Progress In Electromagnetics Research C, Vol. 33, 229–241, 2012

A NOVEL SINGLE AND DUAL-BAND MINIATURIZED MATCHED BAND-STOP FILTER USING STEPPED IMPEDANCE RESONATOR

A. A. Bakhit and P. W. Wong*

Department of Electrical and Electronics Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, Tronoh, Perak 31750, Malaysia

Abstract—In this paper in order to reduce the size and improve the performance of microwave filter, novel single and dual band matched band-stop filters are developed. A stepped impedance dual mode resonator is used, resulting in a much more compact size, than the conventional dual mode ring resonator that has an electrical length of 360°. The proposed prototype is able to achieve high stop band attenuation even with low Q factor values. Moreover, for the short electrical length of this filter, the first spurious resonance occurs at 4.7 times the fundamental resonance frequency. Therefore, the proposed technique selectively removes only the fundamental resonance frequency when such a resonator is implemented. A theoretical analysis, along with an experimental prototype is proposed in order to demonstrate the feasibility of these proposed networks.

1. INTRODUCTION

Wireless communication systems such as iPhones, Black-Berry, Android phones, Blue-tooth and wireless local networks that operate in a 2.4/5 GHz band are the pillar of convenience of today's telecommunication industry. Their development as a whole has been wide and fast, more so in recent years. The relentless march of these technologies is not without obstacles, however, as acute problems of interference have been recently identified. The setting in an aircraft best demonstrates this problem; the provision of an onboard wireless communication access should, in theory, allow the simultaneous use of other systems, and in this environment, it is vital that the interference

Received 16 September 2012, Accepted 11 October 2012, Scheduled 17 October 2012
* Corresponding author: Peng Wen Wong (wong_pengwen@petronas.com.my).

with the aircraft navigation system is suppressed. In order to mitigate potential problems, multiple stop-band filters should be available at specific frequencies.

Various techniques have been proposed and developed in order to realize band-stop filter responses [1, 2, 7, 9, 21–25]. The conventional technique to implement band-stop filters involves the use of shunt stubs with large circuits [1]. The filter then reflects stop-band signals, and the resonator with finite Q tends to reduce and limit the stop-band attenuation.

A new filter topology using lossy resonators has been introduced [2], where the topology can be used to partially compensate for the loss. The shortcoming of this type of filter is its large size, due to the second order resonator, which produces a single notch with an infinite attenuation. To reduce the resonator's size and cost, many research works on dual mode resonator were carried out in the past [3–6]. However, the size was considered to be too large and unacceptable for the design of high performance multi-pole filters, especially at low microwave L or C bands. Consequently, a dual-mode half-wavelength resonator has been introduced recently, where a transmission line of electrical length of 180° with shunt stubs at the mid-plane is constructed in order to achieve a dual-mode response [7].

Another major concern with the conventional single and dual-mode resonator is the spurious resonance frequencies occurring at integral multiples of the fundamental resonance frequency. Recently, a miniaturized stepped impedance dual-mode resonator filter has been introduced [8], where a transmission line with the electrical length of 120° is constructed, alongside a lump element coupling L, shunted at the midpoint. This resonator gives a significant size reduction within the system. Comparatively, none of these techniques utilize the proposed prototype, which is a much more compact system and perfectly matches all frequencies design. The proposed prototype is able to achieve a high stop-band attenuation even with low Q factor values. Additionally, its first spurious resonance frequency occurs at 4.7 times the fundamental resonance frequency due to its short length. Therefore, the proposed technique selectively removes the fundamental resonance frequency signal when such a resonator is used.

