A Ka-band Planar TE011 Mode Cavity Tunable Filter using a Mode-Splitter Ring

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Abstract — A TE011 Ka band tunable filter with a stable and continuous tuning performance is presented in this paper. A novel mode-splitter resonator and coupling configuration enabling cross-coupled planar TE011 filter realization is introduced in this work. The concept can be applied to back-to-back coupled TE011 resonator as well. The idea presented in this paper is verified through fabrication of a three-pole Ka-band tunable filter that demonstrates 500 MHz of tuning range with a stable RF tuning performance.

Index Terms — Tunable filters, TE011, Cavity resonators, Coupling, Reconfigurable architectures,.

I. Introduction

TE011 mode operation of cylindrical cavity resonators offers a high quality factor and a particular field pattern that makes it an attractive choice for a number of applications including high power and tunable filters.

However, this mode of operation is degenerate with a pair of low-quality-factor TM111 modes that needs to be driven away from the operating TE011 mode without causing degradation in quality factor [1]-[2] or overall filter performance. Realization of any desired filter function in a cross-coupled resonator configuration is another challenge to be overcome for TE011 resonator [3].

A. TM111 Mode Control

The most efficient technique to split the degenerate TM111 mode from the operating TE011 mode is shaping the cavity resonator [1][2]. This technique increases the overall filter footprint. Another technique introduced in [3] employs metallic posts to split the degenerate TM111 mode but it suffers from fabrication complexity and performance degradation. A kind of disc loaded technique is presented in [4] for L-band but the efficacy of this technique is not substantiated and clarified. The technique introduced in [4] does not rely on the disc to split the degenerate TM111 mode.

B. Filter Design

All the published TE011 filters use the below resonance iris (short iris) to couple two cavities. This type of iris only realizes one coupling sign in a side-to-side (single layer) direct-coupled cavity configuration. Therefore it does not offer an all-purpose and comprehensive solution to realize any desired filter function in a single layer direct-coupled TE011 cavity filter.

Although the extracted pole technique [5] can be employed to realize a filter response in a planar fashion using the same sign coupling configuration, this technique suffers from a size disadvantage. The extracted pole design is not attractive for tunable-filter design because of the frequency sensitive transmission lines used between cavities.

The back-to-back coupling employing offset cavity technique in two layers described in [3] can provide both positive and negative couplings using the cavity offsetting technique. This method increases the overall filter envelope due to the offset cavity configuration. It is not suitable for tunable applications if intended tuning plate in one layer only.

A single-layer direct-coupled cavity design presented in this paper is an attractive filter configuration particularly for tunable-filter realization. This configuration requires both couplings signs to realize the desired filter function. A design that can address both coupling signs in a single-layer direct-coupled fashion has not been introduced in the literature.

II. End Cap Metal Ring TM111 Mode-Splitter

Electric field distribution of a TE011 cavity resonator is expressed by the following equation

$$E_{\phi} = \frac{-\omega\mu}{k^2-(k_{hmn}^{C})^2}\frac{\chi'_{mn}}{r_0}J'_m\left(\frac{\chi'_{mn}}{r_0}\rho\right)\sin\left(\frac{\pi z}{l}\right) \quad (1)$$

where r_0 and l are the cavity radius and length respectively. TE011 mode electric field vanishes at both the center and corner of the cavity. The electric field decays by more than 20dB for $\rho< 0.03r_0$ and $\rho> 0.96r_0$. Therefore introducing an end cap ring with proper gap and void (Fig. 1) should not affect the TE011 mode operation. TM111 electric field though is very strong at both center and corner of the cavity so its resonance frequency is shifted to a lower frequency depends on the gap and void dimensions of the metal ring.

The detail structure of the metal ring loaded cavity is shown in Fig. 1. The cavity can be loaded with one or two metal rings depend on the application.

A plunger can be introduced in the cavity to make it tunable as shown in the Fig. 1. The enclosure contact should just provide adequate conductivity to create close to short circuit condition. This condition will guarantee that the degenerate TM11 mode and other spurious mode are kept outside of the

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operating frequency range. It is well known that the imperfect conductivity at the enclosure contact does not affect the quality factor of the operating TE011 mode.

Spurious performance of the introduced resonator is shown in Fig. 2. The gap length is varied from 0.05" to 0.09" and spurious free window (TE311-TM11) is computed using a full-wave solver. More than 2GHz of spurious free window is achieved using this technique. The figure shows that the void section shifts the degenerate TM111mode further toward lower frequencies. Therefore end cap ring provides 400 MHz higher spurious free window than disc (without void) for the particular dimension used in this analysis.

