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Design of Butterworth Bandpass Filter for Broadband Wireless Onchip Receiver

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Abstract

This paper gives the simple comparison of bandpass filter and presents the design of Butterworth filter for a wideband wireless receiver. The bandpass filter was designed for covering the major wireless application frequency ranges from 0.4 GHz to 5GHz. The band pass filter was designed to have impedance matching at the input port and output ports. The results achieved shows good input matching at input port (S_{11}) and good output matching at output port (S_{22}) with return loss characteristics of above -300 dB. The transmission characteristics S_{21} gives the effective bandwidth achieved for the design which covers the entire broad pass band with an effective bandwidth of 4.6 GHz. The design of Band pass Filter has been developed in the planar form as strip lines using the design parameters with the simulation software Ansoft designer 4.1.

Keywords: Bandpass filter, Butterworth, Impedance matching, Transmission Characteristics, Planar design.

Introduction

The on-chip antenna (OCAs) is proposed to minimize the antenna feed interconnection losses and also to reduce the size to unprecedented levels of millimetre wave (MMW) frequencies. The size of an antenna is reduced by having silicon substrate with high relative permittivity constant (ε_r=11.9). Antenna in Package (AIP) is used to fabricate antenna on separate substrate and then integrate it with front-end circuits [1]. The high frequency is able to attain high bandwidth and data rate with reduced complexity but they degrade the performance of MOS transistor and they have achieved limited gain [2]. Using OCAs in Wireless personal area network (WPANs) reduces the costs of wireless transceiver which is flexible for the manufacturers [3]. With the help of low-resistivity silicon technology the radiation efficiency can be increased [4]. While using on-chip antenna, the system does not require any bonding or package and also the need of battery. When considering the µRFID, it exhibit features like low-cost, low weight and low area technology [5]. For multi-giga hertz or higher frequency band, silicon-based filters have been used so far due to the higher loss from conductive CMOS substrates which degrades the filter performance. In certain situations designs are used with the micro-matching technology which increases the Q values of inductors and capacitors to extend its application over higher frequency band [6]. For the discrete tenability of both centre frequency and pass band width they proposed a parallel- coupled switched delay line filter which validates the tuning feasibility of a wide resonant frequency range.

The impedance scaling technique is used for the filter network and the theoretical analysis of controlling the pass band width for the broad range variability with loss calculation and the practical analysis is done using microstrip circuit [7]. By using the flexible PerMX polymer substrate a wideband 60 GHz band pass filter have been fabricated with embedded passive device as parallel-coupled half-wavelength resonators filter. A wideband filter can be achieved by the optimization of the narrow gaps between the adjacent resonators. The two different types of filters with and without cover is used where the filter without a cover achieved an insertion loss of 4 dB with centre frequency of 63.5 GHz and returns loss of 10 dB while the filter with cover has an insertion loss of 3.8 dB at 59 GHz and return loss of 13 dB [8].

1.1 Band Pass Filter (BPF)

Band pass filters are used primarily in wireless transmitters and receivers. The main function of such a filter in a transmitter is to limit the bandwidth of the output signal to the minimum necessary to convey data at the desired speed and in the desired form. In a receiver, a band pass filter allows signals within a selected range of frequencies to be heard or decoded, while preventing signals at unwanted frequencies from getting through. A band pass filter also optimizes the signal-to-noise ratio (sensitivity) of a receiver. The Gain-vs. -frequency graph, also called a spectral plot along with the characteristic curve of a hypothetical band pass filter is shown in Figure I.

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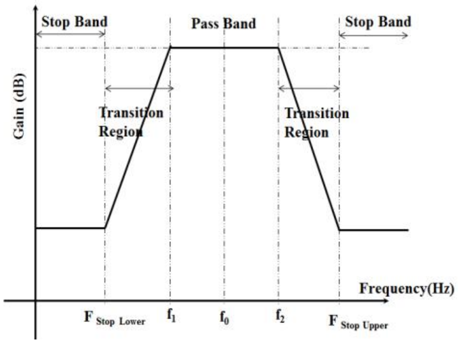

Figure I. Spectral Plot of Band Pass Filter (BPF)

