High-Pass Chebyshev Filter for IEEE 802.16/WiMAX Applications

Nik Nur Shaadah BT Nik Dzulkefli
Department of Electrical Engineering
(Communication)
Universiti Teknologi MARA Malaysia,
40450 Shah Alam, Selangor.

***Abstract* - This paper described the design, simulation of a microstrip high-pass filter. The high-pass filter design for IEEE 802.16/WiMAX application [1]. The filter designed to be operated at frequency of 10 GHz. The microstrip was designed and simulated using *Genesys*. In this design, *Rogers RT Duroid 5870* has been used as substrate with 0.5 mm, relative dielectric constant, ε_r of 2.33 and dielectric loss tangent of 0.0012.**

Index term – High-pass filter, microstrip, IEEE 802.16/WiMAX.

I. INTRODUCTION

Filters play a very important role in communications systems. The designs of filters are highly specialized field within RF engineering [2]. Their main function is to separate analog signals into specific, well-defined frequency bands. High-pass filter is one of the type filters that exist in communications systems today. A high-pass filter is a filter that passes high frequencies and attenuates low frequencies. [3]

The high-pass filter characteristics can be physically synthesized by using Tschebysheff filter. The Tschebysheff (equal ripple magnitude) filter is a high-Q filter. This filter response has steeper initial rate of attenuation beyond the cut-off frequency than Butterworth. This advantage comes at the penalty of amplitude variation (ripple) in the pass-band. Unlike Butterworth and Bessel responses, which have 3dB attenuation at the cut-off frequency, Tschebysheff cut-off frequency is defined as the frequency at which the response falls below the ripple band. The Tschebysheff filter is also used when the passband is no longer required to be flat. With this type of requirements, ripple can be allowed in the passband. The only disadvantage of Tschebysheff filter is it has more ringing in its pulse response than the Butterworth especially for high-ripple designs. [4]

The WiMAX is a portion of frequency spectrum that allocated between 10 – 66 GHz. The filter are designed to operated at 10 GHz with min attenuation -40 dB at 5 GHz and pass-band ripple of 0.5 dB. The high-pass filter specification is given in Table 1. The filter is design using *Genesys* and implemented on *Rogers RT Duroid 5870*. The substrate specification is given in Table 2. This paper concentrated on design Tschebysheff types of filter because of the sharp skirt and the equal ripple response compared to other types of approximation.

Table 1 High-pass filter specification.

Filter specification	Value
Center frequency	10 GHz
Passband ripple	0.5 dB
Min attenuation	-40 dB at 5 GHz

Table 2 *Roger RT Duroid 5870* specification.

Substrate specification	Value
Dielectric constant	2.33
Loss tangent	0.0012
Substrate height	0.5 mm

Section II will discuss about the step by step procedure on designing the filter and method of optimization. Section III will discuss about the result obtained and comparison with the ideal high-pass filter obtained from *Genesys*. While in the last section, Section V will discuss about the future development in high-pass filter design.

II. PROCEDURES

In this paper, the initial step in designing the filter is to obtain the number of element, *n*. The number of element is important in Tschebysheff design; because it will affect the ripple obtain from the response.

The procedure of designing the high-pass filter is start with identified the numbers of element, *n*. The number of element of this filter is $n = 5$.

n – number of element

The reason to use higher number of element value is to obtain a better response.

The prototype value for low-pass filter is shown below;

gc = 1.303   gL = 1.807

gc =1.303   gL = 2.691

gL = 1.807

From the prototype value, the high-pass filter is normalized in low-pass filter.

Value of actual capacitor

$$C = C_{prototype} / Z_o \omega_c \quad (1)$$

Value of actual inductor

$$L = \frac{P_{rototype}(Z_o)}{\omega_c} \quad (2)$$

After the normalized in low-pass filter, then the filter is converted from low-pass to high-pass filter.

Value of high-pass filter capacitor

$$C_{high\ pass} = \frac{1}{Z_o \times 2\pi \times f(GHz) \times g_L} \quad (3)$$

Value of high-pass filter Inductor

$$L_{High\ pass} = \frac{Z_o}{\omega_c \times g_c} \quad (4)$$

Then, the lumped element is converted to the distributed element to observe the simulation of its response in distributed element.

