Design of Quad-Band Bandpass Filter Lumped-Element Using Shunt Resonator and Independent Transmission Zero

Gunawan Wibisono, Taufiq A. Kurniawan, and Mohamad W. Santoso

***Abstract*—In this research, quad-band bandpass filter (BPF) which operated at frequencies of 0.9 GHz, 1.8 GHz, 2.3 GHz, and 2.6 GHz will be designed, fabricated, and evaluated. Design of quad-band BPF is done based on shunt resonator that connected in cascade connection. In filter design, three independent transmissions zero was generated to provide four resonance frequencies by simply connect shunt resonator in series with capacitor or inductor. Transmission zero is also generated to enhance rejection area between each passband and to adjust resonance frequency. Quad-band BPF is design using ADS software and then fabricated in FR-4 substrate. Simulation results show that S11 = -59.12, -25.80, -33.25, -33.84 dB, S21 less than 0 dB, bandwidth 122, 94, 92, 87 MHz and VSWR is 1.002, 1.108, 1.044, and 1.041 for resonance frequency at center frequencies of 950 MHz, 1.85 GHz, 2.35 GHz, and 2.65 GHz, respectively. The frequency center of the fabricated quadband BPF shifted to 776 MHz, 1.526 GHz, 2.435 GHz, and 2.787 GHz. The return loss and VSWR of the fabricated quadband BPF are satisfied to the design specifications.**

***Index Terms*—Bandpass filter, independent transmission zero, quad-band, shunt resonator.**

I. Introduction

Nowadays, wireless communication market has rapidly grown up with various wireless communication services. Multipurpose device which can serve many kinds of telecommunication technologies from one device is becoming the current market trend. Increasing demand for wireless communication applications, more and more wireless communication system are in multiband operation. Bandpass filter (BPF) is important component of wireless systems as it enables band selection in radio frequency (RF) transceiver, separating the different receiver functions of interest and isolating a specific band from interferes in dense received signals. Therefore, multiband BPF becomes an essential component of future telecommunications device.

Design of multiband BPF using lumped components have been proposed by many researchers [1]-[4]. As wireless system converge into common device, it is important to have miniaturized BPF that can select more than one band. One method to miniaturize filter component which has become very popular in RF circuit designs due to its high performance, high integration density, and high reliability is low temperature co-fired ceramic (LTCC).

We had designed quad-band BPF [3], based on the concept proposed in [1]. However, the results of [3] showed that the rejection is not good and the bandwidths are too narrow from the initial specification filter. Another works design filter by using J-inverter technology and additional independent zero transmission was proposed by Sung et.al [4], where this technique can be used to reduce unwanted EM coupling and improve rejection. It is shown that the dual-band characteristics can be obtained by combining two filters in parallel manner so that the two bands do not affect each other that mentioned in [4], [5]. While in [1] dual-band characteristics obtained by the more complex manner because studying the multilayer substrate.

In this research, the design of quad-band characteristics of BPF is obtained by using shunt resonators in cascade connection. The objective of the research is to reduce rejection and improve the bandwidth of the proposed quadband BPF. In here, to enhance rejection area, additional independent transmission zeros are generated by connecting series capacitor or inductor with shunt resonator [6]. Resonant frequency using this approach is tunable by manipulating independent zero position. The fabrication of the proposed quadband BPF is done by using lumped element with co-planar and ground waveguide on FR-4 substrate.

II. Filter Design

Table I shows the specification of the proposed quad-band BPF

TABLE I: Specification of the Proposed Quad-Band BPF

Parameter	Requirement
Center Frequency	0.95/1.85/2.35/2.65 GHz
Insertion Loss	0-3 dB
Return Loss	< -10 dB
VSWR	1-1.3
Bandwidth	90 MHz

The proposed BPF was first designed single band by using T prototype 3rd Chebyshev lumped element filter circuit topology with resonance frequency at 0.9 GHz, is shown in Fig. 1(a) [7]. This conventional topology needs the relatively large inductance and small capacitance values. It causes its performance degraded due to large inductor area and unwanted EM coupling in 3D filter structure [4]. J-inverter then is used to transfer the resonator from serial type to shunt

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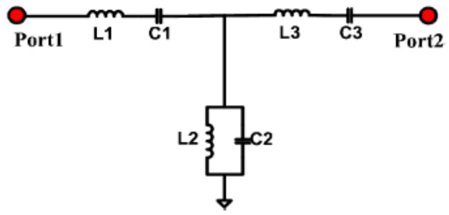
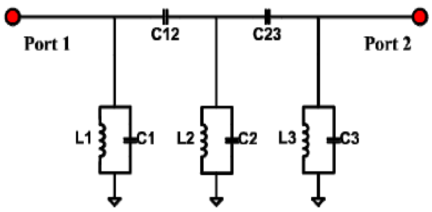
ones to avoid unwanted EM coupling in structural design described in [4]. Then T-type topology shows in Fig. 1(a) is changed to its equivalent circuit shows in Fig. 1(b).



