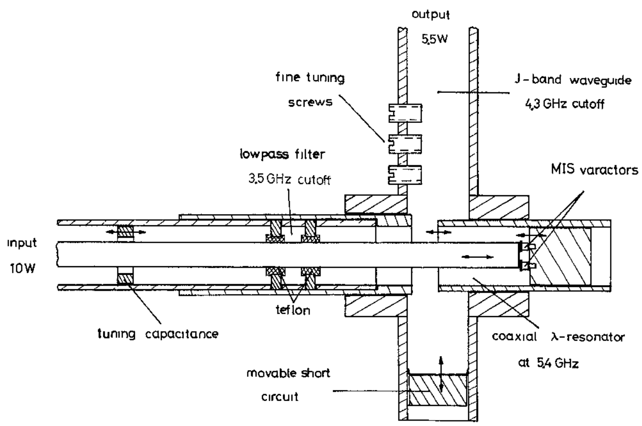


Fig. 2. Frequency doubler from 2.7 to 5.4 GHz.

TABLE II

FREQUENCY DOUBLER PERFORMANCE

| | |
|---|---|
| Input frequency | 2.7 GHz |
| Input power (2 varactors) | 10 W pulsed 50% duty cycle |
| Output frequency | 5.4 GHz |
| Output power (2 varactors) | 5.5 W |
| Overall efficiency (2 varactors) | 55 % |
| 3 dB bandwidth (2 varactors) | 8 % |
| Best efficiency (1 varactor and reduced power) | 65 % |
| Best 3 dB bandwidth (1 varactor and reduced power) | 30 % |

power from the input. Tuning is possible with a movable capacitive iris and an external stub tuner. The 5.4-GHz currents generated within the coaxial line excite propagating fields in the output waveguide. Tuning of the slot width and position, together with the movable waveguide short, permits output matching over a broad frequency range. For fine tuning of the output, three screws are mounted inside the waveguide. Since the waveguide cutoff frequency is 4.3 GHz, the fundamental does not appear at the output port. The varactors are biased externally through the input circuit.

Detailed data for the multiplier are given in Table II. Because of the relatively low reactive part of the input and output impedances [1], the MIS varactor allows large bandwidths to be attained with simple circuits. With only one varactor the bandwidth increased to 30 percent (due to the higher impedance level), but the attainable power decreased. No instabilities have been observed when sweeping the input frequency, and the output is free of spurious signals within maximum sensitivity of the spectrum analyser, which is 60 dB below the output signal.

An undesirable characteristic of MIS varactors, however, is the shift of the *CV* curve, which is caused by tunneling effects between semiconductor and insulator surface states [5], when the applied voltage exceeds a critical value. This value seems to decrease with temperature, since the *CV* characteristic remained stable at 10-W input power with 50-percent duty cycle but not at 10-W CW. It is possible to compensate the shift by readjusting the bias voltage, but the *CV* characteristic shifts again, and after a short time the device is destroyed by irreversible insulator breakdown. A lower thermal resistance (and therefore a lower insulator temperature) should reduce this problem.

It is concluded that the MIS varactor is suitable for broadband frequency multiplication at high power levels. Therefore, the MIS varactor deserves serious consideration for high-power solid-state applications, e.g., transmitters for microwave relay stations.

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# Metallic Frame Beam Waveguide

P. F. CHECCACCI AND A. M. SCHEGGI

***Abstract*—Experimental tests performed on metallic frame beam waveguides are described. Two types of metallic structures have been considered. The first one constituted by thin annular frames has the same attenuation value as that of an iris beam waveguide (infinite slit) of the same aperture, but presents guiding properties which are polarization sensitive. The second type of a more complex structure is essentially a dielectric frame beam waveguide in which the dielectric of suitable refraction index is simulated by metallic parallel plate waveguide sections.**

Beam waveguides consisting of equispaced dielectric frames, introduced as a by-product of a study on rimmed Fabry–Perot (F.P.) resonators [1], [2], have been extensively described in preceding works [3]–[5].

