Design and Simulation of Band Pass Filter using Signal Interference Technique

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Abstract

A band pass filter with wideband characteristics at center frequency of 7GHz and 1-dB bandwidth corresponding to 15dB return loss of 288 MHz is designed. Transmission line sections are incorporated in designing the band pass filter which has an advantage of low complexity structure. This is an effective method for design of band pass filters with steep roll off characteristics. Filtering was achieved by partitioning into components proliferating through a pair of transmission lines possessing varying electrical lengths and impedances. Band pass response was obtained by tuning the electrical lengths and / or impedances. This type of filter gives excellent out of band rejection values. Simulation was carried out using ADS tool, Keysight Technologies.

Keywords: *Band Pass Filter, Signal Interference, Return loss, Insertion Loss, Electromagnetic Simulation*

1.0 Introduction

Band Pass Filter (BPF) is a necessary element in the contemporary communication systems. A wide BPF with excellent in band and rejection of out of band performance characteristics is desired. Only the band of frequencies is allowed to pass with minimum attenuation and other frequencies are highly attenuated. The rate of attenuation depends on the roll off factor which depends upon the number of sections or the order of the filter. In practice, it is difficult to design a BPF with ideal response. The filter does not suppress all the frequencies away from the preferred frequency range; there is a section away from the passband where the unwanted frequencies are diminished. This term is the filter roll-off (measured in dB/decade or dB/octave).

The filter design thrives to produce the roll-off as sharp as practicable. This is realized at the cost of ripple in the frequency of the pass band. Fatima Rani et. al [1] presented BPF implementation using signal interference technique in which the design and simulation were carried out using Microwave CAD tool-Advanced Design System. Hsieh et. al

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[2] presented techniques to obtain very low insertion loss and sharp roll off. Different techniques for achieving sharp cut off and tuning the transmission line parameters to obtain ultra-wide bandwidth are discussed [3, 4]. Design procedure for the filters to reduce cross coupling and increasing the bandwidth is presented [5-6]. Theory and principles of filter design are presented [8, 9]. This research was focused on designing a wideband low complex BPF with steep roll off.

2.0 System Development

2.1 Methodology

Filter with microstrip line stubs incorporating transmission line stubs is shown in Fig. 1. The characteristic impedances Z_1 and Z_2, electrical lengths θ_1 and θ_2 of the transmission lines are defined in terms of wavelength. These lines are bridged at the boundaries at center frequency (f_o). The main aspect of this technique is that the signal is divided using a Tee junction at an end and is made to interfere at other boundary of the line alongside varying signal phase and magnitude. This technique is convenient for designing filters with low insertion loss, sharp roll off and wide band pass characteristics.

Let θ_{01} and θ_{02} be assigned to the electrical length at the designed frequency, and at other frequencies let the electrical lengths be θ_k for k =1,2,…..n, where n is the number of line sections.

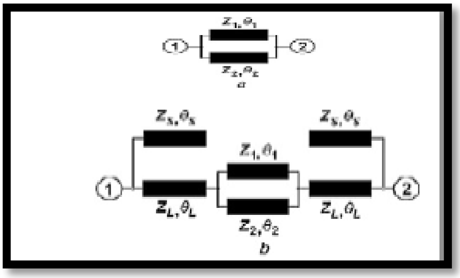

Fig. 1. Filter Design [1]

Considering the transmission line model with lossless traits, the S-Parameters are obtained from ABCD matrix are given by equations (1) and (2):

$$S\,11 = \frac{A1 + \frac{B1}{Z0} - C1Z0 - D1}{A1 + \frac{B1}{Z0} + C1Z0 + D1} \tag{1}$$

$$S21 = \frac{2}{A1 + \frac{B1}{Z0} + C1Z0 + D1} \tag{2}$$

To enhance the out of band filter rejection, a pair of shunt stubs having the same characteristic impedance Zs and length (electrical) θs are bridged at source and load ends. Open stubs are used to improve out of band rejection characteristics. Overall S-parameter of the modified section is given by equation (3) and equation (4):

$$S\,11 = \frac{A2 + \frac{B2}{Z0} - C2Z0 - D2}{A2 + \frac{B2}{Z0} + C2Z0 + D2} \tag{3}$$

$$S21 = \frac{2}{A2 + \frac{B2}{Z0} + C2Z0 + D2} \tag{4}$$

The initial values of the transmission line sections at 7 GHz are obtained using LINECALC utility tool in ADS, the values in Table 2 are the optimized using MIN-MAX solver in ADS tool to get the desired results.

3.0 Simulation of Band pass filter

Microstrip lines were used. W and L values for the given desired impedances and frequency in C-band and substrate parameters were computed. layout simulation was performed using the optimized values.

