TE_{011} MODE SECTORIAL CIRCULAR CYLINDRICAL CAVITY FILTERS*

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ABSTRACT

This paper presents a new cavity resonator for the TE_{011} circular mode which allows a compact mechanical structure for a multiple-cavity filter while retaining many of the electrical characteristics of larger filters. Theoretical values of Q are obtained, mode separation is demonstrated, and a 4-cavity experimental model with an elliptic transfer function is described.

Introduction

Microwave communications systems require filters with sharp frequency selectivity, flat inband slope, and small group delay. Many applications, particularly for satellite systems, necessitate that these characteristics be realized with minimum weight and volume devices. These requirements have been met by constructing narrow bandpass waveguide filters employing multiple-coupled cavities. This paper presents a sectorial circular cylindrical cavity resonator for the TE_{011} circular mode which displays these characteristics.

Theory

The TE_{011} mode[1] in a circular cylindrical waveguide has a single electric field component E_ϕ (Figure 1a). The insertion of perfectly conducting radial planes at $\phi = 0$ and $\phi = \phi_0$ does not change this mode. The resultant sectorial cavity (Figure 1b) will therefore support a resonant TE_{011} mode at the same frequency as its full circle counterpart with the same radius a and length d. This applies to all the TE_{0mn} circular electric modes; however, other TE and TM modes may disappear or be altered depending on the choice of angle ϕ_0.

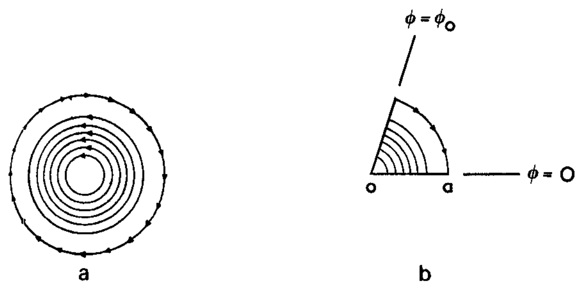

Figure 1. TE_{011} Mode in (a) Circular and (b) Sectorial Cavities

When ϕ_0 is chosen as π/N radians, then 2N coaxial sectorial cavities will exactly fill the cross section of one full circular cavity of the same radius. Apertures in the common radial walls between the cavities can provide positive or negative mutual coupling, and any two cavities may be chosen for input and output coupling. Figure 2 illustrates this arrangement. This configuration yields a multiple-cavity filter in the same space as a single full circle cavity. The potential for reduced filter size and weight is clear.

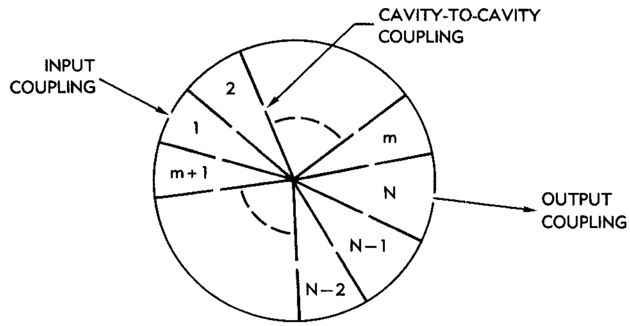

Figure 2. N-Cavity Filter

The sectorial cavity will support additional TE and TM modes at their resonant frequencies. In particular, when $\phi_0 = \pi/N$, these modes are identical to those of the full circular cavity; however, only TE_{pmn} and TM_{pmn} modes with $p = N\ell$, $\ell = 1, 2, 3, . . .$ can exist. The radial planes thus act as mode suppressors. The degenerate TM_{111} mode is eliminated (for N = 2 or greater), and the frequency band around the TE_{011} resonance, which is free of other modes, is increased. Figure 3a shows a mode chart for the full circular cavity, and Figure 3b shows the mode chart for a 90° sectorial cavity (N = 2). The degeneracy of the TM_{111} mode in the full circle cavity can be split;[2] however, complete suppression of the TM_{111} mode as well as the TM_{011}, TE_{311}, TE_{112}, and TM_{012} modes allows a relatively free choice of (2a/d) without danger of spurious responses close to the desired resonance.

