedance mismatch over the operational frequency range. The cone's slight truncated apex forms a part of the antenna feed; a value was assigned

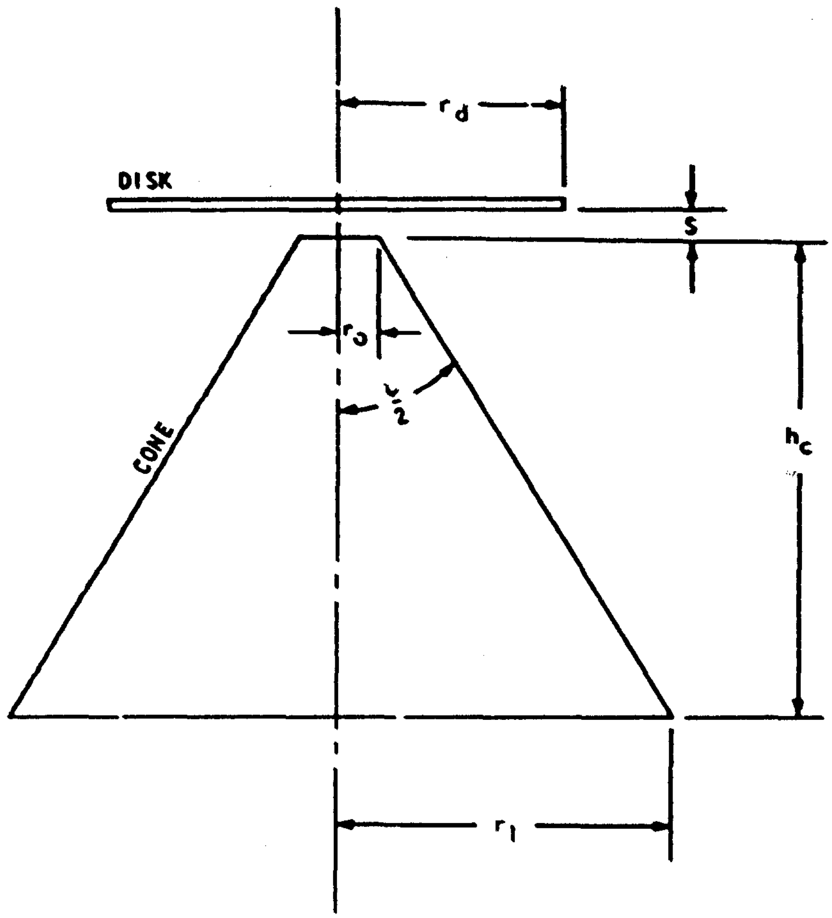


Figure 1. Discone Geometry.

4.1 -- Continued

to $r_o$, the minimum radius at the truncated apex, such that it would be essentially negligible in the geometrical relationship expressed above (i.e., a value of approximately 10 percent or less of the maximum cone radius).

With reference to Figure 1, design compromises were neeeded in the geometrical layout of the discone to achieve desired radiation-pattern characteristics and suitable impedance matches consistent with physical requirements relating to maximum permissible size [i.e., in terms of flare-angle ($\psi$) and height ($h_c$)].

Geometrical values selected for the application were as follows:

$h_c$ : 1.62 inches (0.372 to 0.390 $\lambda$ over the operational frequency range)

$\psi$ : 59 degrees

$r_1$ : 1.00 inch

$r_d$ : 0.70 inch

s : 0.122 inch

$r_o$ : 0.100 inch.

One of the discone elements, prior to assembly, is shown in Figure 2. The three large dielectric disks (with slotted edges) provide support for the cone and small disk and provide a guide for the coaxial cable routing of other discone elements after assembly. The dielectric rods serve as spacers between decks. Figure 3 shows the modular, discone element after assembly with its individually fed coaxial line which connects to one of the ports in a power divider.

Electrical measurements made upon the single element disclosed a VSWR of 1.25 ±0.2 over the operational frequency range, with elevation-pattern half-power beamwidth approximately 50 degrees (i.e., in free space). The free-space directive gain was 3.1 db relative to isotropic at the midband frequency of 2.75 Gc.

## 4.2 Stacked-Discone Array.

Figure 4 shows the assembled, stacked-discone array. Four identical discone modules are stacked, one above the other, with their individual coaxial feed lines spiraling downward and connecting to the power divider. The radiating

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Figure 2. Single-Element Discone Prior to Assembly.

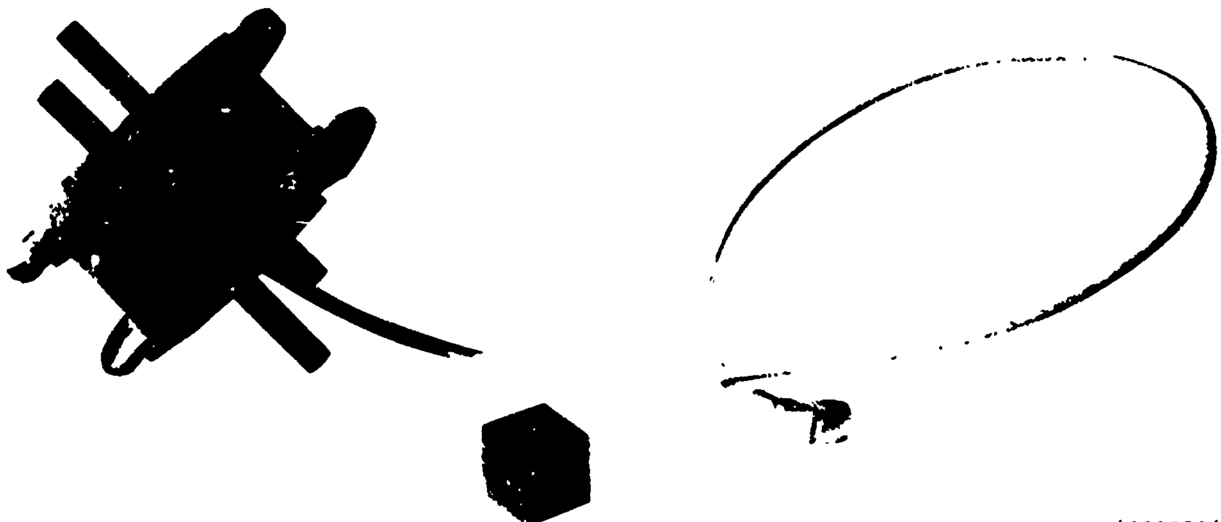

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Figure 3. Assembled Single-Element Discone.

