Design and Analysis of Band Pass Filter for Wireless Communication

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***Abstract*— There are applications in wireless communications, where a particular band of frequencies are needed to be filtered from a wider range of mixed signals. Filter circuits can be designed to accomplish this task by combining the properties of low-pass filter and high-pass filter into a single filter which is referred as band-pass filter. A band-pass filter works to screen out frequencies that are too low or too high, giving easy passage only to certain frequencies within a specific range. At high frequencies, the behavior of the discrete components changes. Hence discrete components are replaced by microstrip transmission lines. Microstrip transmission line is the most used planar transmission line in Radio Frequency (RF) applications. A microstrip transmission line consists of a thin conductor strip over a dielectric substrate along with a ground plate at the bottom of the dielectric. Design of microstrip band pass filter has been carried out in this paper. The design is first carried out using lumped elements, tunable to a given centre frequency, f_o and fractional bandwidth, Δ. Then we realized the band pass filter using microstrip coupled resonator method. Simulation is carried out in Advanced Design System (ADS) to check and verify the desired behavior of the designed band pass filter. The frequency response so obtained shows the satisfactory performance of the band pass filter designed.**

***Index Terms*—filter, coupled resonator, micro strip**
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I. INTRODUCTION

THE need for higher data rates requires to some extent that a larger frequency spectrum be used. Applications like WIMAX, CDMA operates in GHz. Future applications need for higher data rates will push the spectrum to even higher ends. Filtering out the noise at those high frequency ranges cannot be achieved by conventional lumped L,C,R elements due to skin effect phenomena. This leads to undesirable filter response as the values of L,C vary considerably with high frequency. Microstrip lines offer as a solution to this problem, as the values of L,C can be realised easily by varying the lengths and termination impedances. Further it implementation is scalable in terms of frequency and source and load impedances. Microstrip filters can be designed in numerous ways. One of the ways being image parameter method and coupled resonator method. Methods listed in [3] give low-cost image-parameter design techniques for LC lowpass filters. Filter design using a low number of circuit elements results in reduced costs for both parts procurement and manufacturing. The technique applies to highpass filters. A composite highpass filter derived using m-derived terminating half-sections with one or more constant-k interior full sections can be used to increase the filter roll-off factor. Method [4] includes equal-ripple and maximally flat passband filters with general stopbands, as well as equal-ripple stopband filters with general passbands. To solve the approximation problem and to improve numerical conditioning, the design is carried out exclusively in terms of one or two transformed frequency variables.

II. LITERATURE SURVEY

The concept of coupling coefficients has been a very useful one in the design of small-to-moderate bandwidth microwave filters. Method in [5] includes that the group delay of the input reflection coefficients of sequentially tuned resonators containing all the information necessary to design and tune filters. In this method, the group-delay value at the center frequency of the filter can be written quite simply in terms of the low-pass prototype values. This provides an easy method to measure the key elements of a filter.

[7] Describes the design and development of band pass filter (BPF) at 140 GHz. Two different design techniques are used to realize the filter. First design uses capacitive coupled series resonators in suspended strip line configuration and second one uses metal insert filter (MIF) technique in waveguide configuration.

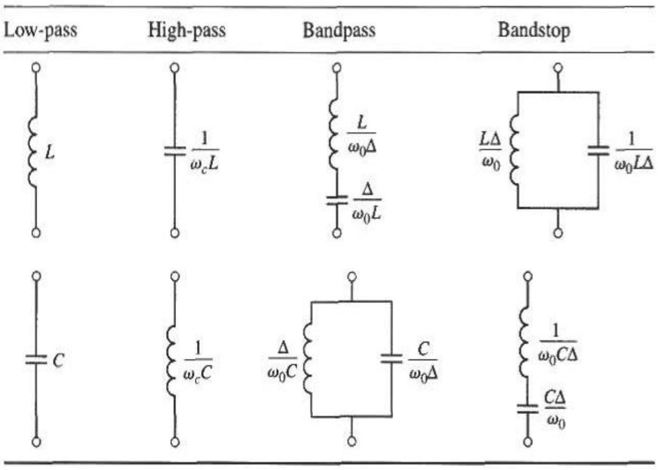
In [10], the design of a compact microstrip bandpass filter is designed using defected ground structure (DGS) with narrow bandwidth. Here a 50 ohm quarter wave microstrip line is used for designing the bandpass filter. A circular head dumbbell shaped DGS in the ground plane of a microstrip line is used which provides the bandstop characteristics. Two series gap slot is introduced for achieving the bandpass characteristics in the conducting strip. These slots in conducting strip are also called defected microstrip structure (DMS). This arrangement provides better coupling in the pass band. In this paper no stubs and via are used. The bandwidth of the filter is 500 MHz and insertion loss less than 0.5 dB in passband at 5.4 GHz. The measured insertion loss (S21) is 0.6 dB at the center frequency 5.4 GHz with a bandwidth of 500 MHz which is good in agreement with measured results after the fabrications.

