TR-1335

TELEMETRY RING ANTENNA

by

Howard Bassen
Ronald Jantz

December 1966

U.S. ARMY MATERIEL COMMAND

HARRY DIAMOND LABORATORIES

WASHINGTON, D.C. 20438

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CONTENTS

ABSTRACT

A quarter-wavelength ring antenna was developed to telemeter active fuzes in flight with a minimum modification to fuze or artillery round. Using principles of strip transmission line theory, general design criteria were established to maximize radiation efficiency within a fixed form factor. Electroplating and selective machining provided for economical, accurate production. Antenna field strength measurements verified expectations as to adequate radiation efficiency and a highly symmetric, ring-shaped pattern. This type antenna provides the ability, for the first time, to telemeter in-flight active fuzes without major shell modification.

1. INTRODUCTION

The need for a fuze telemetry system that would require minimum modification to either fuze or its artillery round provided the impetus for the development of a new antenna system. The concept of a ring antenna mounted on the sleeve between fuze and artillery shell (fig. 1) was deemed most suitable for the above requirements. Of primary concern was the requirement that the radiated energy from this antenna cause no interference with fuze operation. Cost and convenience considerations dictated the need for an antenna compatible with the different standard artillery rounds, i.e., antenna performance should be relatively independent of the body upon which it is mounted and withstand the maximum conditions of a gun-launched, projectile environment. The quarter-wavelength ring antenna was developed to meet all of these requirements and provided a reasonable radiation efficiency.

An empirical approach was taken in the development of a prototype antenna. After basic, qualitative guidelines were established from strip transmission line theory, it was found that the most expedient approach was that of construction and measurement. A hybrid theory involving strip transmission line radiators in the VHF range is practically nonexistent and mathematically overwhelming for nonidealized geometries.

2. DESIGN BACKGROUND

An understanding of the quarter-wavelength ring antenna can be best achieved through a study of strip transmission line theory. The specific antenna under study may be considered as a shorted-termination strip transmission line. At a frequency whose wavelength is four times the electrical length of the transmission line, a parallel resonant situation exists. The input impedance of the line is high and purely real, consisting of the sum of line losses and a resistance that represents the radiated