Table 1. Filter and Substrate Specifications

No	Parameter	Value
1.	Frequency of operation	6.8 GHz – 7.2 GHz
2.	Input / output Return Loss	better than -14 dB
3.	Insertion Loss	better than -1dB
4.	Substrate used	FR4
5.	Permittivity	4.4
6.	Loss Tangent	0.0009
7.	Substrate Thickness	0.8 mm

The design steps are outlined as:

- Width and Length of transmission lines was computed using LINECALC tool of Advanced Design System.
- Layout was generated and updated. FR4 substrate with the relative permittivity of 4.4 and loss tangent of 0.0009 was used.
- Substrate/conductor parameters and frequency range were inputted.
- Layout simulation was performed
- Simulation results were verified for concurrence with design specifications.
- Optimization was performed to match results with that of the specifications of Table 1.

The designed filter topology in C-band was superior to that of the conventional bandpass filter because it has low interference from rain fading, low cost bandwidth in comparison to other bands and commonly adapted in VSAT applications. Fig.2 shows the schematics of the designed BPF.

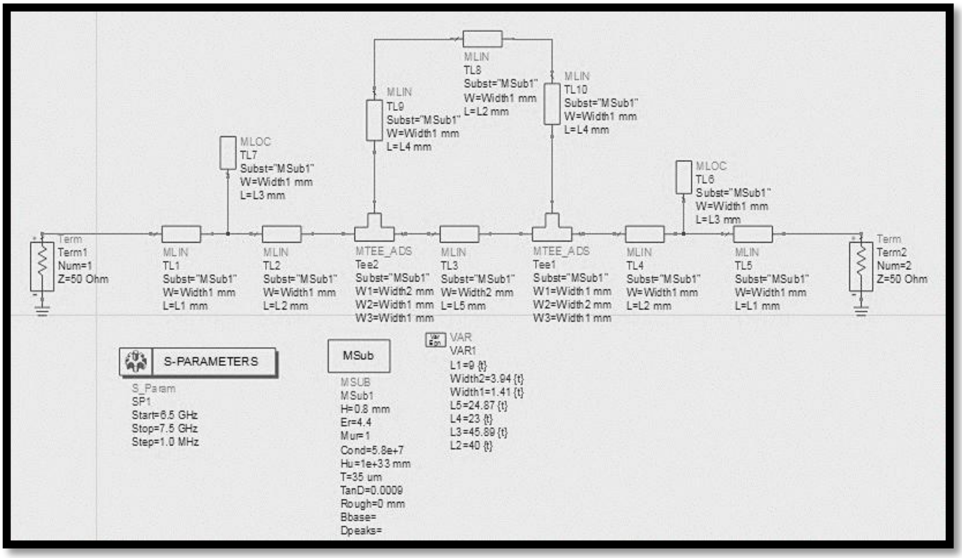

Fig. 2. Schematic of Filter

The optimized values of the transmission line sections at 7 GHz are as presented in Table 2. Referring to Fig. 2, TL# corresponds to the Transmission Line Number along with the width and physical length in mm and electrical length in degrees.

Table 2. Length, Width and Electrical lengths of the Transmission lines

Transmission line section	Width (mm)	Length (mm)	Electrical Length (°)
TL1	1.41	9	136.78
TL2	1.41	40	607.91
TL3	2.94	24.87	392.96
TL4	1.41	40	607.91
TL5	1.41	9	136.78
TL6	1.41	45.89	697.42
TL7	1.41	45.89	697.42
TL8	1.41	23	349.54
TL9	1.41	23	349.54
TL10	1.41	40	607.91

4.0 Schematic Results

The Band pass filter is simulated using Advanced Design system Microwave CAD tool. The results obtained are in agreement with the desired values. The return loss at the input and output is less than -14dB and the insertion loss is approximately -1dB in the frequency range of 6.876 GHz to 7.172 GHz. Fig. 3a and 3b shows the input return loss of filter schematic and the Band pass characteristics.

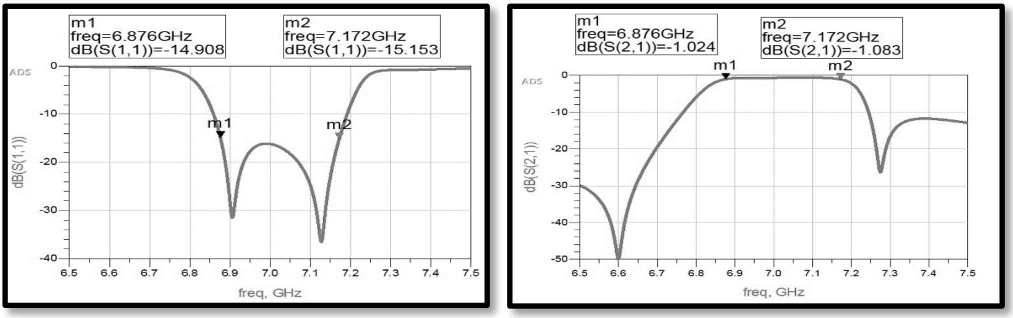

Fig. 3. a) Input Return Loss characteristics and **b)** Band Pass Characteristics

5.0. Layout and Results

The layout simulation is performed using microstrip lines with copper thickness 35μm and the substrate used is FR4 with thickness 0.8mm, relative permittivity of 4.4, and loss tangent of 0.0009. Fig. 4 shows the layout of the band pass filter (layout optimization is performed to obtain the desired results of Table 1.