In [11],the author proposed a compact narrow band bandpass filter with hexagonal dumbbell shaped defected ground structure in ground plane of a 50Ω microstrip line and a closed loop resonator in the conducting strip. This arrangement provides better coupling in pass band. Using DGS structure, forward transmission loss (S21) is -0.5 dB and return loss (S11) is -26.7 dB at the centre frequency 5.4 GHz with narrow bandwidth of 500 MHz

Paper [12] describes the synthesis of band-pass transmission line filters consisting of series of half-wavelength resonant conductors such as strips. In the design, successive strips are parallel coupled along quaterwave length. The resulting coupling between resonators is partly electric and partly magnetic. Several important advantages are gained by this arrangement:

1) the length of the filter is approximately half that of the end coupled type.

TABLE – Summary of Prototype Filter Transformations $\left(\Delta = \frac{\omega_2 - \omega_1}{\omega_0}\right)$



2) The gaps are larger and therefore less critical.

3) The insertion-loss curve is symmetrical on a frequency scale with the first spurious response occurring at three times the center frequency of the pass band.

The main objective is to design a band pass filter with centre frequency f_0=3.2 GHz and fractional bandwidth Δ = 0.03125. This particular centre frequency is chosen as the main application of this bandpass filter is for Worldwide Interoperability for Microwave Access (WiMAX). To do so, first the filter is designed using lumped elements. Secondly, realize it using microstrip and finally simulating the design using ADS.

The report is organised as follows. In section I, the introduction part is discussed. A brief overview of the literature survey is also produced. In section II, details about the theory that has to be known to design a bandpass filter. In section III,IV deals with stating the design specifications and implementing it to get the desired filter. Section V shows the results and also its significance.

III. Filter Design Theory

A. Filter transformation

Low pass prototype filter design can be transformed to have the band pass response. The element transformations from a low pass prototype to a band pass, high pass or band stop filter is summarized in the table above.

B. Impedance and admittance inverter

Often it is required to use only series or only shunt elements while implementing a filter with a particular type of transmission line. This can be achieved by the use of impedance or admittance inverters. Such inverters are useful for bandpass or bandstop filters. Since the inverters essentially form the inverse of the load impedance or admittance, they can be used to transform series connected elements to shunt connected elements or vice versa.

C. Band-pass filter using Quarter-wave resonators

Usually it is observed that band-pass filter calls for elements that can behave as series or parallel resonant circuit. Quarterwave open circuit and short circuit transmission line studs resemble series and parallel resonant circuits respectively. Thus, stubs in short along the transmission line

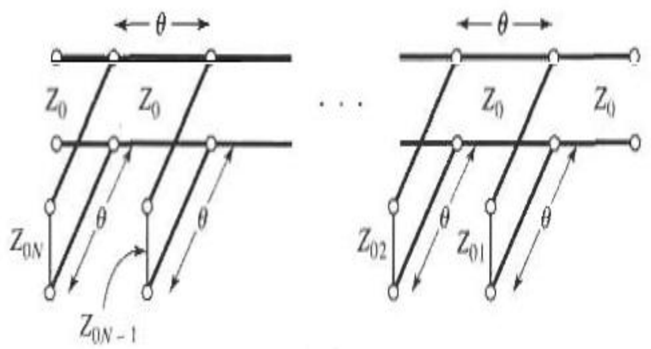


Fig. 1. Quarter wave resonator filter structure

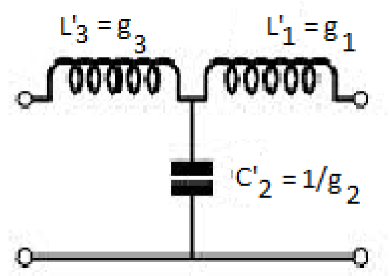


Fig. 2. Low Pass Filter Prototype

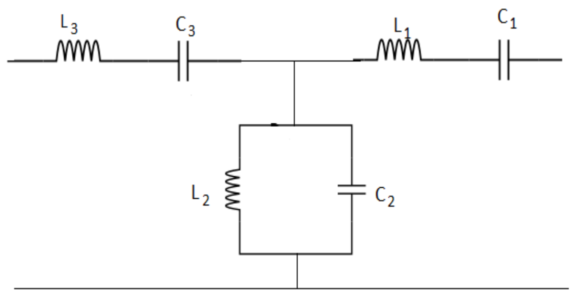


Fig. 3. Transformed bandpass filter with lumped circuit elements

can be used to implement band-pass filter. The quarter-wave section between the studs acts as impedance inverter to convert alternate shunt resonators to series resonators. The stubs and the transmission line sections are $\lambda/4$ long at the centre frequency ω_0.

