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Efficient Microstrip Diplexer Employing a New Structure of Dual-Mode Bandpass Filter

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Abstract

In this paper, a highly efficient design for microstrip diplexer employing a new configuration of dual-mode squared shape bandpass filters is introduced. The proposed diplexer consists of two dual-mode bandpass filters (BPFs), a matching network, which is utilized to ensure that the two BPFs and the antenna port are properly matched resulting in good isolation between the transmitter (Tx) and the receiver (Rx) branches. For the proposed BPFs, the transmission zeros of each BPF are adjusted to the nearest passband center frequency, which makes them very selective to achieve high isolation between the Tx and Rx frequencies. This also provides a low-frequency space ratio and low insertion loss. The proposed diplexer improves the channel isolation, bandwidth with compact size of $(80 \times 50)\, mm^2$. Based on this structure, the proposed diplexer has good insertion losses of about 1.1 dB and 1.2 dB at transmit frequency $f_t = 1.82\, GHz$ and receive frequency $f_r = 2\, GHz$, respectively. The achieved fractional bandwidth is 3.2% at 1.82 GHz and 3.0 % at 2 GHz. The achieved simulated isolation levels are 35.5 dB and 44 dB for Tx and Rx frequencies, respectively. The proposed diplexer is useful for several wireless communication applications such as WLAN, GPS and global mobile system (GMS).

Keywords: Band pass filter (BPF); Diplexer; Impedance matching; Dual-mode resonator (DMR).

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1. Introduction

In this paper, a new microstrip diplexer is designed and simulated for L-band applications such as, Wi-Fi devices, mobile phones systems, GPS systems [1]. The planar diplexers are easier to be manufactured using Computer Numerical Control (CNC) technology, especially the microstrip diplexers. The diplexer is a light weight passive device that offers the advantages of compact size, high performance, high reliability, and low price [2]. These advantages make diplexers very well suited for many applications such as cellular phones, satellite communication systems, wireless, mobile phones G4, GPS systems, WLAN, and commercial applications. The principal role of a diplexer is to route the signal from the transmitter (Tx) to the antenna at desired trans frequency only, and from the antenna to the receiver (Rx) at desired frequency only at the same time. Besides, it isolates the receiver from the transmitter while permitting them to share a common antenna, and it provides compact size components, which are of great importance in modern wireless communication systems [3, 4]. diplexers are essential components used to minimize the number of antennas in modern high-speed wireless communication such as code-division-multiple-access (CDMA), global system for mobile (GSM), and universal mobile telecommunication systems (UMT) which require high-performance, low insertion loss [5, 6]. Due to the rapid development of the wireless communication technology, many applications operate in two discrete frequency bands, that is why we have to use high selectivity band pass filters. The diplexer consists of two dual-mode filters operating at Tx /Rx frequency channels. The filters are connected by a combining network. The combining network is T-junction shape used to guarantee that both filters and the antenna are properly matched. It is used to ensure adequate isolation between Tx and Rx frequencies through a three-terminal matching network [7]. Nevertheless, designing a combining network that can offer excellent transmission in one pass band while also providing high attenuation in the other pass band is a challenging task. The impedance of the T-junction shaped combining network has been frequently utilized in diplexers as a three-port matching. The dimensions of the T-junction must be carefully selected.

Many studies have recently concern developing a high-performance diplexer having a compact size, low insertion loss (IL), excellent frequency selectivity, and high isolation [8]. The coupling feeding line was used to design the microstrip diplexer. It was divided into two-parts to achieve low insertion loss and high isolation; however, it has poor frequency selectivity. To minimize the diplexer size, the Stepped Impedance Resonator (SIR) and the square dual-mode resonator have been utilized as a common resonator [9], but the isolation seemed hard to control. Recently, the diplexer based on left-handed/right-handed (LH/RH) resonators have been introduced, nevertheless, they suffer from high return loss and low isolation. In [10], a compact size diplexer using composite right/left handed transmission line resonators has been proposed, however, the isolation needs further improvement. In this paper, a new microstrip diplexer is introduced. The proposed diplexer consists of two dual-mode bandpass filters (BPFs), and a utilizes combining network. The combining network ensures that the two BPFs and the antenna port are properly matched by connecting them with a conventional T-junction. The T-junction acts as a combining circuit, resulting in good isolation between Tx and Rx frequencies. They also enhance the frequency ratio, scattering parameters, and insertion loss. This enhancement is achieved by adjusting transmission zeros of each filter to the nearest passband center frequency. The proposed diplexer has high channel isolation, narrow bandwidth, and low insertion loss.