The radial planes introduced to form the sector are adjacent to the longitudinal and radial magnetic field components, and hence radial and longitudinal currents flow on their surfaces. These produce losses which reduce the Q of the cavity. The usual perturbational method for calculating Q yields

$$Q\,\frac{\delta_s}{\lambda_0} = \frac{\left[p_1^2 + \left(\frac{\pi}{2}\right)^2 \left(\frac{2a}{d}\right)^2\right]^{3/2}}{2\pi\left[p_1^2 + \left(\frac{\pi}{2}\right)^2 \left(\frac{2a}{d}\right)^3 + \frac{2p_1}{\phi_0}\,F\right]}$$

where $p_1 = 3.832$ is the first zero of J_0'. The factor F is due to the radial walls and is evaluated numerically as

$$F \doteq 7.78 + 3.89\left(\frac{\pi}{2p_1}\right)^2\left(\frac{2a}{d}\right)^2$$

The corresponding formula for the full circle cavity is given by this expression with F = 0. As ϕ_0 decreases,

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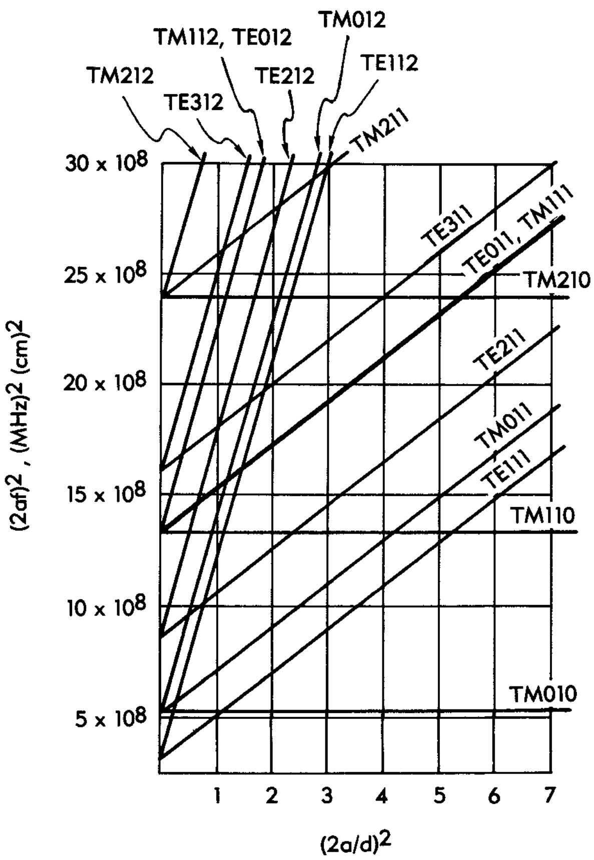
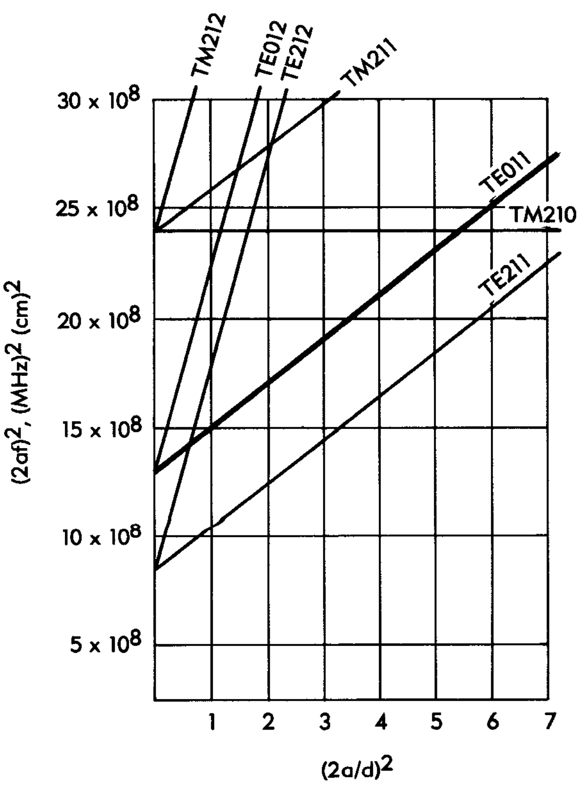


a. Circular Cylindrical



b. Quarter Circle Cylindrical

Figure 3. Mode Charts

the stored energy decreases, and the losses in the end walls and the cylindrical wall (at r = a) decrease proportionately. The loss in the two radial walls remains constant, and hence the Q decreases.