To convert the element, the length of each element in the filter was calculated using equation as shown below:

For inductor;

$$l = \frac{\lambda_g \omega_c L}{2\pi Z_g} \quad (5)$$

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} \quad (6)$$

Where $\lambda_0 = \frac{c}{f}$ (7)

In designing the filter, insertion loss and return are very important. This is because; these losses could give the effect to the performance of any filter. Insertion loss and return loss can be associated by:

$$R = -20 \log |S_{11}| \, dB \quad (8)$$

The return loss expressed from definition of S-parameter.

Return loss is a measure of power reflected from limitations in communications links. It is the ratio of P_{inc} / P_{ref}, representing the power of the incident, or transmitted, wave, (P_{inc}) to that of the wave reflected from the imperfection (P_{ref}). For best performance, the reflected signal should be as small as possible, meaning the ratio P_{inc} / P_{ref} should be as small as possible [3].

$$R = 10 \log \frac{P_{inc}}{P_{ref}} \, dB \quad (9)$$

Return loss associated with P_{inc} and P_{ref},

Return loss is usually expressed in decibels (dB). The return loss value describes the reduction in the amplitude of the reflected energy, as compared to the forward energy. It will always be a loss, and therefore a negative dB. However, it can write as -3 dB which also equal to 3 dB loss, dropping the negative sign and adding loss.

Return losses often occur at junctions between transmission lines and terminating impedances. It is a measure of the dissimilarity between impedances in metallic transmission lines and loads. For devices that are not perfect transmission lines or purely resistive loads, the return loss value varies with the frequency of the transmitted signal.

$$I.L = -20 \log |S_{21}| \text{ dB} \quad (10)$$

The insertion loss expressed from definition of S-parameter.

The insertion loss is a quantity that shows the amount of power reduced by a device when it is inserted between a source and a load. It is the ratio P_o / P, representing the power delivered to the load when the device not inserted, P_o, to the power delivered when the vice is inserted, P [5].

$$I.L = 10 \log \frac{P_o}{P} \text{ dB} \quad (11)$$

Equation 10 shows the power relations with insertion loss.

The insertion loss of a device may also be referred to as attenuation. Line terminations play an important part in insertion loss because they reflect some of the power. Apart from this it is clear that not all of the power which is sent into the line at one end appears at the other. This is because of radiation losses, resistive losses in the conductor as well as losses in the surrounding dielectric. All of these effects can be conceptually modeled as various elements which make up the equivalent circuit of the line.

Filters are sensitive to source and load impedances so the exact performance of a filter in a circuit is impossible to precisely predict. Comparisons, however, of filter performance are possible if the insertion loss measurements are made with fixed source and load impedances. 50 Ω is the universally accepted measurement impedance.

III. SIMULATION RESULTS

The high-pass filter is designed by using *Genesys*. Before simulation and optimization, the filter was designed and constructed in lumped element and the responses of the filter were investigated. The filter in lumped elements is the ideal filter before it converted into distributed elements. The ideal circuit is meant by neglecting losses and considers the condition is ideal. The result was used as for comparison to the designed filter circuit. Whereas the ideal circuit filter is meant by considers the losses and the condition is not ideal. Note that, in these two considerations, the microstrip specification still using the *Rogers RT Duroid 5870* properties. In order to make sure the response can be realized, all the element length and width were calculated automatically by *Genesys*. However, the substrate properties, elements, attenuation and other importance properties were inserted manually.

The response obtained from *Genesys* in lumped elements shown in Fig.1 and Fig.2.

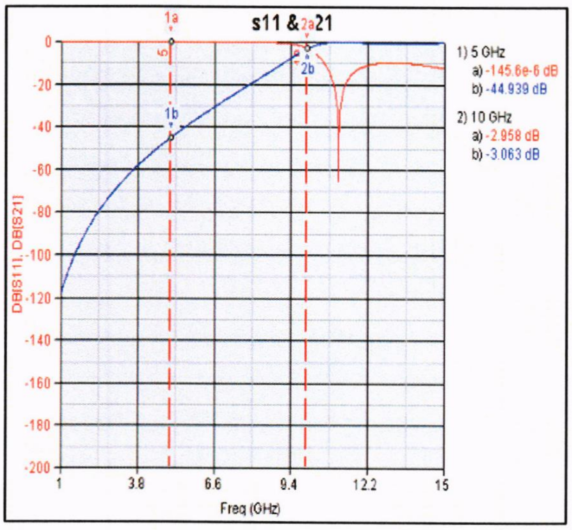

Fig. 1 The figure shows the high-pass filter response which shown by the insertion loss, S_{21} and return loss, S_{11}.

