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Review Article

A Review on the Structure, Application, and Performance of the Passive Microstrip Devices

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ABSTRACT

Microstrip technology is widely applied for design and implementation of several communication devices such as filters, diplexers, triplexers, multiplexers, and couplers. They are utilized to isolate desired signals and remove disturbing signals. The layout of filters, diplexers, and triplexers have two, three, and four ports, respectively. Passive filters have at least one pass channel, whereas diplexers have at least two channels to transmit the desired signal, and multiplexers have more passbands with more channels. To implement the passive components, first a cell called resonator must be designed. Creativity is very important in resonator design. It must be small and novel to get a better device than previous works. Therefore, the layout of the previous reported resonator, used in passive microstrip devices, is studied in this work. There is a fierce competition among designers to miniaturize and increase the device performance. Hence we, will investigate them, from the point of view size and performance, in this work. Some diplexers are multi-channel, which are more difficult to design than two-channel diplexers. Therefore, the multi-channel diplexers are less reported than the two-channel diplexers. The design of multiplexers is also very difficult because several channels must be controlled. Hence, they are less designed than filters and diplexers. The diplexers can be bandpass-bandpass or lowpass-bandpass, where the latest is less designed. This is because designing a lowpass-bandpass diplexer needs lowpass and bandpass resonators, whereas the design of a bandpass-bandpass diplexer needs only a bandpass resonator.

Keywords: Diplexer, filter, microstrip, multiplexer, multi-channel

INTRODUCTION

Modern wireless communication systems widely need to microstrip passive devices such as filters,[1-6] diplexers,[7-22] multiplexers (triplexers[23-30] and quadruplexers,[31-37] five-channel multiplexer[38]), and couplers.[39-49] For all of these passive devices, it is very necessary to have small dimensions, low insertion loss (IL), low return loss (RL), suppressed undesired harmonics, sharp roll-off at the edge of passbands (high frequency selectivity), etc. The number of reported lowpass and bandpass filters (BPF) is very high. Meanwhile, the designers in[1-2] could miniaturize the filters very well. The proposed filter in[1] works at 0.85 and 1.85 GHz for Mobile Communication-850 and 1900 Global Systems. In[3] the filter size is large but it can attenuate 28th harmonics up to 85 GHz, where it operates at 3 and 6.3 GHz. Coupled open loops have been utilized in[4] to obtain a dual band BPF for wireless local area networks. In[5] the number of filter channels are four, which is designed by a circular multi-mode resonator. The reported filters in[6] are single-band with wide and flat passbands. Several types of microstrip diplexers such as two-channel, multi-channel, bandpass-bandpass, and lowpass-bandpass are presented in.[7-22] They have three ports, called; port1, port2 and port3, which pass the desired signal through two different frequency channels. The channels are created among port1-port2 and port1-port3, so port1 is common. The designers have to establish high isolations between all channels. The dual-band bandpass-bandpass diplexers in[7-9] are very small, but the isolation between channels is neither good nor bad. In,[10] the number of channels is increased to four, which leads to increase the size. Two lowpass-bandpass diplexers have been designed in[11-12] with flat channels, while in[13-15] the advantage is their wide stopband. The design process become hard when we decrease the gap between channels. However, the reported diplexer in[16] has quite close channels. In the designs, it can be seen that when the engraved cells are

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used, the channels become relatively narrow.[17-18] The use of meandering cells in[19] and[20] leads to save the size, relatively. In,[21] a wide-band diplexer with low insertion losses at both channels is obtained based on stub loaded coupled lines. The proposed diplexer in[7] has several features in terms of very compact size, low-insertion losses, low-group delays at both channels, and wide fractional bandwidths. Large wide filled cells with spiral structures,[23] stub loaded coupled lines,[24] coupled hairpins,[25-28] and coupled open loops[29] have been used to design triplexers with four ports and three channels. The designers in[30] could get to very high isolation between channels using coupled U-shape structure. However, using this resonator leads to increase the size. Quadruplexers are types of multiplexers with five ports and four passbands.[31-37] In,[32] in addition to the quadruplexer, a five channel multiplexer is designed. Despite of having close channels, a high isolation between channels is obtained,[34] which is a great achievement. Microstrip couplers have four ports, which they should create two passing channels and an isolation channel.[39-49] In addition to losses and selectivity, the phase shift is an important factor. In 90° couplers, the phase difference between the two passing channels should be close ± 90°[39-41]. In zero-degree couplers, the phase difference between the two passing channels should be close to zero.[42]