Figure 4 displays theoretical Q's for the full circle cavity (F = 0) and for the semi-circular ($\phi_0 = \pi$), quarter circular ($\phi_0 = \pi/2$), and eighth circular ($\phi_0 = \pi/8$) cases. The TE_{111} mode Q in the full cavity is shown for comparison. The peak theoretical Q for the TE_{011} mode with a 90° sectorial cavity is reduced by one-half from the peak value in the circular cavity. The TE_{011} circular cavity is typically constructed at diameter-to-length ratios yielding a factor of 0.95 below peak Q to avoid spurious resonant modes.[2]

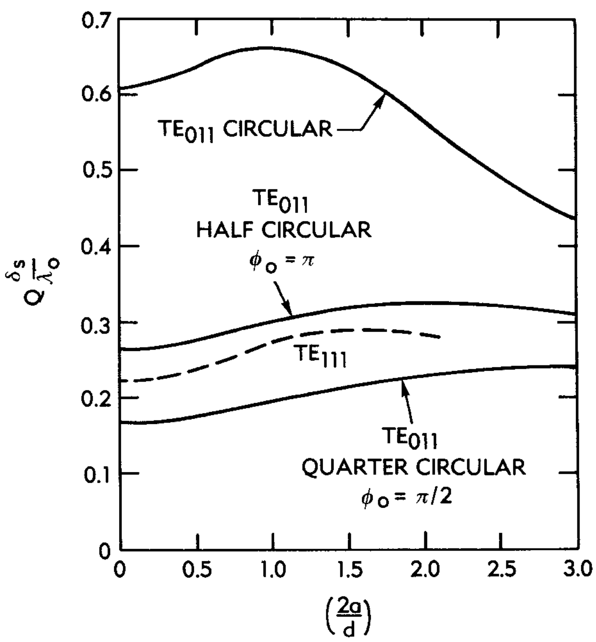


Figure 4. Q for Sectorial and Circular Modes

Longitudinal currents on the radial walls flow onto the end walls where the currents are circular. Since currents must cross the junction between the radial and end walls, good electrical contact between them is essential, and it is not possible to use a noncontacting plunger for tuning as in the full circular case.[2] Tuning may be accomplished by screws inserted into each sector through the end plates.

Positive coupling is obtained from a slot parallel to the magnetic field lines, and negative coupling is obtained from a circular hole in a plane perpendicular to the electric field lines. Slot and hole dimensions may be calculated by formulas similar to those used for the full circle cavity.[3,4] The waveguide-to-cavity coupling formula must be adjusted for the reduced energy stored in the sectorial cavity, and the cavity-to-cavity formula must be modified to include the radial position of the slot.

Experimental Results

A 4-cavity, 4-GHz filter with an elliptic transfer function was designed and built to demonstrate the desirable characteristics of a sectorial cavity filter. The ratio (2a/d) was selected at 1.25. The resonant frequency is related to a and d by

$$\left(2af_0\right)^2 = \left(\frac{p_1 c}{\pi}\right)^2 + \left(\frac{2a}{d}\right)^2 \left(\frac{c}{2}\right)^2$$

giving a radius a of 2.022 in. and a length d of 3.235 in. The mode chart (Figure 3) indicates spurious mode free operation from the TE_{211} mode at 3.373 GHz to the TE_{212} mode at 4.622 GHz. Cavity coupling slot dimensions were determined by using the formulas previously described. Actual coupling values were measured,[5] and the slot size was adjusted. Figure 5 is a photograph of the experimental cavity with the cover removed. This experimental model was constructed with removable top and bottom radial plates and with separate outer sectors which bolt together, tightly clamping the plates.

