SUBSTRATE INTEGRATED WAVEGUIDE BANDSTOP FILTER

Badrul Hisham Ahmad[1], Member, IEEE, Ian C. Hunter[2], Fellow, IEEE

[1]Faculty of Electronic and Computer Engineering,
Universiti Teknikal Malaysia Melaka

[2]Institute of Microwave and Photonics University of Leeds,
United Kingdom

badrulhisham@utem.edu.my, i.c.hunter@leeds.ac.uk

Abstract

One new type of filter is presented in this paper. The propose filter is a transmission mode bandstop filter utilizing substrate-integrated-waveguide cavity resonators to provide the required resonance. The bandstop operated at X band frequencies with 450 MHz bandwidth. Stop band is from 8.7 GHz to 9.2 GHz. Insertion loss achieved is less than 0.5 dB and return loss of more than 15 dB. 3D simulator was used to model the structure and simulation results showed very good response. To date, this is the first time such bandstop substrate-integrated-waveguide filter has been reported

Keywords: *Component, Substrate Integrated Waveguide, Bandstop Filter, Inverse Chebychev and Lumped Element*

I. INTRODUCTION

In 2001, Wu [1] proposed a new technique for high density integration microwave and millimeter wave systems. Using this technique, image guides, non-radiative dielectric waveguides were synthesized inside a dielectric substrate, using rows of dielectric or metal holes. The idea to integrate waveguide inside a dielectric substrate was first proposed in [2]. This was a very useful platform to design high performance microwave circuits such as filters, resonators and antennas. One of the advantages of this type of integration was that it could lead to other planar microwave transmission lines by simple transitions and it preserved the advantages of a waveguide. This paper has introduced new methods to produce a bandstop filter characteristic.

This idea of coupling a line with SIW rectangular cavities originates from classical bandstop designs (see [3] and [4]). The approach that needs to be taken when designing a bandstop filter differs from that used for bandpass filters. In the bandpass case we retain realizable element values by scaling the network so that the couplings become relatively weak. However, in the bandstop case the impedance inverters must remain at unity impedance so that the filter has a broad passband.

Here, a new SIW cavity resonators separated by unity impedance inverters are proposed. Theoretically, they will give a bandstop response with a broad pass band. The size of the resonator can be determined from a set of equation. The length of the SIW resonator is about a quarter guide wavelength long at the center frequency.

II. DESIGN OF TRANSMISSION MODE SUBSTRATE INTEGRATED WAVEGUIDE BANDSTOP FILTER

Idea of producing a transmission mode substrate-integrated-waveguide bandstop filter originated from [3] and [4]. This paper describes how a series of stub stripline resonators are directly coupled to the main stripline to give a bandstop response. The resonator is separated by a quarter wavelength to avoid inter resonance coupling. The design method adopted for this work is based on the inverse Chebychev bandstop characteristics. The principles behind the theory are explained in detail in [3]. The element values for this filter have been obtained from the method by Rhodes, [5].

A three-stage lumped element inverse Chebychev bandstop filter has been designed and the values calculated as shown in Figure 1. Using the reactance slope method, the reactance for each lumped and distributed resonator is equated to give an equivalent length of the resonators. The distance separating the resonators is a quarter of a wavelength long. The resonator length is about half a wavelength. The transmissions zeros that occur at infinity in the original prototype are mapped to odd multiples of the quarter wave frequencies. This explains why there is one transmission zero at the lower side, and one at the higher side of the frequency band. The resonators have been designed using the empirical equations of [6].

A three-stage lumped element inverse Chebychev bandstop filter has been designed and the values calculated as shown in Figure 1. Using reactance slope method, the reactances for each lumped and distributed resonator are equated to give an equivalent length of the resonators.

