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LONGITUDINAL SHUNT SLOT CHARACTERISTICS - AND APPENDIX I

STEGEN, ROBERT J. NOV'51 12PP TABLE, GRAPHS

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ANTENNAS, SLOT
ANTENNAS - RADIATION PATTERNS

ELECTRONICS (3)
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HUGHES AIRCRAFT COMPANY
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LONGITUDINAL SHUNT SLOT CHARACTERISTICS

by

Robert J. Stegen

November 1951

Contract AF 19(122)-454

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ABSTRACT

Experimental results of measurements of narrow longitudinal shunt slots at X-band are presented. Correlation between the phase of the admittance and the phase of the radiated field of a slot has been established analytically and substantiated by measurements. The resonant conductance of these slots has been determined both as a function of their displacement from the wave-guide center-line and as a function of frequency for a particular displacement. Good correlation has been found between these results and Stevenson's expression for a longitudinal shunt slot. Curves of resonant length as a function of displacement at a particular frequency and as a function of frequency for a particular displacement were determined. Radiation patterns as a function of slot displacement have been measured and studied.

INTRODUCTION

Associated with the electromagnetic field in a waveguide is a current distribution over the boundary surfaces. A slot cut in the waveguide will in general constitute a radiating element with the degree of coupling dependent on the current density intercepted by the slot, the length of the slot, and the component of the length transverse to the current lines. The type of circuit element required for a transmission line representation of the slot is a function of the position and orientation of the slot on the waveguide.

A linear array of slots can provide an accurately controlled illumination over a linear aperture, and may be particularly useful as an antenna in the presence of severe space, weight, or windage requirements. The design of such an array requires a knowledge of the relative amplitude and phase of the field from each slot. Linear arrays designed to produce shaped beams and low side lobe levels on the basis of available data gave results below expectation and indicated the need for improved data. In particular, the phase of fields from non-resonant slots was not known.

ADMITTANCE MEASUREMENTS

A series of measurements was performed on slots having their longitudinal axis parallel to, but displaced from, the axis of the waveguide. This type of slot may be represented as a pure shunt element across the transmission line representation of the waveguide. The measurements were conducted at X-band but experience indicates that the necessary information for designing arrays at other frequencies may be obtained by direct scaling of parameters with very few corroborating measurements. The admittance of slots[1] can be determined either by direct measurement using a traveling probe in a slotted waveguide, or by calculations from radiation pattern measurements. Slots of relatevely high conductance, $G > 0.1$, can be measured very accurately by the direct measurement technique. Lower conductance slots are measured more accurately by comparing them to a known high conductance slot by means of a radiation pattern measurement.

The admittances of six slots studied by the pattern technique were plotted in the complex admittance plane. From the circles determined by these experimental points, the maximum conductance of each slot was obtained. The points in Figures 1 and 2 were then determined from these measurements. It is interesting to note that the ratios G/Gm and B/Gm and the phase of the radiation are independent of the center-line displacement of the slots.

Stevenson's[2] theoretical expression for the conductance of a resonant longitudinal shunt slot in rectangular waveguide is

$$G_T = 2.09 \frac{a}{b} \frac{\lambda_g}{\lambda} \cos^2\left(\frac{\pi}{2} \frac{\lambda}{\lambda_g}\right) \sin^2\left(\frac{\pi x}{a}\right) \tag{1}$$

where a = the wide dimension of the waveguide,
b = the narrow dimension of the waveguide,
x = the displacement of the slot off the waveguide center-line,
λ = the free-space wavelength,
and λ_g = the waveguide wavelength.

The measurements made on longitudinal shunt slots in 1.0 x 0.5 inch (0.050 inch wall) waveguide at 9375 mc/s differed from the value obtained from (1) by the factor 0.96. A similar factor was obtained from experimental results with series slots and in that case was shown to be due to the finite thickness of the waveguide wall. The semi-empirical expression for the conductance of a longitudinal shunt slot at 9375 mc/s,

$$G = 0.96 G_T = 1.19 \sin^2\left(\frac{\pi x}{a}\right), \tag{2}$$

is plotted in Figure 3 with measured points indicated. Radiation measurements with a large ground plane about the slots gave essentially the same results as direct admittance measurements without a ground plane.

Measured resonant frequencies of a shunt slot are plotted in Figure 4 along with an empirical curve which is directly proportional to the free-space wavelength. Since slot resonant length is directly proportional to free-space wavelength (other parameters remaining constant) a single curve of slot length as a function of displacement from the waveguide center-line is sufficient. Figure 5 is a plot of the resonant lengths, expressed in free space wavelengths, of longitudinal shunt slots as a function of the displacement off the waveguide center-line.

Watson[3] has shown that for small displacements the theoretical length of a longitudinal shunt slot increases parabolically with its displacement from the center of the broad face. This is experimentally verified by the curve of Figure 5. Figure 6 is the conductance of a resonant slot as a function of frequency. The points are measured and the curve satisfies the equation

$$G = 0.96\, G_T$$

$$= 2.01 \frac{a}{b} \frac{\lambda_g}{\lambda} \cos^2\left(\frac{\pi}{2} \frac{\lambda}{\lambda_g}\right) \sin^2\left(\frac{\pi x}{a}\right) \qquad (3)$$

$$= 1.61 \frac{\lambda_g}{\lambda} \cos^2\left(\frac{\pi}{2} \frac{\lambda}{\lambda_g}\right) \qquad (4)$$

where $a = 0.900$ inch,
$b = 0.400$ inch,
and $x = 0.1833$ inch.

Verification of this frequency dependence of the conductance of a resonant slot allows (3) to be used to calculate the resonant conductance at any frequency and for any position on the waveguide.

