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Design and Fabrication of Duplexer for GSM900 Band Applications

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Abstract: This paper presents the design technique and simulation of Duplexer for GSM 900 band applications using microstrip technology.Two band pass filters with unequal impedance are designed. One filter with the 890-915MHz band and other filter with the 935-960MHz. Then these two filters are combined together in parallel to act as a duplexer with the uplink frequency band as 890-915MHz and downlink frequency band as 935-960MHz.The simulation is done using ADS software. Next, tuning and optimization are applied to achieve the low insertion loss.The proposed duplexer is a proof of concept for realizing duplexer functions using microstrip technology. In general, duplexers are built using high quality factor cavity filters. However, to prove the concept, duplexer is fabricated using FR-4 material which is readily available in India.
Keywords: Advanced Design System (ADS), Bandpass Filter (BPF), Fractional Bandwidth (FBW)

1. INTRODUCTION

The duplexer is a device that isolates the receiver from the transmitter while permitting them to share a common antenna. The duplexer is often the key component that allows two way radios to operate in a full duplex manner. An ideal duplexer provides perfect isolation with no insertion loss to and from the antenna. A conventional duplexer is a three-port device and normally consists of two band pass filters and impedance transforming circuit to allow both filtered to connect to a common antenna port. [4,6]

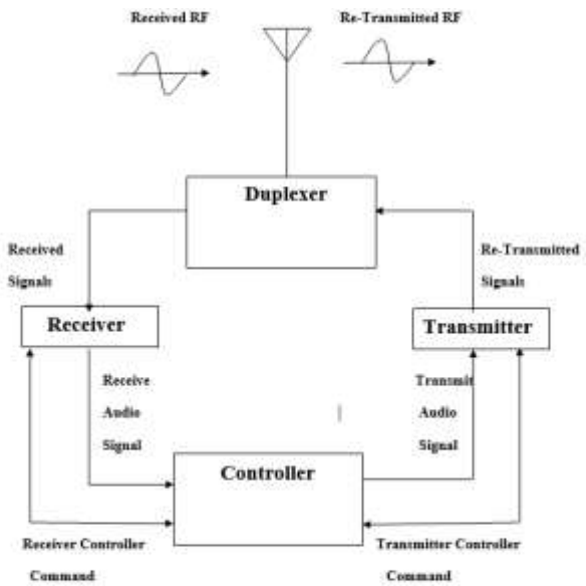

Figure 1:Block diagram illustrating the working of duplexer.

The working of duplexer is as shown in the figure 1. During transmission, signals from controller are transmitted to antenna through transmitter band pass filter which rejects the signals having frequency range other than 890-915MHz.
During reception the signals received by antenna are passed to controller through receiver band pass filter which rejects signals having frequency range other than 935-960MHz.

1.1Band pass filter:

Filters are indispensable devices in many systems and applications including wireless broadband, mobile, satellite communications, radar, navigation, sensing and other systems. With the development of these systems, mostly induced by great commercial interests, limited electromagnetic spectrum has to be shared among more and more systems. Thus, there is an increasing demand for RF, microwave and millimeter wave filters with more stringent requirements.These filters are employed in various systems to select or confine signals with specified spectral limits. Electronic filters are circuits that have signal processing functions. i.e. they transform an input signal to obtain an output signal with the required characteristics. In the frequency domain filters are used to reject unwanted signal frequencies and to pass signals of desired frequencies.

A bandpass filter only passes the frequencies within a certain desired band and attenuates others signals whose frequencies are either below a lower cut-off frequency or above an upper cut-off frequency. The range of frequencies that a bandpass filter allows to pass through is referred as passband. A typical bandpass filter can be obtained by combining a low-pass filter and a high-pass filter or applying conventional low pass to bandpass transformation.A band pass filter is an electronic circuit which allows the signals with the desired frequency band and supresses the signals out of that band.