For a lumped resonator

$$Z(j\omega)=\frac{1}{j\omega_r C_r}+j\omega_r L_r \qquad (1)$$

$$\frac{dZ(j\omega)}{d\omega}=\frac{1}{\omega_r^{2} C_r}-L_r \qquad (2)$$

For a distributed resonator

$$Z(j\omega)=jZ_o \tan\left(\frac{\omega_r l_r}{v_r}\right) \qquad (3)$$

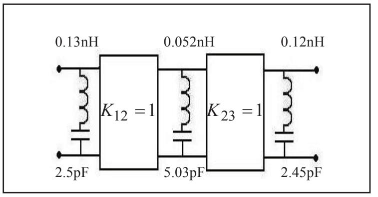

Figure 1: Inverse Chebychev three stage lumped element bandstop filter.

$$\frac{dZ(j\omega)}{d\omega}=\frac{Z_o l_r}{v_r}\sec^2\frac{\omega_r l_r}{v_r} \qquad (4)$$

By equating lumped and distributed

$$\frac{dZ(j\omega)}{d\omega}=\frac{1}{\omega_r^{2} C_r}-L_r=\frac{Z_o l_r}{v_r}\sec^2\frac{\omega_r l_r}{v_r} \qquad (5)$$

The solution of these equations will give the length of the resonator

$l_1=174.4^0$, $l_2=179^0$ and $l_3=181^0$

The equivalent distributed circuit directly coupled with a uniform quarter wavelength main line is shown in Figure 2.

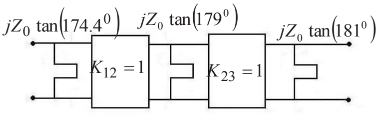

Figure 2 Equivalent circuit for inverse Chebychev three-stage substrate-integrated-waveguide bandstop filter.

The frequency response for the distributed element inverse Chebychev filter is shown in Figure 3, centered at 9 GHz, with 8.7 GHz, lower cut-off frequency, 9.2 GHz upper cut-off frequency, and a bandwidth of 450 MHz. The distance separating the resonators is a quarter of a wavelength long. The resonator length is about half a wavelength. The transmission zeros that occur at infinity in the original prototype are mapped to odd multiples of the quarter wave frequencies. This explains why there is one transmission zero at the lower side, and one at the higher side of the frequency band. Then, each substrate-integrated-waveguide resonator is realized to directly couple with the substrate-integrated-waveguide main line.

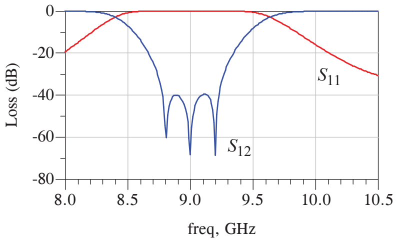

Figure 3 Resonance for a three-stage lumped resonator bandstop filter.

The length of the substrate-integrated-waveguide resonator is varied to give the same response as that of the distributed and lumped resonators, and the separation between the first and the second, and the second and third resonators are optimized to give correct couplings between adjacent resonators. Size and distance between via holes have been calculated by following the simple design rule in [7], and the transition between the substrate-integrated-waveguide and the microstrip line is realized by simple step impedance. Fig. 2 shows the dimension of the filter.

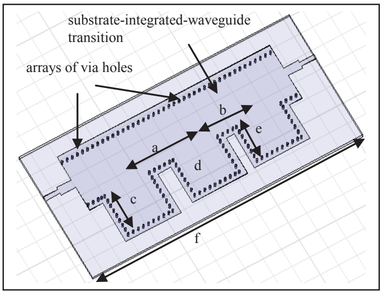

Figure 4 Three-stage transmission substrate-integrated-waveguide bandstop filter (a=18.8 mm, b=17.4 mm, c=10.5 mm, d=9.7 mm, e=9.2 mm, f=58.5 mm, diameter of via hole=0.5mm, distance between adjacent via holes=1.0 mm).

Fig. 3 shows the simulated and measured frequency responses for the three stages of the substrate-integrated-waveguide resonator. There is a slight shift in the frequency and this is caused by the variation in the dielectric permittivity of the substrate. However laser trimming would be needed to achieve optimum results.

The separation between each resonator is 3 quarters of a guide wavelength in order to avoid inter resonator coupling. The two transmission zeros that have occurred are the result of the mappings of the odd multiples of the quarter wave frequency from the original prototypes. This filter has been realized by using a standard PCB process. It uses a substrate with 0.5 mm thickness; and the thickness of the metal is 35 um.