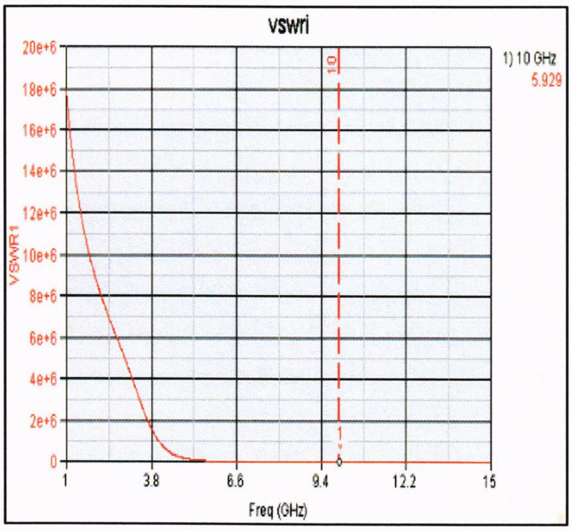

Fig. 2 The figure shows the response of VSWRi of high-pass filter.

After the filter is designed in lumped elements, the filter was then converted into distributed element. The high-pass filter is difficult to realize because it has series capacitor inserted into it. Series capacitors are difficult to realize in distributed form. In this designed the series capacitors were replaced with the micsostrip gap. The responses of the filter were once again investigated. The responses of the filter are shown in Fig.3 and Fig.4 below.

The response obtained from *Genesys* in distributed elements shown in Fig.3 and Fig.4.

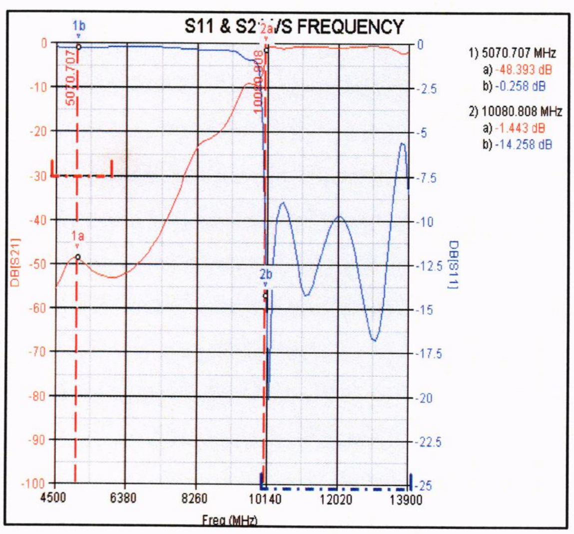

Fig.3 The figure shows the high-pass filter response which shown by the insertion loss, S_{21} and return loss, S_{11}.

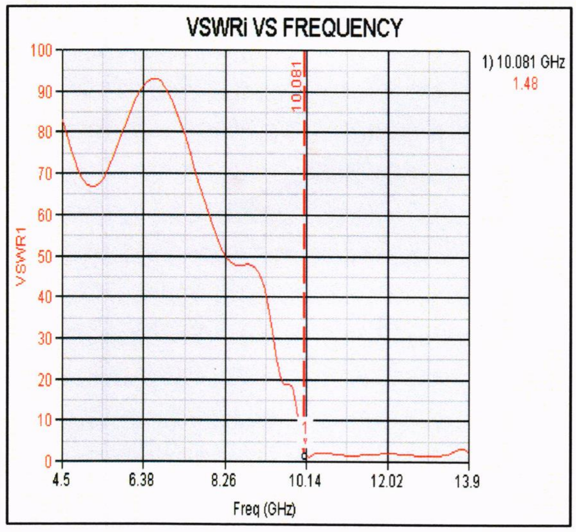

Fig. 4 The figure shows the response of VSWRi of high-pass filter.

Fig. 3 and 4 shows the return loss and insertion loss and VSWRi that achieved from simulations respectively. From these figures, the responses seen were not too different between the lumped elements and distributed elements of the high-pass filter. But the designed filter at fc = 10 GHz is not exactly achieved. From these, it can be conclude that the noise and loss factor consideration would contribute to it. The other thing that may affect the response is the permittivity of the substrate involved.