From literature, it can be seen that many band-stop filters are mainly designed for single-band rejection applications. Currently, dual- or multiple-band filters are very popular. It is envisaged that these filters will prove to be crucial, especially onboard aircrafts, and can play a pivotal role in weakening the interference among communication systems, due to the coexisting narrow band applications. To this end, different topologies are proposed and developed in order to realize filters with multiple band-stop responses [10–20, 26–29]. Dual- or multiple-band filters were first presented by Uchida et al. in [18]. This filter is used for the suppression of close to band inter-modulation distortions in high power systems. Multiple band-stop filters for the purpose of interference suppression for pulse signal in ultra-wide band (UWB) systems are designed in [19], via the adoption of a microstrip structure. Shaman and Hong in [10] described a general configuration for cross-coupled wide band band-stop filters, based on n-stub optimum band-stop filter, with cross-coupling between the I/O feed lines. Tu and Chang in [11] described microstrip band-stop filters using shunt open stubs and spur-lines, and Tu and Chang in [12] described the concept of integrating band-stop filters into a conventional band-stop or band pass filter. Chin in [13] designed and implemented two parallel-connected different length open stubs for resonating at dual anti-resonance frequencies in order to realize a dual-band band-stop filter. Jeng et al. in [14] proposed a distributed perturbation scheme of the ring resonator without the need of extra stubs or notches, while Levy et al. in [15] introduced a new type of band-stop filters with the use of compound resonators having shorter electrical lengths to obtain extended upper pass bands, while Yang et al. in [16] designed and implemented a novel compact microstrip inter-digital filter. This filter exhibited a good band-stop characteristic and tunable center frequency, and it is also easy to fabricate and integrate. Hsieh and Wang in [17] addressed the design and performance of a compact and wide-band microstrip band-stop filter. It is noted that the advantage of this filter over the conventional broadband band-stop filters is its simple fabrication method and compact size. Wang and Guan in [28] reported compact dual mode DGS resonators and filters, and [29] designed and implemented planar dual-mode and triple-narrowband band-stop filter with independently controlled stop bands and improved spurious response. Generally, although the previous solutions are innovative, dual- or multiple-bands band-stop filter, based on stepped resonators for wireless communication, have not been demonstrated.

In this paper, a miniaturized dual-band matched band-stop filter is formed by cascading two single miniaturized matched band-stop filters, with center frequencies of 0.99 GHz and 1.04 GHz. A theoretical analysis, along with an experimental prototype, is presented to demonstrate the feasibility of these proposed networks. The proposed method can be a suitable candidate for future wireless communication. This paper is organized as follows. Section 2 presents the theory describing the stepped impedance dual-mode resonator, while Section 3 discusses the miniaturized matched band-stop filter. Then, the miniaturized dual-band matched band-stop filter is presented in Section 4, followed by the fabrication and measurement in Section 5. Finally, the work is summarized in Section 6.

2. STEPPED IMPEDANCE DUAL MODE RESONATOR

It has been shown that the stepped impedance can be used to realize a miniaturized dual-mode resonator with a significant size reduction in [8]. The practical implementation of this filter is based on the stepped impedance dual-mode resonator model, shown in Figure 1(a). This topology is a symmetrical structure with respect to the plane OO', so ensuring that the resonance condition can be derived by utilizing the classical method of odd- and even-mode analysis, with OO' as its reference plane. Note that z_1 and z_2 represent the characteristic impedances of the transmission line sections, and their electrical lengths are θ_x and θ_y.

The structure is resonant when its input admittance is zero for both even- and odd-modes

$$Y_{odd} = Y_{even} = 0 \tag{1}$$

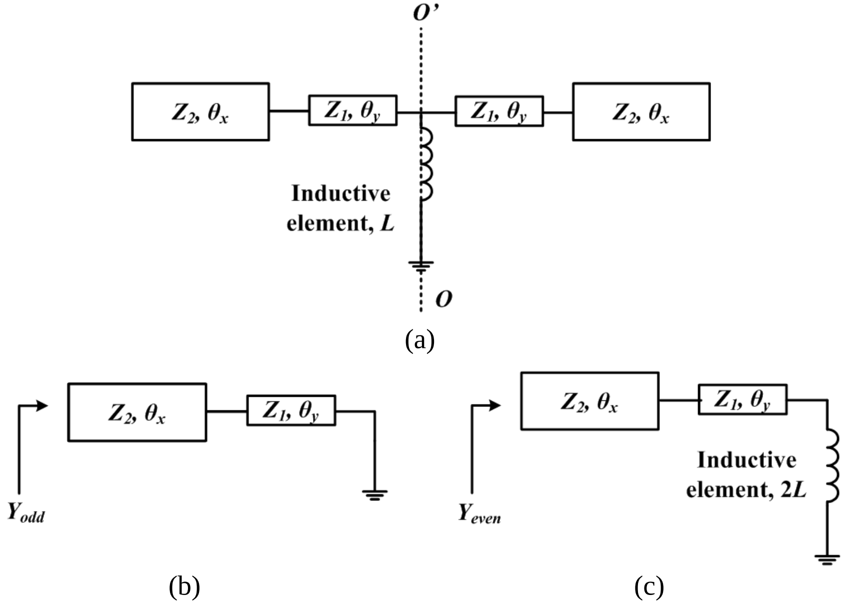

Figure 1. (a) Stepped impedance dual mode resonator, (b) odd mode equivalent circuit, (c) even mode equivalent circuit.

