Magnetically Tunable Substrate Integrated Waveguide Bandpass Filters Employing Ferrites

M. Almalkawi[1], L. Zhu[2], and V. Devabhaktuni[1]

[1] EECS Department, The University of Toledo, 2801 W. Bancroft St., Toledo, OH 43606, USA

[2] COM DEV Int. Ltd., 155 Sheldon Drive, Cambridge, Ontario, N1R 7H6, Canada

***Abstract*—A novel tuning solution for planar reconfigurable microwave filters is presented. The proposed filters are implemented using substrate integrated waveguide (SIW) technology featuring compact size, low cost, high Q, and high power-capacity. Tunablity of the proposed reconfigurable filters is achieved by adjusting dc-magnetic bias applied to the ferrite material. Compared to the previously reported reconfigurable filters based on electrical adjustment enabled by mechanical modifications, the proposed filters offer a relatively wide tuning range and stable tenability, while dramatically reducing the complexity of external control system. Effects of filters parameters' including the ferrite material, magnetic DC bias, and SIW configuration, on reconfigurable performance are discussed. Simulation examples of single-circulator and double-circulators tunable bandpass filters are realized using EM simulations for demonstrating the underlying principle.**

I. Introduction

Bandpass filters implemented using substrate integrated waveguide (SIW) technology [1] are essential component in various microwave and millimeter-wave communication systems. Recently, to meet the stringent requirement of modern multi-band systems, reconfigurable filters with low insertion loss and compact size are desirable. This has led to the development of sophisticated implementations of tunable cavity resonator based filter [2, 3]. Therefore, tunable SIW filters using simple tuning techniques are highly required. In this paper, ferrite material is employed in SIW filters, which provides a possibility of new and simple tuning methods. Design principle of the ferrite SIW filter is based upon the synthesis approach of microwave circulators/isolators. First publication about microwave ferrite devices using SIW technology such as circulators and isolators have been presented in 2004 by D'Orazio et al [4]. For emerging high volume applications, related efforts focused on the integration of SIW circulators [5], advance frequency characteristics [6], and notch filter incorporating junction circulators [7]. However, none has reported the use of circulators as tunable bandpass filters. Therefore, the objective of this communication is to demonstrate that the design principle of waveguide ferrite circulators and isolators can be utilized for realizing a tunable filter response in a planar form.

II. Filter Implementation

The configuration of circulators and isolators are essentially multi-port network. By utilizing the simple structure of a three-port symmetric (*i.e.* all the port separation angles are equal to 120^{o}) waveguide circulator with one port

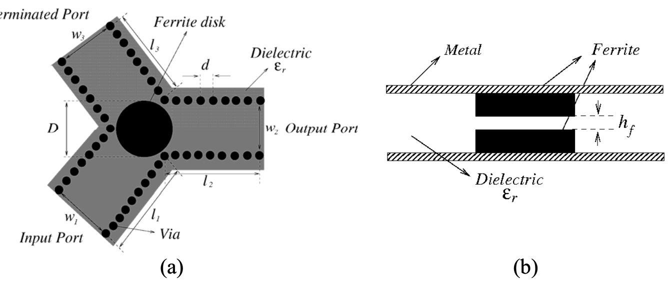


Fig.1. The physical structure of a single-circulator tunable bandpass filter: (a) top view; and (b) side view.

terminated by its matched load (*i.e.* 50 Ω load) leads to the realization of an isolator or a two-port circulator which perform the same function as a section of transmission line. Ferrite resonators could have any threefold symmetry shapes (*i.e.* disk or triangle). However, in our design, we have selected TT2-125 ferrite disk which has better parameter flexibility. Here, the ferrite magnet operates above-resonance in the saturation mode, since much higher magnetic field and low field loss is not a concern as that for resonance and below resonance [8]. To meet this condition, we need

$$4\pi M_S < \frac{\omega}{\gamma} - H_a \tag{1}$$

where $4\pi M_S$ is the ferrite saturation magnetization, ω is the radian frequency of the ferromagnetic resonance, γ is the gyromagnetic ratio, and H_a is the anisotropy field associated with particular material selected. Two examples will now be illustrated.

