# Manifold Multiplexer

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**Abstract**

In wireless communications, bandwidth is a valuable resource that can be smartly shared by multiple users simultaneously utilizing multiplexers. This chapter offers a short review and brief impression of the working principle and the design methodology of the multiplexers in RF and microwave systems. Predominantly used different multiplexer design patterns are discussed here, however the compact manifold multiplexer is discussed in details with an example. It is designed by using advanced design system (ADS) software and implemented utilizing Microstrip technology for its low cost and simplicity.

**Keywords:** manifold multiplexer, diplexer, microwave filters, advanced design system, microstrip technology

## 1. Introduction

The idea of multiplexing has been used in different areas. In telegraph systems, it was used for the first time in 1870s, after few decades it was employed in telephony [1]. Multiplexing is a useful process applied in different wireless communication systems where signals from different users (channels) can be multiplexed or demultiplexed by utilizing the multiplexers in order to use the primary recourse (frequency spectrum) intelligently and to increase the speed of the data transmission. **Figure 1** shows the basic block diagram of the transmitter-receiver pair in the wireless communication system. It consists of antenna, RF front-end and baseband system. Usually, the RF front-end is the set of circuit component after antenna which down converts the RF frequency into the intermediate frequency for further processing in the baseband [2]. The well-known components in the front-end are low noise amplifier (LNA), band pass filter (BPF), power amplifier (PA), local oscillator (LO) and mixers. Microwave multiplexers can also be found in front-end [3–5].

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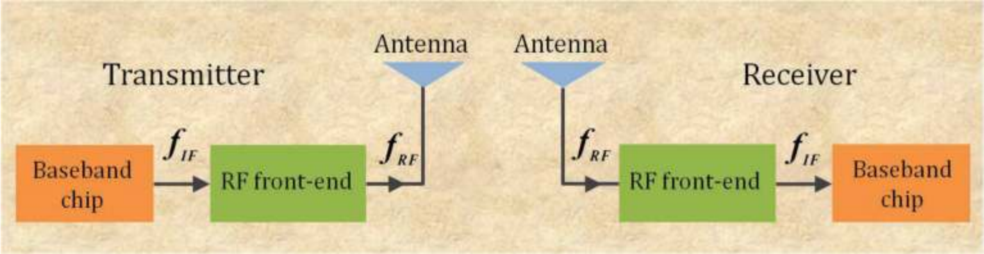

**Figure 1.** Basic block diagram of wireless communication system.

Frequencies more than 1 GHz are typically known as microwave frequencies in which most of the systems operate [3]. High-frequency circuit designs are different compared to the low-frequency circuit design because at high frequency, wave nature of current is needed to be considered (it will be further discussed in microstrip transmission line technology). After the announcement of a wide range of ultra-wide band (UWB) for public use in 2002 by Federal Communication Commission (FCC), many designs dealing with high frequency and wide bandwidth became centre of attraction [4]. With the evolution of the technology, design and implementation of multiplexing networks become more sophisticated. **Figure 2** shows the scheme of sharing the bandwidth among N channels using multiplexing.

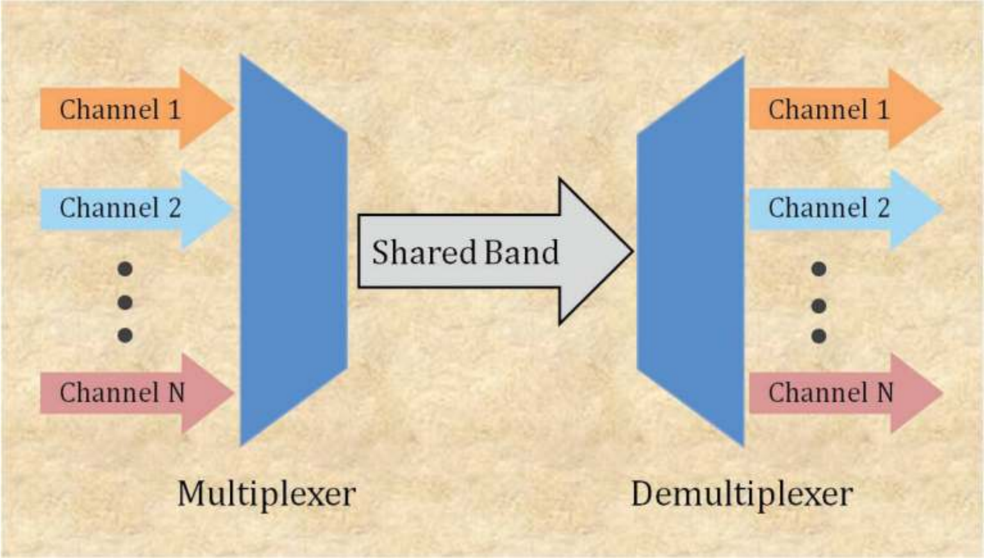

**Figure 2.** N channels multiplexing to share the bandwidth.

## 2. Literature review

In RF and microwave systems, different multiplexer design patterns have been adopted [3–24]. Most of the designs have been implemented by utilizing various technologies such as waveguide and microstrip, and high-temperature superconducting (HTS) materials. Various existing multiplexers are able to deal with the multiple sub-bands with a short guard band. Due to the future generation system, amenable front-end design requirement has become more challenging. Some well-known design patterns of the multiplexer are hybrid-coupled multiplexer, directional filter multiplexer, circulator coupled multiplexer and manifold multiplexer [5–7].

