Tunable Absorptive Bandstop Filter with an Ultra-Broad Upper Passband

Mark D. Hickle and Dimitrios Peroulis
School of Electrical and Computer Engineering, Birck Nanotechnology Center
Purdue University, West Lafayette, IN, 47907 USA

***Abstract*—This paper presents a new broadband external coupling structure for tunable evanescent-mode cavity resonator-based bandstop filters. This coupling method has low levels of parasitic reactances, which when combined with the wide spurious-free range of evansecent-mode cavities enables the implementation of a 3 to 6 GHz tunable bandstop filter which has a measured upper passband with less than 3-dB of insertion loss up to 28.5 GHz.**

***Index Terms*— Filters, microwave filters, passive filters, tunable filters, tunable resonators.**

I. Introduction

In wideband communication systems, it is often necessary to block strong jamming signals which fall within the band of interest. One such example is the ultra-wideband (UWB) communication standard, which spans a 3.1 to 10.6 GHz frequency range. Interference from WLAN systems in the 5 to 6 GHz range, as well as many other sources of interference, can severely degrade the sensitivity of an unprotected UWB receiver [1]. Another example is a receiver designed for intercepting an adversary's wireless communications without prior knowledge of the frequency of the transmission. In this case the receiver would need to be very wideband, but would suffer from the same interference problems as UWB systems. In both of these cases a tunable bandstop filter could be used to selectively reject interfering signals. However, unless the bandstop filter has a low-loss passband which extends up to the maximum frequency of the receiver, the bandstop filter itself will degrade the performance of the receiver. It is challenging to design bandstop filters with very broad upper passbands for two main reasons. First, all practical resonators have spurious resonances which create additional stopbands at finite frequencies. Secondly, the structures used to couple resonators to the filter's through-line often introduce strong parasitics, which can degrade the filter's passband even at frequencies below the first spurious resonance of the resonator.

II. Upper Passband Limits: Resonators and Couplings

The first spurious mode of a half-wavelength microstrip resonator is $2f_0$, where f_0 is the resonator's fundamental resonant frequency. Grounded quarter-wavelength resonators have spurious-free ranges up to $3f_0$, and adding capacitive loading or using structures such as stepped-impedance resonators can further increase this spurious-free range [2]. Additionally, some methods have been proposed for suppressing spurious

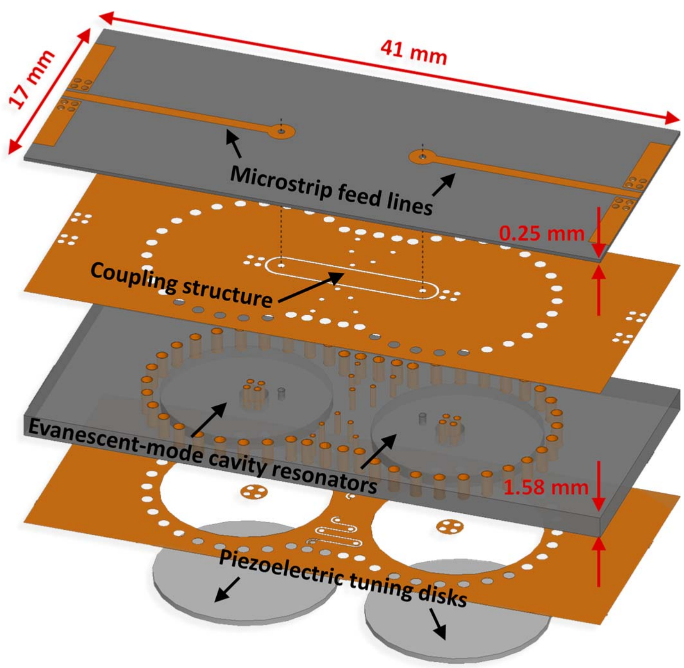

Fig. 1. Diagram of a two-pole bandstop filter which utilizes the proposed broadband external coupling method.

