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DESIGN OF DIELECTRIC-LOADED CIRCUMFERENTIAL SLOT ANTENNAS OF ARBITRARY SIZE FOR CONICAL AND CYLINDRICAL BODIES

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- Cylindrical Antennas
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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

A class of dielectric-loaded slot antennas designed to conform to the shape of various body structures is described. These antennas are flush with the body surface, and designed to occupy minimum space. The basic radiating structure is a low-loss dielectric-core substrate plated with a thin copper wall to form a dielectric-filled cavity. A circumferential radiating slot is in the outer surface of the cavity. The cavity is excited by an inductive post driven from a coaxial line.

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The conformal radiating slot can be designed in the surface of small or large dielectric structures and results in durable antennas that may operate in the UHF or microwave frequency regions. It is efficient, operates very well over a 10-percent bandwidth, and can be designed to produce many desired antenna patterns.

Theory and experimental data on the different modes of radiation are discussed, along with the intrinsic characteristics of the selected dielectric materials. Design techniques, performance characteristics, and illustrations of a variety of prototype antennas are presented.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Contd)

LIST OF ILLUSTRATIONS (Contd)

TABLE

1. INTRODUCTION

Many antennas of conventional types (for example, monopoles, dipoles, and loops) that are currently in use on conical and cylindrical bodies are bulky, severely restricted as to their placement, and at best have only marginal performance. Because of demands to improve such antennas--that is, to reduce the volume, lower the profile, and maintain quality performance--alternate design techniques were investigated. The conformal ring-antenna technique proved to have significant advantages over the traditional antennas, both in its form factor and ease of construction.

The conformal ring antennas are circular cavity-backed slot radiators loaded with a dielectric material to effect size reduction; the dielectric may in fact be a structural part of the system so that essentially no additional space is required for the antenna. The flexibility inherent in the design method allows the antenna to be located at any position along the length of the body and flush with its surface. Each design presented provides solutions to problems peculiar to a certain weapon system.

2. DESIGN CONSIDERATIONS

Much is already known about radiation from slots in airfilled waveguides and resonant cavities. Both theory and experimental work on such radiators are well documented.[1-4]

The effect of an increase in dielectric constant on the characteristics of a dielectric-loaded waveguide or cavity antenna is a change in its input impedance and increase in its resonant wavelength. For a given frequency, a dielectric filled cavity antenna is considerably smaller than a comparable air-filled cavity antenna. The volume reduction realized is accomplished by some sacrifice in bandwidth.

If, for example, a waveguide is filled with a perfect dielectric (ε_1), the wavelength (λ_g) in the guide is given by

$$\lambda_g = \frac{\lambda_o}{\sqrt{\varepsilon_1 - \left(\frac{\lambda}{\lambda_c}\right)^2}} , \qquad (1)$$

---

[1] *Moreno, T.* *Microwave Transmission Design Data, McGraw-Hill Book Co., N.Y., 1948.*

[2] *Sevenson, A. F., Jr. "Theory of Slots in Rectangular Waveguides," Appl. Phys., Vol. 19, 24-38, Jan 1948.*

[3] *Watson, W.H. The Physical Principles of Waveguide Transmission and Antenna Systems, Oxford at the Clarendon Press, England, 1947.*

[4] *Galejs, J. "Admittance of a Rectangular Slot Which Is Backed by a Rectangular Cavity," IEEE Trans. on AP, Vol. AP-11, No. 2, March, 1963.*

where λ_o is free-space wavelength and λ_c is the cutoff wavelength of the air-filled waveguide. The propagation constant of a waveguide filled with perfect dielectric is expressed as[1]

$$\gamma = j\frac{2\Pi}{\lambda}\sqrt{\varepsilon_1 - (\lambda/\lambda_c)^2} \tag{2}$$

The normalized wave impedance (Z_{TE}) of a waveguide filled with dielectric and operating in the TE mode is

$$Z_{TE} = \frac{1 - (\lambda/\lambda_c)^2}{\varepsilon_1 - (\lambda/\lambda_c)^2} \tag{3}$$

The rectangular waveguide cavity[4,5] has a convenient size and a high Q that makes it useful in the UHF and microwave frequency regions. Such a resonant cavity is shown in figure 1. Normally, waveguide cavities have thick metal walls (0.020 to 0.075 in.) and a number of resonant frequencies. The corresponding wavelengths λ_r at which the cavity is resonant are given by[5]

$$\lambda_r = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{c}\right)^2}} \tag{4}$$

where m, n, and p are positive integers (one of which may be zero), and are equal to the number of half-period variations of the field along dimensions a, b, and c, respectively. To use the cavity as an antenna, it is customary to restrict the resonance to the fundamental mode and to introduce a radiating slot into the broad wall.[6] The size may be reduced by loading with a dielectric medium, and a conducting post may be used across the cavity to excite the slot.[7,8] The dielectric-loaded version of a planar L-band cavity-backed slot radiator is illustrated in figure 2.

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[1] *Moreno, T. Microwave Transmission Design Data, McGraw-Hill Book Co., N.Y., 1948.*

[4] *Galejs, J. "Admittance of a Rectangular Slot which is Backed by a Rectangular Cavity," IEEE Trans. on AP, Vol. AP-11, No. 2, Mar 1963.*

[5] *Radio Research Laboratory, Very High-Frequency Techniques, Harvard University, Vol. II, McGraw-Hill Book Co., N.Y., 1947.*

[6] *Cohen, M.H. "The Normal Modes of Cavity Antennas," Technical Report 486-7, Antenna Laboratory, Ohio State Univ., Columbus, Ohio, Dec 1952*

[7] *Jones, H.S. "Slotted Antenna Arrays Can be Smaller," Electronic Design, May 10, 1965.*

[8] *Jones, H.S. and Heinard, W.G. "An Improved Slot Array Using Post Excitation," Microwave Journal, July 1965.*

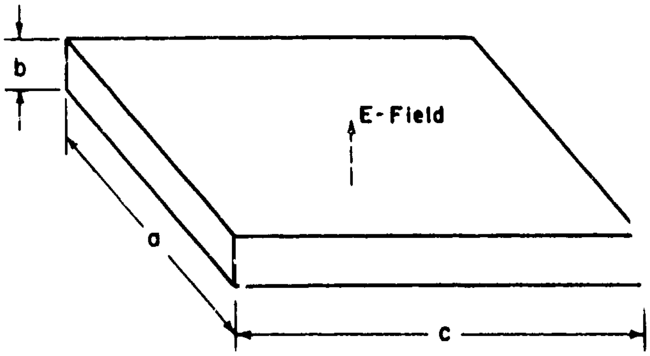

Figure 1. A simple rectangular cavity resonator.

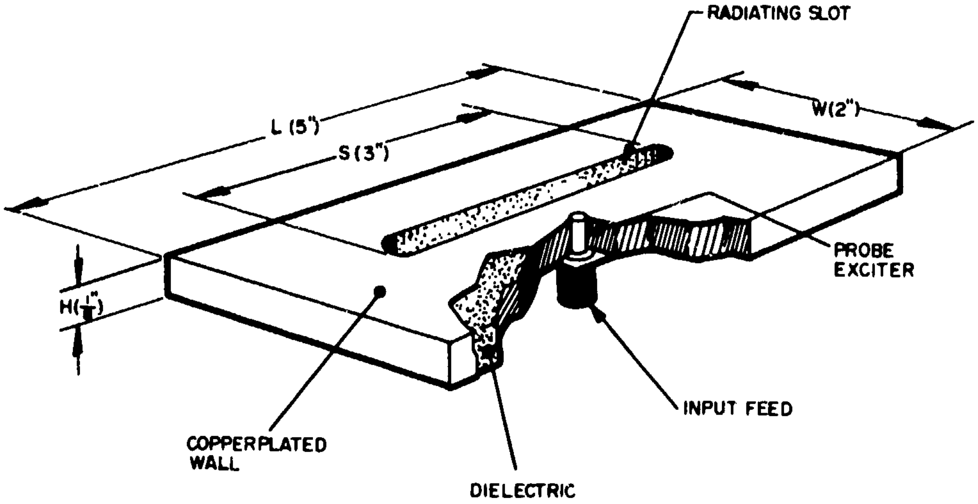

Figure 2. Conceptual view of planar copperplated dielectric-loaded cavity radiator.

Although there is considerable literature available on unfilled rectangular cavity antennas,[9] only limited work has been done on the design of conformal cavity radiators loaded with dielectric. Also, the theory does not always accurately predict the actual characteristics of experimental designs because of problems that arise from the quality of the dielectric, its position in the cavity, nonuniform field densities within it, and poor contact that occurs at the metal wall-dielectric interface. The poor contact alters significantly the behavior of the rf fields. The techniques used in this work tend to minimize some of these effects and make possible the design of miniaturized cavity antennas without a contact problem.