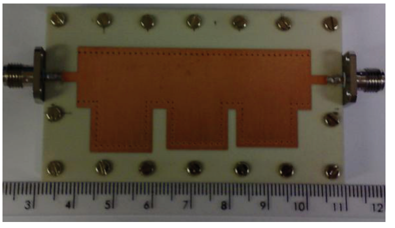

Figure 5 Manufactured transmission mode substrate-integrated-waveguide bandstop filter.

Size and distance between via holes have been calculated by following the simple design rule in [7], and the transition between the substrate-integrated-waveguide and the microstrip line is realized by simple step impedance. The manufactured three-stage substrate-integrated-waveguide bandstop filter is shown in Figure 5. Figure 6 shows the simulated and measured frequency responses for the three stages of the substrate-integrated-waveguide resonator. There is a slight shift in the frequency and this is caused by the variation in the dielectric permittivity of the substrate.

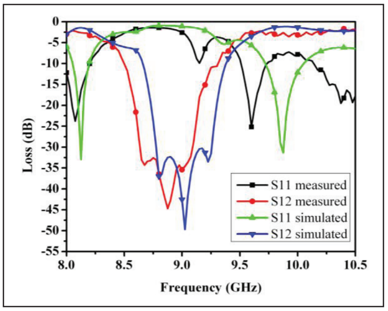

Figure 6 Simulated and measured responses of the transmission mode substrate-integrated-waveguide bandstop filter.

III. LOSSES OF BANDSTOP FILTER

The transition loss by the SIW main line is 1.5 dB.

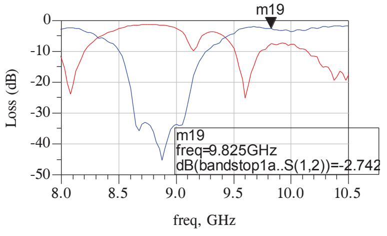

Figure 7 Measured insertion loss at the pass band of the bandstop filter.

From Figure 7, the average loses = 2.7 dB

SIW Bandstop losses
= Average Loss – Transition Loss
= 2.75 – 1.5 = 1.25 dB

The SIW bandstop losses may come from a few factors:

a) dielectric losses;
b) losses through via holes;
c) copper losses.

But these losses are still small compared with the transition loss.

IV. CONCLUSION

This paper has presented a new structure to the design of substrate-integrated-waveguide bandstop filter. The design is a transmission mode substrate-integrated-waveguide bandstop filter. This filter has been manufactured and the measured results are in line with the simulated results.

ACKNOWLEDGMENT

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REFERENCE

[1] Ke Wu, "Integration and Interconnect Techniques of Planar and Non-planar Structures for Microwave and Millimeter-wave Circuits – Current status and Future Trend," Proceedings of APMC2001, Taipei, Taiwan, ROC.

[2] J. Hirokawa and M. Ando, "Single-layer feed waveguide consisting of posts for plane TEM wave excitation in parallel plates," IEEE Trans. Antennas Propag., vol. 46, no. 5, pp. 625-630, May 1998.

[3] I.C. Hunter and J. David Rhodes, "Electronically tunable Microwave Bandstop Filters", IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-30, No. 9, Sept 1982.

[4] Ian C. Hunter, "Theory and Design of Microwave Filter", The Institution of Electrical Engineers, 2001..

[5] J.D. Rhodes, "Theory of electrical filters", John Wiley and Sons Ltd, February 2002.

[6] Dominic Deslandes and Ke Wu, "Single-Substrate Integration Techniques of Planar Circuits and Waveguide Filters," IEEE Transactions on Microwave Theory and Techniques, Vol.51, No. 2, February 2003.

[7] Y. Cassivi, L. Perregrini, P. Arcioni, M. Bressan, K. Wu and G. Conciauro, "Dispersion Characteristics of Substrate Integrated Rectangular Waveguide ," IEEE Microwave and Wireless Components Letters, vol.12, No.9, 2002.