ANNULAR RESONANT SLOTS IN DIELECTRIC-FILLED CIRCULAR WAVEGUIDE

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Summary

Measurements were made to determine the properties of thin annular resonant slots in polystyrene-filled circular waveguide, in which the TE_{11} mode is propagating. Data on the variation of susceptance of these slots as a function of frequency through the X-band region is presented in graphic form. Quantitative information relating the resonant frequency and Q of these slots to their geometry is presented. An empirical expression was found relating the Q of these slots to their gap size.

Introduction

In order to design broadband components in dielectric-filled circular waveguide, it is often necessary to know the properties of resonant obstacles in this type of transmission line. The value of resonant irises for broadband impedance matching is attested to by their extensive use in rectangular waveguide.

Huxley[1] discusses in a qualitative manner the properties of annular resonant slots cut in a transverse conducting plate in circular waveguide in which the TE_{11} mode is propagating. It appeared that this type of obstacle would have a shunt susceptance which would vary with frequency in a manner analogous to a parallel tuned circuit at lower frequencies. Unfortunately, there was little quantitative information available on which to design a resonant slot to have prescribed properties. A program was therefore initiated to measure the properties of such resonant slots in order to obtain the necessary design information.

Measurement Procedure

Eighteen annular slots were constructed as shown in Fig. 1. Twelve of these slots were constructed with various values of mean circumference $\pi(A + B)/2$, but with the same radial gap width $(A - B)/2$. The remaining six slots were made with the same mean circumference and various gap widths. The axial thickness of the transverse plate in which the annular slot was cut, was .011 inches for all eighteen slots.

All measurements were made in a circular polystyrene-filled waveguide transmission line whose inner diameter was .5625 inches. The admittance of each of these slots was measured in the frequency band from 8.2 to 9.6 kmc. Only the TE_{11} mode could propagate. The circuit used to measure frequency and the admittance of these slots is shown in Fig. 2.

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[1] Huxley, L.G.H., <u>Waveguides</u>, Macmillan Co., New York, pp. 142, 149-151; 1947.

Since the waveguide was filled with polystyrene, it would have been extremely difficult to locate a short circuit plane one quarter of a waveguide wavelength on the load side of the slot for every frequency. Therefore, a matched termination was placed on the load side of the slot. The normalized admittance (Y') of the parallel combination of matched load and slot was determined by the customary method of measuring the VSWR and position of the voltage minimum in the slotted line. The normalized admittance of the resonant slot alone was then determined from the following relationship:

$$Y = Y' - 1 \tag{1}$$

All admittances are referred to the plane P of Fig. 1.

Experimental Results

A typical Smith Chart plot of slot admittance as a function of frequency is shown in Fig. 3. It should be noted that this locus of points follows very close to the periphery of the chart as would be expected for a lossless element.

The data obtained from the twelve slots of constant gap were used to plot a family of curves of slot susceptance as a function of frequency (Fig. 4). It can be seen from these curves that for every value of mean circumference, there is a resonant frequency (f_R) where the slot has zero susceptance. Information from the curves mentioned above made it possible to plot a design curve of resonant wavelength (λ_R) as a function of mean circumference (Fig. 5). The resonant wavelength is that wavelength which would exist at the resonant frequency in unbounded space entirely filled with polystyrene. It can best be defined by the equation shown below, and is sometimes called the intrinsic wavelength of the medium:

$$\lambda_R = \frac{c}{\sqrt{\epsilon_r}\, f_R} \tag{2}$$

The six slots of constant mean circumference were measured to determine the manner in which their Q varied with the size of the gap. The Q of these slots is defined by the following equation:

$$Q = \frac{f_R}{f_2 - f_1} \tag{3}$$

In the above equation f_2 and f_1 are the frequencies at which the susceptance (B) is equal to $+Y_o$ and $-Y_o$ respectively. The data obtained from these six slots were used to plot a family of curves of slot susceptance versus frequency (Fig. 6). The resonant frequencies of these slots, although very close, were not all the same. In order to demonstrate more clearly the effect of gap size on Q, the susceptance was plotted against normalized frequency (f/f_R). Using the above curves in conjunction with equation (3), it was possible to determine the Q of these resonant slots.

When the Q of these slots was plotted against gap size on log-log graph paper, it was found that a straight line resulted (Fig. 7). From the slope and intercept on the G = 1 line, it was determined that the relationship of the Q to the gap size could be stated by the following empirical expression:

$$Q = 45\, G^{-.54} \tag{4}$$

It is believed that the Q of these slots is a function of the axial thickness as well as the gap size. This phenomenon was not investigated, however.