2. Related Work

There are many literature papers that aimed to improve the performance of microstrip diplexer. In [1], authors proposed a high-isolation microstrip diplexer with enhanced stopband characteristics for GSM and Wireless Local Area Network (WLAN) application. Their diplexer consists of two compact bandpass filters (BPFs) using short-circuit centered stepped impedance resonators (SCSIRs). In [10], authors proposed A compact triplexer based on E-stub-loaded composite right-/left-handed (ESL-CRLH) resonators with quasi-lumped impedance matching network for high isolations among the ports and low in-band insertion losses of the three filter channels. Authors in [12] proposed a new compact short stub-loaded composite right/lefthanded (SSL-CRLH) resonator. Their work aimed to realizes size miniaturization and have a tunable center frequency and bandwidth by changing the length of the CRLH-TL unit cell and the short stub, respectively. In [8], authors proposed a highly efficient microstrip diplexer with low insertion loss, high selectivity, and high isolation by employing two compact size coupled squared open-loop resonator (SOLR) based band pass filters (BPFs). The authors claimed that their proposed diplexer is useful for several wireless communication applications such as WiMAX. in [16], authors proposed A high selective bandpass filter and a high isolation diplexer by using mixed electromagnetic coupling. In [17], authors proposed a high isolation substrate integrated waveguide (SIW) diplexer using dual-mode resonators. While in [15], a compact wideband diplexer is designed by combining two wideband filters based on stub-loaded square ring resonator (SLSRR). By adjusting the length of the stub or square ring, the passband bandwidth can be adjusted. A new diplexer design of a new-coupled composite right/left-handed (CRLH) resonator to serve the LTE applications is proposed in [18]. The realization of the diplexer is designed as coupled two zeroth order π-CRLH resonators to represent with zero electrical length and hence attaining a significant size reduction.

3. Proposed Diplexer

In this section, the proposed diplexer is discussed in detail. The proposed three-terminal diplexer consists of two bandpass filters with two resonance frequencies of 1.82 GHz and 2 GHz. The selected frequencies are used to design the diplexer to build up the required band pass filters for desired frequencies. The proposed diplexer is designed and simulated on Arlon AD1000 substrate having a thickness $h = 1.27\ mm$ and a relative dielectric constant $\varepsilon_r = 10.2$. The simulations are carried out using the Computer Simulation Technology (CST) microwave studio software package (CST-MWS-2018). The diplexer design procedure followed two steps:

- Design of the proposed two bandpass filters BPFs at the desired Tx and Rx frequencies.
- Design of the proposed microstrip diplexer by combining the proposed BPFs.

3.1. The proposed dual-mode resonator-based BPFs

The first squared shape dual mode resonator was proposed by Wolff (1972). It has been widely used in modern microwave communications. It has attractive features of low radiation loss, low fabrication cost, and narrow bandwidth. The microstrip dual-mode bandpass filter resonator is one of the most basic and commonly used structure for filter construction [10]. Figure 1 shows the proposed bandpass filter based on square closed loop resonator. It is designed at 2 GHz with a small perturbation element of dimension $(p \times p)\ mm$. This square loop resonator is designed to have perimeter length equal to the guided wavelength (λ_g), which depends on the desired frequency and specifications of the dual-mode BPF. To enhance the coupling between input and output ports, they are connected to the square ring resonator through middle coupling arms at 180° and 270° as shown in Figure 1. The perturbation stub is positioned at 45° from square resonator center and the feed lines are positioned orthogonally to the square center. The mean perimeter of the square resonator (D) is given by:

$$D = 4\, l_o = n\lambda_g \qquad (1)$$

$$f_o = \frac{nc}{4lo\sqrt{\varepsilon_{eff}}} \qquad (2)$$

Where n is the mode number, λ_g is the guided wavelength, lo is the mean width of the square resonator, ε_{eff} is substrate relative permittivity, and c is speed of light. By feeding a microwave signal into port #1, the microwave signal is split up into two components [11], which are transmitted through two different paths along the square resonator. The two components reach port #2 after travelling 90° and 270° and combined as an output microwave signal into the desired band pass frequency. The two transmission zeros are adapted to the required frequency to isolate any other frequencies to guarantee high frequency selectivity. The simulation results show a good reflection characteristic, whereas they show a relative low insertion loss of about 0.96 dB and a 3dB bandwidth of about 70 MHz:

