A Review on Design & Performance Analysis of a Multi-Band Microwave Filter

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Abstract— *Filters play important roles in many RF/microwave applications. Emerging applications such as wireless communications continue to challenge RF/microwave filters with ever more stringent requirements—higher performance, smaller size, lighter weight, and lower cost. The recent advances in novel materials and fabrication technologies, including high-temperature superconductors (HTS), low-temperature cofired ceramics (LTCC), monolithic microwave integrated circuits (MMIC), microelectromechanic system (MEMS), and micromachining technology, have stimulated the rapid development of new microstrip and other filters for RF/microwave applications. The manuscript presented here is a representative collection of the latest advances in the field of Microwave Filter design and a range of methods that are causative to its growth are presented. The dazzling features of this paper include discussion of many novel microstrip filter configurations with advanced filtering characteristics, we also presents the design of steped impedance microstrip filter and one hairpin-line filter and their results are discussed in the paper along with some new design techniques, and methods for filter miniaturization.*

Keywords— Multiband Bandpass Filters (BPFs), Stepped-impedance filters, Open-Stub Filters, Hairpin-line Filters

I. INTRODUCTION

With the development of modern wireless communication systems, the demand for dual-band microwave systems has increased rapidly and high-performance microwave dual or multiband bandpass filters (BPFs) are highly desirable [1,2] to handle different frequency bands and bandwidths (BWs). To meet these requirements, the design method for dual-band BPFs is very important for the next generation of wireless communication systems. There are various microstrip based filter which is popular in designing dual-band BPFs because they have the advantages of small size, lightweight, and easy fabrication. Moreover, design theories and methods described in this paper are not only for microstrip filters but directly applicable to other types of filters, such as waveguide filters. The contents of the paper are organized in following manner. Section 2, describe the basic concepts and design equations for microstrip lines, coupled microstrip lines, and discontinuities, as well as lumped and distributed components. Section 3 discuss different filters such as stepped-impedance filters, open-stub filters, hairpin-line filters, etc. Section 4 is devoted to the discussion of various results obtained by different filter design technique. And finally, a conclusion is reached in section 5.

II. RESONANT CHARACTERISTICS OF MICROSTRIP

In general, the design of microstrip filters involves with the selection of microstrip line and resonating structure, converting transmission line equivalent of lumped element components for a filter and its characteristics are then obtained by equating the impedances of the transmission lines to the impedances of lumped elements of microstrip line and resonating structure used in designed filter. The choice of the type of response will depend on the required specifications of filter. The different parameters which effects the design of microstrip filter is discussed in this section.

A. Effective Dielectric Constant & Characteristic Impedance

Transmission characteristics of microstrips are described by two parameters, namely, the effective dielectric constant ε_{re} and characteristic impedance Zc, which may then be obtained by quasi-static analysis [1] [2],

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{10}{u}\right)^{-ab} \tag{1}$$

where $u = W/h$, and

$$a = 1 + \frac{1}{49}\ln\left(\frac{u^4 + \left(\frac{u}{52}\right)^2}{u^4 + 0.432}\right) + \frac{1}{18.7}\ln\left[1 + \left(\frac{u}{18.1}\right)^3\right] \tag{2}$$

$$b = 0.564\left(\frac{\varepsilon_r - 0.9}{\varepsilon_r + 3}\right)^{0.053} \tag{3}$$

The accuracy of this model is better than 0.2% for $\varepsilon_r \leq 128$ and $0.01 \leq u \leq 100$.
The expression for the characteristic impedance is

$$Z_c = \frac{\eta}{2\pi\sqrt{\varepsilon_{re}}}\ln\left[\frac{F}{u} + \sqrt{1 + \left(\frac{2}{u}\right)^2}\right] \tag{4}$$

where $u = W/h$, $\eta = 120\pi$ ohms, and

$$F = 6 + (2\pi - 6)\exp\left[-\left(\frac{30.666}{u}\right)^{0.7528}\right] \tag{5}$$

B. Classification of Resonators & Microstrip Discontinuities

There are different types of resonators, depending upon the shape and performance characteristic of the resonator, which is classified as Single mode, Dual mode, Triple mode and Quadruple mode [1,3].

