A New Type of Annular Ring Waveguide Cavity for Resonator and Filter Applications

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Abstract

A new type of annular ring waveguide cavity has been developed as a waveguide component for the design of resonators, filters, and multiplexers. H-plane and E-plane annular ring waveguide cavities have been investigated thoroughly as regular and forced mode resonators. A dual resonant mode filter using a single H-plane annular ring waveguide cavity has been built with a bandwidth-center-frequency ratio of 0.77%, a stopband attenuation of more than 40 dB, and a sharp gain slope transition. Another dual resonant mode filter which was formed by cascading two E-plane annular ring waveguide cavities has also been fabricated with a bandwidth-center-frequency ratio of 1.12%, a stopband attenuation of 60 dB, a mode purity of 2 GHz around the center frequency of 26.82 GHz, and a sharp gain slope transition. Electronically-tuned resonators are also discussed in this paper.

INTRODUCTION

The annular ring structure has been studied thoroughly for the planar microstrip and slotline transmission structures [1,2]. Many attractive applications of planar annular ring circuits have also been published [1]-[5]. This paper presents a new type of annular ring waveguide cavity which can be used as a resonator or a building component of filters. Compared with microstrip circuits, the waveguide ring has a higher Q and can handle higher power. With the advantage of simple design procedure, this new type of waveguide component has the flexibility of mechanical and electronic tuning as well as good predictable performance.

The annular ring waveguide cavity can be classified as either an H-plane annular ring waveguide cavity or an E-plane annular ring waveguide cavity. Figures 1(a) and (b) illustrate the mechanical structures of the H-plane and E-plane annular ring waveguide cavities. The H-plane annular ring waveguide cavity shown in Figure 1(a) is formed by a circle of rectangular waveguide that is curved in the plane of the magnetic field. The E-plane annular ring waveguide cavity shown in Figure 1(b) consists of a circle of rectangular waveguide that is curved in the plane of the electric field. Both waveguide and coaxial couplings are suitable for exciting the annular ring waveguide cavities. The external feeds of the annular ring waveguide cavities in this paper use coaxial to waveguide transitions. The H-plane annular ring waveguide cavity shown in Figure 1(a) has coaxial feeds on the top side of the cavity, whereas the E-plane annular ring waveguide cavity shown in Figure 1(b) has coaxial feeds on the annular side of the cavity. These coaxial feeds for the H-plane and E-plane annular ring waveguide cavities are designed to excite the dominant TE_{10n} modes, where n is the mode number of the annular ring resonators.

Symmetric external feeds excite the regular resonant modes in the annular ring resonators. The resonant frequency of the nth regular resonant mode is determined by

$$f_n = \frac{nc}{2\pi r}\sqrt{1+\left(\frac{\pi r}{na}\right)^2} \qquad (1)$$

where r is the mean radius of the annular ring waveguide cavity, a is the length of the broad side of the rectangular waveguide, and c is the speed of light in free space. Two test circuits were fabricated to verify the design. The H-plane annular ring waveguide cavity shown in Figure 1(a) was designed to operate in K-band with the following dimensions: (i) mean radius r=16.185 mm, (ii) broad side of rectangular waveguide a=10.73 mm, and (iii) narrow side of rectangular waveguide b=4.44 mm. Whereas the E-plane annular ring waveguide cavity shown in Figure 1(b) was also designed as a K-band waveguide cavity with the following dimensions: (i) mean radius r=10.11 mm, (ii) broad side of rectangular waveguide a=10.20 mm, and (iii) narrow side of rectangular waveguide b=3.88 mm. Figures 2 and 3 show the measured frequency response results for the H-plane and E-plane annular ring waveguide cavity, respectively. Figure 4 shows the comparison between the calculated and measured results of the resonant frequencies. As shown in Figure 4, the resonant frequencies of the annular ring waveguide cavities can be predicted correctly within an error of less than 2.5%. Easy and correct prediction of the resonant frequencies and a simple design procedure make the annular ring waveguide cavity a good candidate for waveguide filter circuit design.