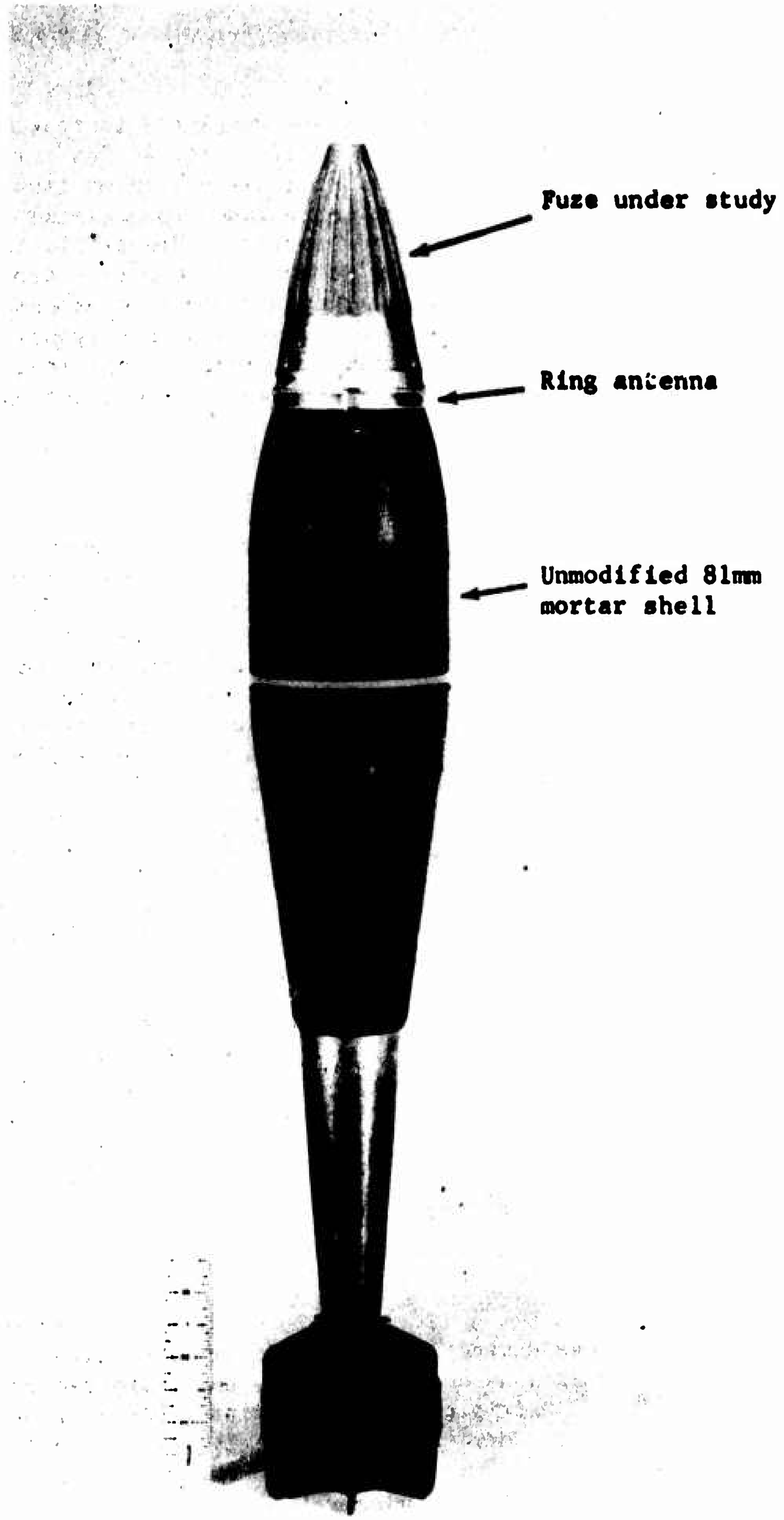

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Figure 1. Ring antenna mounted on 81mm mortar shell.

power dissipation factor. Moving the driving point away from the input lowers the impedance measured at the driving point. This value, relative to the high value of input impedance, is a function of the ratio of driving point length (measured from the shorted end) to total line length. Thus a variety of real impedance values is available by the proper selection of driving point locations. For the specific antenna under study, an impedance of 50 ohms was chosen since this value was compatible with the widest range of laboratory instruments and coaxial cables. The length of an epoxy-fiberglass, 227-MHz unit was 7.35 in. while the driving point on this unit was approximately 0.5 in. from the shorted end.

Consideration of an idealized, theoretical, strip transmission line yields several important concepts that may be utilized in the adaptation of a strip transmission line to an antenna system. Figure 2 illustrates the idealized case of two infinite parallel conducting planes separated by distance h and of width a. A right-handed, Cartesian coordinate system is utilized with z being the direction of propagation of a steady-state, sinusoidal, electromagnetic wave of angular frequency ω. In this first analysis, the remainder of the x-z planes will be retained as guard plates to simplify the geometry. From Maxwell equations the following relationships are obtained*:

$$\partial I/\partial Z = - j\omega\epsilon\epsilon_o (a/h) V$$

and

$$\partial V/\partial Z = - j\omega\mu_o (h/a) I$$

where

I = longitudinal current

V = voltage between plates

$\mu_o = 4 \times 10^{-7}$ H/m

$\epsilon_o = (1/36) \times 10^{-9}$ F/m

From these equations, the inductance L and capacitance C per unit length are established as

$$L = \mu_o \, h/a$$

and

$$C = \epsilon\epsilon_o \, a/h$$

where

h = separation between plates

a = strip width

ϵ = relative dielectric constant of material between plates

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*W. Watson, "The Physical Principles of Wave Guide Transmission and Antenna Systems," Oxford at the Clarendon Press, 1947, p 2.