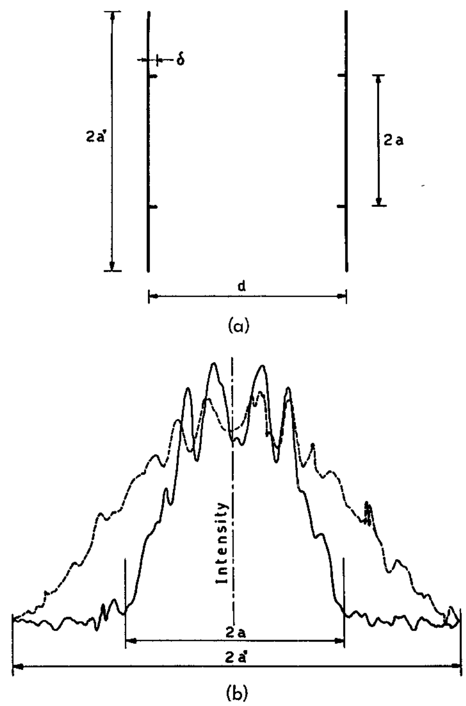


Fig. 1. (a) The Fabry–Perot resonator with thin rims perpendicular to the mirror surfaces. (b) Intensity field patterns across the mirror aperture with and without thin rims.

This short paper is concerned with an experimental investigation performed on another type of the same class of beam waveguides. It consists of a sequence of thin metallic annular frames and constitutes the analogy of an F.P. resonator having end mirrors with thin rims perpendicular to the mirror surfaces [Fig. 1(a)]. Experimental tests performed on an $X$-band model of such a resonator have shown that the losses oscillate with a quasi-periodical trend as a function of the rim depth with periodicity $\sim\lambda/2$, due to resonances in the current systems over the rims. Hence, for suitable values of the rim depth, the field is confined and the losses decrease. This is

Manuscript received February 23, 1973; revised June 6, 1973.
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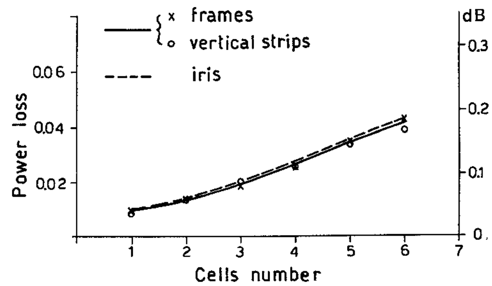


Fig. 2. Measured power losses versus cell number for short circuited sections of the infinite strip iris and of the metallic frame waveguide. $2a = 28\ \lambda$ and $d = 40\ \lambda$.

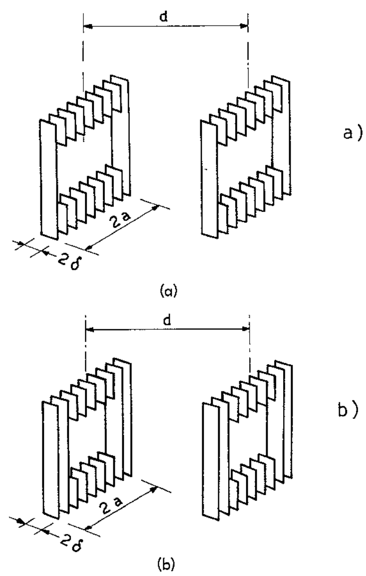


Fig. 3. Multiple plate structures.