The hybrid-coupled multiplexer design pattern has been adopted by many researchers [8–10]. This design approach is easy to tune and there is no interaction between channel filters, so it can accommodate any change in channel frequencies or addition of new channel. Hybrid multiplexers are comparatively large due to the presence of two hybrid and two filters for each channel. Jonathan et al. [8], designed hybrid coupled multiplexer using microstrip technology. Mansour et al. [9] studied the possibility of building HTS using hybrid-coupled multiplexers. Rubin [10] represented the frequency multiplexer with the hybrid-coupled configuration by two-port analysis.

In another design pattern of multiplexer, four port directional filters are used [6, 11, 12]. By keeping one port terminated the other three ports are used for incident input, filtered output and reflected signals. Unlike hybrid-coupled multiplexers, it uses one filter per channel which can be designed separately and can be easily modified without changing the whole design [6]. Despite all these benefits, its use is constrained due to narrow bandwidth. Volker et al. [11], in their study, presented a microwave design based on directional filters. This paper shows the measured and simulated results for the triplexer with centre frequencies of 1.472, 2.944 and 4.416 GHz. Ref. [12] shows the design and implementation of the miniaturized coupled-line directional filter multiplexer in a multilayer microstrip technology.

The circulator-coupled multiplexer is another design which is used in different applications [6, 7, 13, 14]. This multiplexer consists of channel dropping circulators along with one filter per channel. It provides no interaction between channel filters but have comparatively high insertion loss in later channel circulator. Raafat [7] presents experimental results for a three-channel circulator-coupled multiplexer using HTS materials for microwave. Chen et al. [13] used an optical multiplexer employing multiport optical circulator (MOC) using optical fibre. Theoretical and experimental studies which were carried out upon a waveguide multiplexer that consists of two branches joined by a circulator are presented in Ref. [14].

The manifold multiplexer is a well-known design pattern used to realize multiplexers. This approach is the focus of this chapter. It provides better insertion loss and amplitude response. It has been used in HTS thin film integrated technology and it shows better loss performance but is sensitive to the material defects [15]. On the other hand, tuning this multiplexer is little complex because of its need to deal with all filters at the same time. So, it is not flexible to frequency changes or additional channel frequency and in the case of any modification in frequency arrangement, the whole multiplexer need to be redesigned.

This topology has been presented in many research papers using waveguides and microstrip technology. Morinil et al. [15] presented an improvement in the dual manifold multiplexer to design the reconfigurable multiplexer. Ho and Battensby [16] discuss the application of microwave active filter manifold in multiplexing. Ten-channel manifold multiplexer by using waveguide is presented with contiguous and non-contiguous channels [17]. In Ref. [18], the theory of manifold multiplexer using helical filter is discussed. Although the reconfigurable filter technology still not fully developed, a theoretical study of tunable manifold multiplexer has been carried out with five channels [19].

**Figure 3** illustrates the most adopted structural patterns of the manifold multiplexer with one filter for each channel and these are the most compact design approach patterns [6, 7]. Several manifold multiplexer designs with all filters on the same side are presented in **Figure 3(a)** [20]. An alternate filter design as shown in **Figure 3(b)** is presented in Refs. [21, 22]. Both this approaches have been adopted according to requirements. Cameron and Yu [6] classified the manifold multiplexer design patterns into three categories namely comb, herringbone and end-fed (can be applicable in both **Figure 3(a)** and **(b)**, where one filter feed the manifold design).