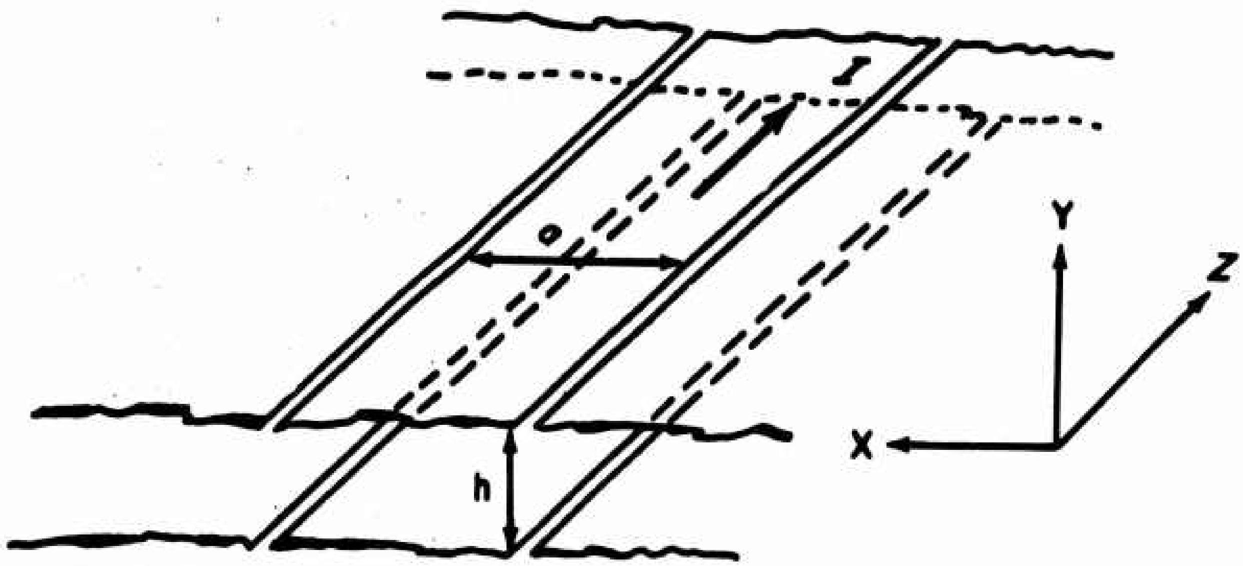

Figure 2 - Theoretical, infinite conducting planes.

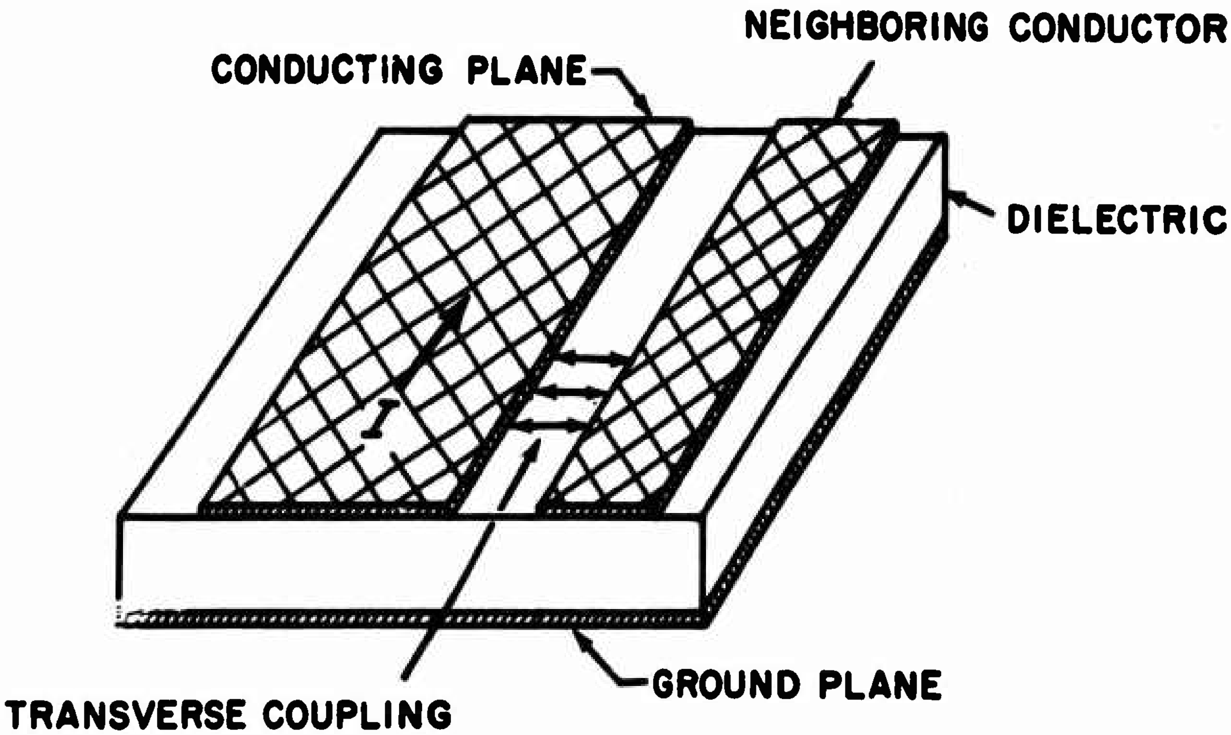

Figure 3 - Illustration of transverse coupling effects.

Neither separation between plates nor the strip width determine the resonant frequency ω_0 of a fixed-length line since cancellation of the a and h terms occurs in the following relation: $\omega = 1/\sqrt{LC}$. Strip length solely determines the resonant frequency of a line at a frequency whose wavelength may be expressed as $\lambda = 2\pi v/\omega_0$, where v = velocity of propagation $v = 1/\sqrt{\epsilon\epsilon_0\mu_0}$. By selecting a material with a suitable dielectric constant ϵ, a fixed physical dimension may be made compatible with a desired electrical length since the dielectric-loaded line length may be shortened by a factor of $1/\sqrt{\epsilon}$ relative to an air dielectric line.

