Implementation of a Highly Selective Microstrip Diplexer with Low Insertion Loss Using Square Open-Loop Resonators and a T-Junction Combiner

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Abstract. *In this paper, the design and hardware implementation of a squared open-loop resonator (SOLR)-based microstrip diplexer with high isolation, low insertion loss, and high selectivity are introduced. We employed four SOLRs, with each pair of coupled SOLRs used to build a high selectivity bandpass filter (BPF). To assemble the proposed diplexer, the designed BPFs are linked together via a T-junction combiner that is matched to the two filters and the antenna port. For transmit and receive modes, the proposed diplexer has two resonance frequencies of* $f_t = 1.81$ *GHz and* $f_r = 2.03$ *GHz, respectively achieving a small frequency space ratio of R = 0.114. The simulated structure exhibits good insertion losses of about 1.98 dB and 1.9 dB for the two channels, respectively, with fractional bandwidths of 2.25% at 1.81 GHz and 3% at 2.03 GHz. For 1.81 GHz and 2.03 GHz, the simulated isolation values are 58 dB and 46 dB, respectively. While the fabricated structure exhibits better insertion losses of about 1.25 dB and 1.22 dB at the measured transmit and receive frequencies of 1.801 GHz and 2.001 GHz, respectively, with smaller fractional bandwidths of 2.23% at 1.801 GHz and 2.98% at 2.001 GHz. For 1.801 GHz and 2.001 GHz, the measured isolation values are 48.99 dB and 57.02 dB, respectively.*

Keywords

Band-pass filter (BPF), microstrip diplexer, square open loop resonator (SOLR), T-junction combiner

1. Introduction

The recent advancements in radio frequency and microwave applications have accelerated the development of new wireless communication systems. This research focuses on mobile communication systems, where the diplexer is commonly used to share a single antenna for signal transmission and reception. Thereby, developing a low-cost and high-performance diplexer is a top priority. For many years, square open-loop resonators have been utilized in the design and execution of compact high-performance microwave bandpass filters, which are at the core of the design of diplexers [1], [2]. In bandpass filter-based diplexer systems, the spurious response of a bandpass filter results in a poor isolation performance. As a result, developing new configurations of square open-loop resonators is needed. As a solution for miniaturizing the filter and diplexer construction, a compact diplexer based on a square open loop with stepped impedance resonators has been presented in [2]. In the design of microstrip diplexers, the T-junction is one of the most often utilized combining circuits. Its dimensions must be carefully calculated so that each filter can match the antenna in one band while providing an open circuit in the other [3]. In [4], a microstrip diplexer design for RFID applications is proposed, which is based on combining two square open-loop resonator-based bandpass filters through a T-junction. Despite its tiny size, this diplexer offered high selectivity, low insertion loss, and good isolation larger than 40 dB, according to the presented simulation and measurement results. In [5], a new microstrip diplexer has been developed by coupling a dual-band bandpass filter via two individual channel filters. In contrast to the traditional design technique, which requires separate connections or junctions for energy distribution, this design eliminates the need for external junctions in diplexer construction. The simulation and experimental measurements demonstrated a 50 dB isolation between transmit and receive bands of the diplexer. It did, however, provided high insertion losses of 2.88 dB and 2.95 dB in transmit and receive bands, respectively. In [6], a new microstrip diplexer with good selectivity and isolation has been introduced. It is developed for LTE applications and is based on combining two small-size bandpass filters made up of open/shorted lines and an open stub.

In this paper, a new design for a three-port microstrip diplexer with high isolation and minimal insertion loss is introduced. The proposed diplexer is realized on a Rogers TMM4 substrate of thickness $h = 1.52$ mm, relative permittivity $\varepsilon_r = 4.5$, and tangent loss $\delta = 0.002$. The structure exhibits good insertion losses of about 1.98 dB and 1.9 dB

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for transmit and receive channels, respectively, with fractional bandwidths of 2.25% at 1.81 GHz and 3% at 2.03 GHz. For 1.81 GHz and 2.03 GHz, the simulated isolation values are 58 dB and 46 dB, respectively. Fortunately, the manufactured prototype of the proposed diplexer exhibits superior measured characteristics than the simulated ones. The measured insertion losses are 1.25 dB and 1.22 dB that are smaller than the simulated ones, in addition to achieving smaller fractional bandwidths of 2.23% and 2.98% at the measured transmit and receive frequencies 1.801 GHz and 2.001 GHz, respectively.