A. Single-circulator tunable bandpass filter

Fig. 1 illustrates the physical structure of a single-circulator tunable bandpass filter. The structure is supported by a 1.575 mm thick FR4 substrate with a dielectric constant of 4.4 and a loss tangent of 0.02. Full-wave EM simulations were performed with the aid of *ANSYS* HFSS leading to the following optimal dimensions of the proposed filter: $w_1 = w_2 = w_3 = 11.68$mm, $l_1 = l_2 = 6.98$mm, $l_3 = 8.51$mm, $d = 1$mm, $D = 13.1$mm, $h_f = 0.3$mm, via diameter = 0.5mm. As depicted in Fig. 1, two ferrite disks coupled in the middle of the waveguide junction. Fig. 2 shows the frequency performance of the configuration in Fig. 1 with the minimum internal bias (*i.e.* 2100 Gauss) required for saturating the ferrite magnet. The plot has a passband center frequency at 10.45 GHz with an insertion loss of 1 dB. Fig. 3 shows that for a given passband center frequency, increasing the diameter of the ferrite disk leads to a decrease in the bandwidth.

978-1-4577-0509-0/11/$26.00 ©2011 IEEE

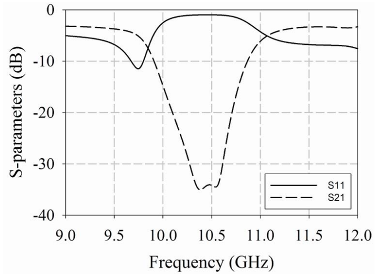


Fig.2. Simulated frequency response of a single-circulator bandpass filter.

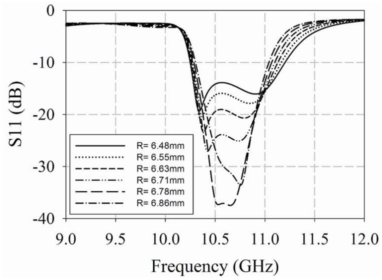
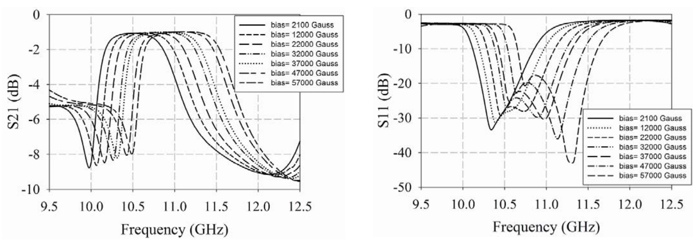


Fig.3. Simulated frequency characteristics of a single-circulator filter with bandwidth control.



(a) (b)

Fig.4. Variation of the passband center frequency with the applied magnetization field of the single–circulator tunable filter: (a) S_{21} response; and (b) S_{11} response.

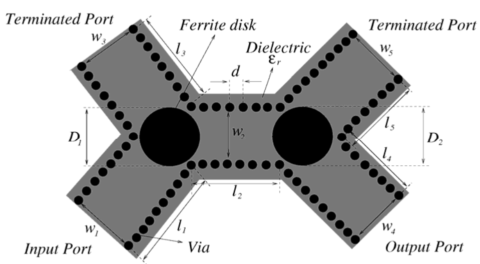
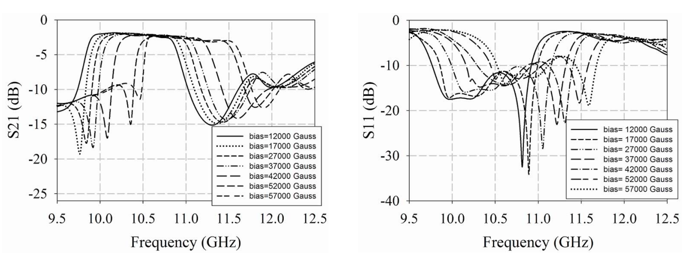


Fig.5. Structure of a double-circulator tunable filter (top view).