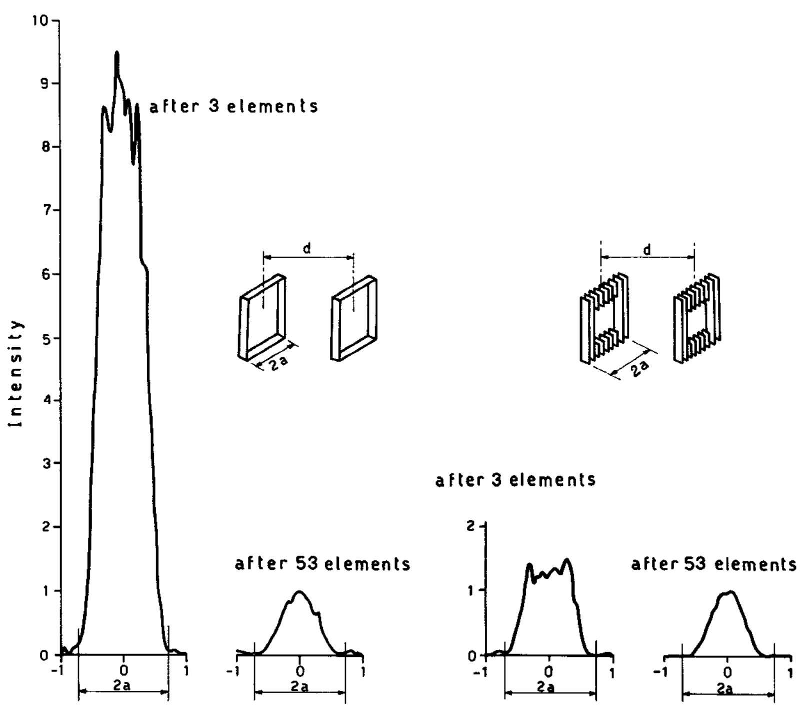


Fig. 4. Metallic frame beam waveguides. Intensity field patterns measured at two distances along the guide axis for the two types of tested structures.

evidenced in Fig. 1(b) where the measured field intensity pattern along the horizontal median line of a mirror of aperture $2a'$ is compared with that measured along the same line but in the presence of thin rims spaced by $2a$.

The corresponding beam waveguide can be constituted by a sequence of iris surrounded by metallic annular frames, and as for the case of the dielectric frame beam waveguides [3], [4], the opaque screens can be eliminated due to the field confinement produced by the frame itself. However, this confinement is polarization sensitive.

Experimental tests have been performed on an $X$-band resonant section and on a prototype waveguide at 37 GHz constituted by 53 frames having aperture of $28 \times 28\ \lambda$ and spaced by $40\ \lambda$. The measured attenuation at 37 GHz is quite high due to the lack of confinement and, hence, to free propagation in the direction parallel to the electric field. Consequently, it is not possible to derive the attenuation per unit length of the guide; however, the measured total attenuation (over 53 cells) of 10 dB against 17 dB for the free-space attenuation over the same distance confirms the guidance in one plane. The tests performed on the $X$-band resonant section consisted of $Q$ measurements for a variable length of the resonating section so that mirror losses and coupling losses can be taken into account. The coincidence of the $Q$'s values in the cases of square frames and only vertical strips confirms that, due to the polarization (vertical electric field), only the vertical strips are effective. Fig. 2 shows the power losses versus number of cells for the square frames and for the vertical strips compared with the losses of an iris beam waveguide of the same size. These curves represent losses for the infinite strip case because the measured values have been corrected for the losses due to the finite size of the end mirrors in the direction of no confinement. It can be observed that this waveguide presents the same losses as the iris waveguide with the advantage of avoiding the large absorbing screen. However, the polarization sensitivity does not make this waveguide practically usable.

Other types of metallic structures can be conceived for avoiding the lack of confinement; for instance, one could use a row of parallel plates acting as waveguides which causes a suitable phase jump and gives rise to the field confinement in the vertical direction [Fig. 3(a)]. This concept can be extended to the vertical sides of the frame [Fig. 3(b)]. However, it is to be noted that in this case the structures, although metallic, are equivalent to dielectric frames because the parallel plate waveguides constituting the new metallic frame simulate a dielectric of suitable refractive index.

Measurements performed on a waveguide constituted by 53 elements like those sketched in Fig. 3(b) have given a value for the attenuation of 0.075 dB/cell or 0.21 dB/m. This is the same order as that of the dielectric frame waveguide of the same aperture. The performance of this last structure can be observed also in Fig. 4, which shows field patterns measured across the frames at two different positions along the waveguide axis in the cases of simple and multiple metallic plates, respectively. Such field patterns have been normalized with respect to the maximum amplitude after 53 elements.