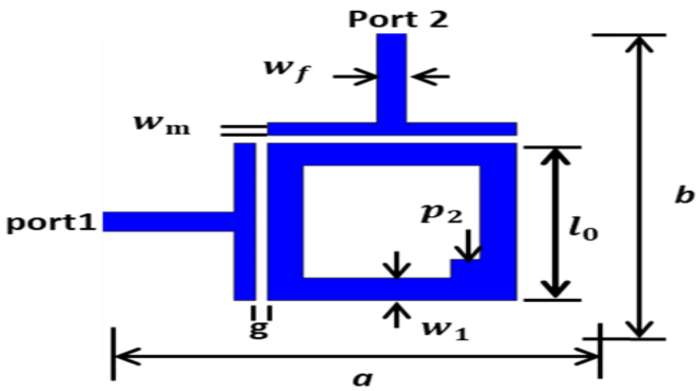


Figure 1: The configuration of proposed dual-mode BPF.

Table 1: The dimensions of the proposed BPF in (mm).

w_1	l_0	w_m	a
4	18.4	0.5	60
w_f	p_2	g	b
1.2	1.8	0.2	50

For more performance enhancement, the feed line is situated in the middle of the resonator because the resonator cannot be stimulated at that position. The use of asymmetric feeding and electric coupling, improves the BPF characteristics by adapting two transmission zeros on both sides of the pass band and, hence, the BPF selectivity is significantly increased [12]. Figure 2 displays the simulation results of the proposed BPF using the CST-MWS simulator. The BPF has a center frequency of 2 GHz, a fractional bandwidth of 3.3%, and an insertion loss of 1.05 dB.

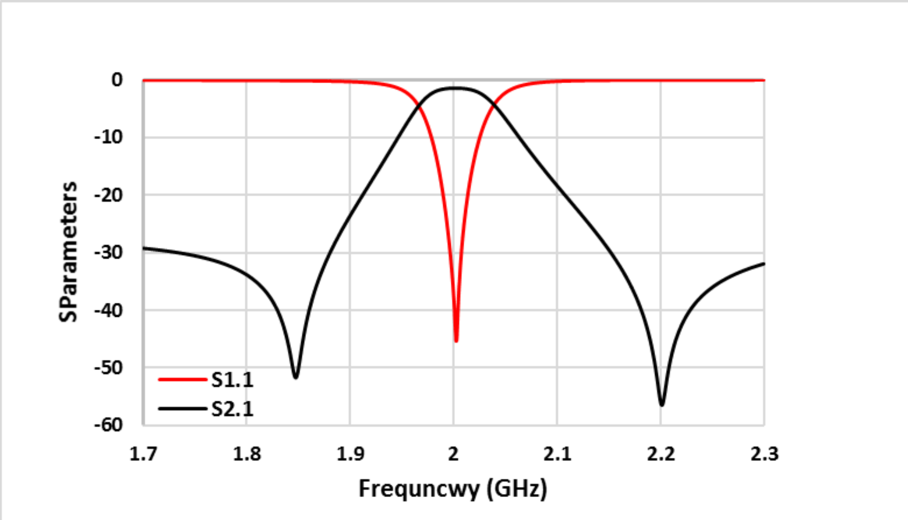


Figure 2: Simulated scattering parameters of the proposed BPF.

3.2. Structure of the Proposed Microstrip Diplexer

Microstrip diplexers are designed using different types of filter combinations, such as low pass and high pass filters, or bandpass and band stop filters [13]. In the proposed diplexer, two band pass filters are used. The proposed diplexer construction begins with the design of two based BPFs operating at 1.82 GHz and 2 GHz for transmitting and frequencies, respectively. The two filters are connected to each other through T-junction to feed the transmit, receive and the antenna ports [14]. The isolation between Tx and Rx frequencies is dependent on the suitable choice of the width and length of the T-junction branches. Figure 3 clarifies the final configuration of the proposed diplexer, which shows two Square Loop Resonator SLRs-based PBFs with the dimensions listed in Table 2.