modes to enable even wider upper passbands [3]. However, tunable microstrip-based filters have limited performance in terms of quality factor and linearity, and thus are not suitable for all applications. Evanescent-mode cavity resonators [4] are an attractive alternative to varactor-tuned microstrip filters due to their wide tunability, high unloaded quality factor, and high linearity and power handling [5], [6]. They can also possess very large spurious-free ranges of up to 40:1. However, the upper passband of an evanescent-mode bandstop filter is typically limited by the reactances introduced by the external coupling structure [7]. This coupling is usually implemented through a coupling aperture in the resonator's ground plane, which is shared between the microstrip feeding transmission lines and the cavity resonator itself. The aperture introduces a large inductance in the ground path of the microstrip through-line, which eventually causes high levels of reflection and limits the upper passband of the filter. A new coupling structure which mitigates this problem was introduced in [8], which routes the microstrip line through the cavity instead of coupling through an aperture. This structure avoided many of the parasitics associated with the typical coupling apertures, and

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enabled a 0.65 to 1.65 GHz tunable filter to have a 3-dB passband extending up to 11.1 GHz. Despite the filter's exceptional performance, the design is relatively difficult to accurately manufacture with standard printed circuit board (PCB) milling machines. This fabrication inaccuracy, along with the small but still-present parasitics associated with the coupling structure, prevent this design from being extended to higher operating frequencies. This paper introduces a new coupling structure which improves upon the design of [8] by reducing parasitics and fabrication complexity, enabling the implementation of a 3 to 6 GHz tunable bandstop filter with a 3-dB upper passband extending up to 28.5 GHz.

III. Broadband Coupling Structure

The proposed coupling structure is similar in concept to the one in [8], in that it consists of a section of transmission line routed through the cavity resonator instead of the more traditional method of using a coupling aperture. A diagram of the proposed coupling structure is shown in Fig. 2. To realize the external coupling, the microstrip transmission line which serves as the input to the filter is transferred to a coplanar waveguide (CPW) transmission line which is embedded in the ground plane of the cavity. The magnetic fields of this section of CPW line extend into the cavity and couple with its magnetic fields, allowing the desired coupling between the through-line and cavity to be realized. This structure does not have any of the resonant apertures that the traditional method does, which allows the filter to have a well-matched passband extending up to very high frequencies as long as the dimensions of the microstrip and CPW lines are chosen so that they are both have 50-Ω characteristic impedances. The proposed structure can be fabricated simply and accurately using any standard multi-layer PCB process. In contrast, the structure of [8] required copper features to be patterned at a specified depth inside of a cavity routed into the substrate, a process which is difficult to perform accurately and is not compatible with standard PCB fabrication processes.

The most notable source of parasitic reactances is the via which connects the microstrip line to the CPW line. This presents a small series inductance to the signal path, but the effect of this series inductance can be partially compensated for over a range of frequencies by adding a small shunt capacitance. This shunt capacitance can be realized by decreasing the impedance of the transmission line near the via - in this case, by adding a circular patch to the microstrip line at the location of the via.

The strength of the coupling realized with this structure is determined by the width and length of the section of CPW line inside the cavity, as well as the distance between the CPW line and the cavity's center post. The dependence of this structure's coupling coefficient on the length of the CPW line is shown in Fig. 3.

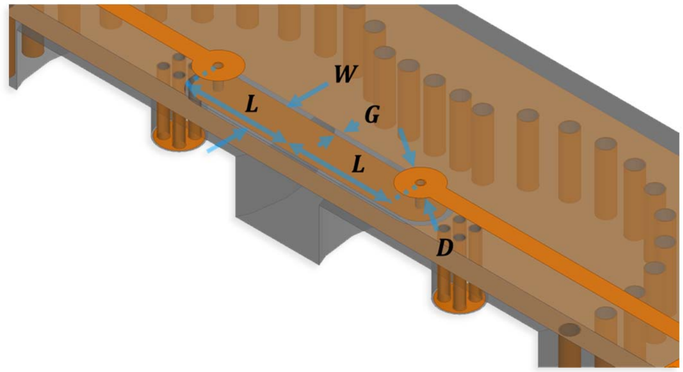

Fig. 2. Close-up view and critical dimensions of the proposed coupling structure. $L = 5.05\ mm, W = 1.9\ mm, G = 0.26\ mm, D = 1.9\ mm$.

