



Design of X band parallel coupled line BPF by analytical approach

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Abstract

The design of maximally flat band pass filter for 10 GHz center frequency with 500 MHz bandwidth for X band applications is presented in this paper. An analytical approach is discussed here along with design using EDA tool. The simulated and measured values of various parameters such as insertion loss – 1.3 dB, return loss – 22.65 dB, group delay 1.35 nS and VSWR 1.16 are compared. The measured values insertion loss – 1.3 dB, return loss – 22.65 dB, group delay 1.35 nS and VSWR 1.16 offers a very good filter response. It gives slight compromising results. The physical dimensions of the micro strip filter structure are tuned manually for better result after the analytical calculations of the dimensions. It gives clear picture that the length of the micro strip lines has major role in shifting the pass band, width and space between the lines plays a conformal contribution in varying the bandwidth, attenuation levels. The filter is matched to 50 Ω micro strip lines at both ends.

Keywords Microwave BPF · Microstripline BPF · X band filter

1 Introduction

Microwave band pass filters play a significant role in wireless communication systems. Transmitted and received signals have to be filtered at a certain center frequency with a specific bandwidth. The filter design is proposed to implement using microstrip lines. In designing a micro strip filters, the first step is to carry out an approximated calculation of microstrip lines length, width and spacing between them [1, 2]. Experimental verification gives comparison, how close the theoretical results and measurements look alike.

To construct specific filters, the desired frequency characteristics are related to the parameters of the filter structure. The general synthesis of filters proceeds from

tabulated low-pass prototypes. Various physical forms of filters such as parallel coupled line filters, edge coupled line filters, interdigital filters and combline filters can be realized in distributed structures.

The parallel coupled line filter consists of a cascade of pairs of parallel coupled open circuited lines. The lines are quarter wave long at the center frequency of the filter [3, 4]. There are $N + 1$ coupled line section including input and output transformers in an N th degree filter is shown in Fig. 1.

The parallel coupled line filter is often used in microwave subassemblies as it is easy to fabricate due to the absence of short circuits.

A pair of coupled lines and its equivalent circuit is shown below in Fig. 2. Here it is noted that the equivalent circuit consists of series-open circuited stubs separated by an unit element (UE) in Fig. 2. Z_{oe} and Z_{oo} are the even and odd mode characteristic impedances of the coupled line pair as depicted in Fig. 3. The UE may be decomposed into a pair of open circuited stubs separated by an inverter as shown in Fig. 4. Combining this with the equivalent circuit in Fig. 2, a final equivalent circuit consisting of series open circuit stubs separated by inverters are obtained as shown in Fig. 5 is obtained.

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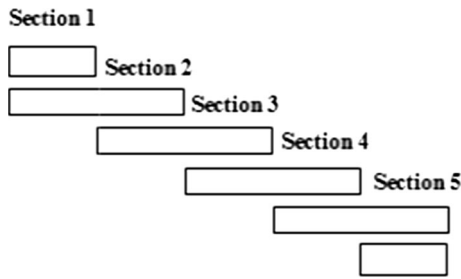


Fig. 1 Parallel coupled line filter of degree 5

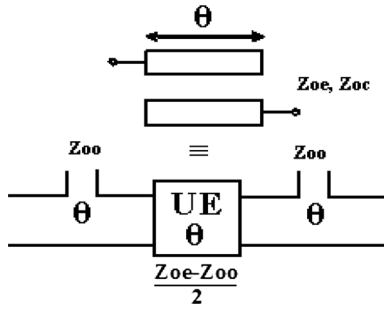


Fig. 2 Equivalent circuit of a parallel coupled line pair

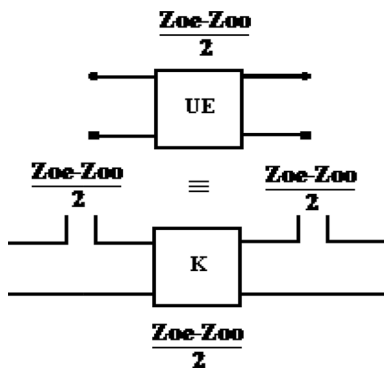


Fig. 3 Equivalent circuit of a unit element

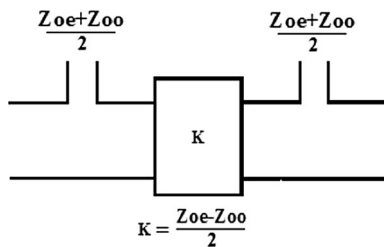


Fig. 4 Equivalent circuit of a coupled line pair

A cascade of $N + 1$ coupled line pair results in a circuit consisting of N series stubs separate by inverters as in Fig. 5.