Table 2: The dimension of the proposed diplexer in (mm).

w_1	p_1	l_{01}	g	w_m	a
3.2	1.76	19.1	0.2	0.5	80
w_2	p_2	l_{02}	w_f	w_{inp}	b
2.8	1.59	17.2	1.2	1.2	50

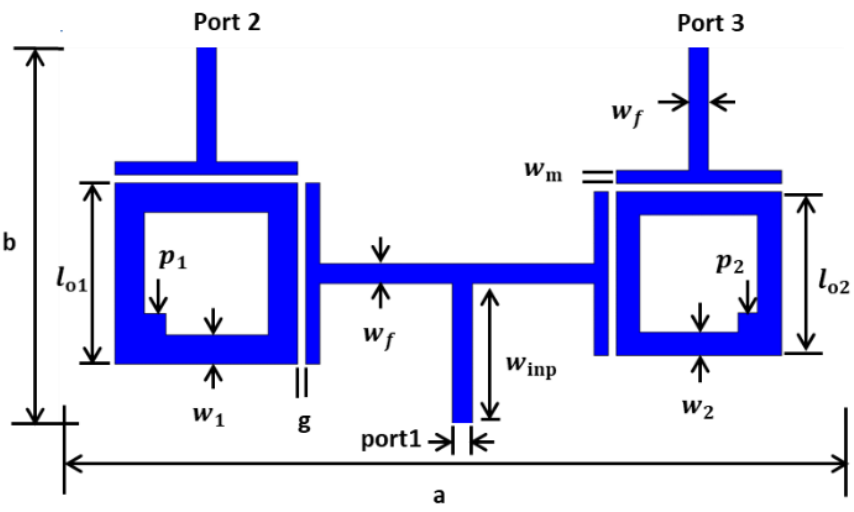


Figure 3: The final configuration of the proposed diplexer.

To obtain a high degree of isolation between Tx and Rx frequencies, the design involves moving one of the transmitter filter zeros in the middle of the receiver filter frequency. This concept improves the mutual interference between Tx and Rx frequencies and explains the good isolation between them. Figure 4 shows simulation results of the scattering parameters |S11|, |S12|, |S13|, and |S32| versus frequency. It also clarifies that the proposed isolation is successfully achieved around 40 dB for the two bands. By analyzing the results, it is found that the insertion loss of the two BPFs are 1.1 dB and 1.2 dB at 1.82 GHz and 2 GHz, respectively with 3 dB bandwidths of 0.06 GHz for the 1.82 GHz band and 0.06 GHz at the 2 GHz band, with realized fractional bandwidths of 3.2% and 3% at 1.82 GHz and 2 GHz bands, respectively.

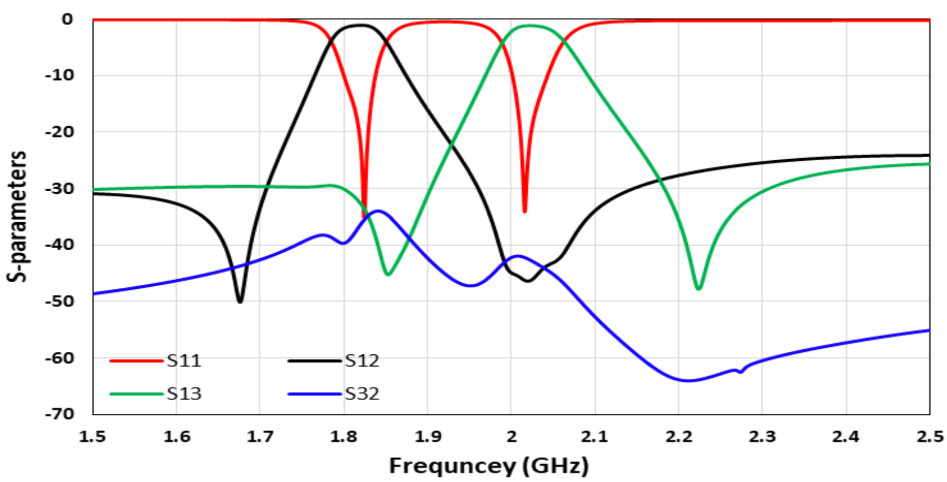
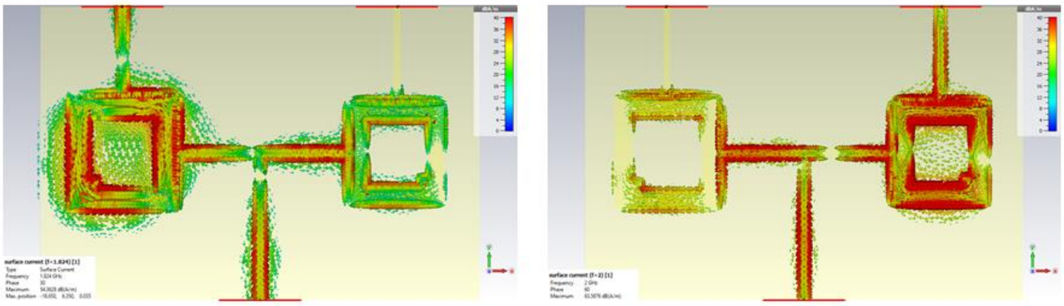