2. Proposed SOLR-Based Microstrip Diplexer

In this section, the computer simulation technology (CST) microwave studio software package (CST-MWS-2019) is used to introduce a new design for a highly efficient microstrip diplexer operating at f_t = 1.81 GHz and f_r = 2.03 GHz for transmit and receive modes, respectively. The proposed diplexer is realized on the aforementioned Rogers TMM4 substrate. The proposed diplexer is mainly based on combining two selective BPFs tuned at the desired transmit and receive frequencies f_t = 1.81 GHz and f_r = 2.03 GHz, respectively. The two BPFs are combined using a T-junction. Accordingly, the design procedure of the proposed diplexer can be performed in two steps as follows:

- Design of transmit and receive BPFs.
- Assembly of the proposed microstrip diplexer.

2.1 Design of the Transmit and Receive BPFs

In this section, the designs of transmit and receive BPFs using electrically coupled SOLRs are introduced. The SOLR was chosen as it is one of the most basic and widely used structures for filter design owing to its compact size of approximately $(\lambda_g/4)\times(\lambda_g/4)$, where λ_g is the guided wavelength at the center frequency of the operating band [9]. For transmit BPF design, two electrically coupled SOLRs are utilized as shown in Fig. 1, each with a total length of about $(\lambda_g/2)$ at the transmit frequency f_t = 1.81 GHz. The dimensions of the filter are listed in Tab. 1. The separation gap g_2 controls the internal capacitance of each resonator, which, along with the width and length of the trace line, regulates the filter's selectivity and insertion loss.

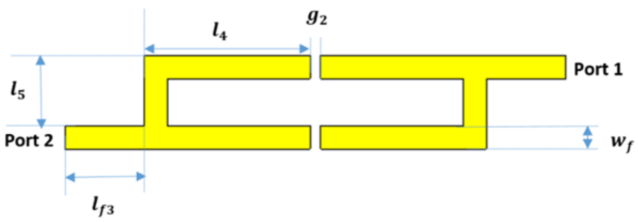


Fig. 1. The geometrical structure of the electrically coupled SOLR-based transmit BPF with resonance frequency f_t = 1.81 GHz.

l_4	l_5	l_{f3}	g_2	w_f
20.95 mm	8.86 mm	10 mm	1.3 mm	2.86 mm

Tab. 1. Dimensions of the proposed transmit BPF.

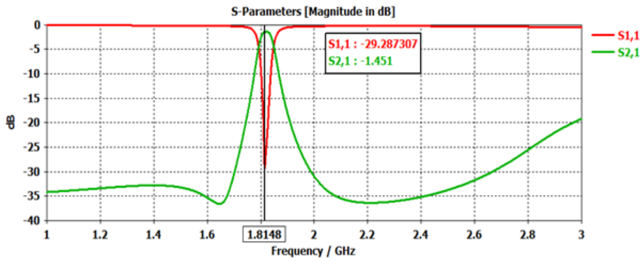


Fig. 2. Simulated S-parameters of the transmit BPF.

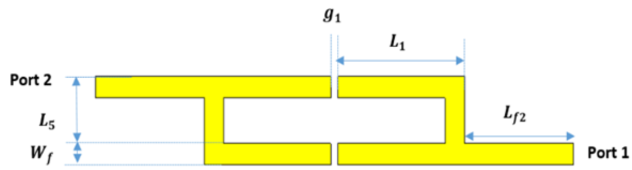


Fig. 3. The geometrical structure of the electrically coupled SOLR-based receive BPF with resonance frequency f_r = 2.03 GHz.

L_1	L_5	L_{f2}	g_1	W_f
18.45 mm	8.86 mm	15.94 mm	1.1 mm	2.86 mm

Tab. 2. Dimensions of the proposed receive BPF.

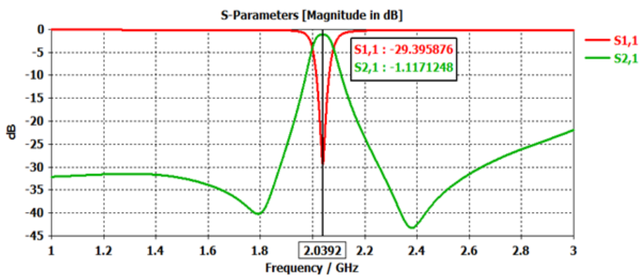


Fig. 4. Simulated S-parameters of the receive BPF.

Figure 2 displays the simulated scattering parameters of the proposed transmit BPF using the CST microwave studio. The BPF has a center frequency of 1.81 GHz, a 3dB bandwidth of 67.1 MHz, a fractional bandwidth of 3.7%, a return loss of 29.28 dB, and an insertion loss of 1.451 dB.

