Analysis and Design of Dual-Band Planar Band Pass Filters using Resonators for Wireless Applications

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ABSTRACT
This paper describes the design and analysis of planar dual-band bandpass filters using stepped impedance resonators. In the proposed filter configurations, dual-band bandpass filters are designed, and realized by using inverted stepped impedance (SIR) resonators. The conventional half wavelength open circuited stub single frequency resonators are replaced with dual band simple two section stepped impedance resonators. Simple equations to design the dual-band SIR's are derived using transmission line analysis. To increase the performance of the filter, and to reduce the size, compact resonators are proposed. This resonator with compact coupling and size reduction are proposed by using split ring stepped impedance resonators with two inner coupling. The performance of the filter structures is investigated using IE3D electromagnetic simulators, where good agreement with the theoretical prediction is observed.

Keywords
Bandpass filter, compact, dual-band, IE3D, SIR.

1. INTRODUCTION
Microwave Bandpass (BPFs) filters are key components of radio transceiver in wireless communication systems. Such filters play a main role passing the desired signals and filtering out the unwanted signals. BPFs have found many applications in modern microwave/millimeter wave systems where numerous components including diplexers and switches are comprised of BPFs [1-3]. Microstrip filters have the advantage of low-weight, low-cost, and ease of implementation. Numerous conventional structures of microstrip BPFs like transmission line filters, coupled resonator filters, parallel coupled half wave length resonator filters, hairpin-line filters, inter-digital filters, combline filters, , open-stub filters and semi-lumped element filters have been presented in the specialized literatures [1–7]. The various forms of bandpass filters can be realized in distributed element as well as in lumped element structures. Conventional microstrip BPF, typically, uses half-wavelength uniform resonators at the operating frequency. Particularly, Stub-line filters composed of shunt open circuited half-wavelength resonators with quarter-wavelength connecting lines are widely used in many RF/microwave applications [1, 2, 4, 5].

These filters could meet the required specification at the fundamental frequency band. However, to impose new requirements recent advances in modern communication is required, such as operation of multiple-band, on the design of RF passive circuits. Dual-band circuits provide the benefits of reducing the overall size and the fabrication cost of multiband wireless communication systems and modules [8]. However, there is a need for further work since the communications development continually demands simpler and more-compact structures with better operational flexibility.

In this paper, the design and analysis of dual-band planar bandpass filters is presented. The desired dual-band operation is accomplished by using inverted two-section stepped-impedance resonators. Each branch with half-wavelength is converted to its equivalent two-section stepped impedance shaped section. The resulted basic filter configuration will have a selectable dual band operation. Further to increase the filter performance and reduce the size of the filter the compact resonators are presented. The final layout of the basic filters is designed based on the formulas and, then, analyzed using a full wave electromagnetic IE3D simulator. To verify the design concept, a microstrip bandpass filters is realized on FR4/epoxy substrate.

2. PROPOSED BANDPASS FILTERS
The conventional single-band microstrip-based bandpass filter can be derived from the lowpass filter (LPF) prototype. The design starts with n-section low pass filter in the form of LC structure that employs series inductors and shunt capacitors. The parameters and the element values of the basic lowpass filter prototype are determined from the bandwidth and filter response specifications. However, to create a structure proper transformation should be used and has only series transmission with line admittance inverter sections and shunt open stubs. A suitable transformation is used to scale the design to the proper bandpass frequency region with physical dimensions that could be realized by microstrip sections. For a single frequency microstrip BPF, open-circuited stub resonators are half-wavelength ($\lambda/2$) and they are connected by quarter-wavelength ($\lambda/4$) transmission lines as shown in Figure1.

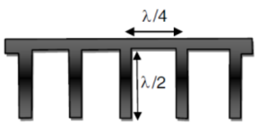

Fig .1. Conventional microstrip BPF with half-wavelength open-circuited stub resonators

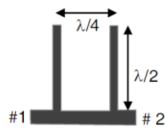

Fig .2. Conventional half-wavelength open-circuited stub BPF structure.

Figure 2 depicts a layout of conventional half-wavelength open-circuited stub resonators BPF [1, 2]. The bandwidth of the conventional bandpass filter shown in Figure 2 is basically determined from the characteristic impedances of the stub-resonators that are transformed from the basic lowpass prototype parameters [1, 2].The characteristic impedance of the quarter-wave admittance inverters are determined from the basic filter response reflected in the lowpass filter prototype design. The filter section parameters are usually optimized for microstrip technology realization. In the present work, to obtain dual band operation of the stub BPF resonator, each half-wave length ($\lambda/2$) open-circuited stub in Figure 2 is converted to a dual-band inverted stepped impedance shaped resonator as shown in Figure 3. The stepped (shaped) transmission line model in Figure 3 consists of two transmission line sections. The correspondence between the uniform half-wavelength open-circuited stub and the non-uniform stepped impedance line is investigated using transmission line theory as presented in Equations (1) to (4).