SLOT RADIATION PATTERNS

The design of an array of shunt slots to give a specified radiation pattern requires that the radiation pattern of a single slot be known. For a shunt slot array in straight waveguide, the pattern of primary interest is the H-plane pattern. A typical H-plane pattern for a single slot is shown in Figure 7. When a large ground plane was placed about the slot, the pattern was altered only by the elimination of the backward lobe. This pattern is the same as one-half of an E-plane pattern of a half-wavelength wire dipole in free space. This field pattern is proportional to $\frac{\cos(\pi/2 \cos\theta)}{\sin\theta}$. It is of interest to compare the E-plane patterns of a low conductance slot (Figure 8), a high conductance slot without a ground plane (Figure 9), and a slot with a large ground plane about it (Figure 10). The asymmetry of the high conductance slot on the surface of the waveguide caused the radiation pattern to tilt off the normal. Symmetry in the pattern resulted when the slot was surrounded by the large ground plane. The amplitude variations in the radiation pattern of Figure 10 are due to interference effects caused by reflections from the edges of the ground plane (See Appendix I). The change in the field patterns due to lateral displacement must be compensated for when designing an array using these slots in the surface of plane waveguide. No compensation is necessary when the surface about the slot is a large ground plane.

APPENDIX I

EFFECT OF THE SIZE OF A GROUND PLANE ON A RADIATION PATTERN

It has been shown[4] that a slot in a finite ground plane will produce a field which is partially reflected from the edge of the ground plane. These waves will interfere with the direct wave from the slot producing maximums and minimums in the radiation pattern at calculable angles. The angles from the normal for the maximums and minimums in the pattern are

$$\theta = \text{arc sin}\,\frac{n\lambda}{2d},$$

λ = the free-space wavelength,
d = the distance from the slot to the edge of the ground plane,
and n = an integer.

For 2d = 19 inches and λ = 1.283 inches, the measured and calculated positions are listed in Table I.

TABLE I

MINIMUMS, DEGREES			MAXIMUMS, DEGREES		
MEASURED		CALCULATED	MEASURED		CALCULATED
4.8	-4.5	3.9	0.0		0.0
12.0	-12.5	11.7	7.2	-8.0	7.8
20.0	-22.2	19.7	15.7	-17.0	15.7
27.0	-29.2	26.2	23.5	-24.5	23.9
36.5	-39.5	37.4	32.0	-33.5	32.7
47.5	-49.8	47.9	41.8	-43.5	42.5
60.0	-63.5	61.4	54.0	-55.5	54.1
			70.5	-70.5	70.9

ACKNOWLEDGMENTS

The author wishes to acknowledge the non-resonant slot experimental results of T. T. Taylor, W. G. Sterns and R. A. Hanschke.

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2. A. F. Stevenson, "Theory of Slots in Rectangular Waveguides," Journal of Applied Physics, Vol. 19, 1948, pp. 24-38.

3. W. H. Watson, The Physical Principles of Waveguide Transmission and Antenna Systems, Oxford University Press, London, 1947, p. 200.

4. H. J. Reich, Very High Frequency Techniques, Vol. I, Harvard RRL Series, McGraw-Hill Book Company, Inc., New York, 1947, p. 114.

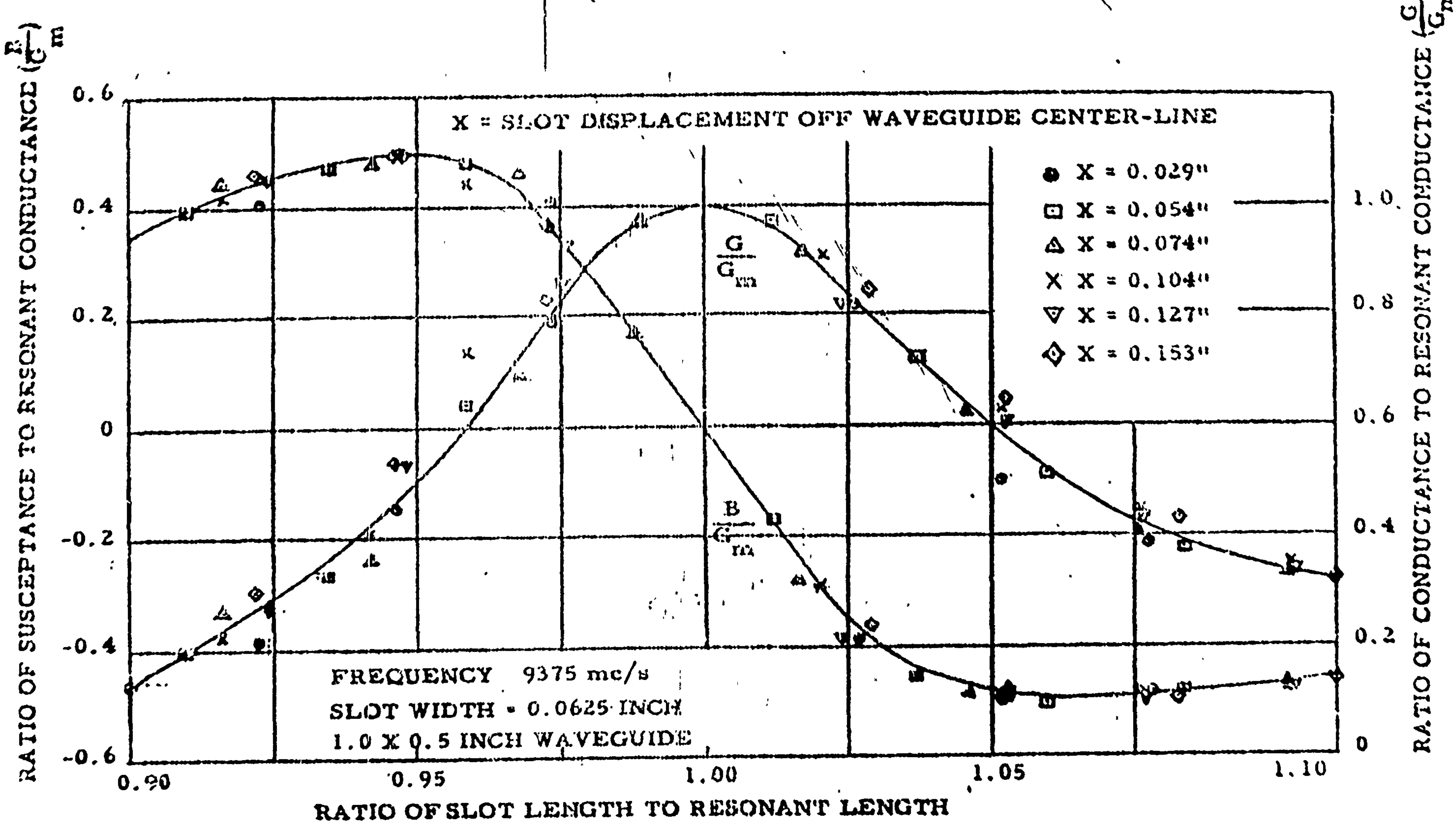

FIGURE 1 - VARIATION OF THE COMPONENTS OF THE ADMITTANCE OF A LONGITUDINAL SHUNT SLOT.