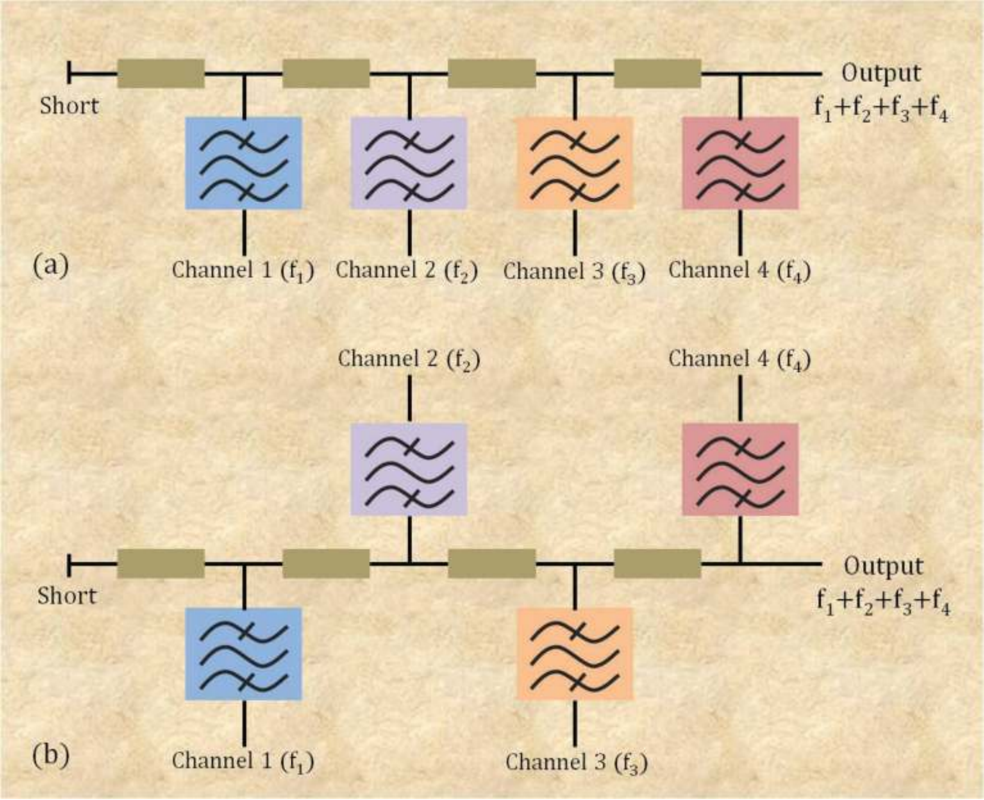

**Figure 3.** Manifold multiplexer design pattern, (a) all channels on one side, and (b) filters on alternate sides.

Compared to other multiplexer patterns, manifold has no isolation between channels, which make it act as a whole circuit but at the same time, which make it more complicated when the number of channels are increased. However, it gives small losses due to the absence of the lossy isolation. That is why manifold design is the preferred choice of the circuit designer aiming for small losses and miniaturized circuit. With the help of circuit design software, complexities in the design can be overcome.

## 3. Frequency multiplexing network

**Figure 4** shows the working principle of the frequency multiplexing network (FMN) using manifold approach for *N* number of channels with one filter per channel. Filters are interconnected by using quarter wavelength transformer and horizontal transmission line. The

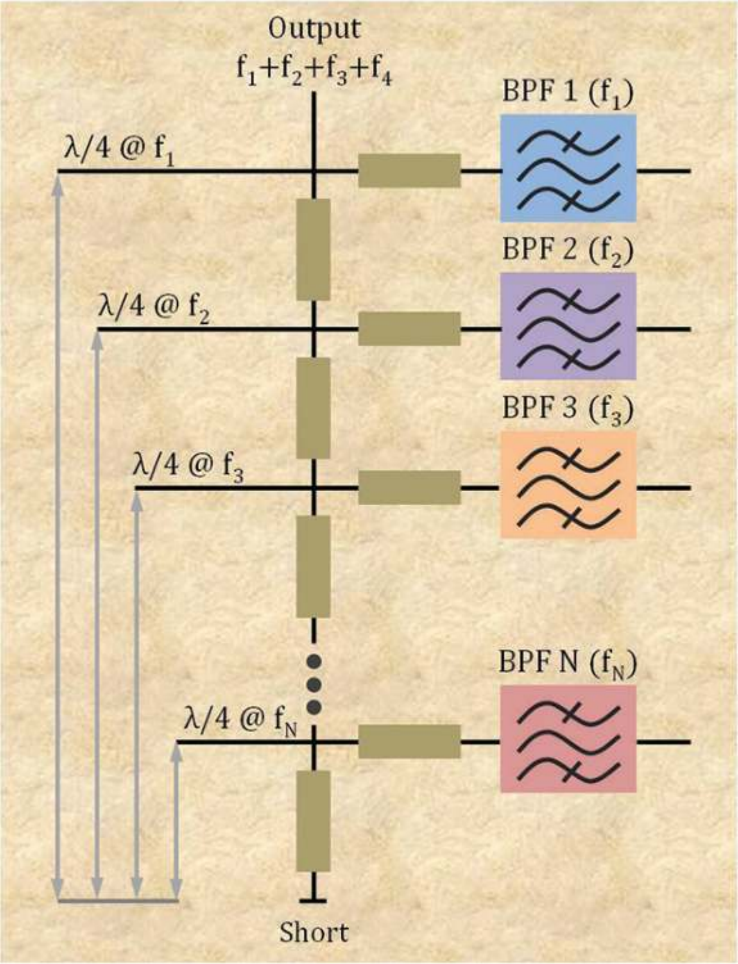

**Figure 4.** Frequency multiplexing network [23].

available frequency bandwidth is divided into $N$ channels with frequencies $f_1, f_{2, \ldots,} f_N$, where $f_1$ is lowest frequency band and $f_N$ is the highest frequency band. Quarter wave transmission lines provide the high impedance to the corresponding frequency band, where as horizontal transmission lines help in tuning that band. FMN is a passive network that can be used as a multiplexer in the transmitter and demultiplexer in the receiver. The presence of a suitable guard band can prevent overlapping of the sub-bands. The minimum guard band is always preferred as this band will not be used in transmission. Normally the guard band of less than 10% relative bandwidth is used most of the time [4].