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[9] *Brownell, F. P. Jr. and Kendall, D. E. "Miniaturized Cavity-Fed Slot Antennas," IRE Wescon Conv. Rec., Pt. 1, pp 158-166, 1960.*

The important design parameters that are considered in the design of the cavity-backed dielectric-loaded slot radiators discussed here are the cavity dimensions, dielectric characteristics, and the slot length location. Adjustment and control of these parameters have a decided effect on the resonant frequency of the antenna and its overall performance. Also, much attention is given to the design and construction of the dielectric-loaded cavity radiator so that maximum energy is radiated.

3. CONSTRUCTION TECHNIQUES AND MATERIALS

Antennas described in this report are essentially constructed as an annular dielectric core or substrate machined to the desired shape for the body on which it is used. In most cases the bodies are cones, frustums of cones, or cylinders. Walls, holes for short circuits, input feeds, and matching posts are incorporated in the dielectric structure during fabrication. The finished dielectric core is then copperplated, using electroless plating techniques to form the dielectric-filled cavity. A circumferential radiating slot is cut at the appropriate position on the outer surface by removing a narrow strip of copper. Finally, the input coaxial feed is soldered in place on the inside surface.

This construction method is illustrated in principle by the planar dielectric-loaded slot cavity radiator shown in figure 2. The L-band radiator shown here was made from a rectangular slab (2 × 5 × 0.125 in.) of silicone fiberglass material; the copperplated wall is 0.003 in. thick. The coaxial connector serves as an input feed, and is also a means of exciting the slot.[8] This technique of exciting the slot in the cavity is used in most of the models shown in this report.

Choosing the proper dielectric material for loading the antennas is obviously a very important factor in achieving maximum efficiency. Generally, the dielectric materials used had low loss, dielectric constants ε_r ranging from $\varepsilon_r = 2.2$ to 9.0, and stable electrical and physical characteristics. A list of these materials along with their dielectric constant and loss tangent values are given in table I. In the initial experiments, cross-link polystyrene with high purity TiO_2 and polypropylene materials (5 and 7, table I), both having very low loss and predictable electrical characteristics, were selected to prove design feasibility and provide a measure of the maximum efficiency obtainable. Subsequently, other commercial materials such as teflon, silicone, and epoxy-based dielectrics (table I) were tested and found to be quite satisfactory. These materials have the practical virtue of being rugged, machinable, resistant to fairly high temperatures, and readily available in various shapes and sizes at a reasonably low cost.

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[8] *Jones, H. S. and Heinard, W. G. "An Improved Slot Array Using Post Excitation," Microwave Journal, July 1965.*

TABLE I
ANTENNA DIELECTRIC MATERIALS

	MATERIALS	DIELECTRIC CONSTANT (ϵ_r)	TAN δ	MANUFACTURER
1	SILICONE, FIBERGLASS BASE, LAMINATE	3.0	8×10^{-3}	CONTINENTAL DIAMOND
2	EPOXY, TEXTOLITE LAMINATED PLASTIC, G-10	4.5	2.2×10^{-2}	GENERAL ELECTRIC
3	MELAMINE, GLASS G-5	6.1	1.1×10^{-2}	GENERAL ELECTRIC
4	POLYTETRAFLUOROETHYLENE GLASS BASE, LAMINATE	2.6	6×10^{-3}	3M COMPANY
5	CROSS-LINK POLYSTYRENE (W/HIGH PURITY TiO_2)	3.0-4.0	1×10^{-3}	CUSTOM MATERIALS INC
6	FUSED SILICA MULTIFORM (7941)	3.35	1×10^{-3}	CORNING GLASS WORKS
7	POLYPROPYLENE RESINS	2.2	7.0×10^{-4}	AMOCO CHEMICAL CORP., CHICAGO, ILL.
8	ALUMINUM OXIDE (Al_2O_3)	9.2	1.1×10^{-3}	U.S. STONEWARE CO ORRIVILLE, OHIO

When used in constructing cavity radiators, all of these materials must accept copperplating without deformation or changes in their electrical characteristics. Most of these materials were compatible with the electroless plating method used, and were machinable so that the desired surface finish for the plating could be obtained. The teflon, silicone, and epoxy-laminated materials provided a slightly stronger copper-to-dielectric bond than did the polystyrene and polypropylene, and their electrical characteristics were found to be consistent and reliable. However, because of its higher dielectric constant (favorable for reducing size) and its low cost, the epoxy fiberglass laminate material was used more extensively than were the others. Some efficiency was sacrificed because of the slightly higher loss tangent.

Electroless copperplating is a technique by which a thin layer of copper is deposited on the surface of the dielectric by chemical means, and electrolytic methods are employed to obtain an additional buildup of copper. A smooth uniform thickness of metal is obtainable on surfaces of any desired shape. The technique has been used successfully in plating both organic and inorganic dielectric materials and the copper adheres strongly to the dielectric surface in most cases. A thickness of the copper suitable for the application can be chosen. Although electroless plating of dielectrics has many advantages in the construction of dielectric cavity radiators, the chemicals left on the substrate cause a small attenuation of energy. This tends to lower the efficiency slightly.

4. CYLINDRICAL ANTENNA DESIGN

The initial investigation of the dielectric-loaded cavity radiators began with the planar design shown in figure 2. This antenna (E-field across the slot) and modified versions of it proved to be very successful and simple to construct.

The coordinate system used for radiation pattern measurements for this and other antennas discussed in this report is given in figure 3. Radiation patterns of the planar copperplated dielectric-loaded cavity (fig. 2) taken in a ground plane are shown in figure 4. Patterns were taken in two principal planes--one perpendicular to the plane of the antenna and parallel with the slot [$E_\theta(\phi)$, $\theta = 90$ deg], and the other perpendicular to both the plane of the antenna and the slot length [$E_\theta(\theta)$, $\phi = 90$ deg]. This antenna has broad radiation coverage in one plane, a relatively high gain considering its size, and at least a 10-percent bandwidth.

From the antenna shown in figure 2, a cylindrical ring antenna was developed by folding a planar design around a 2-in. diameter so that the shorted ends came within a narrow gap of being together. This antenna with its circumferential radiating slot is shown in figure 5c. Another version of this antenna was produced by replacing the short circuit at the ends of the cavity and a simple conductive post across the cavity (diametrically opposite to the feed) as shown in figure 6. This antenna, which uses a plated-through process to produce the conductive post, is extremely compact (2.375-in. diam, 1.0 in. high, and 0.125 in. thick) and operates in the L-band region. It has an epoxy fiberglass core, and a circumferential radiating slot that is slightly longer than a half-wavelength.

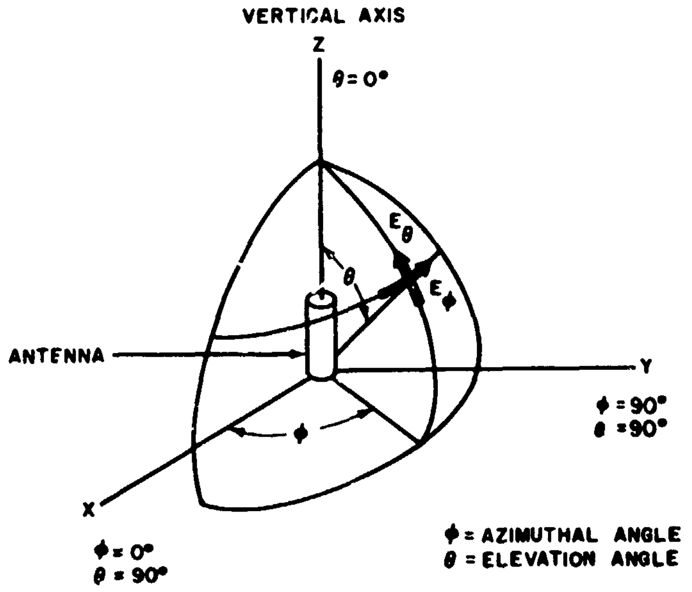

Figure 3. Coordinate system for antenna radiation pattern measurements.

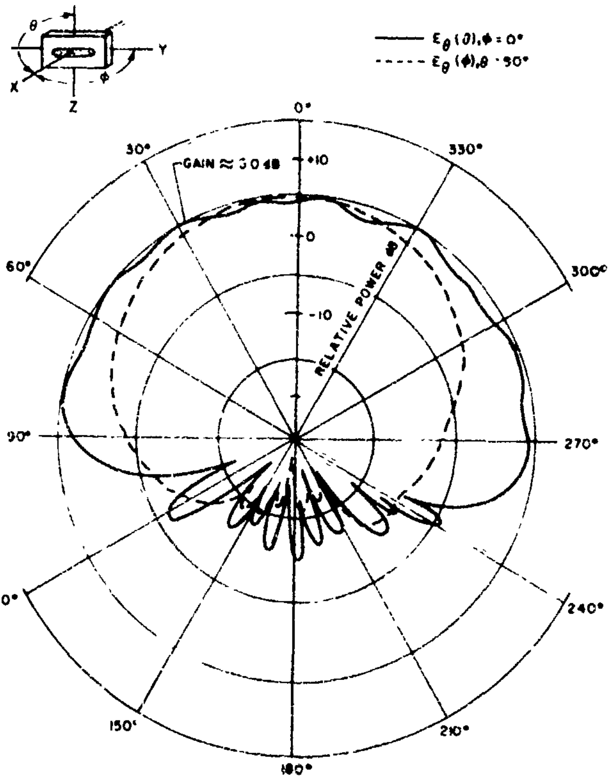

Figure 4. Radiation patterns of planar copperplated dielectric-loaded cavity radiator.