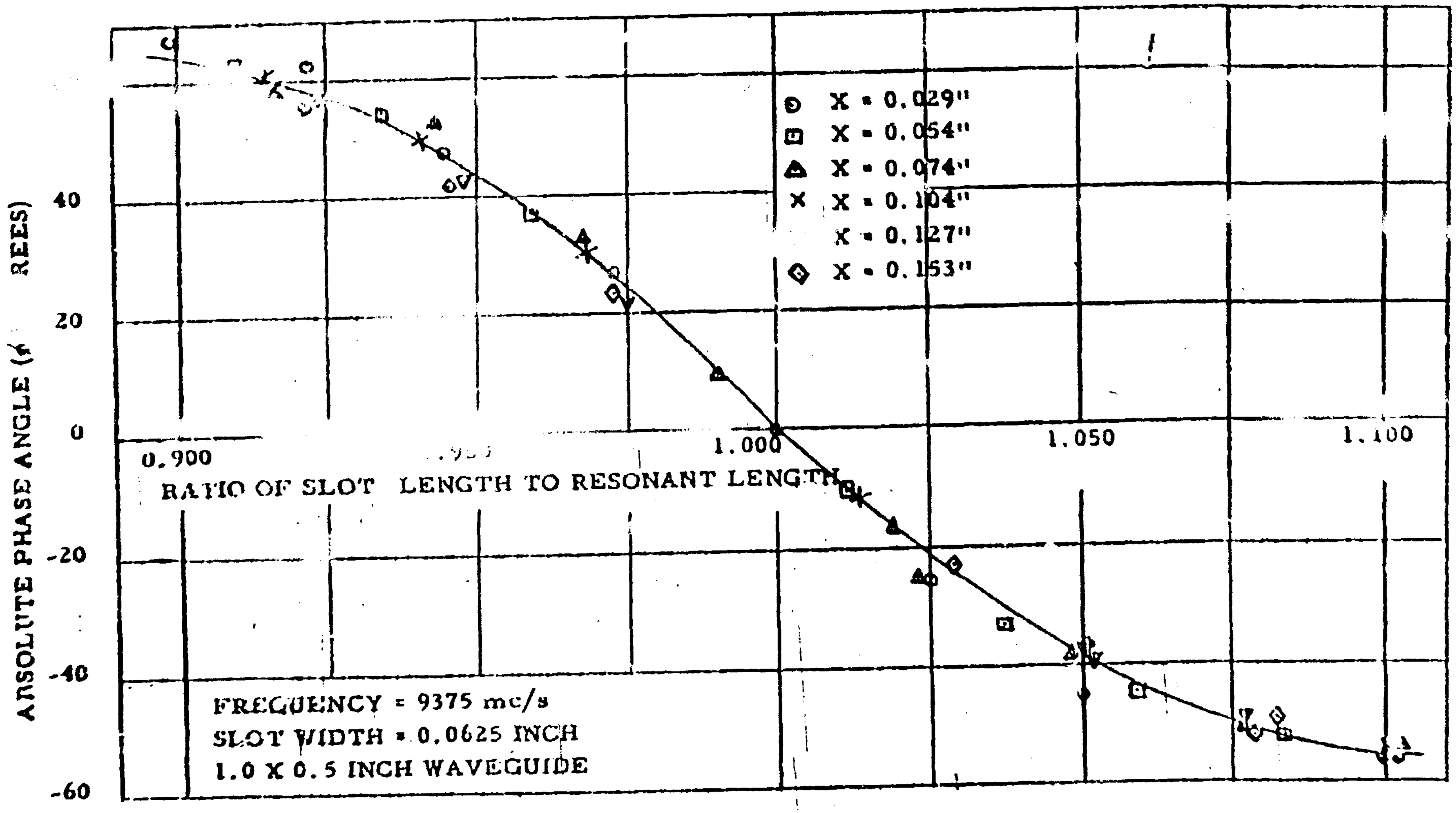

FIGURE 2 - ABSOLUTE PHASE ANGLE OF SLOT RADIATION VS THE RATIO OF LENGTH TO RESONANT LENGTH.