## 4. Microstrip transmission line technology

Transmission line is a special purpose medium intended to transmit high-frequency signals which have short wavelengths. According to the rule of thumb, signal carrying medium will be considered as the transmission line, if the wavelength of the signal is less than the ten times the circuit component [24]. **Figure 5** shows the microstrip transmission line, which has two conductors separated by the dielectric material of permittivity $\varepsilon_r$ and substrate height $h$. Here $L$ is the length, $W$ is the width and $t$ is the thickness of the microstrip. It can be manufactured utilizing a double-sided printed circuit board (PCB). Input impedance ($Z_{in}$) of a terminated transmission line can be represented as [24]:

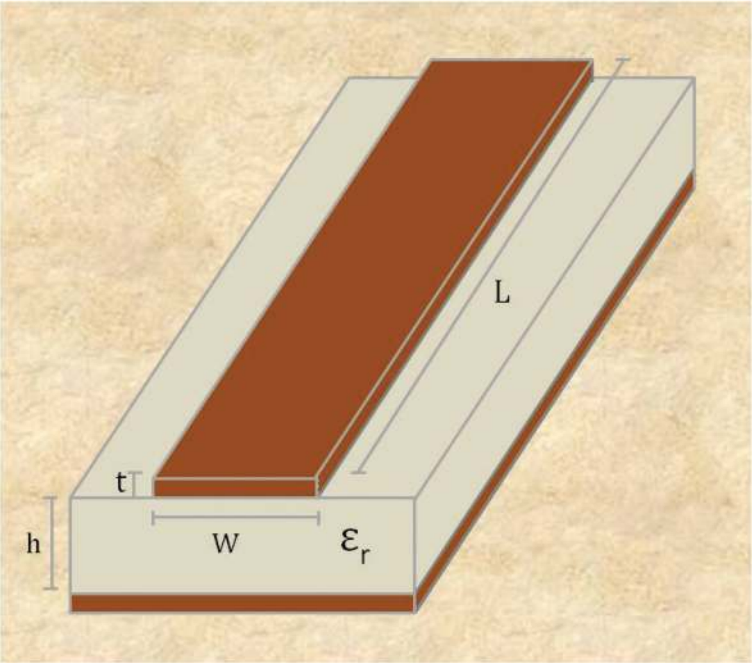

**Figure 5.** Microstrip transmission line.

$$Z_{in}(d) = Z_o \frac{Z_L + j Z_o \tan(\beta d)}{Z_L - j Z_o \tan(\beta d)} \quad (1)$$

where $Z_L$ is load impedance, $Z_o$ characteristic impedance, $d$ is the length of transmission line and $\beta$ is the wave number.

In order to achieve the maximum power transfer we need to match the source and load power, which can be done by using a passive network known as matching network. Many types of matching networks are using discrete components as a cheapest solution in circuit designing such as LC network, T network and Pi network in low-frequency applications. A combination of lumped and discrete component matching network can be used for comparatively high frequencies and purely discrete components have been used in high frequencies of the order GHz. Quarter wavelength transmission line, single and double stub are examples of discrete matching networks.

Quarter wavelength transmission line or transformer is a simple matching network. The impedance of the quarter wavelength transmission line can be calculated for matching load and source. **Figure 6** shows the quarter wavelength microstrip transmission line.

From Eq. (1) for ($Z_S$=$Z_L$ )

$$Z_{\text{in}}\left(d = \frac{\lambda}{4}\right) = \frac{Z_o^2}{Z_L} \text{ or } Z = \sqrt{Z_{\text{in}} Z_L} \quad (2)$$

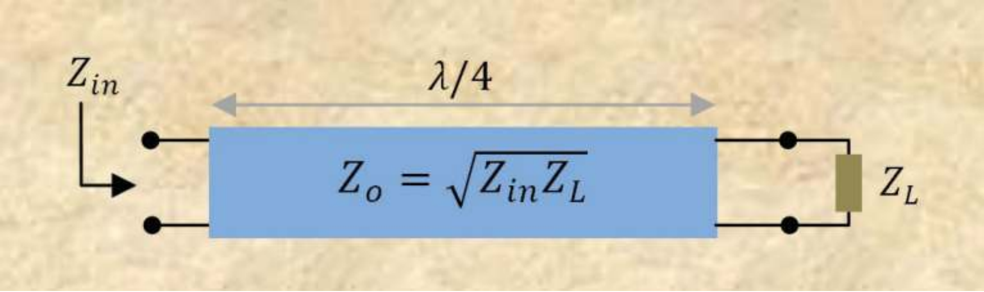

**Figure 6.** Quarter wavelength microstrip transmission line.

## 5. Frequency division multiplexing

When the available bandwidth of the medium is more than that of communicating devices, then it is better to share the medium. FDM can enhance the data rate of the transmission by parallel processing [4, 5]. Multiplexing can be done in various ways, which can depend on the target application. Some of these famous schemes for multiplexing are:

- Frequency division multiplexing (FDM)
- Time division multiplexing (TDM)
- Wavelength division multiplexing (WDM)

In wireless communications, different schemes are applied to efficiently use the valuable bandwidth. FDM is mostly used in the radio frequency band. It is the analog multiplexing schemes which divide the available bandwidth into two or more frequency bands (channels). **Figure 7** shows the schematic of frequency division for the multiple channels utilizing FDM. The guard band (narrow portion of the band spectrum which is not used in communication but used to protect sub-bands from interference) is present between each neighbouring channel. One antenna pair is sufficient for the communication of all the users of the sub-bands.

