Scientific Journal of Impact Factor(SJIF): 3.134
e-ISSN(O): 2348-4470
p-ISSN(P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 2,Issue 4, April -2015

DESIGN OF DUPLEXER USING MICROSTRIP FILTERS FOR LOW POWER GSM APPLICATIONS

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Abstract*-A duplexer for low power applications is designed using a combination of highpass and lowpass filters that separates the input signals into two output ports. It isolates the GSM receiver from the high power transmitter by preventing the addition of unwanted noise on to the receiver noise floor. Duplexer allows both transmitter and receiver to be connected to a common antenna there by avoiding requirement of two separate antennas (one for Transmitter and another for receiver). These duplexers can be used in modern cellular repeater amplifiers that rebroadcast cellular signals inside femto cells (that is, in residential or small business environments). Microstrip technology is used to design the duplexers, which has the advantage of providing flexibility and device miniaturization when compared with cavity-based designs while still delivering good performance.*

Keywords*-GSM, duplexer, microstrip filters, matching circuits*

I. INTRODUCTION

A duplexer is an essential three terminal component for channel separation in a multiband communication system. This device allows a transmitter operating on one frequency and a receiver operating on a different frequency to share one common antenna with a minimum of interaction and degradation of the RF signals. Duplexer is a key component for a full duplex communication.

The paper aims to design and analyzecompact microstrip lowpass and highpass filters which in turn is used in duplexers. The design procedure of the duplexer consists of three simple steps, starting from the design of a low pass / high pass filters using open and short circuited microstrip lines. Followed by the development of compact microstrip duplexers composed of these filters and finally using the optimized T-junction matching technique. Microstrip technology is used to design the duplexers,due to their compact size, lightweight, easy to fabricate and low-cost integration using theprinted circuit technology, while still delivering good performance.The duplexer is designed and analyzed using Agilent's ADS tool.

II. METHODOLOGY AND DESIGN OF DUPLEXER

III.

The duplexer is designed on FR4 substrate having a thickness of 1 mm, a dielectric constant of 4.2, and a loss tangent of 0.02. It is designed using a low pass and a high pass filter which is designed using resonator short/open circuit stub resonators method and matching between these two filters obtained using T-junction matching economizes the circuit size. Chebyshev approximation is used because, in this approximation, steep roll-off rate in its stop band frequency and tolerable ripple level in pass band can be achieved by using very less number of filter reactive elements , and it also facilitates low insertion loss and small filter size.

The low pass and band pass filter must be a commensurate line distributed filter where the shunt capacitors of the lumped prototype become open circuit stubs and the series inductors become series lines. The low pass filter line lengths are chosen to be $\lambda/4$.

A. Low Pass filter design

The filter specifications is given in Table 1

Using the Chebyshev filter coefficients table, the elements of the low pass prototype filter for N=7(no. of elements) are

$g_0 = g_8 = 1$

$g_1 = g_7 = 1.7372$

$g_2 = g_6 = 1.2583$

$g_3 = g_5 = 2.6381$

$g_4 = 1.344$

Table1. Lowpass Filter Specifications

Response type	Chebyshev 0.5dB passband ripple
Cut off frequency	890 MHz
Stop band attenuation	30 dB
Return loss	15 dB
Source and load impedance	50 Ω
Substrate height	1 mm
Dielectric constant	4.2

Formulas to calculate L_k and C_k

$L_k = R_0 * g_k / \omega_c$ (1)

$C_k = g_k / \omega_c * R_0$ (2)

The corresponding L and C values are

L1 = L7 = 15.02 nH

C2 = C6 = 4.514 pF

L3 = L5 = 23.2 nH

C4 = 4.45 pF

For each inductance and capacitance, line width and length is calculated using 'Linecalc' tool in ADS (which applies Richard Transformation). The calculated size of the microstrip is shown in the Table 2.