The band-pass filter using short circuit stub is as shown in the fig-1 with characteristic impedance of $Z_{0n} = \frac{\pi z_0 \Delta}{4 g_n}$. This result is applicable to filters having input impedance and output impedance of Z_0 and cannot be used for equal ripple design with N even.

IV. Design Specification And Implementation

Centre frequency, f_0 = 3.2 GHz, fractional bandwidth Δ = 0.03125. For our design, we choose a low pass filter prototype with order N=3 as shown in fig-2 Where g_1 = 1.596, g_2 = 1.0967 and g_3 = 1.5963 are the circuit components values of a low pass filter, with cut off ω_0 = 1rad/sec and R_0 = 1 ohm.

Now we modify the above circuit to a band pass filter, as shown in fig-3 where, the values of L_1C_1, L_2C_2, L_3C_3 are derived using frequency scaling of $\omega_0 = 2\pi 3.2 10^6$ GHz and impedance of R_0 = 50 ohm The transformations used are

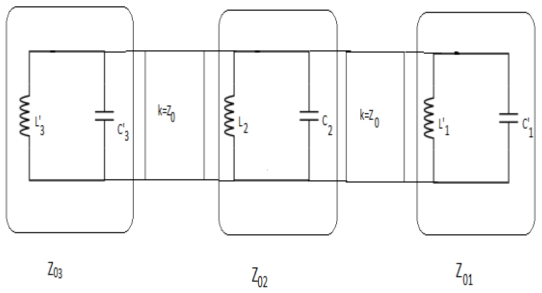


Fig. 4. Equivalent filter circuit using resonator and admittance inverters

$$L_1 = \frac{g_1 R_0}{\omega_0 \Delta} \quad C_1 = \frac{\Delta}{\omega_0 g_1 R_0}$$
$$L_2 = \frac{g_2 R_0 \Delta}{\omega_0} \quad C_2 = \frac{1}{\omega_0 g_2 R_0 \Delta}$$
$$L_3 = \frac{g_3 R_0}{\omega_0 \Delta} \quad C_3 = \frac{\Delta}{\omega_0 g_3 R_0}$$

Now, to realise the above circuit using transmission line, we utilise two transmission components.

1) A short circuit transmission line of wavelength $\lambda/4$, of suitable characteristics impedance. To simulate a shunt LC circuit.

2) A transmission line section of wavelength $\lambda/4$ and impedance Z_0 = 50 to get an impedance inverter to invert a parallel LC circuit into a series LC circuit.

With above two components in place, the circuit becomes as shown in fig-4 Now, the characteristics impedances, of the respective sections are given as $Z_{0n} = \frac{\pi z_0 \Delta}{4 g_n}$, which for our case comes down to

$$Z_{01} = \frac{\pi 50 0.03125}{4 g_1} = 0.7687\Omega$$
$$Z_{02} = = \frac{\pi 50 0.03125}{4 g_2} = 1.11898\Omega$$
$$Z_{03} = = \frac{\pi 50 0.03125}{4 g_3} = 0.7687\Omega$$

V. Implementation Using ADS

MSUB defines the properties of the microstrip lines, for this simulation we use RO4350B. RO4000 Series High Frequency Circuit Materials are glass reinforced hydrocarbon/ceramic laminates (Not PTFE) designed for performance sensitive, high volume commercial applications. Double click on MSUB and set the following parameters:

H- 1.52mm(substrate thickness)
Er- 3.48(relative dielectric constant)
Cond- 5.8e+07 S/m(conductor conductivity)(copper)
T- 0.06mm(conductor thickness)
TanD- 0.004(dielectric loss tangent)

Further the configuration parameters of the Microstrip Line Short Circuit(MLSC) elements used in simulation are

TL6:
Subst=MSub1, W=15715.511811mil, L=495.377953mil
TL7:
Subst=MSub1, W=10777.362205mil, L=495.685039mil
TL8:
Subst=MSub1, W=15714.094488mil, L=495.377953mil

