# 5. 8GHz Bandpass Filter Design Using Planar Couple Microstrip Lines


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*Abstract*--**Using microstrip lines to design a planar couple band-pass filter encounter some approximate errors due to the tolerance in PCB processing and coupling effects. Sometimes it causes unacceptable errors and it will be significant to reduce this error. In this paper, we use admittance inverters to design an 5.8GHz bandpass filter for Chebyshev attenuation response of 0.5dB. Modification of section lengths, widths and gaps by applying the iterative method used previously for synthesizing a coupler to compensate coupling effects and the tolerance in PCB processing. The simulation tool ADS and implemented filter measurements are performed to verify the adapted modified method and show very good results to our specified filter specifications. The method can be used to design any other bandpass filter.**



*Keywords:* microstrip line, bandpass filter


## I. BANDPASS FILTER SPECIFICATIONS

We design a parallel coupled microstrip bandpass filter having Chebyshev response characteristics with passband ripple of 0.5dB between the bandedge frequencies 5.8GHz and 6.2GHz. The microwave bandpass filter sepecs are defined as follows:

Center frequency fc = 5.8 GHz
Bandwidth BW=400 MHz
Ripple at pass-band = 0.5 dB
Insertion loss at 6.2GHz >30 dB

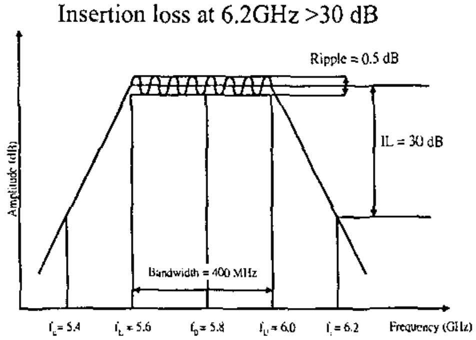


Fig 1. Band-pass filter specification

## II. DESIGN TECHNIQUES

The filter type chosen to realize is Chebyshev-type filter with 0.5dB ripple level. The insertion loss characteristics of Chebyshev filters can be described by the Chebyshev polynomials $T_N(\omega)$ in the following form

$$IL = 10\log[1 + a^2 T_N^2(\omega)] \qquad (1)$$

where

$$T_N(\omega) = \cos\{N[\cos^{-1}(\omega)]\} \quad \text{for } |\omega| \leqq 1 \qquad (2)$$

$$T_N(\omega) = \cosh\{N[\cosh^{-1}(\omega)]\} \quad \text{for } |\omega| \geqq 1 \qquad (3)$$

For our design, IL is equal to 0.5dB in the frequency range $|\omega| \leqq 1$. Thus, the value of $a$ should be chosen as

$$a = \sqrt{10^{0.5/10} - 1} = 0.3493 \qquad (4)$$

Moreover, in order to decide the order N to meet the requirements of this filter, we need to transfer the band-pass filter frequency parameters to the low-pass ones. The frequency transformation is then

$$\omega = \frac{2}{\delta}\left(\frac{f_i - f_0}{f_0}\right) \qquad (5)$$

where $\delta$ is the fractional bandwidth

$$\delta = \frac{f_U - f_L}{f_0} \qquad (6)$$

According to the specification listed above, the center frequency $f_0$ is 5.8GHz and the values of $f_U$ and $f_L$ are respectively 6.0GHz and 5.6GHz. Moreover, $f_i$ is set to be 6.2GHz. The normalized frequency element $\omega$ can be obtained using the equations (5) and (6). Therefore, for our design, the value of $\omega$ is calculated to be 2.

Having obtained the value of $\omega$ and , the order N can be calculated by the equation (1) with the side-lobe suppression requirement, insertion loss >30 dB at 6.2GHz. Thus, the constrain on order N is N>3.94 where N is an integer

As a result, we choose the order N of the Chebyshev filter to be 5 in our design. From list formulas [2], the filter coefficients of Chebyshev filter with 0.5 dB ripple are

g1=1.7058
g2=1.2296
g3=2.5408
g4=1.2296
g5=1.7058
g6=1.0000

In our design, the structure we use is the cascade of parallel-coupled planar microstrip bandpass filters. A general microstrip configuration is shown in Fig 2 as a reference. The maximum coupling is obtained between physically parallel microstrip lines when the length of the coupled region is $\lambda_g/4$.

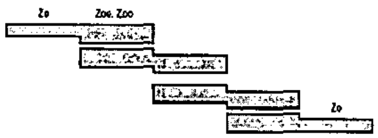

Fig 2. Coupled line filter configuration

The equivalent circuit of two coupled $\lambda_g/4$ open lines can be shown to be as depicted here:

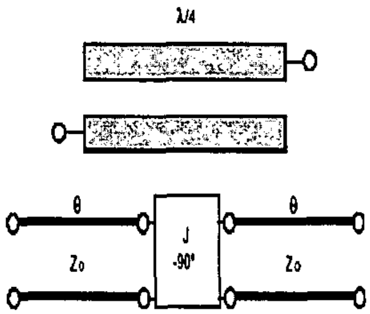


Fig 3. Equivalent circuit of coupled λ/4 open lines

The admittance inverter parameters are given by:
For the first coupling structure [1]

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi\delta}{2g_0g_1}} \quad (7)$$

For the intermediate coupling structures:

$$\frac{J_{j,j+1}}{Y_0} = \frac{\pi\delta}{2\sqrt{g_jg_{j+1}}} \quad (8)$$

for j=1 to (n-1)
For the final coupling structure:

$$\frac{J_{n,n+1}}{Y_0} = \sqrt{\frac{\pi\delta}{2g_ng_{n+1}}} \quad (9)$$

where δ is the fractional bandwidth calculated according to equation (6).