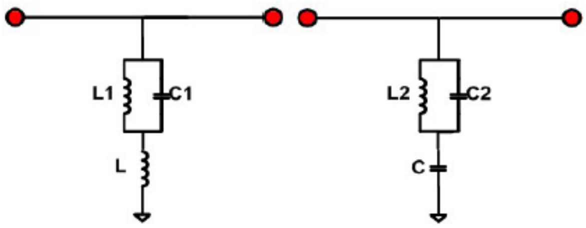
(a)



(b)

Fig. 1. 3rd orders Chebysev bandpass filter (a) and it J-inverter equivalent circuits (b) [4].

Maximum rejection characteristic and independent transmission zeros can be obtained by simply adding capacitor or inductor in series with desired shunt resonator. Fig. 2(a) and (b) show circuit with additional capacitor or inductor in shunt resonators to get transmission zero. Resonator structure in Fig. 3(a) is used to get one transmission zero at the upper stop-bands of the filter while Fig. 3(b) for lower stop-band of the filter.



(a) (b)

Fig. 2. Resonator structure that providing independent transmission zero at (a) upper and (b) lower pass band.

Fig. 2(a) can be characterized by the following frequency dependence of input admittance, where w_0 is the resonance frequency, and w_p is the zero frequency, which given as follows

$$B_L(\omega) = \frac{1}{\omega(L_1 + L)} \cdot \frac{\frac{\omega^2}{\omega_0^2} - 1}{\frac{\omega^2}{\omega_D^2} - 1} \tag{1}$$

$$\omega_0 = \frac{1}{\sqrt{L_2 C_2}}, \omega_P = \frac{1}{\sqrt{L_S + C_1}} \tag{2}$$

$$L_S = L_1 L / (L_1 + L) \tag{3}$$

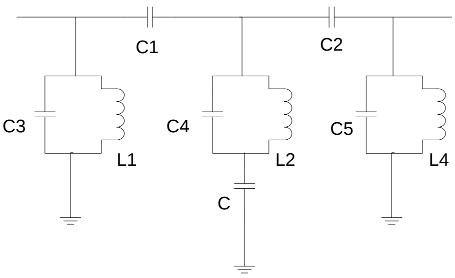
For Fig. 2(b), zero frequency can be expressed as

$$\omega_P = \frac{1}{\sqrt{L_2(C_2 + C_1)}} \tag{4}$$

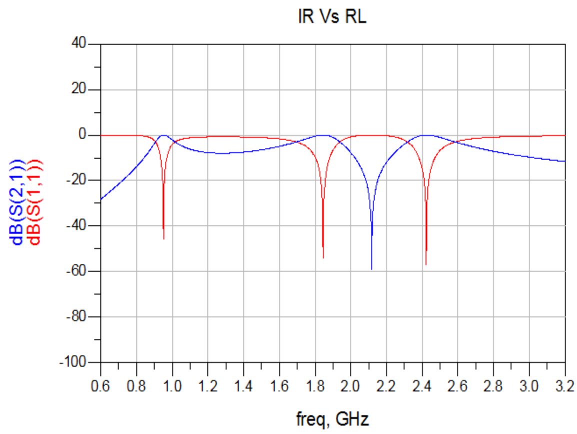
Quad-band filter characteristic is obtained by connected shunt resonator and generate transmission zero carefully using equation (1)- equation (4).

Dual-band responses from J-inverter topology in Fig. 2(b) easily obtained by provide different resonant frequency for each shunt resonator. At this rate, two shunts resonant frequency is set at 2.3 GHz and the other at 0.9 GHz.

Fig. 3(a) shows the additional independent zero is added. It is shown from Fig. 3(a), the zero that produced by C can create triple-band characteristics by adjust it to proper value for upper band designed in Fig. 3(a). Fig. 3(b) shows simulation results of BPF which can operate at three bands with center frequencies of 950 MHz, 1.85 GHz, and 2.35 GHz, respectively.