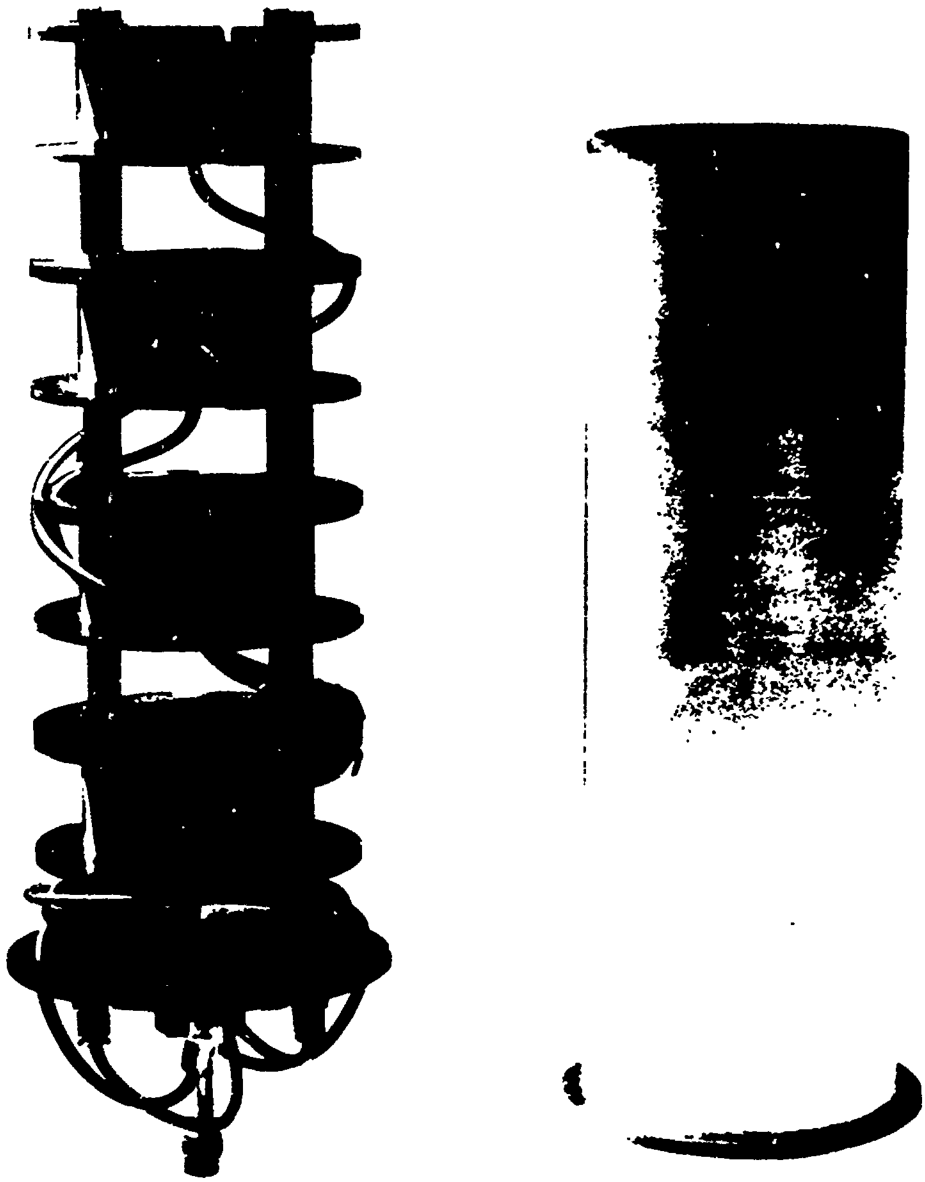

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Figure 4. Assembled Stacked Discone Array with Radome Removed

4.2 -- Continued

elements are 270 electrical degrees apart and are fed in phase by equal lengths of coaxial line. The lengths of coax for the lower elements are wound around the base support of the power divider. The larger dielectric disks, in addition to serving as guides for the spiraling coaxial lines, also serve as guides for mounting the radome (shown to the right in Figure 4)

The four-element stacked-discone array antenna with radome assembled is shown in Figure 5. This antenna array has an overall height of 20 inches including the power divider. The height of the radome is 15-5/8 inches with an outside diameter of approximately 5-1/16 inches. Maximum overall diameter at the base of the assembly is 5-3/4 inches. Total weight of the antenna array is 6.25 pounds. (No attempts were made to restrict weight in this breadboard model. The experimental discone elements were constructed of brass, which is very easy to machine.)

4.3 Radiation Pattern.

For a vertical array of discone elements, maximum free-space radiation occurs in the horizontal direction when all of the radiating elements are operated in phase. The elevation pattern characteristic of a vertically discone array may be expressed thus[4].

$$F(\beta) \approx \cos\beta \left[ \frac{\sin n\left(\frac{s^{o}}{2}\sin\beta - \frac{\varphi}{2}\right)}{\sin\left(\frac{s^{o}}{2}\sin\beta - \frac{\varphi}{2}\right)} \right]$$

where $\beta$ - elevation angle

$n$ number of discone elements

$s^{o}$ - spacing (electrical degrees) between discones

$\varphi$ : phase difference between adjacent discones.

The individual feed of this antenna array makes it convenient to shift the axis of the main beam slightly (i.e., up or down in elevation) by altering the individual lengths of coaxial line. The electrical phase difference between adjacent discones ($\varphi$), as expressed in the above relationship, can be varied in accordance with the following relationship

$$\varphi = s^{o} \sin\beta_{T}$$

where $\beta_{T}$ - the desired angle of beam tilt

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Figure 5. Four-Element Stacked Discone Array Antenna with Radome Assembled.

4.3 --Continued

Equal lengths of coaxial line were used to feed the discone elements in phase for initial system testing. A problem was encountered in the precise placement of the separate coaxial transmission lines in order to achieve the least disturbance in azimuth pattern characteristic. As in most vertically oriented omnidirectional structures, the supporting mast or, in this case, the multiple transmission line feeds have currents induced in them by the radiating elements; these induced currents (and their resultant reradiated energy) cause slightly distorted or scalloping effects in the omnidirectional radiation pattern. In this application, pattern distortion was minimized by spiraling the coaxial lines past the discone apertures to spread the effects of aperture-blocking more evenly in azimuth. The radome ensures that the rather critical positions of the coaxial cables will not be disturbed by handling the model. Radiation-pattern measurements disclosed that maximum deviations from omnidirectional approximated 2 to 2.5 db.

Typical free-space radiation-pattern measurements are shown in Figures 6 and 7. Figure 6 shows the free-space elevation pattern at midband for the stacked-discone array. Half-power beamwidth is about 17 degrees; directive gain relative to isotropic is approximately 8 db. Typical deviations from the perfectly omnidirectional characteristic are shown in the azimuthal radiation pattern of Figure 7. Here, a deviation of 1.5 db can be observed at a midband frequency of 2.75 Gc. Cross-polarization approximates minus 12.5 db maximum.

