Butterworth Band-pass Filter (BBPF) Using Parallel Coupled Lines for WiMAX

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Abstract—*This paper describes the design, simulation and analysis of a Butterworth band-pass filter using parallel coupled line for WiMAX application. Butterworth approach was used in designing the filter and the simulation was carried out using Genesys simulation software. The performance of the filter was simulated based on Rogers Duroid 4350B with dielectric substrate (Єr) is 3.48. The operating frequency range from 5.7175GHz to 5.8225GHz with the cut-off frequency 5.770 GHz with the consideration of 100MHz bandwidth. It was observed that both the simulated and measured values were close.*

***Keyw**ords*—*Filter, microstrip, parallel coupled line, low-k substrate.*

I. INTRODUCTION

A band-pass filter is an essential part especially in microwave communication system. It usually used in both receivers and transmitters. The quality of the band-pass filter is important and currently used for fabricated using printed circuit technology and it was suitable for commercial applications [1].

Band-pass filter has the property that one band of frequency is transmitted while two band of the frequencies namely those below and above the pass-band are blocked. Microwave filter is two port network used to control frequency response within a system by allowing the transmission of certain frequencies in pass-band while attenuating frequencies in the stop- band [2].

The parameters of the BBPF consist of the length, *l* and the width, *w* of the coupled lines, as well as the distance between the two coupled lines known as space gaps, *s* [3]. The beauty of Butterworth band-

Abstract—

pass filter is the frequency response is maximally flat and no ripples in the pass band [4].

This work involved with design and simulation, fabrication and analysis of the BBPF based on low-k substrate. The design is focused for WiMAX application.

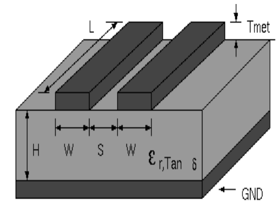

Fig.1: Parallel coupled microstrip line

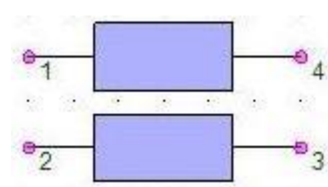

Fig.2: Transmission line represented

WiMAX stand for Worldwide Interoperability for Microwave excess is a form a broadband wireless excess system. WiMax also has several advantages such us high speed voice and multifunctional applications like data transfer, telephone services and video applications [5].

II. SCOPE OF THE WORKS

The work was limited to a Butterworth band-pass filter incorporated parallel coupled lines using commercial simulation software; *Genesys*. Band-pass filter was designed based on the following specification:

Table 1
Band-pass Filter Design Specification

Number of order(n)	3
Center Frequency	5.770GHz
Lower cut-off frequency	5.7175GHz
Upper cut-off frequency	5.8225GHz
Bandwidth	100MHz

The simulation was carried out to determine the optimum values for the length, *l*, width, *w* and the gaps, *s* of BBPF. Finally, to produce a prototype Butterworth band-pass filters on the RT Roger Duroid 4350B substrate with dielectric 3.48.

III. METHODOLOGY

The flowchart Fig.3, described all the works involved in designing the filter. Literature review was done to obtain information on Butterworth low-pass filter for low-k material. A CAD tool was used for designing and simulation purposes.