In this work, we will study the structure advantages and disadvantages of these passive microstrip devices. Since filter design is the basis of other designs, several filters will be studied first. Then, the types of diplexers will be examined and compared. After that, the structure of triplexers and quadruplexers with their performance comparison will be presented. Finally, couplers structures and their performance will be studied.

STRUCTURES, PERFORMANCE, AND APPLICATIONS OF FILTERS

Several types of microstrip filters are reported. To design a filter, first a resonator is designed. This structure is then developed and optimized to obtain the desired frequency response. A high performance filter should have low IL and RL, high frequency selectivity, and no disturbing harmonics before and after the passband. Among the filters, three structures that lead to relatively good frequency response are shown in Table 1. Throughout this article, λ_g represents the guided wavelength at first resonance frequency. As shown in Table 1, designers had to increase the size to eliminate harmonics. In,[1] the structure is new, very elegant, and complex. Its advantage is small size, low loss, and wide bandwidth. In,[3] using coupling structure, several capacitors are created to control the stopband, where we can see many transition zeros. According to the resonance frequencies, the designed filter in[4] is suitable for wireless local area networks. To investigate the advantage and disadvantages, the performance of some microstrip filters is compared in Table 2. In Table 2, NOC represents the number of channels, IL and RL, respectively. As presented in Table 2, best IL and RL are obtained by[3] and,[1] respectively, while the design of a microstrip device with more channels is hard.

STRUCTURES, PERFORMANCE, AND APPLICATIONS OF DIPLEXERS

Diplexers are three-port devices which uses two different channels to separate and transmit the desired signals. They are

Table 1: Layout and frequency response of dual-band bandpass filters (dimensions are in mmm)

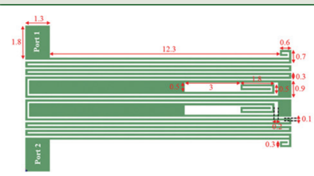
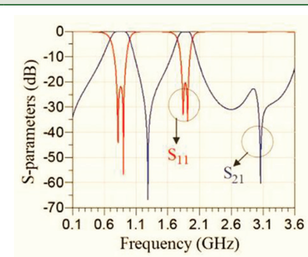
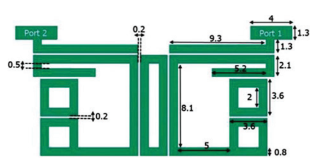
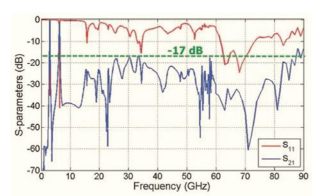
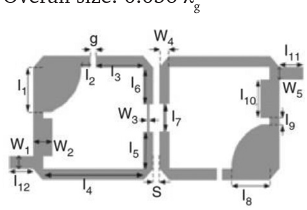
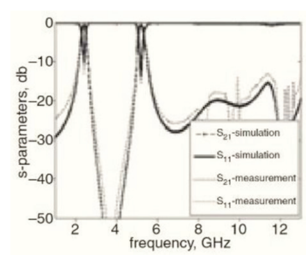
References	Layout	Frequency response
[1]	 Overall size: 0.0017 λ_g^2	
[3]	 Overall size: 0.056 λ_g^2	
[4]	 Overall size: 0.036 λ_g^2 (320mm²)	

Table 2: Performance comparison of some microstrip filters

References	ILs (dB)	RLs (dB)	FBWs	Type	NOC
[1]	0.05, 0.1	21.7, 20	36%, 13.5%	Bandpass	2
[2]	0.8, 0.67, 1.2, 0.97	20.7, 22.7, 17.8, 20	5.3%, 5.5%, 3.2%, 3.6%	Bandpass	4
[3]	0.3, 1.3	35, 42	---	Bandpass	2
[4]	0.53, 0.59	10, 13.4	---	Bandpass	2
[6]	0.19	13	43%	Bandpass	1
[50]	0.1	11.47	---	Lowpass	1

