ACKNOWLEDGMENT

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Characteristics of a New Serrated Choke

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Summary—**A new type of serrated choke will permit cuts or gaps anywhere on the walls of a rectangular waveguide. The low gap impedance is provided essentially by closely spaced, quarter-wavelength, open-ended, two-wire-line stubs. Low power and high power characteristics of many designs are presented.**

INTRODUCTION

A NEW choke has been designed and tested which will permit cuts, slots, or gaps on waveguide walls hitherto considered impossible. Previously, only slots on the center of the broad wall of a guide supporting the dominant TE_{10} mode as well as gaps in a transverse plane, such as a choke flange, were permitted. However, with the new serrated choke, slots or gaps are permitted anywhere on the guide walls; *e.g.*, on the narrow wall in the longitudinal direction, on the broad wall not at its center, cuts or gaps at any angle on any wall, etc. Applications of the new choke are possible in microwave components and scanning antennas.

Essentially the required low impedance across a gap is provided by closely spaced quarter-wavelength open-ended two-wire line stubs. A schematic diagram of a longitudinal serrated choke is shown in Fig. 1(a). The second conductors of the two-wire line stubs are provided by the images of the serrations as shown in Fig. 1(b) and Fig. 1(c).

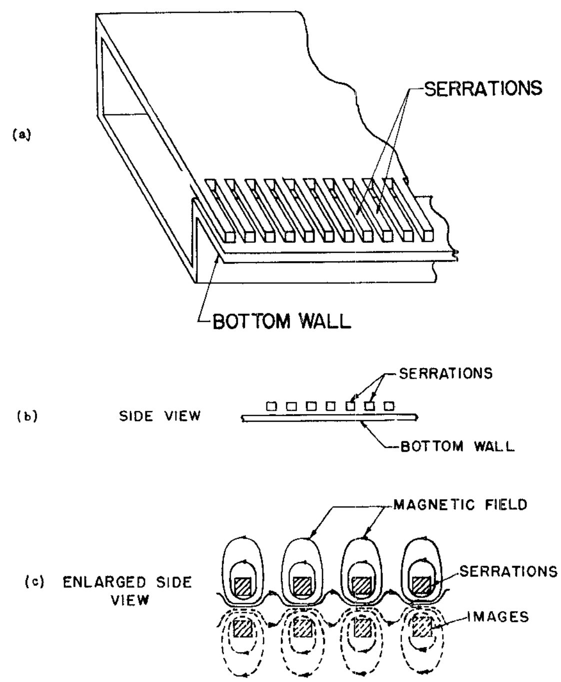

Fig. 1—The serrated choke.

It may appear feasible to design a longitudinal choke without the serrations. Such a choke was actually tried but without success. A section of a waveguide 12 inches long with unserrated choke was connected into a $1\times\frac{1}{2}$ inch rectangular waveguide measuring setup. The input vswr varied from 1.05 to 3 and the insertion loss varied from 0.5 to 3 db as the effective length of the unserrated choke was varied using an adjustable short. The large variation in characteristics is due to the coexistence of two propagating waveguide modes in the choked waveguide region. These two modes could be considered as the $TE_{1/2,0}$ and $TE_{3/2,0}$ modes relative to the choked waveguide. The latter mode yields the dominant TE_{10} mode in unchoked rectangular waveguide. Inasmuch as these two modes have different cutoff wavelengths, whose ratio may be about 4, the respective propagation velocities will differ. This will result in a spatial beating and hence partial power transfer characteristics between the primary waveguide and the "choke" waveguide.[1] By serrating the choke, the $TE_{1/2,0}$ mode will not propagate and the desired low impedance will be provided across the gap.

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[1] K. Tomiyasu and S. B. Cohn, "The transvar directional coupler," PROC. IRE, vol. 41, pp. 922–926; July, 1953.

An investigation was conducted to obtain information which would make possible the design of a choke having minimum vswr and insertion loss and also high power-handling ability. To make the data complete, the frequency and phase velocity characteristics of the choke were also obtained. Since fabrication is a factor in determining the design of a component, chokes having a circular cross section were studied along with those having a rectangular cross section.

Circular Cross Section Chokes

A cross section of the 12 inches long X band fixture used to test circular cross section chokes and a definition of symbols are given in Fig. 2. The choke pins, set in V shaped grooves, are held in place with a beryllium-copper strip and silver paint, thus allowing variation of pin length, diameter, and spacing. Image planes of various thicknesses, T, are used to vary the waveguide gap, G.