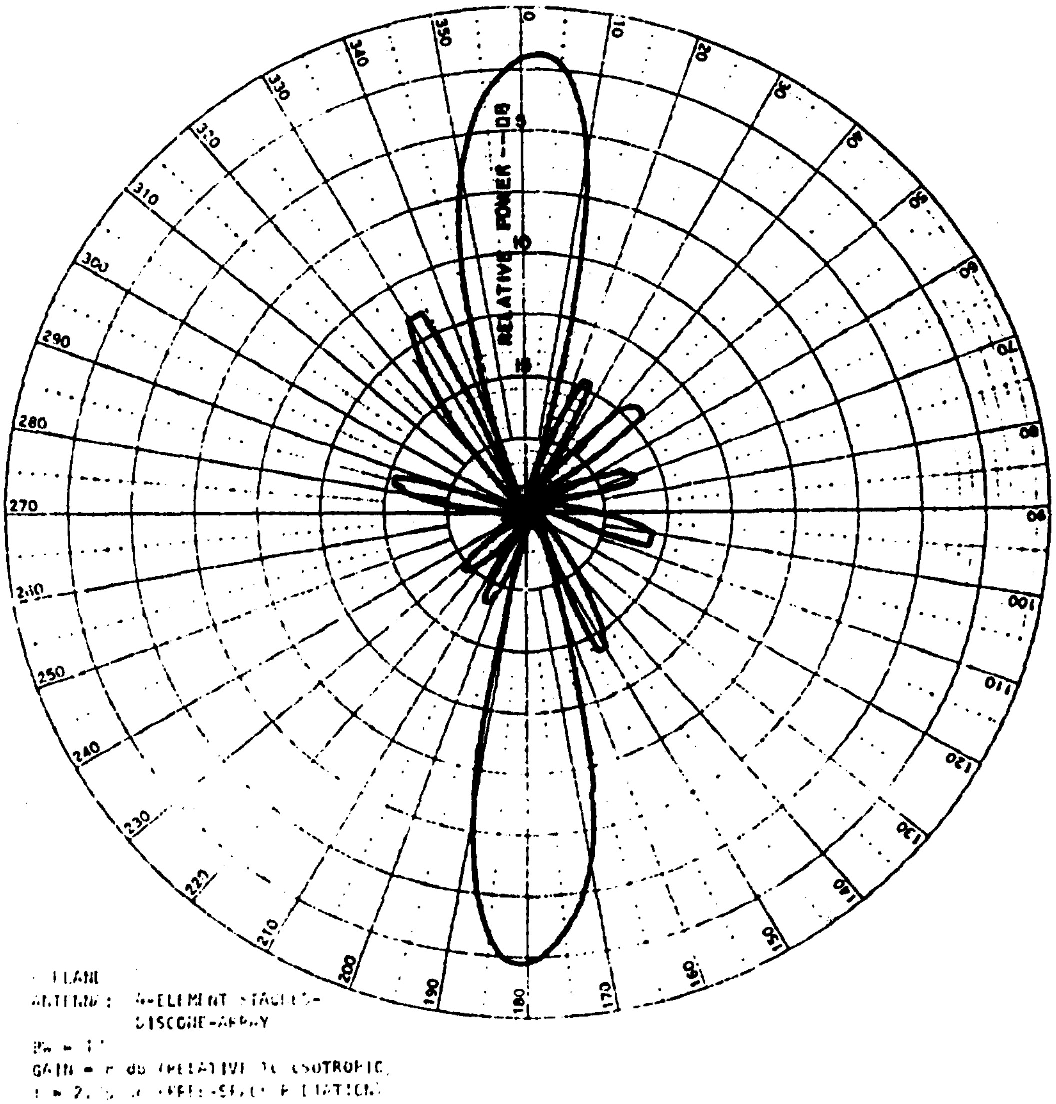
Over the frequency range of 2.7 to 2.85 Gc, free-space directive gain of the four-element stacked-discone array is about 7.5 to 8 db with an average beamwidth of 17 degrees. Maximum side lobe level over this frequency range is minus 9 db.

VSWR values over the operational frequency range are about 1.3 ± 0.2 for the array. Figure 8 provides a comparison of VSWR values the array of four elements and for a single element.

## 5 GROUND EFFECTS

### 5.1 Theoretical Considerations

The important effect that height above ground has upon the radiated power level of a microwave antenna can be described mathematically using the following theoretical concepts. For an antenna's free-space radiation pattern it is assumed that a reflecting surface (or surfaces) is infinitely far




[illegible] Radiation Pattern — Elevation

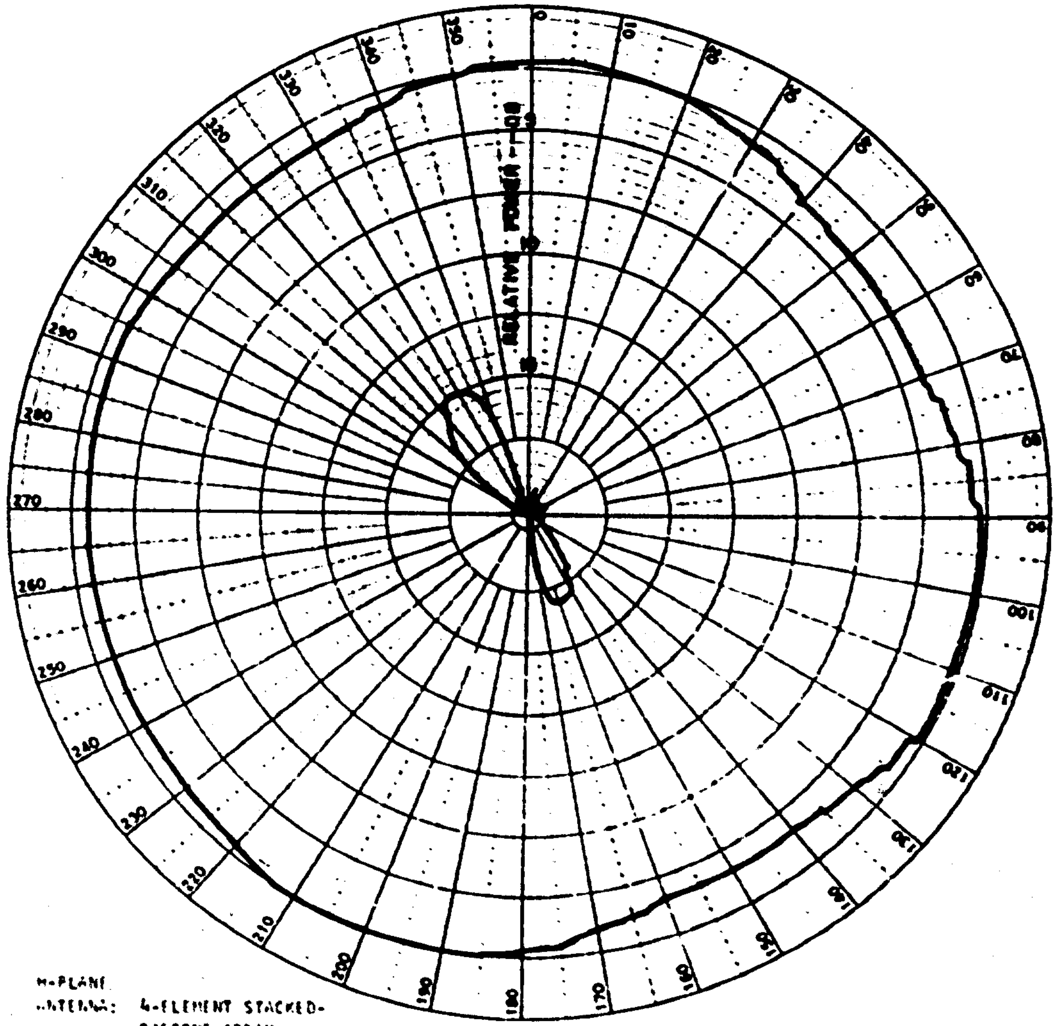



Figure 7. Radiation Pattern -- Azimuth.