Conclusions

The results shown in Figs. 5 and 7 give the information required to build annular resonant slots for the type of transmission line herein described. It should be noted in Fig. 5 that at resonance the intrinsic wavelength is almost equal to the mean circumference. From Fig. 5 it can be shown that a change of only .001 inches in the mean diameter of the slot will cause a shift of approximately 40 mc in the resonant frequency. Therefore, if it is necessary to build these slots to be resonant very close to a prescribed frequency, extremely close tolerances must be held on the slot dimensions.

These slots could be used for filter elements as well as for impedance matching devices in dielectric-filled circular waveguide. Since these slots are radially symmetrical, their properties are independent of the plane of polarization. They can therefore be used in lines in which a circularly polarized wave is propagating.

Acknowledgment

The author would like to thank Messrs. Helmut Schrank and Herbert Grauling of the Radiation Laboratory of The Johns Hopkins University for their helpful suggestions in the preparation of this paper.

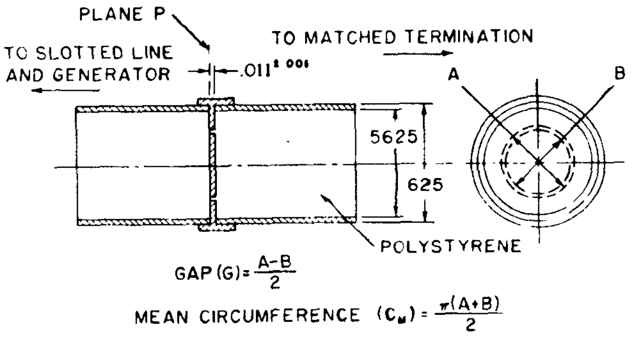


Fig. 1 - Details of annular resonant slot.

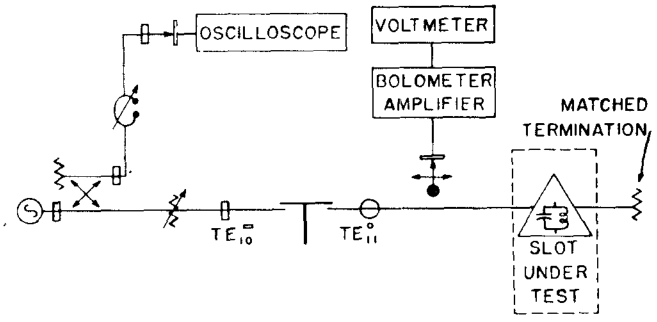


Fig. 2 - Circuit for measurement of admittance and frequency.