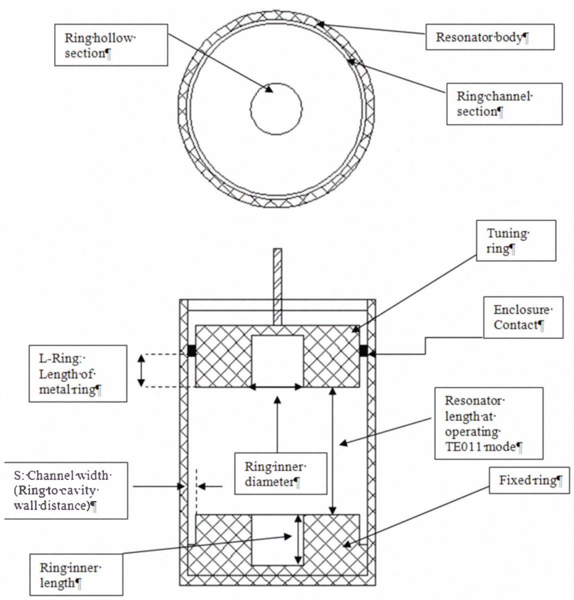


Fig. 1. A tunable TE011 resonator with mode-splitter rings.

III. A Long Iris for Positive Coupling

A coupled TE011 resonator is shown in Fig. 3. Coupling is realized through an iris that is an opening aperture between two cavities. Utilizing an iris with a length of shorter than free space half wavelength (below resonance) is a common practice to create proper coupling. We call this type of iris a short iris in this paper. The short iris provides only negative coupling.

Introducing an iris with positive coupling grants a significant benefit to TE011 filter design since it provides positive coupling. An iris with a length longer than half free space wavelength (over the resonance length) can provide positive coupling between cavities. We call this kind of iris a long iris in this paper. Following is an example on how these two irises are different.

Table 1 shows the simulated odd and even-mode frequencies for short and long irises in a side-to-side TE011 coupled resonators .It has to be noted that cavity should be properly sized to fit long iris without degradation. It is clear from this table that the coupling sign of long iris is opposite of the one for the short iris. The idea of long iris is also applicable to the back-to-back coupled resonator.

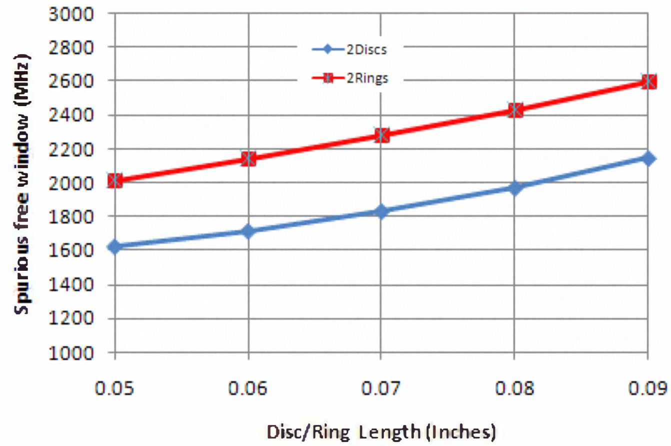


Fig. 2. Spurious free window for a 20 GHz TE011 resonator with metal ring mode-splitter.

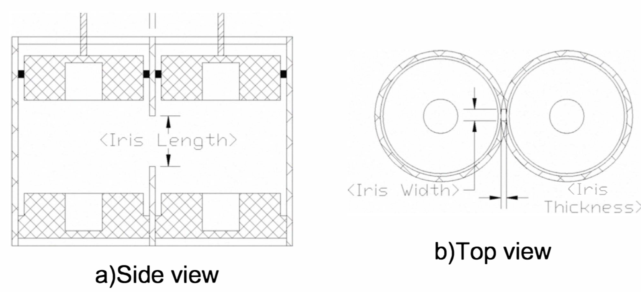


Fig. 3. Two TE011 metal ring loaded resonators coupled through an iris

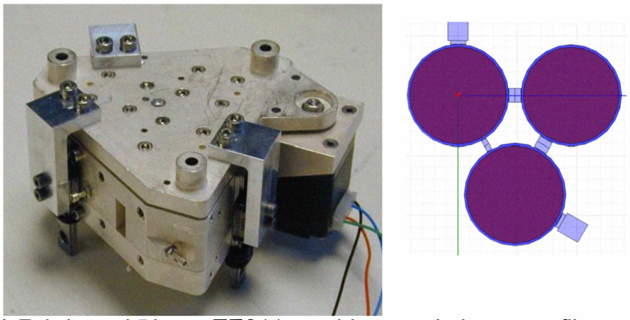
Table 1. Both coupling signs for a direct coupled TE011 cavities.