Microstrip discontinuities commonly encountered in the layout of practical filters include steps, open-ends, bends, gaps, and junctions. Figure.1, 2, 3 and 4 illustrates all of the above discontinuities structures and their equivalent circuits. The effects of discontinuities can be frequently used in the filter design.

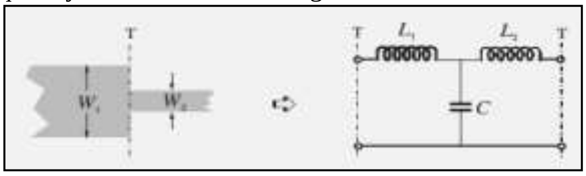

Fig. 1: Microstrip step discontinuities.

The capacitance and inductances of the equivalent circuit indicated in Figure 1 for a symmetrical steps can be approximated by the following formulation.

$$C = 0.00137h\,\frac{\sqrt{\varepsilon_{re1}}}{Z_{c1}}\left(1-\frac{W_2}{W_1}\right)\left(\frac{\varepsilon_{re1}+0.3}{\varepsilon_{re1}-0.258}\right)\left(\frac{W_1/h+0.264}{W_1/h+0.8}\right)\text{(pF)} \quad (6)$$

$$L_1 = \frac{L_{w1}}{L_{w1}+L_{w2}}L, \quad L_2 = \frac{L_{w2}}{L_{w1}+L_{w2}}L \quad (7)$$

Where,

$$L_{wi} = Z_{ci}\sqrt{\varepsilon_{rei}}/c \quad (8)$$

$$L = 0.000987h\left(1-\frac{Z_{c1}}{Z_{c2}}\sqrt{\frac{\varepsilon_{re1}}{\varepsilon_{re2}}}\right)^2 \text{(nH)} \quad (10)$$

Likewise different discontinuity are used for design of microstrip filter by calculating required parameters.

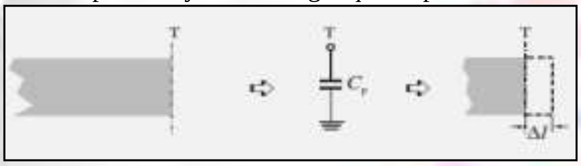

Fig. 2: Microstrip open-end discontinuities.

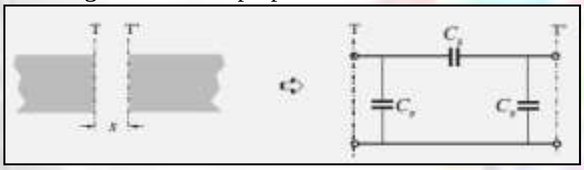

Fig. 3: Microstrip gap discontinuities.

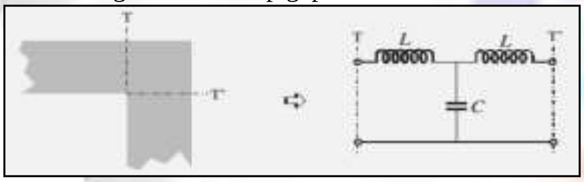

Fig. 4: Microstrip bend discontinuities.

C. Lumped Inductors & Capacitors

Some typical configurations of planar microwave lumped inductors and capacitors [8,9,24] are shown in Figures 5 and 6.

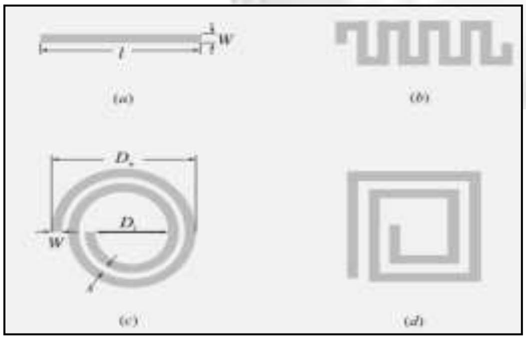

Fig. 5: Lumped-element inductors: (*a*) high-impedance line; (*b*) meander line; (*c*) circular spiral; (*d*) square spiral.