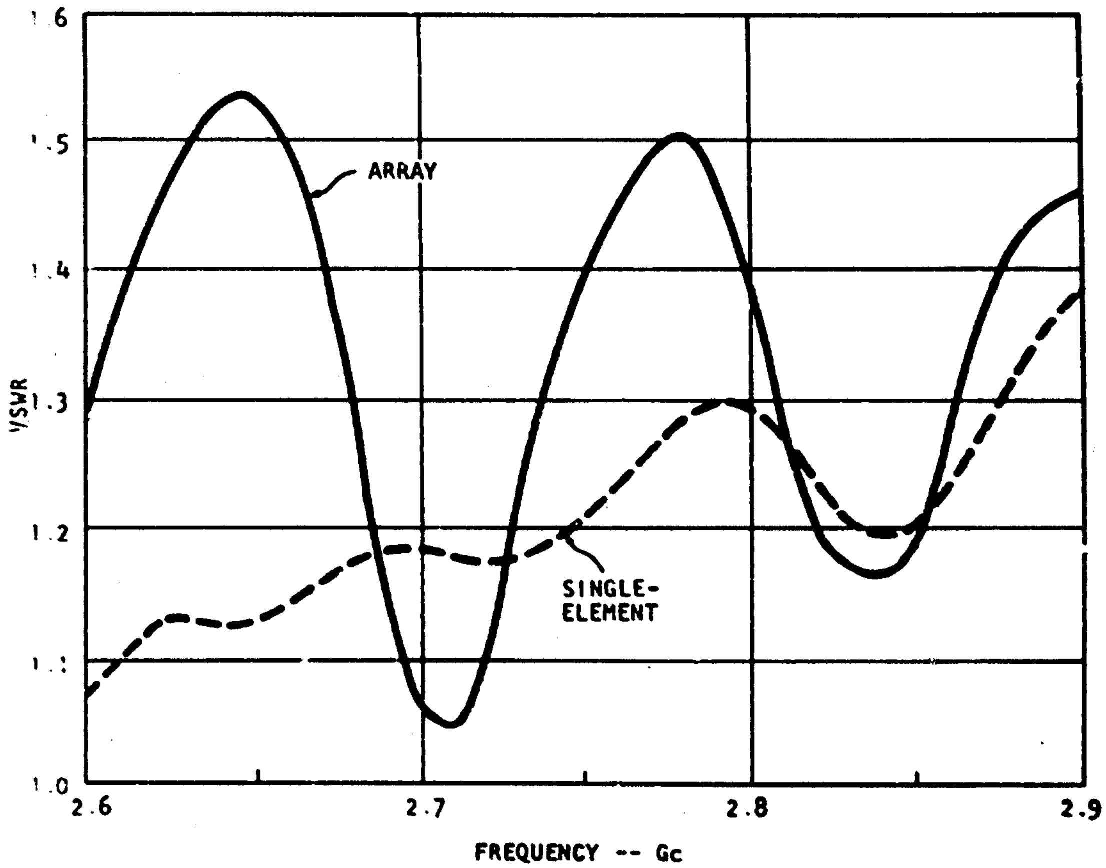



Figure 8. VSWR as a Function of Frequency.

5.1 --Continued.

away from the antenna or that the surface's reflection coefficient is negligible. In the presence of perfectly flat earth infinite in extent and at a distance of many wave-lengths from a microwave antenna, field intensity (relative to that in free space) may be expressed thus

$$\frac{E}{E_o} = \left[ 1 + \rho \quad e^{j\Delta} + \quad . \right] .$$

where $\frac{E}{E_o}$ · field intensity relative to that in free space

$|\rho|$ = magnitude of the reflection coefficient

$\Delta$ - phase difference between the incident and reflected waves

Other terms are considered to be negligible here (i.g., surface wave, secondary ground effects, induction field, etc ).

In this generalized relationship, the first term (which has a value of unity) represents the direct wave; the second term represents the reflected wave. Rewriting the expression in terms of relative power level we obtain

$$\frac{P}{P_o} = \frac{E}{E_o}^2 = \left[ 1 + |\rho \quad e^{j\Delta} \right]^2$$

$$= \cdot P_o \left[ 1 + |\rho| \quad (\cos \Delta + j \sin \Delta) \right]^2$$

The term contained within the brackets is known as the ground effect and tends to alter the antenna's free-space radiation-pattern power level ($P_o$) in accordance with the magnitude of the reflection coefficient ($|\rho|$) and the difference in phase which exists between the incident and reflected waves ($\Delta$)

5.1 --Continued.

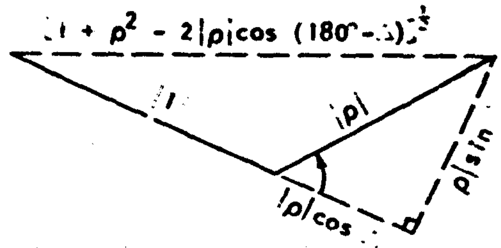



Figure 9. Vector Relationship.

From the vector relationship shown in Figure 9, the ground-effect term is the vector sum or resultant of the incident and reflected waves, as established by the law of cosines:

$$\left[1+|\rho|\,(\cos\Delta+j\sin\Delta)\right]^2 = \left[\left\{(1)^2+|\rho|^2-2|\rho|\cos(180^\circ-\Delta)\right\}^{\frac{1}{2}}\right]^2$$
$$= \left[1+\rho^2+2|\rho|\cos\Delta\right].$$

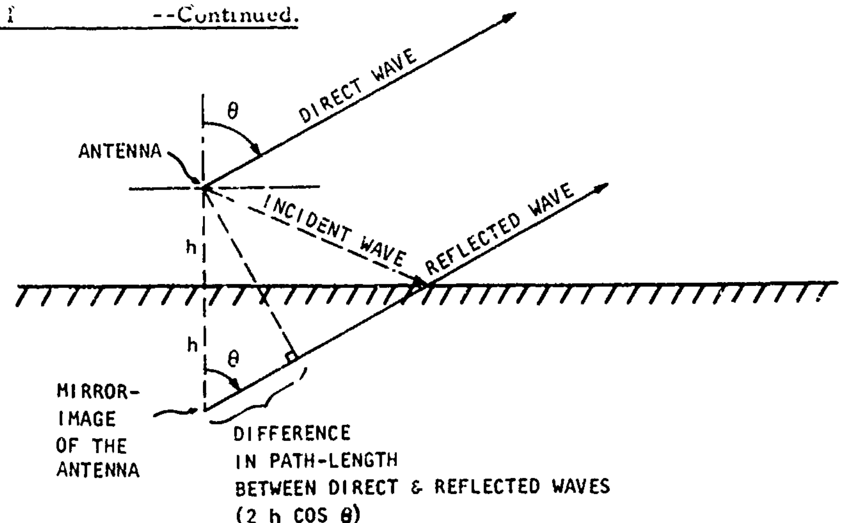
The difference in phase ($\Delta$) which exists between the incident and reflected waves can be expressed thus:

$$\Delta = (\alpha - \delta),$$

where $\alpha$ = phase angle of the reflection coefficient (i.e., the phase change occurring at reflection)

$\delta$ = phase angle associated with the effective change in path length (i.e., between the antenna's direct wave and the reflected wave, as expressed in wave-length).

5.1 --Continued.




$$\left[\delta = \text{ELECTRICAL LENGTH} = \left(\frac{2\pi}{\lambda}\right)(2\ h\ \cos\theta) = \frac{4\pi h\ \cos\theta}{\lambda}\right]$$

Figure 10. Geometry of a Microwave Antenna and its Mirror Image.