In conclusion the tests have shown that the thin annular metallic frame waveguide presents the same losses as those of the iris waveguide (infinite slit), but with the advantage of a much smaller structure as the absorbing screens are no longer necessary. However, the lack of confinement in one direction due to its polarization sensitivity limits its practical use. On the contrary, practical applications can be found for the frame waveguide with multiple metallic plates which, although more complicated than the dielectric frame structure, presents the same properties.

### Acknowledgment

The authors wish to thank F. Cosi and F. Cecconi for their helpful collaboration in performing the experimental tests.

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# Bandwidth Enhancement in Dielectric-Lined Circular Waveguides

G. N. TSANDOULAS

***Abstract*—The increase in $TE_{11}$–$TM_{01}$ mode bandwidth obtained by inhomogeneously loading (dielectric lining) a circular waveguide is systematically documented. Maximum bandwidth is about 31.83 percent of center frequency (up from about 26.54 percent for fully filled or empty circular waveguides). This makes circular waveguides competitive with square waveguides (bandwidth≈34.3 percent) as radiators in wide-band dual-polarization arrays. Certain interesting symmetries involving the $TE_{21}$–$TM_{01}$ modal inversion are also examined.**

## Introduction

Phased-array technology has been increasingly concerned with wide bandwidth performance. Radiators capable of wide bandwidth (~60 percent of center frequency) have been described by various authors [1], [2]. These are linearly polarized rectangular-waveguide arrays in which the bandwidth limit is essentially determined by the cutoff frequencies of the first two ($TE_{10}$–$TE_{20}$) waveguide modes. For dual-polarization arrays [3] it is desirable to use radiators with at least two planes of identical symmetry such as square and circular waveguides. Based on the cutoffs of the first two ($TE_{10}$–$TE_{11}$) waveguide modes, maximum available bandwidth for square waveguides is about 34.3 percent of center frequency. For circular waveguides bandwidth is only about 26.5 percent of center, $TE_{11}$–$TM_{01}$, cutoff frequency. Thus circular waveguides compare unfavorably with square waveguides as far as maximum bandwidth is concerned. In many phased-array applications the circular radiator shape is advantageous for symmetry and for other reasons. If bandwidths in excess of about 17 percent (maximum circular-waveguide bandwidth reduced by about 10 percent to allow good matching to the exciter at the low end of the frequency band) are required, a method of increasing the available bandwidth is desirable. It has been known [4] that a dielectric lining on the inside of a circular pipe may, under proper parameter selection, increase the $TE_{11}$–$TM_{01}$ bandwidth by differentially loading these two modes. A similar, if stronger, effect may also be obtained by periodically loading the guide with dielectric disks [5], [6].

In this short paper a systematic quantitative documentation of the bandwidth properties of the dielectric-lined circular waveguide is carried out. Design information for a wide variety of cases is tabulated and some new and interesting properties of the structure are presented. Meier and Wheeler's [4] good, but very limited, experimental study is used as a point of departure for this study which is carried out on the basis of the theoretical transcendental propagation equations.

## Results

The geometry of the structure is shown in Fig. 1. $\epsilon_1$ and $\epsilon_2$ are dielectric constants relative to free space. The waveguide is described as dielectric-lined in the sense that $\epsilon_2 > \epsilon_1$ with $\epsilon_1$ not necessarily restricted to the free-space value $\epsilon_0$. The case $\epsilon_2 < \epsilon_1$ may result in complicated modal hierarchies [7] and is not of direct interest in this work. The characteristic equations for the geometry of Fig. 1 are well known [7], [8] and will not be repeated here. A computer program was written for the solutions and the following results have been obtained by means of this program.

The bandwidth figures in this short paper are given as percentages with respect to the center frequency between mode cutoffs and not with respect to the lower mode cutoff as has been usually the case in the past. This is a more realistic definition from an operational radar waveform point of view where deviation from center frequency is the meaningful quantity. This bandwidth is computed from the formula

$$\mathrm{BW} = \text{Total percent bandwidth} = 200 \left[ \frac{TM_{01}{}^{c} - TE_{11}{}^{c}}{TM_{01}{}^{c} + TE_{11}{}^{c}} \right] \qquad (1)$$

Manuscript received April 5, 1973. This work was sponsored by the Department of the Army.
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