IL: Insertion loss, RL: Return loss

Table 3: Layout and frequency response of some diplexer (dimensions are in mm)

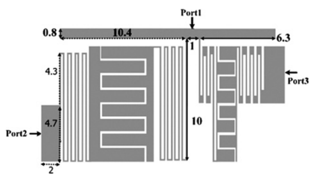
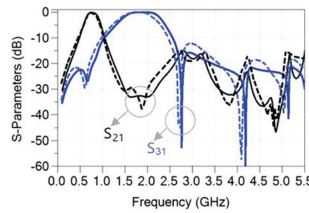
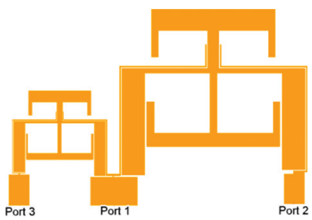
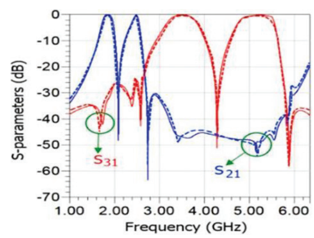
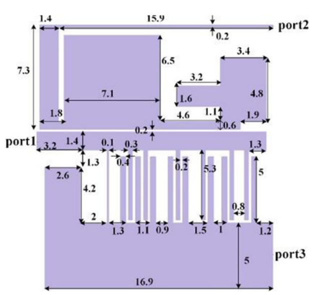
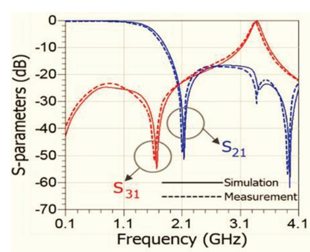
References	Layout	Frequency response	Type
[8]	 Overall size: 0.002 λ_g^2		Dual-Band Bandpass-Bandpass
[10]	 Overall size: 0.056 λ_g^2		Four-Channel Bandpass
[11]	 Overall size: 0.018 λ_g^2		Dual-Band Lowpass-Bandpass

Table 4: A comparison between microstrip dual-band bandpass-bandpass diplexers

References	ILs (dB)	RLs (dB)	Size (λ_g^2)	F_{o1}, F_{o2} (GHz)	FBWs%	Isolation (dB)
[13]	0.12, 0.18	21 , 17	0.037	3.5, 5	16.4, 26	20
[14]	0.85, 0.8	15.7, 24	0.047	2.58, 2.72	---	23.5
[15]	0.06, 0.07	28.6, 20	0.004	1.4, 3	47, 45	20
[16]	0.43, 0.35	16, 19.6	0.036	1.67, 1.88	---	22.13
[17]	0.17, 0.30	19, 21	0.026	0.78, 1.85	---	42
[19]	0.25, 0.26	18.4, 17.4	0.038	2.12, 3.94	---	24
[20]	0.45, 0.60	27, 24	0.0081	1.6, 3	34, 38	20
[21]	0.1, 0.16	33, 22	0.054	1.6, 2.1	16.8, 11	22

IL: Insertion loss, RL: Return loss

consisting of two filters integrated by a matching circuit. To design a lowpass-bandpass diplexer, it is necessary to design two different lowpass filter and BPF, while a bandpass-bandpass diplexer needs to design a resonator, only. A diplexer may have more than two channels. If a resonator be multi-mode, it can create more than one channel. Therefore, it is suitable for designing a multi-channel diplexer. In Table 3, the structure and frequency response of three types of diplexers have been presented. They are dual-band bandpass-bandpass,[8] quad-band bandpass,[10] and lowpass-bandpass[11] diplexers. As shown in Table 3, the use of interdigital resonators next to the spiral cells has a significant effect on reducing the structure size. However, we must not forget that the production of four channels is more difficult. To create a two-band resonator, when thin and wide lines are coupled together, better results