(a)

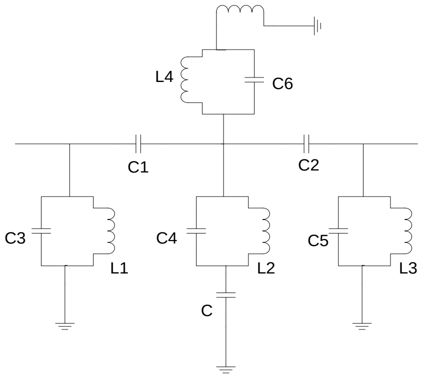


(b)

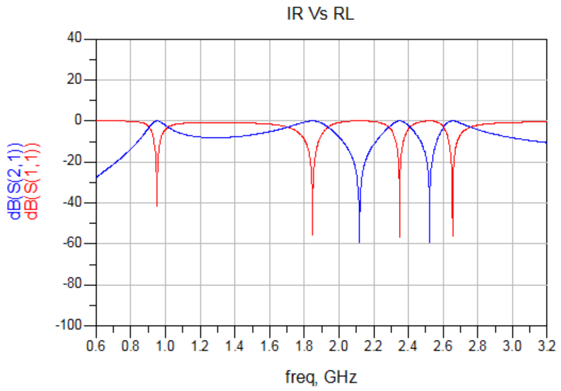
Fig. 3(a). Triple-band topology configuration and. (b) lower pass band.

Additional shunt resonator needed to provide last resonant frequency. Fig. 4(a) shows additional resonator added in middle resonator from Fig. 3(a). Additional series inductor L is added to produce a zero at upper band-stop frequency of 2.3 GHz and create last resonance frequency at frequency 2.65 GHz. Fig. 4(b) shows simulation result of quad-band BPF filter with topology in Fig. 4(a).

Simulation result for quad-band BPF with topology in Fig. 4. (a). did not meet filter specification in Table I. To meet the filter specification the proposed BPF is optimized by removing capacitor C1 and C2 and generate additional zero between 0.9 GHz and 1.8 GHz band. Fig. 5 shows the proposed topology quad-band BPF.



(a)



(b)

Fig. 4(a) Quad-band topology configuration and (b) its insertion loss and return loss simulation result.

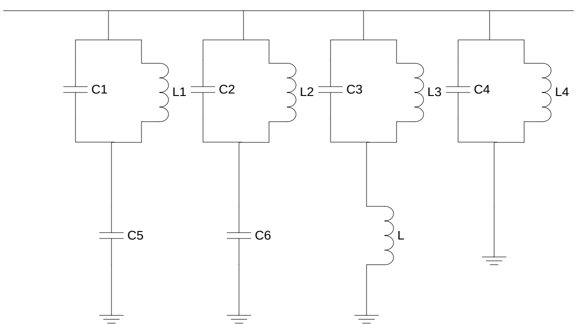


Fig. 5. Proposed quad-band lumped- bandpass filter

Removing C1 and C2 makes each shunt resonator directly connected to each other and makes resonance frequency vary from equation (2). But, zero frequency still determined by equation (2) and (4). Since resonance frequency occur between two zero frequencies, by adjusting zero frequency at proper value, then desired resonant frequency can be obtained.

III. Fabrication

Fabrication of quad-band BPF is done by using lumped element with co-planar and ground waveguide on FR-4 substrate with a relative dielectric constant of 4.3, a loss tangent of 0.002 and a thickness of 1.6 mm. To maintain 50 Ohm characteristic impedance, transmission line is designed with transmission width 1.2 mm, gap between lines and ground was 0.3 mm, and substrate thickness was 0.8 mm. Fabricated result of the proposed quad-band BPF is shown in Fig. 6.

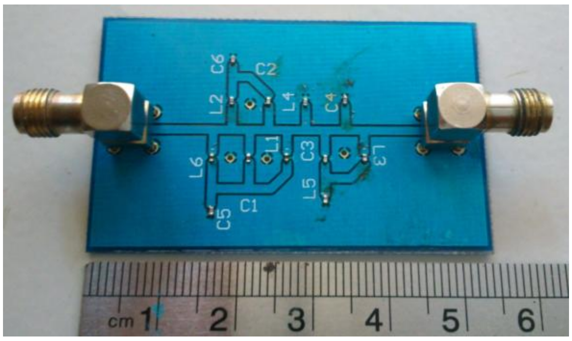


Fig. 6. Fabricated the proposed quadband BPF.

IV. Results

The proposed quad-band BPF is designed and simulated by using Advance Design System (ADS) software. Insertion loss, return loss, input impedance, VSWR, and noise figure are simulated and analyzed using ADS software. Simulation results for return loss S_{11} and insertion loss S_{21} quad-band BPF BPF are shown in Fig. 7.