The radiation of energy from a transmission line can be analyzed in an effort to maximize this phenomenon for antenna applications. In the ideal case, only the TEM mode is present (true if spacing between conducting strip and ground plane is less than one-half wavelength). Under these conditions, radiated power P_r relative to power transmitted in the line P is expressed as*:

$$P_r/P = (K_1/Z_0)(\pi h/\lambda)^2$$

Thus

$$P_r/P = K_2\ (ha)/(\lambda^2)$$

where

Z_0 = characteristic line impedance

h = height of conducting strip above the ground plane

a = conducting strip width

K_1 & K_2 = constants

λ = wavelength of propagated wave in the strip transmission line.

It can therefore be stated that a change in either strip width or spacing will cause a directly proportional change in radiated power relative to input power.

Power flow between conducting and ground planes is restricted to an area in the immediate vicinity of the transmission line.**

*D. Grieg and H. Engelmann, "Microstrip—A New Transmission Technique for the Kilomegacycle Range," IRE Proceedings, Vol 40, Dec 1952, pp 1644-1651,

**F. Assadourian and E. Rimai, "Simplified Theory of Microstrip Transmission Systems," IRE Proceedings, Vol 40, Dec 1952, pp 1651-57.

It is standard practice in analysis of strip transmission lines to consider a ground plane infinite in width if it is greater than three times the width of the conducting strip. This implies that a strip transmission line radiator is virtually independent of its surroundings. The property of relative independence of the body upon which it is mounted is characteristic of this family of antennas.

Consideration must be given to the power loss that occurs due to transverse coupling effects. The proximity of the conducting strip to either ground or other conducting strips leads to coupling of the transverse components of radiated energy. Attenuation of transversely radiated energy is expressed as*:

$$\alpha_t = 27/b$$

α_t = attenuation in db/unit distance

b = distance of conducting strip from transverse conducting plane

By maximizing the distance of the conducting strip from conductors parallel to the direction of propagation, the transverse coupling effect may be made negligible.(fig. 3).

From the above considerations one may draw several basic conclusions in the adaptation of strip transmission lines to an antenna system. Wavelength and resonance are strictly functions of strip length and dielectric. Radiated power increases directly with increasing dimensions of strip width and spacing above the ground plane. Power flow is restricted to the area in the immediate vicinity of the line, implying that only limited excitation of the surroundings occur. Spacing of the center conductor with respect to conducting areas running parallel to the plane of the center conductor should be adequate to avoid transverse coupling effects.

3. FABRICATION

The fabrication of a prototype that could be cheaply yet accurately reproduced in large quantities was achieved through the technique of electroplating. Figure 4 illustrates an epoxy-fiberglass ring completely plated with a 0.002-in. copper layer, then machined to create a circular strip transmission

*W. Fromm, "Characteristics and Some Applications of Stripline Components," IRE Transactions on Microwave Theory and Technique, Vol MTT3 #2, March 1955, pp 13-17.

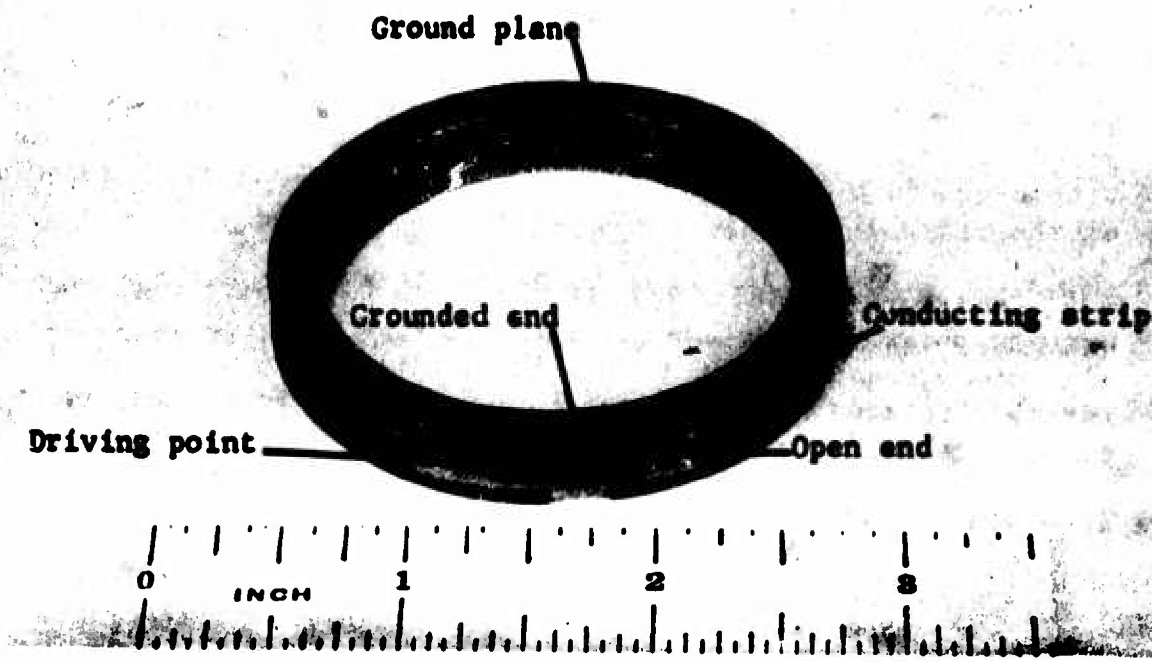

Figure 4. Epoxy fiberglass ring antenna.