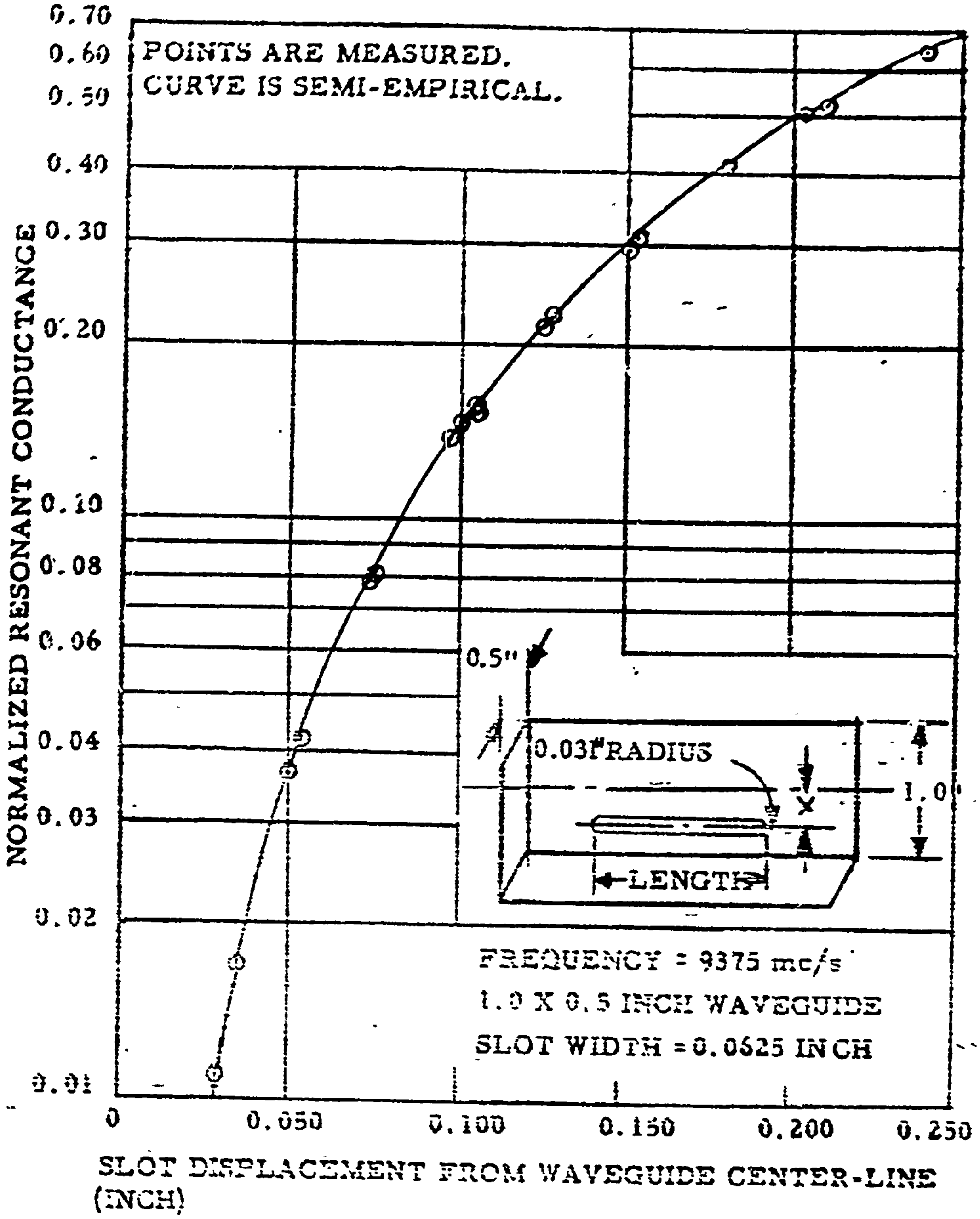

FIGURE 3 - RESONANT CONDUCTANCE OF LONGITUDINAL SHUNT SLOT VS SLOT DISPLACEMENT.