The cut off frequencies, f_1 and f_2, are the frequencies at which the output signal power falls to half of its level at f_0, the center frequency of the filter. The range of frequencies between f_1 and f_2 is used to obtain the filter pass band.

$$\mathrm{BW} = \mathrm{f}_2 - \mathrm{f}_1 \qquad (1)$$

1.2 Types of Band Pass Filter

1.2.1 Butterworth Filter

The Butterworth filter has essentially flat amplitude versus frequency response up to the cut off frequency. In the Butterworth low pass prototype, the insertion should be as flat as possible at zero frequency and rise monotonically as fast as possible with increasing frequency. Although Butterworth filters achieve the sharpest attenuation, their phase shift as a function of frequency is non-linear. Butterworth filters are also known as maximally flat type filters. This class of filters approximates the ideal filter well in the pass band. The Butterworth filter is the best compromise between attenuation and phase response. They are normalized to a frequency of 1 rad/sec and impedance of 1 Ω. It has no ripple in the pass band or the stop band, and because of this is sometimes called a maximally flat filter. The Butterworth filter achieves its flatness at the expense of a relatively wide transition region from pass band to stop band is shown in Figure II, with average transient characteristics. The poles are spaced equidistant on the unit circle, which means the angles between the poles are equal

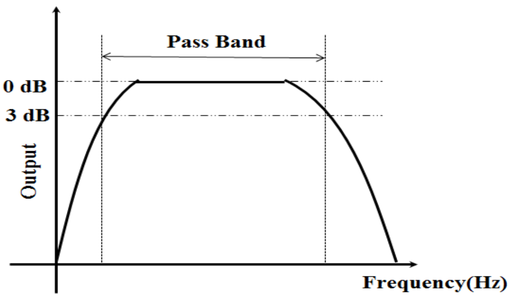

Figure II. Butterworth Response

The values of the elements of the Butterworth filter are more practical and less critical than many other filter types.

1.2.2 Chebyshev Filter

The Chebyshev filter has a smaller transition region than the same order Butterworth filter, at the expense of ripples in its pass band. This filter gets its name because the Chebyshev filter minimizes the height of the maximum ripple, which is the Chebyshev criterion. Chebyshev filters have 0 dB relative attenuation at dc. Odd order filters have an attenuation band that extends from 0 dB to the ripple value. Even order filters have a gain equal to the pass band ripple. The number of cycles of ripple in the pass band is equal to the order of the filter. The poles of the Chebyshev filter can be determined by moving the poles of the Butterworth filter to the right, forming an ellipse.

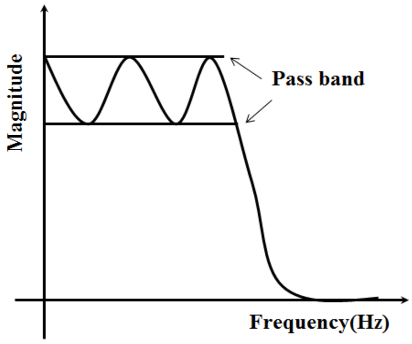

Figure III. Chebyshev Response

The Chebyshev filter, also called the equal ripple filter, gives a sharper cut off than the Butterworth filter in the pass band. In the Chebyshev response is shown in Figure III.The Chebyshev filter provides a filter with equiripple pass band amplitude characteristics but with arbitrarily then both symmetric and asymmetric frequency response can be generated.

Table I. Comparisons of Butterworth and Chebyshev Filter

Sl.No	Butterworth Filter	Chebyshev Filter
1	They have Flat response (No ripples) within its pass band and adequate Roll-off	They produces addition roll-off at ripples
2	Transition band is more and poles lies in Circle	Transition band is less and poles lies in Ellipse
3	Good amplitude response and Linear phase response and low overshoot	They produces ringing due to ripples/peak
4	Magnitude response increases with decrease in frequency	Magnitude response produces ripples in pass band as well as in stop band
5	Does not provide sharpest cut-off	Better rate of attenuation beyond the pass-band