For the odd-mode excitation, the symmetry plane OO' will be short-circuited; the equivalent circuit is given in Figure 1(b). The equivalent circuit for the odd-mode is now composed of two transmission line sections with different characteristic impedances of z_1, and z_2. Therefore, the resulting input admittance for the odd-mode can be expressed as:

$$Y_{odd} = j\frac{\frac{z_1}{z_2}\tan(\theta_x)\tan(\theta_y) - 1}{z_1\tan(\theta_x) + z_2\tan(\theta_y)} \tag{2}$$

The input admittance for the odd-mode at resonance condition is given by:

$$Y_{odd}\big| = 0 \;\Rightarrow \tan(\theta_x)\tan(\theta_y) = \frac{z_2}{z_1} \tag{3}$$

Assume that the electrical length of the two transmission line sections shown in Figure 1(b) are the same ($\theta_x = \theta_y$). Then, the odd-mode resonates when

$$\tan^2(\theta_y) = \frac{z_2}{z_1} \tag{4}$$

Therefore, it is shown that with the control of the impedance ratio $R = \frac{z_2}{z_1}$, the total electrical length of the resonator ($\theta_T = 4\theta_y$) could be much less than half-wavelength at the resonant frequency. To explain more clearly, by setting $R = 1/3$ while using Equation (4), it can be seen in Figure 2 that the total electrical length of the resonator is 120°. It can also be seen in the same figure that the resonator length becomes half of the wavelength when the impedance ratio is $R = 1$, which corresponds to uniform impedance resonator (UIR), making the analysis useful in UIR. It should also be noted that the resonator length can be reduced only if R is less than 1.

For the even-mode resonance excitation, the symmetry plane OO' will be an open circuit, and the equivalent circuit is shown

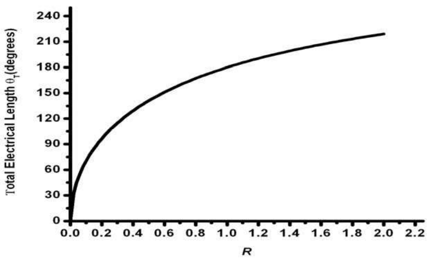

Figure 2. Total electrical length of the resonator (θ_T) Vs impedance ratio R.

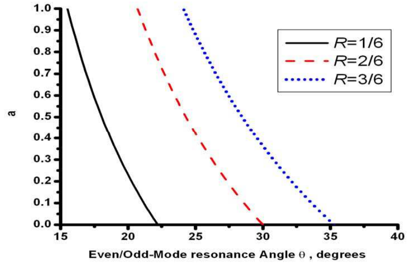

Figure 3. Electrical length (θ) of even and odd ($a = 0$) mode resonant as function of a.

in Figure 1(c). The equivalent circuit for the even-mode is now composed of two transmission line sections with different characteristic impedances z_1 and z_2, and terminated by a load inductance. The input admittance for the even-mode can be expressed as:

$$Y_{even} = j\frac{\frac{z_1}{z_2}\tan(\theta_y+\theta_L)\tan(\theta_y)-1}{z_1\tan(\theta_y+\theta_L)+z_2\tan(\theta_y)} \tag{5}$$

where $\theta_L = a\theta_y$ represents the electrical length of the short inductive element L, shunted at the midpoint of the resonators. The input admittance for the even-mode at the resonance condition is given by

$$Y_{even} \mid= 0 \Rightarrow \tan(\theta_y+\theta_L)\tan(\theta_y) = \frac{z_2}{z_1} \tag{6}$$

The electrical length of the even-mode resonance as a function of parameter a is shown in Figure 3. It can be seen that with a finite value of a, an even-mode resonant exists, resulting in a dual-mode resonant. By selecting a small value for a, the even-mode resonance is exhibited to be close to the odd-mode resonance, where the odd-mode resonance can be identified from Figure 3 when a is zero.