SINGLE CAVITY DUAL MODE FILTER

The H-plane annular ring waveguide cavity for the single cavity dual mode filter was built with the same dimensions as those in Figure 1(a). As shown in Figure 5(a), the resonant modes of the single H-plane annular ring waveguide cavity, which has a 90 annular degree split-up of the external feedlines without a tuning post, display a maximum insertion loss for those resonant modes with odd mode numbers. The experimental results shown in Figure 5(a) agree with the prediction of the *Standing Wave Pattern* analysis [1]. From the analysis, dual mode operation can be excited by inserting a post at 45 or 135 degrees along the ring [1,2].

By using a tuning post at 45 annular degrees, the dual resonant mode shown in Figure 5(b) is obtained with mode number n=5. If the tuning post is at 135 annular degrees, the seventh resonant mode shown in Figure 5(c) becomes the dual resonant mode. As shown in Figure 5(b), a dual resonant mode filter with mode number n=5, which used a single H-plane annular ring waveguide cavity with a tuning post at 45 annular degrees, has been achieved with the following results: (i) center frequency f_0=20.28 GHz, (ii) bandwidth BW=250 MHz, (iii) loaded Q value Q_L=81.12, (iv) midband insertion loss IL=2.68 dB, and (v) stopband attenuation A=40 dB. The midband insertion loss of 2.68 dB corresponds to unloaded Q value of 304.68. The other dual resonant mode filter using a tuning post at 135 annular degrees, as shown in Figure 5(c), was obtained with mode number n=7 and the following results: (i) center frequency f_0=24.61 GHz, (ii) bandwidth BW= 190 MHz, (iii) loaded Q value Q_L=129.57, (iv) midband insertion loss IL=1.5 dB, and (5) stopband attenuation A=48 dB. The midband insertion loss of 1.5 dB corresponds to unloaded Q value of 816.95.

2-CAVITY DUAL MODE FILTER

A 2-cavity dual mode filter using two E-plane annular ring waveguide cavities with 90 annular degree split-ups of the external feedlines was designed to improve the stopband attenuation. The test circuit was built by cascading two E-plane annular ring waveguide cavities. Each E-plane annular ring waveguide cavity has the same dimensions as those in Figure 3. Two tuning posts located at 45 and 135 annular degrees have also been used in each E-plane annular ring waveguide cavity. The measured frequency response results for the 2-cavity dual mode filter are shown in Figure 6. As shown in Figure 6, a 2-cavity dual mode filter has been achieved with the following results: (i) center frequency f_0=26.82 GHz, (ii) bandwidth BW=300 MHz, (iii) loaded Q value Q_L=89.41, (iv) insertion loss IL=2.63 dB, and (v) stopband attenuation A=60 dB. A mode purity of 2 GHz around center frequency of 26.82 has been obtained. The midband insertion loss of 2.63 dB corresponds to unloaded Q value of 341.43. The insertion loss of 2.63 dB can be reduced by replacing the coaxial connection between two E-plane annular ring cavities with irises. Also, a more precise machining and a gold-plated waveguide cavity can be implemented to improve the insertion loss and increase the unloaded Q value.

ELECTRONICALLY-TUNED RESONATORS

A varactor-tuned annular ring waveguide cavity was developed for fast electronic tuning. The varactor-tuned annular ring waveguide cavity has a post mounted with a varactor. The post is located at 90 annular degrees. Due to the variance of the capacitance with bias voltage, the resonant modes can be tuned between regular resonant modes and forced resonant modes. The measured frequency response results of the varactor-tuned annular ring waveguide cavity are shown in Figure 7 for different varactor bias voltages. The tuning range shown in Figure 7 is 190 MHz which is limited by the tunable capacitance of the varactor and circuit configuration. The tunable capacitance of the varactor is varied from 2.64 pf to 0.75 pf which is controlled by varying the bias voltage from 0 V to 25 V. A varactor with large tunable capacitance can be used to achieve better tuning range.