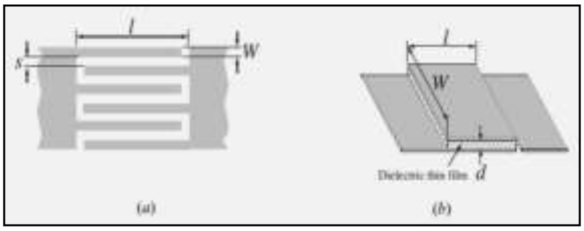

Fig. 6: Lumped-element capacitors: (*a*) interdigital capacitor; (*b*) MIM capacitor.

The various lumped parameter based on resonating structure of microstrip structure is shown in fig. 5 and fig 6. The matellic patch line in different orientation represents high impedance line of inductance and capicatance [23,24].

III. Different Type of Microstrip Filter

In a general structure of the stepped-impedance microstrip filters [5,11], which use a cascaded structure of alternating high and low impedance transmission lines. These are much shorter than the associated guided wavelength, so as to act as semilumped elements. The high-impedance lines act as series inductors and the low-impedance lines act as shunt capacitors [14,15]. Therefore, this filter structure is directly realizing the L-C ladder type of lowpass filters shown in Figure 7 *(a)* and (*b*).

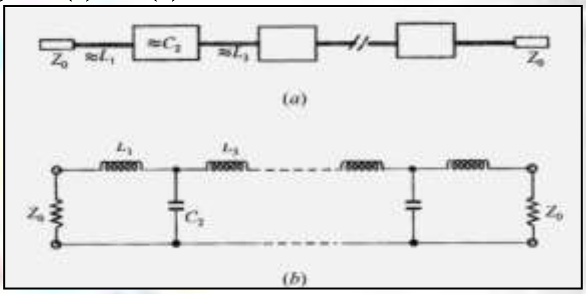

Fig. 7: (*a*) General structure of the stepped-impedance lowpass microstrip filters. (*b*) L-C ladder type of lowpass filters to be approximated.

The general configuration of an end-coupled microstrip filter is illustrated in Figure 8, where each open-end microstrip resonator [20,21,22] is approximately a half guided wavelength long at the midband frequency f0 of the bandpass filter. The coupling from one resonator to the other is through the gap between the two adjacent open ends, and hence is capacitive.

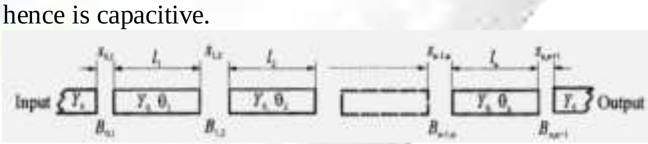

Fig. 8: General configuration of end-coupled microstrip filter.

Figure 9 illustrates a general structure of parallel-coupled (or edge-coupled) microstrip bandpass [23,24,25] filters that use half-wavelength line resonators. They are positioned so that adjacent resonators are parallel to each other along half of their length.

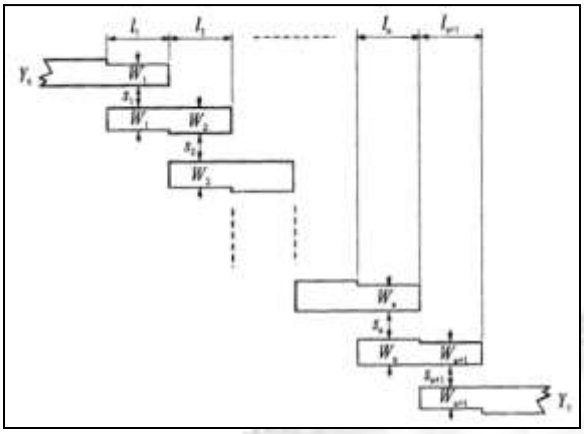

Fig. 9: General structure of parallel (edge)-coupled bandpass filter.