Let $\theta 1$ and $\theta 2$ denote the effective electrical lengths of the lines with $Z1$ and $Z2$ characteristic impedances, respectively. Investigating the input admittance *Yin* of the stepped impedance section, the following equation can be derived:

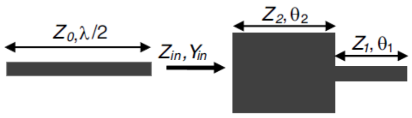

Fig.3. Equivalent structures of half-wavelength open-circuited stub and stepped impedance resonators.

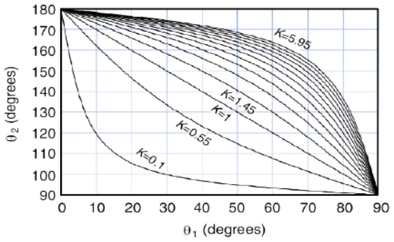

Figure.4. $\theta 1$ versus $\theta 2$ for different values of *K*.

$$Z_i = jZ_2 \frac{Z_1 tan\theta_1 + Z_2 tan\theta_2}{Z_2 - Z_1 tan\theta_1 tan\theta_2} \qquad (1)$$

Let $Z_i = \frac{1}{Y_i} = 0$, then the parallel resonance condition can be obtained as follows:

This can be obtained when

$$K = Z_1/Z_2 \qquad (2)$$

Design curves are drawn in Figure 4 for different values of *K*. The total electrical length of the resonator is given by;

$$\theta_t = \theta_1 + \theta_2 \qquad (3)$$

It is noted that for K=1 (uniform resonator), the total electrical length is π and the total length of the non-uniform resonator decreases as the impedance ratio *K* decreases and vice versa. A half-wavelength uniform open circuit resonator will resonate at its fundamental frequency and at its multiples whereas the non-uniform stepped impedance resonator will resonate at the fundamental frequency and at another frequency that is controlled by the impedance ratio *K*. For practical realization of microstrip lines, the characteristic impedances should be, typically, bounded, approximately, in the region ($25\Omega \leq Z \leq 150\Omega$). Consequently, the corresponding practical impedance ratio *K* must be in the range ($0.14 \leq K \leq 7$).

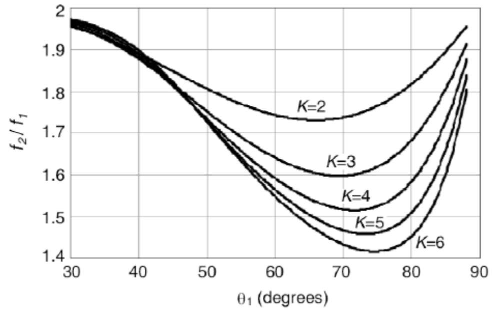

Fig. 5. Variation of the second resonant frequency with the impedance ratio *K*.

Utilizing Equation (2), the second resonant frequency (f_2) of the stepped impedance resonator can be deduced since the equality will be repeated at each resonant frequency. The ratio of the second resonant frequency to the first (center) frequency (f_2 / f_1) depends on the values of the impedance ratio *K* as well as on the stepped-sections electrical lengths. Figure 5 illustrates the control of the second resonant frequency by the impedance ratio *K* for varying $\theta 1$ value while Figure 7 compares the frequency responses of a conventional uniform and an inverted stepped single resonator filter with *K* = 5 and $\theta 1$ = 73° that is represented in Figure 6.

Fig. 6. The uniform (left) and the inverted stepped (right) resonators

It is manifested from these figures that the higher the impedance ratio *K*, the closer is the second resonant frequency region in the proposed dual-band resonator structure. As inferred from these figures, reentrant responses in a typically realizable single inverted stepped-

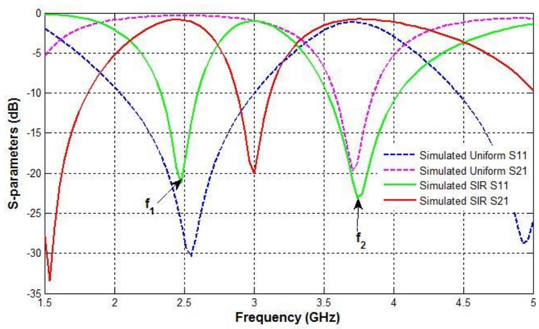

Fig .7. The resonant frequencies of the uniform and the stepped resonators.

-impedance resonator can be located as close as at 1.35 times of the (first) center frequency. Examining Equation (3) and Figure 6 for the relation between $\theta 1$ and $\theta 2$ for different values of *K*, the symmetry of $\theta 1$ and $\theta 2$ values around constant *K* lines can be discerned.