Difference in path length between the direct and reflected waves can be conveniently determined by assuming a mirror-image beneath the antenna as shown in Figure 10. Expressed in electrical length:

$$\delta = (2h \cos\theta)\left(\frac{2\pi}{\lambda}\right)$$

$$= \frac{4\pi h \cos\theta}{\lambda}$$

| | | | |
|---|---|---|---|
| where | $h$ | = | antenna height above the ground plane |
| | $2h$ | = | distance between the antenna and its mirror-image |
| | $\theta$ | = | angle of the antenna's direct wave as measured with respect to vertical |
| | $\lambda$ | = | operating wavelength (in free space). |

Hence,

$$\Delta = (\alpha - \delta) = \left[\alpha - \left(\frac{4\pi h \cos\theta}{\lambda}\right)\right] .$$

5.1 --Continued.

Substituting this term into the generalized relationship.

$$P = P_o \left[1 + \rho^2 + 2|\rho| \cos \Delta\right] = P_o \left[1 + \rho^2 + 2|\rho| \cos \left(\alpha - \frac{4\pi h \cos \theta}{\lambda}\right)\right]$$

From this relationship it will be noticed that $P_o$, the power level of the antenna's free-space radiation pattern, is modified in accordance with a cosine function involving antenna height above ground, expressed in terms of wavelength. Maxima and minima are introduced within the ground-effect term. A maximum occurs when the direct and ground-reflected waves are in phase, a minimum occurs when the reflected wave is 180 degrees out of phase (or nearly so) with the direct wave.

5.2 Computation Results

The results of computations based upon theoretical concepts presented in Section 5.1 are shown graphically in Figures 11 through 16. The data do not include effects due to irregular terrain, obstructions, or vegetation. Only flat terrain is assumed; the data should be considered representative only for the idealized-terrain condition. Actual conditions encountered in the field will vary widely from this basic assumption.

In these computations, values assigned to the complex reflection coefficient (i.e., for average ground[7]) ranged from 0.995 $/180^\circ$ to $/0.77^\circ$ at elevation angles between 0.05 and 2.0 degrees, respectively. A frequency of 2.75 Gc (i.e., midband) was assumed throughout the calculations. It should be noted that all calculations involving the antenna array and its ground effect were based upon the measured free-space elevation-pattern characteristic shown in Figure 6. Therefore, a free-space directive gain of 8 db (relative to isotropic) serves as the basis upon which comparisons may be made with radiated power levels over flat terrain.

Elevation angle (i.e., $90^\circ - \theta$) versus power level as a function of antenna height above ground is shown in Figure 11 for vertical antenna-array orientation. At a very small elevation angle, say 0.05 degree, the radiated power level can be increased 6 db by doubling the antenna height. For instance, a power level of minus 8 db at an antenna height of 5 feet can be increased to minus 2 db by doubling the height to 10 feet. As elevation angle is permitted to increase, the radiated power levels gradually increase and (for this, the theoretically flat-terrain case) eventually reach maxima between plus 12.9 and plus 13.8 db for antenna heights of 2-1/2 and 12-1/2 feet, respectively. First maximum and first minimum can be readily observed in Figure 11 for the vertically oriented case. A maximum level of only plus 8 db can be expected in situations where variations in terrain

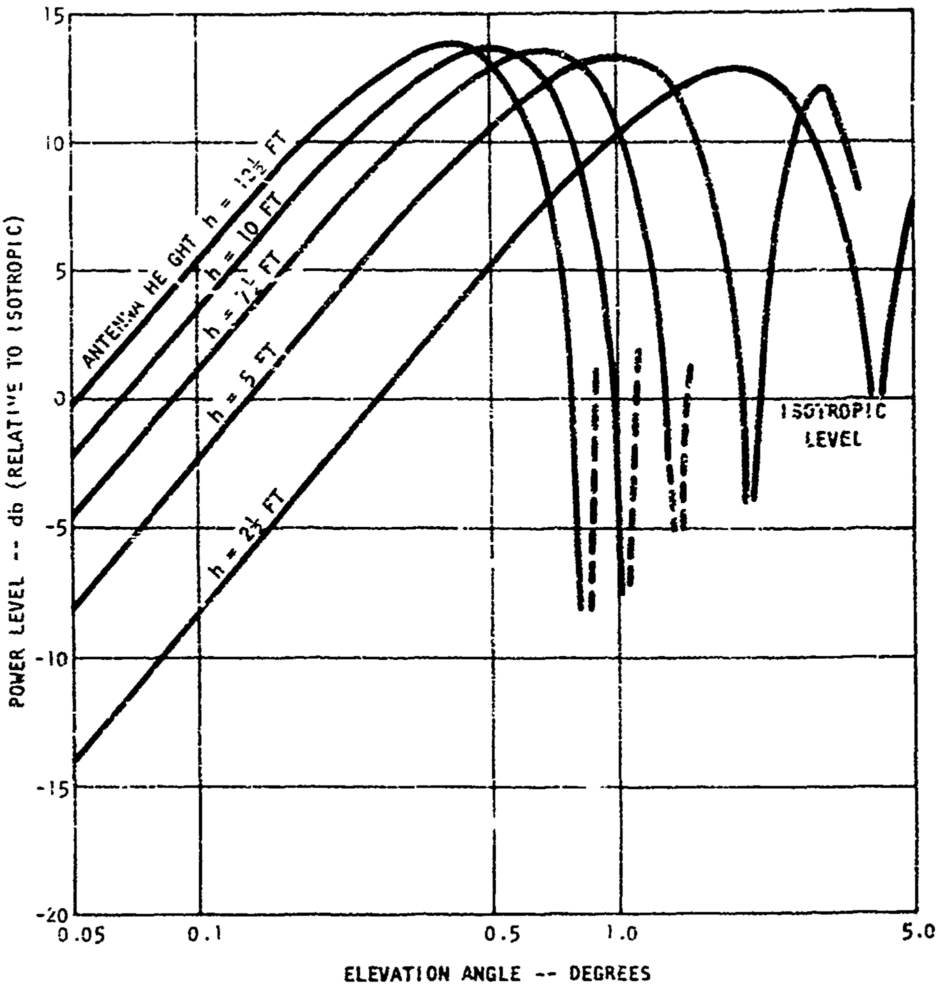



Figure 11. Power Level as a Function of Elevation Level and Antenna Height.

5.2 -- Continued.

contour are almost comparable to that of the antenna's height.

Figure 12 shows radiated power-level characteristics for an antenna-array orientation of 5 degrees off vertical. A radiated power level of minus 9.3 db now exists at an antenna height of 5 feet; minus 3.3 db exists at 10 feet for 0.05 degree elevation. Therefore, a 1.3-db reduction occurred between vertical orientation and 5 degrees off vertical. Tilting the beam upward and downward produces an appreciable difference in radiated power level in the vicinity of 3 to 5 degrees in elevation. When the beam is pointed downward 5 degrees at an antenna height of 2-1/2 feet a null in excess of minus 10 db exists at 4 degrees elevation; when the beam is pointed upward 5 degrees, however, the level of the null increases to plus 4.5 db. At elevation angles less than 2 degrees, upward and downward beam tilts produce no noticeable difference in radiated power level.