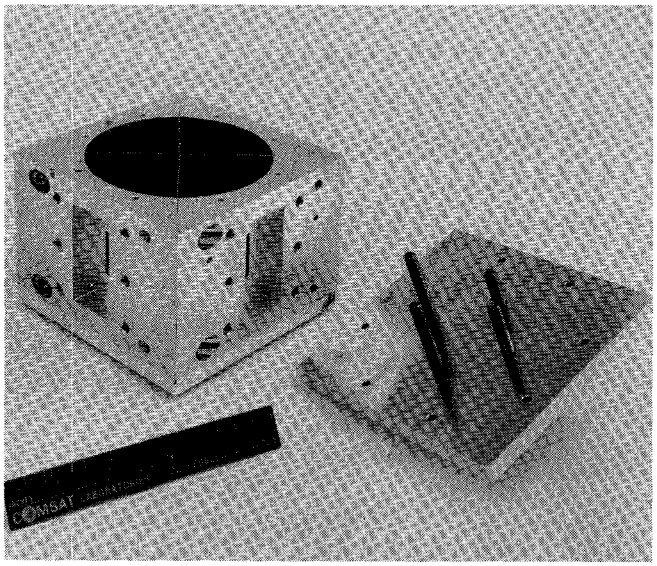


Figure 5. Experimental 4-Cavity Filter

The measured experimental response is shown in Figure 6. The calculated response, also shown in Figure 6, is for the measured values of the coupling coefficients. The center frequency loss of 1.5 dB corresponds to an unloaded Q of 5,000 for the sectorial cavity compared to a calculated value in aluminum of 11,400. It is probable that losses in the electrical contact between the radial plates and the outer cylindrical walls and the top and bottom plates account for the difference between these values. Additional measurements will be made after the entire device is plated and soldered for improved electrical performance. Figure 7 is a wideband insertion loss sweep.

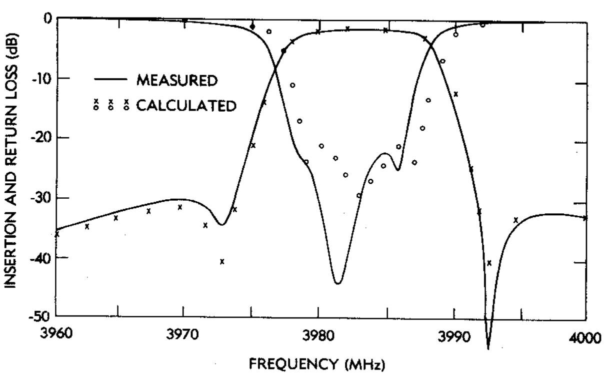


Figure 6. 4-Cavity Filter Response

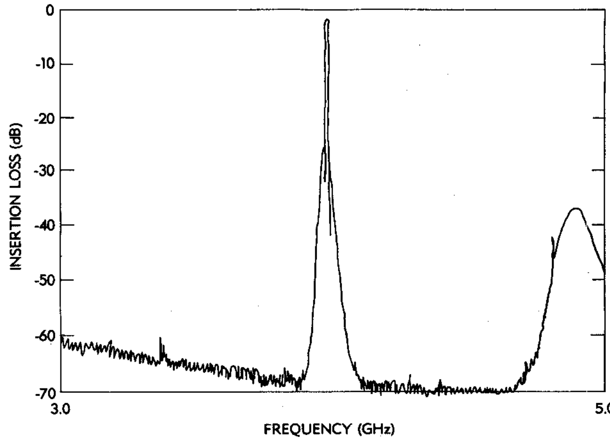


Figure 7. Broadband Sweep

Discussion and Conclusions

This paper has demonstrated the feasibility of TE_{011} sectorial cavity filters. The experimental filter response indicates additional investigation of the losses is required. It has been shown that filter response requiring positive and negative coupling elements is achievable and that spurious modes are widely separated from the desired response. Fabrication could be accomplished by electroforming the cavities around the coupling plates. The intrinsically small size of the N cavity device should lead to a significant reduction in weight and volume.

Acknowledgment

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References

1. R. E. Collin, Foundations for Microwave Engineering, New York: McGraw-Hill, 1966, pp. 107-113, 326-329.

2. A. E. Atia and A. E. Williams, "General TE_{011} Mode Waveguide Bandpass Filters," IEEE Transactions on Microwave Theory and Techniques, MTT-24, No. 10, October 1976, pp. 640-648.

3. G. L. Matthaei, L. Young, and E.M.T. Jones, Microwave Filters, Impedance Matching Networks and Coupling Structures, New York: McGraw-Hill, 1965, pp. 232-243, 924-926.

4. Technique of Microwave Measurements, C. G. Montgomery, Ed.; Radiation Laboratory Series, Vol. 11. New York: McGraw-Hill, 1947, pp. 858-862.

5. A. E. Atia and A. E. Williams, "Measurements of Intercavity Couplings," IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-23, pp. 519-522, June 1975.