Iris type	Short Iris (Iris Length shorter than half free-space wavelength)	Long Iris (Iris Length longer than half free-space wavelength)
Freq (GHz)	20	20
Cavity Length	0.519	0.519
Free Space $\lambda/2$	~0.295	~0.295
Iris Length	0.200	0.400
Iris width	0.150	0.150
f_{odd}	19.808	20093
f_{even}	19.913	19880
Coupling sign	Negative ($f_{odd} < f_{even}$)	Positive ($f_{odd} > f_{even}$)

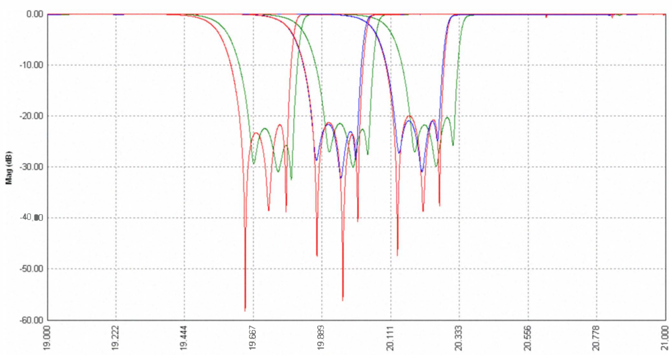
IV. A Tunable TE011 Filter

The tunable filter in [6] is complex and does not address bandwidth tenability. It is known that bandwidth adjustment is realized by cascading two (a low pass and a high pass) tunable filters. Both bandwidth and center frequency can then be tuned by tuning each filter center frequency in respect to each other.

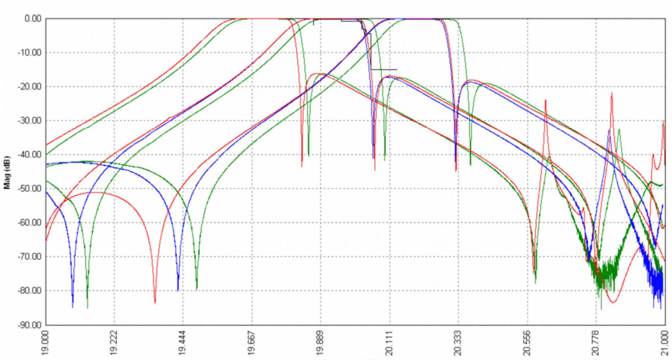
Both filters should maintain their in-band and rejection performance when tuning center frequency. This is the main challenge in the cascade approach, particularly at microwave frequencies. The introduced tunable metal-ring loaded TE011 cavity and long coupling iris with positive sign are the key elements to realize such a stable tunable filter response.



a) Fabricated Planar TE011 tunable pseudo low pass filter incorporating all long irises, tuning plate and sliding contact



b) Simulated (Red) and measured (Green and Blue) return loss for a pseudo low pass direct coupled TE011 tunable filter



c) Simulated (Red) and measured (Green and Blue) transmission response for a pseudo low pass direct TE011 tunable filter

Fig. 4: Layout, picture and tuning performance of a fabricated tri-section TE011 tunable filter for 500 MHz tuning range at 20 GHz

A cross-coupled tri-section layout for both pseudo low-pass and pseudo high-pass filters is shown in Fig. 4-a. A picture of fabricated Ka-band TE011 tunable pseudo low-pass filter is shown in Fig. 4-a. The low-pass version is not realizable without positive coupling [7] so the introduced concepts are used to design this filter. The filter is tuned by adjusting the tuning plate attached to the plungers of the three cavities. Simulated and measured tuning-performance is shown in Fig. 4-b and c. The in-band performance is clean and the degenerate TM11 mode is driven out as expected. The filter exhibited stable tuning performance, maintaining its in-band and out-of-band performance over a wide tuning range.

More than 500 MHz of center-frequency tuning range is demonstrated by +/-27 mills of tuning plate adjustment. Notch level variation is less than 1 dB, and return loss is better than 20 dB without losing any of its three peaks over the entire tuning range. The change in the 3dB bandwidth is less than 7 MHz comparing to the 3dB bandwidth of 245 MHz at the neutral position that means less than 2.7% bandwidth variation over the tuning range of 500 MHz.

VII. Conclusion

A cross-coupled planar TE011 cavity resonator incorporating end cap metal ring feature and a novel long iris that realizes positive coupling in a direct-coupled cavity layout is introduced in this paper. The long iris allows for any transmission zero locations to be realized in a cross-coupled planar TE011 configuration. The idea can also be used to design a stack-up TE011 filter without need to offset cavities. A higher order tunable filter with stable tuning performance over a wide tuning-range can be designed by employing the introduced elements.

Acknowledgement

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