L-Band High-Q Tunable Quasi-Absorptive Bandstop-to-All-Pass Filter

Wei Yang[1], Mark D Hickle[1], Dimitra Psychogiou[2], and Dimitrois Peroulis[1]

[1] School of Electrical and Computer Engineering, Birck Nanotechnology Center,
Purdue University, West Lafayette, IN 47907, USA.

[2] Department of Electrical, Computer and Energy Engineering, University of Colorado Boulder,
Boulder, CO 80309, USA

Email: yang208@purdue.edu, mhickle@purdue.edu, dimitra.psychogiou@colorado.edu, dperouli@purdue.edu

***Abstract*— This paper presents a high-Q tunable quasi-absorptive bandstop-to-all-pass filter in the 1.1 to 2 GHz frequency range. The filter can continuously tune from an all-pass response to an absorptive bandstop response with high isolation (70 dB) across its entire frequency range. The insertion loss in its all-pass state varies from 2.27 to 3.14 dB. The filter topology requires only one tuning element per resonator. The filter topology is implemented with evanescent-mode cavity resonators and tuned with low-power piezoelectric actuators. The extracted unloaded resonator Q-factor is 400.**

***Index Terms*— Tunable filter, absorptive bandstop filter, evanescent-mode cavity filter, bandstop-to-all-pass filter.**

I. Introduction

Tunable microwave bandstop filters are critical components in protecting receivers from strong interferers. Conventional filter performance is typically limited by its resonators Q-factors. On the other hand, in absorptive bandstop filter topologies [1,2] it is theoretically possible to achieve infinite attenuation with finite resonator Q-factor. Absorptive bandstop filters have been demonstrated in various frequency bands and with various topologies [2-8]. Most presented topologies require 90-degree transmission line coupling between source and load that limit the tuning range of the filter. The topology employed in this paper does not require this 90 degree transmission line and therefore achieves deep attenuation over a wide frequency range. Furthermore, only two tuning elements are required to obtain the bandstop-to-all-pass response. Variable attenuation is achieved by adjusting either resonator.

II. Bandstop-to-All-Pass Filter Topology and Design

A general bandstop-to-all-pass filter coupling diagram is shown in Fig. 1(a) [2]. This topology consists of two parallel branches. The upper one is a bandstop configuration with external coupling of J_1, and transmission line of electrical length θ_T. The lower one is a bandpass configuration with external couplings of J_2 and $-J_2$. Using Y-parameter analysis, the S-parameters are derived in (1) and (2), where Y_1 and Y_1 correspond the admittance of resonator 1 and 2 in Fig. 1(a), which can be represented as

$$Y = \frac{i}{Z_R}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right) + \frac{i}{Z_R}B + \frac{1}{Z_R Q_u} \quad (3)$$

where Z_R is the impedance of a resonator and B is the susceptance, or detuning of the resonator. The following subsections demonstrate how resonator detuning is employed to satisfy bandstop and all-pass conditions.

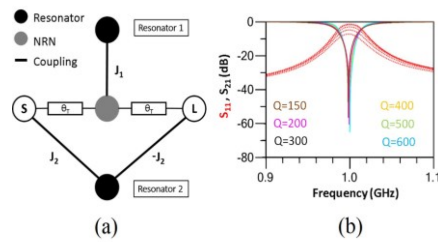

Fig. 1. (a) Topology of a quasi-absorptive bandstop-to-all-pass filter, and (b) the effects of resonator Q-factor on quasi-absorptive response.

A. All-pass condition

The all-pass condition is satisfied when S_{11} is set to 0 across the whole frequency band. Ignoring the effect of a finite resonator quality factor, two relations are obtained:

$$k_2 = \frac{\pm k_1}{2\sin\theta_T} \quad (4)$$

$$B_1 - B_2 = \frac{k_1^2}{2}\cot(\theta_T) \quad (5)$$

where k_n is the normalized coupling coefficient.