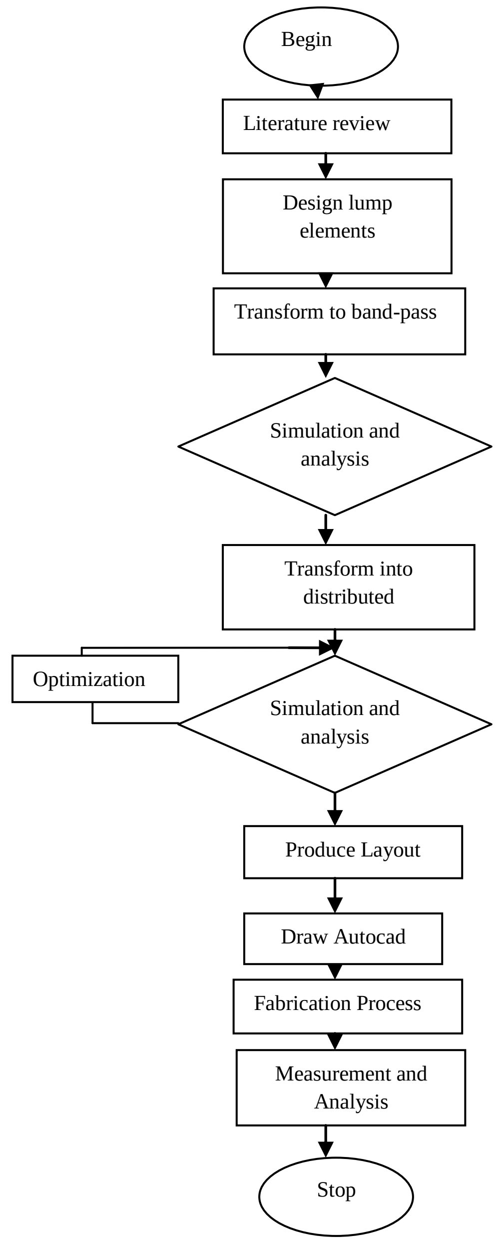

Fig.3: Design flowchart

A. Design Procedure

Parallel coupled lines filter in this part was developed on Roger Duroid substrate where the characteristics as shown in Table 2.

Table 2
RT/Duroid 4350B Substrate Properties

Microstrip properties

Dielectric constant, ε	3.48
Height	1.542mm
Loss tangent	0.0001
Frequency	5.770GHz

Table3

Microstrip conductor

Thickness	0.035mm
Resistivity	1.000 rel Au

The first step to design filter is to determine the filter specification such as operating frequency range, the order the filter (n), and impedance matching of the filter. This filter was designed with number of order n=3, which represent number of the element of the filter. By referring to the design data of Butterworth low-pass filter, the element values obtain as shown in Table 4. The quantities g is referred to the prototype element values which is selected according to the order (n) of the filter from the Butterworth table. The low-pass prototype elements values obtained can be represent as shown by Table 4. Based on the prototype values, the values are denormalized to obtain the actual value by using the following formula (1), (2) and (3).

Table 4
Butterworth filter table for n=3

g_0	g_1	g_2	g_3	g_4
1.000	1.000	2.000	1.000	1.000

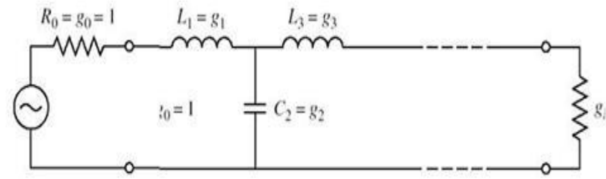

Fig. 4: In the Ladder circuit for low –pass filter prototype beginning with series element

$$L_n = R_g \times g(n) \quad (1)$$

$$Cn = \frac{g(n)}{Rg} \quad (2)$$

$$R_g = 50 \quad (3)$$

Based on conventional band-pass filter design [6], the low-pass filter has to be converted to band-pass filter by computing the following calculation based on equation (5) to (14).The band-pass filter elements obtained can be represented as shown in Fig 5.

Fractional Bandwidth,

$$f_b = [f_b\,(\%) \times f_c] - 2 \quad (4)$$

Lower frequency,

$$f_l = f_c - f_b \quad (5)$$

Angular lower frequency

$$\omega_l = R_l \times 2\pi \times f_c \quad (6)$$

Upper frequency,

$$fu = f_c + f_b \quad (7)$$

Upper ratio,

$$R_u = \frac{fl}{fc} \quad (8)$$

Angular upper frequency,

$$\omega_u = R_u \times 2\pi \times f_c \quad (9)$$

Capacitors and inductors values:

$$L_1 = L_3 = \frac{Ln}{\omega u - \omega l} \tag{10}$$

$$C_1 = C_3 = \frac{\omega u - \omega l}{\omega o^2 Ln} \tag{11}$$

$$L_2 = \frac{\omega u - \omega l}{\omega o^2 Cn} \tag{12}$$

$$C_2 = \frac{Cn}{\omega u - \omega l} \tag{13}$$

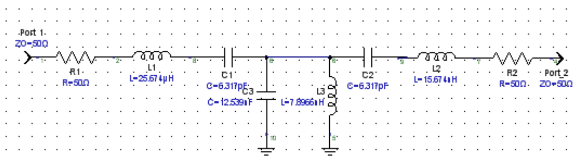

Fig. 5: Third order band-pass filter

All the lumped elements components will undergo the translation process to the distributed elements due to the high operating frequency. Translation process has been done based on the value of the lumped elements to ensure that the distributed element for the parallel blocked had the characteristics impedance value based on the lumped element prototype. To design such as structure that meets a particular band-pass filter specification, a number of computations have to be performed. The fractional bandwidth of the pass-band was obtained by using the equation in (15). The purpose of the fractional bandwidth calculation is that allow parameters such as the coupling structure, intermediate, coupling structure to be calculated based on equation (16) and (18) .