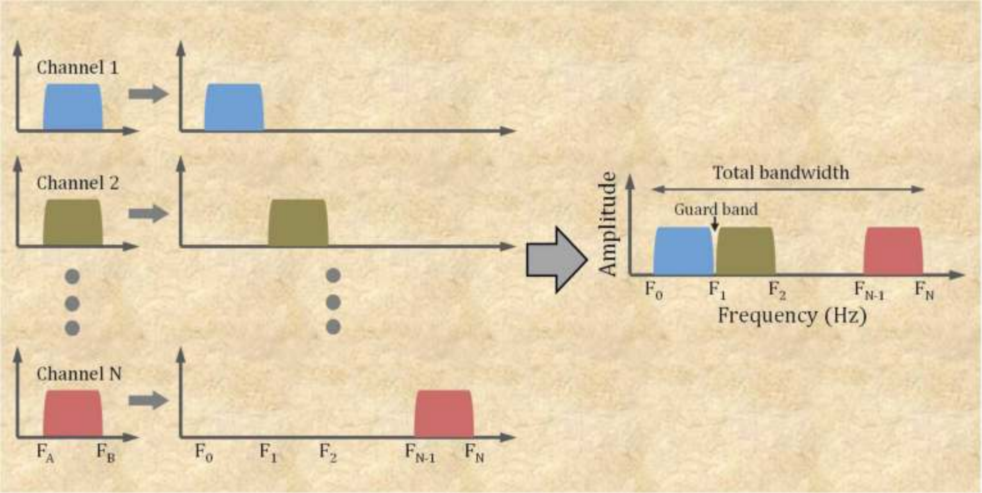

**Figure 7.** Multiple sub-bands (channels) in available bandwidth using FDM scheme.

## 6. Design and implementation of manifold multiplexer

This section will give the detailed designing process of the diplexer (an example of manifold multiplexer) using advanced design circuit (ADS) from Agilent's simulation software and implementation on a double-sided PCB. Finally, the prototype will be measured by a two-port vector network analyser.

### 6.1. Frequency diplexer network (manifold multiplexer)

By using the working principle of the FMN (discussed earlier), a diplexer is designed. **Figure 8** shows the block diagram of the frequency diplexer network (FDN). It has two channels in the UWB frequency range from 6 to 9 GHz. The guard band of 200 MHz is present between these two sub-bands (6–7.4 and 7.6–9 GHz). As discussed earlier all the filters in the manifold design are needed to be tuned at the same time. However, individual channel filters are optimized and then combined with a matching network which is a systematic approach to make the designing process simple.

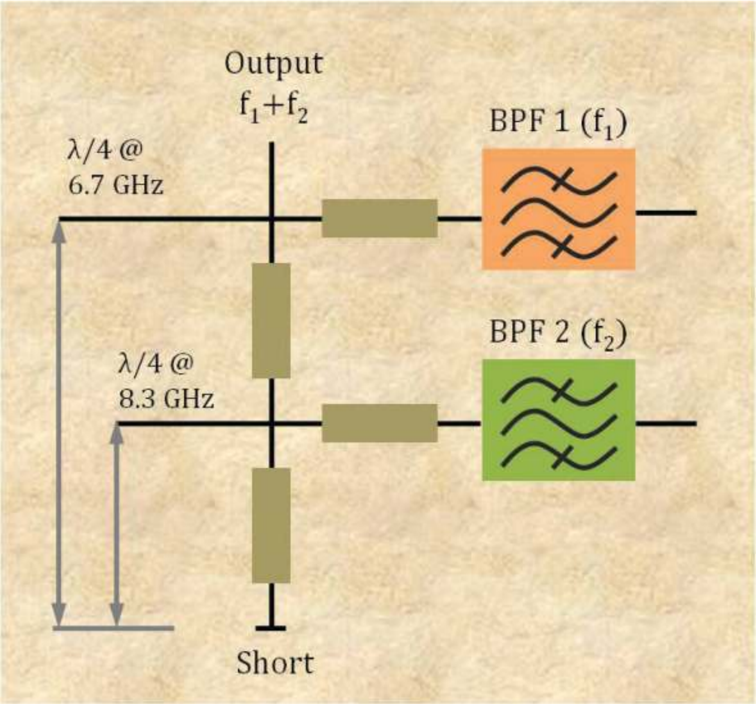

**Figure 8.** Frequency diplexer network [21].

### 6.2. Systematic processes

In order to understand the process of design and implementation it is categorised into the four following steps [4].

1. Schematic designing by using selected substrate properties of PCB to show the ideal behaviour.
2. Layout of the schematic design to see the real behaviour by running momentum tool.
3. Analysis of schematic and momentum results together by using layout in schematic for final simulation results.
4. Implementation of the approved design on to the PCB and comparison of the measured results with simulation results.

#### *6.2.1. First step*

Rogers 4350B is used in many high frequency electronic circuits. It is a double-sided PCB and selected here for the design implementation. **Table 1** shows the substrate properties of PCB.

| | |
|---|---|
| Dielectric thickness | 254 μm |
| Relative dielectric constant | 3.48 |
| Metal thickness | 25 μm |
| Metal conductivity | 58 MS/m |

**Table 1.** Substrate properties of Rogers 4350B.

Diplexer can be divided in three blocks as first channel filter, second channel filter and matching network. **Figure 9** shows the schematic view of the first filter in ADS. MSub and S-parameters show the substrate properties and frequency plan, respectively.

