FACTA UNIVERSITATIS (NIŠ)
Series: Electronics and Energetics vol. 11, No.2 (1998), 249-254

E–PLANE FILTERS WITH RESONATORS OF DIFFERENT CUTOFF FREQUENCY

Djuradj Budimir

Abstract. An E–plane bandpass filter with metal insert when mounted introduces ridges in the resonators which achieves improved stop band performance is considered. Higher order mode interaction between E–plane discontinuities is included in the design. The predicted filter performance shows improved stop band performance and reduced filter dimensions compared with conventional E–plane bandpass filters.

1. Introduction

All–metal insert placed in the E–plane of a rectangular waveguide along the waveguide axis offer the potential of realising low cost, mass producible, and low dissipation loss millimetre wave filters [1]. However, despite their favourable characteristics, the attenuation in the second stop band (i.e. where the resonators are about one wavelength long) may often be too low and too narrow for many applications, such as for diplexers, when frequency selectivity and high stop band attenuation are considered to be important filtering properties. In recent years, much effort has been devoted to the study of E–plane bandpass filters with improved stop band performance. Several different solutions have been proposed so far to improve stop band performance [2]–[8]. Although most of these solutions lead to a higher passband insertion loss, this is at the expense of increased manufacturing complexity. In this paper, therefore, an E–plane filter with resonators of different cutoff frequencies and characteristic impedances is investigated.

Manuscript received July 7, 1998.

Djuradj Budimir is with the Department of Electronic Systems, University of Westminster, London W1M 8JS, United Kingdom. E-mail: budimid@westminster.ac.uk.

2. Proposed configuration

Based on the existing idea to use different waveguide resonators with different characteristic impedances and different cutoff frequencies [7], improved stop band performance may be met by the E–plane filter configurations shown in Figure 1.

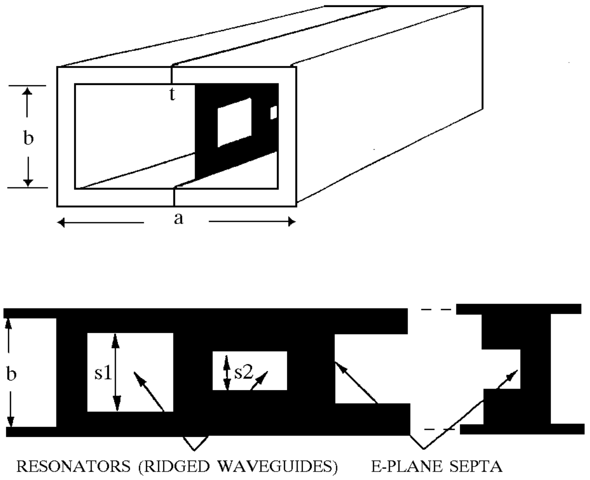

Figure 1. Configuration of the proposed E-plane filter structures.

This is mainly due to suitably altered fundamental mode cutoff frequencies in the resonator sections. The proposed filter configurations are constructed of direct coupled ridged waveguide sections which in general have different cut–off frequencies and characteristic impedances (viz., a non–uniform ridged waveguide), and reactive elements (metal septa) arranged in the sections in a manner such that each section is resonant at the same fundamental frequency. As the guide wavelengths differ in the different sections, the sections are not all simultaneously resonant at any higher frequency. The main features of the new structures are the use of conventional rectangular waveguide housing and the use of a metal insert which when mounted introduces ridges in the resonators. This improvement in the upper stop band associated with the superior electrical performance of ridged waveguide, such as cutoff frequency reduction, provides a convenient way to realize E–plane bandpass filters with improved stop band performance. The structure is simple and compatible with the E–plane manufacturing process.

2.1 Design procedure

A common approach to the design of the conventional E–plane bandpass filters (as described in [1], can be used with minor modifications, for filter structures with different impedances and cutoff frequencies such as E–plane bandpass filters with improved stop band performance. The most important steps in this design procedure, which should include the concept of impedance inverters and impedance scaling of the impedance levels of the prototype filter have been presented in [9]. The main limitations of this approach are the frequency dependence of the guide impedances and the frequency dependence of the impedance inverters or the inaccurate approximation of the E–plane septa made in the derivation of the design procedure. Once the dimensions of the filter have been found, the frequency response of the overall filter at each frequency can be simulated by cascading the ABCD matrices of the resonators and the septa.