Figure 13 shows the case of a stacked-discone array oriented 10 degrees off vertical. Since the free-space half-beamwidth is 8.5 degrees, much less power now radiates at small elevation angles. For an antenna height of 5 feet, for instance, a radiated power level of minus 14.5 db now exists at 0.05-degree elevation; correspondingly, at 10 feet, a radiated power level of minus 8.5 db exists. A reduction of 6.5 db has occurred between vertical orientation and 10 degrees off vertical orientation. Tilting the beam upward and downward produces a difference in radiated power level above 1-degree elevation, as can be seen in Figure 13. Below 1-degree elevation, upward and downward beam tilts produce no noticeable difference in radiated power level.

A composite set of curves for an antenna-array height of 5 feet at various orientations appears in Figure 14. At an elevation angle of 0.28 degree, the radiated power level for vertical orientation is plus 6.5 db; for 5 degrees off vertical, the radiated power level is plus 5 db; and at 10 degrees off vertical, the power level is 0 db relative to isotropic.

Figure 15 shows a set of curves for a single-discone radiating element. In free space the single element's half-beamwidth is 25 degrees; orientation angels for vertical to approximately 15 degrees off vertical do not significantly affect the power level near the horizon and are, therefore, accommodated in this set of curves. Measured free-space directive gain of the single-discone element is approximately plus 3 db (or 5 db down from the four-element array's free-space gain of plus 8 db). This reduction in radiated power level can be readily observed from the curves in Figure 15. For instance, at an antenna height of 5 feet and at 0.05 degree elevation, the radiated power of a single-discone element is minus 13 db for any orientation from vertical to about 15 degrees off vertical.

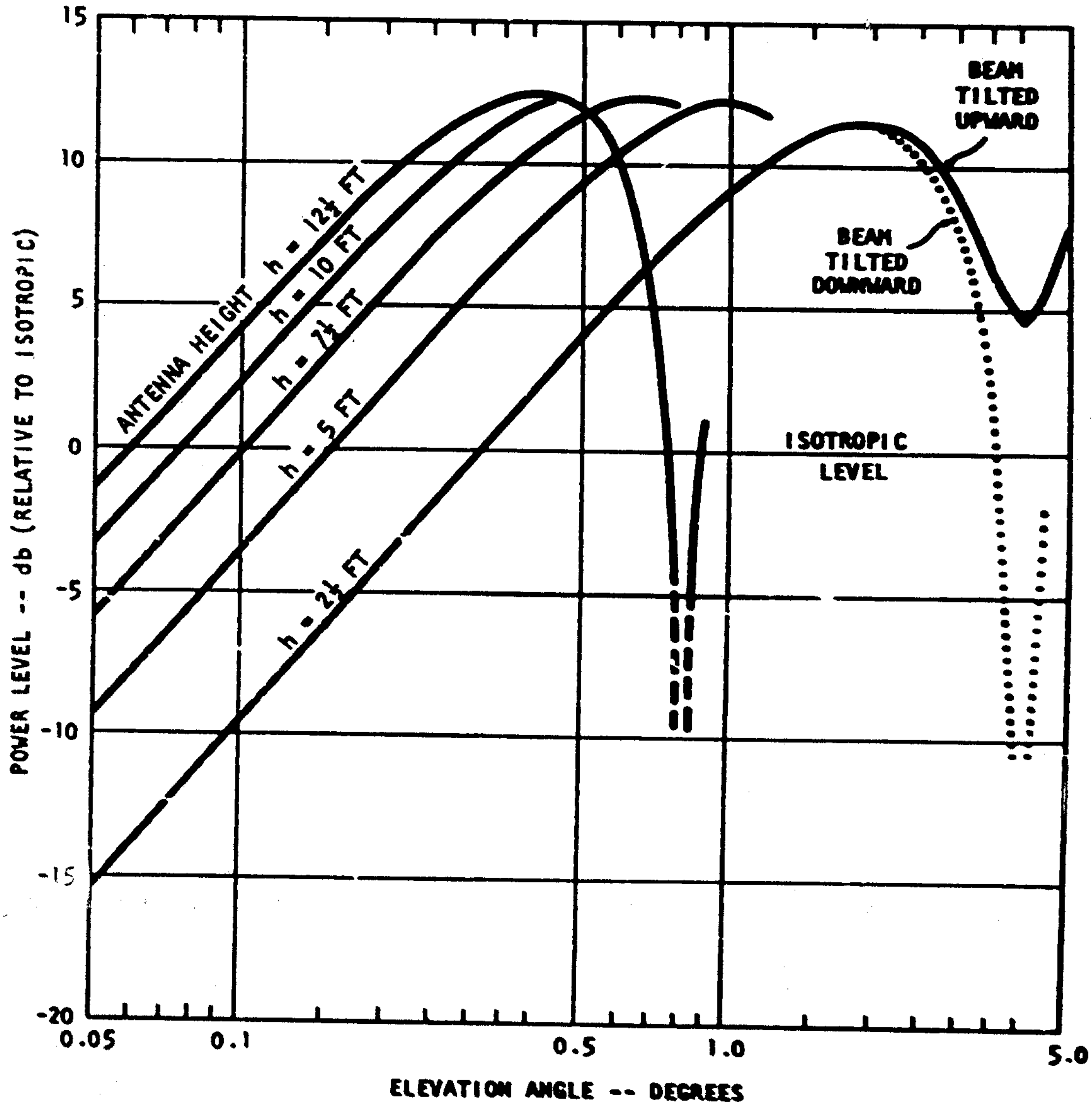



Figure 12. Power Level as a Function of Elevation Level and Antenna Height.