1.2 Microstrip

Microstrip is an electrical transmission line which can be fabricated using printed circuit board technology and is used to convey microwave frequency signals[1][7]. It consists of conducting strip separated from a ground plane by a dielectric layer known as substrate as shown in figure 2.
Microstrip line is used to carry electromagnetic waves or microwave frequency signals. Microstrip lines will have low to high radiation, will support 20 to 120 ohm impedance, supports Q factor of 250.

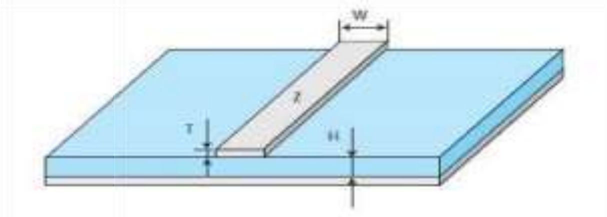

Figure 2: Microstrip structure

Microwave components such as Antennas, Couplers, Filters, Power dividers etc. can be formed from microstrip, the entire device existing as the pattern of metallization on the substrate.
Microstrip is much less expensive than traditional waveguide technology, as well as being far lighter and more compact.

1.3.ADS Software

Advanced Design system (ADS) is an automation software produced by Agilent EEsof EDA, a unit of Agilent technologies. It provides an integral design environment to designers of RF electronic products such as mobile phones, pagers, wireless networks, satellite communication etc.
Agilent ADS supports every step of the design process like layout, simulation, frequency-domain and time-domain circuit simulation and electromagnetic field simulation allowing engineers to full characterize and optimize RF design without changing the tools.

2. DESIGN FLOW

Two chebyshev bandpass filters are designed with the frequency bands 890-915MHz and 935-960MHz. The pass band ripple is taken as 0.5dB.Insertion loss and return loss are required to be maximum of 2dB and minimum of 10dB respectively.
The job in designing any type of filter is to calculate its order. So the order of the filters are calculated by using the below equation

$$N \geq \frac{La + Lr + 6}{20 \log_{10}\left(S + \sqrt{(S^2+1)}\right)} = 6 \ldots\ldots\ldots\ldots 1$$

Where, N is the order of the filter
La= Attenuation in stop band
Lr=Ripple in pass band=0.5
S =Selectivity factor of the filter

$$= \frac{Stop\ band\ frequecy}{Pass\ band\ frequency} \geq 1$$

The chebyshev filter coefficients are obtained from the table 1.

Table.1:Chebyshev filter coefficients with 0.5 dB ripple.

N	g1	g2	g3	g4	g5	g6	g7	g8	g9	g10	g11
1	0.6986	1.0000									
2	1.4029	0.7071	1.9841								
3	1.5963	1.0967	1.5963	1.0000							
4	1.6703	1.1926	2.3661	0.8419	1.9841						
5	1.7058	1.2296	2.5408	1.2296	1.7058	1.0000					
6	1.7254	1.2479	2.6064	1.3137	2.4758	0.8696	1.9841				
7	1.7372	1.2583	2.6381	1.3444	2.6381	1.2583	1.7372	1.0000			
8	1.7451	1.2647	2.6564	1.3590	2.6964	1.3389	2.5093	0.8796	1.9841		
9	1.7504	1.2690	2.6678	1.3673	2.7939	1.3673	2.6678	1.2690	1.7504	1.0000	
10	1.7543	1.2721	2.6754	1.3725	2.7392	1.3806	2.7231	1.3485	2.5239	0.8842	1.9841

From the table chebyshev filter coefficients for low pass filter with order N=6 are,
g0=1,g1=1.7254,g2=1.2479,g3=2.6064,g4=1.3137,g5=2.4758,
g6=0.8696,g7=1.9841.