Figure 5. Copperplated, dielectric-loaded slot-cavity antenna designs.

Radiation patterns for this antenna (fig. 6) are shown in figures 7 and 8. These patterns were taken with the antenna mounted in the center of a cylindrical ground plane about two wavelengths long. The patterns in figure 7 were taken in two principal planes--that is, a

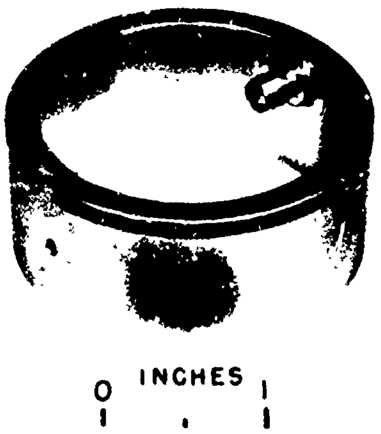

Figure 6. Cylindrical dielectric-loaded ring antenna.

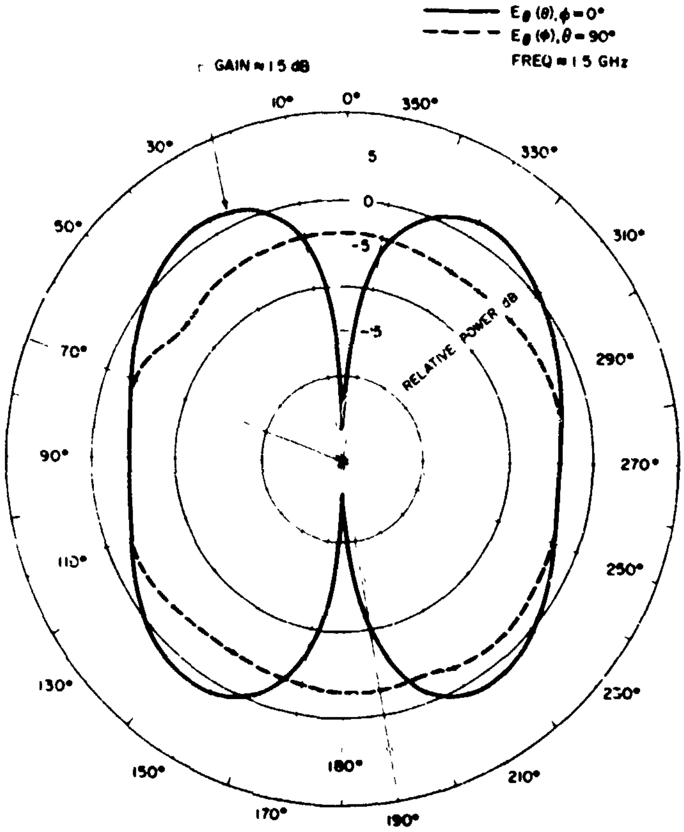

Figure 7. Radiation patterns of cylindrical dielectric-loaded ring antenna (2.375-in. dia).

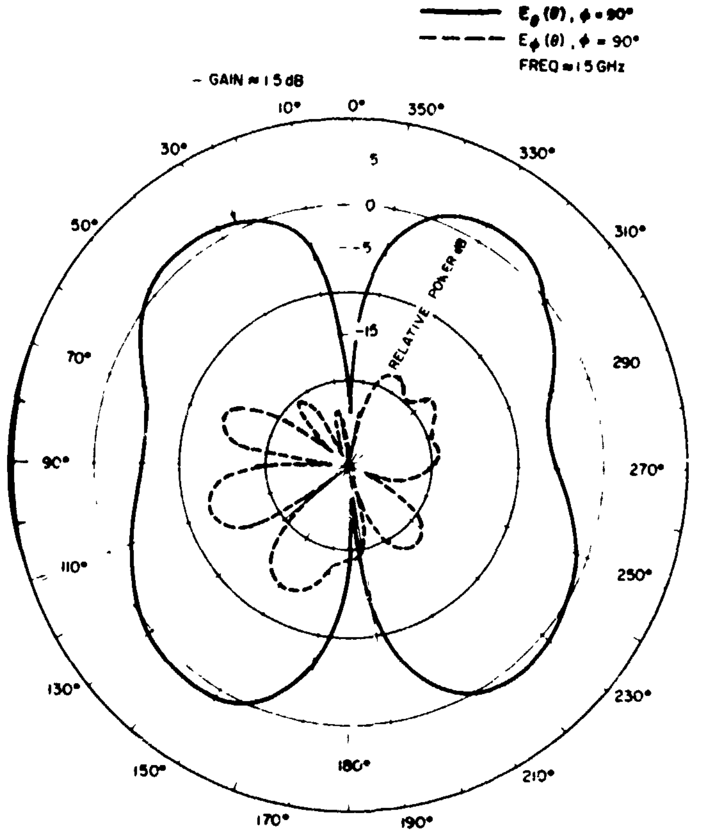

Figure 8. Patterns of vertically and horizontally polarized radiation from a cylindrical, dielectric-loaded, ring antenna (2.375-in. dia).

E_Θ (Θ) pattern taken where $\phi = 0$ deg, or through a plane containing both the feed and the short circuit; in the other plane, a E_Θ (ϕ) pattern was taken where $\Theta = 90$ deg. Figure 8 shows the radiation pattern (E_Θ) taken in the Θ plane, where $\phi = 90$ deg. Also included in this figure is the cross-polarized radiation pattern, which shows the cross-polarized component to be down considerably from the vertically polarized component taken in the same plane. It is observed from the Θ patterns that most of the energy is concentrated in a region perpendicular to the ring, and nulls are produced along the axis of the cylinder.

A plot of VSWR as a function of frequency is shown in figure 9. These data indicate resonance at 1.5 GHz, where the VSWR is 1.35. The bandwidth, where the VSWR is 2 or less, is 175 MHz. The input impedance of this antenna is approximately 50 Ω and this can be altered if desired by changing the cavity thickness.

Other experiments on the small cylindrical dielectric-loaded antenna include its use in an array of elements, and the measurements of decoupling between adjacent elements of such an array. Specifically, three of these antennas were stacked on a cylinder and were phased to produce a more forward radiation. The radiation pattern of the array excited in this manner is shown in figure 10. There is a noticeable enhancement in gain; the energy is concentrated in the forward lobe 40 deg off the axis, and the back radiation is reduced considerably.

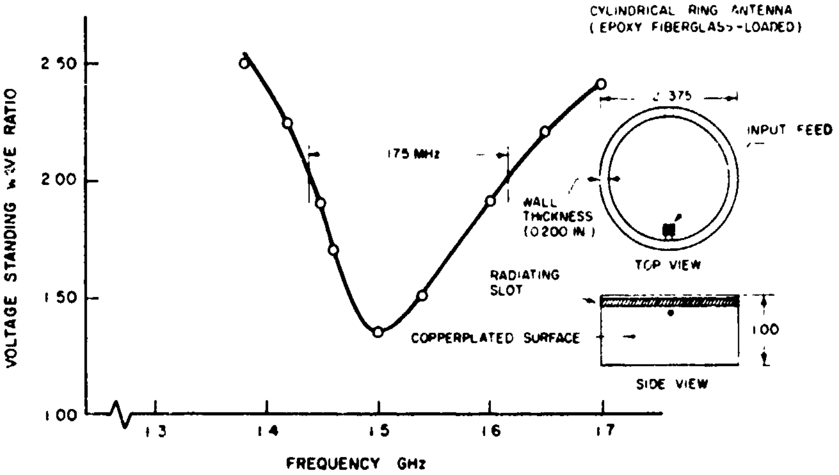

Figure 9. Voltage standing wave ratio as a function of frequency for small, cylindrical ring antenna.

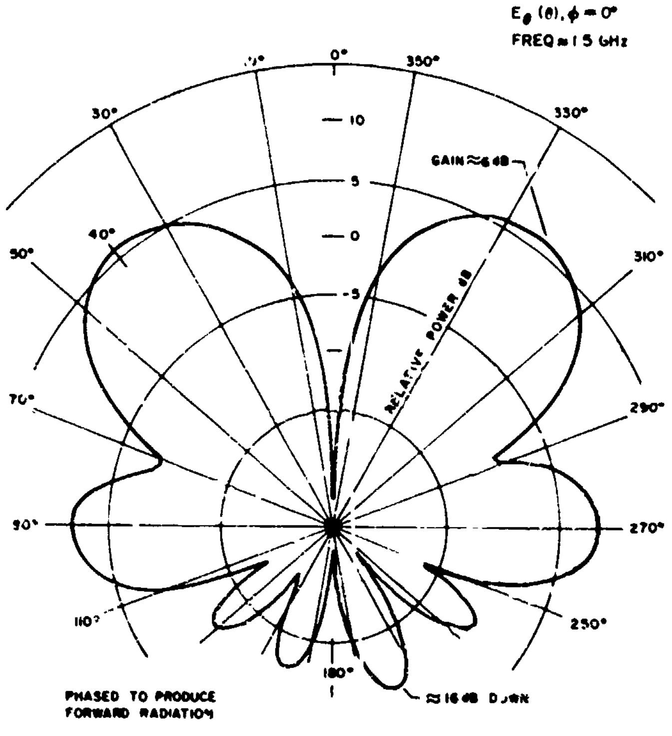

Figure 10. Radiation pattern of three cylindrical ring antennas.