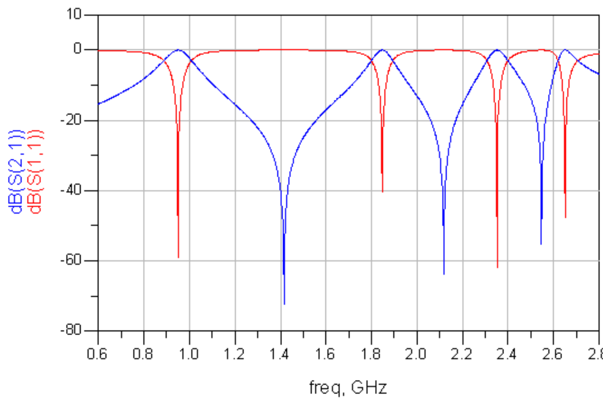


Fig. 7. Simulation results for S_{11} and S_{21} of the proposed quad-band BPF.

It is shown from Fig. 7, that the proposed quad-band BPF operate at four resonance frequencies at center frequency of 0.95 GHz, 1.85 GHz, 2.35 GHz, and 2.65 GHz. These results indicate that the proposed BPF can operate in four different bands concurrently. It is also shown from Fig. 7 show that S11 = -59.12, -25.80, -33.25, -33.84 dB, S21 less than 0 dB, bandwidth 122, 94, 92, 87 MHz for resonance frequency at center frequencies of 950 MHz, 1.85 GHz, 2.35 GHz, and 2.65 GHz, respectively. It is shown from Fig. 7 that the return loss and insertion loss of the proposed quadband BPF are satisfied to the design requirements which shown in Table I.

The VSWR value of the proposed quad band BPF VSWR is 1.002, 1.108, 1.044, and 1.041 at the center frequency of 0.95 GHz, 1.85 GHz, 2.35 GHz, and 2.65 GHz, respectively.

Performance comparison of the simulation and measurement results of return loss are shown in Fig. 8. Red line is for measurement result and blue line for simulation result. It is shown from Fig. 8 the center frequency of the fabricated results are shifted to 776 MHz, 1.526 GHz, 2.435 GHz, and 2.787 GHz. The measurement results of return loss and VSWR are given by -20 dB, -13.6 dB, -36.8 dB, -34.6 dB and VSWR = 1.22, 1.52, 1.03, and 1.04 at the frequency center of 776 MHz, 1.526 GHz, 2.435 GHz, and 2.787 GHz, respectively. It is shown from the measurement results that return loss and VSWR of the fabricated quadband BPF is satisfied to the design requirement.

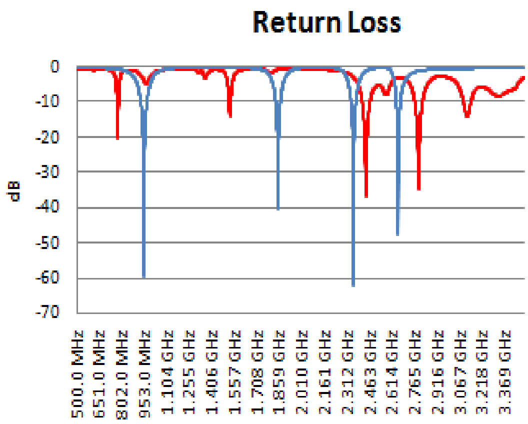


Fig. 8. Return loss result for measurement (red line) and simulation (blue line) result.

Simulation result for proposed quad-band bandpass filter meets filter requirements. Since more zero applied, rejection characteristic between each passband enhance and show better result from [3].

V. Conclusion

Quadband BPF with lumped element using shunt resonator and independent transmission zero which can operate at four frequencies concurrently, has been designed, analyzed, and fabricated. It is shown from the simulation results that proposed quadband BPF can operate at four different frequencies at center frequency of of 950 MHz, 1.85 GHz, 2.35 GHz, and 2.65 GHz, respectively. From the simulation results, S11 = -59.12, -25.80, -33.25, -33.84 dB, S21 less than 0 dB, bandwidth 122, 94, 92, 87 MHz and VSWR is 1.002, 1.108, 1.044, and 1.041 for resonance frequency at center frequencies of 950 MHz, 1.85 GHz, 2.35 GHz, and 2.65 GHz, respectively. It is shown that the simulation results of return loss, insertion loss, VSWR, and the bandwidth of the proposed quadband BPF are satisfied to the design specifications. The frequency center of the fabricated quadband BPF shifted to 776 MHz, 1.526 GHz, 2.435 GHz, and 2.787 GHz. The return loss and VSWR of the fabricated quadband BPF are satisfied to the design specifications, while the center frequency is shifted from the design specification.

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