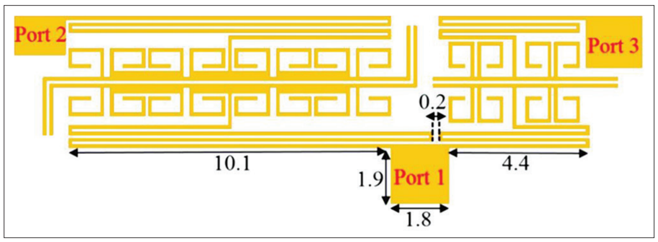


Figure 1: Layout configuration of the diplexer in[15]

can be obtained.[10] For the lowpass-bandpass diplexer, λ_g is calculated at the cut-off frequency of lowpass channel.

Since dual-band bandpass-bandpass diplexers are more reported than the other types, we compare the size and dimensions of them in Table 4. In Table 4, the ILs, common port RLs, fractional bandwidths (FBWs), first operation frequency (F_{o1}), and second operational frequency (F_{o2}) are given for the reported structures under consideration. As shown in Table 4, the lowest ILs at both channels is achieved by[15] while its size is very compact. Moreover, it has most flat channels with highest FBWs. These features are obtained using a novel structure presented in Figure 1. It consists of coupled spiral resonators with helical structures. According to the operating frequencies, the proposed diplexers in,[13,14] and[15] are suitable for Worldwide Interoperability for Microwave Access (WiMAX), Global System for Mobile Communications (GSM-4G), L-band, and S-band wireless applications, respectively. Due to having close channels, the designed diplexer in[14] and[16] is appropriate for frequency division duplex. The reported diplexer in[17] is designed for GSM. The highest isolation between channels is obtained in[19] using irregular meandrous microstrip cells. It operates at 2.12 and 3.94 GHz for Wideband Code Division Multiple Access and WiMAX applications, respectively.