Figure 5. Antenna mounted on fuze hardware. 672-66

line. The machining process was made extremely simple in the following manner: Before plating, a circular groove is machined around the center of the ring while a second, lateral groove is machined perpendicular to the first. After plating, the raised edges bordering the circular groove are removed in a lathe. A continuous circular strip of copper, grounded by the lateral groove, remains on the ring. A 1/16-in. break in the lateral groove is cut in the copper, creating a strip transmission line with a ground plane comprising the back, top and bottom sides of the ring.

Semirigid coaxial cable is connected to the appropriate driving point through a hole drilled in the wall of the ring. With epoxy encapsulation to ruggedize this joint, the antenna assembly is made sturdy enough for most present artillery environments. Figure 5 illustrates a unit fitted in this manner.

4. EVALUATION

The quarter-wavelength ring antenna was evaluated in two ways, through a study of impedance and reflection parameters and by a comparison with standard dipoles and similar reference radiators. Presented in figures 6 and 7 are the impedance and VSWR versus frequency characteristics of an epoxy-fiberglass-dielectric ring antenna. Figure 8 shows the antenna mounted for test measurements. A usable bandwidth of approximately 6 MHz at a frequency of 227 MHz is well within the limits of existing telemetry transmitters. While first units evaluated were approximately 14 dB below a reference dipole, further studies indicate a 10-dB figure is entirely feasible using the theoretical guidelines presented in this report. The achievement of this 10-dB value represents a high figure of merit for an antenna of this physical size and frequency range. The relatively narrow bandwidth of this antenna can be utilized advantageously by using the antenna as the tuned circuit of a coaxial oscillator whose bandwidth will consequently be narrow. It should be noted that by decreasing line losses, through the use of lower-loss dielectrics, a proportional decrease in bandwidth occurs.

Antenna field strength patterns illustrated in figure 9 indicate the symmetrical pattern characteristic of this type antenna. The very uniform circular azimuthal field strength pattern is of major significance in both telemetry and fuze considerations. Of particular interest is the fact that no radiation of power occurs in the nose region of the shell, implying that telemetry transmission should not interfere with the active fuze. The wide 3-dB angle of dispersion (60°) of this antenna is of great value for telemetry applications