CONCLUSIONS

A new type of annular ring waveguide cavity has been developed for the design of resonators, filters, and multiplexers. Designs of resonators and dual mode filters have been investigated. Also, varactor-tuned annular ring waveguide cavities were demonstrated with predictable tuning ranges. With a simple design procedure, a well predictable performance, and a flexible tuning property, this new type of annular ring waveguide cavity should have many applications in waveguide circuit design.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. F. Lu and Mr. J. A. Navarro for helpful discussions and technical assistance, and Dr. H. F. Taylor for constant encouragement. This work was supported in part by the Office of Naval Research and the State of Texas Higher Education Coordinating Board's Advanced Technology Program.

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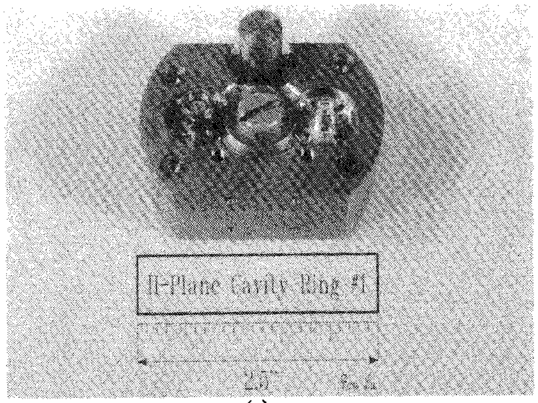
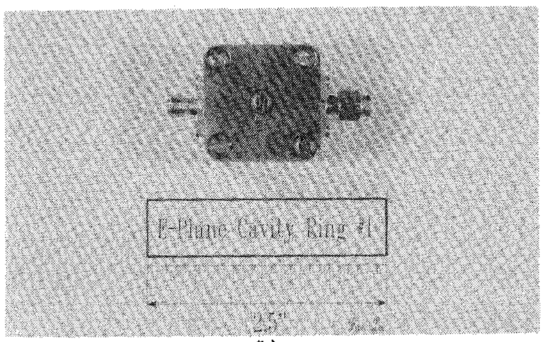


(a)



(b)

Figure 1 (a) H-plane ring cavity. (b) E-plane ring cavity.

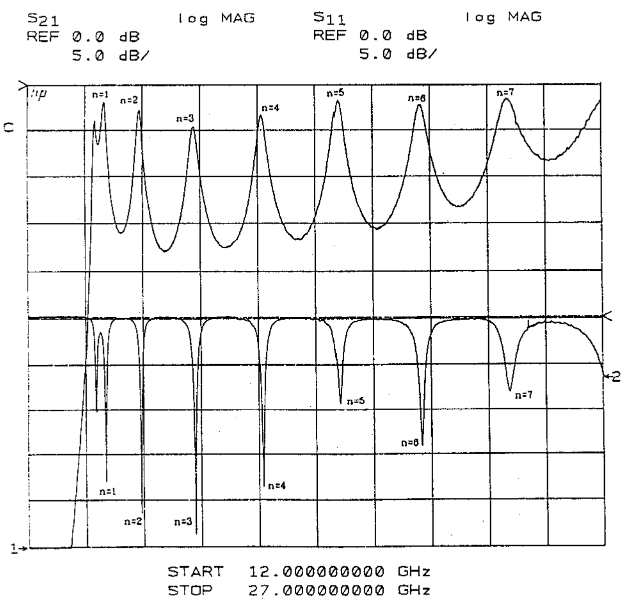


Figure 2 Insertion loss of H-plane ring resonator.