Using the equation (7), (8) and (9) with the filter coefficients obtained above, the corresponding coupling elements are the

| $J_{01}$ | $J_{12}$ | $J_{23}$ | $J_{34}$ | $J_{45}$ | $J_{56}$ |
|---|---|---|---|---|---|
| 0.252 | 0.075 | 0.061 | 0.061 | 0.075 | 0.252 |

To proceed with the microstrip design, the odd- and even-mode coupled-line impedances $Z_{oo}$ and $Z_{oe}$ are required. They are given by

$$Z_{oe\,j,j+1} = Z_o[1 + J_{j,j+1}Z_o + (J_{j,j+1}Z_o)^2] \quad (10)$$

$$Z_{oo\,j,j+1} = Z_o[1 - J_{j,j+1}Z_o + (J_{j,j+1}Z_o)^2] \quad (11)$$

where $Z_o$ is the system characteristic impedance.

The even- and odd-mode impedances of the coupled parallel lines can be obtained using the equation (10) and (11) with the coupling elements listed above and the characteristics impedance in our design is set to be 50 Ω. The results are shown in the following table1.

Table 1 Even and Odd Characteristic Impedances

| Section | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| $Z_{oe}$ (Ω) | 65.77 | 54.02 | 53.25 | 53.25 | 54.02 | 65.77 |
| $Z_{oo}$ (Ω) | 40.57 | 46.54 | 47.12 | 47.12 | 46.54 | 40.57 |

For our design, the substrate permittivity is $\varepsilon_r$=3.48 and its thickness is 20 mil. With the help of the CAD tool - ADS LineCalc, the parameters of each parallel coupled lines can be obtained with the previously calculated data. In the calculation, the component type is chosen to be the microstrip coupled lines. Here list the parameters of the final results.

| Section | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| W (mil) | 38.6 | 44.5 | 44.7 | 44.7 | 44.5 | 38.6 |
| S (mil) | 7.3 | 33.8 | 40.1 | 40.1 | 33.8 | 7.3 |
| L (mil) | 312.5 | 307.6 | 307.5 | 307.5 | 307.6 | 312.5 |

where W stands for the width of microstrip line, S is the spacing between the coupled lines and L is the length of them.

In the following, with the help of the simulation tool –ADS, the circuit response is simulated with the parameters obtained above. The schematic drawing of the microstrip circuit is shown in Fig 4. In the figure, the parameters of these parallel couple lines are finely tuned to meet the specification requirements of the desired band-pass filter. On the other hand, the spacing of the narrowest coupled lines are expanded to a feasible one for the manufacturing consideration. The final frequency response of the simulated band-pass filter is also shown in Fig 5.

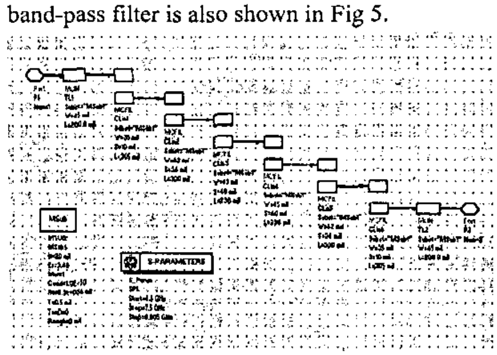

Fig 4. Schematic of parallel coupled lines

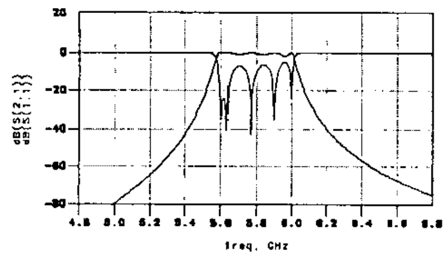

Fig 5. Simulation result of the designed band-pass filter

## III. IMPLEMENTATION AND RESULTS

With the parameters obtained from the above design, two pieces of band-pass filter are actually implemented. The used substrate is FR4 PCB and its thickness is 20 mils. The photo of the filters is shown in Fig.6.