3. Numerical results

In order to demonstrate the advantages of the new E–plane bandpass filter over the conventional E–plane bandpass filter, a five resonator X–band conventional E–plane bandpass filter and E–plane ridged waveguide bandpass filter (in which the widths of the ridges are arbitrarily chosen) with the following specifications

Passband: 9.25 – 9.75 GHz
Bandwidth: 0.5 GHz
Number of resonators: 5
Passband return loss: 20 dB

have been designed. The parameters for these filters are given in Table 1.

The overall filter response (insertion loss (L_I) and return loss (L_R)) can be expressed in terms of elements of the total ABCD matrix of the filter at each frequency (by directly combining the ABCD matrices of the individual filter sections) as

$$L_I = 20 \log_1 0 \left(\frac{A + B + C + D}{2} \right). \tag{1}$$

$$L_R = 20 \log_1 0 \left(\frac{A + B + C + D}{A + B - C - D} \right). \tag{2}$$

The elements of the ABCD matrices of the individual filter sections are calculated using the mode–matching method. Figure 2 shows the calculated insertion loss as a function of frequency of the conventional E–plane filter with ideal impedance inverters designed to pass a band of frequencies (0.5 GHz) in the vicinity of 9.5 GHz. The dotted line (3) shows a minimum stop band attenuation of 50 dB between 10.27 and 14.25 GHz and the location of the second passband at 14.88 GHz.

Table 1. Parameters of X–band five resonator ridged
waveguide E–plane bandpass filters
ridged waveguide gaps = 9/1/8/2/7 *mm*
insert thickness = 0.10 *mm*

Figure	2			
	dotted line	dashed line	solid line	dash–dotted line
Normalized element value of ideal impedance inverters ($K's$) and septum lengths ($d's$ in mm)	$K_1 = 0.3964$	$d_1 = 1.3334$	$K_1 = 0.3937$	$d_1 = 1.4294$
	$K_2 = 0.1350$	$d_2 = 6.2502$	$K_2 = 0.0994$	$d_2 = 5.0914$
	$K_3 = 0.1005$	$d_3 = 7.6076$	$K_3 = 0.0734$	$d_3 = 6.4568$
	$K_4 = 0.1005$	$d_4 = 7.6076$	$K_4 = 0.0814$	$d_4 = 6.4374$
	$K_5 = 0.1350$	$d_5 = 6.2502$	$K_5 = 0.1095$	$d_5 = 4.7229$
	$K_6 = 0.3964$	$d_6 = 1.3334$	$K_6 = 0.3863$	$d_6 = 1.1115$
Resonator dimensions (mm)	$l_1 = 21.8748$	$l_1 = 15.8258$	$l_1 = 21.7926$	$l_1 = 15.813$
	$l_2 = 21.8748$	$l_2 = 16.1814$	$l_2 = 17.9614$	$l_2 = 13.8175$
	$l_3 = 21.8748$	$l_3 = 16.2054$	$l_3 = 21.5551$	$l_3 = 16.1633$
	$l_4 = 21.8748$	$l_3 = 16.1814$	$l_4 = 18.6711$	$l_4 = 14.5730$
	$l_5 = 21.8748$	$l_5 = 15.8258$	$l_5 = 21.1974$	$l_5 = 15.6943$
Ridged waveguide gap dimensions (mm)	10.16		9.00	
	10.16		1.00	
	10.16		8.00	
	10.16		2.00	
	10.16		7.00	

Figure 2 also shows the calculated insertion losses of the corresponding ridged waveguide E-plane filter with ideal impedance inverters (with rwg. gap = 9/1/8/2/7 *mm*) (solid line (4)) with a minimum stop band attenuation of 50 dB between 10.27 and 14.25 GHz and the location of the second passband at 14.88 GHz. When the frequency dependence of the septa used to realise the impedance inverters in the prototypes is included there is a deterioration in performance. The calculated insertion loss of the ridged waveguide E–plane bandpass filter when the frequency dependence of discontinuities is included in the model (Figure 2, dash-dotted line (2)) shows a minimum stop band attenuation of 50 dB between 10.80 and 12.60 GHz and the location of the second passband is at 14.80 GHz.

For comparison, Figure 2 also shows the calculated insertion losses of the corresponding conventional E-plane bandpass filter when frequency dependence of discontinuities is included in the model (dashed line (1)) with a minimum stop band attenuation of 50 dB between 10.66 and 12.13 GHz and the location of the second passband at 13.95 GHz.