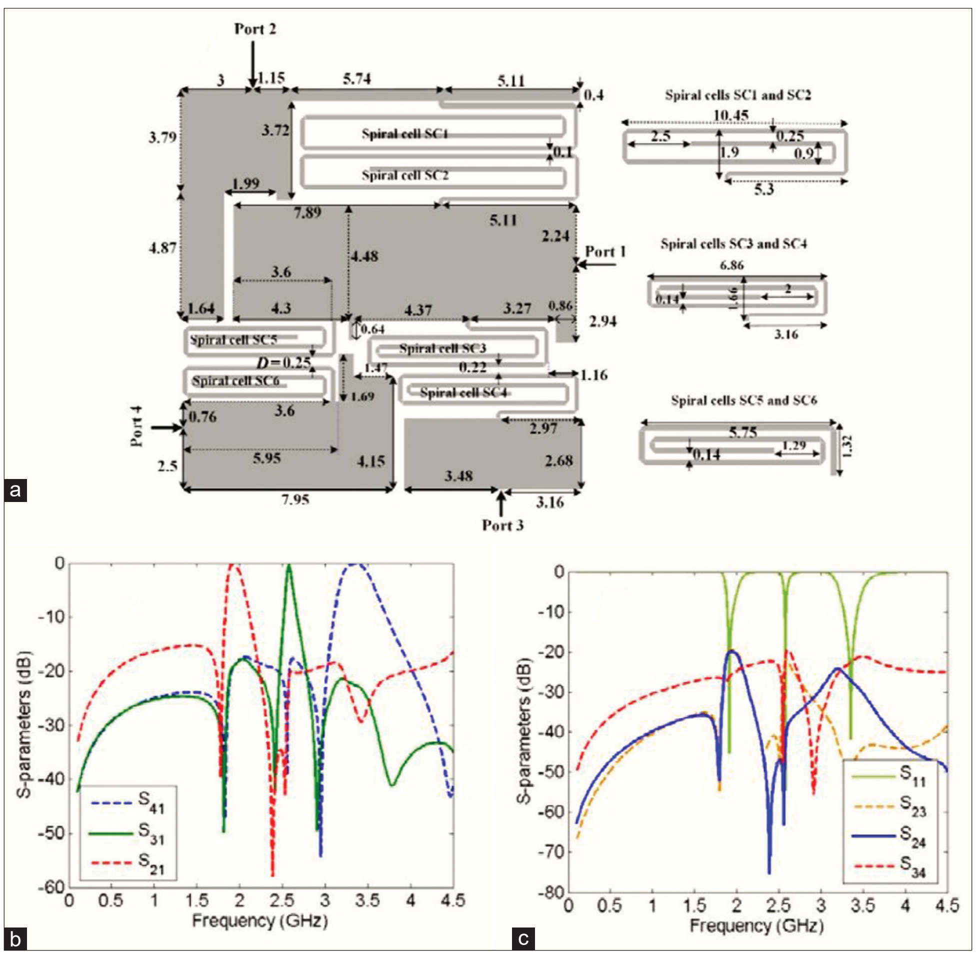


Figure 2: (a) Layout of triplexer (dimensions are in mm), (b) its frequency response (S_{21}, S_{31}, and S_{41}), and (c) common port RL (S_{11}) and isolation between channels (S_{23}, S_{24}, and S_{34})

STRUCTURES, PERFORMANCE, AND APPLICATIONS OF MULTIPLEXERS

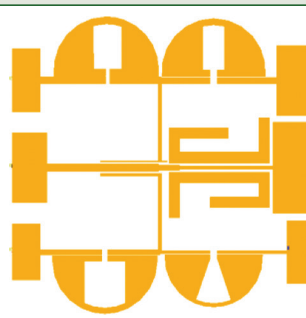
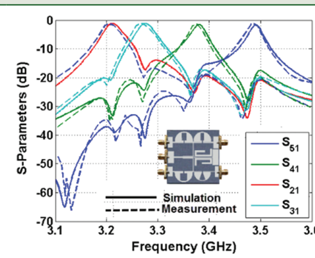
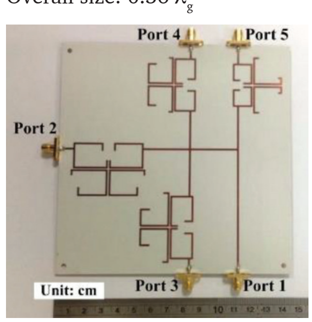
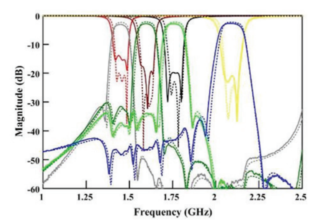
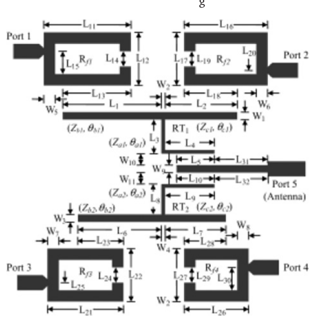
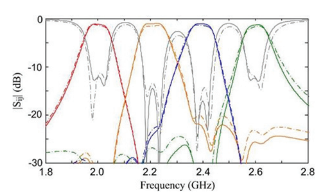
Among the microstrip multiplexers, triplexers and quadruplexers have been reported more. Triplexers have four ports and three channel while quadruplexers have five ports and four channels. [Figure 2a-c] show the layout of a triplexer with its frequency response that designed and presented in.[23] It consists of spiral and patch cells with four ports. [Figure 2b] shows its three channels with high selectivity. However, it cannot attenuate the harmonics. In [Figure 2c], S_{23}, S_{24}, and S_{34} show the isolation between channels while S_{11} is the common port RL. This multiplexer occupies an area of 0.017 λ_g^2. The RLs of this device at all channel are very good.