Table2.Width and Length of Stubs

Impedance (ohm)	Length (degrees)	Width (mm)	Length (mm)
Z1=Z7= 72.25	17.64	0.25	4.9
Z2=Z6= 30.09	57.29	1.06	27.6
Z3=Z5= 162.35	31.797	0.336	22.55
Z4 = 45	57.29	0.59	28.8

Finally the transformation from prototype to microstrip looks like as shown in the Figure 1

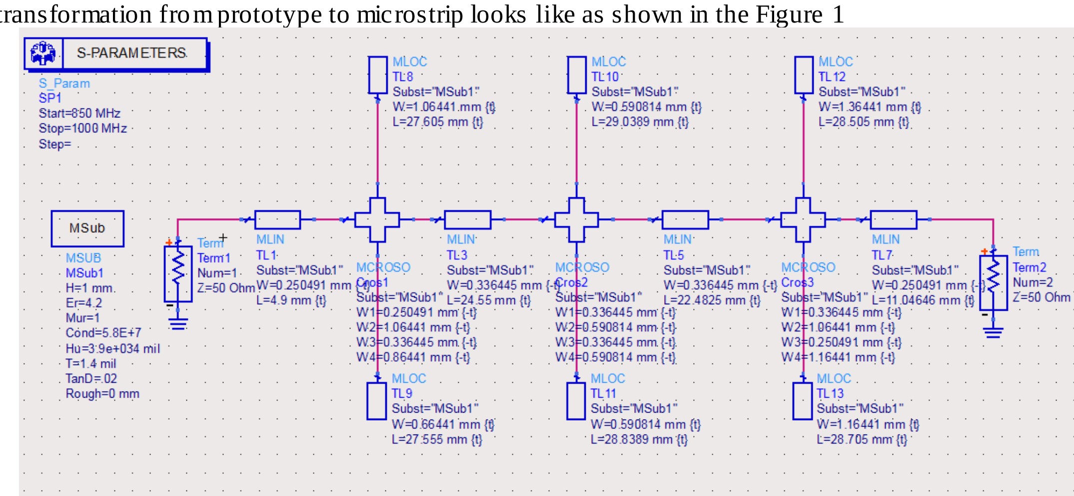

Figure1. Schematic of microstrip lowpass filter

The layout of the low pass filter is as shown in Figure 2.

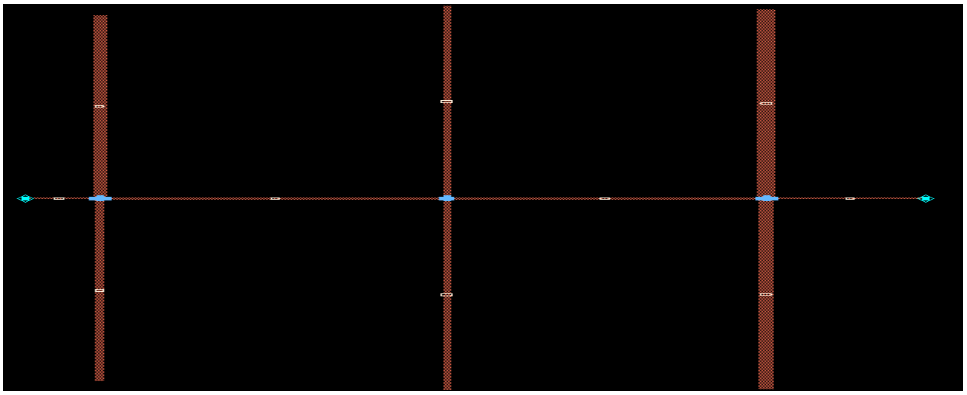

Figure2. Layout of microstrip lowpass filter

B. High Pass filter design

The filter specifications is given in Table 3

Table3. Highpass Filter Specifications

Response type	Chebyshev 0.5dB passband ripple
Cut off frequency	960 MHz
Stop band attenuation	30 dB
Return Loss	15 dB
Source and load impedance	50 Ω
Substrate height	1 mm
Dielectric constant	4.2

Using the Chebyshev filter coefficients table, the elements of the high pass prototype filter for N=6(no of elements) are

$g_0 = 1$ $g_1 = 1.7254$
$g_2 = 1.2479$ $g_3 = 2.6064$
$g_4 = 1.3137$ $g_5 = 2.4758$
$g_6 = 0.8696$ $g_7 = 1.9841$

Formulas to calculate L_k and C_k

$L_k = R_0 / \omega_c * g_k$ (3)
$C_k = 1 / \omega_c * R_0 * g_k$ (4)

The corresponding L and C values are
C1 = 9 pF C3 = 1.9305 pF
C5 = 2.13305 pF C7 = 11.4 PF
L2 = 6.374 nH L4 = 5773 nH
L6 = 6.874 nH