2. Butterworth Bandpass Filter

The design of Butterworth Band Pass Filter has been done using LC Network. The Filter is designed to allow the frequency range of 0.4GHz to 5GHz, which covers a broadband covering the major applications like RF-ID, GSM, GPS, Bluetooth, IMT, WiMax, WiFi etc. The input section needs to meet impedance matching with Z_o having a value of 50 Ω. To achieve this, the value of Resistance is chosen as 50 Ω. The LC network with Pi section is designed for the operating frequency band of 0.4 GHz as lower cut off band and 5GHz as higher cut off frequency. The parameters are designed with the formulas to achieve the values for L_1 . L_2 , C_1 and C_2.

$$L_1 = \frac{Z_0}{\pi(f_H - f_L)}\text{Henry} \qquad (2)$$
$$L_1 = 3.46nH.$$

$$L_2 = \frac{Z_0(f_H - f_L)}{4\pi f_H f_L}\text{Henry} \qquad (3)$$
$$L_2 = 9.16nH.$$

$$C_1 = \frac{(f_H - f_L)}{4\pi f_H f_L Z_0}\text{Farad} \qquad (4)$$
$$C_1 = 3.66pF.$$

$$C_2 = \frac{1}{\pi(f_H f_L) Z_0}\text{Farad} \qquad (5)$$
$$C_2 = 1.385pF.$$

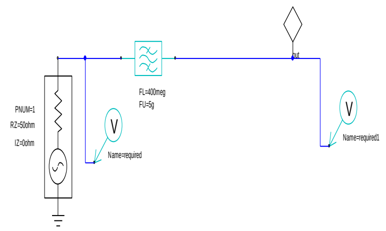

Figure IV. Circuit for BPF in Ansoft Designer

The Band Pass Filter was designed over a frequency range of 0.4GHz to 5GHz with input and output matching port. The design implementation is done with simulation environment as shown in Figure 4. The S-parameter of the circuit is analyzed using the above circuit using the Voltage probe. The input and output ports are assigned with 50 Ω impedance to achieve impedance matching. By taking -3 dB, the transition of signal has been noted over the designed frequency. The Lumped elements are placed inside a Nexxim device for the design of front end receiver section. The obtained frequency response curve is shown in Figure V.

The Simulated Band pass Filter has a Bandwidth of 4.6GHz

Bandwidth $=F_H-F_L$ (6)

BW=5-0.4 (GHz)

BW=4.6GHz

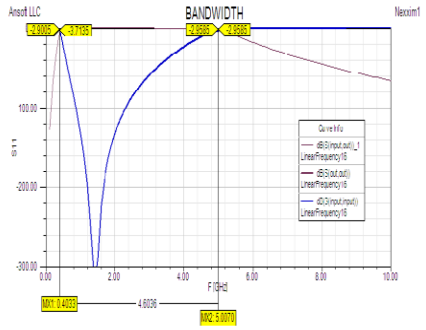

Figure V. Frequency Response of BPF

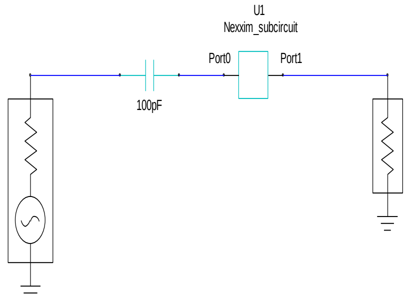

Figure VI. Band Pass filter as Nexxim Circuit

By making the Band Pass Filter block into Nexxim shown in Figure VI, the front end receiver section is developed. The S_{11}-parameter was analysed for input impedance matching with the insertion of System block into the circuit.

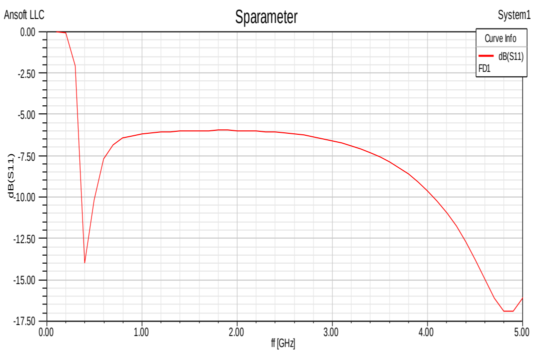

Figure VII. Nexxim Frequency Response Curve

From the Figure VII, around 0.4 GHz the matching is well good and allows the signal to pass through till 4GHz and also has better matching around frequency of 4.8 GHz.