Table 5: A comparison among microstrip triplexers, where F1, F2, and F3 are the 1st, s and third resonance frequencies, respectively

References	F1, F2, F3 (GHz)	ILs (dB)	RLs (dB)	Size (λ_g^2)
[23]	1.9, 2.5, 3.3	0.25, 0.4, 0.11	45, 54, 40	0.017
[24]	2.3, 3.2, 3.6	0.78, 1.1, 0.62	19.8, 10, 28	0.095
[25]	1, 1.25, 1.5	2.7, 1.8, 3.2	16, 16, 16	0.064
[26]	3.3, 3.89,4.56	2.2, 2.3, 2.3	14, 14, 14	0.275
[27]	2.15,2.95, 3.8	2.2, 1.9, 1.7	<20	0.0164
[29]	1.4, 1.7,1.9	3.4, 3.5, 3.6	---	0.358
[30]	1.5, 1.7, 1.9	4.9, 5.8, 5.95	---	0.132

Some information is compiled in Table 5 to make a comprehensive comparison among triplexers. According to the provided information, triplexers generally occupy more space than diplexers. As shown in table, the triplexer presented in[23] occupies the least space compared to other triplexers. Moreover, the lowest losses at all channels are the other advantages of this work. Three different structures of microstrip quadruplexers with their frequency responses are presented in Table 6. In,[31] engraved semicircular cells have been coupled to each other, where similar to the other quadruplexers, it has five ports and four channel. It operates at 3.211, 3.276, 3.38, and 3.491 GHz for IEEE 802.16 WiMAX applications. Since the channels are very close, it is suitable for FDD scheme. The proposed

Table 6: Structure and frequency response of quadruplexers

References	Physical structures	Frequency responses
[31]	 Overall size: 0.36 λ_g^2	
[32]	 Overall size: 1.114 λ_g^2	
[33]	 Overall size: 0.25 λ_g^2	

multiplexer in[32] has a good selectivity, but at the same time has a large implementation area.

Similar to triplexer, some quadruplexers are compared in Table 7. As presented in this table, the lowest insertion losses are obtained in.[34] However, the narrow channels of this multiplexer are its disadvantage. The multiplexer presented in[35] has the most compact size and widest FBWs, which is designed based on tri-mode net-type resonators. In general, quadruplexers are larger in size than filters, triplexers, and diplexers. Therefore, it can be concluded that the size of a device will be increased by increasing the number of ports.

Table 7: Comparison among quadruplexers

References	ILs (dB)	RLs (dB)	Size (λ_g^2)	FBWs%
[31]	1.1, 1.1, 1.5, 1.6	25, 20, 25, 42	0.36	0.92, 0.9, 0.87, 0.63
[32]	3.1, 2.8, 2.8, 2.7	Better than15	1.114	6.3, 6.45, 6.34, 6.6
[33]	1.1, 1.4, 1.3, 1.5	---	0.26	---
[34]	0.4, 0.3, 0.3, 0.4	19/19/19/20	1.1	0.2, 0.2, 0.2, 0.2
[35]	2.5, 2.4, 2.3, 2.1	10, 10, 15, 10	0.0547	8, 8, 8, 8
[36]	2.2, 2.5, 1.8, 2.1	---	0.156	2.2, 2.5, 1.8, 2.1
[37]	1.8, 2.5, 1.8, 2.6	Better than17	0.16	4.8, 5.2, 3.4, 3.6

Another five-port four-channel multiplexer is presented in.[38] It consists of stub-loaded open loop resonators, which is presented in [Figure 3a]. It occupies a relatively compact size of 0.08 λ_g^2. The frequency response of this multiplexer is depicted in [Figure 3b and c]. As shown in [Figure 3b], the resonance frequencies of this multiplexers are located at 2.2, 2.8, 3.5, and 4 GHz for multi-band RF wireless communications systems. It has FBWs of 6.9%, 2.1%, 5.1%, and 4.1% with 40, 29, 22, and 32 dB RLs and 0.14, 0.39, 0.21, and 0.27 ILs.