Following the same concept, the proposed receive BPF is shown in Fig. 3 whose dimensions are listed in Tab. 2. The simulated scattering parameters of the receive BPF are shown in Fig. 4. By analyzing the curves, it is found that the BPF has a center frequency of 2.03 GHz, a 3dB bandwidth of 89.7 MHz, a fractional bandwidth of 4.42%, a return loss of 29.39 dB, and an insertion loss of 1.117 dB.

2.2 Assembly of the Proposed Microstrip Diplexer

In this section, the entire configuration of the proposed diplexer is introduced by connecting the two afore-

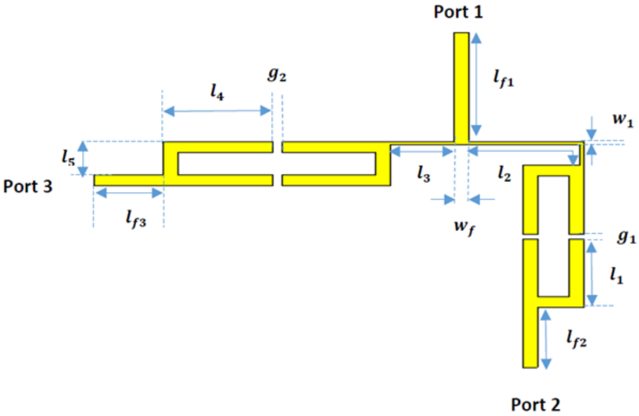


Fig. 5. The structure of the proposed diplexer.

l_{f1}	l_{f2}	l_{f3}	l_1
29.34 mm	15.94 mm	13.4 mm	18.45 mm
l_2	l_3	l_4	l_5
28.25 mm	12.4 mm	20.95 mm	8.86 mm
g_1	g_2	w_f	w_1
1.22 mm	1.789 mm	2.86 mm	0.655 mm

Tab. 3. Dimensions of the proposed diplexer.

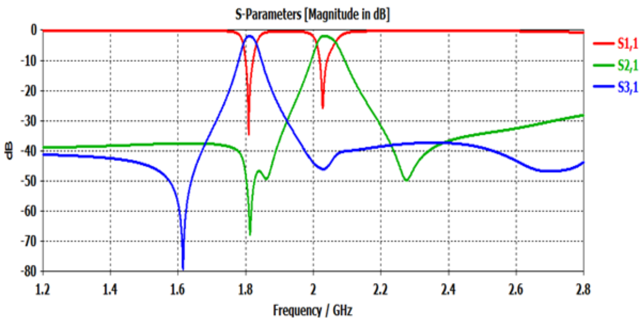


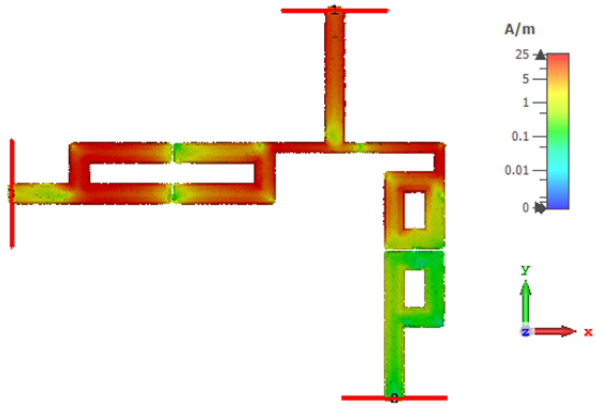
Fig. 6. Simulated S-parameters of the proposed diplexer.

mentioned SOLR-based BPFs presented in Sec. 2.1 through a T-junction as shown in Fig. 5. The width and length of the T-junction branches control the isolation between transmit and receive channels. The dimensions of the proposed diplexer are listed in Tab. 3.