Hairpin-line bandpass filters [1,3,19] are compact structures. They may conceptually be obtained by folding the resonators of parallel-coupled, half-wavelength resonator filters, which were discussed in the previous section, into a "U" shape [18,19]. This type of "U" shape resonator is the so-called hairpin resonator.

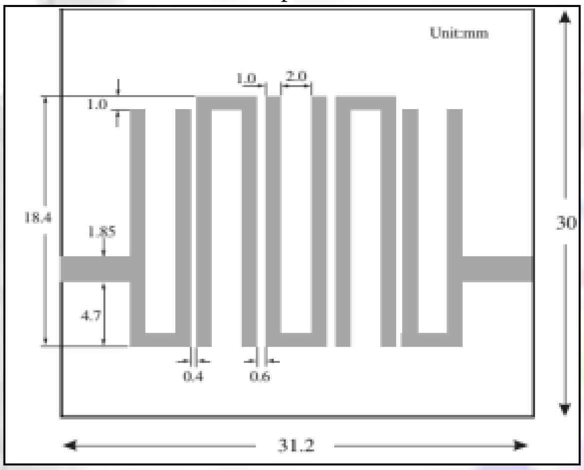

Fig. 10: Hairpin-line microstrip filter

IV. Results

In this section we will consider some latest results of preexisting of microstrip filters. In first case the results of latest step microstrip filter is shown as a reference with the different excitation condition of the elements IEEE [2016] Lakhpat Singh Purohit, Dr. Lokesh Tharani [5] et. al. In the first case microstrip D1, D2, D3 utilized as switching component. Presence and absence of strip is equivalent to Diode ON and Diode OFF respectively and other dimensions of filter are kept constant during these diode configurations.

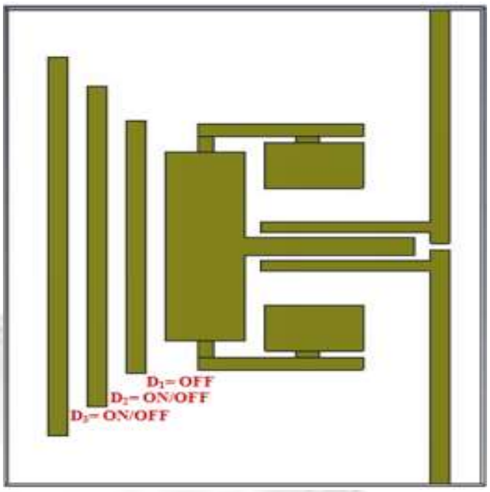

Fig. 11: Patch design of BPF Under Study

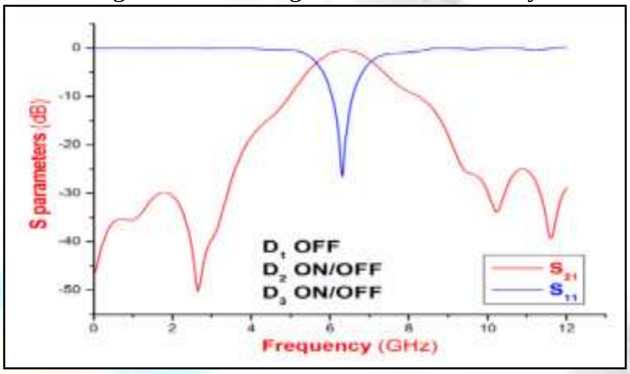

Fig. 12: Result of BPF Under Study

The overall result for different excitation condition of the microstrip filter under study is summarized in the Table I along with the numbers of bands, center frequency, Return loss and insertion loss.