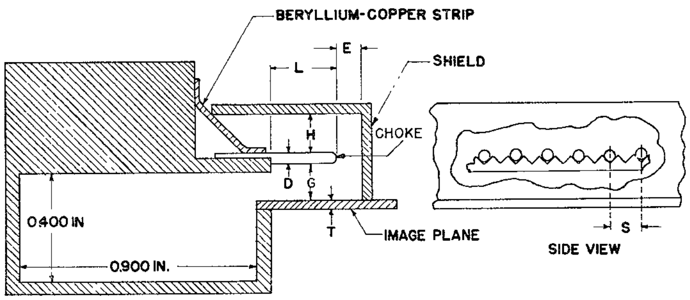

Fig. 2—Fixture used to test longitudinal serrated chokes, cross sectional view.

The first choke pins had a diameter of 0.040 inch, was spaced 0.060 inch center to center, and extended 0.312 inch. With the shield left off and a gap, G, of 0.060 inch, it was found that the radiation was quite excessive. The gap was reduced and it was noted that, even for a gap of approximately 0.015 inch, shielding was necessary. It was also determined that the position of the shield affected the operation of the chokes. When the enclosed volume of the shield is made too large, resonances within the shield structure occur; this resulted in high insertion losses at certain frequencies. With a fixed gap of 0.060 inch, the best characteristics were obtained when the shield was located at $H=0.150$ inch and $E=0.060$ inch.

Using the 0.040 inch diameter pin, the effect of pin length on the insertion loss is shown in Fig. 3 and on the vswr in Fig. 4. A residual insertion loss of 0.2 db of the fixture when the chokes were shorted out has been subtracted so that only the losses due to the chokes are plotted in Fig. 3. The data indicate that a length of approximately 0.312 inch (0.99 $\lambda_0/4$ at 9,370 mc) gives the best results. λ_0 is the free-space wavelength. However, a length of 0.250 inch (0.80 $\lambda_0/4$ at 9,370 mc) also gives good results, so that the length can be varied between these two values without greatly affecting the vswr and insertion loss.

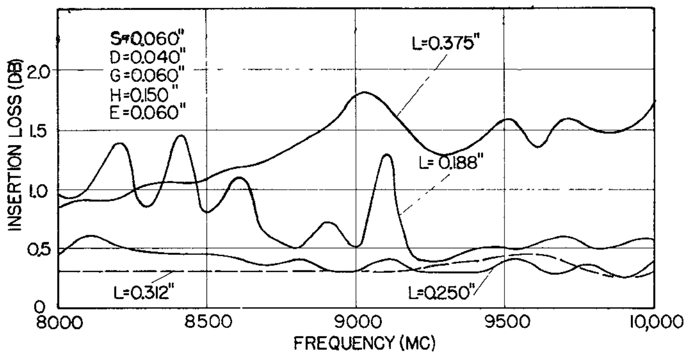

Fig. 3—Insertion loss as a function of frequency for circular cross section chokes with pin length as parameter.

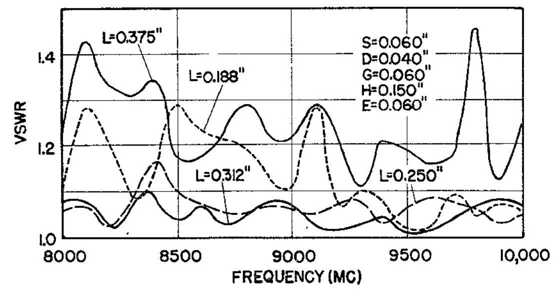

Fig. 4—Vswr as a function of frequency for circular cross section chokes.

Another characteristic of the chokes investigated is the phase velocity in the "choked" waveguide. This was measured by varying the position of a short circuit in the guide. With a fixed probe position in the slotted line, the short was moved through an integral number of half wavelengths to yield an average guide wavelength in the choked waveguide. By comparing this with the calculated value of guide wavelength for an unperturbed rectangular waveguide (obtained by measuring frequency), the change in guide wavelength or phase velocity in the choked waveguide was computed. The phase velocity characteristics for the several pin lengths

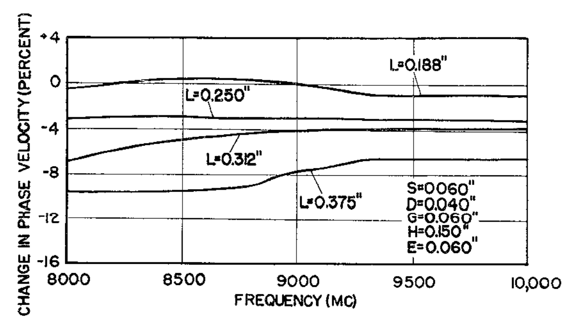

Fig. 5—Per cent change in phase velocity as a function of frequency for circular cross section chokes.

used are given in Fig. 5 and show that the phase velocity (or guide wavelength) in the choked portion is reduced.