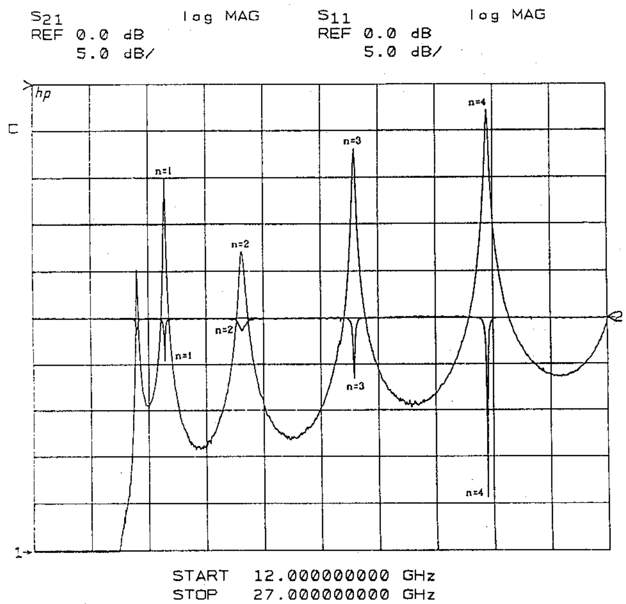
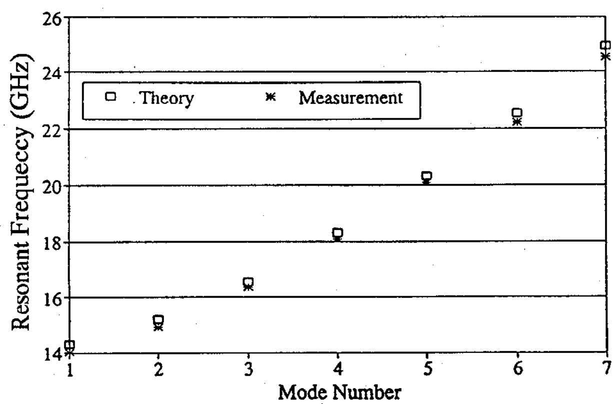
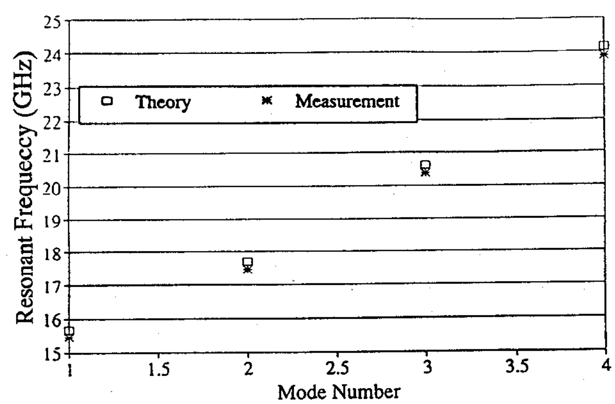


Figure 3 Insertion loss of E-plane ring resonator.

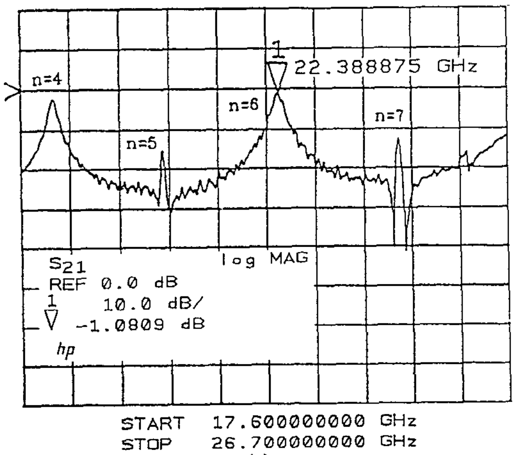


(a)

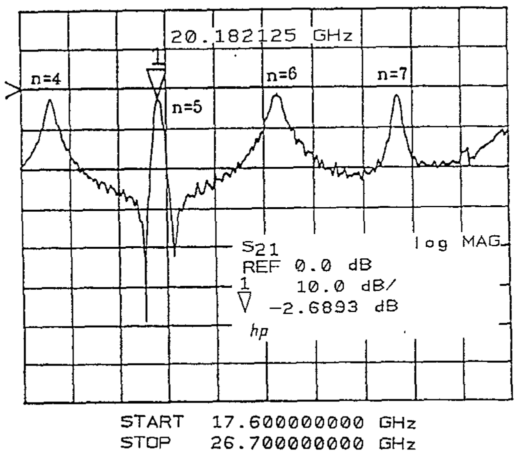


(b)

Figure 4 Resonant frequencies: (a) H-plane ring cavity. (b) E-plane ring cavity.