(a) (b)

Fig.6. Variation of the passband center frequency with the applied magnetization field of the double–circulator filter: (a) S_{21} response; and (b) S_{11} response.

Fig. 4 illustrates the simulated S-parameter results when tuned from 10.45 to 11.3 GHz by vertically applying different internal dc-magnetic bias intensities.

B. Double-circulator tunable bandpass filter

After the successful implementation of the single-circulator filter, double-circulator filter was implemented. The structure of the double-circulator bandpass filter (Fig. 5) was simulated using HFSS following the same guidelines presented in the single-circulator filter leading to the following optimized dimensions: $w_1 = w_3 = w_4 = w_5 = 11.68$mm, $w_2 = 10.9$mm, $l_1 = l_4 = 5.1$mm, $l_3 = l_5 = 5.8$mm, $l_2 = 12.45$mm, $d = 1$mm, $D_1 = D_2 = 13.36$mm, *ferrite-gap* = 0.1mm, via diameter = 0.5mm.

This was mainly to prove the validity of the underlying design principle and to improve the selectivity of the proposed filter. Fig. 6 shows the simulated S-parameter frequency performance that is tuned from 10.45 to 11.3 GHz. As depicted, Fig. 6(a) clearly exhibits an improved stopband attenuation compared to the results in Fig 4(a).

III. CONCLUSION

A new class of SIW bandpass filter, with robust tuning ability is presented. The passband of the proposed filters can be reconfigured by adjusting the dc-magnetic bias applied to a pair of ferrite disk located at the edge of an SIW cavity. With the employment of the gyromagnetic material, the proposed filters are essentially directional and switchable directional filters can thus be realized. The applied magnetic field controls the passband center frequency of the SIW filter, while dramatically reduces the complexity compared to traditional electronic control methodologies. It is foreseen that this type of filters will find numerous applications in advanced RF front-ends where simple and stable tunability are of the essence.

REFERENCES

[1] D. Deslandes and K. Wu, "Integrated microstrip and rectangular waveguide in planar form", *IEEE Microwave Wireless Compon. Lett.*, Vol. 11, pp. 68-70, Feb. 2001.

[2] H. Joshi, H.H. Sigmarsson, S. Moon, D. Peroulis, and W. Chappell, "High-Q fully reconfigurable tunable bandpass filters", *IEEE Trans. Microwave Theory Tech.*, Vol. 57, pp. 3525-3533, Dec. 2009.

[3] J. Krupka, A. Abramowicz, and K. Derzakowski, "Magnetically tunable filters for cellular communication terminals", *IEEE Trans. Microwave Theory Tech.*, Vol. 54, pp. 2329-2335, June 2006.

[4] W. D'Orazio, K. Wu, and J. Helszajn, "A substrate integrated waveguide degree-2 circulator", *IEEE Microwave Wireless Compon. Lett.*, Vol. 14, pp. 207-209, May 2004.

[5] W. D'Orazio and K. Wu, "Substrate-integrated-waveguide circulators suitable for millimeter-wave integration", *IEEE Trans. Microwave Theory Tech.*, Vol. 54, pp. 3675-3680, Oct. 2006.

[6] H. Razavipour, R. Safian, G. Askari, F. Fesharaki, and H.M. Sadeghi, "A new dual-band high power ferrite circulator", *Progress in Electromagnetics Research C*, Vol. 10, pp. 15-24, 2009.

[7] H. How, C. Vittoria, and C. Carosella, "Novel filter design incorporating asymmetrical stripline Y-junction circulators", *IEEE Trans. Microwave Theory Tech.*, Vol. 39, pp. 40-46, Jan. 1991.

[8] D.K. Linkhart, *Microwave Circulator Design*, Artech House, Massachusetts, 1989.