3. MINIATURIZED MATCHED SINGLE BANDSTOP FILTER

In this section, a technique that will allow us to achieve a miniaturized matched single band-stop filter for a wireless communication is proposed, which is accomplished by incorporating an inverter $K_3 = 90°$ between the input (I/P) and output (O/P) of the stepped impedance

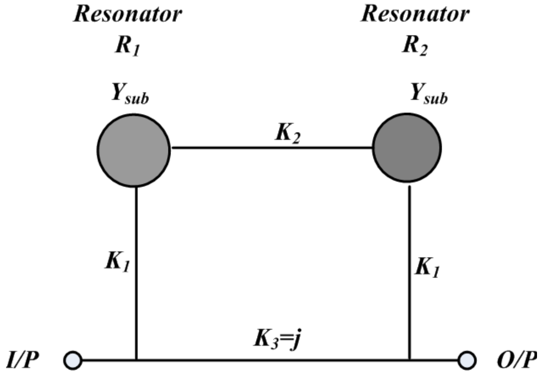

Figure 4. Generalized coupled-resonator model of a matched band-stop Filter [7].

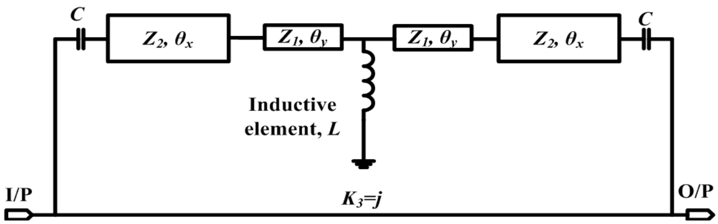

Figure 5. Circuit implementation of miniaturized matched band-stop filter.

dual mode resonator, shown in Figure 1(a). The new band-stop filter and its equivalent circuit are displayed in Figures 4 and 5.

It can be seen in Figure 5, just as the method discussed in Section 2, that the low z section of both the left and right sides have an electrical length of θ_x, and a characteristic impedance of z_2. The high z sections of both the left and right sides have an electrical length of θ_y and characteristic impedance of z_1. The coupling K_1 between the input and output is obtained by a microstrip inter-digital capacitor available in Agilent's Advanced Design System (ADS). The inter-resonator coupling K_2 is realized by a short circuit via hole shunted at the midpoint of the resonator.

The even- and odd-mode admittances of the generalized coupled resonator model shown in Figure 4 are [7]:

$$Y_{even}(p) = -j + \frac{K_1^2}{Y_{sub} + jK_2} \tag{7}$$

and

$$Y_{odd}(p) = \frac{1}{Y_{even}(p)} \tag{8}$$

The transmission and reflection functions of the filter can be calculated from the odd- and even-mode admittance and are given by [1]

$$S(1,2) = \frac{Y_{odd}(p) - Y_{even}(p)}{(1 + Y_{odd}(p))(1 + Y_{even}(p))} \tag{9}$$

$$S(1,1) = \frac{1 - Y_{even}(p)\,Y_{odd}(p)}{(1 + Y_{odd}(p))(1 + Y_{even}(p))} \tag{10}$$

4. MINIATURIZED DUAL BAND MATCHED BAND-STOP FILTER

In this section, a novel structure of perfectly matched dual-band band-stop filter is proposed. The circuit model of this filter is shown in Figure 6. The proposed topology is designed by cascading the single miniaturized matched band-stop filters, as shown in Figure 5. This filter is fabricated on Roger RT/Duroid 5880 substrate, having a relative dielectric constant of 2.2, with a thickness of 787 μm, at fundamental resonance frequencies of 0.99 GHz and 1.04 GHz.

5. FABRICATION AND MEASUREMENT

This section contains the measurements obtained from the proposed prototypes. The section is divided in two subsections: Subsection 5.1 shows the measured results concerning the band-stop filter, while Subsection 5.2 describes the results concerning dual-band matched band-stop filter. All measurements were done after an open, short, load, through calibration, setting the measurement reference plane at the SMA coaxial connectors used to interface the filter with the measurement equipment.

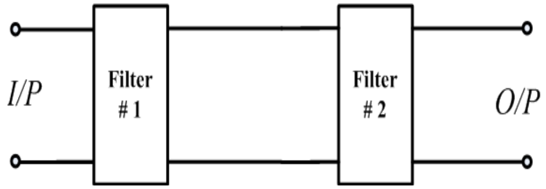

Figure 6. Model of the miniaturized dual band matched band-stop filter.

