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Conformal and Small Antenna Designs

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Select antennas are described that can be used effectively on conformal surfaces. Most of these antennas are compact, are electrically and physically small, and can be easily integrated into conical and cylindrical bodies. Edge-slot, microstrip, and dielectric rod radiator design techniques are employed in the development of these antennas. Critical design parameters, modes of radiation, empirical data, and theoretical considerations are discussed. The intrinsic properties and characteristics of selected dielectric materials are considered.

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20. **Abstract** (Cont'd)

Several unique design configurations are illustrated. Performance data on prototype antenna models such as impedance, gain, polarization, radiation patterns, and bandwidth characteristics are presented. Salient features and advantages realized from the use of these design techniques are summarized.

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1. INTRODUCTION

Over the past few years, there has been an increasing interest in the development and use of efficient antenna systems that have certain desirable characteristics and can be easily integrated into various shaped bodies, conforming to their outer surfaces. Equal attention has been given to the need for reducing the size of antennas, especially in cases where there are space limitations and the antennas must be conformal to surfaces. At first glance, satisfying these requirements would appear to be a formidable task because, despite the difficulties involved in achieving these goals, in most antenna systems there can be no sacrifice in electrical performance. However, antenna systems that can be designed to include these features can solve many problems and have numerous applications.

Antenna research work performed at the Harry Diamond Laboratories in recent years has been directed toward solving many of the difficult problems. Both theoretical and experimental studies on antenna designs and material development were fully exploited. Other investigations included the determination of certain overall system requirements, to effect optimum antenna performance that would result in improvements over conventional antennas. From this research effort, several unique conformal antenna designs were conceived that made possible some antenna systems that are compatible with a variety of body shapes.

This report summarizes much of the research and development effort involving certain basic design techniques that are applicable to conformal and small antennas. The results of the overall effort have made possible the antenna designs that are operational in the ultrahigh frequency (uhf) region through the millimeter wave frequency range.

2. EDGE-SLOT RADIATORS

The edge-slot radiator design approach is a unique method used for designing antenna systems that are functional and compatible with conformal surfaces.[1-4] The basic radiator is a thin structure usually in the form of a circular disk or a similar shape that consists of two parallel conducting surfaces separated by a low-loss dielectric material and fed from a coaxial line. When the radiator is incorporated into a body such as a cone or a cylinder, its outer edge is intended to coincide with the surface of the body. This outer edge is the radiating aperture. In the case of the circular disk, the radiating aperture is circumferential, and the radiation pattern is uniformly symmetrical around the body.

Although most of the emphasis is focused on the flat circular disk type radiator, there are modifications that include semicircular and wedge shapes, as well as other design configurations. Typical illustrations showing how the edge-slot radiators are effectively used in bodies of revolution are included in other sections of this report.

Some of the features of edge-slot antennas are as follows:

a. They can be integrated quite well into conformal bodies.

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[1] *Daniel H. Schaubert, Howard S. Jones, Jr., and Frank Reggia, Conformal Dielectric-Filled Edge-Slot Antennas for Bodies of Revolution, Harry Diamond Laboratories HDL-TR-1837 (September 1977).*

[2] *F. Reggia and H. S. Jones, Conformal Edge-Slot Radiators, U.S. Patent 4,051,480 (27 September 1977).*

[3] Daniel H. Schaubert, Howard S. Jones, Jr., and Frank Reggia, Conformal Dielectric-Filled Edge-Slot Antennas with Inductive-Post Tuning, IEEE Trans. Antennas Propag., 27 *(September 1979), 713-716.*

[4] *Dipak L. Sengupta and Luis F. Martins-Camelo, Theory of Dielectric-Filled Edge-Slot Antennas, IEEE Trans. Antennas Propag.,* 28 *(July 1980), 481-490.*

b. Antenna systems can be designed in several frequency bands.

c. Electronic scanning is possible.

d. The technique provides a simple means of construction at low cost.

e. Radiation patterns from edge-slot radiators have good azimuthal symmetry.

2.1 *Single Edge-Slot Radiator Characteristics*

In the previous section, a typical edge-slot radiator is described as a compact circular disk. This basic design operates at some fundamental frequency, depending on its diameter and the dielectric material characteristics. However, by placing inductive posts in certain positions across the parallel conducting plates, the antenna characteristic can be altered, particularly its impedance and frequency of operation. An example of the basic edge-slot radiator with inductive posts is shown in figure 1.

Two-element, four-element, and eight-element antennas are shown in figure 2. The number of elements in the radiator is determined by the number of rows of inductive posts.[1,3] Also, the frequency can be affected by a change in the number of posts in the row.

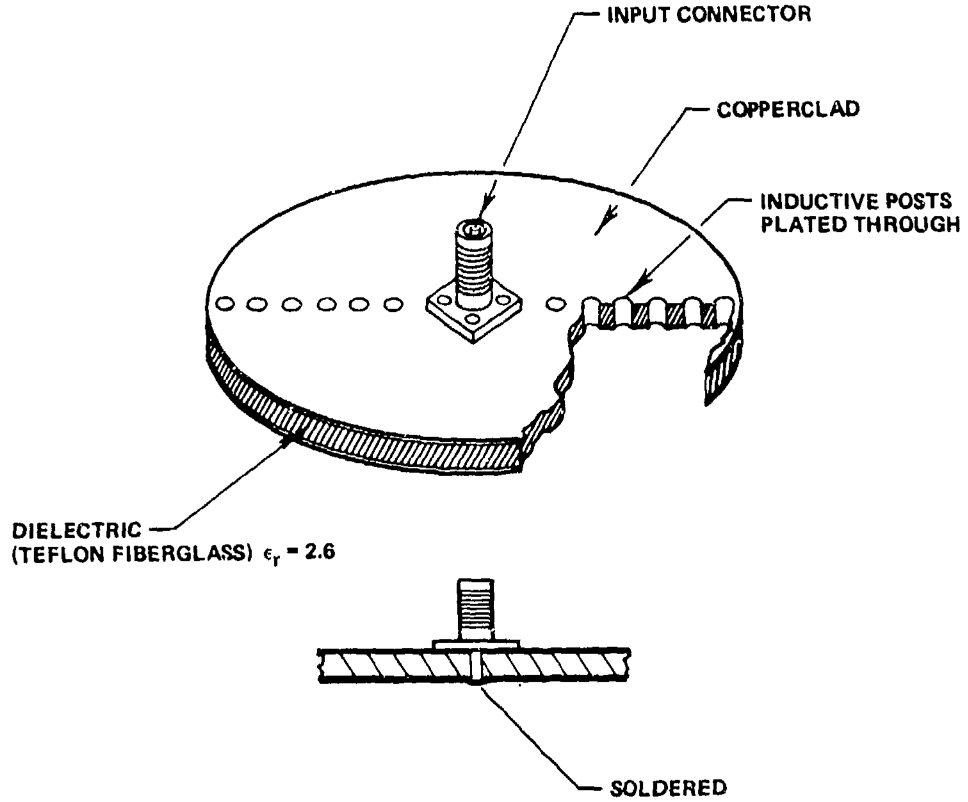

Figure 1. Single edge-slot radiator.

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[1] *Daniel H. Schaubert, Howard S. Jones, Jr., and Frank Reggia, Conformal Dielectric-Filled Edge-Slot Antennas for Bodies of Revolution, Harry Diamond Laboratories HDL-TR-1837 (September 1977).*

[3] *Daniel H. Schaubert, Howard S. Jones, Jr., and Frank Reggia, Conformal Dielectric-Filled Edge-Slot Antennas with Inductive-Post Tuning, IEEE Trans. Antennas Propag., 27 (September 1979), 713-716.*

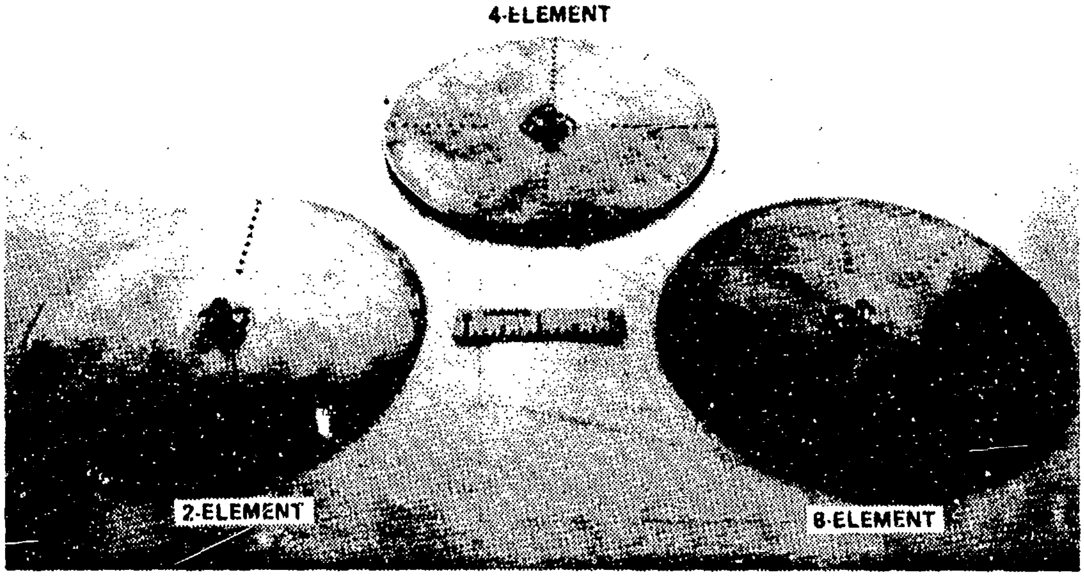


Figure 2. Two-, four-, and eight-element edge-slot radiators.

Data illustrating frequency characteristics as a function of the number of posts for multiple elements are shown in figure 3.

2.1.1 *Radiators in Bodies of Revolution*

When used with typical weapon configurations, the edge-slot antenna can be mounted conformally between portions of a conducting body of revolution. Because the aperture is very narrow and it couples strongly to the body, full advantage can be taken of the radiation properties of the antenna used on large and small structures. Furthermore, the rotational symmetry of the antenna and the body preserves the desired azimuthal symmetry of the radiation pattern. This symmetry can be seen in the patterns of an 8-in. (20.32-cm)-diameter, two-element edge-slot radiator mounted at the center of a 16-in. (40.64-cm)-long cylinder shown in figure 4.

2.1.2 *Material Characteristics*

In most cases, copperclad dielectric laminated materials (printed-circuit boards) were used to design the individual radiators. Typical dielectric materials used were low-loss Teflon fiberglass, epoxy glass, and silicone glass laminates. Also, polystyrene foam dielectric and selected inorganic dielectrics were used for certain experiments. The dielectric constant and the loss tangent of the materials were important design factors. Most of the materials lend themselves well to electroless copperplating techniques used to provide the parallel conducting surfaces and the plated-through holes for the inductive posts.

2.2 *Practical Edge-Slot Antenna Designs*

Because the edge-slot radiator can be easily integrated into conformal surfaces, it is used advantageously on both large and small bodies. The design technique is often sought for use to satisfy critical electrical and mechanical problems. In some designs, practically no additional space is needed for the antenna. The space saved is frequently used to package electronic circuitry. This area is also isolated from the external radiation fields of the antenna.