Two of these elements were mounted on a cylindrical structure--one is used as a transmitter and the other as a receiver. The measure of decoupling between antennas as a function of frequency is given in figure 11. Because the E-fields across the slots are parallel, strong coupling of energy from one element to the other would be expected. However, the data indicate a variation of coupling between about -16 and -26 dB in the frequency range from 1.3 to 1.6 GHz. These measurements were found to be sensitive to the mechanical coupling between the antennas. Also, variations occurred when the azimuthal orientation of one ring was changed with respect to the other. By inserting an rf absorbing ring between the antennas, the decoupling was increased, and the results were more stable.

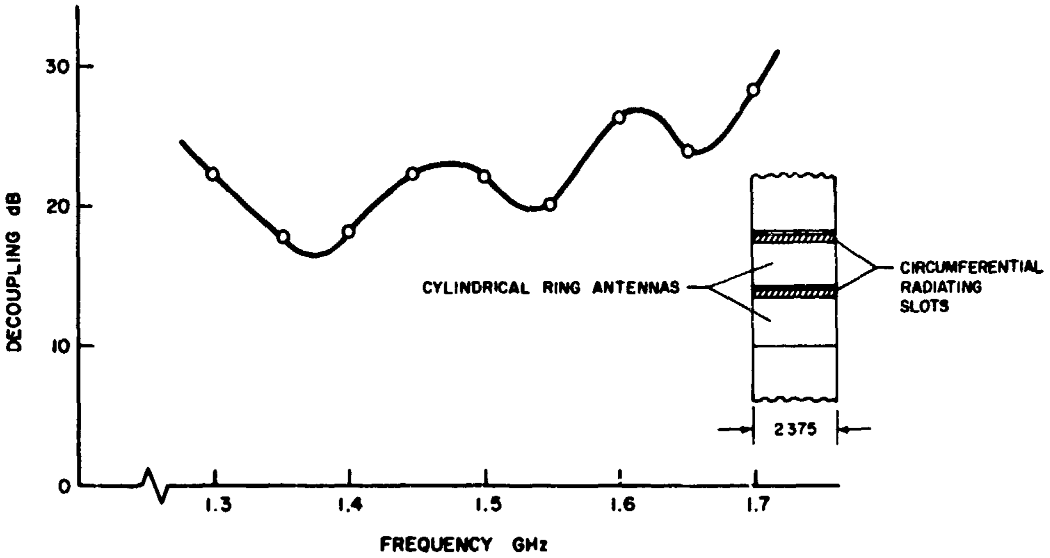

Figure 11. Decoupling versus frequency for two cylindrical ring antennas on a cylinder.

5. DUAL-CAVITY RING ANTENNA DESIGN

The compact single-cavity cylindrical dielectric-loaded ring antenna constructed from teflon, silicone, and epoxy fiberglass laminates is ideally suited for use on small diameter bodies. However, when considering antennas for a structure of slightly larger diameter, a single-cavity design may not provide the radiation coverage that is needed. In this case, a dual-cavity design can be employed. An antenna of this type is shown in figure 5d.

Because of its larger diameter (5.0 in.), the dielectric ring can be divided into two elements, each equivalent to the volume of the single cavity with a smaller diameter. In this case, the cavities are electrically separated by two conductive posts (plated-through holes) diametrically opposite each other on the ring. Each section has its individual input and half-wavelength radiating slot.

Several experimental models of these dual-cavity ring antennas with variable heights (1.0 to 1.5 in.) were constructed and tested to determine the effect of the change in volume on the resonant frequency. The antennas were fabricated from epoxy fiberglass material. Design data for these models are shown in figure 12. The black dots in the figure are the resonant frequency points taken from a single cavity of each antenna, and the circles indicate data from both cavities excited in-phase, looking through a matched-tee section. These results indicate that the resonant frequency decreases with increased cavity height.

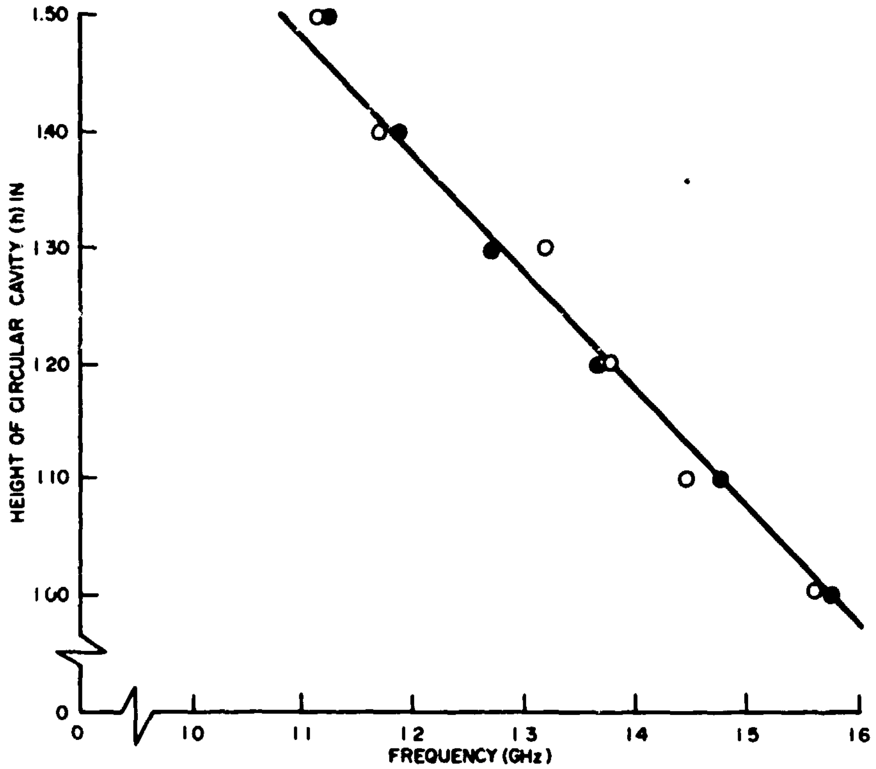

Figure 12. Variation of cylindrical cavity height as a function of frequency.

Often it is necessary to match or tune the cavity to improve its performance. An experimental method was developed during this investigation and used successfully for this purpose. It involved drilling a matrix of small holes (0.015 to 0.020 in. dia) across the cavity in a region between the feed and the short circuit. A conductive post or wire is placed in the selected holes making good contact with the copperplated walls to determine the location of the post for best performance. The post is then secured in place, or the hole can be plated through with copper.

It was also observed that adjustments in the length of the radiating slot in the vicinity of resonance, in some cases, provided improved performance. This adjustment was made in the final attempts to improve performance.

5.1 Performance Characteristics

As a result of the previous experimental work, another slightly modified dual-cavity antenna was developed. The finished model and its bare epoxy fiberglass substrate is shown in figure 13. It has a 5-in.-inside diameter and the outside wall is slightly tapered to conform to the conical body on which it is mounted for testing. The height is 0.800 in., and the wall thickness is 0.200 in. at the top and 0.300 in. at the bottom. This antenna was designed to operate in the L-band frequency range. Considerable effort went into the design of this particular antenna since its use in several applications was contemplated. Antennas of the type shown in figure 13, as well as the design shown in figure 6, have been used successfully in high-g telemetry systems, where they have withstood shock accelerations of 15- to 16-thousand g's and 200 rps with no noticeable deterioration in performance.

Figure 13. Dual-cavity ring antenna.

Experiments were performed to optimize critical parameters, and radiation patterns taken in different planes around the body were thoroughly analyzed. Radiation patterns for one cavity of this antenna, and a sketch of the antenna mounted on the structure are shown in figure 14. As shown in this figure, the beam is directed broadside or perpendicular to the axis. However, there is good radiation coverage in both planes with the peak gain at 3.0 dB. Shown in figure 15 are the elevation and azimuthal patterns of the antenna taken on the same body with both cavities excited in-phase. Maximum radiation occurs 15 deg off the axis--forward and rearward--with nulls on the axis at 0 and 180 deg. Both radiation patterns are fairly symmetrical, with the azimuthal pattern uniformly distributed around the body.