Having cut off frequency f_c = 960 MHz, passband ripple of 0.5dB upto 915 MHz. The electrical length θ_c can be found from the following equation

$$\left(\frac{\pi}{\theta c} - 1\right)f_c = 915 \quad (5)$$

This gives $\theta_c = 33.75°$. Choosing element values for N=6 and $\theta_c = 30°$, we can find the element values for $\theta_c = 33.75°$ by interpolation. As an illustration, for N = 6 and $\theta_c = 33.75°$, the element value y1 is calculated as follows:

$$y_1 = 0.35346 + \frac{0.48096 - 0.35346}{5} X\ 0.375 = 0.44909 \quad (6)$$

In a similar way, the rest of element values are found to be:
$y_{1,2} = 1.03446$, $y_2 = 0.63221$, $y_{2,3} = 1.00443$, $y_3 = 0.71313$, $y_{3,4} = 0.99734$
Using the characteristic impedance $Z_0 = 50\Omega$ the line elements are
$Z_1 = Z_6 = 111.3\ \Omega$,
$Z_2 = Z_5 = 79.1\ \Omega$,
$Z_3 = Z_4 = 70.1\ \Omega$,
$Z_{1,2} = Z_{5,6} = 48.3\ \Omega$,

$Z_{2,3}$= $Z_{4,5}$ = 49.8 Ω,
$Z_{3,4}$= 50.1 Ω

Foreach inductance and capacitance, line width and length is calculated using 'Linecalc' tool in ADS. Using the above mentioned impedances and considering electrical lengths at the cutoff frequency, namely, θ_c = 33.75° for all the stubs and $2\theta_c$ = 67.5° for all the connecting lines. The calculated size of the microstrip is shown in the Table 4.

Table4.Width and Length of Stubs

Impedance (ohm)	Length (degrees)	Width (mm)	Length (mm)
Z_1= Z_6 =111.3	33.75	0.2311	17.0046
Z_2= Z_5 = 79.1	33.75	0.5696	16.55
Z_3= Z_4 = 70.1	33.75	0.8404	16.3863
$Z_{1,2}$= $Z_{5,6}$ = 48.3	67.5	2.1353	31.5449
$Z_{2,3}$= $Z_{4,5}$ = 49.8	67.5	2.29322	31.61
$Z_{3,4}$= 50.1	67.5	1.9722	31.6268

Finally the transformation from prototype to microstrip looks like as shown in the Figure 3.

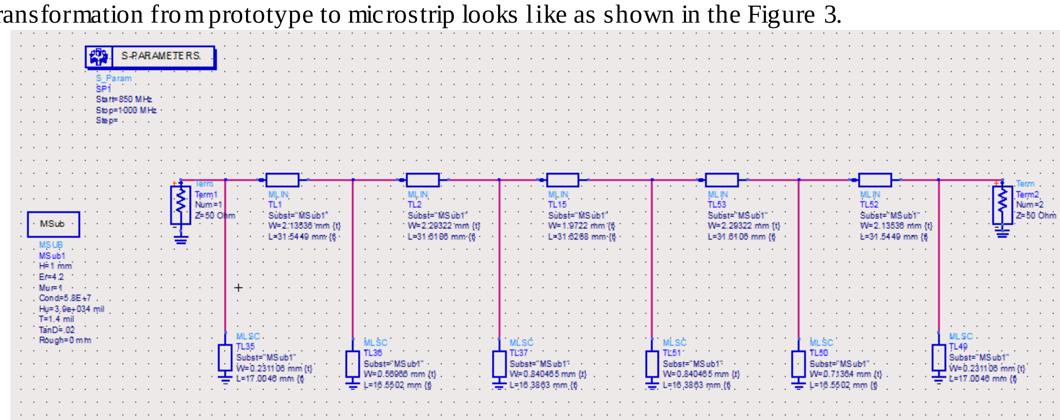

Figure3. Schematic of microstrip highpass filter

The layout of the high pass filter is as shown In Figure 4.