Figure 4: Simulated scattering parameters of the proposed diplexer.

The lower-band transmit BPF is designed with its two transmission zeros such that one of them is located in the passband of the higher-band receive BPF, in the transmit BPF's passband, the higher-band receive BPF has a transmission zero. Based on this concept, the lower and upper passbands are well isolated which improves their mutual interference, depicts the optimal simulation results of the three scattering parameters |S11|, |S21|, and |S31| as a function of frequency for the proposed diplexer, as well as the success of the suggested isolation concept. Figure 5 (a), and (b) show the surface current distributions of the proposed diplexer at Tx and Rx frequencies, respectively. When the diplexer is operating at the Rx passband, 2 GHz, high surface current is concentrated mostly in the Rx channel and antenna port, whilst the Tx channel is good isolated, and vice versa.



(a) (b)

Figure 5: Distributions of surface currents of the proposed diplexer (a) $f_t = 1.82\ GHz$ and (b) $f_r = 2\ GHz$.

4. Comparison With Related Work

In this section, a comparison is performed between the proposed diplexer and the related work to demonstrate the benefits of the proposed diplexer, as shown in Table 3. The proposed diplexer has the lowest insertion loss for both Tx and Rx frequencies so far. Regarding to the isolation, the proposed diplexer is superior than other related work except for [8] and [14], which have greater isolation but yet less fractional bandwidth. Even though the proposed diplexer has a somewhat larger size than [10] and [15], the proposed diplexer has significantly higher selectivity and better isolation. Finally, the design in [8], on the other hand, has a less fractional bandwidth and higher isolation but yet greater insertion loss and larger size. This comparison shows that the proposed diplexer outperforms the competitors in terms of size and performance characteristics.

Table 3: A comparison between proposed diplexer and the related work.

Diplexer	Frequency (GHz)	Fraction BW %	Insertion loss (dB)	Isolation (dB)	Size w. r. to λ_g^2
This work	1.82/2	3.2 /3	1.1 /1.2	35/45	0.26
Ref. [1], 2013	1.8/2.45	3.8/8.2	1.9/1.38	NA	0.32
Ref. [10], 2018	1.86/2.41/3.25	7.5/5.3/6.3	2.35/2.33	>30	0.053
Ref [12], 2017	2.6/2.9	6.1/5.3	1.93/2.02	>23	(0.31×0.09)
Ref. [8], 2021	2.5/2.8	2.8/3.2	1.6/1.3	70/50	0.32
Ref.[16], 2015	2.4/3.42	7.2/7.2	1.43/1.56	> 40	0.27
Ref. [17], 2020	8.04/9.07	4.23/4.19	2.35/2.33	49.53	4.6
Ref. [15], 2021	4.3/8.75	50/51.4	2.3/3.0	25	0.13
Ref.[18], 2021	2.1/2.6	4/4	1.4/1.3	> 40	0.59

5. Conclusion

In this paper, a highly efficient design for a microstrip diplexer with very good selectivity, good isolation, and lowest insertion loss based on the utilization of two dual-mode BPFs is introduced. The diplexer utilized the T-junction as a combining circuit to connect the two BPFs, which in turn improved the insertion loss for the transmitting and receiving bands of the diplexer. The proposed diplexer has a compact size of $0.26\,\lambda_g^2$. The achieved isolation is around 40 dB for the two bands. It also provided low insertion losses of 1.1 dB and 1.2 dB at 1.82 GHz and 2 GHz, respectively with 3 dB bandwidths of 0.06 GHz for the 1.82 GHz band and 0.06 GHz at the 2 GHz band, with realized fractional bandwidths of 3.2% and 3% at 1.82 GHz and 2 GHz bands, respectively.

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