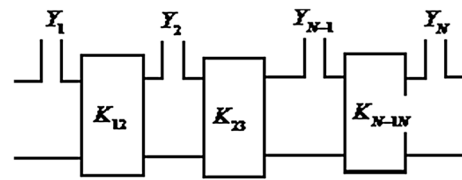


Fig. 5 Equivalent circuit of a parallel

Table 1 Design specification

Center frequency	10 GHz
ϵ_r of the dielectric material	3.66
Height of the substrate	0.508 mm
Thickness of the conducting trace	0.035 mm
Loss tangent	0.0013
Fractional bandwidth	5%

2 Procedure and design of bandpass filter

Narrowband bandpass filters can be made with cascaded coupled line sections of the form shown in Fig. 1. The design starts with the specifications mentioned as in the Table 1.

The fractional bandwidth (FBW) is calculated as, [5–8]

$$\Delta = \frac{f_2 - f_1}{f_0}$$

$$\Delta = \frac{10.25 - 9.75}{10} = \frac{0.5}{10} = 0.05 \tag{1}$$

Using Fig. 6 the attenuation at the stop bands is estimated [9].

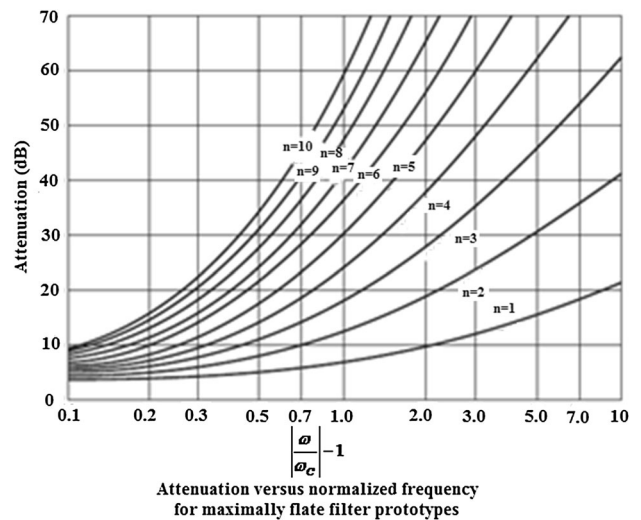


Fig. 6 Attenuation versus normalized frequency for maximally flat

Table 2 Element values for maximally flat low pass filter prototypes

Element values for maximally flat low pass filter prototypes ($g_0 = 1, \omega_c = 1, N = 1-10$)											
n	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	2.0000	1.0000									
2	1.4142	1.4142	1.0000								
3	1.0000	2.0000	1.0000	1.0000							
4	0.7654	1.8478	1.8478	0.7654	1.0000						
5	0.6180	1.6180	2.0000	1.6180	0.6180	1.0000					
6	0.5176	1.4142	1.9318	1.9318	1.4142	0.5176	1.0000				
7	0.4450	1.2470	1.8019	2.0000	1.8019	1.2470	0.4450	1.0000			
8	0.3902	1.1111	1.6629	1.9615	1.9615	1.6629	1.1111	0.3902	1.0000		
9	0.3473	1.0000	1.5321	1.8794	2.0000	1.8794	1.5321	1.0000	0.3473	1.0000	
10	0.3129	0.9080	1.4142	1.7820	1.9754	1.9754	1.7820	1.4142	0.9080	0.3129	1.0000

To convert this frequency to the normalized low pass form

$$\omega \leftarrow \frac{1}{\Delta} \left(\frac{\omega}{\omega_o} - \frac{\omega_o}{\omega} \right) \text{ is used}$$

$$\omega \leftarrow \frac{1}{0.05} \left(\frac{9.5}{10} - \frac{10}{9.5} \right) = 20(0.95 - 1.0526) = -2.052 \tag{2}$$

The approximate order of the filter is found with the required stop band attenuation

$$\left| \frac{\omega}{\omega_c} \right| - 1 \tag{3}$$

$\left| \frac{\omega}{\omega_c} \right| - 1 = |-2.052| - 1 = 1.052 \approx 1.1$ [10, 11]. This indicates an attenuation of 25 dB for $N = 4$. The low pass prototype element values are given in Table 2.