B. Bandstop condition

The quasi-absorptive bandstop condition is satisfied when S_{21} is set to 0 at the center frequency. Considering also (4), we get equations (6) and (7):

$$B_1 = \pm\sqrt{\frac{k_1^4}{4} - \frac{1}{Q^2}} \quad (6)$$

$$S_{21} = \frac{2(i\cos(\theta_T)+\sin(\theta_T))(Z_0^2 J_1^2 J_2^2 \sin^2(\theta_T) - Y_1 Y_2 - i J_2^2 Y_1 Z_0 \sin(2\theta_T))}{(2J_2^2 Y_1 + J_1^2 J_2^2 Z_0)(-iY_2 J_1^2\cos(\theta_T) + (2J_1^2 J_2^2 Z_0 + Y_2 J_1^2)\sin(\theta_T))} \quad (1)$$

$$S_{11} = \frac{iZ_0 J_1^2 J_2^2 (i\cos(\theta_T)+\sin(\theta_T))(-2J_2^2 Y_1 + Y_2 J_1^2 + 2J_2^2 Y_1\cos(2\theta_T) + iZ_0 J_1^2 J_2^2 \sin(2\theta_T))}{(2J_2^2 Y_1 + J_1^2 J_2^2 Z_0)(-iY_2 J_1^2\cos(\theta_T) + (2J_1^2 J_2^2 Z_0 + Y_2 J_1^2)\sin(\theta_T))} \quad (2)$$

978-1-5090-6360-4/17/$31.00 ©2017 IEEE

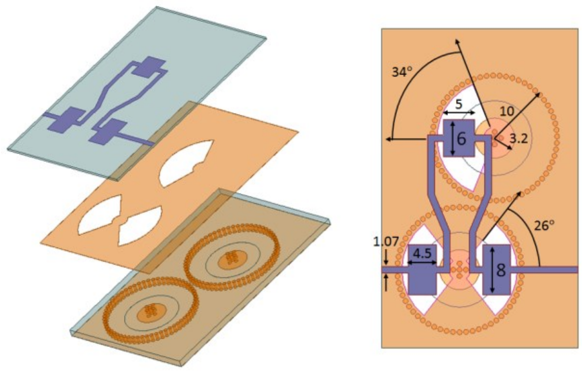

Fig. 2. Simulation model and dimensions in mm of the evanescent-mode cavity filter in HFSS.

$$B_2 = -\frac{1}{2}k_1^2 \cos\left(\theta_T\right) \mp \sqrt{\frac{k_1^4}{4} - \frac{1}{Q^2}} \tag{7}$$

To compensate the transmission line electrical length variation, a correction factor can be added in B_2 in (7). The simulated absorptive bandstop responses with various Q-factors are shown in Fig. 1(b). Considering all these relations, the quasi-absorptive bandstop response is simplified to a 2nd-order Butterworth bandstop response:

$$|S_{21}|^2 = \frac{4p^4}{4p^4 + (k_1^2)^4} \tag{8}$$

with 3-dB bandwidth of $\sqrt{2}k_1^2$. Fully-absorptive bandstop response can be obtained by setting both S_{21} and S_{11} to 0 (this is not discussed further in this paper).

III. Filter design and Implementation

An evanescent-mode cavity resonator technology is employed to implement this topology due to its high Q factor [9]. Cavity resonators are loaded with a post forming a small gap with the ceiling of the cavity. This gap can be tuned with piezoelectric actuators to tune the capacitance and cavity resonance. Figure 2 shows the layer-by-layer HFSS simulation model for the filter and dimensions of the cavities and coupling apertures. The filer is designed to tune from 1 to 2 GHz with a gap tuned from 10 to 40 μm. The simulated loaded resonator Q-factor is approximately 440. The top layer with the 50-Ω microstrip line source-to-load coupling is fabricated on a 0.508-mm thick Rogers 4003 substrate ($\varepsilon_r = 3.38,\ \tan(\delta) = 0.0027$) with a PCB milling machine. The resonators are fabricated on a 1.524-mm thick Rogers 4003 substrate (Fig. 3).

IV. Measurement Results

The fabricated filter was measured with an Agilent N5230C network analyzer and a Keithley 2410 source providing ± 200 V DC bias to piezoelectric actuators.

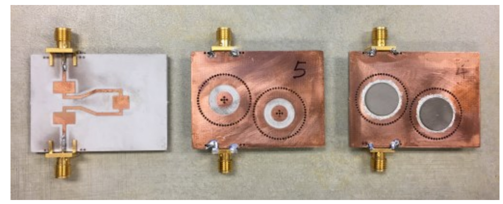

Fig. 3. Fabricated bandstop-to-all-pass cavity filters without and with piezoelectric actuators.