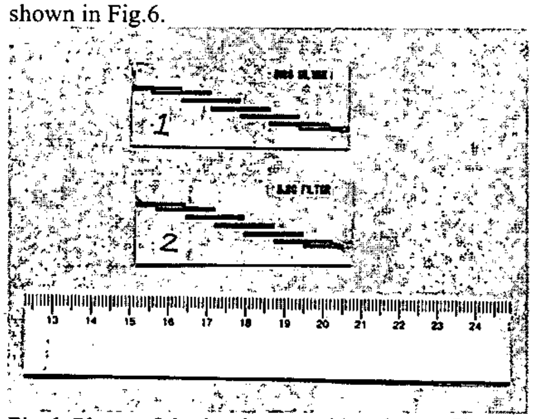

Fig 6. Photo of the implemented band-pass filters

The S11 and S21 frequency response of these two filters are respectively shown in Fig7 and Fig8. The instrument used for the measurement is Anritsu 37369A vector network analyzer. In these two figures, the blue solid- and dot-line are the data measured from network analyzer. The red ones are the simulations with the actual dimensions of the implemented filters. Here, the dielectric loss tangent is taken into consideration. The value of it is set to be 0.005 in the following simulation.

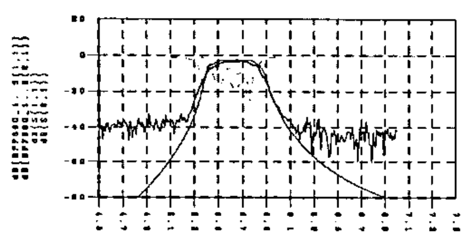

Fig 7. Frequency response of band-pass filter 1

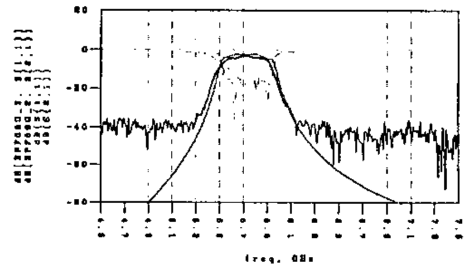

Fig 8. Frequency response of band-pass filter 2

## IV. DISCUSSION

In Table 1, the product of the calculated data of $Z_{oe}$ and $Z_{oo}$ somewhat doesn't equal the following formula

$$Z_{oe} \times Z_{oo} = Z_o^2.$$

Obviously it will cause error. From the Figure 5, the simulation results of the designed band-pass filter are not in good condition.

Due to the coupling effects and the tolerance in PCB processing, the actual dimensions of the filters are deviated from the designed ones by applying the iterative method used for synthesizing a coupler shown in the previous document [3]. The formulas and calculation are somewhat tedious. In the following lists the measured dimensions of the implemented filters. In comparison with the dimensions listed previously in the design stage, it is apparently that there is a small difference between them.

Filter 1

| Section | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| W(mil) | 38.2 | 47.6 | 50.8 | 49.6 | 47.6 | 37.0 |
| S (mil) | 7.9 | 29.1 | 34.6 | 35.8 | 29.9 | 8.7 |
| L (mil) | 304.3 | 304.3 | 306.7 | 304.3 | 309.8 | 308.3 |

Filter 2

| Section | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| W(mil) | 37.0 | 45.3 | 47.2 | 47.6 | 45.28 | 34.6 |
| S (mil) | 7.8 | 33.5 | 36.2 | 35.4 | 36.42 | 7.9 |
| L (mil) | 307.1 | 301.6 | 300 | 301.5 | 301.5 | 307.8 |

In order to verify the accuracy of simulation model provided by Agilent ADS software, the measured dimensions and the dielectric loss tangent are taken into the simulation. From the results shown in Fig 7 and 8, the simulated data are in good approximation with the measured. The characteristics of the implemented band-pass filters are summarized in Table2.

Table 2. Summary of the implemented filters and the filter specification

| Item | Unit | Specs | Filter 1 | Filter 2 |
|---|---|---|---|---|
| Center frequency $f_C$ | GHz | 5.8 | 5.65 | 5.73 |
| Amplitude at $f_C$ | dB | | -3.6 | -3.0 |

| | | | | |
|---|---|---|---|---|
| Bandwidth BW | GHz | 0.40 | 0.38 | 0.43 |
| Amplitude at $f_c$+0.40GHz | dB | | -33.5 | -34.5 |
| Amp($f_c$)-Amp($f_C$+0.40GHz) | dB | >30 | 29.9 | 31.5 |

The bandwidth in Table 2 is defined as the 3-dB bandwidth, which is a little different from the one listed in the specification. However, for the steep drop down of the ideal band-pass filter, the difference mentioned is small enough to skip. In the simulation of the band-pass filter, it is found that the center frequency $f_c$ is very sensitive to the length of the parallel-coupled lines and the frequency response profile is sensitive to the spacing and width of the coupled lines. As a consequence, if the implementation process of the PCB can be well controlled, a good band-pass filter can be actually realized from the conclusion drawn above.

## REFERENCE


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[2]. W. Alan Davis, Microwave Semiconductor Circuit Design, Van Nortrand Reinhold Company, 1984, p47.

[3] L.A. Trinogga, Guo Kaizhou, I.C. Hunter, Practical Microstrip Circuit Design, Ellis Horwood Limited, 1991, p350 ~ 352.