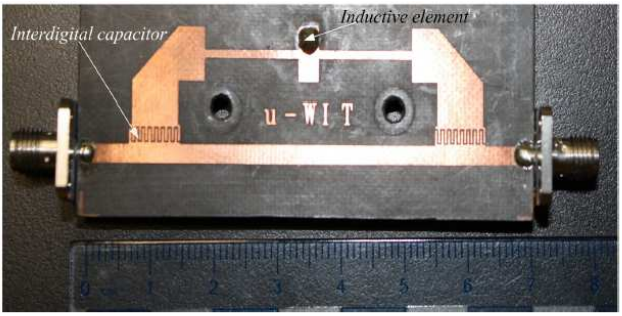

Figure 7. Photograph of the miniaturized matched band-stop filter.

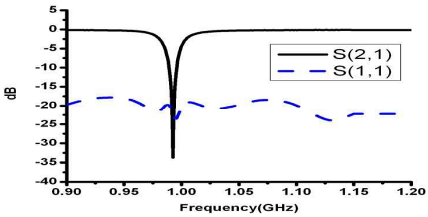

Figure 8. Measured transmission and reflection responses of the miniaturized matched band-stop filter.

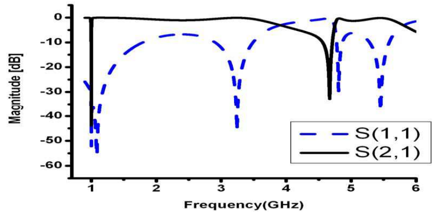

Figure 9. Simulated broadband transmission and reflection responses of the miniaturized matched band-stop filter.

5.1. Measured Results Concerning Single Band-stop Filter

To experimentally demonstrate this type of filter, a novel matched band-stop filter, based on a stepped impedance resonator was designed and fabricated on a Roger Rt/Duroid 5880 substrate, with a relative dielectric constant of 2.2 and thickness of 787 µm. The microstrip circuit prototype is shown in Figure 7. The total size of the circuit is 7 cm × 3 cm, and the measured frequency responses of insertion loss S (2, 1) and return loss S (1, 1) are shown in Figure 8, obtained using an Agilent network analyzer. The insertion loss is around 33.70 dB, while the return loss is around 18 dB. Additionally, simulation of the broadband transmission and reflection responses is shown in Figure 9, where the first spurious resonance occurs at 4.7 times the fundamental frequency. As a result, the spurious resonance frequencies do not equal the integral multiples of the fundamental resonance frequency. This band-stop filter therefore selectively removes only the fundamental resonance frequency signal when such a resonator is implemented. The principal advantage of the miniaturized matched band-stop filter is that it exhibits ideal interference attenuation and provides system impedance matched compared to the conventional band-stop filter.

5.2. Measured Results Concerning Dual Band Band-stop Filter

A miniaturized dual-band matched band-stop filter is designed by simply cascading the two single miniaturized matched band-stop filters with a centre frequencies of 0.99 GHz and 1.04 GHz.

Figure 10 shows the microstrip circuit prototype of the new dual band-stop filter. The measured transmission and reflection responses are shown in Figure 11, which shows the existence of two notches, centered at 0.99 GHz and 1.04 GHz. The measurements show that

Figure 10. Photograph of dual-band band-stop filter design.

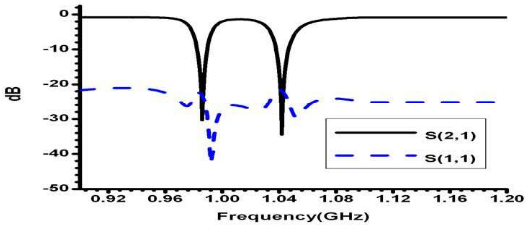

Figure 11. Measured response for miniaturized dual band matched band-stop filter.

by cascading two single miniaturized matched band-stops filter at center frequencies of 0.99 GHz and 1.04 GHz, we are still able to obtain a perfectly matched response at all frequencies. Note that such a performance cannot be achieved using the conventional band-stop filter. Therefore, the new scheme is capable of generating multiple stop-bands at desired frequencies, which makes it suitable for wireless applications.

6. CONCLUSIONS

A miniaturized matched band-stop filter has been proposed, based on a stepped impedance resonator. In contrast to a dual-mode ring resonator that has an electrical length of 360°, this filter yields a circuit size reduction of 50%. Two filters of this kind have been cascaded to achieve a dual-band matched band-stop filter. The proposed dual-band shows high stop-band attenuation. Note that such results cannot be obtained using a conventional band-stop filter. The new prototypes were designed to suppress the interference among communication systems due to coexisting narrowband applications, especially in an aircraft flight system. Potential future work includes the realization of reconfigurable band-stop to all pass filters.

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