Fractional bandwidth:

$$\Delta = \frac{\omega u - \omega l}{\omega 0} \tag{14}$$

First coupling structure:

$$Z_0 J_{0.1} = \sqrt{\frac{\Delta\pi}{2 g_0 g_1}} \tag{15}$$

Intermediate coupling structure:

$$Z_o J_{i,j+1} \quad = \frac{\pi\Delta}{2\sqrt{gigi+1}} \tag{16}$$

Final coupling structure:

$$Z_{oJn,n+1} = \sqrt{\frac{\Delta\pi}{2gngn+1}} \tag{17}$$

The coupled line can be decomposed into even-mode excitation and odd-excitation [7]. To obtain the even and odd coupled lined impedance Zo_e and Zo_o are calculated by using this equation (18) and (19) where $a = J_{i,i+1}$ and Z_o = 50Ω.The overall circuit performance is the multiplying of square root due to the both even-mode and odd-mode excitation. The overall circuit performance is the multiplying of the square root due to the both even-mode and odd-mode excitation. The impedance parameters are as follows equation (20).

For even (Z_{oe})

$$Z_{oei,i+1} = Z_0[1 + Z_O J_{i,i+1} + (Z_0 J_{i,i+1})] \tag{18}$$

For odd (Z_{oo})

$$Z_{00i,i+1} = Z_0[1 + Z_O J_{i,i+1} + (Z_0 J_{i,i+1})] \tag{19}$$

$$\left(Z_{0i,i+1}\right) = \sqrt{(Z_{0ei,i+1})} x \sqrt{(Z_{00i,i+1})} \tag{20}$$

Finally coupling for each couple line is computed by using the equation (22) .When even-mode and odd-mode impedance characteristic are determined from the calculation, the physical parameters for each parallel coupled line such as width, length and lined spacing can be obtained from line calculator, *Linecalc.*

Coupling factor in dB

$$C_{i,i+1}=20\ log\,\frac{Z_{oe\ i,i+1}-Z_{00\ i,i+1}}{Z_{oei,i+1}+Z_{ooi,i+1}}\quad \text{(dB)} \qquad (21)$$

B. CAD simulation

Simulation was carried by using *Genesys* software. Distributed filter element prototype is depicted in Fig 6, and the layout of parallel coupled is illustrated in Fig.7 based on distributed element dimension.

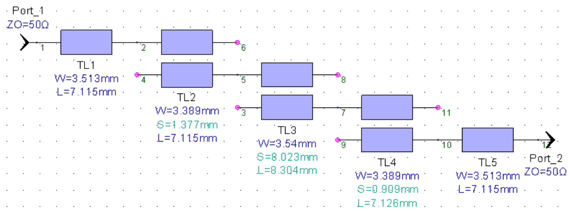

Fig.6: Distributed element prototype

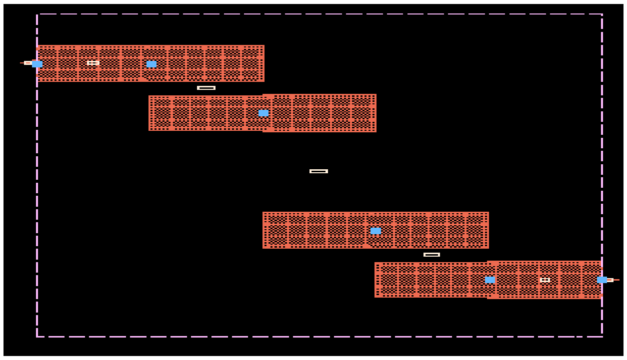

Fig.7: Butterworth parallel coupled line band-pass filter physical layout.

V. RESULT AND DISCUSSION

Fabrication of the prototype was realized by using the low-k material as shown in Fig 8. Optimization procedure was used to obtain the best layout of the filter.