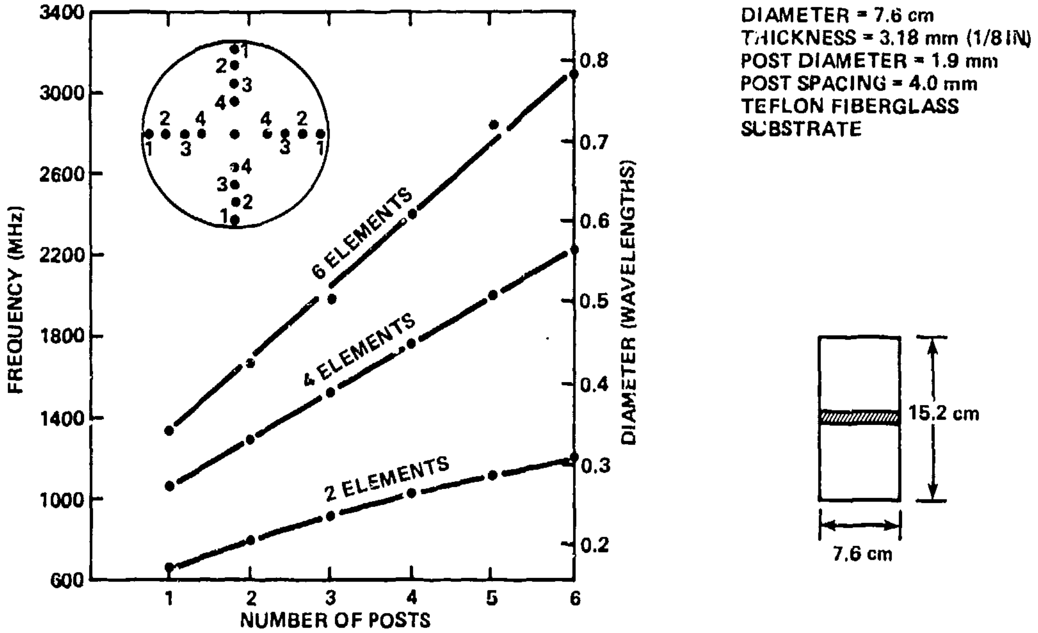


Figure 3. Frequency versus number of posts for multiple elements.

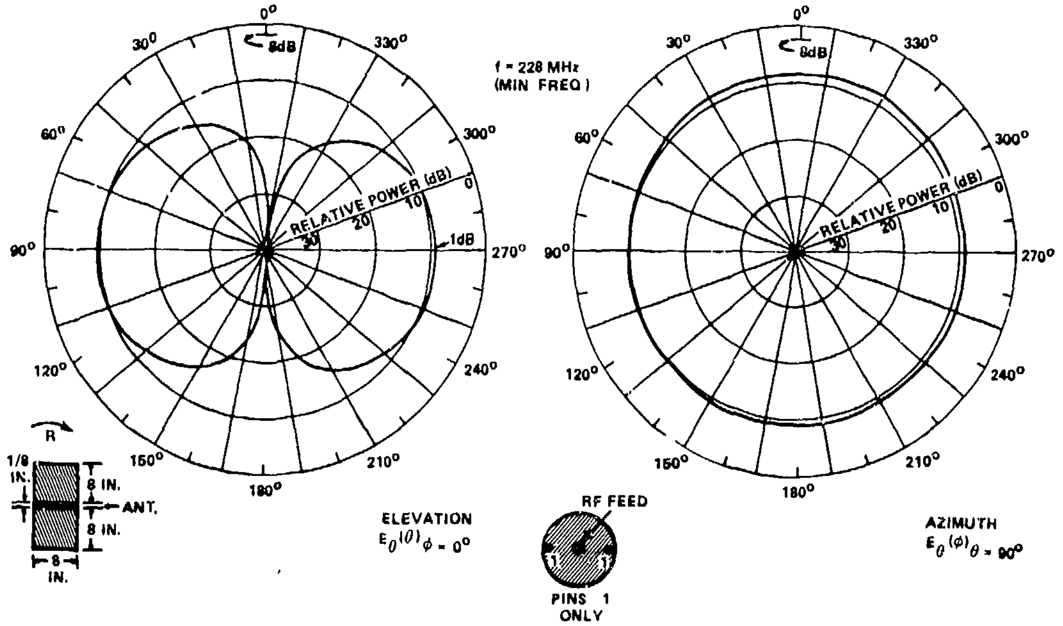
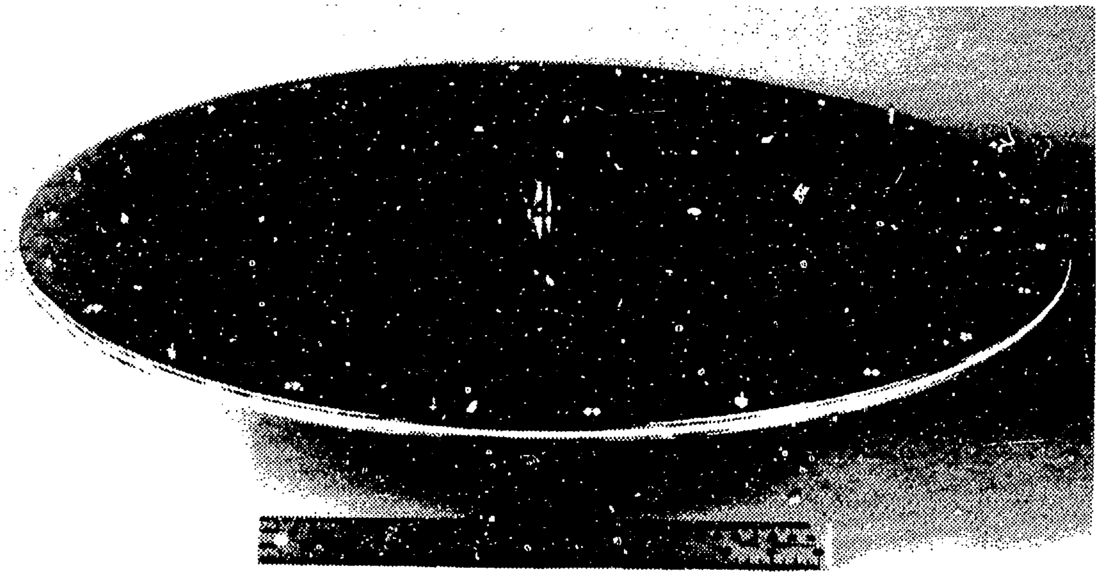


Figure 4. Radiation patterns of dual element edge-slot radiator at center of 8-in.-diameter cylinder.



24.5 IN. DIAM.
24 ELEMENTS
FREQ. = 1510 MHz
1/8 - IN TEFLON BETWEEN 1/8 - IN. ALUMINUM

Figure 5. Edge-slot telemetry antenna for Honest John Missile.

2.2.1 *Large and Small Edge-Slot Radiators*

It is sometimes difficult to obtain the proper radiation coverage around a body (projectile or missile) employing conventional antenna designs. The inherent properties of the edge-slot radiator allow full symmetrical radiation coverage around both large and small bodies. A typical example is a 24.5-in. (62.23-cm) telemetry (TM) edge-slot antenna developed for use on an Honest John Missile for multiple launch rocket system (MLRS) tests. A photograph of this antenna is shown in figure 5. Radiation patterns taken in both azimuthal and elevation planes are shown in figure 6. This antenna satisfied all radiation pattern requirements. Also, there was no sacrifice in structural integrity, and the design was cost effective.

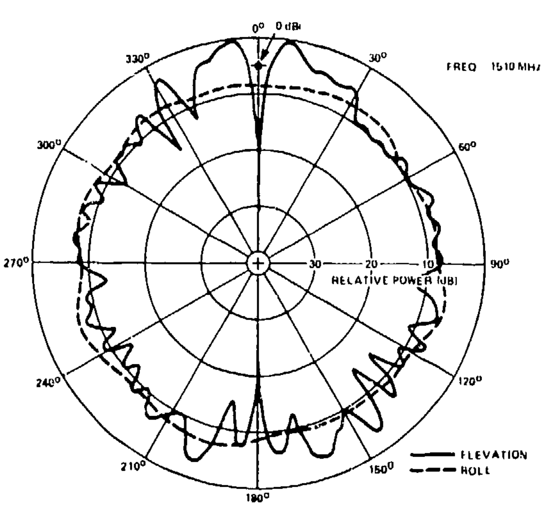


Figure 6. Radiation patterns of telemetry antenna for Honest John Missile.

The planar disk is not the only configuration for the edge-slot radiator. It can also be designed by using other shapes producing very good results. An example is the conical shape edge-slot antenna shown in figure 7. This four-element antenna is designed in the shape of a hollow nose cone (copperplated dielectric) for use on an 81-mm projectile. The feed is at the inside tip of the nose cone, and the aperture is at the base 3.33 cm from the apex. The space inside the nose cone is available for other circuitry.

Thirteen inductive posts separate the elements and give an operating frequency of 6330 MHz with an impedance bandwidth (voltage standing wave ratio—VSWR ≤ 2) of 150 MHz. Radiation patterns for this conical edge-slot antenna also are shown in figure 7. The peak gain is directed in the forward region.

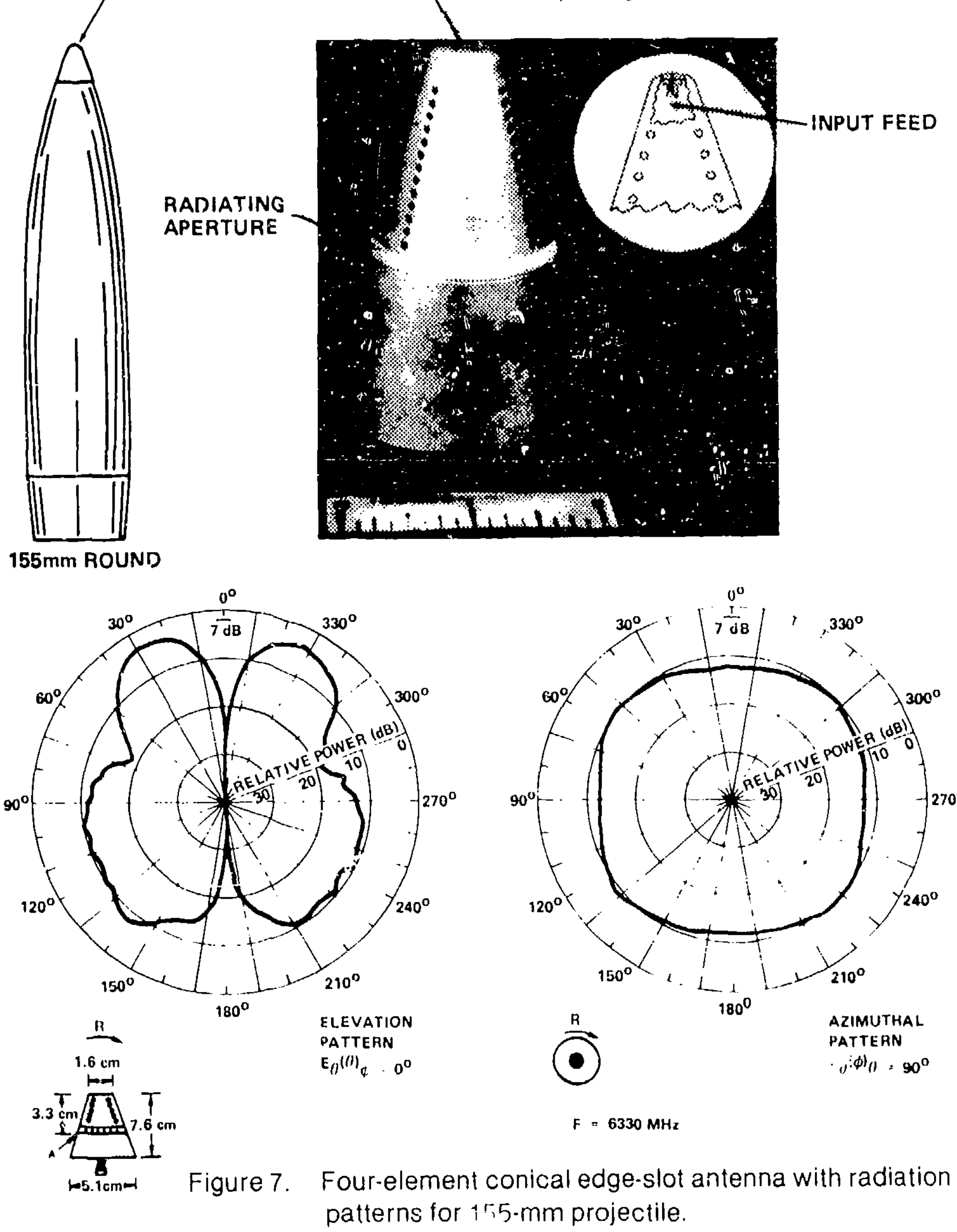


Figure 7. Four-element conical edge-slot antenna with radiation patterns for 155-mm projectile.