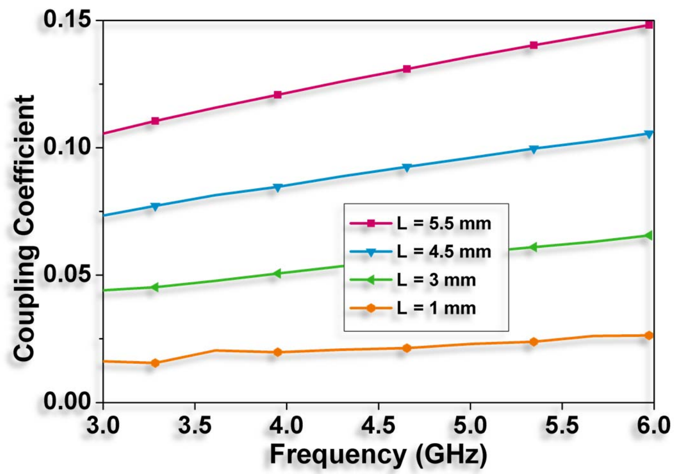

Fig. 3. Dependence of external coupling coefficient on the length of the CPW line.

IV. Experimental Results

Using the coupling structure presented in Section II, a two-pole tunable bandstop filter was designed, as shown in Fig. 1. The filter was designed to have a 3 to 6 GHz tuning range, with a 1.6% 3-dB fractional bandwidth at 4.5 GHz. In order to increase the stopband rejection, the two resonators were coupled together with a small amount of interresonator coupling in order to implement an absorptive bandstop filter design [9]. The filter was fabricated using a standard PCB milling, laminating, and plating system. The signal and cavity substrates were made out Rogers 5880, and were laminated together using Rogers 2929 bondply material. Commercially-available piezoelectric disks, metalized with thin silver membranes and attached on top of the cavities using electrically-conductive silver epoxy, were used as the tuning elements. More details regarding general design, fabrication, and operating principles of tunable evanescent-mode filters can be found in [7] and [10]. The fabricated filter is shown in Fig. 4.

The measured S-parameters of the filter when tuned across its 3 to 6 GHz tuning range are shown in Fig. 5, demonstrating

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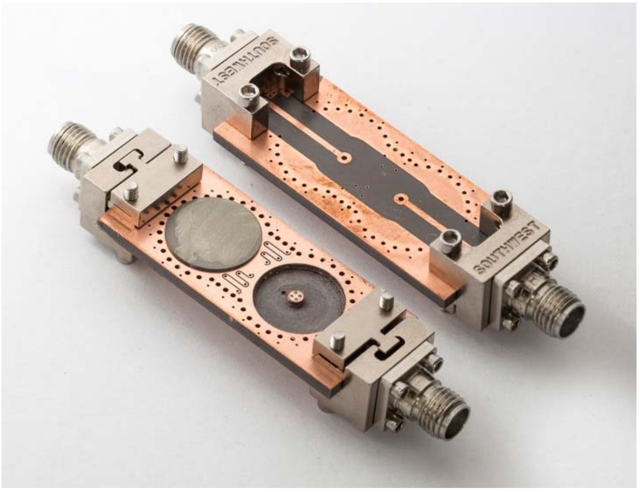

Fig. 4. Photograph of the fabricated filter.

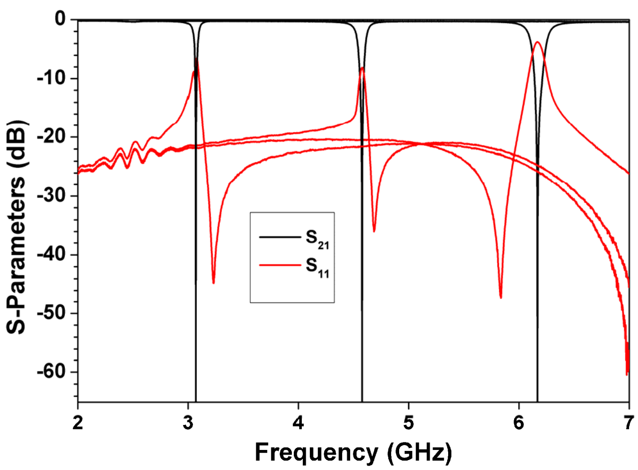

Fig. 5. Measured response of the filter demonstrating its octave tuning range.