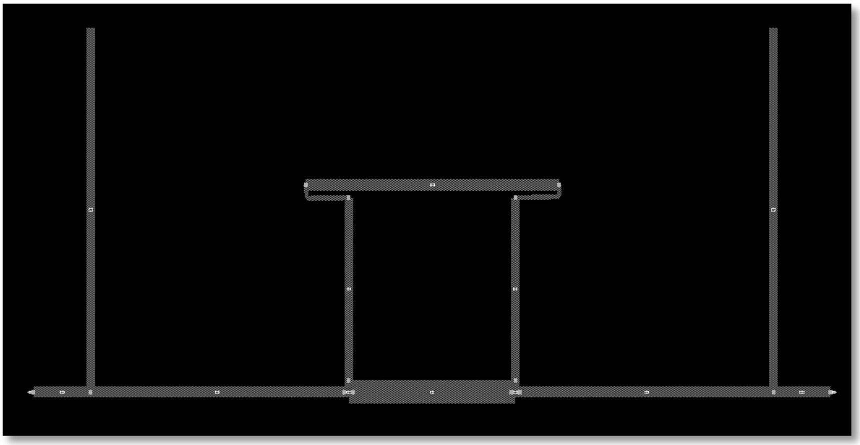

Fig. 4. Layout of the filter

The return loss at the input and Band Pass characteristics of the filter layout is shown in Fig. 5a and 5b respectively. The results obtained are in agreement with the desired values as in Table 1. The return loss at the input and output is less than -14 dB and the insertion loss is approximately -1dB in the frequency range of 6.839 GHz to 7.127 GHz.

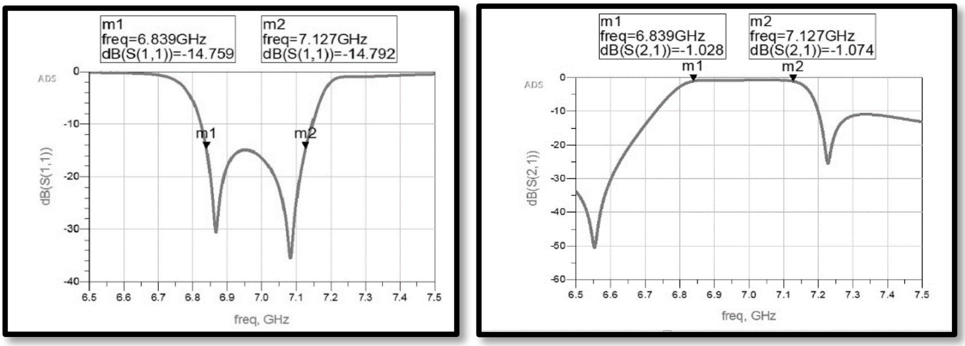

Fig. 5. a) Return Loss characteristics and **b)** Band Pass characteristics

A Wideband band pass filter is designed and simulated on an FR4 substrate possessing the properties as shown in Fig. 2. Here the bandwidth obtained is 288MHz (>100MHz in C Band) and hence known as wideband. By suitably tuning the stubs and using a different substrate (permittivity/thickness) the bandwidth obtained can be varied.

Table 3 gives the summary of the work carried out in this paper and that of the references.

Table 3. Validation of Results

Ref	Technique	Band	Advantage / Disadvantage	Bandwidth achieved
[1]	Signal Interference	S	low insertion loss, ease of realization	500 MHz
[2]	Signal Interference using Ring Resonator	Inter Band	increases width of rejection band, low insertion loss	4 GHz
[3]	Signal Interference using Coupled Lines	Inter Band	high selectivity, linear performance / fabrication complexity and cost	7 GHz
[4]	Signal Interference	C	high out of band rejection / fabrication complexity and cost	2 GHz
[5]	Signal Interference	Inter Band	simple construction	691 MHz
Present work	Signal Interference	C	simple construction, ease of realization on low cost FR4 substrate, scope for increasing bandwidth by varying dimensions of stubs.	288z

6.0 Conclusions

A practical configuration using transmission-line sections and open circuited shunt stubs is demonstrated for the design of wideband band pass filter. The major features are low insertion loss, uncomplicated structure and ease of realization. The filter is simulated using Microwave CAD tool Advanced Design System, Keysight Technologies. This finds use in applications such as ISM, and satellite communications because it is less susceptible to rain fading effects. This band is used for weather radars and communication between earth and space in Deep Space Communication Network.

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