If order of the filter is N, then the microstrip coupled line filter will have N+1 coupled lines. So that here the number of microstrip coupled lines in both the filters will be 7.
To design the microstrip coupled line band pass filters,the admittance, odd and even mode excitation line impedances of each coupled lines are to be calculated. These parameters are calculated by using the below equations.

$$J_{01} = \frac{1}{Z_O} \times \sqrt{\left(\frac{\pi}{2} \times \frac{FBW}{g_0 g_1}\right)} \ldots\ldots\ldots\ldots 2$$

$$J_{i,i+1} = \frac{1}{Z_O} \times \frac{\pi}{2} \times FBW \sqrt{\left(\frac{1}{g_i g_{i+1}}\right)} \ldots\ldots\ldots 3$$

$$J_{n,n+1} = \frac{1}{Z_O} \times \sqrt{\left(\frac{\pi}{2} \times \frac{FBW}{g_n g_{n+1}}\right)} \ldots\ldots\ldots\ldots 4$$

Where,J – Admittance
Z_O = 50 Ohm;
FBW = $\frac{\omega_2 - \omega_1}{\omega_0}$
The admittance of each microstrip coupled lines of both the filters are calculated by using the equations 2-4.
The above calculated admittance values are used to obtain the odd and even mode line impedances using below equations:

$$Z_{oe} = Z_O (1 + Z_O J + (Z_O J)^2) \ldots\ldots\ldots\ldots 5$$

$$Z_{oo} = Z_O (1 - Z_O J + (Z_O J)^2) \ldots\ldots\ldots\ldots 6$$

The odd and even mode line impedance values will be substituted in Linecalc tool of ADS.At this point we need to decide the type of substrate to be used in fabrication of designed filters.So here we have taken the FR-4 substrate. The specifications of FR-4 substrate are tabulated in the table 2.

Table 2: FR-4 substrate specifications

Thickness	35um
Height	1.6mm
Dielectric constant,**ε**r	4.6

The admittance,odd and even mode line impedances for 890-915MHz uplink band pass filter are tabulated in the table 3.

Table 3: Admittance, Zoe Zoo values for uplink filter

MCLIN	Admittance(Ohms)	Zoe(ohms)	Zoo(ohms)
MCLIN 1	0.173732555	60.1957	42.8225
MCLIN 2	0.035490933	51.8375	48.2884
MCLIN 3	0.028876315	60.1957	42.8225
MCLIN 4	0.028143854	51.4467	48.6324
MCLIN 5	0.028876618	51.4855	48.5978
MCLIN 6	0.035492342	51.8376	48.2883
MCLIN 7	0.173733896	60.1958	42.8224

The admittance, odd and even mode line impedances for 935-960MHz downlink band pass filter are tabulated in the table 4.

Table 4: Admittance, Zoe Zoo values for down link filter

MCLIN	Admittance(Ohms)	Zoe(ohms)	Zoo(ohms)
MCLIN 1	0.173732555	59.9210	42.9542
MCLIN 2	0.033809354	51.7476	48.3666
MCLIN 3	0.027508141	51.4132	48.6624
MCLIN 4	0.026810383	51.3764	48.6954
MCLIN 5	0.027508428	51.4132	48.6624
MCLIN 6	0.03810696	51.9779	48.1672
MCLIN 7	0.169568152	59.9160	42.9592

The Width (W),length (L) and Spacing(S) of microstrip conductor calculated by using Linecalc tool are tabulated in the table 5 and 6.

Table 5: Width, Spacing andLength of uplink filter

MCLIN	Width (mm)	Spacing(mm)	Length(mm)
MCLIN 1	2.7354	0.7	45.1944
MCLIN 2	2.1371	2.5206	43.3990
MCLIN 3	1.9955	4.3427	44.7556
MCLIN 4	4.0815	5.4698	44.7577
MCLIN 5	2.3382	6.9602	44.7556
MCLIN 6	2.8274	4.4069	45.2838
MCLIN 7	1.7816	0.3	45.6463

Table 6: Width, Spacing and Length of downlink filter

MCLIN	Width (mm)	Spacing(mm)	Length(mm)
MCLIN 1	2.4757	1.029	43.0272
MCLIN 2	2.9619	5.2224	42.618
MCLIN 3	2.9749	6.4583	42.6326
MCLIN 4	3.0955	6.1750	42.6346
MCLIN 5	2.6228	6.3106	42.6326
MCLIN 6	2.9051	4.5305	42.6100
MCLIN 7	1.3462	0.7309	43.4570