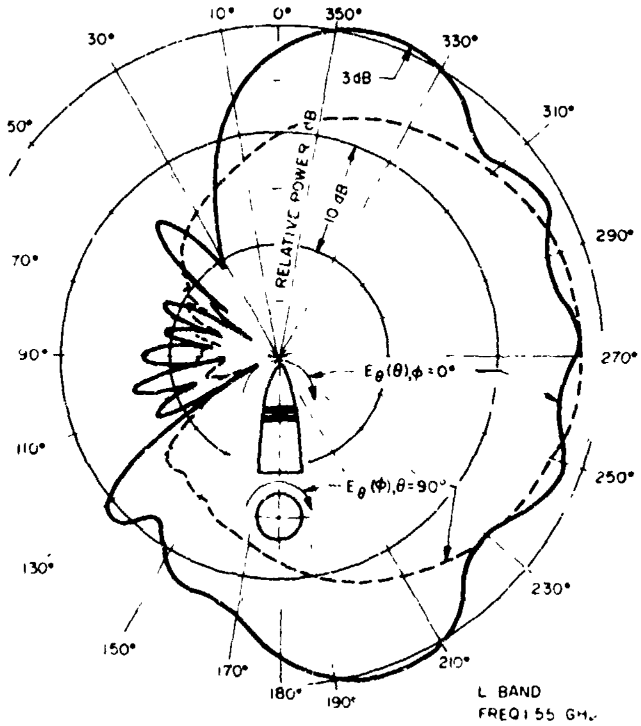

Figure 14. Radiation patterns for one element of the dual-cavity ring antenna.

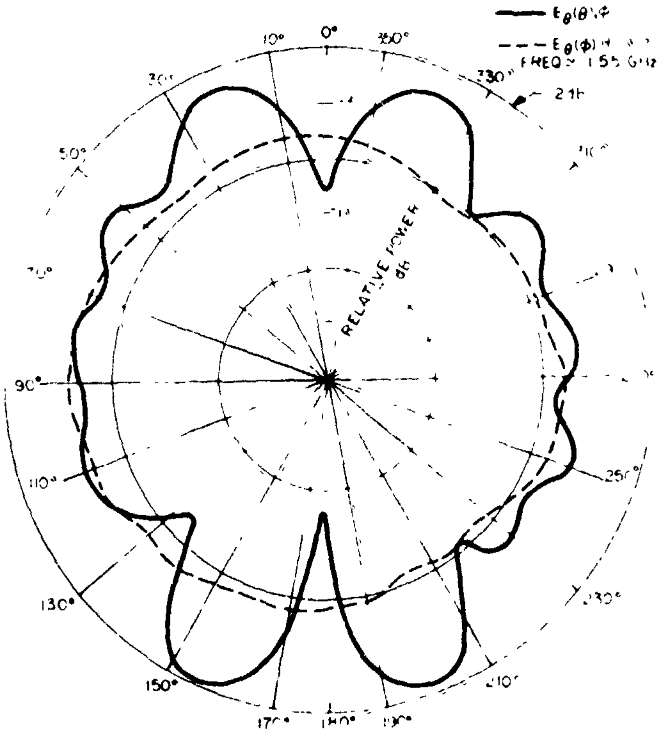

Figure 15. Radiation patterns of the dual-cavity ring antenna with both cavities excited in-phase.

The radiation pattern with the dual cavities excited out-of-phase is shown in figures 16 and 17. Figure 16 shows that excitation of the cavities out of phase causes energy to be directed along the axis at 0 and 180 deg, which is one advantage of the dual-cavity antenna. The same figure further shows that the cross-polarized component is also very strong along the axis. Exciting the cavities in this manner also changes the characteristics of the azimuthal pattern as shown in figure 17.

Figure 18 plots the VSWR as a function of frequency for the dual-cavity dielectric-loaded ring antenna. Measurements were made on each section, as well as the dual section through a matched coaxial-tee. Each cavity had a VSWR of approximately 1.35 at the center frequency, and less than 2 to 1 over a 130-MHz bandwidth, whereas the VSWR for the dual-cavity was less than 2 to 1 measured over a 180-MHz band.

Recently, a large quantity of antennas of this design was produced that incorporated a thin teflon window over the slot. A typical production model selected for testing with a teflon window is shown in figure 19. Also shown in this figure is the coaxial feed network designed for inphase feeding.

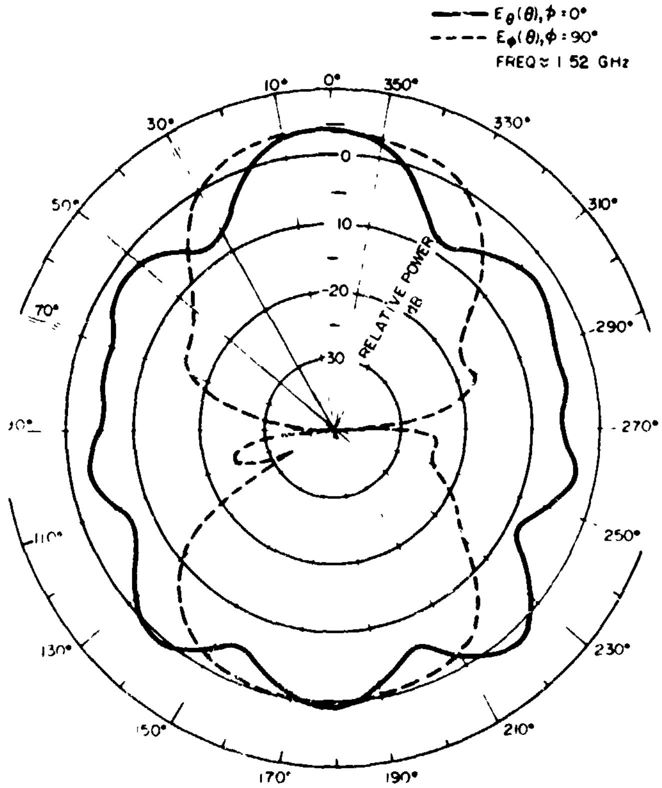

Figure 16. **Radiation patterns of dual-cavity ring antenna with the cavities excited out-of-phase.**

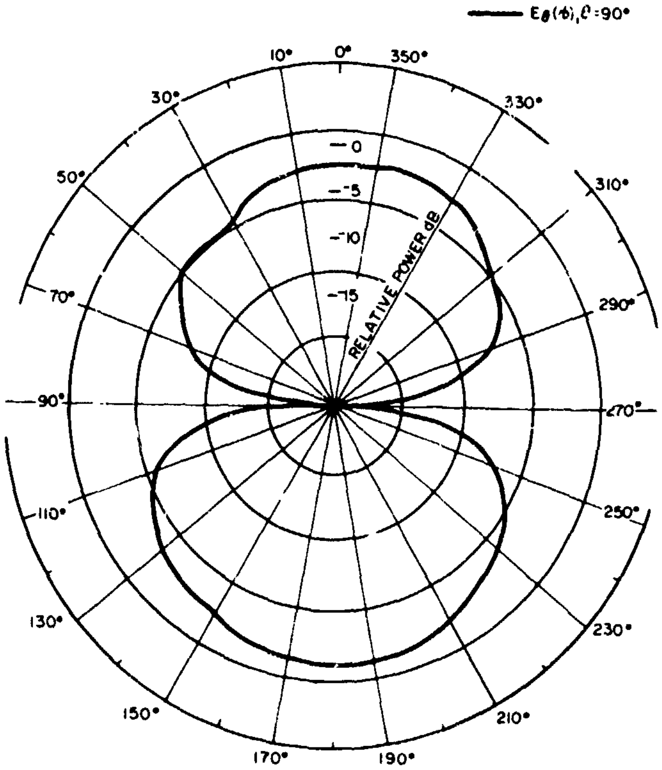

Figure 17. Radiation pattern in the horizontal plane (E-field, vertical) of the dual-cavity ring antenna with cavities excited out-of-phase.

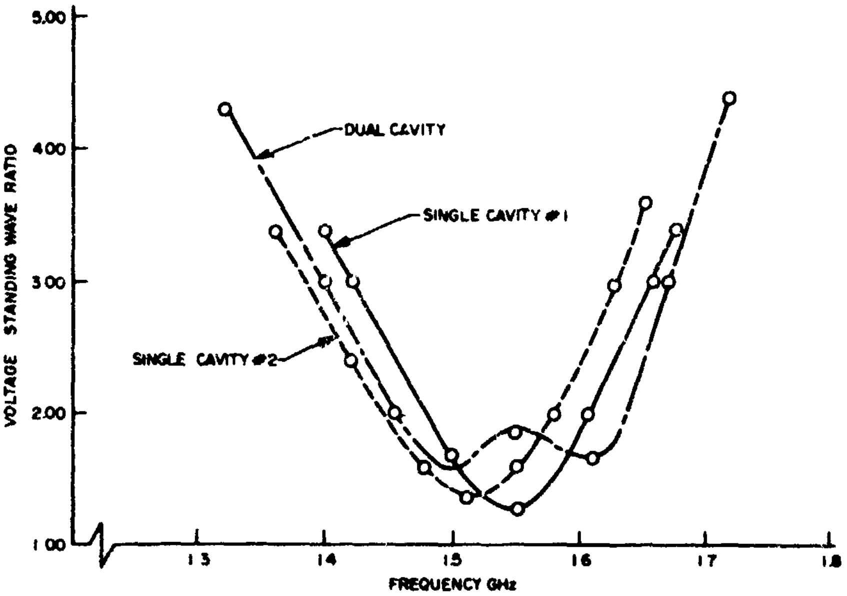

Figure 18. Voltage-standing-wave ratio as a function of frequency for dual-cavity dielectric-loaded ring antenna.