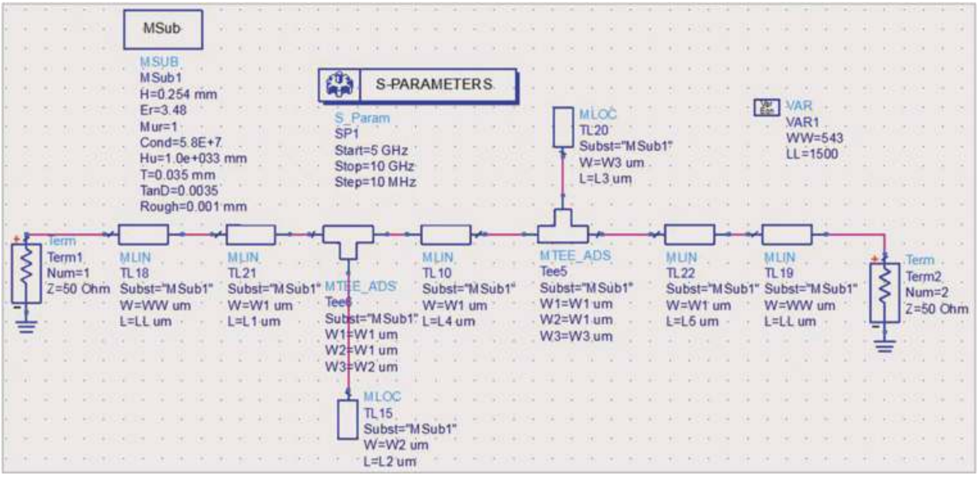

**Figure 9.** Schematic diagram of first filter for 6–7.4 GHz.

**Figure 10** presents the simulated forward transmission and input reflection result for the first filter in S-parameter. In a similar way, schematic of the second filter can be designed. After the optimization of the filters, both can be combined by the transmission line network as shown in the FDN figure to form the diplexers. Now tune the whole circuit together to get the optimization. Different tuning tools are available in ADS which can be used to tune the circuit.

### 6.2.2. Second step

After getting the optimized diplexer's schematic, second step is to convert the whole schematic into a layout as shown in **Figure 11**. It has three inputs/outputs and one connected to ground, so four ports are assigned to this FDN. Now run momentum, to see the real behaviour of the design which is a simulation engine use for the layout. It has two modes, RF and microwave (microwave mode gives full electromagnetic simulation with radiation effect and RF mode is quick simulation for the designs which do not radiate).

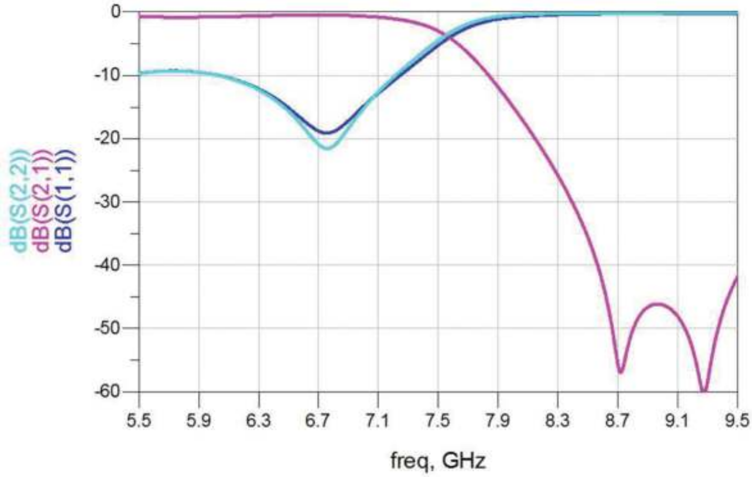

**Figure 10.** Forward transmission and input reflection for first filter for 6–7.4 GHz.

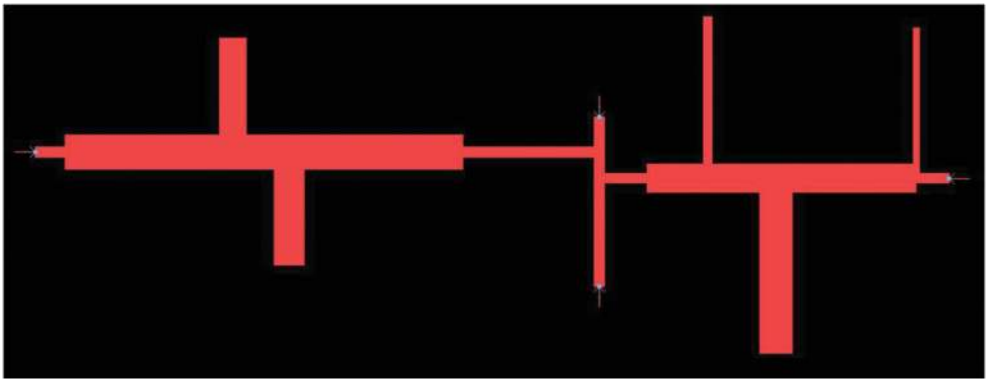

**Figure 11.** Layout of the FDN.

### 6.2.3. Third step

Third step is to convert the layout of the FDN into the component and call this component into the schematic as shown in **Figure 12**. Here schematic and layout simulate together and provide final simulation results in terms of ideal and real physical design.

**Figure 13** shows the final simulated results of the FDN in terms of the S-parameters. Forward transmission (S21, S31) and input reflection (S11, S22, S33) show flat response in their respective bands jamming others. Appropriate values of group delay can be observed from the results that show small variations.