3. IMPLEMENTATION IN ADS

As a final step, the coupled line band pass filters are designed in the ADS simulation software environment. It accepts filter parameters and produces physical dimensions of the filter layout and a simulation of the filter response.[2]

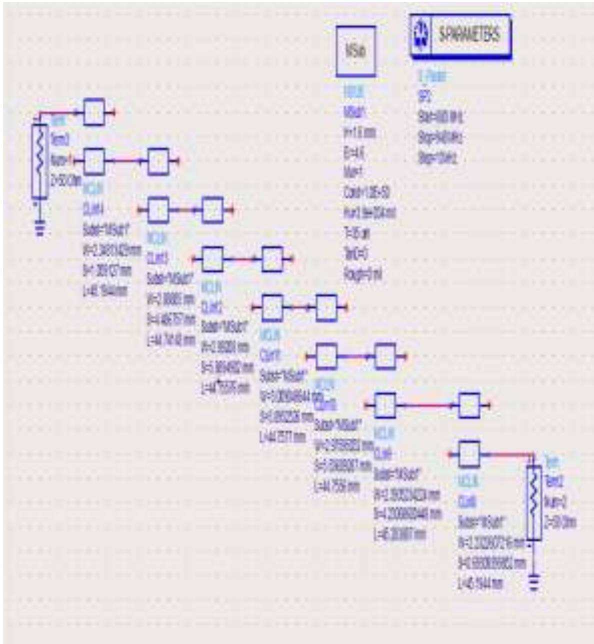

Figure 3: Schematic of uplink band pass filter

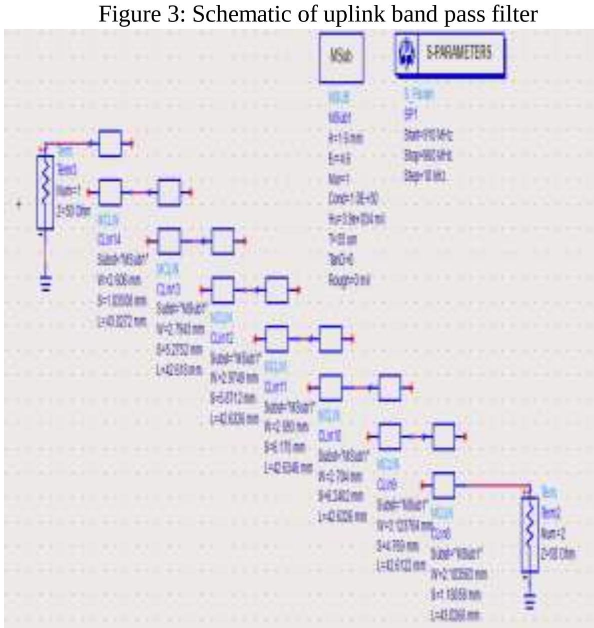

Figure 4: Schematic of downlink band pass filter

The figures 3 and 4 shows the ADS schematics of uplink (890-915MHz) and downlink (935-960MHz) respectively. Both the filters are designed with the unequal impedance condition such that the impedance at the input and output of each filter are 50 ohms and 100 ohms respectively.

To design a duplexer, these two band pass filters are combined in parallel. There are different approaches to combine the BPF's to make a duplexer. One among that is, by using the power divider. When a power divider is used, there will be a 3 dB loss occurs. So that, here we have used a novel approach of 2 unequal impedance filters combined in parallel without a power divider. As a result, net impedance of parallel combined filters will be 50 ohms at all the 3 ports.So that this acts as a DUPLEXER as shown in figure 5.