Figure 19. Dual-cavity ring antenna with thin teflon window.

Radiation patterns of this production model with the cavities excited in-phase are shown in figures 20 through 22. In these patterns the radiation characteristics can be observed in different planes around the cylinder. Also, the cross-polarized radiation pattern for each plane is given. Figure 20 shows the Θ pattern taken in the plane where ϕ = 0 deg. The same pattern taken in the plane where ϕ = 45 deg is shown in figure 21, and the Θ pattern taken where ϕ = 90 deg is shown in figure 22.

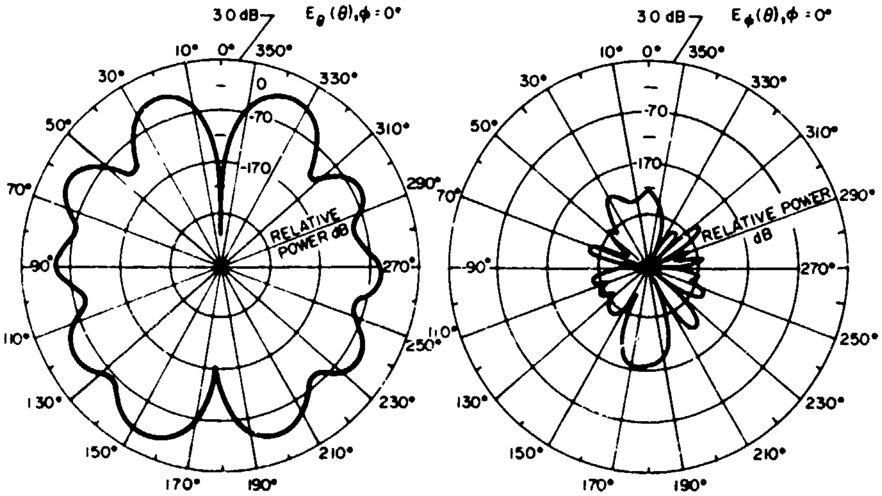

Figure 20. Vertically and horizontally polarized radiation patterns (θ = 0 deg) of dual-cavity ring antenna.

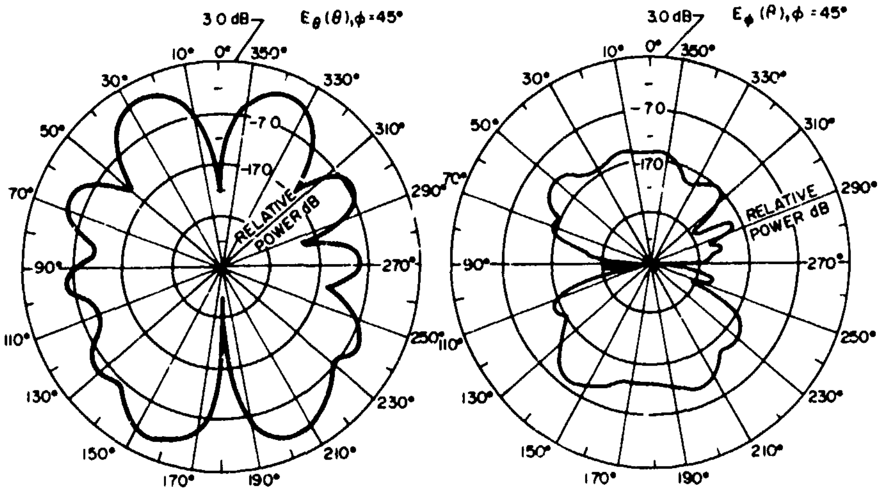

Figure 21. Vertically and horizontally polarized radiation patterns (θ = 45 deg) of dual-cavity ring antenna.

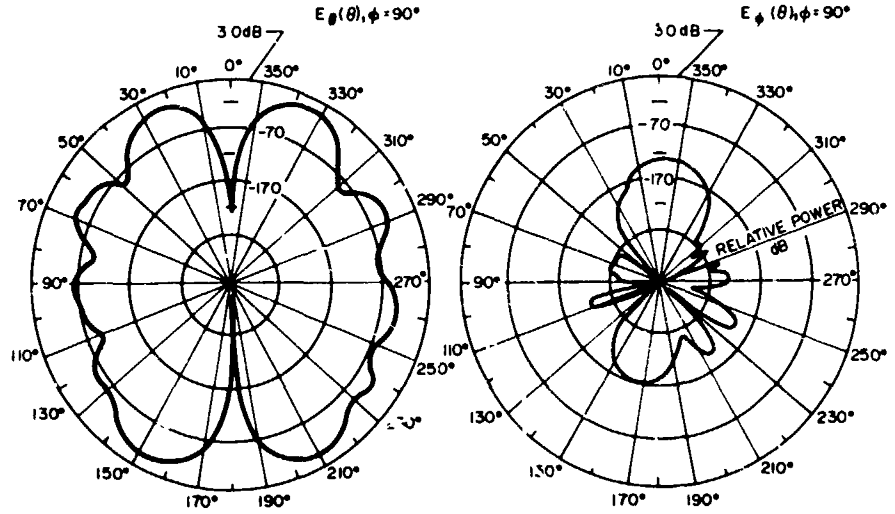

Figure 22. Vertically and horizontally polarized radiation pattern (θ = 90 deg) of dual-cavity ring antenna.

5.2 Large Diameter Antennas

Since the techniques used in designing the 3- and 5-in. diameter dielectric-loaded cylindrical cavity antennas were successful, further work was initiated to design antennas for larger diameter bodies at lower frequencies (UHF). The first prototype (450 MHz) antenna was designed into the base of a large conical structure. It is a single-cavity design loaded with silicone fiberglass. It has a 15-in. base diameter, is 3 in. high, and has walls 0.250 in. thick. The radiating slot is 0.250 in. wide and slightly more than a half-wavelength long. Preliminary tests were performed with the antenna mounted at the base of an aluminum cone. The length of the cone was approximately 70 in.

Radiation patterns for this configuration are shown in figure 23. Most of the energy from this antenna is directed forward, concentrated in a region ± 45 deg off the axis; the peak gain is about 3.5 dB. Radiation around the body shown in the azimuthal pattern is uniformly distributed. The lack of radiated energy rearward is due to the location of the antenna on the surface of the cone near the base.

A 15-in. diameter dual-cavity dielectric-loaded antenna is shown in figure 24. This antenna was designed for operation at a higher frequency in the UHF range (800-900 MHz). The radiation patterns, as well as gain and bandwidth data obtained, were quite satisfactory. The results verify that these antennas can be scaled from the L-band region to the lower frequencies.

Usually in the UHF region, there is a constant need for smaller antennas. Construction in this manner offers a substantial reduction in size. Further reductions in size are offered by incorporating a ridge in the waveguide cavity. Antenna designs have been successfully constructed at S-band by using the combination of dielectric and ridge loading. Some bandwidth is sacrificed; however, if an 8- to 10-percent bandwidth is adequate, the technique should be satisfactory.

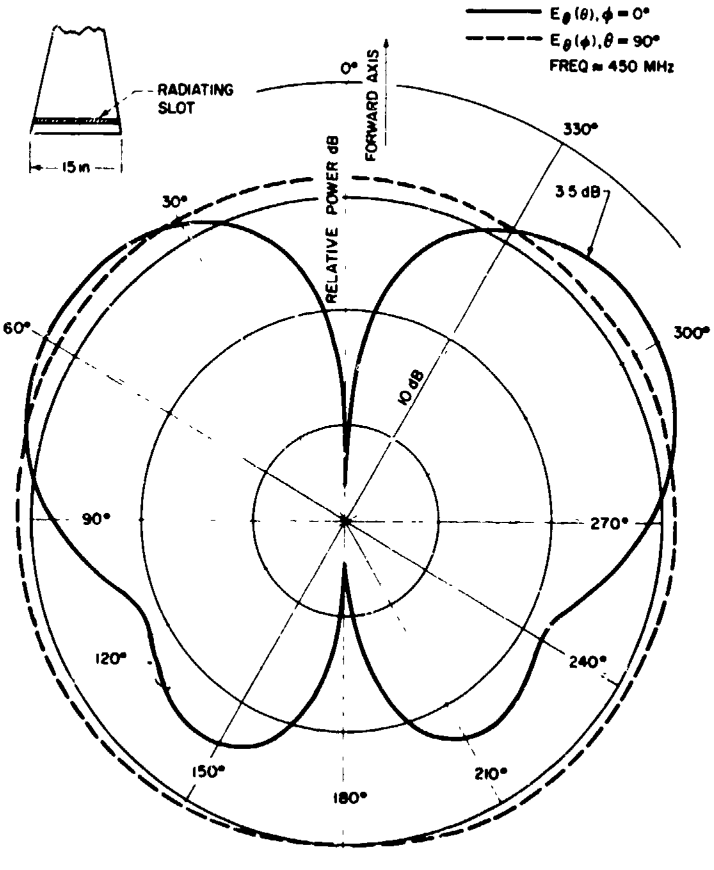

Figure 23. Radiation patterns of a large diameter conical dielectric-loaded ring antenna.