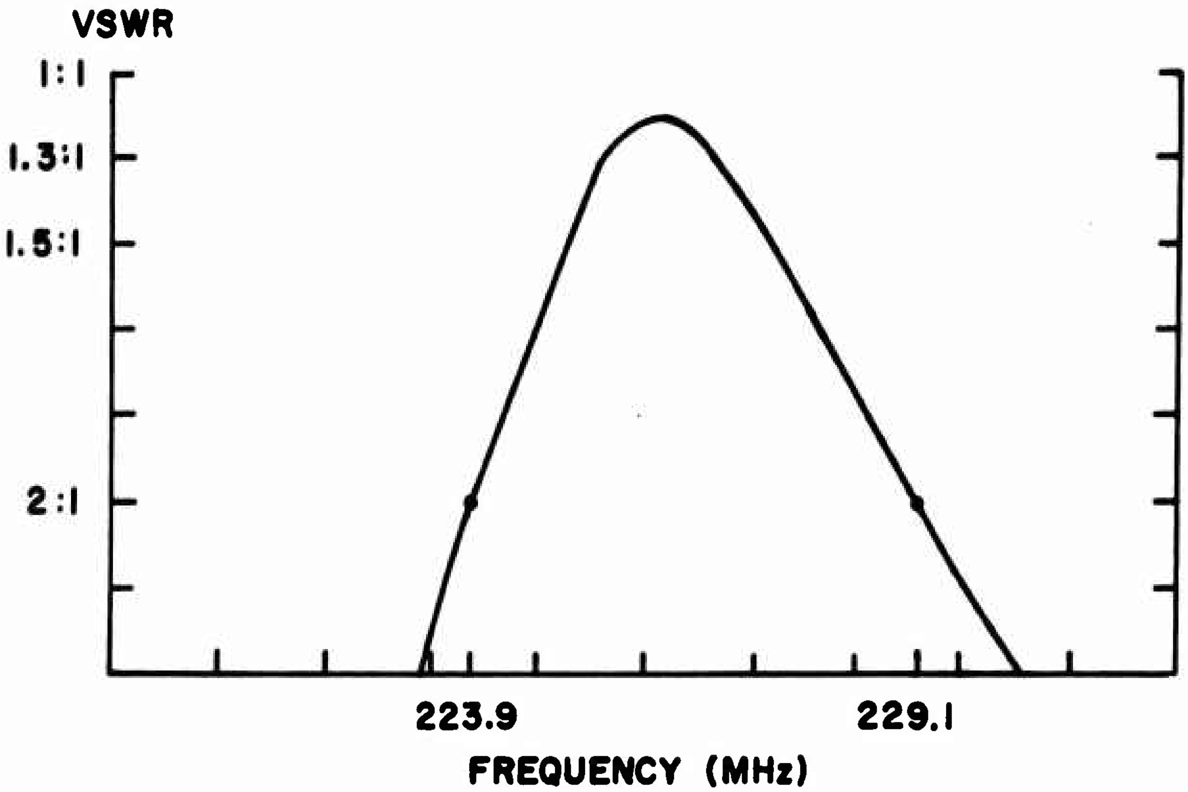

Figure 6. VSWR versus frequency.

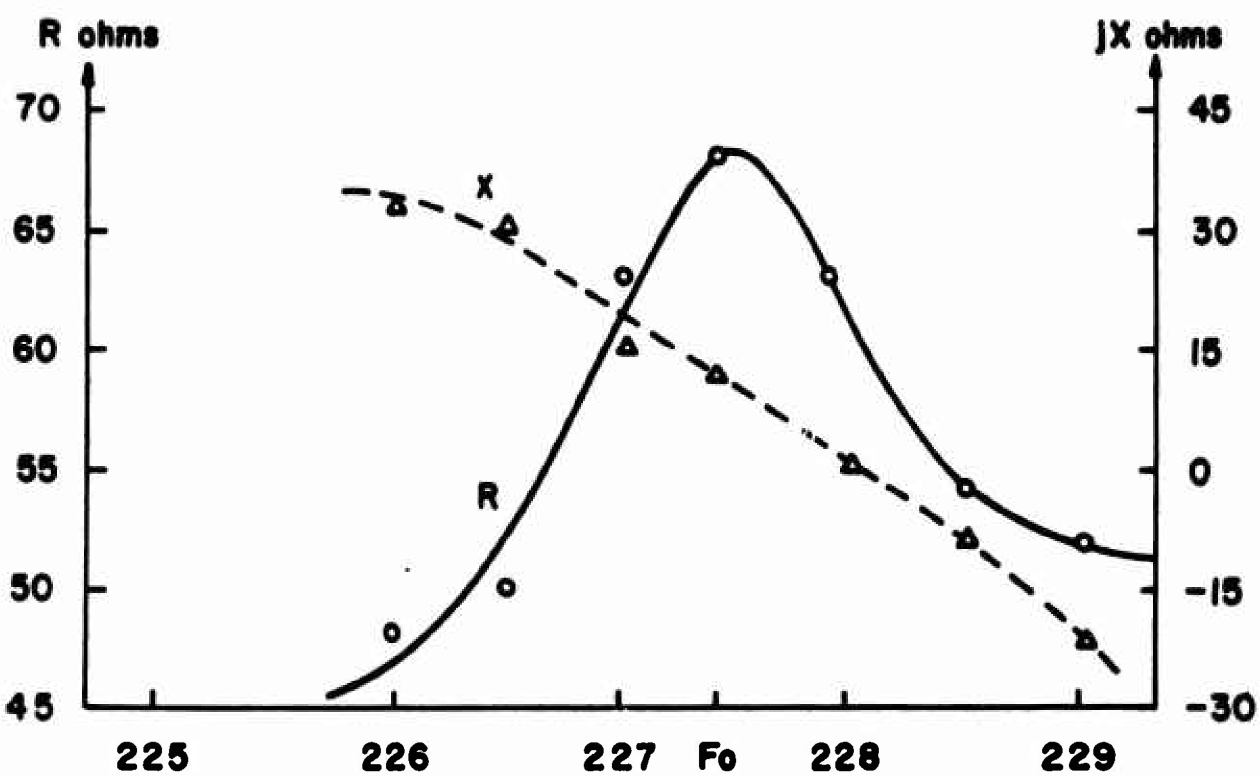

Figure 7. Impedance versus frequency.