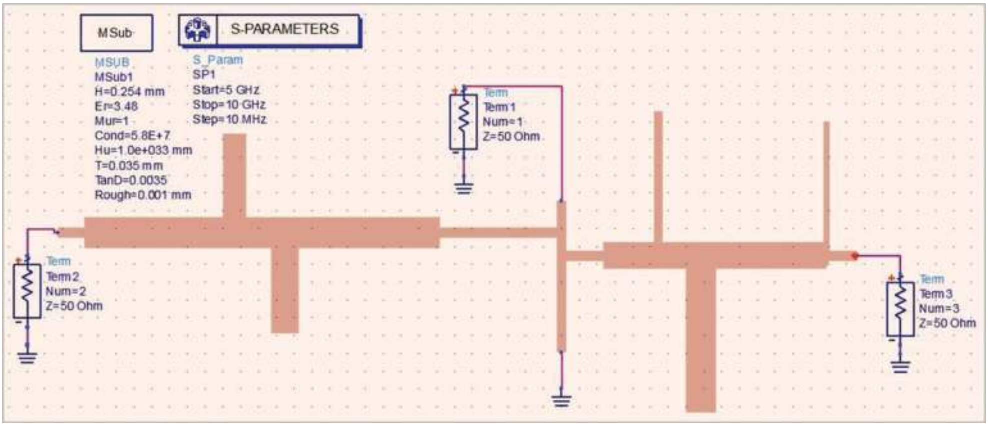

**Figure 12.** FDN as layout component in schematic representation.

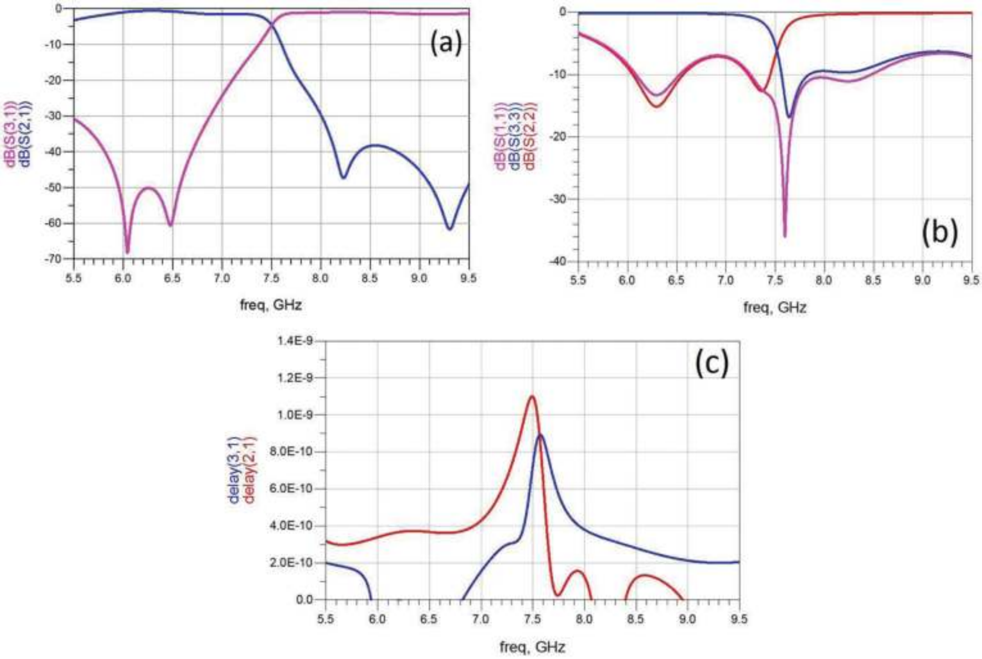

**Figure 13.** Simulated results for FDN, (a) forward transmission, (b) input reflection, and (c) group delay.

### 6.2.4. Fourth step

Finally, the layout of the PCB is prepared for the implementation on the double-sided PCB. **Figure 14** shows the top ground plane connected with the bottom ground plane through ground via hole. Small diameter circles are placed in already defined layer for holes. The number of holes depend on the highest operating frequency by RF design rules. The ground plane on the top can reduces the possible crosstalk between transmission lines. Now the final design file is ready to be exported from ADS for the implementation on PCB.

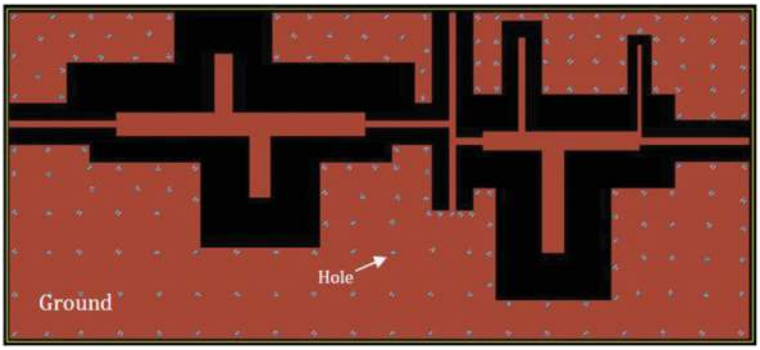

**Figure 14.** Layout of FDN for PCB.

PCB manufacturing has various steps, such as film processing, CNC drilling, brushing, plating, laminating photoresist on PCB, UV-exposure of photoresist, development of photoresist and etching. After etching, a visual inspection of PCB is needed in order to remove any possible copper remained during etching. **Figure 15** shows the final prototype of the diplexer with 50 Ω line at the input/output extended for connecting the big size SMA. Three SMA connectors have been soldered in the PCB in order to measure the results.