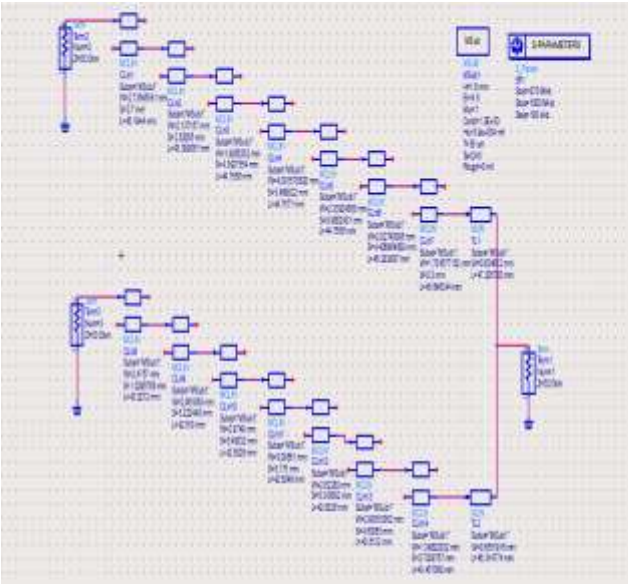

Figure 5: Schematic of Duplexer

3.1 Simulation

Uplink (890-915MHz) response:

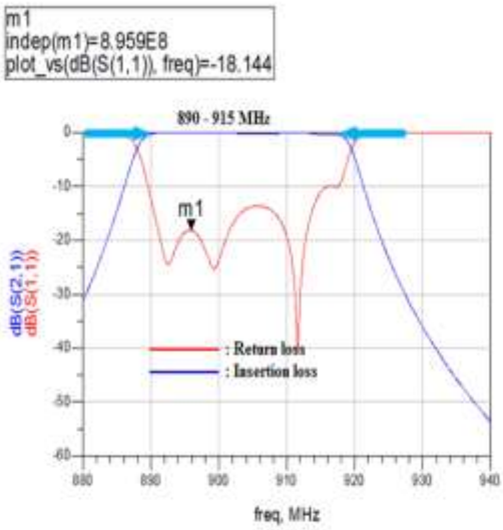

Figure 6: Response of uplink band pass filter

The figure 6 shows the response of uplink band pass filter. The filter passes the signal with the band 890-915MHz, has the ripple less than -1dB and return loss < -10dB.

Downlink (935-960MHz) response:

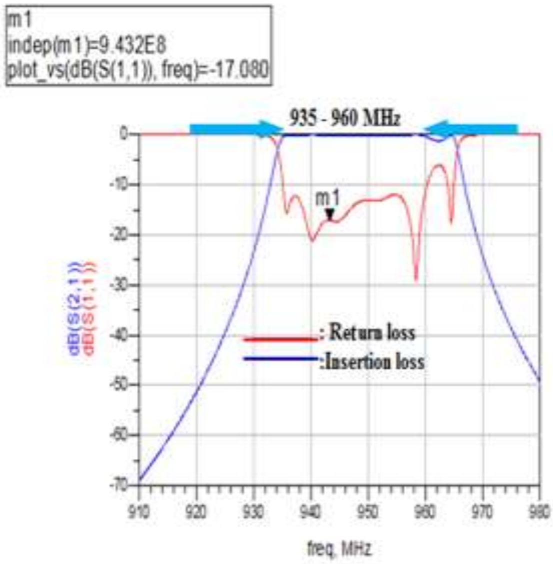

Figure 7: Response of downlink band pass filter

The figure 7 shows the response of downlink band pass filter. The filter passes the signal with the band 935-960MHz, has the ripple less than -1dB and return loss < -10dB.