2.2.2 *Quadrature Edge-Slot Radiator*

Figure 8 shows a novel low-profile quadrature edge-slot antenna with polarization diversity and the capability of performing several functions.[5] It consists of four conformal parallel plate edge-slot radiators (one in each quadrant). Each radiator can be independently excited in any phase relationship for changing direction and polarization of the radiation field. The model shown in figure 8 is 2-1/2 in. (6.35 cm) high and has a 5-in. (12.7-cm) diameter; it can be designed to operate in the 600- to 700-MHz range. Also, shown in the figure is the same antenna designed into a hemispherical dielectric foam radome. Because the dielectric material has low-loss characteristics, there are only slight changes in the radiation patterns in the presence of the radome

2.3 Arrays of Edge-Slot Radiators

It has been shown that the frequency of an edge-slot radiator can be changed in a number of different ways.[1] Also, further investigations have indicated that diode devices can be effectively employed to perform similar functions for array designs.[2] These and other techniques used for designing multiple radiator systems have been developed. The advantages derived from the use of edge-slot radiators in arrays, especially for small diameter bodies, have been quite beneficial.

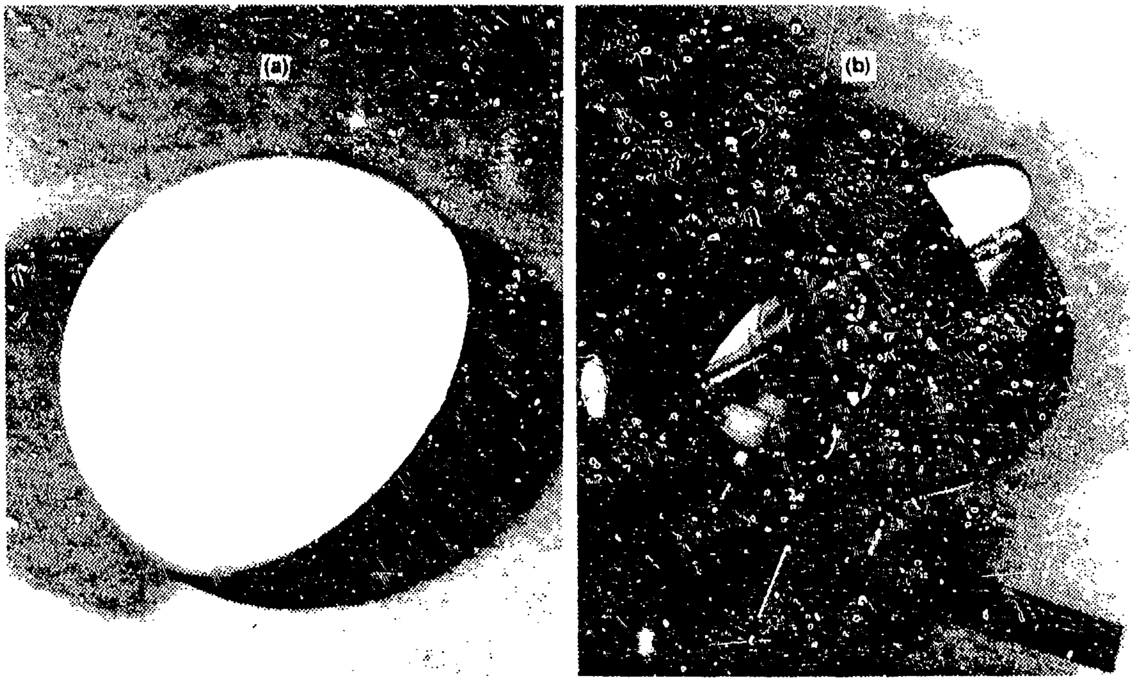


Figure 8. Multifunction low-profile quadrature edge-slot uhf antenna (a) with and (b) without radome.

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[5] *F. Reggia and H. S. Jones, Low Profile Quadrature-Plate UHF Antenna, U.S. Patent 3,987,458 (19 October 1976).*

[1] *Daniel H. Schaubert, Howard S. Jones, Jr., and Frank Reggia. Conformal Dielectric-Filled Edge-Slot Antennas for Bodies of Revolution, Harry Diamond Laboratories HDL-TR-1837 (September 1977).*

[2] *F. Reggia and H. S. Jones, Conformal Edge-Slot Radiators, U.S. Patent 4,051,480 (27 September 1977).*

2.3.1 *Parallel Fed Antennas*

Because edge-slot radiators are thin and can be placed close together without physical interference, they satisfy severe space requirements, while providing adequate radiation pattern coverage. Also, sometimes it is necessary to design an antenna for a particular operating frequency with certain bandwidth requirements. In several cases, these requirements were satisfied with an edge-slot antenna array fed in parallel. Figure 9(a) shows two edge-slot radiators fed in parallel. The antenna is incorporated into the forward section of a 40-mm projectile. It consists of eight elements and operates at 8300 MHz.

Radiation patterns of a single radiator and the two radiators working together, excited in phase and spaced one-half wavelength ($\lambda/2$) apart, are shown in figure 9(b). The impedance bandwidth (VSWR $\leq$ 2) of a single antenna on the 40-mm mockup was 1000 MHz (>12 percent).

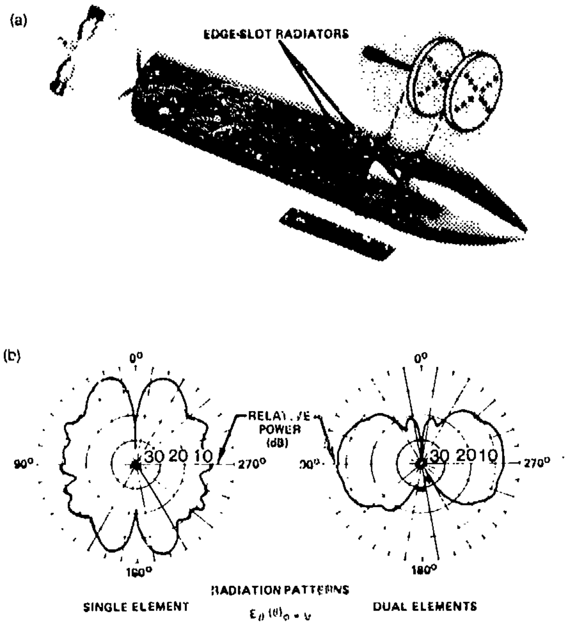

Figure 9. Edge-slot radiator system designed into 40-mm projectile body and radiation patterns.

Other edge-slot arrays containing as many as eight radiators have been developed using corporate feed structures. An array of edge-slot radiators currently being developed for use in a conical body is illustrated in figure 10. Despite the different diameters, each radiator can be designed to resonate at the same frequency. This type of antenna can be designed for use as a fixed angle system, monopulse array, or electronic scanned array.

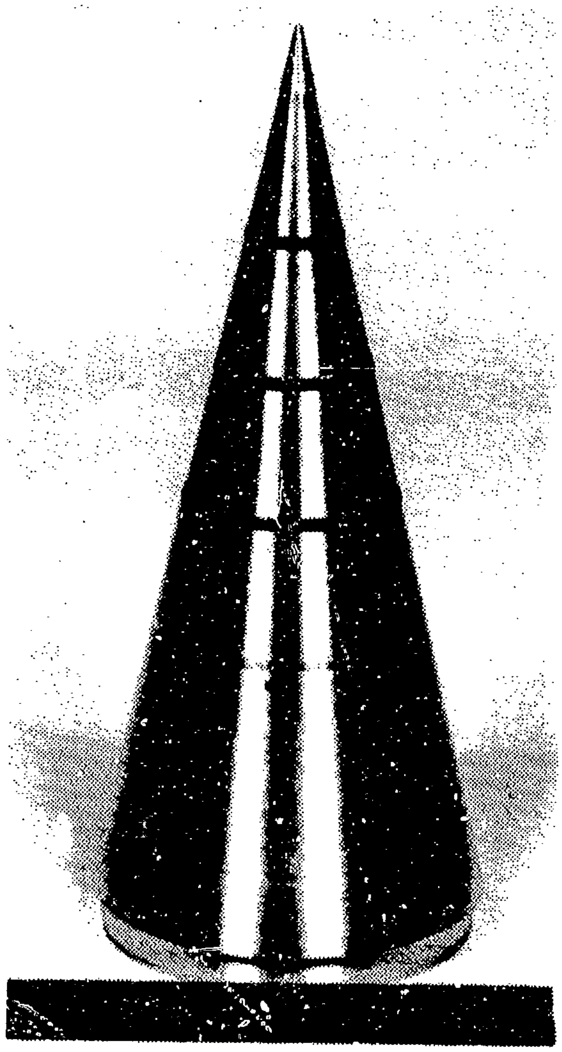

Figure 10. Edge-slot array in conical body.

2.3.2 *Series-Fed Antennas*

Series-fed dielectric-filled edge-slot (SDE) antennas have been extensively investigated, and practical multifunctional designs have resulted.[6] A prototype design of an SDE antenna consisting of three radiators mounted in a 30.2-cm-long cylinder is shown in figure 11(a). The transmission and reflection characteristics of this three-radiator model are shown in the same figure. The dissipation maxima at 675, 790, and 875 MHz (fig. 11b) correspond to transmission minima and agree well with predicted operating frequencies for one-, two-, and three-post antennas. The radiation patterns of this multiradiator antenna are omnidirectional in the azimuthal plane. In the elevation plane, the patterns are controlled by the size of the cylinder and the locations of the antennas on the cylinder.

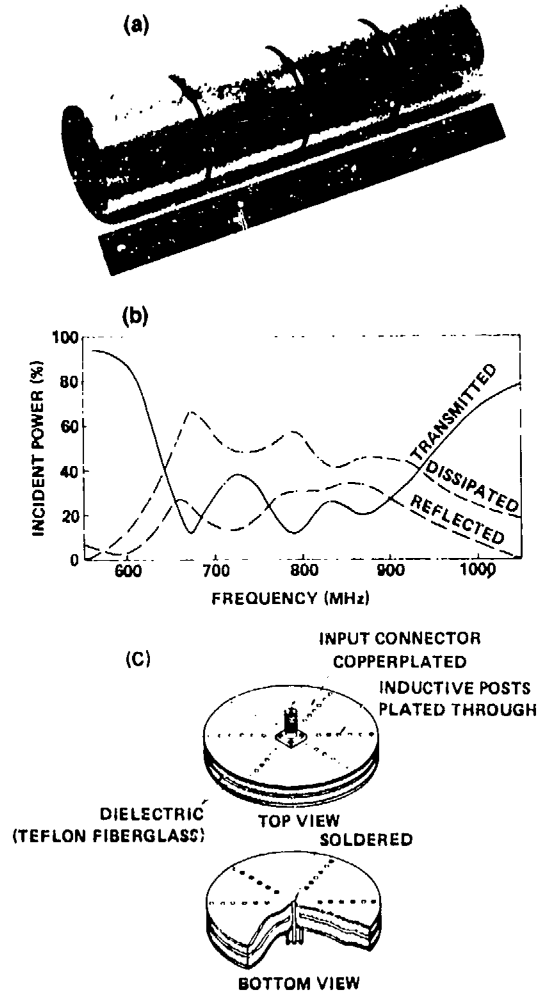

Figure 11. Series-fed antennas and transmission characteristics.