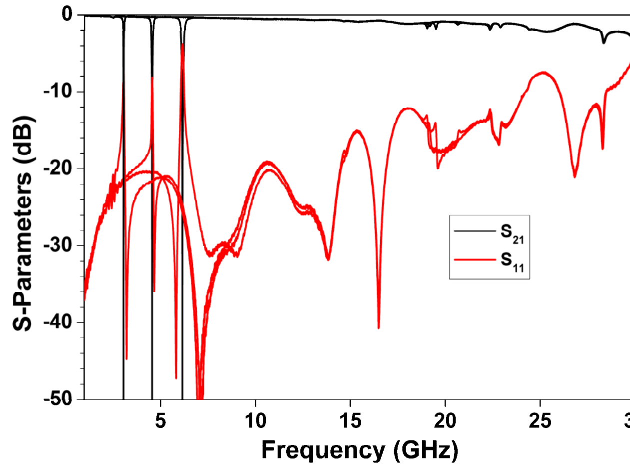

Fig. 6. Measured wideband response of the filter, showing its broad upper passband.

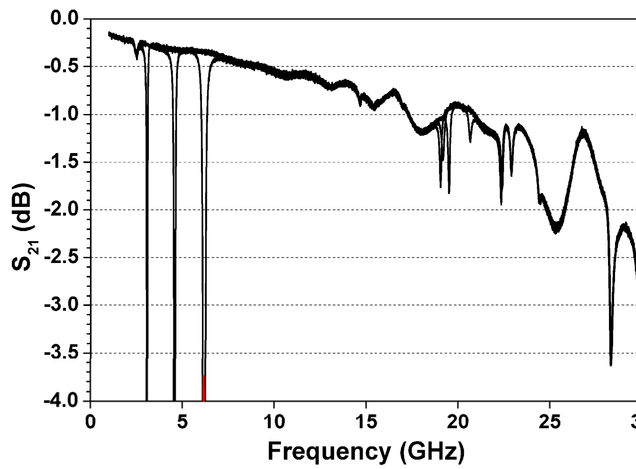

Fig. 7. Close-up view of the filter's measured insertion loss. The 3-dB passband extends up to 28.5 GHz.

that the filter can achieve more than 60 dB of stopband rejection over an octave tuning range, with a 1.25% to 2.3% 3-dB bandwidth. Passband insertion loss and return loss are both very low within the filter's tuning range, at less than 0.37 dB and better than 20 dB, respectively. The broadband frequency response of the filter is shown in Fig. 6. It can be seen that the filter's return loss is better than 10 dB up to 24.2 GHz, and better than 7.5 dB up to 29.5 GHz. A close-up view of the filter's insertion loss is shown in Fig. 7. The insertion loss is less than 1 dB up to 17.3 GHz, less than 2 dB up to 24.9 GHz, and less than 3 dB up to 28.5 GHz.

The inclusion of the interresonator coupling iris for increased stopband rejection increases the electrical volume of the filter structure compared to an individual resonator, which reduces the spurious-free range of the filter. With the specific geometry used in this filter, the first spurious mode of the filter occurs around 19 GHz. However, this spurious mode is very weakly coupled, and adds less than 1 dB of insertion loss to the passband. In applications where upper passband insertion loss is of higher importance than stopband rejection, the interresonator coupling could be removed in order to eliminate these spurious notches.

The upper passband is ultimately limited by the inductance of the vias connecting the microstrip feed lines to the CPW coupling section, as well as the transition from the microstrip lines to the coaxial end-launch connectors. Using a thinner signal substrate would decrease the inductance of the vias, and along with more careful design of the microstrip-to-coaxial transition this is expected to allow this filter to have an even wider upper passband which is limited only by more strongly coupled spurious modes of the resonators.

V. Conclusion

In this paper, a new broadband external coupling mechanism for evanescent-mode cavity resonators has been developed and demonstrated. This structure improves upon the design [8] by simplifying the fabrication procedure and reducing parasitics, which allows it to operate up to higher frequencies.

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A 3 to 6 GHz tunable bandstop filter with a 3-dB passband extending to 28.5 GHz is demonstrated. Though the ratio of its maximum upper passband frequency to notch center frequency is less than that in [8], the new coupling method proposed in this work is able to operate at higher frequencies, enabling a wider absolute upper passband. The 28.5 GHz upper passband demonstrated in this work represents a 157% improvement over the filter in [8], which had an 11.1 GHz upper passband.

ACKNOWLEDGEMENT

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