The design equations for a bandpass filter with $N + 1$ coupled line sections to calculate the admittance inverter constants J_n are listed here [12, 13].

For the first section J inverter

$$Z_0 J_1 = \sqrt{\frac{\pi \Delta}{2g_1}} \tag{4}$$

For the intermediate sections the J inverters are

$$Z_0 J_n = \frac{\pi \Delta}{2\sqrt{g_{n-1}g_n}} \text{ for } n = 2 \text{ to } N \tag{5}$$

and for the last section the J inverter is

$$Z_0 J_{N+1} = \sqrt{\frac{\pi \Delta}{2g_N g_{N+1}}} \tag{6}$$

where N is the order of the filter and g_0, \dots, g_{N+1} are the ladder type low pass filter elements. Finally the even and odd mode characteristic impedances are found using, [14–16]

$$Z_{oe} = Z_0 \left[1 + JZ_0 + (JZ_0)^2 \right] \tag{7}$$

$$Z_{oo} = Z_0 \left[1 - JZ_0 + (JZ_0)^2 \right] \tag{8}$$

The calculated values of the J inverters and their Odd and Even impedances are given in Table 3.

From Table 3 it is obvious that the filter sections are symmetric about the midpoint. The physical dimensions, width (W) and length (L) of the coupled line sections and space (S) between them are calculated with the help a transmission line calculator available in NI/AWR Microwave Office Tool [17]. With respect to the electrical length $\beta l = \frac{\lambda}{4}$ at the center resonance frequency f_o , the length of all sections are calculated for substrate $\epsilon_r = 3.66$, $h = 0.508$ mm and copper trace thickness $t = 0.035$ mm. The results are presented in Table 4 below with the corresponding space between them.

The filter structure with the calculated width, space and length delivers approximate results only as it is. After the manual tuning and optimization, the physical dimensions slightly get modified and give good results.

Table 3 Values of the J inverters, odd and even impedances

n	g_n	$Z_o J_n$	Z_{oe} (Ω)	Z_{oo} (Ω)
1	0.7654	0.3202	71.14	39.12
2	1.8478	0.0660	53.52	46.92
3	1.8478	0.4248	80.22	37.78
4	0.7654	0.0660	53.52	46.92
5	1.0000	0.3202	71.14	39.12

Table 4 Width, length and space of the coupling sections

n	W (mm)	S (mm)	L (mm)
1	0.8296	0.1659	4.1415
2	1.0508	1.0685	4.0093
3	0.7057	0.1118	4.2062
4	1.0508	1.0685	4.0093
5	0.8296	0.1659	4.1415

3 Simulation and results

An analytical approach for the design of narrowband BPF is presented based on the conventional 4th order parallel coupled line structure. The measured results agree with the simulated results with negligible deviations. The filter is capable to pass signals in the frequencies between 9.75 and 10.25 GHz. The filter response is linear and flat throughout the pass band. The performance parameters are tabulated in the Table 4.

Figure 7 depicts the two dimensional actual filter layout. At ports 1 and 2, SMA connectors are connected for practical measurements with the network analyzer. The Insertion loss, Return loss, VSWR and group delay of the filters are shown through Figs. 8, 9 and 10.

Periodic structures generally exhibit pass band and stop band characteristics in various bands of wave number determined by the nature of the structure [18]. This was originally studied in the case of waves in crystalline lattice structures, but the results are more general. The presence or absence of propagating wave can be controlled by these periodic structures. Figure 7 shows the 2D view of the proposed BPF.