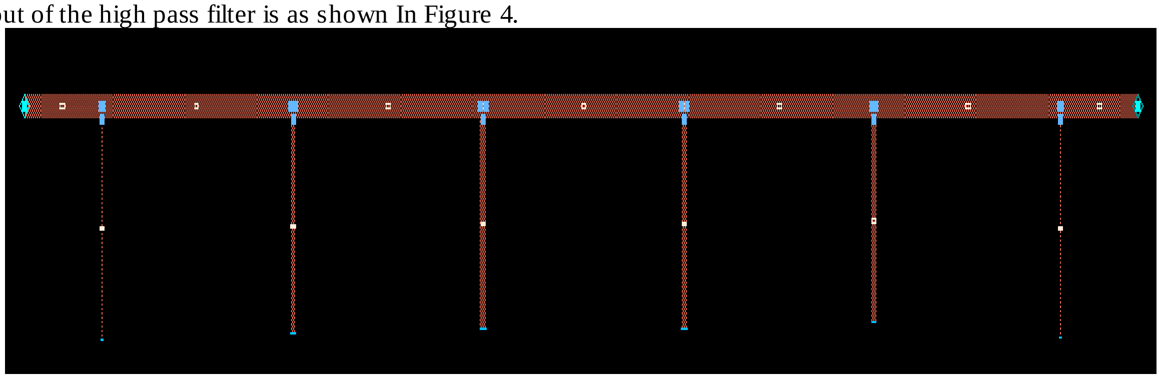

Figure4. Layout of microstrip highpass filter

C. Matching circuit design

The Matching network and combining circuit ensure that both filters match the antenna and have good isolation between them. The length and width of its two branches must be chosen carefully. The T-shaped resonator is composed of a three-section transmission line. Each section has an adjustable characteristic impedance and length.

To build a duplexer, both designed filters should be combined using some matching circuit. One port of this circuit should be matched at the center frequency of filter and the other port should be open-circuit, i.e. the circuit should meet the condition of no reflection at the center frequency of one passband and total reflection at the center frequency of the other passband, and vice versa. This method features the Filter A (Filter B) an open-circuit-load shunted to the Filter B (Filter A) at the frequency of the latter, as shown in Figure 5.

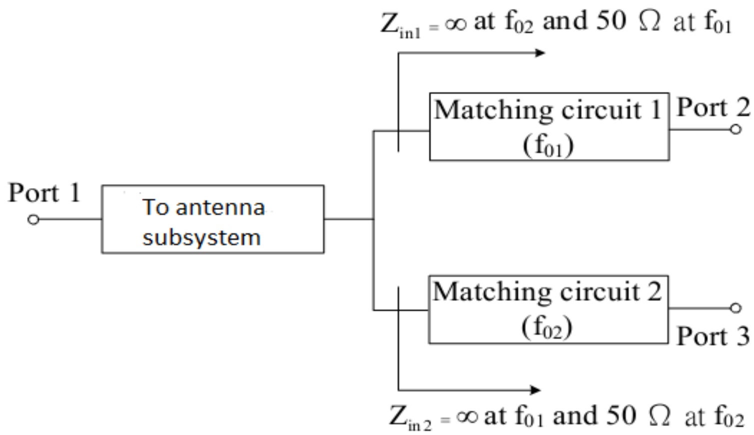

Figure5. Matching circuit design

We calculate the three impedances by using T- Matching networks impedance formulas.

- Select the desired bandwidth and calculate Q = f/BW, where f is operating frequency and BW is Bandwidth
- Calculate $X_L = Q.\ R_g$ (7)
- Calculate $X_{c2} = R_L.\ \sqrt{\frac{Rg(Q2+1)}{RL-1}}$ (8)
- Calculate $X_{c1} = R_L.\ \sqrt{\frac{Rg(Q2+1)}{Q(\frac{QR\,L}{QR\,L - Xc2})}}$ (9)
- Calculate the inductance and capacitance
  $L = \frac{XL}{2\pi f}$ (10) and $C = \frac{1}{2\pi f XC}$ (11)
- Width and length of each impedance is calculated by 'Linecalc' , as given in Table 5

Table5.Section Values for T- Junction

Section	Impedance	Impedance values	Width	Length
T-junction stubs	Z_a	64.330 Ω	6.36 mm	47.2615 mm
	Z_b	45.891 Ω	16.5335 mm	43.8278 mm
	Z_c	2.657 Ω	9.1223 mm	45.4799 mm

Thus the final schematic and layout of the duplexer with the low pass filter, high pass filter and the matching network is as shown in Figure 6 and Figure 7 respectively.