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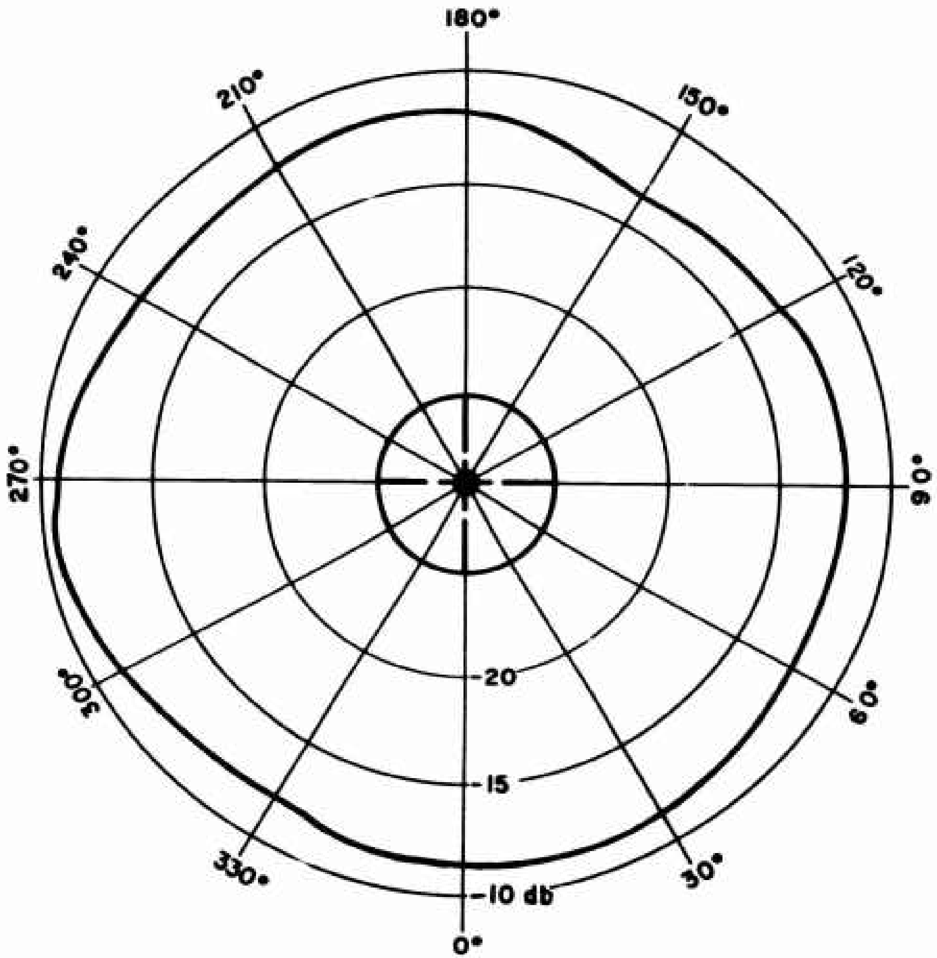
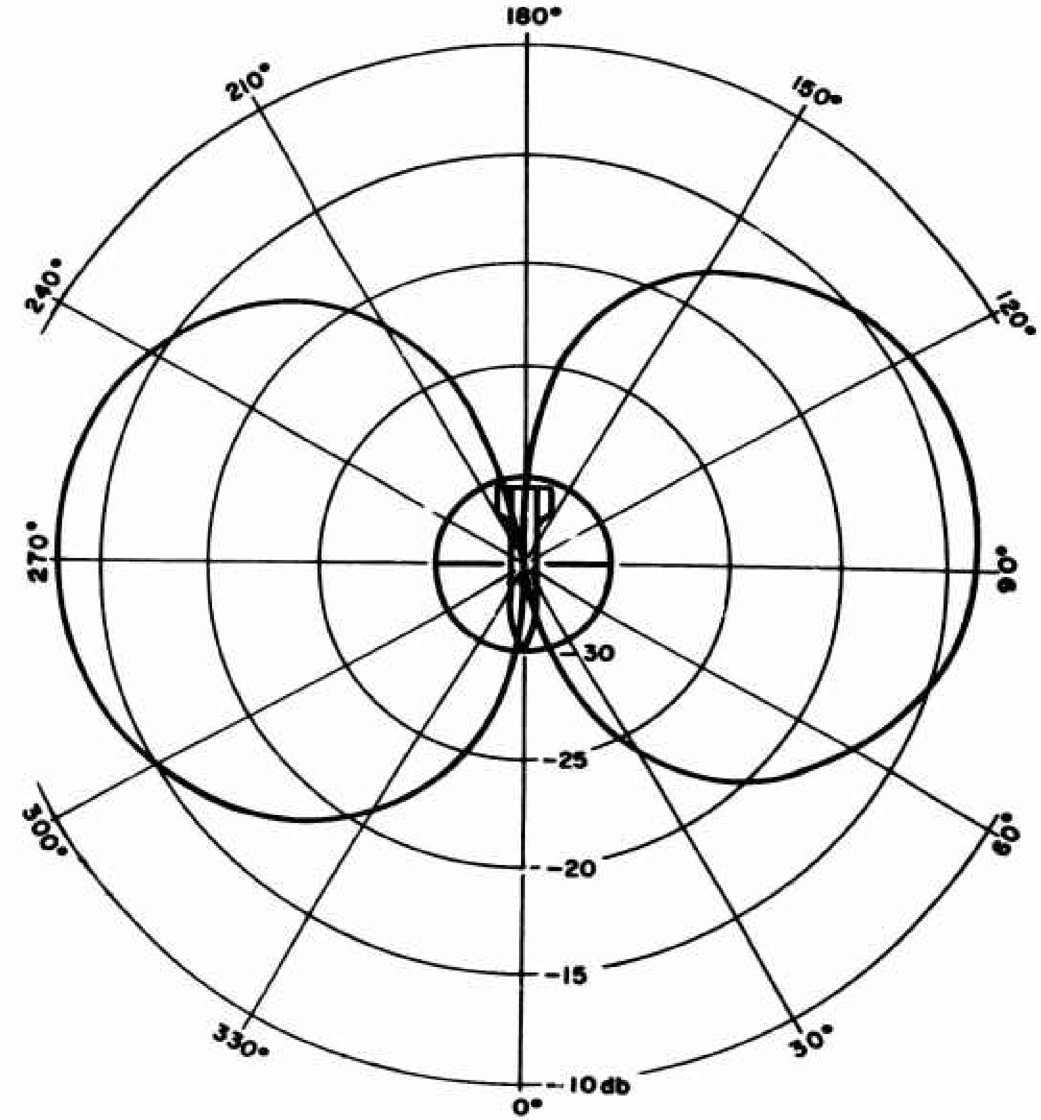
Figure 8. Ring antenna in test fitting.