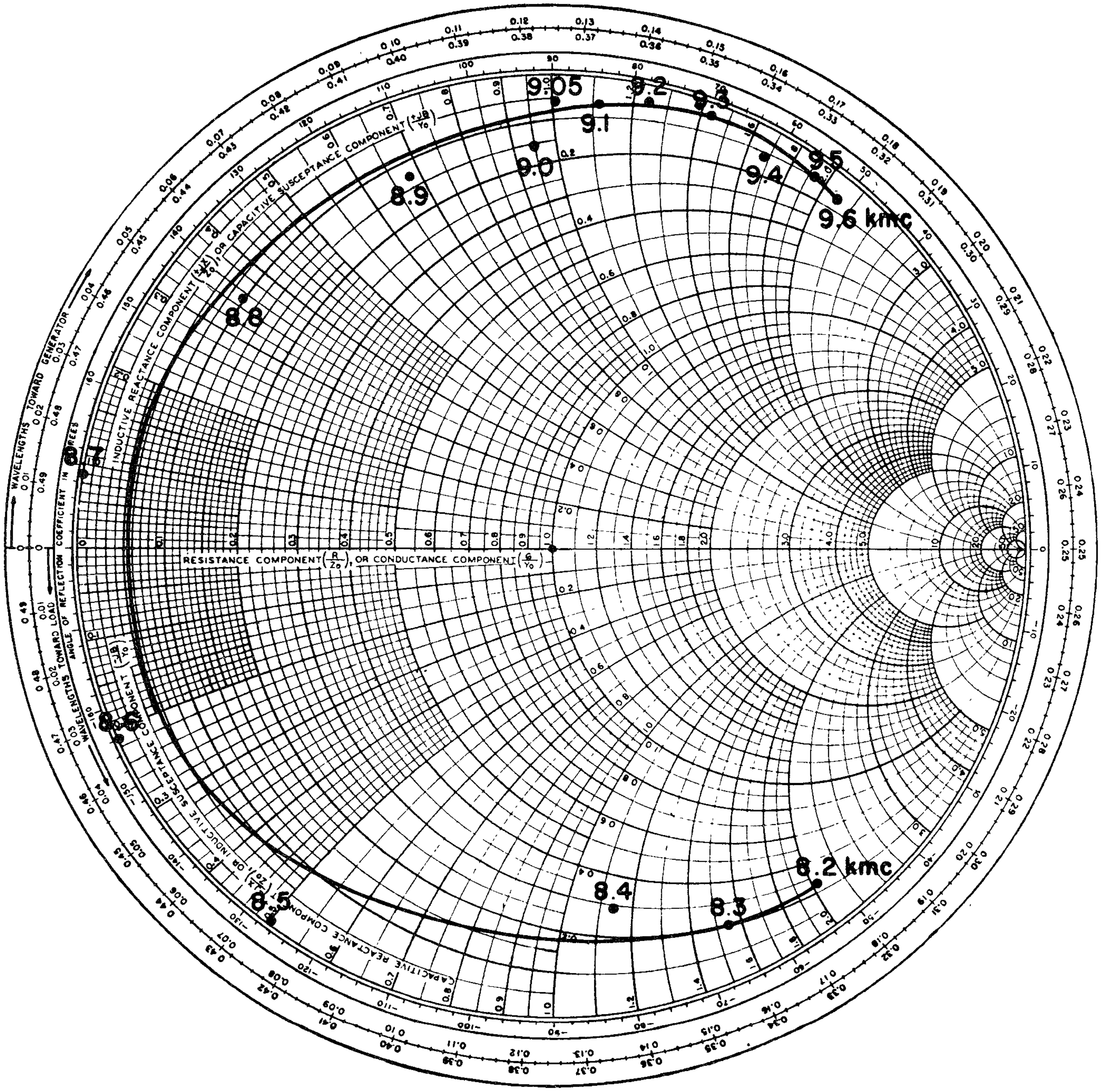


Fig. 3 - Typical Smith Chart plot of slot admittance as a function of frequency. G_M = 2.28 cm, G = .011 inches.

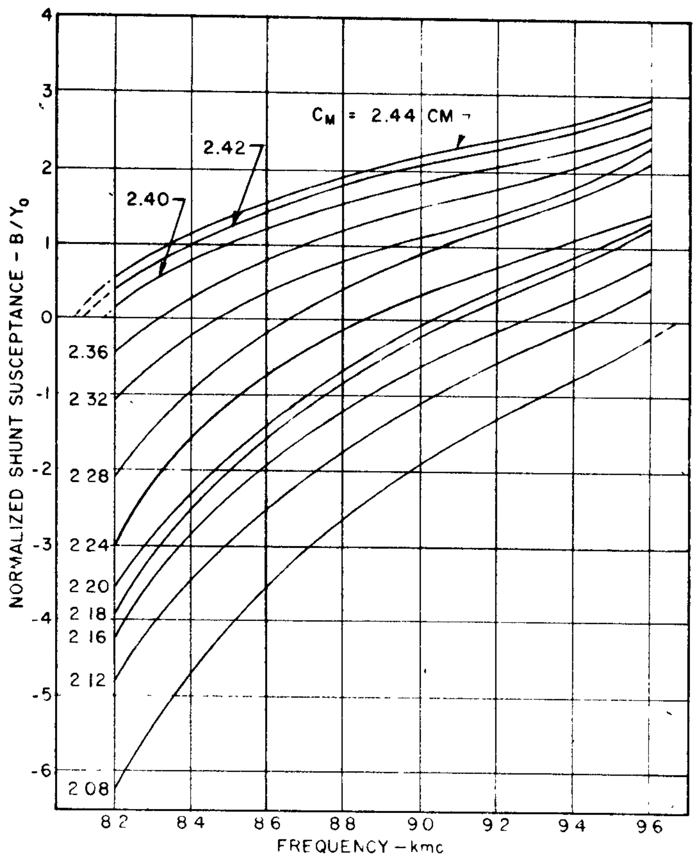


Fig. 4 - Normalized slot susceptance B/Y_0 as a function of frequency for various values of mean circumference C_M. The radial slot gap G equals .011" for all twelve slots. The dotted sections of the curves were extrapolated beyond the band of frequencies which could be measured.