Another version of the series-fed antenna also is shown in figure 11(c). It depicts two radiators (each with six radiating sections) stacked together, fed in series, and terminated in a short circuit. By using a different number of posts in each radiator, a thin dual frequency antenna design with omnidirectional azimuthal radiation coverage is possible.[6]

3. MICROSTRIP ANTENNAS

Until recently, very little had been published on the theory of microstrip radiators. However, the design technique is being increasingly used. A considerable amount of experimental and development work has been done, and a number of unique antenna designs have been demonstrated.[7,8] Modifications can be made easily to enhance its performance. Notwithstanding the narrow bandwidth, these microstrip radiators have been widely used in microwave antenna systems. Microstrip antennas are attractive because they are low profile, compact, lighweight, rugged, and easy to fabricate, and they can be manufactured at low cost using printed-circuit techniques.

The basic microstrip radiator is a thin structure consisting of a rectangular conducting patch that is mounted over a parallel ground plane, excited by an inductive post fed from a coaxial line. The conducting patch is usually approximately λ/2 and separated from

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[6] *D. Schaubert and H. S. Jones, Series-Fed, Dielectric-Filled, Edge-Slot Antenna, International Symposium Antennas and Propagation, Seattle, WA (1979).*

[7] *Robert E. Munson, Conformal Microstrip Antennas and Microstrip Phased Arrays, IEEE Trans. Antennas Propag.,* AP-22 *(January 1974), 74-78.*

[8] *John Q. Howell, Microstrip Antennas, IEEE Trans. Antennas Propag.,* AP-23 *(January 1975), 90-93.*

the ground plane by a thin low-loss dielectric material. Various widths (1/32, 1/16, and 1/8 in.—0.3, 0.6, and 1.2 mm) of copperclad dielectric laminated materials are commonly used in the construction of microstrip antennas. An illustration of the basic microstrip radiator is shown in figure 12.

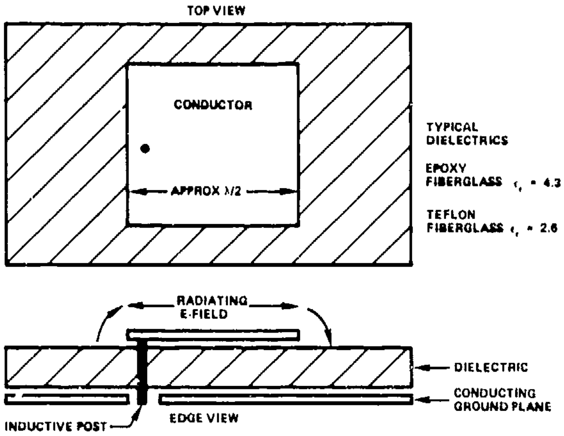

Figure 12. Basic microstrip radiator.

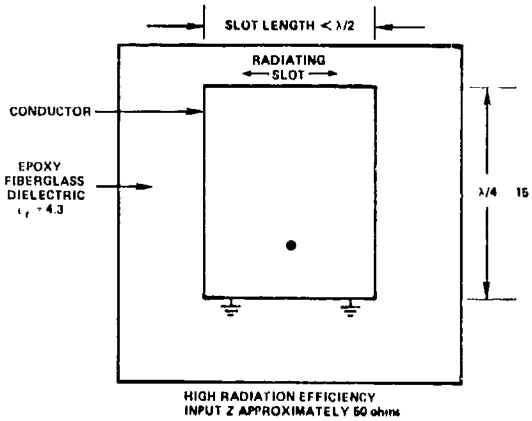

Figure 13. Quarter-wavelength microstrip radiator.

3.1 *Quarter-Wavelength Microstrip Radiator*

Although much attention has been given to the λ/2 radiator, there are certain advantages realized from the use of the λ/4 radiator. One of the chief benefits is that it conserves space. The λ/4 microstrip radiator is shown in figure 13. It is short-circuited at one end and fed at the center near the short circuit. Impedance matching the microstrip radiator is fairly easy; various techniques are used. The radiation patterns obtained from both λ/4 and λ/2 radiators are very broad and therefore quite useful for many applications.

3.2 *Conformal Microstrip Antenna Designs*

The microstrip technique lends itself well to the design of conformal antennas. Because of the benefits derived from this design approach, extensive effort has gone into experimental research to develop antennas that are applicable to various weapon systems. As a result, several novel concepts and useful conformal antenna systems have been successfully designed. Illustrations and performance characteristics of some of these antennas integrated into different body configurations are included in the following sections.

3.2.1 *Two-Element Microstrip Antenna*

The microstrip antenna is gradually replacing the cavity-backed slot, stripline, and waveguide cavity antennas because it requires less space, the construction cost is minimal, and there is very little sacrifice in performance. Furthermore, it can be easily designed into most conformal bodies that use low-loss dielectrics. An example of a two-element microstrip antenna design that replaced a cavity-backed slot antenna is shown in figure 14. The azimuthal radiation pattern is shown in the same figure. In this case, all system requirements were satisfied in addition to the benefits cited above.

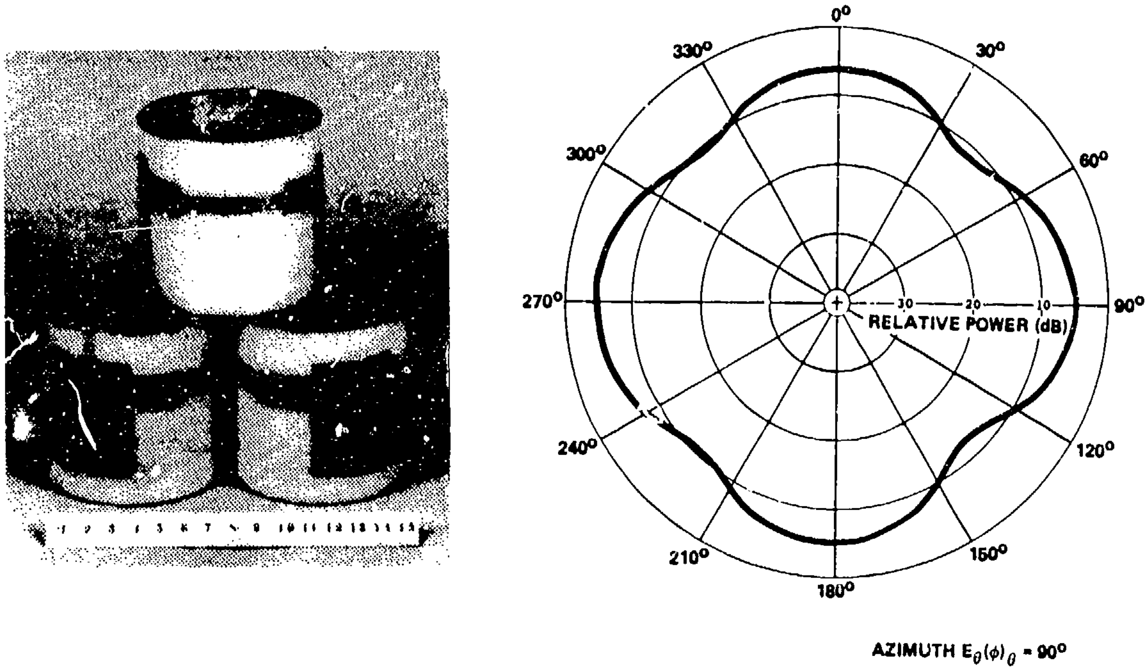

Figure 14. Two-element microstrip telemetry antenna and radiation pattern.

3.2.2 *Dual Frequency Microstrip Arrays*

A further indication of the exploitation and increasing use of microstrip radiators is observed in their successful application in the design of linear, planar, and conformal arrays. Results of recent investigations have shown that microstrip arrays can be integrated quite well into radome structures. Various flush-mounted design configurations that are compatible with their body structures have been demonstrated.

The flush-mounted piggyback microstrip antenna designed into a silicone fiberglass radome on a missile body is illustrated[9] in figure 15. Here, four dual linear arrays, one array in each quadrant, are designed into the radome (copperplated on the surface). Each of four elements of the array consists of two radiators, one mounted on top of the other in a piggyback fashion. The bottom radiator is a $\lambda/2$ design, and the top radiator is a $\lambda/4$ design. The dielectric radome has a 0.2-in (0.5-cm)-thick wall, and the inside of the radome has complete copperplating, which provides the ground plane for the dual radiating elements. These elements that make up the array are excited in parallel from a corporate feed.

The $\lambda/4$ section of the dual radiator has plated-through holes along its bottom edge, which form the short circuit. An inductive post, which is also a plated-through hole, matches the bottom $\lambda/2$ radiator. In addition, it provides a passageway to feed the $\lambda/4$ radiator, as shown in figure 15. The elevation and azimuth plane radiation patterns of each radiator are shown in figure 16.

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[9] *H. S. Jones, D. Schaubert, and F. Farrar, Flushmounted Piggyback Microstrip Antenna, U.S. Patent 4,162,499 (24 July 1979).*

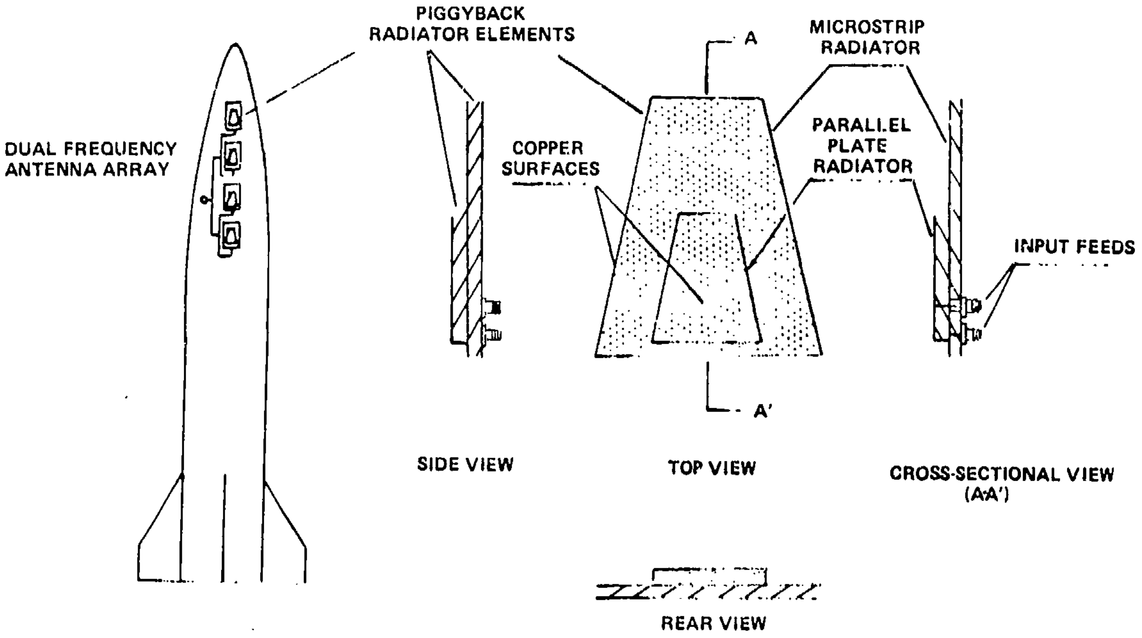

Figure 15. Piggyback microstrip radiator.