Duplexer response:

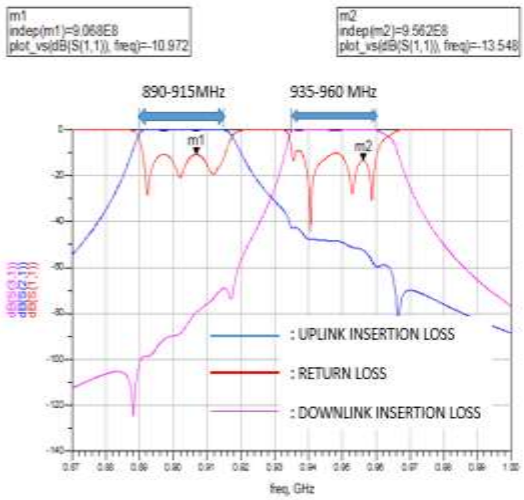

Figure 8: Response of Duplexer

The figure 8 shows the response of duplexer in which the transmitter has the band 890-915MHz and receiver has the band 935-960MHz. High isolation between transmitter and receiver is achieved .The return loss and ripple is obtained as less than -10 dB and -0.5 dB respectively.

The Layout of combined microstrip coupled line band pass filter of un-equal impedance (DUPLEXER) for 890-915 MHz and 935-960 MHz band is shown in the figure 9.

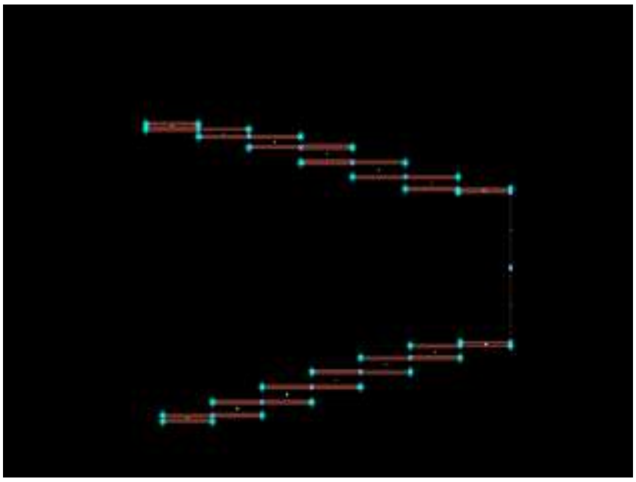

Figure 9: Layout of DUPLEXER

3.2 Fabrication and Tested Results

The designed duplexer is fabricated by using the flame retardant -4 (FR_4) substrate which is readily available in india. Generally, the FR-4 material has 0.3 dB loss per 10 mm.So that the large length designs fabricated using FR-4 materials results in high insertion loss.
The image of the fabricated duplexer is shown below.

Figure 10: Fabricated Duplexer

Tested values of the duplexer are tabulated in the table7and 8.

Table 7: Uplink tested results

Parameter	Lower Frequency (890MHz)	Upper Frequency (915MHz)	Centre frequency (902.6MHz)
S21	-32.26dB	-31.16dB	-23.955dB
S11	-5.34dB	-9.663dB	-12.073dB

Table 8: Downlink tested results

Parameter	Lower Frequency (935MHz)	Upper Frequency (960MHz)	Centre frequency (947.4MHz)
S21	-41.781dB	--30.6dB	--31.621dB
S11	-4..677dB	-8.616dB	-8.354dB

4 CONCLUSION

The designed duplexer is a proof of concept for realizing duplexer function using microstrip technology. In general, duplexers are built using high quality factor (Q) cavity filters. However, to prove the concept, Duplexer is fabricated using FR-4 material which is readily available in INDIA.
The 'Q' achievable in microstrip technique is 100 times less than the cavities. Further FR-4 material is highly lossive for long transmission length like parallel coupled filter, where length is more than 300 mm. Such large lengths result in high insertion loss of the order of 24 to 30dB. Since tangent factor of FR-4 is 100 times less than RT duroid material.

6. FUTURE SCOPE

For the duplexer realization, the isolation required is around 60dB. However recently less than 60 dB is also being used. In this paper, an attempt is made to build the duplexer using microstrip technology at low frequencies in GSM band.
In future the activities carried out in the proposed paper may be taken as basis and improve upon the design by using different materials for realizing high isolation between transmitter and receiver.

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