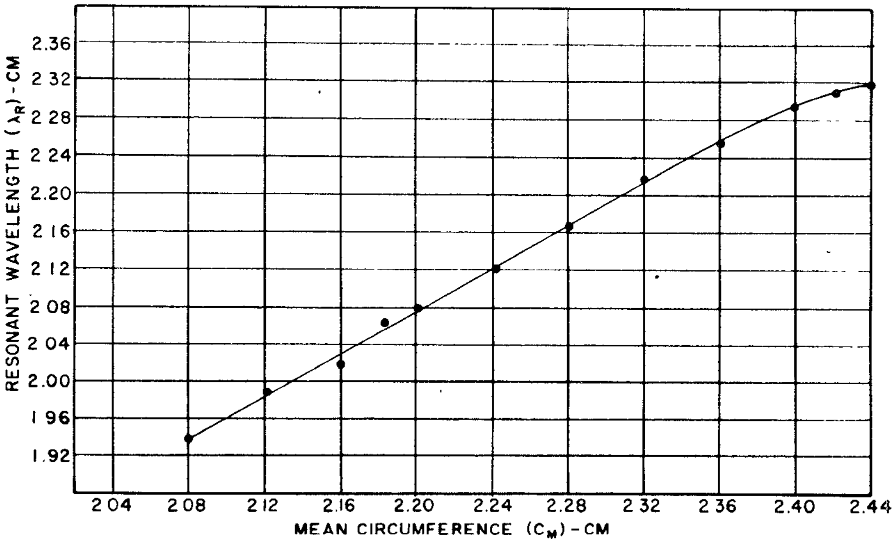
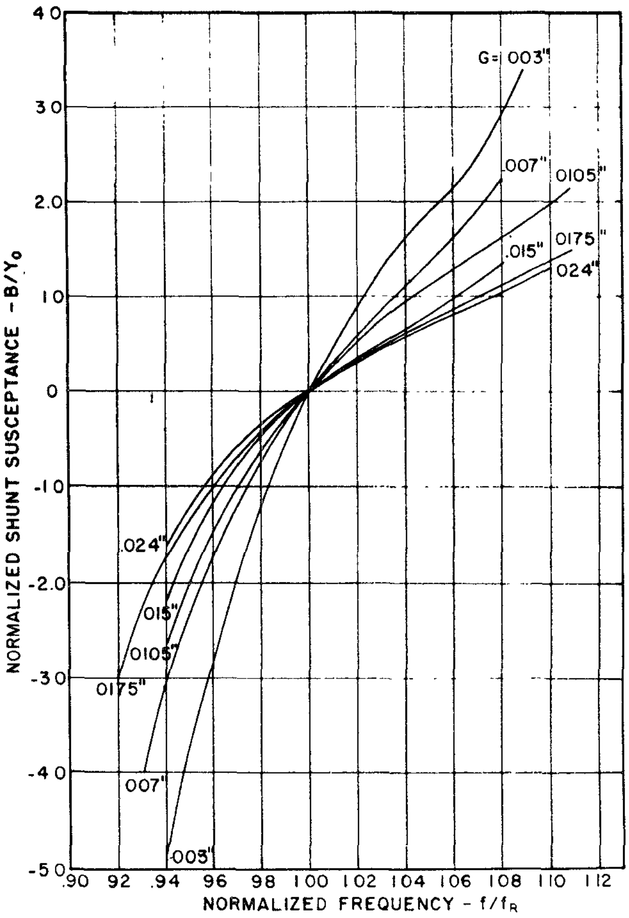
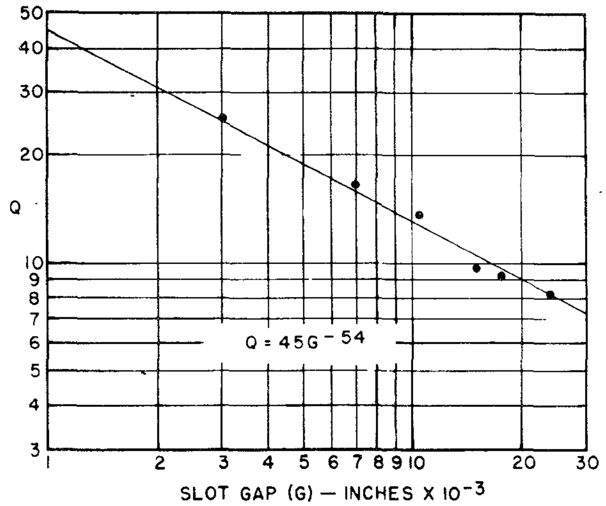


Fig. 5 - Resonant wavelength λ_R versus mean circumference C_M for twelve slots of constant gap G = .011". (Data for this curve was obtained from Fig. 1.)





Q versus slot gap G for six resonant slots of constant mean circumference $C_M = 2.28$ cm.

Fig. 7

Normalized slot susceptance B/Y_0 versus normalized frequency f/f_R for various values of slot gap G. The mean circumference C_M was equal to 2.28 cm for the six slots.

Fig. 6

ERRATA

We should like to call attention to the following corrections to be made in connection with the last issue of the Transactions of the Professional Group on Microwave Theory and Techniques, vol. 1, no. 1:

1. The reflection chart in Figure 3 on page 11, showing circles of constant phase of the impedance should be labeled "Carter Chart."

2. Figure 5 on page 12 should be interchanged with Figure 4 on page 21.