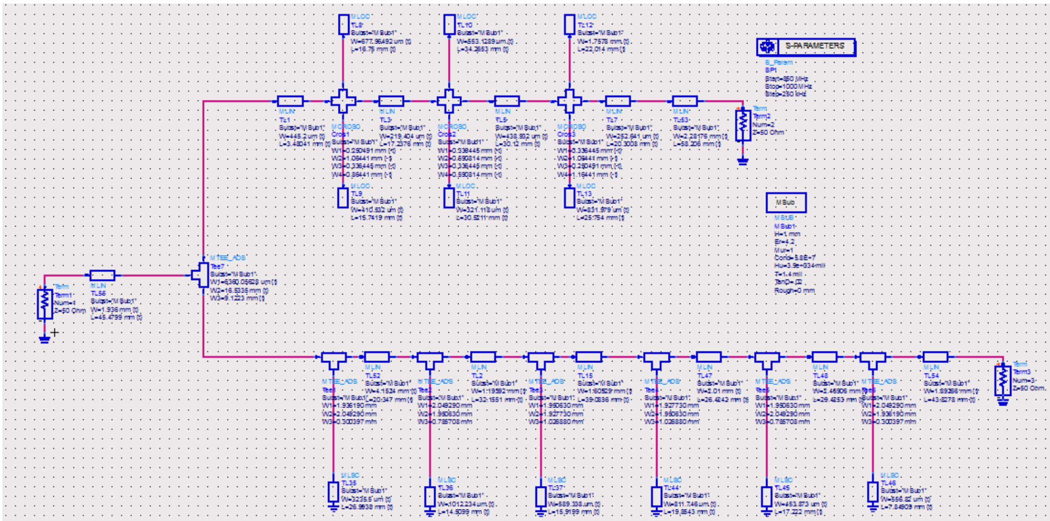

Figure6. Schematic of duplexer using filters and matching circuit

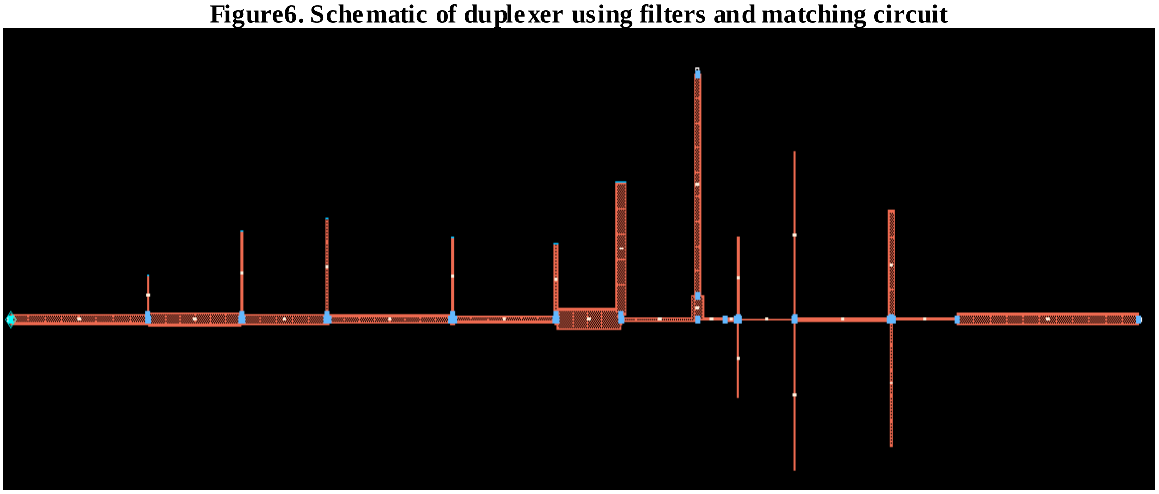

Figure7. Layout of duplexer using filters and matching circuit

IV. SIMULATION RESULTS

The proposed architecture can provide very adequate insertion loss and good isolation between the output ports while at the same time keeping the overall size small.

The Figure 8 shows a combination of transmission parameter of low pass filter (the red graph) and transmission parameter of high pass filter (the blue graph). The duplexer provides a transmission loss of about 3dB for both the passbands. The 3dB insertion loss is due to the fact that the T-junction matching used at the input acts as a power divider, dividing power into the two filters.

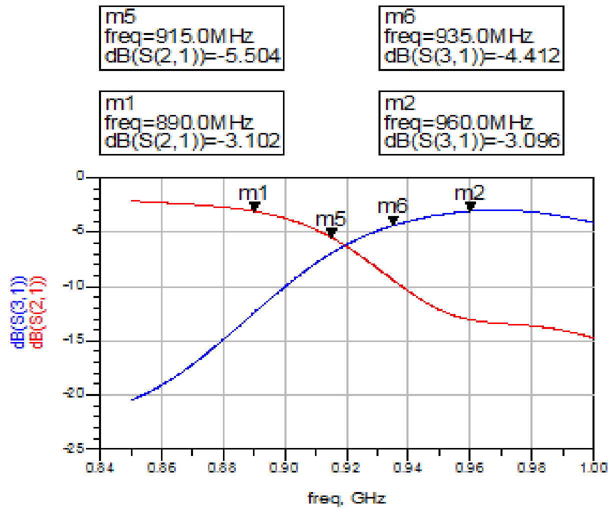

Figure8. Transmission loss of the duplexer

The overall return loss for the uplink (890-915 MHz) is -15.532 dB whereas the overall return loss for the downlink (935-960 MHz) is obtained as -17.947 dB as shown in the Figure 9.