(a)



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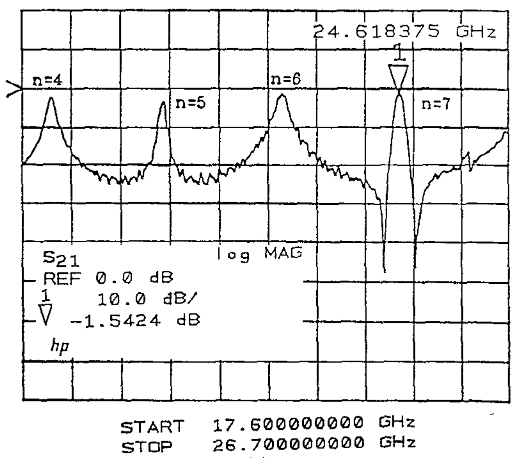

(c)

Figure 5 Insertion loss of single cavity dual mode filter: (a) without tuning post. (b) with a tuning post at 45°. (c) with a tuning post at 135°.

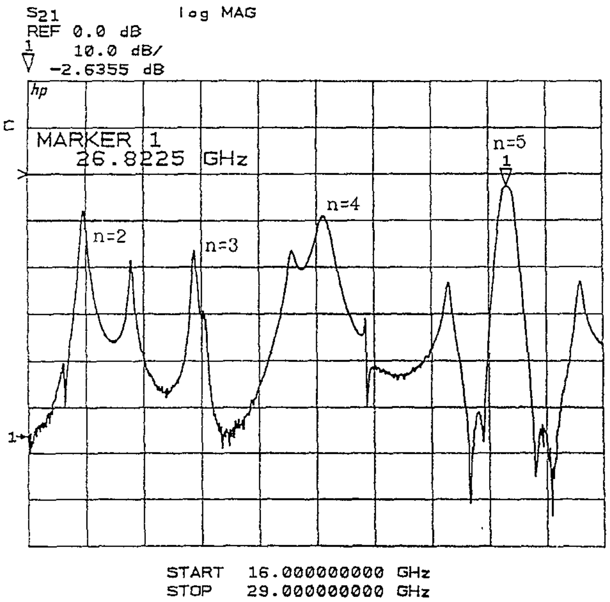

Figure 6 Inseriton loss of 2-cavity dual mode filter.

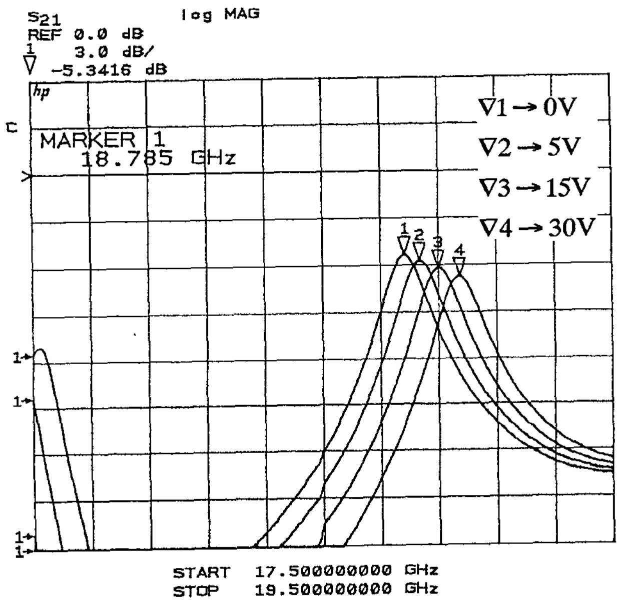

Figure 7 Response of electronically-tuned H-plane ring cavity resonator.