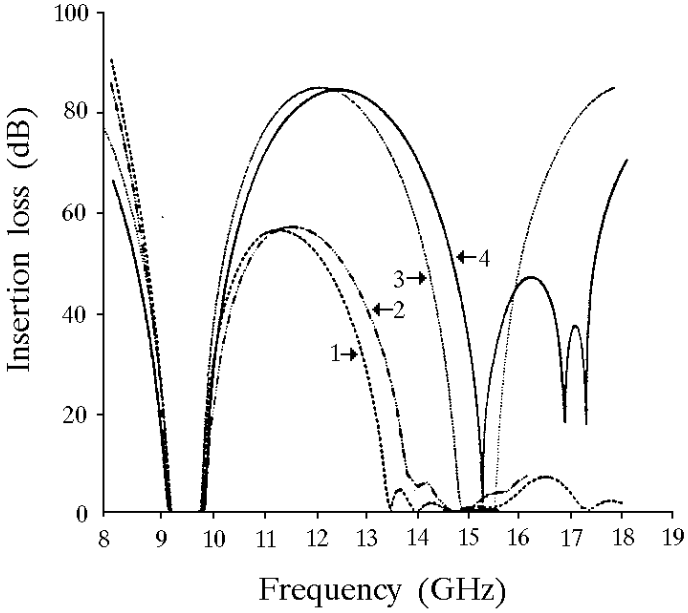

Figure 2. Comparison of calculated insertion loss of X–band five resonator E–plane bandpass filters. Dotted line (3) – conventional E–plane bandpass filter with ideal impedance inverters, dashed line (1) – conventional E–plane bandpass filter with real impedance inverters, solid line (4) – ridged waveguide filter (rwg gap=9/1/8/2/7 mm) with ideal impedance inverters, dash–dotted line (2) – ridged waveguide filter (rwg gap=9/1/8/2/7 mm) with real impedance inverters.

4. Conclusion

The design of a prototype consisting of ideal impedance inverters separated by rectangular waveguide resonators, and a prototype consisting of ideal impedance inverters separated by ridged waveguide resonators was presented. The broadband high attenuation behaviour in the second stop band was achieved by E–plane bandpass filters unequal ridges introduced in resonator sections. The predicted filter performance showed improved stop band performance and reduced filter dimensions compared with conventional E–plane bandpass filters. Also, when the frequency dependence of the septa was introduced, a deterioration in performance of the filters was observed.

REFERENCES

1. V. Postoyalko and D. Budimir: *Design of Waveguide E–plane Filters with All–Metal Inserts By Equal–Ripple Optimization.* IEEE Trans. Microwave Theory & Tech., vol.MTT–42, pp. 217–222, February 1994.
2. F. Arndt, J. Bornemann, R. Vahldieck and D. Granerholz: *E–Plane Integrated Circuit Filters with Improved Stopband Attenuation.* IEEE Trans. Microwave Theory & Tech., vol. MTT–32, pp. 1391–1394, Oct. 1984.
3. V.P. Gololobov and M.Yu. Omel'yanenko: *Filters Based on Multilayered Metallic Structures in a Waveguide.* Soviet J. Commun. Technol. Electron., vol.33, pt.8, pp. 69–74, 1988.
4. F. Arndt, D. Heckmann, H. Semmerow, J. Bornemann and R. Vahldieck: *Stopband Optimized E–Plane Filters with Multiple Metal Inserts of Variable Number per Coupling Elements.* IEE Proc., vol.133, Pt.H, pp. 169–174, June 1986.
5. R. Vahldieck and W.J.R. Hoefer: *Finline and Metal Insert Filters with Improved Passband Separation and Increased Stopband Attenuation.* IEEE Trans. Microwave Theory & Tech., vol. MTT–33, pp. 1333–1339, Dec. 1985.
6. J. Bornemann and F. Arndt: *Waveguide E–plane Triple–Insert Filter.* 15th European Microwave Conf. Dig. (Paris), pp.726–731, 1985.
7. H.J. Riblet: *Waveguide filters having nonidentical sections resonant at same fundamental frequency and different harmonic frequencies.* US Patent No 3,153,208, 1964.
8. J. Bornemann and F. Arndt: *Metallic E–plane Filter with Cavities of Different Cutoff Frequency.* Electronic Letters, vol.22, pp. 524–525, May 1986.
9. D. Budimir: *E–plane Filters with Improved Stopband Performance.* IEEE Trans. Microwave Theory & Tech., vol. MTT–45, pp.212–220, February 1997.
10. D. Budimir: *Generalized Filter Design by Computer Optimization.* Artech House, 1998.
11. D. Budimir: *DBFilter, Softver and Users Manual.* Tesla Communications, London, UK, 1997.