Since the decrease in guide wavelength may be due not only to the loading effect of the chokes but to errors in the various parameters, an analysis of latter was made using general wavelength equation for TE_{10} mode:

$$\lambda_g = \frac{\lambda_0}{\sqrt{\epsilon_r - \left(\frac{\lambda_0}{2a}\right)^2}} = \frac{1}{\sqrt{\epsilon_r\left(\frac{f}{c}\right)^2 - \left(\frac{1}{2a}\right)^2}} \quad (1)$$

where

λ_g = guide wavelength
λ_0 = free-space wavelength
ϵ_r = relative dielectric constant of medium inside waveguide
f = frequency
c = velocity of light
a = inside broad dimension of waveguide.

Taking the natural logarithm of (1) and then the derivative results in the following:

$$\frac{\Delta\lambda_g}{\lambda_g} = -\frac{1}{2}h\frac{\Delta\epsilon_r}{\epsilon_r} - h\frac{\Delta f}{f} + h\frac{\Delta c}{c} - (h-1)\frac{\Delta a}{a} \quad (2)$$

where

$$h \equiv \epsilon_r\left(\frac{\lambda_g}{\lambda_0}\right)^2.$$

By using typical values of errors in these parameters it was found that the factor $\Delta a/a$ ($\approx 1/900$) gave the greatest contribution to a 0.35 per cent change in phase velocity at the low frequency end of the waveguide band ($h = 3.1$). Since the measured change in phase velocity exceeds 0.35 per cent it can be deduced that the loading effect of the chokes is the greater factor.

To determine the effect of pin spacing, this dimension was increased from 0.060 to 0.120 inch. Since the vswr and phase velocity were not appreciably changed by this increase, the pin spacing was determined as not being critical, but should be about two times the pin diameter, D.

With respect to pin diameter, it was found that 0.040 to 0.050 inch gave the best over-all results at X band frequencies. The insertion loss of the 0.062 inch pins was higher than that for 0.040 inch pins and the 0.062 inch pins reduced slightly the change in phase velocity.

When all factors are considered, a pin length of 0.90 $\lambda_0/4$ seems to yield a good compromise in the characteristics of vswr, insertion loss and phase velocity change.

Rectangular Cross Section Chokes

For particular applications where choking action is desired over a considerable length, fabrication of circular cross section chokes may become a problem. For this reason, a choke having a rectangular cross section of the type shown in Fig. 6 was investigated in the fixture in Fig. 2. Several test sections were fabricated, each having a different choke width, W (dimension in the direction of propagation). The separation between choke pins was 0.125 inch in all cases. The thickness of all chokes was 0.125 inch and the length, L, was varied by removing material from the ends of the chokes. These choke sections were tested in the fixture shown in Fig. 2 by removing beryllium-copper strip and adding a mounting block to which choke sections could be bolted.

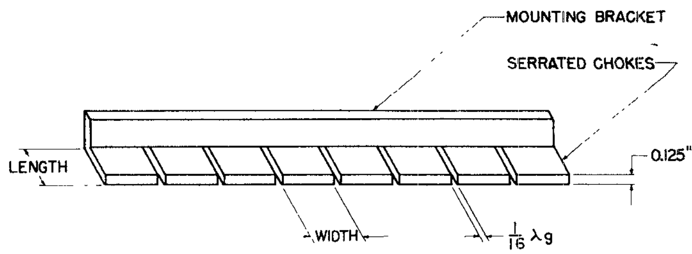

Fig. 6—Rectangular cross section choke which was mounted on fixture in Fig. 2.

It was found that this type of choke was particularly useful in places where no shielding could be used and the gaps encountered were less than 0.025 inch. For this particular application, it was found that chokes having a width, W, of 0.450 inch gave the best results when no shield was used. It is believed that this is due to the smaller amount of radiation obtained from this choke configuration. The effect of length was also investigated, and it was found that a length of 0.320 inch gave optimum performance. The vswr characteristics for this choke as a function of gap size are shown in Fig. 7. Furthermore, the insertion loss and phase velocity measurements show that for $G = 0.010$ inch they are about 0.3 db and -2 per cent change respectively over the same frequency band.

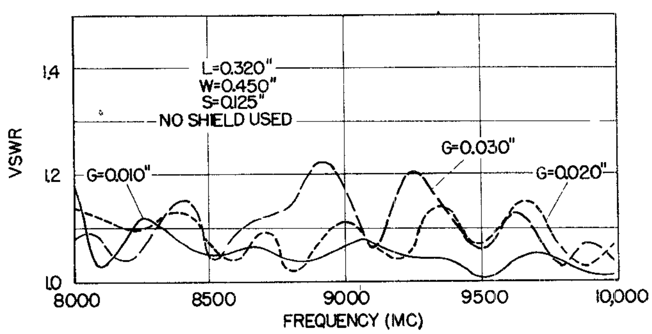

Fig. 7—Vswr as a function of frequency for rectangular cross section chokes with gap size as parameter.