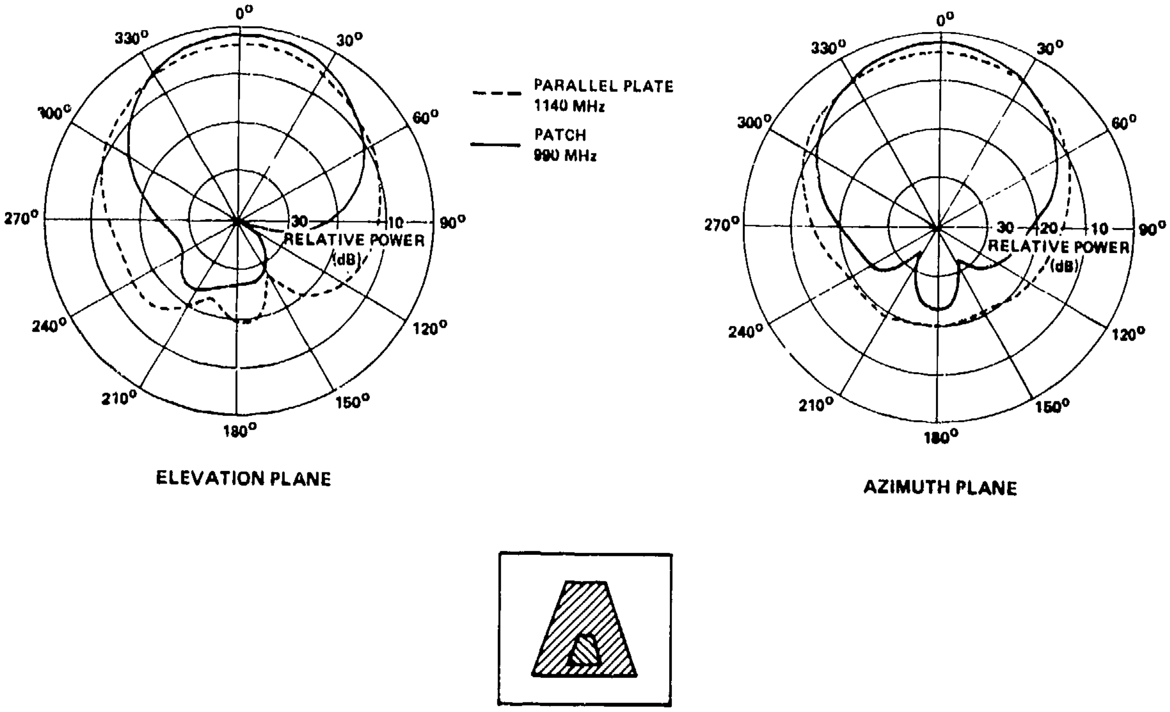

Figure 16. Radiation patterns of piggyback antenna.

The design of a dual frequency microstrip antenna integrated into a section of conical radome is shown[10] in figure 17. This antenna consists of two linear arrays; one has four radiators and the other has eight. All of the radiators are λ/4. Although the arrays operate in different frequency bands, they are physically separated far enough to minimize mutual coupling. Furthermore, the elements in one array are staggered with respect to those in the other. This staggering provides additional decoupling between arrays. Radiation patterns of the four-element array also are seen in figure 17.

3.2.3 *Multifunction Radome Antenna*

Dielectric radomes of various shapes and sizes are commonly used on the forward end of military weapons. They provide a sound and rugged aerodynamic structural housing, within which is located antenna systems, electronic hardware, and other devices. Efficient, functional antenna systems can be designed and constructed into these radomes without having their structural integrity destroyed. A concept was conceived and developed that makes full use of the dielectric radome in the design of a multifunction antenna system.[11,12]

A typical example of this design concept is shown in figure 18. Here, the parallel plate microstrip radiators are designed

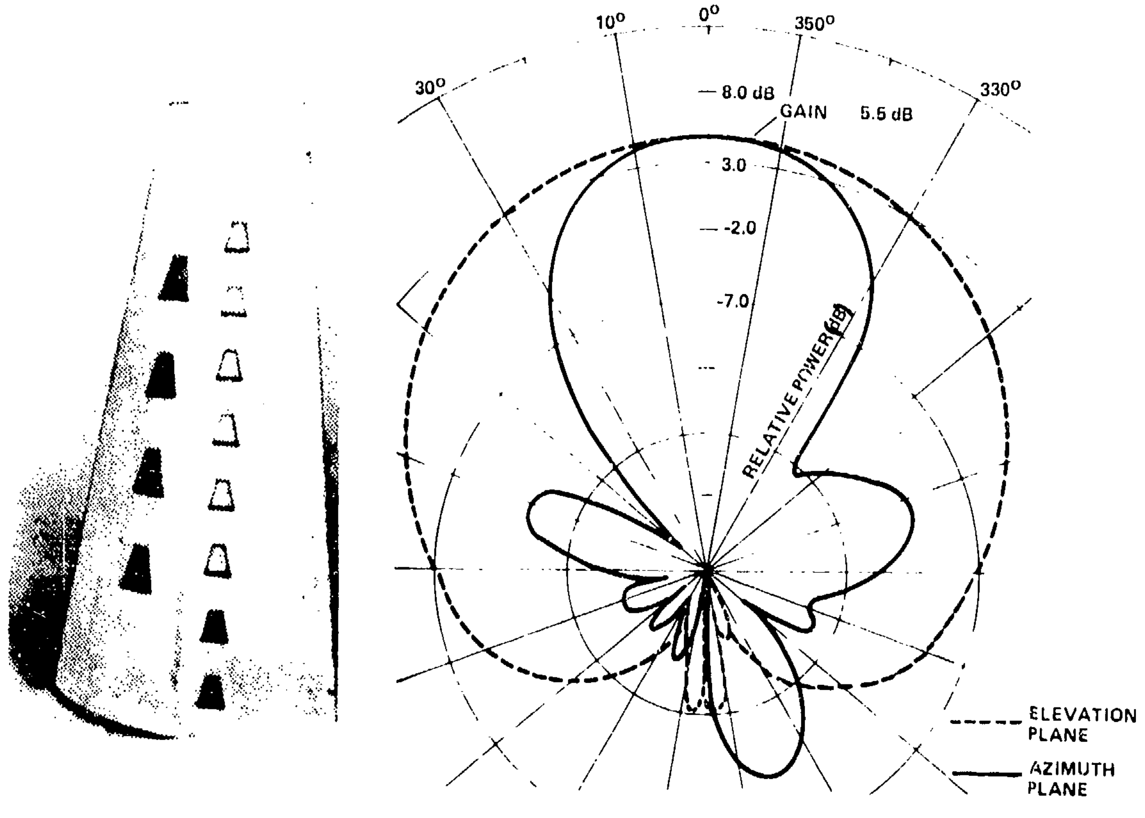

Figure 17. Dual frequency radome antenna with radiation pattern of four-element array.

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[10] *H. S. Jones, Multifrequency Antenna Integrated into a Radome, U.S. Patent 4,101,895 (18 July 1978).*

[11] *H. S. Jones, Multi-Function Integrated Radome-Antenna System, U.S. Patent 4,010,470 (1 March 1977).*

[12] *H. S. Jones, A Novel Technique for the Design of Integrated Radome-Antenna Systems, Proceedings of 13th Symposium on Electromagnetic Windows (September 1976).*

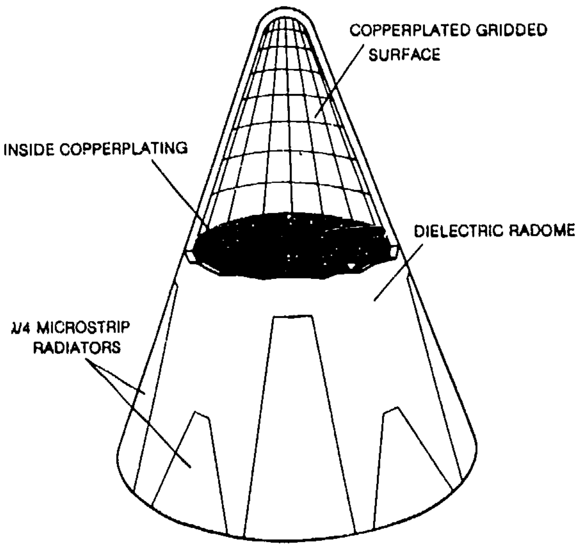

Figure 18. Multifunction integrated radome antenna system.

into the radome at the base and positioned at points around the circumference. These $\lambda/4$ radiators copperplated on the outer surface extend around the base connecting with the inside conducting surface (ground plane), where they are excited from a coaxial probe near the base. The parallel plate radiators are designed to operate in the uhf region.

The inside of the radome is completely copperplated except for the forward region of the cone, which is a conductive gridded surface. This dielectric loaded gridded region can be designed to act as a spatial filter. That is, it is transparent to transmission at certain frequencies; for example, at X-band, energy can be transmitted through the medium with minimum loss and distortion. Yet, at the low frequencies (uhf), this region is opaque to transmitted energy. These design features allow the radome antenna (fig. 18) to serve a variety of functions.

3.2.4 *Spiral Microstrip Antenna*

The spiral-slot antenna is an electrically small flush-mounted microstrip radiator designed for small-diameter missile or projectile applications.[13] High radiation efficiency is obtained by strongly coupling radio frequency (rf) currents to the body of a missile and exciting the dipole mode of radiation. When the antenna operates in the uhf band, an instantaneous bandwidth of approximately 2 percent is achieved. The spiral-slot antenna produces an axially polarized radiation field and a dipole radiation pattern with isotropic gain.

The antenna is fabricated from a copperclad tube of epoxy fiberglass dielectric. A thin rectangular sheet of conductor, wrapped in a spiral around the outer surface of a cylindrical tube of dielectric, forms the basic spiral-slot antenna. In figure 19, the spiral-slot antenna is shown in a typical application, mounted in the nose tip of a 2-m-long rocket. The radiation patterns from the antenna mounted on the body are shown in figure 20. The peak gain is about +1 dBi.

Main-polarized and cross-polarized radiation-pattern gains over a narrow frequency range are plotted in figure 21. The spiral-slot antenna displays a 3-dB gain bandwidth of 9 MHz or approximately 3 percent. The instantaneous impedance (VSWR = 2:1) bandwidth is 4 MHz or about 2 percent. The cross-polarized field component is at least 9 dB down and decreases to about 14 dB down at the design center frequency (238 MHz).

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[13] *D. H. Schaubert, A. R. Sindoris, and F. G. Farrar, The Spiral Slot, a Unique Microstrip Antenna. Proceedings of 1978 Antenna Applications Symposium, University of Illinois, Monticello, IL (October 1978).*

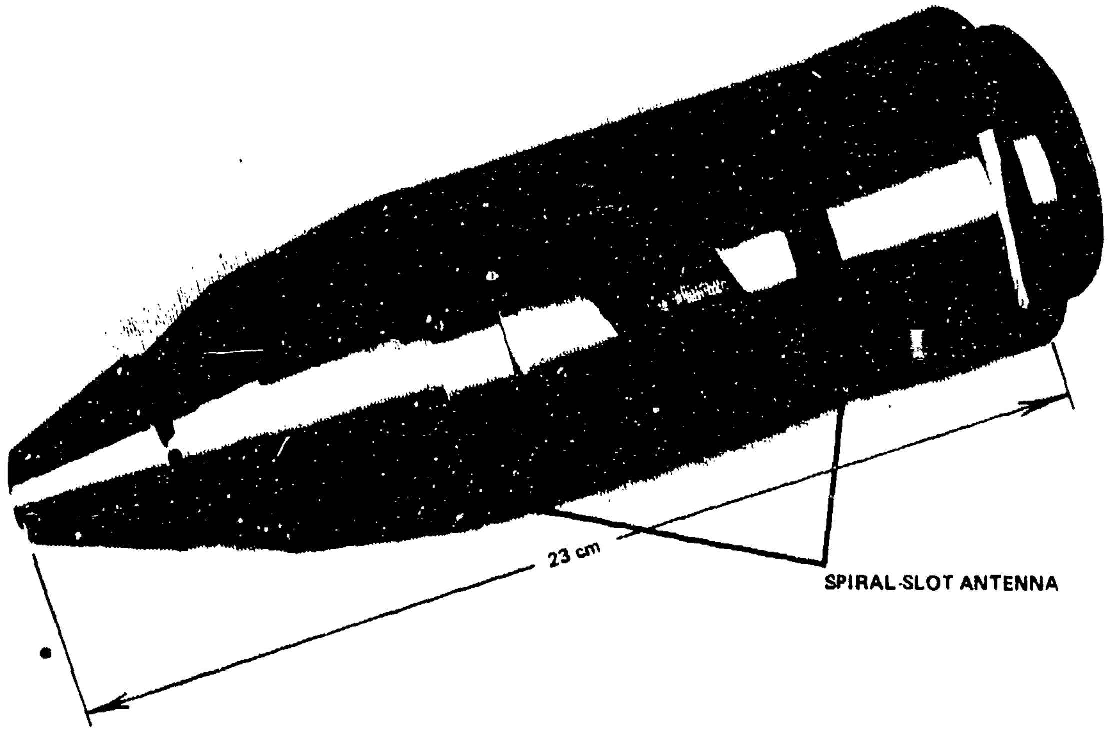

Figure 19. Spiral-slot antenna mounted in nose of 2-m-long rocket.