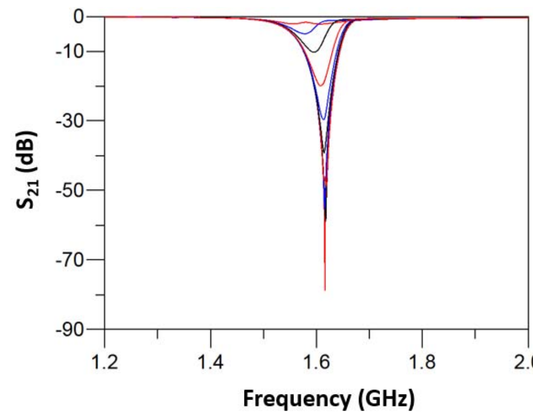

Fig. 4. Measured bandstop response with tunable attenuation levels from 80 dB to 2.16 dB.

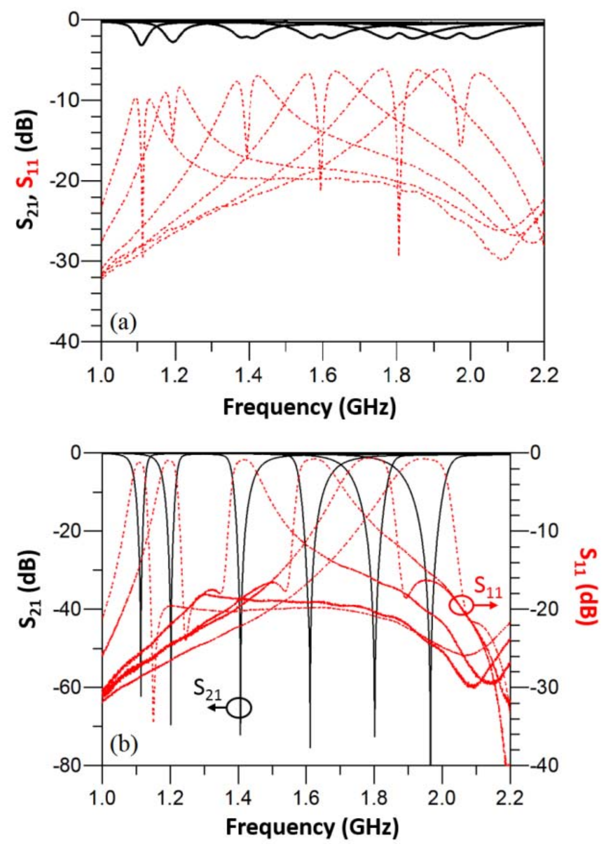

Fig. 5. Measured frequency response of (a) all-pass state across its entire tuning range and (b) absorptive bandstop state.

978-1-5090-6360-4/17/$31.00 ©2017 IEEE

The filter can continuously tune from an all-pass to an absorptive bandstop response with high isolation (70 dB) across its entire frequency range from 1.1 to 2 GHz. It is also possible to obtain over 80 dB isolation but this requires fine tuning of the resonator bias voltages. Figure 4 shows the measurement results for various attenuation levels. This filter demonstrates a higher than 70-dB deep attenuation across its entire tuning range (Fig. 5). The measured 3-dB bandwidth is 4.3% at 1.1 GHz, and monotonically increases to 9% at 2 GHz. The measured 10-dB bandwidth is 2.3% at 1.1 GHz and increases to 4.9% at 2 GHz. The filter tuning range can be further improved by reducing the initial gap (10 μm) of the cavity.

The measured all-pass state insertion loss is decreasing from 3.14 dB at 1.1 GHz to 2.27 dB at 2 GHz as the resonator Q-factor increases along frequency. Figure 5(a) shows the frequency response of the all-pass states across its tuning range. The extracted unloaded resonator Q-factor is approximately 400. Figure 6 shows the obtained good agreement between measurement and simulation results in HFSS for both the all-pass and the absorptive bandstop states.

V. Conclusion

A high-Q tunable quasi-absorptive bandstop-to-all-pass filter is presented with evanescent-mode cavity resonators in the 1.1 to 2 GHz frequency range. With only two tuning elements (one per resonator), the filter can tune continuously from an all-pass response to an absorptive bandstop response with high isolation (70-dB) across its entire frequency range. The all-pass state insertion loss is measured from 3.14-dB at 1.1 GHz to 2.27-dB at 2 GHz. The bandstop response is a 2nd-order Butterworth response.

VI. Acknowledgment

This research was developed with funding from the Office of Naval Research Contract N00014-16-C2001. The views, opinions, and/or findings contained in this article are those of the authors and should not be interpreted as representing the official views or policies of the Department of Defense or the U.S. Government.