IV. MEASUREMENT

The high frequency measurement is important owing to the different technique and nature of measurements involved. The high frequency measurement is different and cannot be distinguished by conventional experiments because of the wave-like nature of high frequency [3].

Vector network analyzer, VNA, was chosen as the measurement device for the high-pass filter. The VNA is chosen because of the practicality and accuracy of the measurement.

The importance of measurements is to compare the results obtained from simulations and fabricated device. In simulation, noise or disturbances were not included. So, by measurements, there should be significant changes in the results.

From the VNA, the result acquire is the return loss, S_{11} and insertion loss, S_{21}. All the response is shown in Figs. 5 and 6 below.

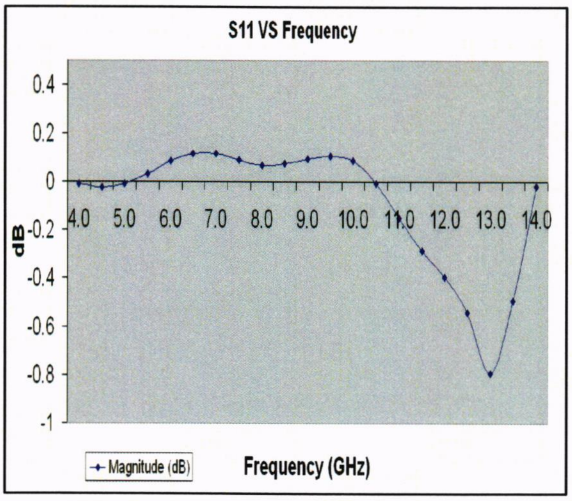

Fig. 5 Measured S_{11} versus frequency.

Fig. 5 above shows that the measured S_{11} is quite similar to simulation.

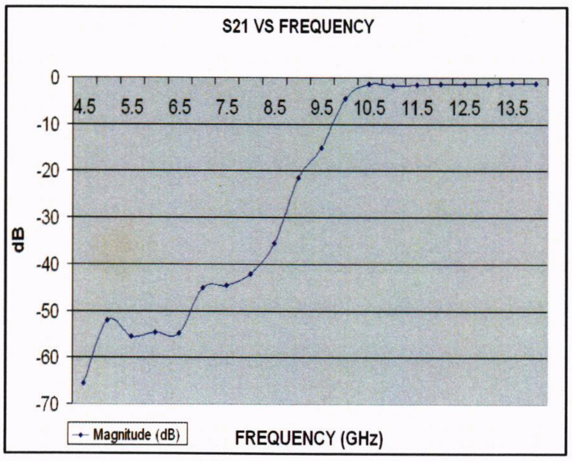

Fig 6 Measured S_{21} versus frequency.

Fig. 6 above shows the measurement result of insertion loss, S_{21}. The result of insertion loss quite similar to the simulation result which shown in Fig. 3 before.

V. CONCLUSIONS

From the results, the high-pass filter designed was met the specifications. But the designed filter at desired frequency not fully achieved. The reasons is, first, the design flaw itself. Wherever a design is simulated using CAD, not all parameter is considered into simulation, such as noises and losses. In this filter design, there are a lot of noises and losses associated in it.

The design of this filter met some difficulties because there include series capacitor where this kind of elements is hard to realized in designing it. This is because there is no specific formula to transform such elements into other elements such as microstrip line.

Other than that, when a microwave device is design, it should be designed with a box for RF shielding. When any RF signal is transmitted or flow through a device, there's a probability of the signal flowing to air or outside of the transmission line. The RF signal is propagate and behavior like wave. One of the ways to prevent this is using a higher permittivity material.

VI. FUTURE DEVELOPMENT

For the future development, this project can be changed to improve the filter performance. It is recommended that to explore on other material and replace the material use in this design. Other material that can be considered is gallium arsenide, GaAs, silicon germanium, SiGe, gallium nitrate and indium phosphate, InP.

Since the final decade of the twentieth century, data networks have known steadily growing success. The need is now becoming more important for wireless access. Therefore, the development of high-pass filters has emphasized compact size and high performance. So, for further development of this filter, it hope that the filter can be realize easily which the series capacitor can be changed into distributed element with specific formula and will improve the performance of the filter.

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