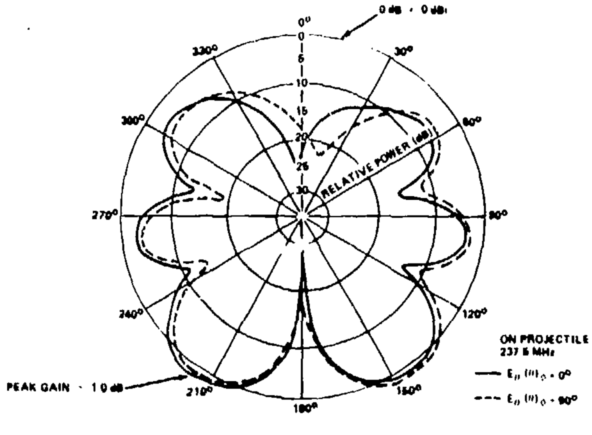

Figure 20. Radiation patterns of spiral-slot antenna in 2-m-long rocket.

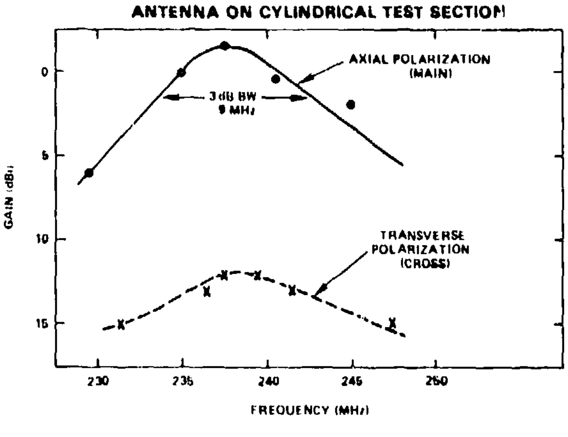

Figure 21. Gain-bandwidth (BW) characteristics of spiral-slot antenna.

4. DIELECTRIC ROD ANTENNAS

The theory of dielectric rod radiators is well known.[14] They are highly suited for use in military weapon systems to perform a variety of functions. These end-fired radiators have high gain, low side lobes, high decoupling between radiators, and in some cases broad bandwidth characteristics. They are efficient with good directivity and can be compactly designed into small apertures. Because of these and other features, dielectric rod radiators offer many advantages when used in the design of small and conformal antennas.

4.1 *Single Dielectric Rod Designs*

A considerable amount of research and development has been performed on dielectric rod radiators operating in the X-band region.[15] Although a number of different materials can be used as dielectric rod radiators, the material that is used most often is aluminum oxide (Al_2O_3). It has a dielectric constant of 9.0 and a loss tangent of 0.0011.

The use of waveguide is a simple and convenient means of launching a wave into the dielectric rod. In this case, the waveguide is operated in its dominant TE_{10} mode, and as the wave passes into the rod it is transformed into the hybrid mode of the rod.[15] A dielectric rod radiator design using X-band waveguide is shown in figure 22. The dielectric rod is tapered to a point at one end for matching to the waveguide. A more gentle taper is on the output end to provide a smooth transfer of the energy to space. The lossless dielectric foam seen in figure 22 is used to position the rod in the center of the waveguide. Shown in the same figure are elevation and azimuth plane radiation patterns taken at 9.0, 9.2, and 9.4 GHz.

4.1.1 *Decoupling Characteristics*

Because the energy tends to adhere to the rod, there is very little coupling of energy between rods placed close together.[16] Two radiators were used with three different orientations of their electric fields to determine the decoupling characteristics between radiators as a function of separation. The results of this experiment are shown in figure 23. Here, it is observed that when two rods are separated by only 1 in. (2.54 cm) and polarized in the same plane, the decoupling is greater than 30 dB. In one orientation, as much as 70-dB decoupling is obtained.

4.1.2 *Coaxial-Fed Dielectric Rod Radiator*

Dielectric rod radiators can be designed simply and effectively by feeding the rod from a coaxial input; however, the bandwidth is narrow. In this case, a portion of one end of a cylindrical dielectric rod is metallized (or copperplated). The rod is fed from this enclosed metallized end by a coaxial line whose center probe extends into the dielectric. The other unbound end of the cylindrical rod is tapered to match the radiated energy to free space. An X-band dielectric rod radiator designed and constructed in this manner with its radiation pattern is shown in figure 24. This radiator is mounted in a circular ground plane and is housed in a small conical radome.

Another coaxial-fed dielectric rod radiator design that operates at 3.0 GHz is shown in figure 25. This small antenna was designed for use in a projectile nose cone conformal with its apex. The overall length of the antenna is about 2 in. (5.08 cm), and it provides broad radiation coverage in the forward direction.

---

[14] *D. F. Halliday and D. G. Kiely, Dielectric-Rod Aerials, IEEE J.,* **94** *(1947), Part IIIA, 610-618.*

[15] *Howard S. Jones, Jr., Design and Development of Dielectric Rod Antennas, Harry Diamond Laboratories HDL-TR-1640 (July 1973).*

[16] *H. S. Jones, Dielectric Rod Antenna System, U.S. Patent 3,858,214 (31 December 1974).*

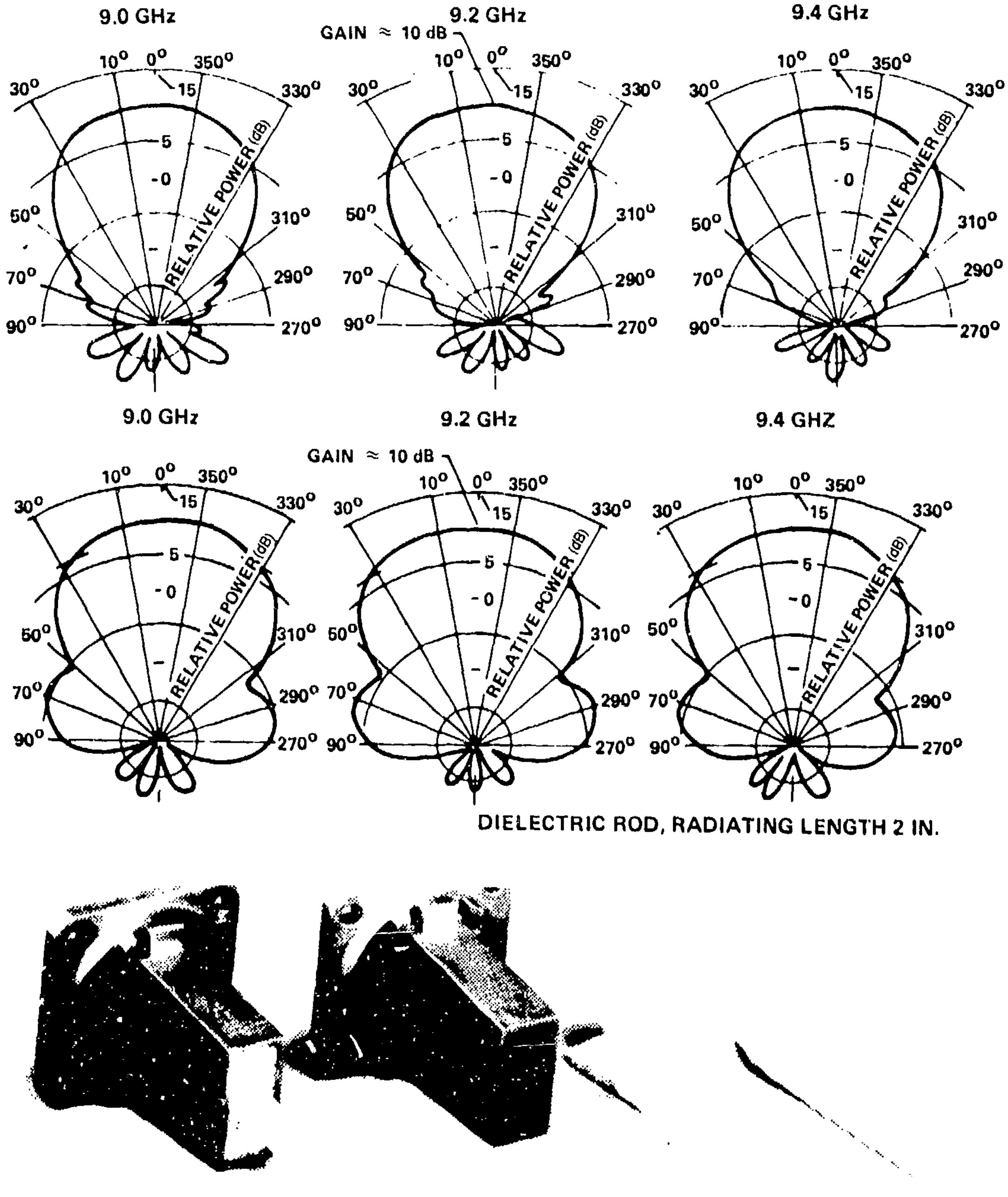

Figure 22. Single rod dielectric radiator and radiation patterns.

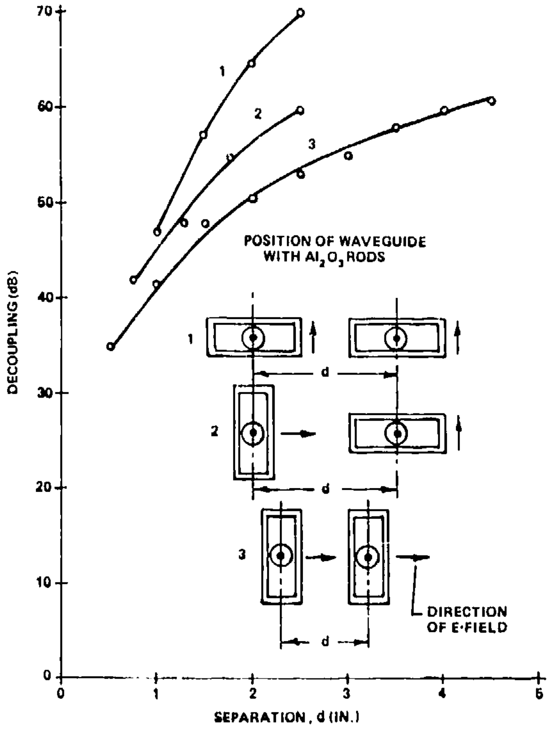

Figure 23. Decoupling as function of dielectric rod separation for three waveguide orientations.