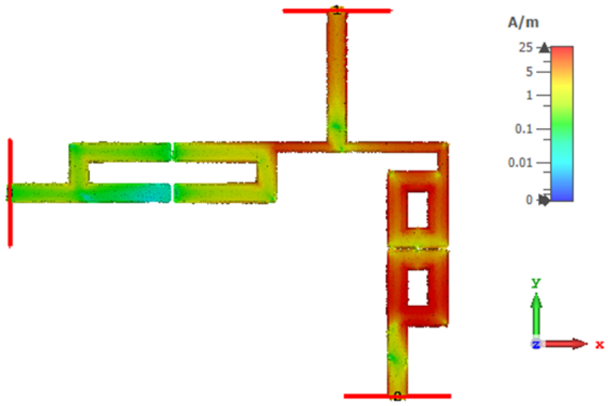
The simulation results of the scattering parameters $|S_{11}|$, $|S_{21}|$, and $|S_{31}|$ versus frequency for the proposed diplexer are shown in Fig. 6. The structure exhibits good insertion losses of about 1.98 dB and 1.9 dB for the transmit and receive channels, respectively, with fractional bandwidths of 2.25% at f_t = 1.81 GHz and 3% at f_r = 2.03 GHz. In other words, the 3dB bandwidths of transmit and receive bands are 40.8 MHz and 61.1 MHz, respectively. At 1.81 GHz and 2.03 GHz, the simulated isolation values are 58 dB and 46 dB and the return losses are 34.6 dB and 26 dB, respectively. Furthermore, the proposed diplexer achieves a small frequency space ratio R = 0.114 that is defined as the ratio between the spacing between transmit and receive frequencies $\Delta_f = |f_r - f_t|$ and the central frequency $f_c = (f_r + f_t)/2$ such that R is given by [7]

$$R = \Delta_f / f_c. \quad (1)$$

The simulated current distributions of the proposed diplexer at transmit and receive frequencies are shown in



(a)



(b)

Fig. 7. Surface current distribution of the proposed diplexer at (a) f_t = 1.81 GHz, and (b) f_r = 2.03 GHz.

Fig. 7. When the diplexer is set to transmit at f_t = 1.81 GHz, the path from port 1 to port 3 has a high current density, whereas the path from port 1 to port 2 is deemed open circuit, as illustrated in Fig. 7(a). On the other hand, when the diplexer is working at the receive frequency f_r = 2.03 GHz, the path from port 1 to port 2 has a high current density, but the path from port 1 to port 3 is deemed open circuit, as illustrated in Fig. 7(b). As a result, there is strong isolation between transmit and receive channels.

3. Manufactured Prototype of the Proposed Diplexer

The proposed diplexer is shown in Fig. 8 as a manufactured prototype on the Rogers TMM4 substrate with size of (109.34 × 83.785) mm^2. Figure 9 shows a comparison between the measured and simulated S-parameters $|S_{11}|$, $|S_{21}|$, and $|S_{31}|$ of the proposed diplexer using the Vector Network Analyzer (VNA) whose model is (Rohde & Schwarz ZVL20). While Fig. 10 shows a comparison between the measured and simulated scattering parameter $|S_{32}|$ of the proposed diplexer. The measured and simulated S-parameters at the measured transmit and receive frequencies f_t = 1.801 GHz and f_r = 2.001 GHz, respectively are listed in Tab. 4. It is evident that the fabricated structure exhibits better insertion losses of about 1.25 dB and 1.22 dB at the measured transmit and receive frequencies of 1.801 GHz and 2.001 GHz, respectively, with smaller fractional bandwidths of 2.23% at 1.801 GHz and 2.98% at 2.001 GHz. For 1.801 GHz and 2.001 GHz, the measured isolation values are 48.99 dB and 57.02 dB, respectively.

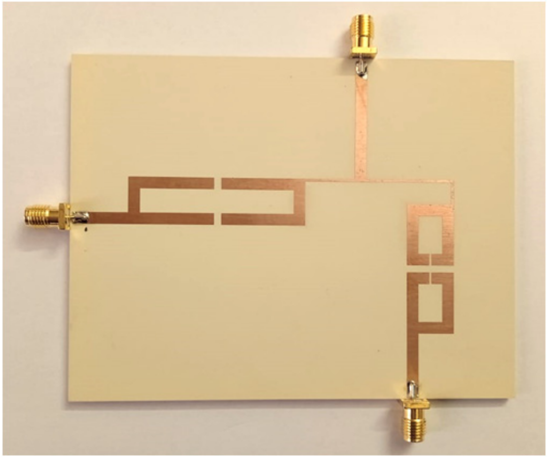


Fig. 8. Fabricated prototype of the proposed diplexer.

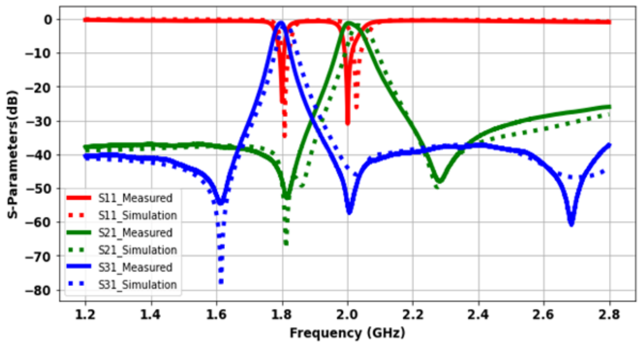


Fig. 9. Comparison between the measured and simulated scattering parameters of the proposed diplexer.