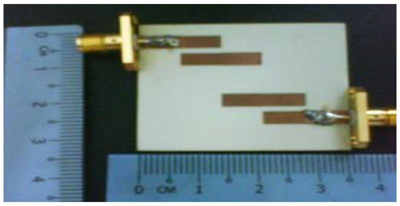

Fig.8: Fabricated band-pass filter

Table 4
Result Simulation and Measurement

	Simulation	Measurement
Center frequency (*fc)*	5.790GHz	5.55GHz
Lower Cut-Off Frequency (*fl)*	5.751GHz	5.5225GHz
Upper Cut-Off Frequency (*fu*)	5.812GHz	5.584GHz
Insertion Loss(S21)	<-0.5dB	-6.746dB
Return Loss(S11)	-23dB	-13.9896dB
Bandwidth	61MHz	62MHz

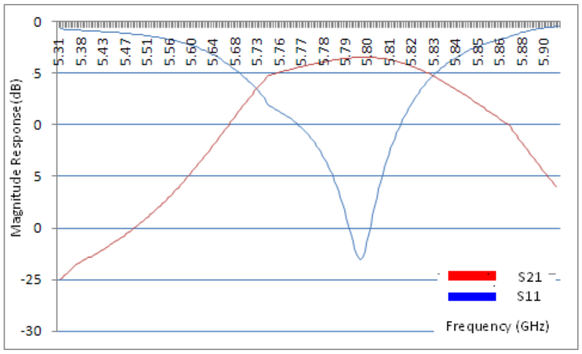

Fig.9: Result S11 and S21 simulation

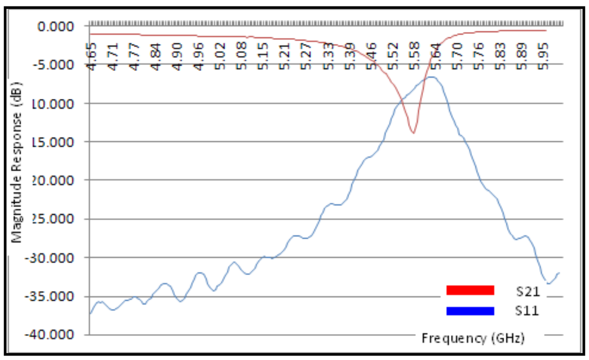

Fig.10: Result S21 and S11 from VNA

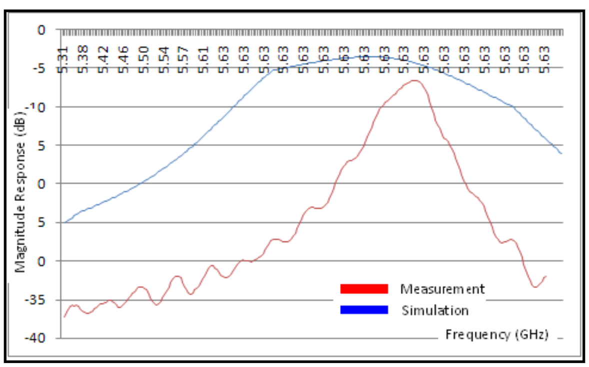

Fig.11: Result S21 simulation and measurement VNA

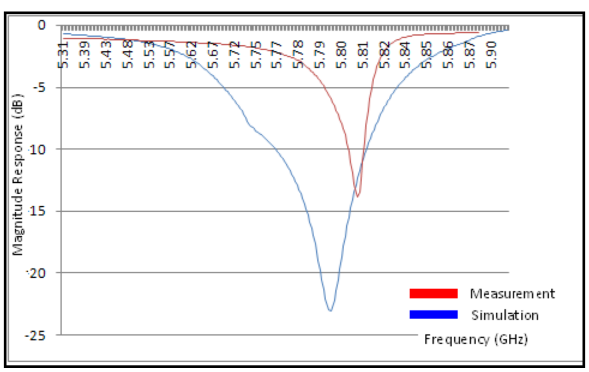

Fig.12: Result S11 simulation and measurement VNA

Measurement of the parameters of the prototype was carried out by using a vector network analyzer (VNA). Standard calibration procedure was used prior to the measurement [8].Figure 9, 10, 11 and 12 shows the measurement values from VNA and the values from simulation by Genesys software. It was observed that, they were discrepancy between measured and simulated values. These may be due to the effect of connector and error in fabrication and parasitic losses.

VI. CONCLUSION

A prototype BBPF was successfully designed, simulated, fabricated and analyzed. It was very small, compact, light and with low of fabrication [1]. There was a slight discrepancy between measured and simulated values.

VII. FUTURE DEVELOPMENT

In future, the filter should be fabricated carefully and make sure the 50 ohms transmission line is short as possible to reduce the connector losses.This parallel coupled line filter can be further developed on different substrates of Rogers Duroid or other high-k substrates and in different frequency range for other various applications.

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