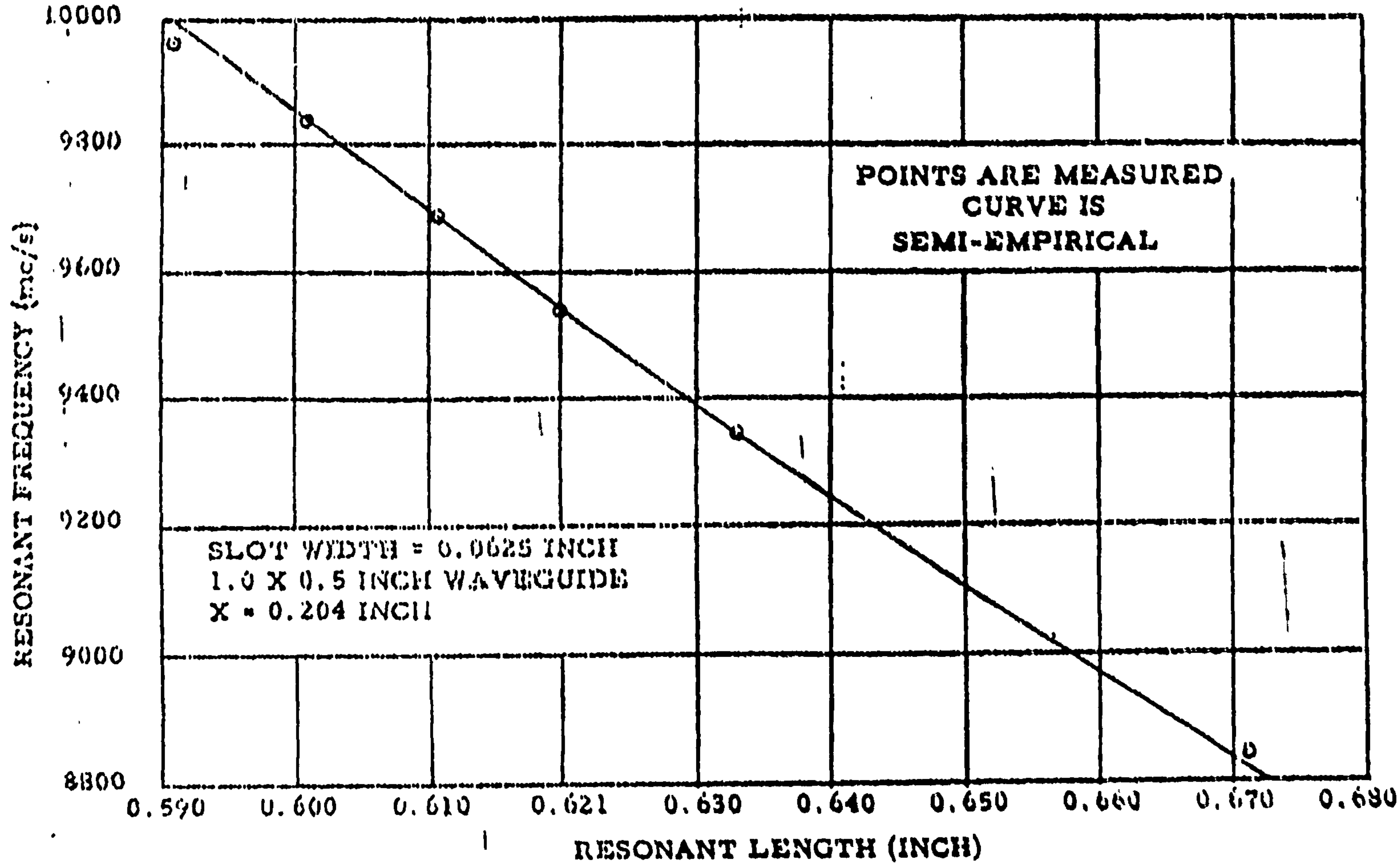

FIGURE 4 - SHUNT SLOT RESONANT FREQUENCY VS LENGTH

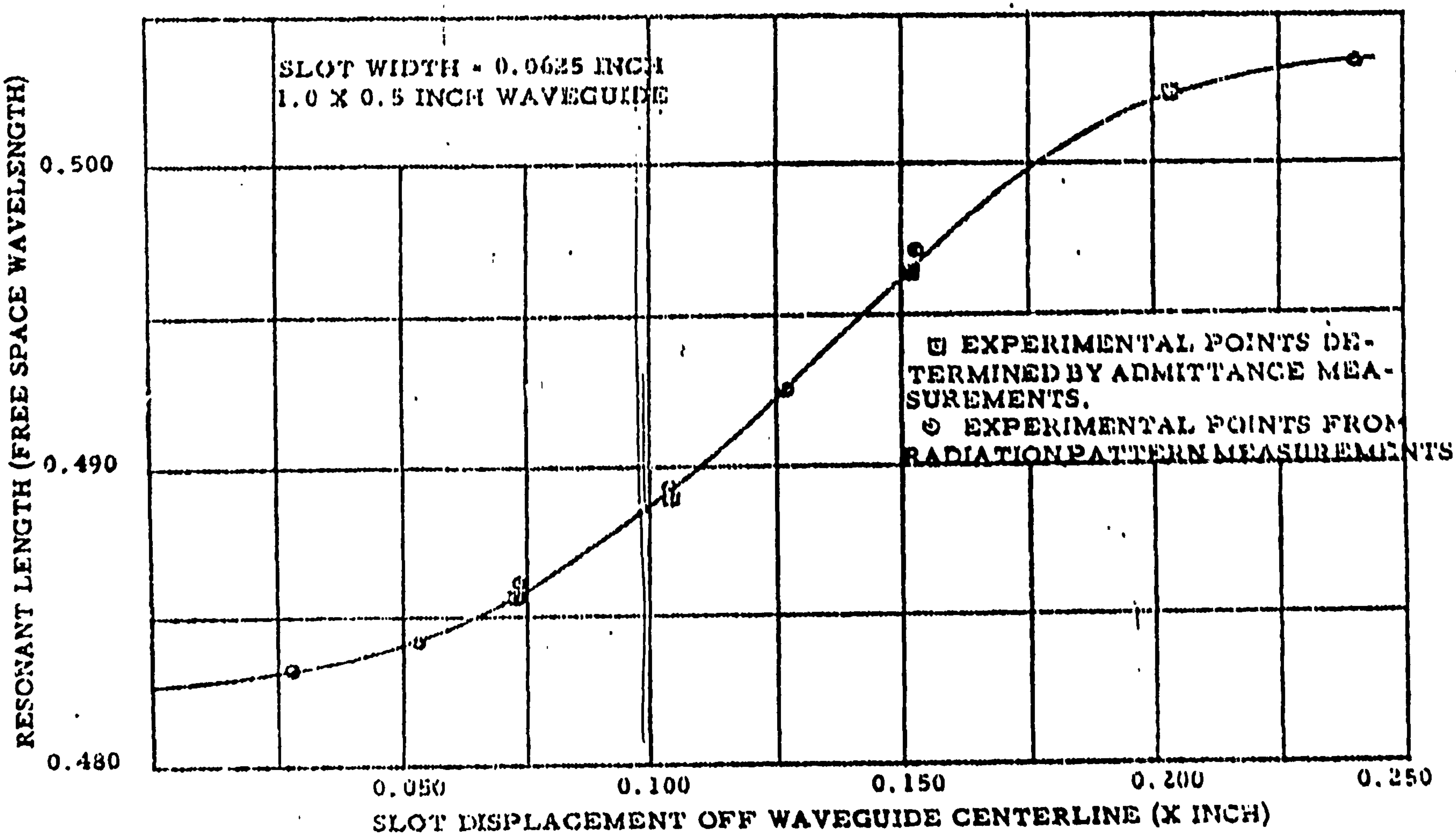

FIGURE 5 - SHUNT SLOT RESONANT LENGTH VS DISPLACEMENT OFF WAVEGUIDE CENTERLINE.