References

[1] D. R. Jachowski, “Compact, frequency-agile, absorptive bandstop filters,” *IEEE MTT-S International Microwave Symposium Digest*, pp. Long Beach, CA, pp. 1-4, 2005.

[2] A. C. Guyette, I. C. Hunter and R. D. Pollard, "Design of absorptive microwave filters using allpass networks in a parallel-cascade configuration," 2009 *IEEE MTT-S International Microwave Symposium Digest*, Boston, MA, pp. 733-736, 2009.

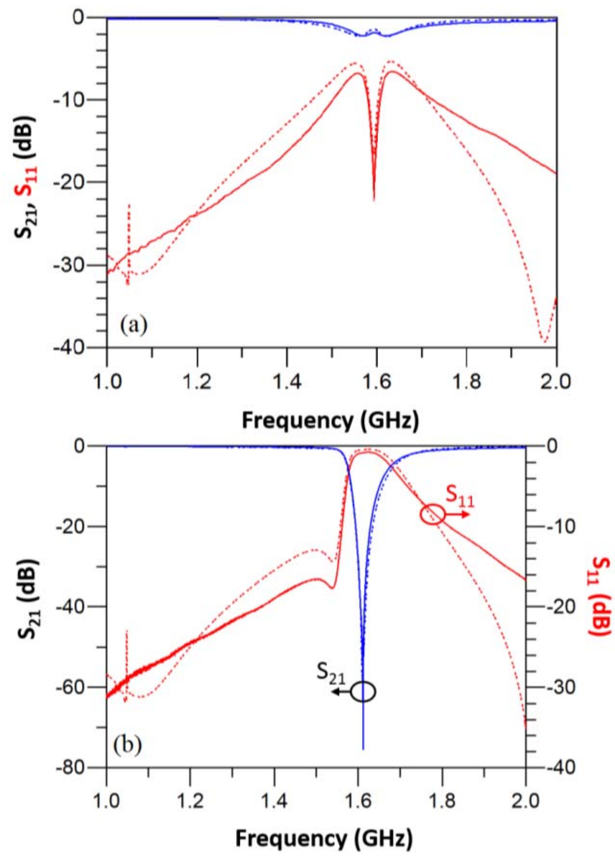

Fig. 6. Measured versus HFSS simulated frequency response of (a) all-pass state and (b) absorptive bandstop state.

[3] E. J. Naglich, J. Lee, D. Peroulis and W. J. Chappell, “Switchless Tunable Bandstop-to-All-Pass Reconfigurable Filter,” in *IEEE Transactions on Microwave Theory and Techniques*, vol.60, pp. 1258-1265, May 2012.

[4] T. C. Lee, J. Lee, E. J. Naglich and D. Peroulis, “Octave tunable lumped-element notch filter with resonator-Q-independent zero reflection coefficient,” *2014 IEEE MTT-S International Microwave Symposium*, Tampa, FL, pp. 1-4, 2014.

[5] D. Psychogiou, R. Gmez-Garca and D. Peroulis, “RF-design of narrow-band absorptive bandstop filters for UHF applications,” *Wireless and Microwave Technology Conference (WAMICON)*, 2015 IEEE 16th Annual, Cocoa Beach, FL, pp. 1-4, 2015.

[6] M. D. Hickle, M. D. Sinanis and D. Peroulis, “Tunable high-isolation W-band bandstop filters,” *2015 IEEE MTT-S International Microwave Symposium*, Phoenix, AZ, pp. 1-4, 2015.

[7] M. D. Hickle, M. D. Sinanis and D. Peroulis, “Design and implementation of an intrinsically-switched 22-43 GHz tunable bandstop filter,” *2016 IEEE 17th Annual Wireless and Microwave Technology Conference (WAMICON)*, Clearwater, FL, pp. 1-3, 2016.

[8] E. J. Naglich and A. C. Guyette, "Reflection-Mode Bandstop Filters With Minimum Through-Line Length," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 63, no. 10, pp. 3479-3486, Oct. 2015

[9] X. Liu, L. P. B. Katehi, W. J. Chappell and D. Peroulis, “High- Q Tunable Microwave Cavity Resonators and Filters Using SOI-Based RF MEMS Tuners,” in *Journal of Microelectromechanical Systems*, vol. 19, no. 4, pp. 774-784, Aug. 2010.

 978-1-5090-6360-4/17/$31.00 ©2017 IEEE