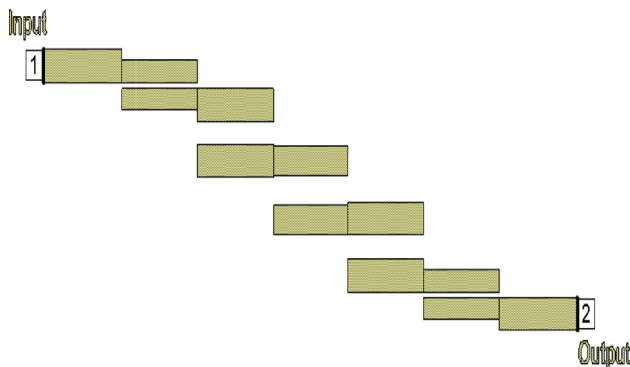


Fig. 7 Two dimensional view of the band pass filter

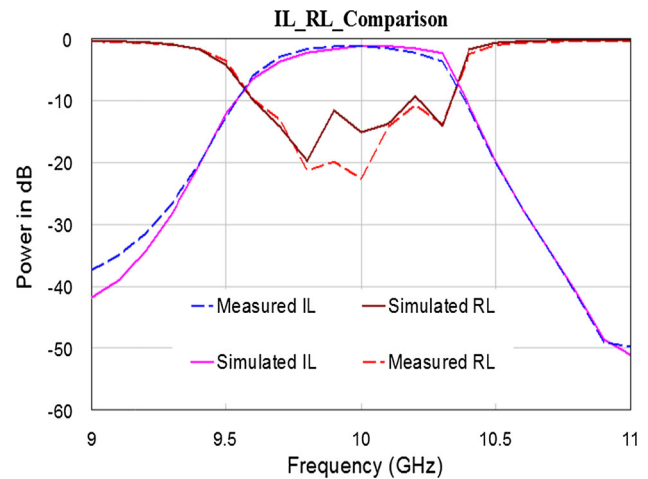


Fig. 8 Insertion loss and return loss

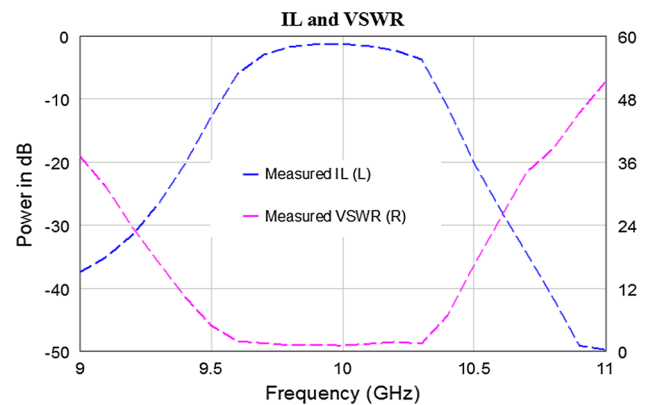


Fig. 9 Return loss and VSWR

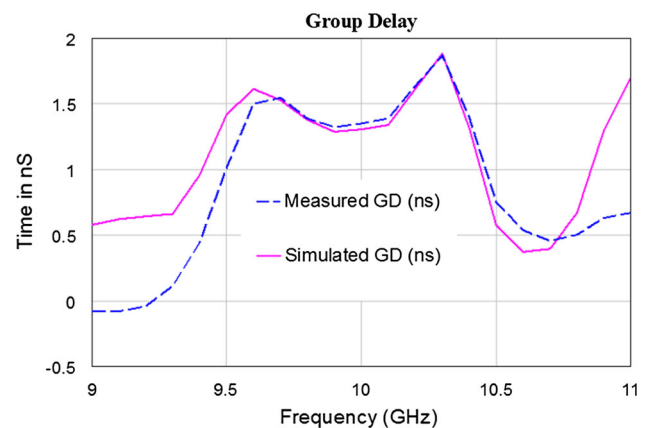


Fig. 10 Group delay

4 Conclusion

The filter is designed to give smooth cutoff at both lower and upper ends. The insertion loss, return loss, VSWR and group delay can be further reduced by incorporating either PBG/EBG or DGS structures on the signal path of the filter

Table 5 Filter performance parameters

Parameter	IL in dB	RL in dB	Group delay in nS	VSWR
Circuit simulated value	– 1.18	– 15.00	1.31	1.43
EM structure value	– 1.30	– 22.65	1.35	1.16

[18]. These periodic structures offer a promising value of these parameters. Periodic structures generally exhibit pass band and stop band characteristics in various bands of wave number determined by the nature of the structure. This was originally studied in the case of waves in crystalline lattice structures, but the results are more general. The presence or absence of propagating wave can be controlled by these periodic structures. The filter could also be designed along with the Antenna and LNA for better performance. In such case the terminal impedances at both ends may be matched with the output impedance of the antenna and the input impedance of the LNA rather than 50 Ω characteristic impedance. This will allow the reduction of the group delay (Table 5).

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