Diode configuration	Type of filter	Center Frequency (GHz)	Return loss (Db)	Insertion loss (Db)
D1 = OFF D2 = ON/OFF D3 = ON/OFF	Single band BPF	6.312	26.53	0.41
D1 = ON D2 = OFF D3 = ON/OFF	Dual band BPF	5.34 7.56	27.34 38.05	0.046 0.0002
D1 = ON D2 = ON D3 = OFF	Tri band BPF	4.68 6.37 7.65	29.14 28.40 40.68	0.313 0.30 0.013
D1 = ON D2 = ON D3 = ON	Quad band BPF	4.452 5.196 8.384 7.644	29.25 25.99 33.07 40.00	0.103 0.12 0.01 0.008

Table I. Summary of Filters Designed using Different Diode Configurations.

The next case describe a hair pin microstrip filter IEEE [2017], Haiwen Liu, Baoping Ren [1], et. al. In this manuscript, a compressed dual-mode hairpin ring resonator (HRR) with two controllable resonances is proposed, shown in figure. 13

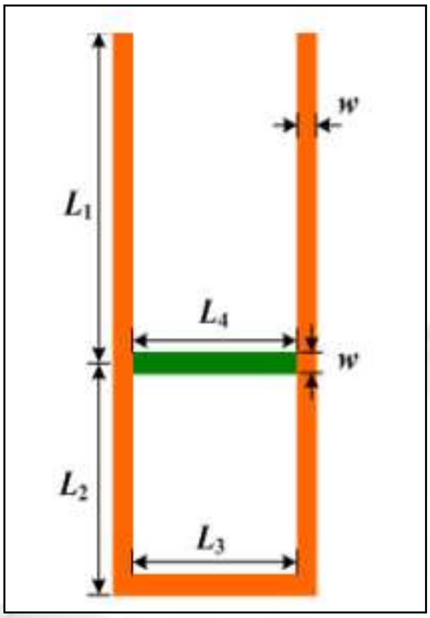

Fig. 13: Patch design of HRR Under Study

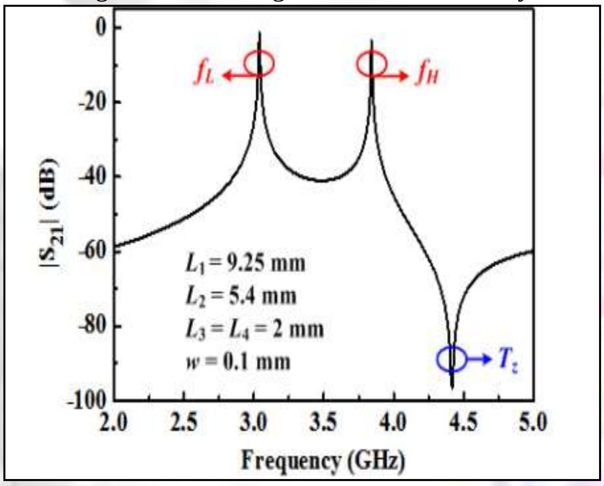

Fig. 14: Result of HRR Under Study

The frequency response of the HRR under study and its S21 magnitude under weak coupling is shown in figure 14.

V. Conclusion

This paper performs the proportional study of microstrip filter design methods. Finally this review concludes that Microstrip filter designs involve a number of considerations, including careful choice of topologies and substrates. Some design examples of new topologies with advanced filtering characteristics have been described, including stepped-impedance filters, open-stub filters, hairpin-line filters are discussed. Based on applications and emerging device technologies, many new and advanced microstrip filters have been developed and their designs are available in open literatures.

VI. Research GAP

Other then the above concluding remark the various microstrip filter design techniques discussed in the manuscript also faces some of the problems which can be treated as the gap between various research paper and need of hours, these problems can be act as the seed of future work. The proposed structure composed of one piece of substrate like Rogers RT/duroid 5880, FR4_epoxy [2,3] so we will further work on the comparison of same design for different substrate and draw a concluding remark for the future work.

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