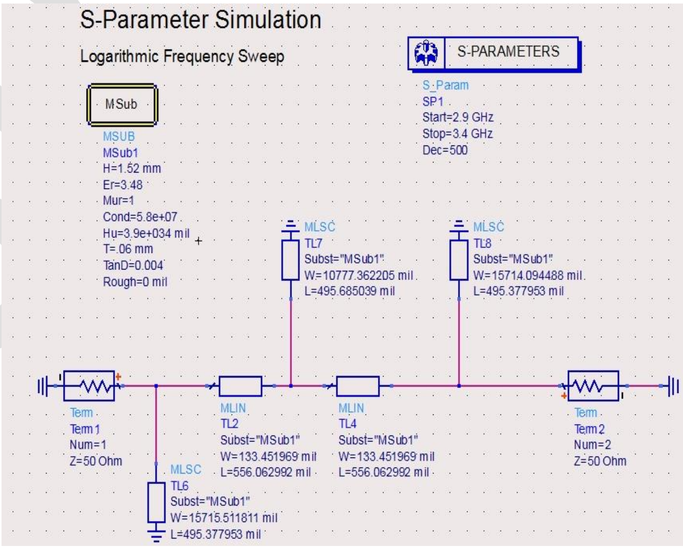


Fig. 5. Design of band-pass filter using microstrip transmission line in ADS

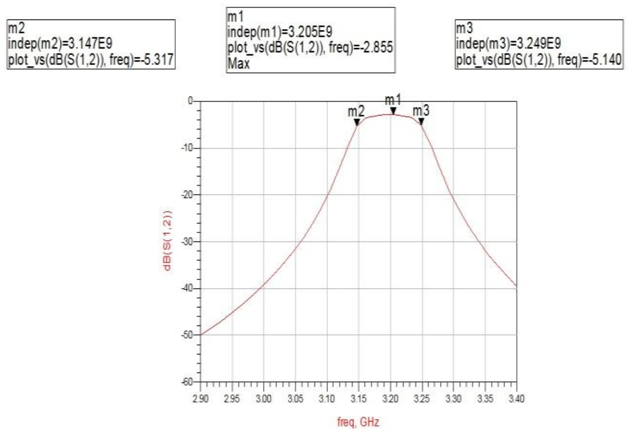


Fig. 6. Frequency response of designed microstrip filter in ADS

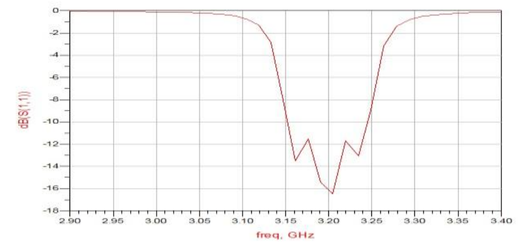


Fig. 7. Variation of scattering parameter $S_{1,1}$ with frequency for the microstrip filter

The details of the transmission line section used are
TL2:
Subst=MSub1, W=133.062992mil, L=556.062992mil
TL4:
Subst=MSub1, W=133.062992mil, L=556.062992mil

V. RESULTS AND DISCUSSION

Fig-5 gives us the final microstrip filter design that satisfies the objective and all the specifications of centre frequency, $f_0 = 3.2$ GHz and fractional bandwidth, $\Delta = 0.03125$. In the fig-6, the frequency response of the microstrip filter is shown. m1 indicates the dB gain at centre frequency, $f_0 = 3.22$GHz. The two side frequencies $f_1 = 3.147$GHz (marked m2) and $f_2 = 3.249$GHz (marked m3), are at dBs of -5.317 and -5.140 respectively, which are approximately 3dB below the -2.855dB gain at $f_0 = 3.2$GHz, having a fractional bandwidth of $\Delta = \frac{3.249-3.147}{3.205} = 0.0318$, which is in close tally with the target Δ of 0.03125. The overall frequency response shows an acceptable performance of a typical bandpass filter, as defined by our design objective.
Fig-7 corresponds to the power reflected back to the network from the load impedance $Z_0 = 50$. Clearly at $f_0 = 3.2$ GHz, the fraction reflected back is minimum, indicating the return loss is minimum. At frequencies, $f > f_0$ or $f < f_0$, the return loss gradually increases, indicating attenuation of signal in stopband is high.

CONCLUSION

In this paper, the filter is designed at centre frequency $f_0 = 3.2$GHz so as to enable applications of WiMAX since the range of WiMAX is 2-11 GHz for fixed WIMAX (3.5 GHz in Europe) and 2-6 GHz for mobile WiMAX. In future, a study could be conducted as the possible way to realise two series capacitor in microstrip which could in turn help to realise in microstrip, the lumped circuit derived by image parameter method.

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