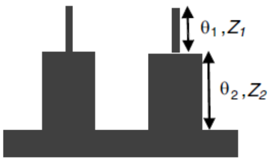

Fig. 8. Proposed inverted stepped-impedance BPF

2.1 Design, Simulation And Results

A dual-band BPF is designed at 2.5GHz and 3.55GHz. Based on the previously outlined design procedures with $Z0 = 50\Omega$, the filter parameters will be: $Z1 = 115\Omega$, $Z2 = 25\Omega$, $\theta1 = 75^\circ$ and $\theta2 = 138^\circ$. The designed BPF is simulated using a full wave EM software package and then realized on FR4/epoxy substrate ($\varepsilon r = 4.2$, $h = 0.8$mm). Figure 8 shows the layout of the designed BPF. The inverter section impedance is tuned to improve the return loss of the upper passband. Figure 9 shows simulation *S*-parameter results. The return loss $S_{11}$is greater than -40 dB. The bandwidths of the dual-band stepped impedance filter at both passbands are, basically, the same as the designed bandwidth of the conventional filter with open circuited half-wavelength resonators. It is observed that the value of the realizable (stepped) impedance ratio *K* has no effect on the first frequency bandwidth and little effect on the second frequency bandwidth if the microstrip sections design is well optimized. Selecting the less-frequency sensitive (lower slope) region of the curves shown in Figure 5 for the second band that yield $\theta1$ values around 73 degrees will, mostly, preserve the basic design bandwidth.

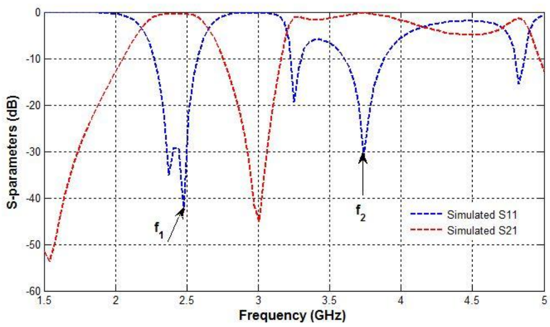

Fig. 9. Simulation results of the dual-band inverted stepped impedance bandpass filter.

The above analysis and results have validated the design concept and demonstrated the quality of the simple dual-band BPF based on single and double inverted stepped impedance resonators. The frequency response, particularly the bandwidth in both passbands, can be accustomed by cascading multiple similar inverted step resonators [1, 2].

3. COMPACT STEPPED IMPEDANCE RESONATOR

In the above filter design the second pass band is at 3.55GHz. In order to reduce the size of the filter, we are going for compact microstrip SIR, which resonates at same frequency so we can replace with the earlier resonators Fig8 with the compact SIR structure as shown below.

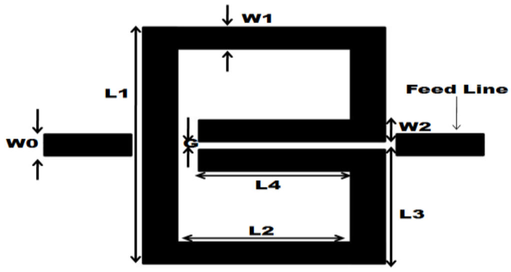

Fig. 10(a). Proposed compact stepped-impedance resonator

4. DESIGN, SIMULATION AND RESULTS

A compact stepped-impedance resonator is designed at 3.55GHz.the substrate is used in this has a relative dielectric constant of 4.3 and a thickness of 1.6 mm. A 50Ω microstrip feed line with a width of, the filter will be: $Z_1 = 85\Omega$ (W_1 =1.1mm), Z_2 = 66Ω (W_2=1.86mm), L_1 = 12mm, L_2 = 7.8mm, L_3 = 5mm, L_4 = 6mm, G = 0.4 mm, S = 0.3 mm. with the help of IE3D. Fig 10(b) shows the photograph of the resonator shown in Fig 10(a). The dimensions excluding two SMA connectors, the measurement was performed with Agilent N5230A vector network analyzer test system.

Fig.10 (b). Photograph of the fabricated resonator on an FR-4 substrate.

The measured results of S-parameters are depicted with the simulated results. The SIR has a resonant peak at about 3.53GHz as shown in Fig 11.

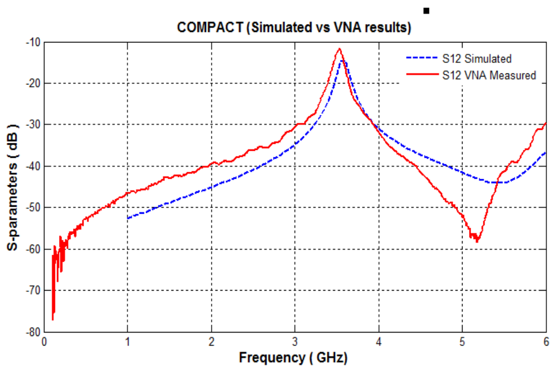

Fig 11: Resonant property of SIR

5. CONCLUSIONS

This project represents analysis and design of a dual-band planar bandpass filter. Comparing the performance of the uniform and inverted steeped impedance resonators, therefore the response of inverted SIR is 1.4 times of the (first) center frequency. The basic design configuration uses dual-band inverted stepped impedance resonators via transformation of the half wavelength open-circuited stub resonator of the filter with no lumped elements or via holes. Practical and simple design procedures are developed. The design of a basic dual-band bandpass filter is examined using a full wave EM software simulator. To reduce the size of the filter compact SIR is designed and verified with an example. Design examples and implementations of prototype filters have been verified through simulations and measurements.

6. REFRENCES

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