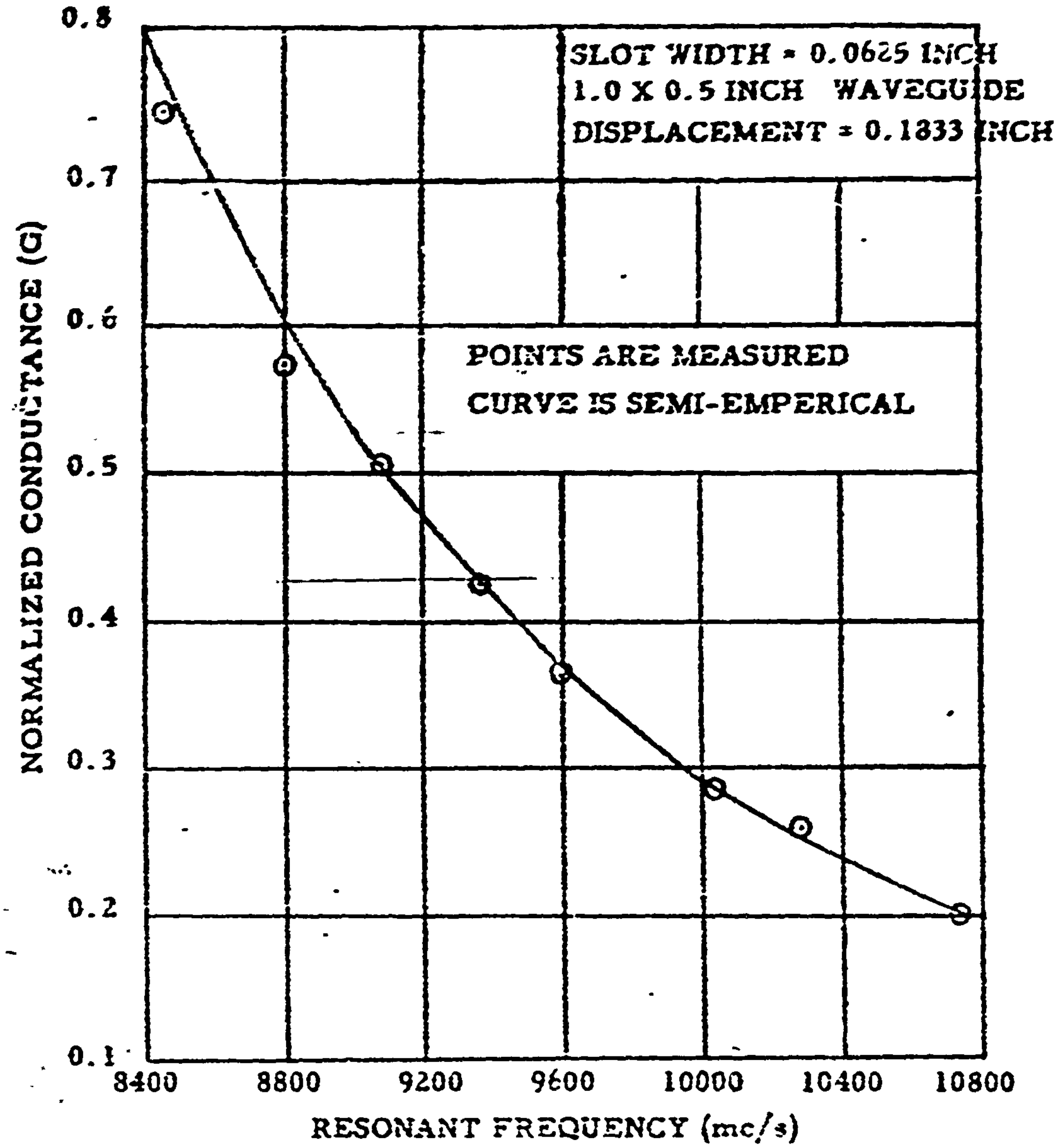

FIGURE 6 - RESONANT CONDUCTANCE OF A LONGITUDINAL SHUNT SLOT.

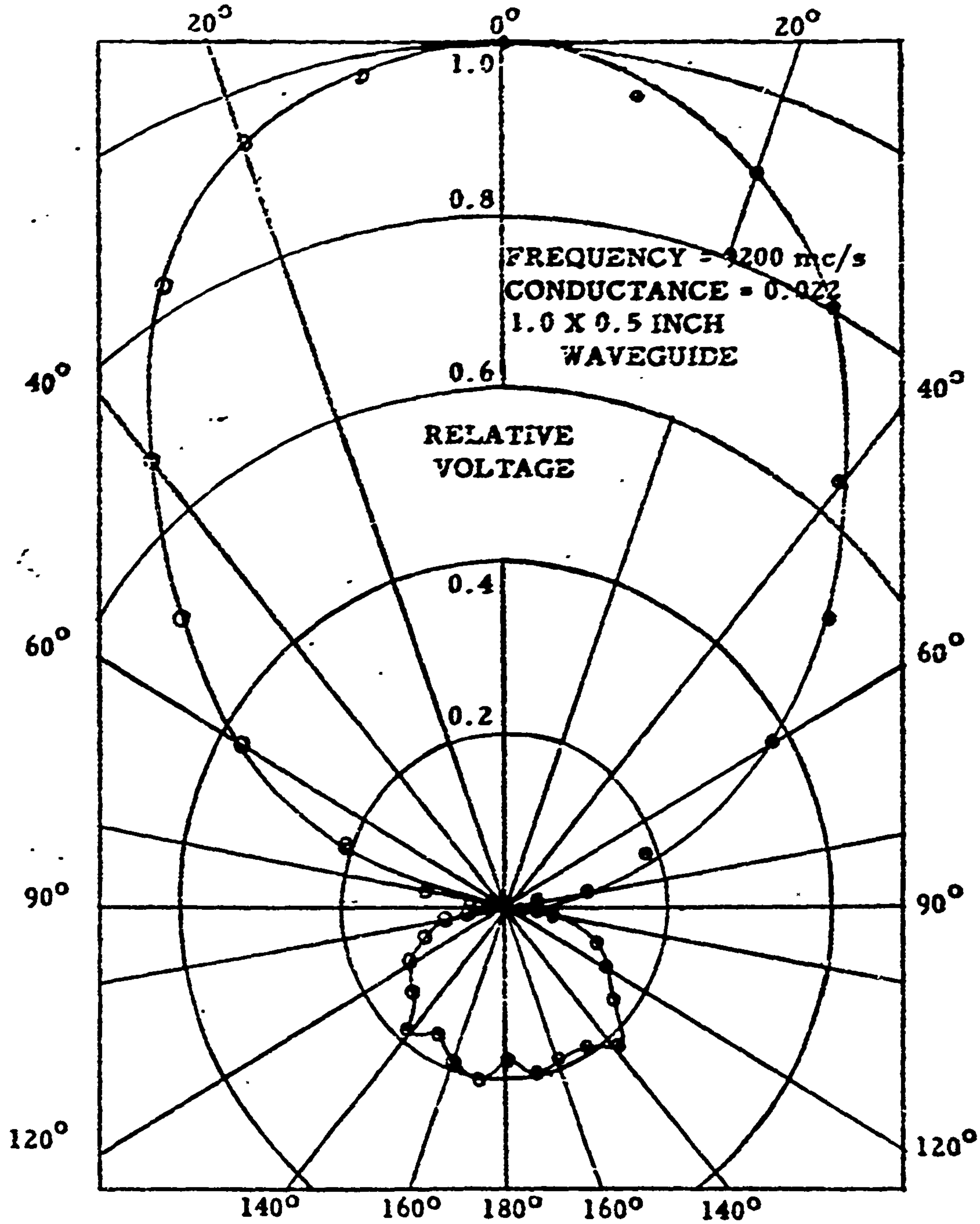

FIGURE 7 - H PLANE RADIATION PATTERN OF A LONGITUDINAL SHUNT SLOT.