Figure 24. Large-diameter dual-cavity dielectric-loaded antenna.

6. CONICAL ANTENNA DESIGNS

Most of the basic experimental work involved in the design of the copperplated dielectric-loaded slot-cavity antennas was performed on the single and dual-cavity cylindrical designs. These same techniques are applicable to the conical antenna designs. An example of a small conical cavity S-band antenna developed during this investigation is illustrated in figure 5a. This antenna is essentially a frustum of a cone that is used as a single cavity having a 2-in.-diameter base, and a 3-in. height. The dielectric loading material is polypropylene resin which has a dielectric constant of 2.2. Because of the low-dielectric constant, the operating frequency of this antenna is slightly higher than the same type antenna constructed from the epoxy laminated material (table 1).

Radiation-pattern measurements taken with this antenna (fig. 5a) mounted on the tip of a conical body (approx 5 wavelengths) are shown in figure 25. The general radiation pattern characteristics of this antenna--that is, radiation off the side and nulls along the axis--are quite similar to those of the cylindrical antennas. Because of its location at the forward tip of the structure, the peak gain (3.5 dB, is rearward. Also, the pattern lacks symmetry, and the distribution of radiated energy in the azimuthal pattern is not uniform. The VSWR characteristics of this antenna are also about the same as those for the cylindrical models. The antenna bandwidth is slightly greater, however, because the material has a lower dielectric constant.

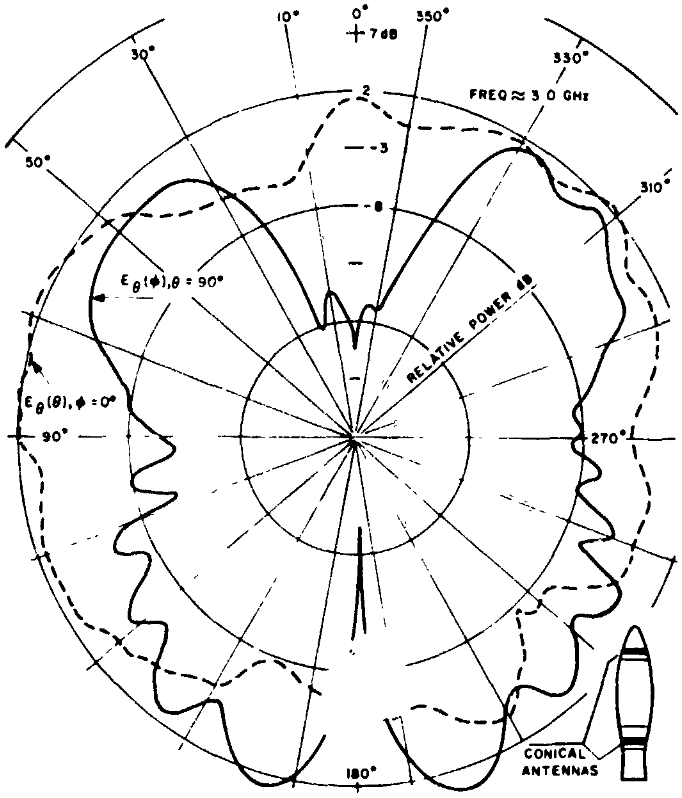

Figure 25. Radiation patterns of a small conical dielectric-loaded cavity antenna (base diameter 2.0 in.).

6.1 Open-End Conical Cavity

To make better use of dielectric cones or radomes on the apex of conical bodies, the idea of constructing antenna elements into them was exploited. An antenna recently developed along these lines is the open-ended, conical, dielectric-loaded cavity shown in figure 26.[10] The cone is epoxy fiberglass which is copperplated on the inside--around the base and part way along the outer surface. Plating the dielectric in this manner forms a cavity that is open-ended. This antenna is excited with a probe across the structure fed from a coaxial line. Diametrically opposite the feed point is a short circuit in the form of a post across the cavity (fig. 26). When the field in the cavity is perturbed by the probe, energy is radiated from the open end through the dielectric and coupled into free space.

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[10] *U. S. Patent 3,798,653, "Cavity Excited Conical Dielectric Radiator," issued 19 Mar 1974.*

Figure 26. Open-ended conical dielectric-loaded cavity antenna.

The dielectric constant of the material, the size of the cavity, and the position of the probe determine the operating frequency. Primary resonance for this antenna (fig. 26) occurs at 1.27 GHz, but another resonant frequency point was observed at about 3.7 GHz. Radiation patterns of this antenna taken at 1.27 GHz on a 20-in.-long body are shown in figure 27. The Θ pattern taken where $\phi = 0$ deg shows nulls at 0 and 180 deg. Peak gain of 5.0 dB occurs rearward at 150 deg. The azimuthal pattern taken in the $\Theta = 90$-deg plane shows uniform coverage around the body. Figure 28 shows the VSWR characteristics for this antenna. At 1.27 GHz, the VSWR was 1.12; measured over a 135-MHz bandwidth, it was less than 2 to 1.

Another antenna of this type using aluminum oxide ($\varepsilon_r = 9.0$) was designed and tested. This antenna was about the same size as the model shown in figure 26. The performance characteristics were also similar; however, the operating frequency was in the vicinity of 1.0 GHz. Here again, it can be seen that the design technique lends itself to a small, compact antenna for low-frequency operation.

6.2 Multifunction Conical Cavity

Another conical antenna developed during this investigation was the multifrequency, monolithic dielectric-loaded cavity radiator.[11] It is capable of being designed with two or more radiation elements in a one-

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[11] *U. S. Patent S/N 478,204 filed 11 June 1974, "A Monolithic, Electrically Small, Multifrequency Antenna."*

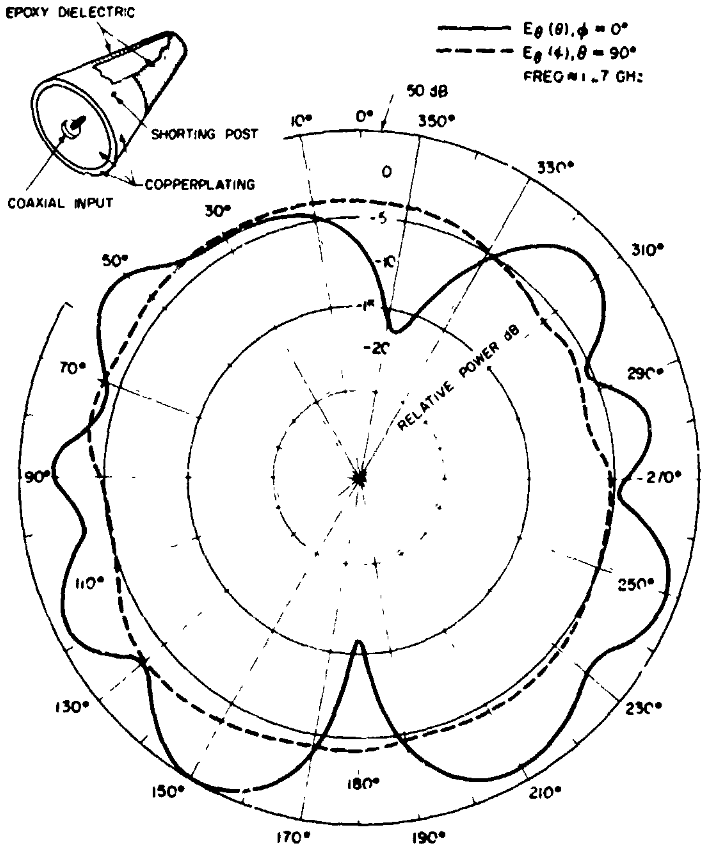

Figure 27. Radiation patterns of open-ended conical cavity antenna.