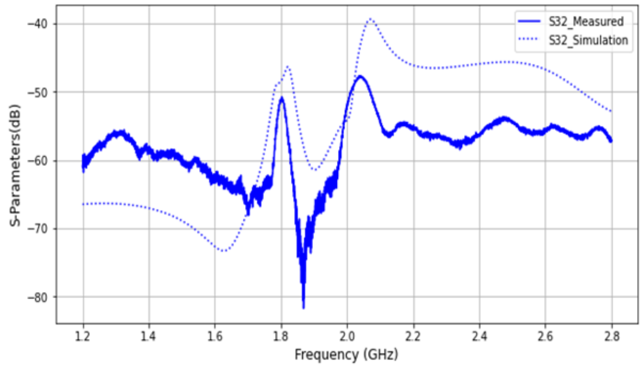


Fig. 10. Comparison between the measured and simulated scattering parameter $|S_{32}|$ of the proposed diplexer.

4. Comparison with State-of-the-Art Work

This section compares the proposed diplexer to the state-of-the-art work to show the proposed diplexer's features, which are presented in Tab. 5. In spite of the proposed diplexer having the largest size, it presented many effective features, and it may be suitable for the applications where the size is not a critical issue. Except for [2], which has a frequency space ratio $R = 0.1$, the proposed fabricated diplexer has the smallest FBWs of 2.23% and 2.98% (best selectivity) and the smallest frequency space ratio $R = 0.105$ so far. Furthermore, when compared to [2, 4, 6, 8, 9, 10, 11], the manufactured diplexer has the lowest insertion losses of IL = 1.25 dB / 1.22 dB and the greatest isolations of 48.99 dB / 57.02 dB at the measured frequencies f_t = 1.801 GHz and f_r = 2.001 GHz, respectively, with the exception of [10], which has the lowest insertion losses of 0.4 dB / 0.5 dB. In terms of fractional bandwidth, inser-

	Central frequency f_t and f_r (GHz)	$\|S_{11}\|$ (dB)	$\|S_{21}\|$ (dB)	$\|S_{31}\|$ (dB)	$\|S_{32}\|$ (dB)
Simulated	f_t = 1.81	–34.62	–48.99	–1.98	–47.61
Measured	f_t = 1.801	–24.47	–58.58	–1.25	–51.22
Simulated	f_r = 2.03	–26.1	–1.9	–46.03	–52.46
Measured	f_r = 2.001	–30.96	–1.22	–57.02	–52.09

Tab. 4. Comparison between the measured and simulated scattering parameters of the proposed diplexer at the measured and simulated transmit and receive frequencies.

Diplexer	Frequency (GHz)	FBW (%)	Insertion loss (dB)	Isolation (dB)	ε_r	R	Size λ_g^2
This work (Simulated)	1.81/2.03	2.25/3	1.98/1.9	58/46	4.5	0.114	1.5
This work (Measured)	**1.801/2.001**	**2.23/2.98**	**1.25/1.22**	**48.99/57.02**	**4.5**	**0.105**	**1.5**
[2]	1.9/2.1	3.07/2.8	3/3	<45	6.15	0.1	NA
[4]	2.2/2.6	4.55/5	1.6/1	<40	4.4	0.167	NA
[6]	1.8/2.1	5.5/6.2	2/1.8	<40	2.65	0.154	0.167
[8]	8.04/9.07	4.23/4.19	2.35/2.33	49/53	2.6	0.12	4.6
[9]	1.8/2.4	6/5.8	NA	<30	2.2	0.286	0.35
[10]	1.5/1.76	3.8/3.2	0.4/0.5	<30	3.38	0.159	0.19
[11]	0.9/1.8	NA	2.5/2.17	<20	2.2	0.667	0.097

Tab. 5. Comparison with state-of-the-art work.

tion loss, and isolation characteristics, the proposed manufactured diplexer surpasses the competition.

5. Conclusion

In this paper, a highly efficient microstrip diplexer with high selectivity, high isolation, low frequency space ratio, and low insertion loss is introduced. The manufactured diplexer exhibits low insertion losses *IL* = 1.25 dB / 1.22 dB and high isolations of 48.99 dB / 57.02 dB at the measured frequencies $f_t = 1.801$ GHz and $f_r = 2.001$ GHz, respectively. Furthermore, the proposed diplexer has a low frequency space ratio of $R = 0.105$ with small fractional bandwidths of 2.23% and 2.98% for the transmit and receive channels, respectively, which reflects the high selectivity of the diplexer.

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