STRUCTURES, PERFORMANCE, AND APPLICATIONS OF THE COUPLERS

Microstrip couplers are passive devices with four ports, called; port1, port2, port3, and port4, and two passbands for selecting desired signals. A desired signal passes through a path between ports 1 and 2. The second desired signal passes through another path between ports 1 and 3. On the other hand, no signal passes between ports 1 and 4. This is because of the fourth port is built for isolation. The phase difference between S_{21} and S_{31} should be near 0°, ±90° or ±180°. Table 8 depicts some couplers with their frequency responses. The

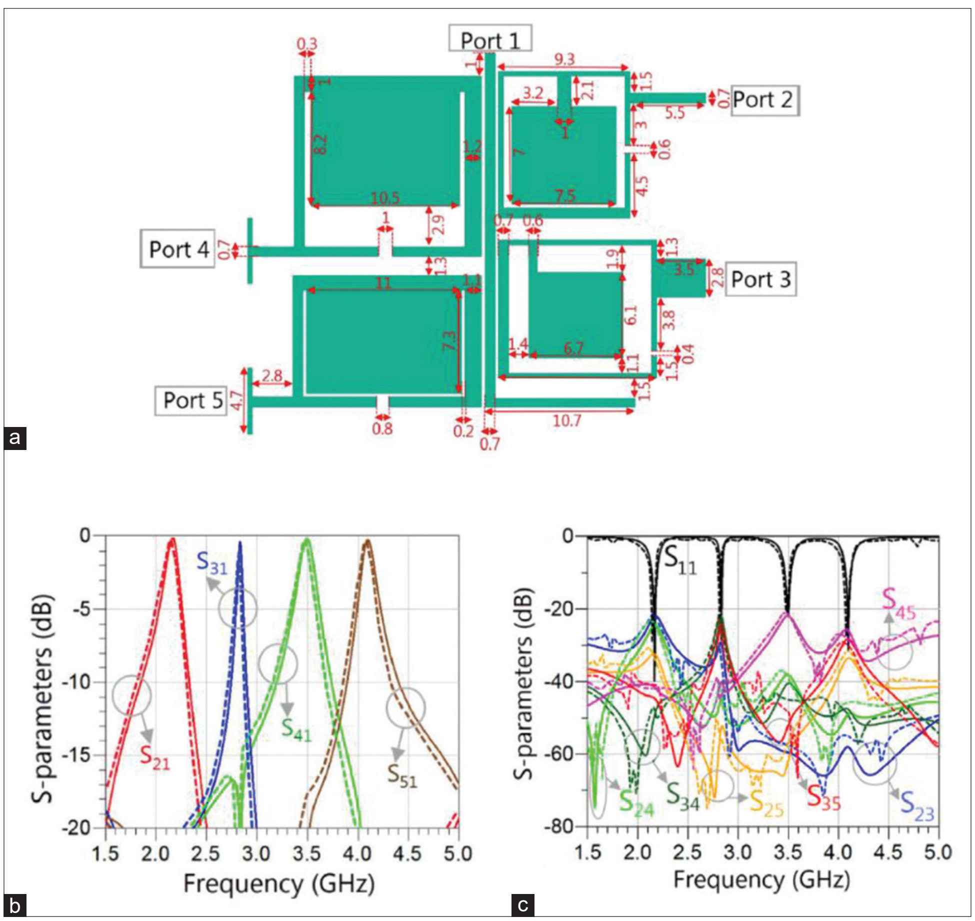


Figure 3: Proposed multiplexer in;[39] (a) Physical structure (all dimensions are in mm), (b) Transition parameters (S_{21}, S_{31}, S_{41}, and S_{51}), and (c) Isolation between channels and common port RL