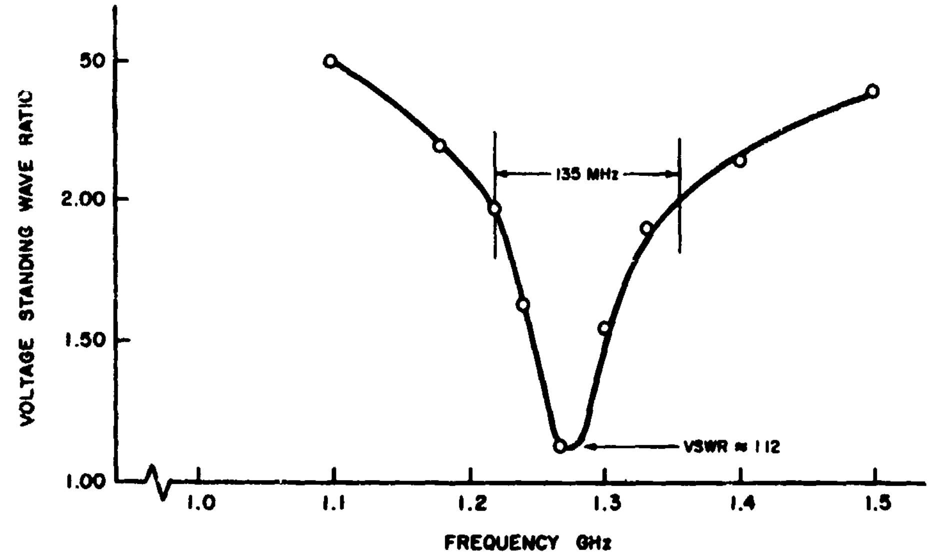

Figure 28. Voltage-standing-wave ratio as a function of frequency for an open-ended conical cavity antenna.

piece cone. Also, a combination of design frequencies can be chosen to perform varied functions depending on the application. A model of this antenna with its three radiating elements is illustrated in figure 29. This antenna, constructed on an epoxy fiberglass cone, has a dual-cavity conical radiator at the base that operates in S-band and an open-end conical cavity radiator at the forward end designed for operation in L-band. Details of its construction are given in figure 29. The dual-cavity antenna at the base is separated from the open-end antenna by a conductive wall, in the form of closely spaced plated-through holes around the circumference of the cone.

Radiation patterns for one of the dual-cavity elements (the base-mounted radiator) are shown in figure 30. These patterns were taken with the multicavity antenna mounted on the tip of a conical body (20 in. long). The elevation pattern shows the energy directed off the body, normal to the slot. The radiation coverage shown is over a 180-deg sector, with a maximum gain of 5.0 dB. In the azimuthal plane, the radiation coverage is about 60 deg at 3-dB points. Energy radiated 180 deg from the slot is down slightly below the 10-dB level as expected.

The open-end cavity radiator on the forward end of the cone (fig. 29) is similar to the design discussed in section 6.1 except that it is smaller in size and is resonant at 1.91 GHz. Radiation patterns of this radiator are shown in figure 31. As seen in the elevation pattern, the maximum radiation (gain ≈ 6.0 dB) occurs rearward about 15 deg off axis. The azimuthal pattern is essentially uniformly distributed around the body; otherwise, the radiation pattern characteristics are similar to those in figure 27. The measured VSWR of each of these antennas was in the vicinity of 1.3 at their respective operating frequencies.

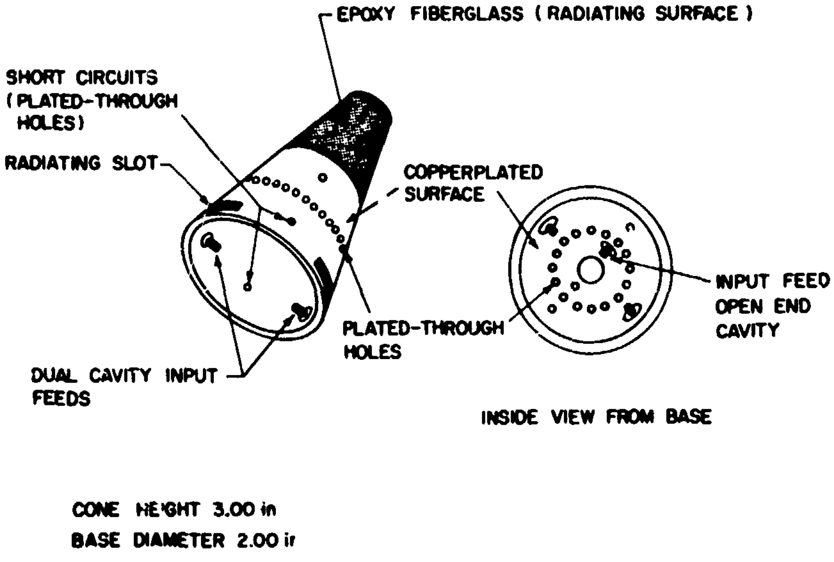

Figure 29. Multifrequency, monolithic conical dielectric-loaded cavity antenna.

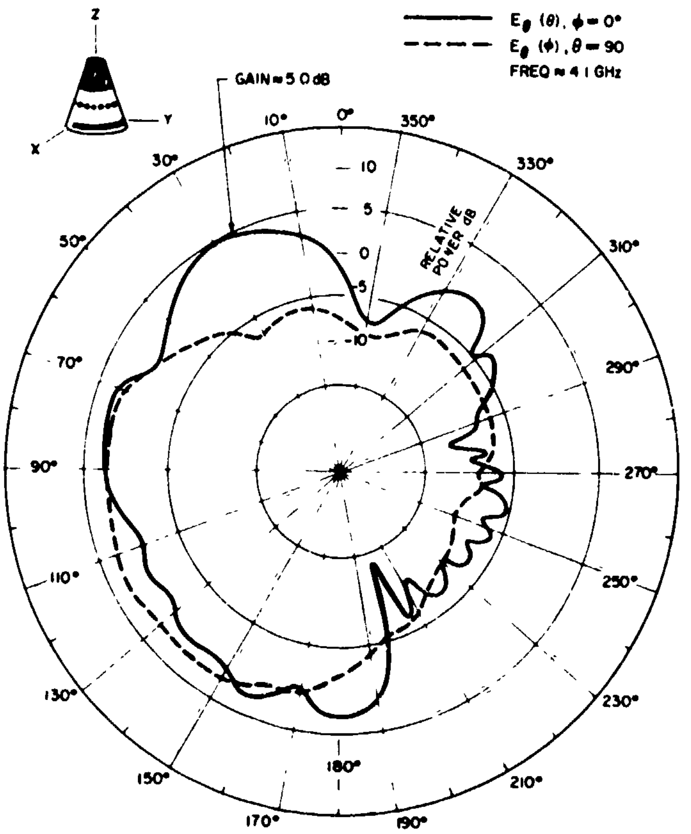

Figure 30. Radiation patterns of a single cavity of the multifrequency conical dielectric-loaded antenna.

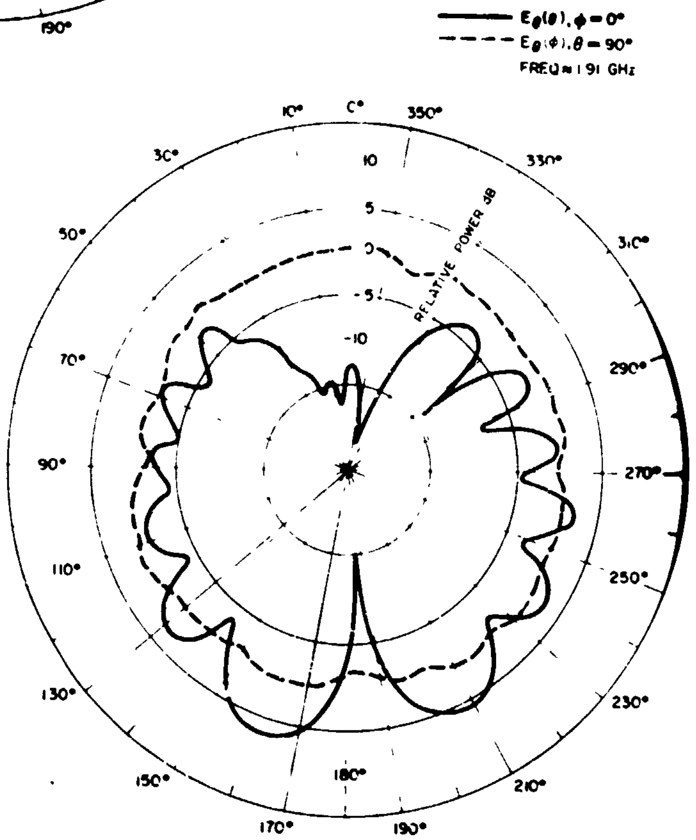

Figure 31. Radiation patterns of the open-ended cavity section of the multifrequency conical dielectric-loaded antenna.

7. CONCLUSIONS

Several circular conformal antennas designed to be compatible with dielectric radomes and projectile structures have been successfully demonstrated. Each antenna has electrical and mechanical characteristics favorable for many applications. Highly satisfactory performance has been obtained from special designs when used on projectiles where high-g accelerations are required. This antenna design and construction technique offers many advantages, which include compactness, provisions for flushmounting to avoid protrusions from the body surface, and the capability to integrate the antenna with the body structure while preserving the structural integrity of the body and the electrical performance of the antenna. Results show that the electrical performance for each design is more than satisfactory for many applications, and there is a variety of radiation-pattern configurations obtainable. Further development of antennas designed in this manner should yield even better results and provide substantial space and cost savings when used in either conventional or more sophisticated electronic systems.

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