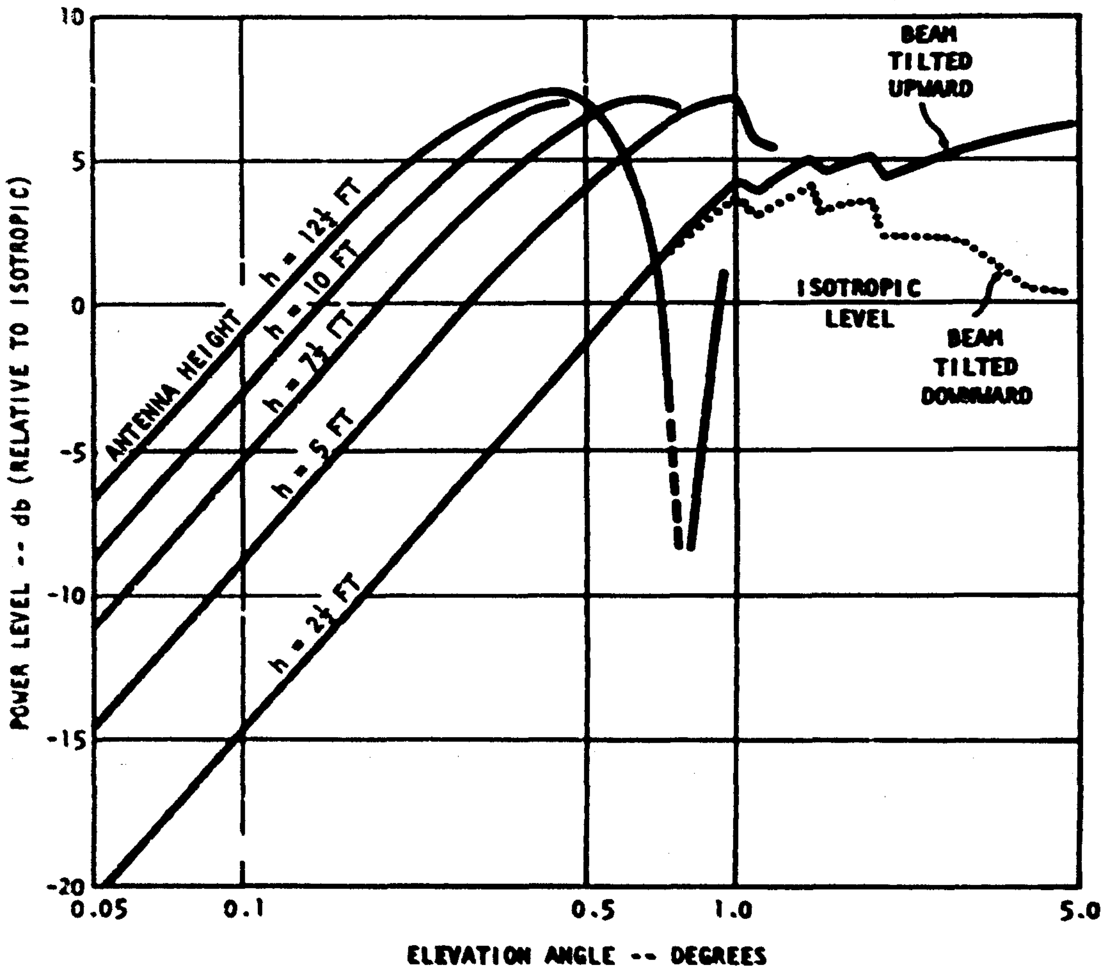



Figure 13. Power Level as a Function of Elevation Angle and Antenna Height.

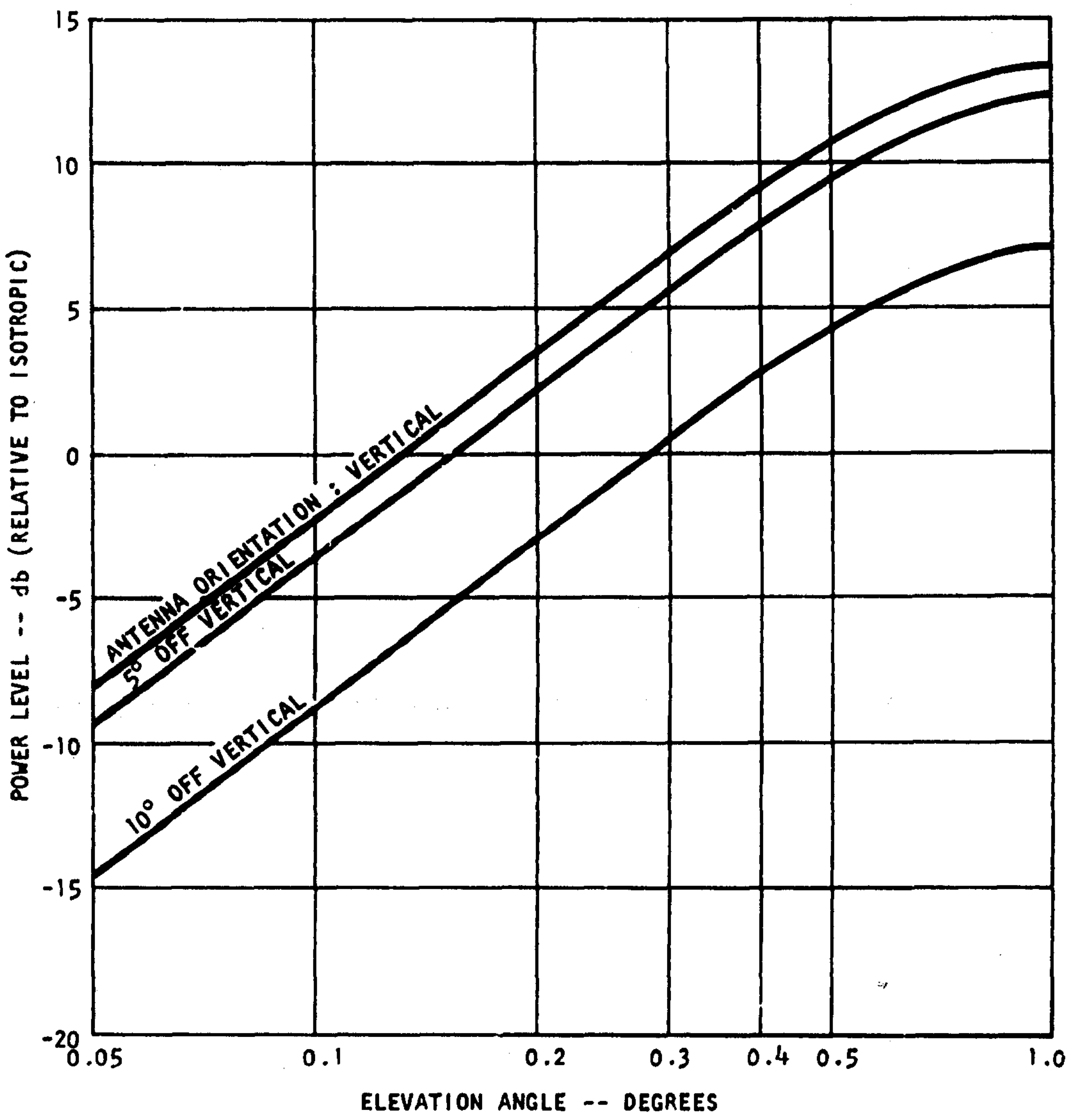



Figure 14. Power Level as a Function of Elevation Angle and Antenna Orientation.