Table 8: Coupler structures and their frequency response

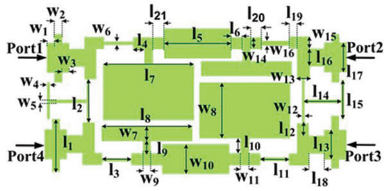
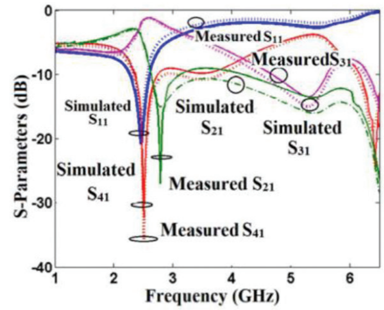
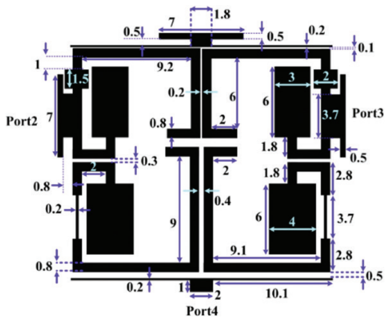
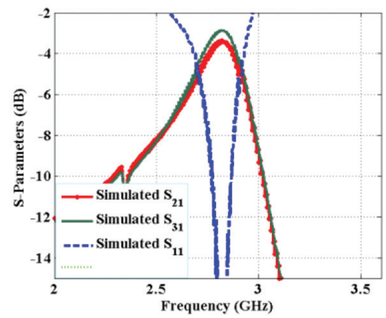
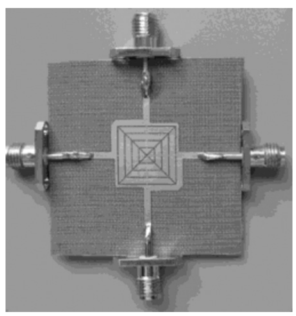
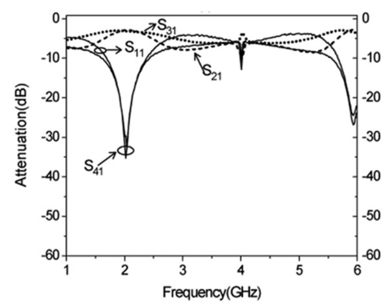
References	Physical structures	Frequency responses
[39]	 Overall size: 0.023 λ_g^2	
[42]	 Overall size: 0.0754 λ_g^2	
[45]	 Overall size: 265.69 mm²	

Table 9: Comparison among previous reported couplers

References	S_{11} (dB)	S_{21} (dB)	S_{31} (dB)	S_{41} (dB)	Phase shift	Size (mm²)
[39]	21.4	3.3	3.3	42.9	0.09°	175.1
[40]	19.4	2.3	2.6	20.4	0.8°	110
[41]	20.2	3.37	3.42	22.9	1°	1361
[42]	29.5	3.3	2.8	31.3	0.97°	534.36
[43]	20	3	3	20	0°	1322
[44]	20	3.5	3.5	20	---	673
[45]	---	3.11	3.39	---	1°	265.69
[46]	8	5	4	11	10°	1553
[47]	29.33	7.3	2.25	21.5	2.36°	819
[48]	20.93	4.07	4.39	27.4	2.14°	2218

designed structure in[39] is a 90° coupler. The novel structure is the advantage of the reported couplers in[39] and[42]. We can see that any signal cannot pass from port 4. As shown in Table 8, in,[45] an engraved patch is introduced. The common problem of[39] and[45] is undesired frequency selectivity. However, in,[42] the selectivity is improved.

The size and performance of some couplers are compared in Table 9. In this Table, S_{21} and S_{31} are calculated at resonance frequencies where S_{11} and S_{41} are calculated at the intersection of two channels. As shown in Table 9, the insertion losses of all couplers are not good. By manipulating the proposed structures, it may be possible to reduce it. The designers in[40] could reduce the size significantly. The lowest phase shift is obtained in[43] but it has a large size. The problem of large physical size is remained in[46] and.[48] According to the operational frequency, the applications of couplers are different. For an example, the proposed couplers in[39-40] are suitable for WLANs, while the coupler designed in[43] is appropriate for wireless applications. Meanwhile, the device in[47] is designed for S-Band Radar System. The presented coupler in[49] is designed for 3 G EH Mixers.

CONCLUSION

Several types of passive microstrip devices were studied in this work. These devices were filters, diplexers, triplexers, quadruplexers, and couplers. The structure of some devices was presented and investigated. The size and performance of each passive device were stated and compared with other. The applications of some passive devices in telecommunication systems were explained according to their operating frequencies. According to the information extracted from the previous works, it is concluded that the physical dimension increases as the number of ports increases.

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