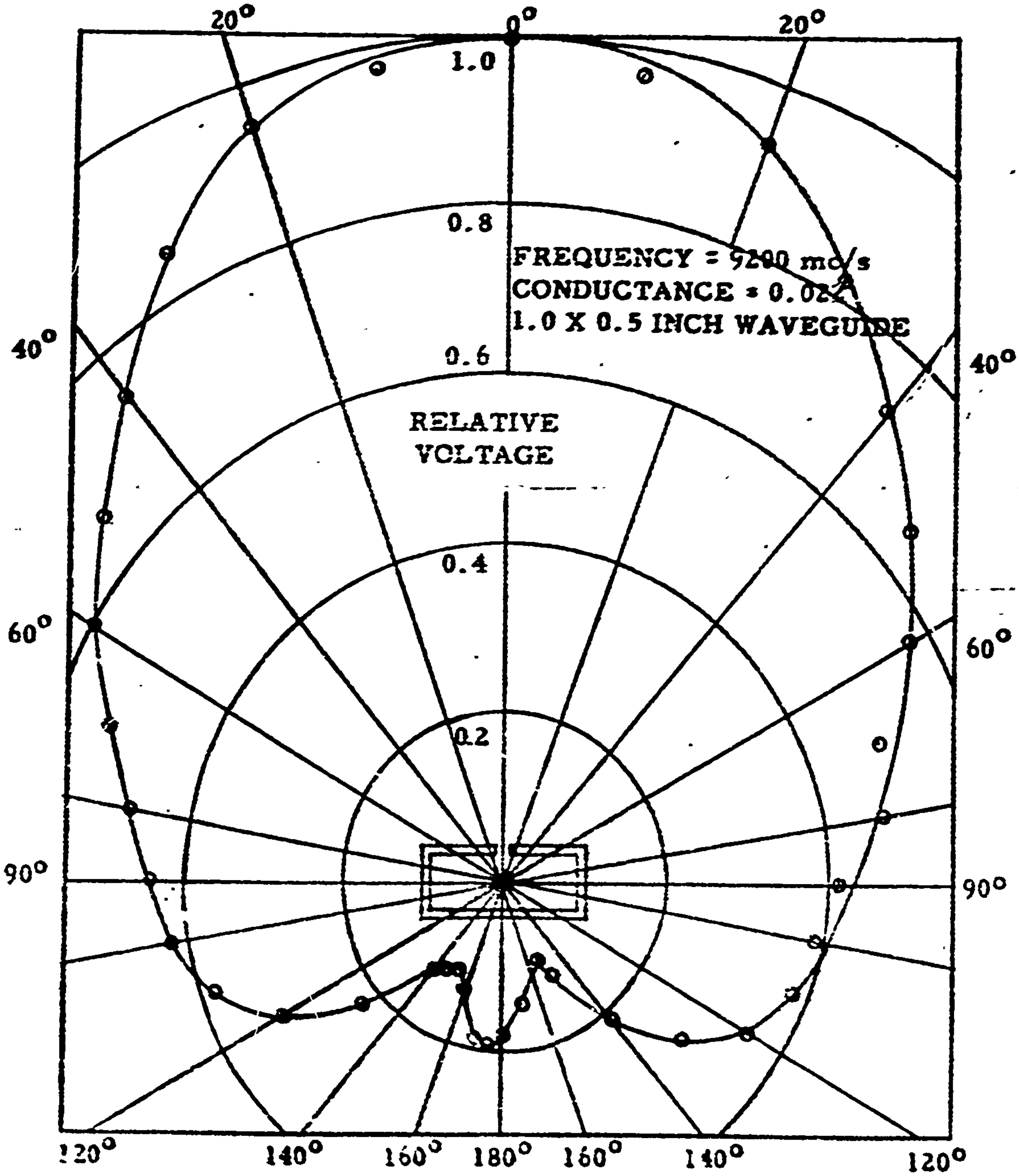

FIGURE 8 - E PLANE RADIATION PATTERN OF A LOW CONDUCTANCE LONGITUDINAL SHUNT SLOT.