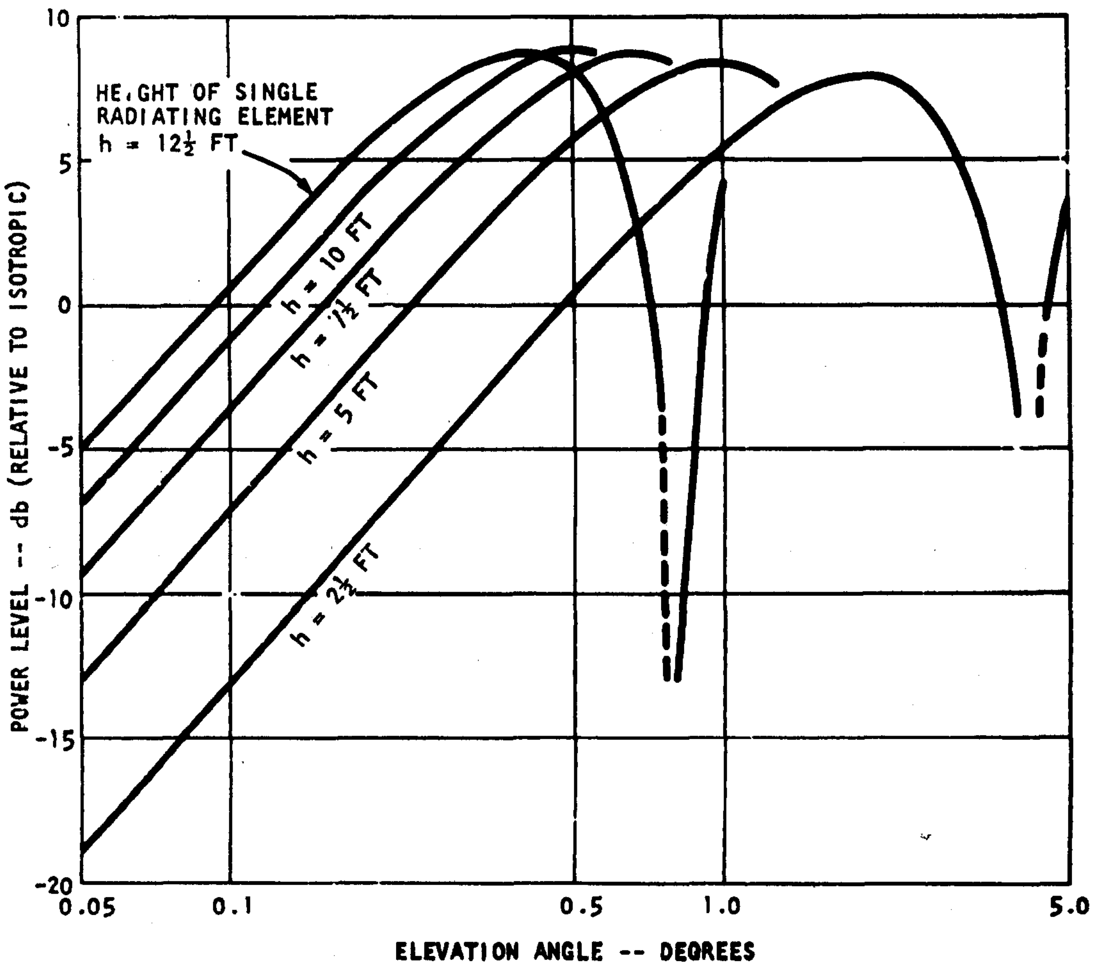



Figure 15. Power Level of a Single Element as a Function of Elevation Angle and Antenna Height.

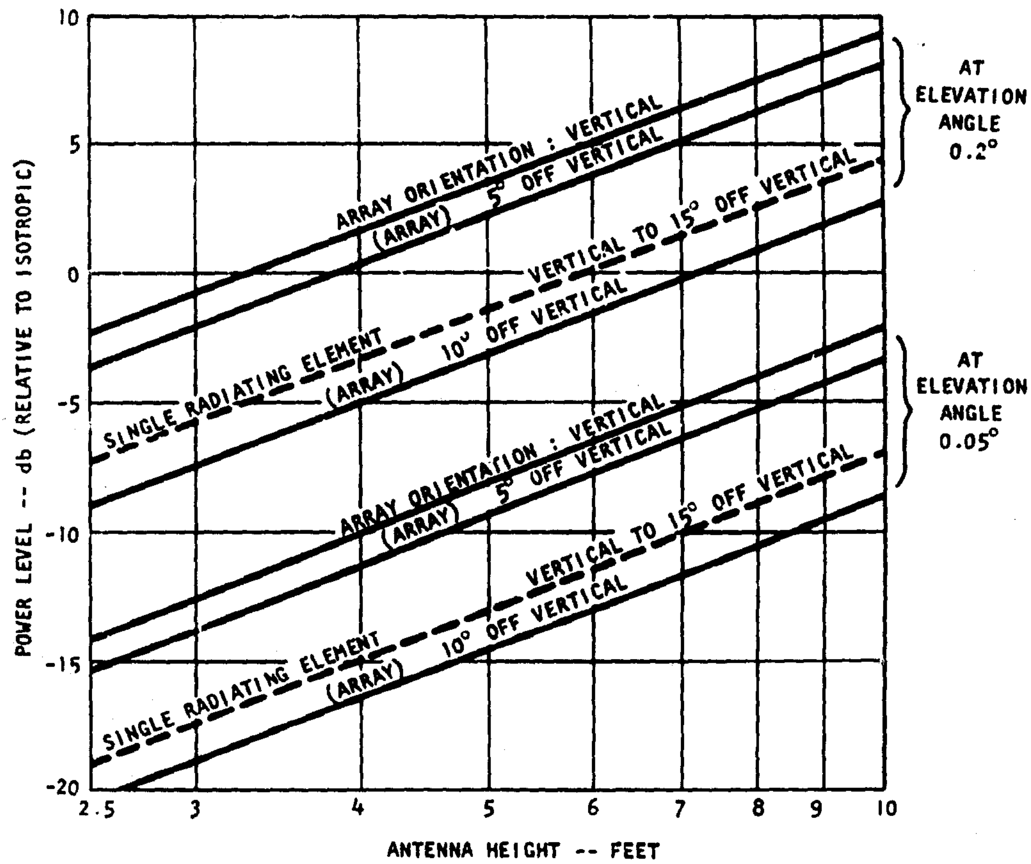



Figure 16. Power Level as a Function of Antenna Height and Antenna Orientation for Low Elevation Levels (Flat Earth).

5.2 --Continued

For final comparisons, Figure 16 has been plotted for two small elevation angles only, 0.05 and 0.20 degrees. Here the graphical data have been plotted such that the solid lines represent characteristics of the four element array (i.e for various orientations discussed earlier) and the dashed lines represent characteristics associated with the single-discone element. It should be noted that in this illustration antenna height, instead of elevation angle, has been plotted along the abscissa Perhaps the most significant feature to observe in this set of curves is that a compromise must eventually be reached between maximum allowable antenna height above ground and minimum elevation angle for a specific radiated power level. For example, from Figure 16 it can be seen that the radiated power levels for either an array or a single element at 0.2-degree elevation and 2 5-foot antenna height are comparable to the radiated level which occurs at the reduced elevation angle of 0 05 degree and correspondingly increased antenna height of 10 feet

## 6 RESULTS OF INVESTIGATION.

A compromise must be reached between various system requirements to achieve a specified effective radiated power output from a microwave omnidirectional (in azimuth) antenna which is in relatively close proximity to flat earth If maximum effective radiated power is required at the lowest possible elevation angle, antenna height above ground must be increased accordingly

Should maximum antenna orientation off vertical pose serious problems in radiated power level for a particular elevation angle and antenna height, directive gain of the antenna may have to be sacrificed for broader beam width to help solve the antenna-orientation problem From the foregoing data approximately 5 db in radiated power level must be sacrificed when it appears desirable to substitute a broad-beamwidth single-discone element for a vertically oriented four element, stacked-discone array. However, for 10 degrees off-vertical orientation, 2 db in radiated power level can actually be gained by substituting the single-discone element for the four-element array

The heart of the antenna coupling problem is the important effect that height above ground has upon the antenna's radiated power level at low elevation angles For the successful tactical operation of a microwave jammer against a target near the horizon, antenna coupling problems essentially reduce to a series of compromises in antenna and system requirements under various environmental conditions

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Adequate electromagnetic coupling is essential to the successful tactical operation of a microwave jammer against a target. Factors such as reflecting surface and obstructions between antennas affect antenna coupling. the heart of the problem centers around antenna height above ground.

Engineering data related to the development of an 8-db (relative to isotropic) omnidirectional in azimuth antenna breadboard model and its measured free-space radiation are presented. Based upon theoretical ground-effect considerations, data are presented in graphical form to show the important effect that height above ground has on the antenna's

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28. Transmission
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