PROJECTILE VERTICAL



PROJECTILE HORIZONTAL

STANDARD DIPOLE = 0 DB

FIGURE 9 — FIELD STRENGTH PATTERNS FOR QUARTER WAVE RING ANTENNA AT 227 MHz MEASURED WITH HELICAL RECEIVING ANTENNA

since it permits greater flexibility in the positioning of receiving stations while maintaining uniform received signal levels.

5. ADAPTATION OF THE QUARTER-WAVELENGTH RING ANTENNA AS A FUZE ANTENNA

The physical and aerodynamic characteristics of fuze-carrying missiles usually impose strict limitations upon the fuze antenna. The antenna must be small, rugged enough to withstand high velocities and temperatures, and still give a radiation pattern that will produce the desired target sensitivity. The fuze antenna should also require no modification when used on various projectiles. The doppler fuze depends on the interference between an incident wave and a wave reflected from the target. This interference is analytically equivalent to a load variation on the transmitting oscillator caused by a changing antenna impedance. This principle is applied in adapting the ring antenna for fuze use.

Two common fuze antenna types are the loop antenna and the cap antenna. Use of the cap antenna for vehicle excitation results in satisfactory radiation, but the size and shape of the vehicle have a great influence upon the radiation pattern and the frequency used. Loop antennas operate as part of the tank circuit of the oscillator as well as the radiating elements. Design problems are complicated since the use of a loop antenna requires suitable loop dimensions and an operating frequency must be chosen for efficient operation and desired impedance values. The ring antenna, however, is independent of vehicle length and can be tuned to the frequency desired. The use of the quarter-wave ring antenna means it is possible to choose the antenna impedance and operating frequency desired and then tune the antenna to these parameters.

The quarter-wave ring antenna has a considerable mechanical advantage over a loop antenna. Whereas the loop antenna is placed with its axis parallel to the axis of the missile and requires a certain amount of height, the ring antenna is mounted in a plane perpendicular to the missile axis, as shown in figure 1. This results in a large saving in space. For a fixed frequency, several ring diameters are also possible by choosing materials with different dielectric constants, since the physical length is inversely proportional to the square root of the dielectric constant.

The ring antenna produces a typical longitudinal pattern as shown in figure 9, when the antenna is mounted on the missile as shown in figure 1. This radiation pattern is very similar to that produced by the loop antenna. As is true for the loop antenna, the small size of the quarter-wave ring antenna means a relatively inefficient radiation system. The missile, however, is relatively free from vehicle excitation when the quarter-wave ring antenna is used. Since any impedance values are available, the phasing of two or more rings can be accomplished to give more pattern flexibility.

The quarter-wave ring antenna may be applied to the development of a short intrusion fuze. This type antenna provides various new mounting configurations along the missile axis.

6. CONCLUSION

A quarter-wavelength ring antenna for telemetering artillery fuze functions has been developed. The design is such that it may be mounted without modifying the shell and offers considerable leeway in locating the receiver, because of its wide beam angle. This type antenna will provide the ability, for the first time, to telemeter in-flight, active fuzes without major shell modification. The application of the ring antenna for use as a fuze antenna is also suggested.

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