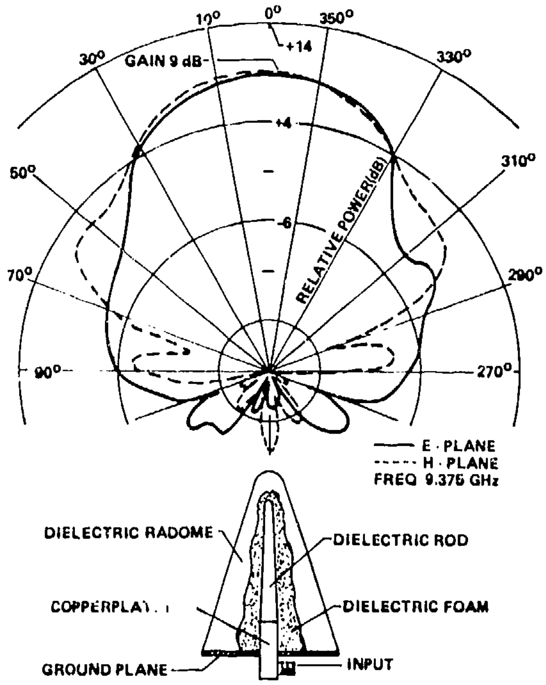

Figure 24. Radiation patterns of X-band coaxial-fed dielectric rod antenna in radome.

4.1.3 *Cylindrical Dielectric Rod Radiator*

The cylindrical dielectric antenna was designed to be small, compact, and capable of producing a radiation pattern with the null on axis. This antenna is a 1-in.-high dielectric (machinable glass) cylinder with a 1/16-in. (0.6-mm) wall with a solid base on one end and open on the other end. It is completely copperplated on the inside On the outside, the base and only a small portion of the outer surface are copperplated. The copperplated dielectric structure is fed from coaxial line at the center of the base and is mounted in a 2-1/2-in. (6.35-cm) circular ground plane. Figure 26 sketches a prototype model. In the same figure are radiation patterns, one taken with a thin absorber over the ground plane and the other taken without the absorber. There are other versions of this antenna currently under investigation.

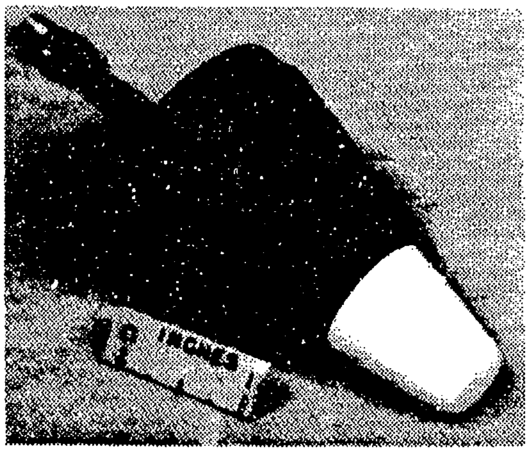

Figure 25. S-band dielectric rod radiator designed into small nose cone.

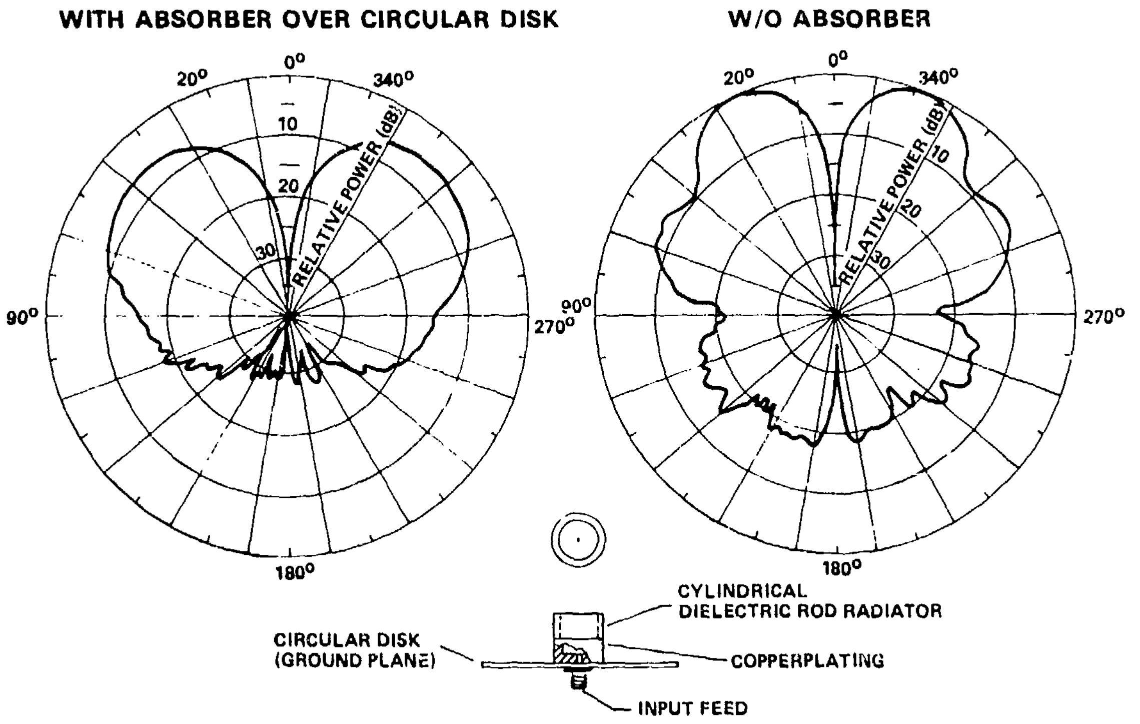

Figure 26. Radiation patterns of small cylindrical dielectric radiator.

4.2 *Dielectric Rod Monopulse Antenna*

A typical dielectric rod monopulse antenna is illustrated in figure 27 (p. 24). The antenna consists of a hybrid tee, a dual 90-deg twist to rotate the plane of polarization, and two H-plane tee junctions that support the four dielectric rods. These rods are separated approximately 1 in. The hybrid tee has two inputs: one feeds the two output channels in phase and the other feeds the output channels out of phase. Each of these outputs (through the twist section) feeds a pair of rods that are mounted in each series tee junction. This configuration allows each pair of rods to be excited in phase or out of phase with each other. Figure 28 (p. 25) shows the sum and difference patterns of the dielectric rod monopulse antenna taken in a ground plane.

4.3 *Millimeter Wave Dielectric Rod Radiators*

Single dielectric rod radiators launched from waveguide have been designed at 70 and 94 GHz. The experimental model of the 70-GHz radiator with its radiation patterns is shown in figure 29. This antenna uses a sapphire rod whose dielectric constant $\varepsilon_r = 8.6$ and loss tangent $\tan \delta = 0.0014$. The radiating length of the rod is 0.75 in. (1.905 cm) measured from the waveguide (RG98/U) aperture.

In the design of dielectric rods for operation at 94 GHz, two dielectric materials were used, TPX ($\varepsilon_r = 4$) and custom HiK ($\varepsilon_r = 3.3$). The radiating ends of the rods were designed in a pyramidal and tapered wedge configuration (fig. 30, p. 27). The input ends were tapered to a point at the center to provide an optimum match to the waveguide. Radiation pattern characteristics of these dielectric rod radiators are shown in figure 31 (p. 28). The TPX wedge design had a peak gain of about 16 dB.

5. OTHER DESIGNS

In addition to the antennas that have been discussed, modifications and other antenna designs employ the same techniques and are useful and noteworthy. Several of these antennas were designed into a small dielectric nose cone that is commonly used on projectiles. These are typical examples of electrically and physically small antennas. In most cases, these antennas conform to the conical body and consume very little space. A selected group of these small compact antennas and a brief description of each are shown in figure 32 (p. 28).

6. CONCLUSION

The antenna techniques discussed here have many outstanding features. Each technique lends itself to the design of conformal and small antennas. Also, with these techniques, antennas can be designed in several frequency bands, an additional advantage. The antennas illustrated are efficient, functional, low cost, and capable of being used in a variety of applications.

There has been increasing interest in conformal and small antennas. For example, the continued use of microstrip radiators in planar, conformal, and phased arrays has been heavily emphasized. Further research and investigation into the use and exploitation of these and other techniques are continuing at the Harry Diamond Laboratories.

Figure 27. X-band dielectric rod monopulse antenna.

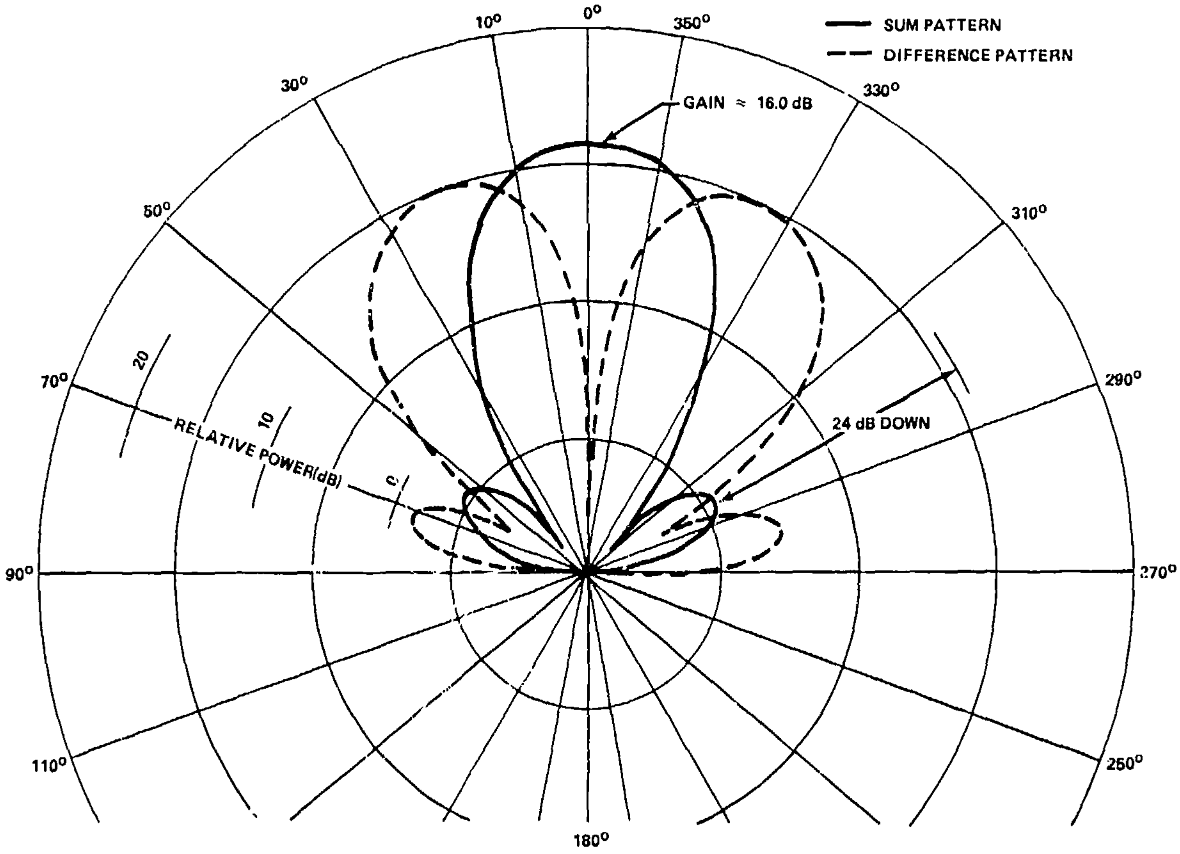

Figure 28. Radiation patterns of X-band dielectric rod monopulse antenna, taken in ground plane.