The Noise Figure of a filter must be in the range of 3 to 5 dB. The Butterworth filter designed resulted with a minimum noise figure of about 3dB around frequency of 4.5GHz and gets further reduced to 2.56dB at 5GHz as shown in Figure VIII.

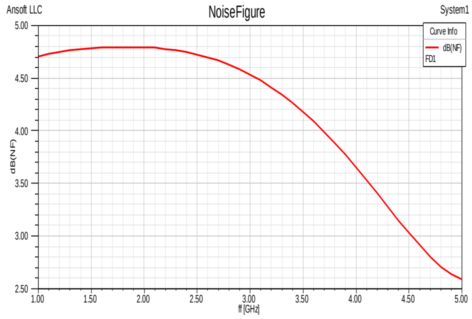

Figure VIII. Noise Figure of Butterworth BPF

By using above design flow formulae the lumped parameter were obtained and these lumped elements are connected using transmission line for matching the network as shown in Figure IX.

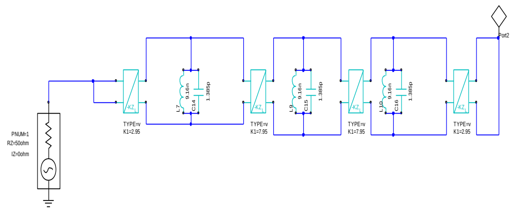

Figure IX. BPF – Lumped Element

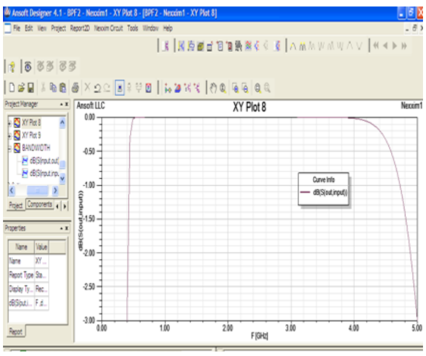

Figure X. Frequency Vs S_{12}

Using the lumped elements, the design achieved a bandwidth of 4.6GHz over a frequency range of 0.4GHz to 5GHz as shown in Figure X.

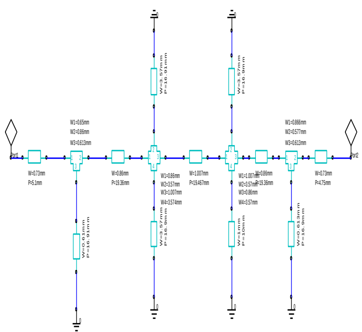

Figure XI. BPF- Distributed Element

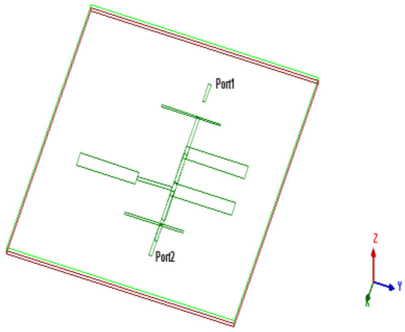

Figure XII. Planar Structure of BPF

From the distributed element which has been shown in Figure XI, the planar structure obtained in Figure XII, is achieved using strip lines design in Ansoft designer. The port one and two is for matching network of input as well as output. The Planar structure helps to design and implement the filter in onchip receiver applications.

3. Conclusion

The design of Butterworth filter was chosen for the design with the frequency range of 0.4 GHz to 5GHz using the Ansoft Designer version 4.1. The band pass filter was designed to have impedance matching at the input port and output ports. The results achieved shows good input matching at input port (S_{11}) and good output matching at output port (S_{22}) with return loss characteristics of above -300 dB. The transmission characteristics S_{21} gives the effective bandwidth achieved for the design which covers the entire pass band with an effective bandwidth of 4.6 GHz. The broad bandwidth covers all major wireless applications making the filter applicable for any front end receiver circuit. The design of Band pass Filter was developed in the planar form using the simulation software to prove that the bandpass filter can be effectively used in the design of onchip transceivers. The entire design steps were designed and simulated using the Ansoft designer 4.1 software.

4. References

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