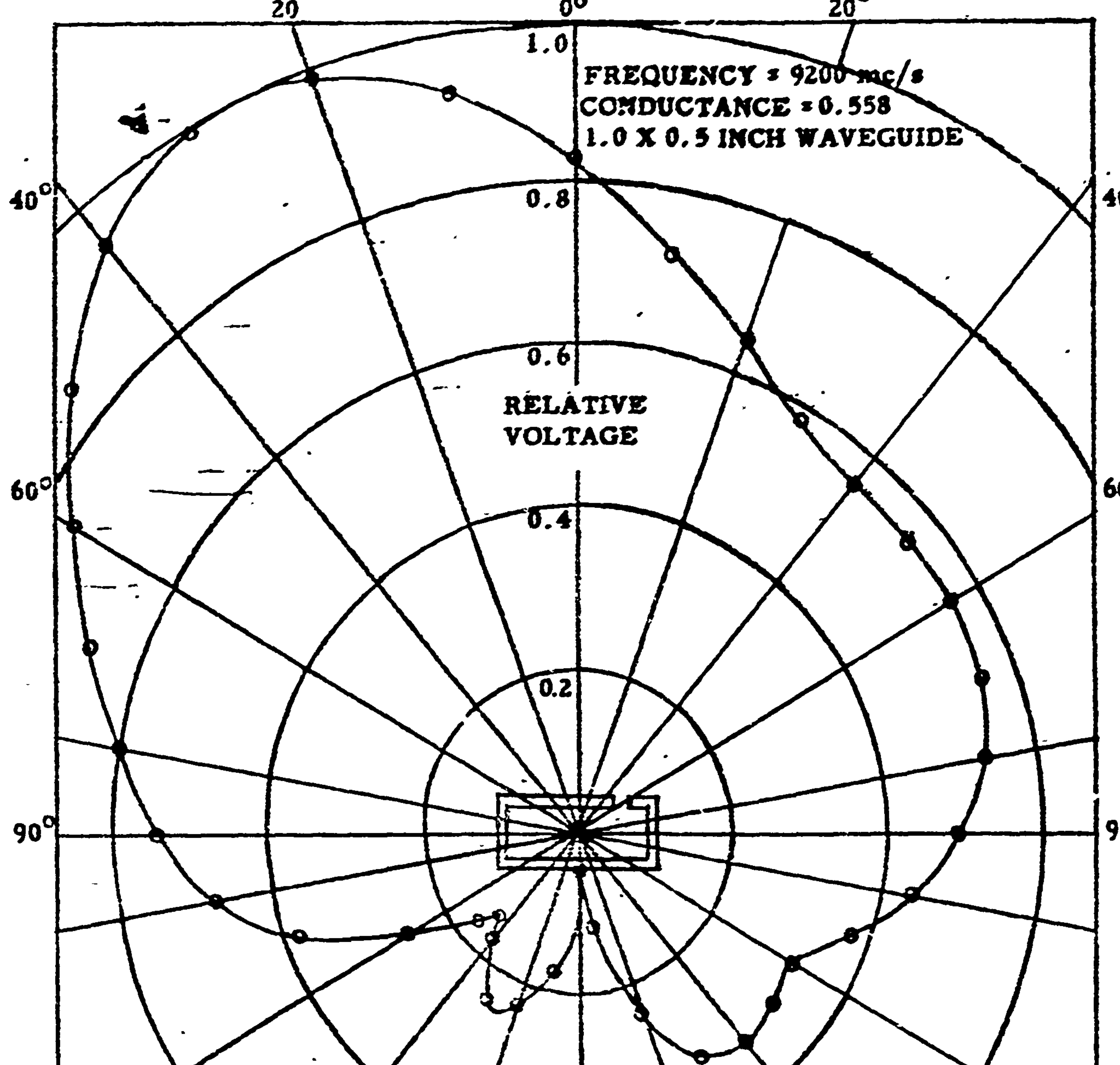

FIGURE 9 - E PLANE RADIATION PATTERN OF A HIGH CONDUCTANCE LONGITUDINAL SHUNT SLOT.

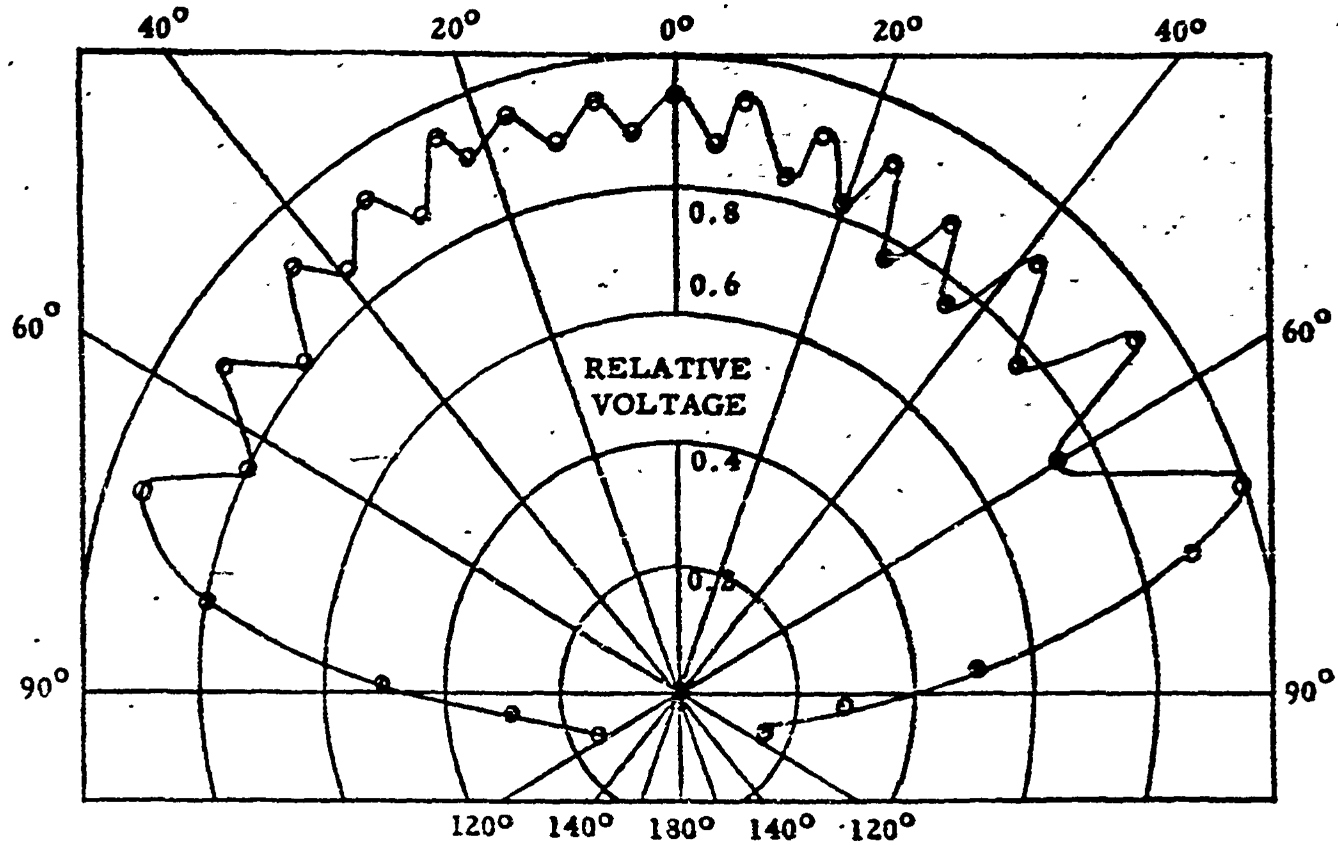

FIGURE 10 - E PLANE RADIATION PATTERN OF A SLOT IN A 19-INCH SQUARE GROUND PLANE AT 9200 mc/s.