High Power Measurements

The circular and rectangular cross section chokes were tested at high power using a fixed tuned 4J50 magnetron operating at 9,375 mc. The pulse width used was 1.2 μsec, with a repetition rate of 800 cps and a peak power of approximately 240 kw. The air gap, G, used when testing the circular cross section chokes was approximately 0.010 inch. The choke pin diameter was 0.040 inch, and the center-to-center distance, S, was 0.060 inch. These chokes were able to carry the maximum available peak power of 240 kw without any evidence of breakdown for choke lengths ranging from 0.280 to 0.320 inch.

Rectangular cross section chokes having widths, W, of 0.225 and 0.450 inch, spacing between chokes of 0.125

inch, and a thickness of 0.125 inch were tested. The gap was varied from 0.030 to 0.070 inch and the length was varied from 0.320 to 0.280 inch without any sign of the breakdown at the peak power of 240 kw. The corners and edges of these chokes were not rounded in any way. These high-power measurements indicate that both types of chokes are able to carry full rated waveguide power.

Remarks

While it is possible to use the serrated choke on waveguides other than rectangular in cross section, it should be noted that since effective gap impedance is actually nonzero, higher order modes are generated at gap.

In considering the use of the new choke for specific applications and configurations, the array of choke pins and its image plane can be interchanged. Also greater utility may be achieved by rotating the plane of the chokes to any other angle about an axis parallel to the longitudinal axis of the waveguide.

Acknowledgment

The initial limited development on this choke, carried out in 1950, was a part of a program sponsored by the Bureau of Ships under Contract No. Nobsr-42419. The greater portion of the data presented here was obtained under a subsequent contract AF30(120)-440 with the Rome Air Development Center.

Microwave Filters Utilizing the Cutoff Effect

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Summary—**Two band-rejection microwave filters employing the waveguide cutoff effect are discussed. One type utilizes the cutoff property in the series arm of an *E* plane tee to improve the filter's characteristics, while the other utilizes this property in the *E* and *H* arms of a magic tee. Experimental data for both single and multistage filters are presented. Methods of obtaining low standing wave ratios over a broad pass-band are also presented.**

Introduction

IN GENERAL, the design of microwave filters has been treated from an equivalent circuit point of view. That is, low frequency filter theory is used to determine the configuration and from this the microwave analog is constructed. For example, by using resonant cavities and irises, the microwave equivalent of the series, shunt, and ladder type filters have been made.[1–4] In addition, *m* derived filter theory has been applied to microwaves for the design of band-rejection filters.[5] On the other hand, the design of a microwave filter sometimes entails the use of a property peculiar to waveguides. An example of this is the cutoff filter. In normal waveguide theory, the application of the boundary conditions at $x=0$ and $x=a$ (Fig. 1) to Maxwell's field equations reveals the fact that the electromagnetic wave (rectangular TE_{10} mode) will only propagate unattenuated above the frequency f_c, where

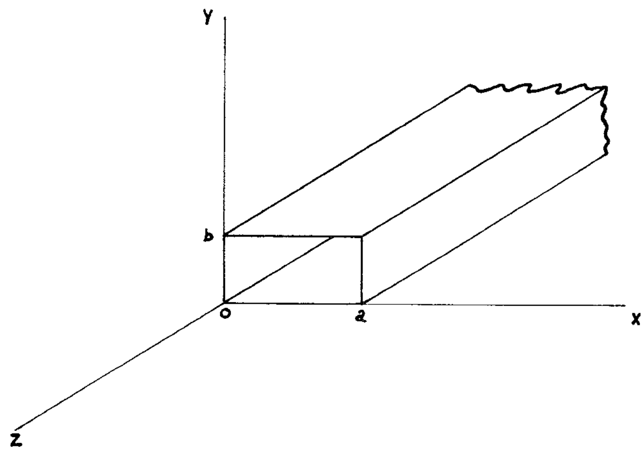

Fig. 1—Rectangular waveguide structure.

$$f_c = \frac{1}{2a\sqrt{\mu\epsilon}}.^{6} \tag{1}$$

For frequencies below f_c, the wave will attenuate at the rate of α nepers per meter, where

$$\alpha = \frac{\pi}{a}\sqrt{1 - \left(\frac{f}{f_c}\right)^2}. \tag{2}$$

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