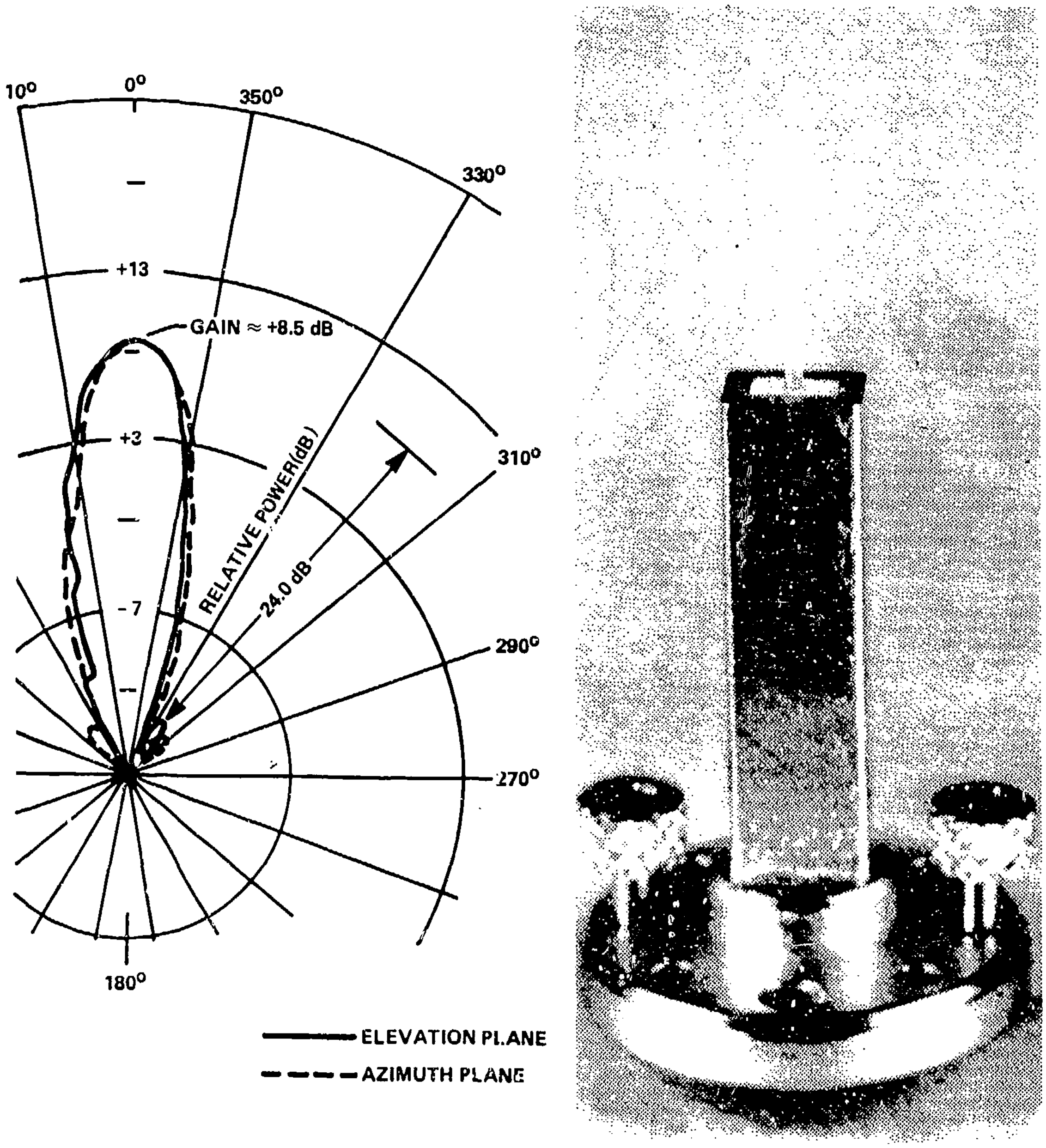

Figure 29. Millimeter wave dielectric rod radiator (70 GHz) with radiation patterns.

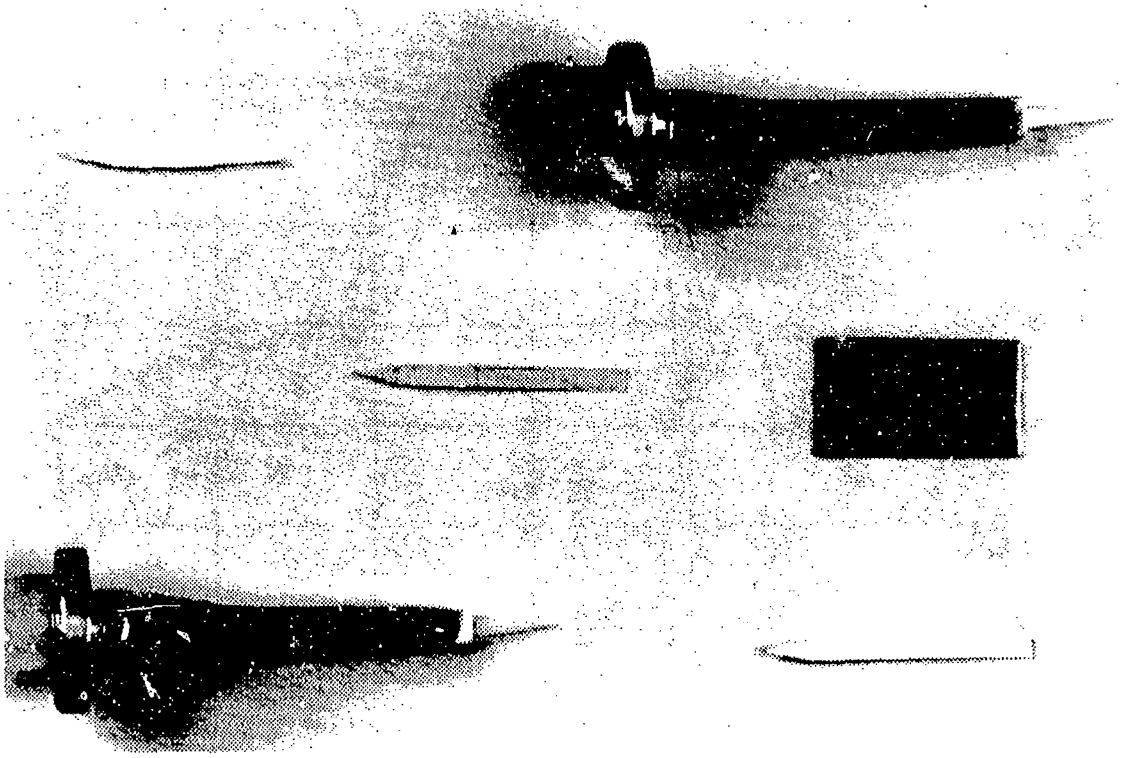

Figure 30. Millimeter wave dielectric rod radiators (94 GHz).

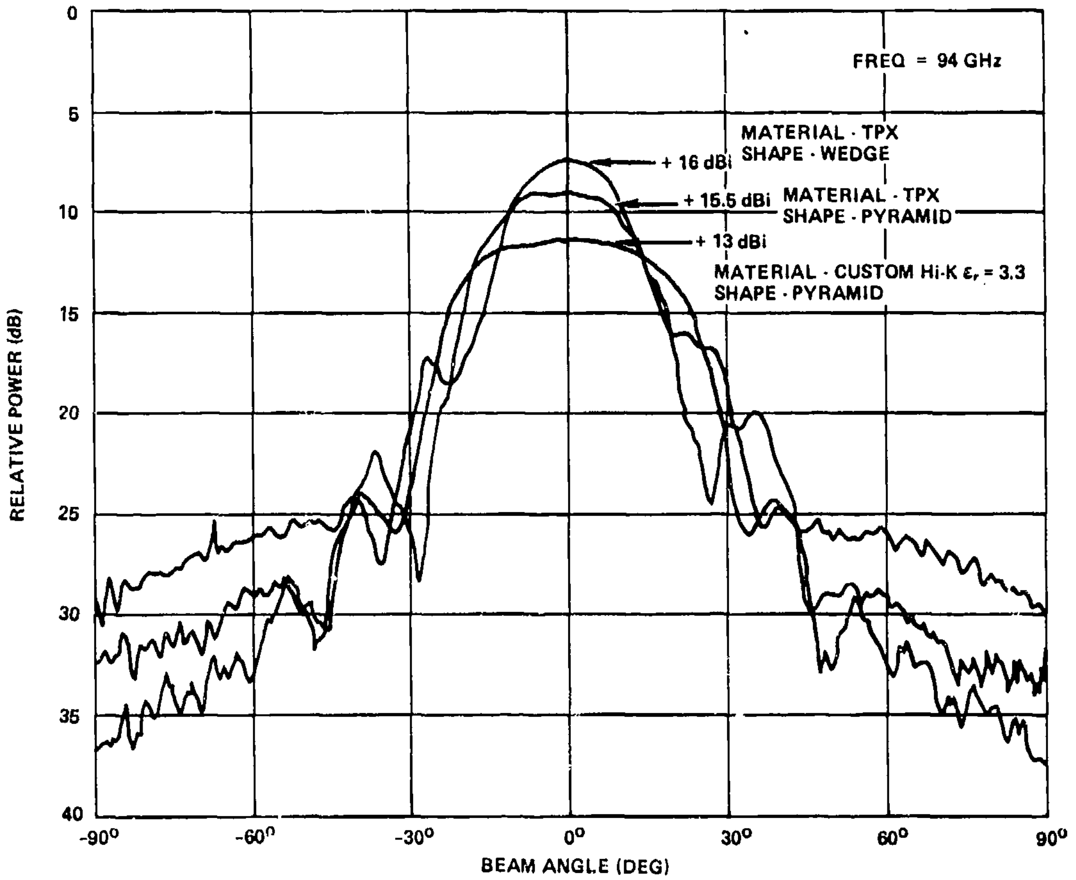

Figure 31. Radiation patterns of millimeter wave antennas (94 GHz).

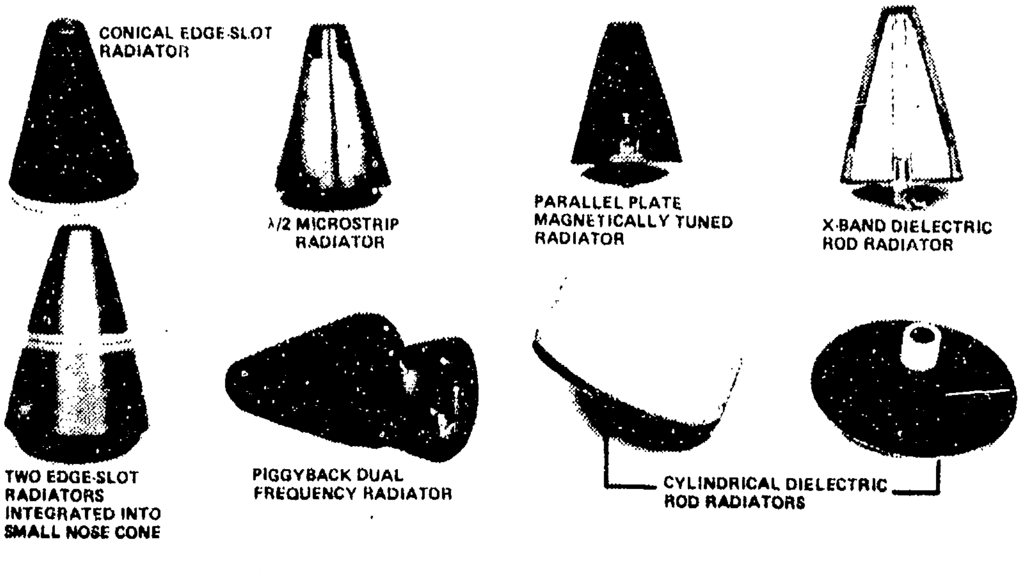

Figure 32. Small compact low-profile antennas.

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