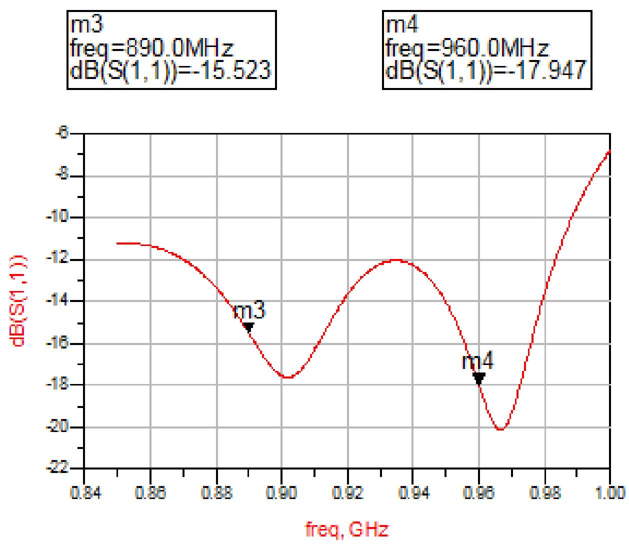

Figure9. Return loss of the duplexer

The uplink is adequately isolated from the downlink as shown in the Figure 10. The isolation obtained is above -20 dB. The low insertion loss is due to the fact the uplink and the downlink band is separated by a narrow band of 25MHz and microstrip filters are not capable of providing a very high isolation.

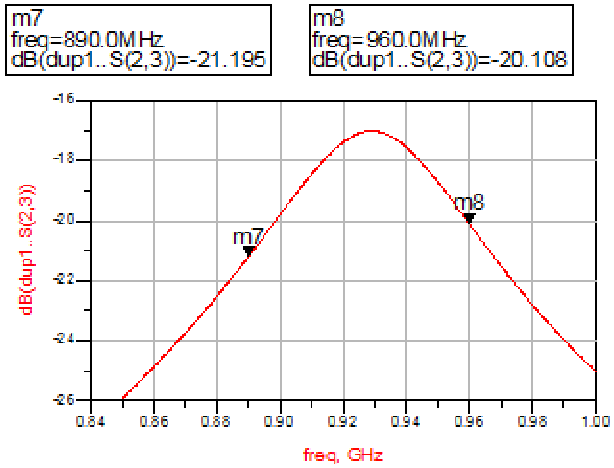

Figure10. Isolation of the duplexer

V. CONCLUSION

The conventional duplexer uses a cavity filter based designed to operate as a part of the combining systems of cellular GSM900 base station installations. The duplexer usually consists of two interdigital band-pass filters, which are connected together by a cross-over network. In contrast this paper attempts to design a duplexer based on microstrip technology which has the advantage of providing flexibility and devices miniaturization when compared with cavity-based designs while still delivering good performance.

This paper presents a new technique to design a duplexer using microstrip technology, which is a combination of low pass filter and highpass filter. While many approaches for microstrip filter implementations are available like stepped impedance filters, coupled line filters etc. A different approach is adapted in this paper that uses a combination of open circuited stub low pass filter and a short circuited stub high pass filter. A T-junction matching network designed to match the duplexer to the antenna that matches the low pass filter to 50Ω antenna for uplink frequencies(890MHz-915MHz) while offering infinite impedance to downlink filter spectrum(935-960 MHz of high pass filter). Similarly it matches the high pass filter to 50Ω antenna for downlink frequencies while offering infinite impedance to uplink filter spectrum. The design analyzed using ADS 2013, produces interband isolation with a minimum of -20dB. The insertion loss obtained is around than -3 dB. The overall return loss is less than -16.5 dB. The duplexer can be used in low power applications. It can also be used in GSM repeaters and in-building coverage systems to share two channels using a common antenna.

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