**Figure 16** shows the measured results of the prototype which are measured using a Rhode and Schwartz ZVM vector network analyser. Any possible difference between measured and the simulated results can be due to the soldering and SMA [25].

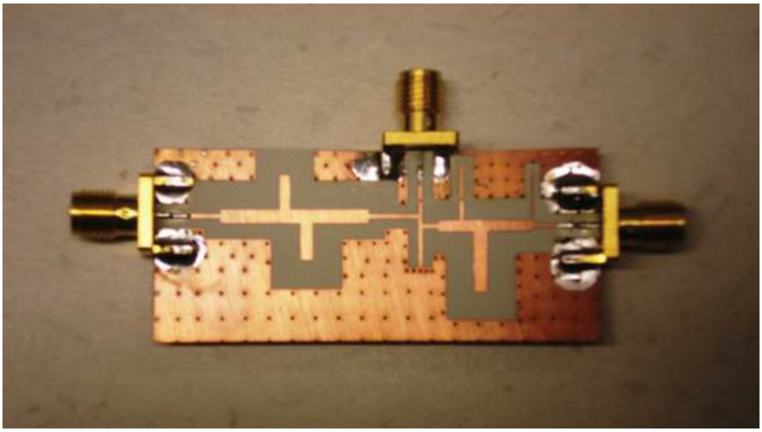

**Figure 15.** Prototype of FDN.

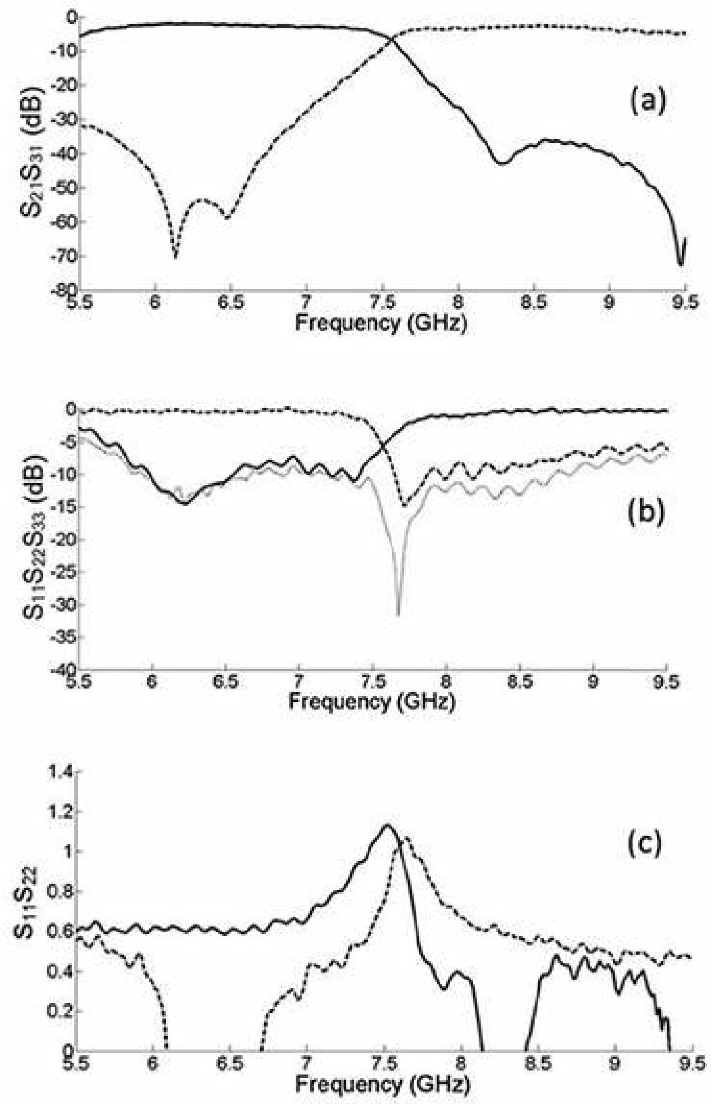

**Figure 16.** Measured results for FDN, (a) forward transmission, (b) input reflection, and (c) group delay.

*Note:* Here a diplexer is designed and implemented on the basis of FMN (**Figure 4**) and to see the design and implementation of the triplexer with a different BPF, see Ref. [22].

## Acknowledgements

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## Appendices and nomenclatures

| | |
|---|---|
| ADS | Advanced Design System |
| BPF | Band Pass Filter |
| FCC | Federal Communications Commission |
| FDM | Frequency Division Multiplexing |
| FDN | Frequency Diplexer Network |
| FMN | Frequency Multiplexing Network |
| HTS | High-Temperature Superconductor |
| LO | Local Oscillator |
| LNA | Low Noise amplifier |
| MOC | Multiport Optical Circulator |
| PA | Power Amplifier |
| PCB | Printed Circuit Board |
| PPM | Pulse Position Modulation |
| PSM | Pulse Shape Modulation |
| SMA | Sub-Miniature version A |
| TDM | Time Division Multiplexing |
| UWB | Ultra-Wide Band |
| WDM | Wavelength Division Multiplexing |

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