

An Optimal Microstrip Bandpass Filter Design Method for WiMAX Applications

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Abstract— Design, analysis and optimization of a parallel-coupled microstrip bandpass filter for WiMAX application is presented in this paper. The filter is designed at a center frequency of 5.2 GHz with 3.84 % bandwidth. Half wavelength long resonators and admittance inverters are used to design the filter. A brief description of coupled microstrip lines and immittance inverters is also included. Design equations to compute physical dimensions of the filter are given in the paper. The filter is simulated using ADS design software and implemented on RT. Duroid RT 6006 substrate.

Key-Words— Bandpass filters, coupled microstrip lines, parallel-coupled microstrip filter, immittance inverter.

1. Introduction

Bandpass filters are used as frequency selective devices in many RF and microwave applications. Filters are designed using lumped or distributed circuit elements. However with the advent of advanced materials and new fabrication techniques, microstrip filters have become very attractive for microwave applications because of their small size, low cost and good performance. There are various topologies to implement microstrip bandpass filters such as end-coupled, parallel coupled, hairpin, interdigital and combline filters [1].

This paper presents the design of a parallel-coupled microstrip bandpass filter centered at 5.2GHz, bandwidth BW = 200 MHz with minimum attenuation of -20 dB at 5.9 GHz, passband ripple of 0.1 dB. The filter is

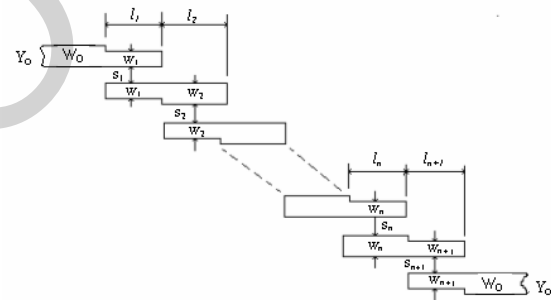
designed using half wave long resonators and admittance inverters. Theory of general immittance inverters and coupled lines is briefly described.

General layout of a parallel coupled microstrip bandpass

filter is shown in Figure 1. The filter structure consists of open circuited coupled microstrip

lines. These coupled lines are quarter wavelength, $\lambda/4$ long and are equivalent to shunt resonant circuits. The coupling gaps correspond to the admittance inverters in the lowpass prototype circuit. Even and odd-mode characteristic impedances of parallel-coupled half-wave resonators are computed using admittance inverters. These even and odd mode impedances are then used to compute physical dimensions of the filter.

The filter is implemented on RT. Duroid RT 6006 substrate with dielectric constant of 6.15, loss tangent of 0.002 and substrate height of 1.27 mm



$$Y_0 = \frac{1}{Z_0}$$

Figure 1 : General layout of parallel coupled microstrip bandpass filter [2]

Impedance inverters play a very important role in filter design. They are used to transform a filter circuit into an equivalent form that can be easily implemented using various microwave structures. Impedance inverters are either impedance or admittance inverters. Because of the inverting action, a series inductance with an inverter on each side looks like a shunt capacitance and a shunt capacitance with an inverter on each side looks like a series inductance. Impedance inverters are shown in Figure 2.

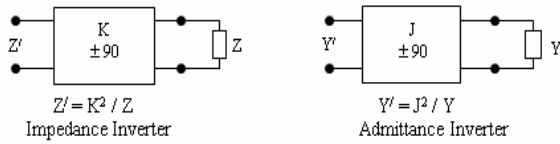


Figure 2 : Imittance inverter

Making use of the properties of immittance inverters, bandpass filters may be realized by series L.C. resonant circuits separated by impedance inverters (K) or shunt L.C. parallel resonant circuits separated by admittance inverters (J).

To design a bandpass filter, first of all a lowpass prototype circuit is modified to include immittance inverters. These low pass structures are then converted to bandpass circuits by applying conventional lowpass to bandpass transformation [1].

3. Coupled Microstrip Lines

Coupled microstrip lines are widely used for implementing microstrip filters [2]. Coupled lines can be analyzed by various techniques. But symmetrical coupled lines (lines having same characteristic impedance) can be conveniently analyzed using even and odd-mode method [3] [1]. For an even mode excitation, both microstrip lines have the same polarity and for odd mode excitation, polarity of both microstrip lines is different. Both modes are not pure TEM in nature, therefore they propagate with different phase velocities which mean they experience different permittivities. Therefore, even and odd mode effective dielectric constants are calculated in order to compute the even and odd mode characteristic impedances. These impedances are then used to compute physical dimensions of the coupled lines [1].

$$Z_c = \sqrt{Z_{ce} Z_{co}} \quad (1)$$

where

Z_c = Characteristic impedance of the microstrip transmission line

Z_{ce}, Z_{co} = Even and odd mode characteristic impedances of the coupled lines.

Design equations for coupled lines are available [1] [2] [4] [5].

$$\epsilon_{re_eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \cdot \left(1 + \frac{10}{v}\right)^{-a_e b_e} \quad (2)$$

Where

ϵ_{re_eff} is even mode effective dielectric constant

$$v = \frac{(g^2 + 20) \cdot u}{g^2 + 10} + g \cdot \exp(-g)$$

$$a_e = 1 + \left[\left(\frac{1}{49} \right) \ln \left[\frac{v^4 + \left(\frac{v}{52} \right)^2}{v^4 + 0.432} \right] + \frac{1}{18.7} \ln \left[1 + \left(\frac{v}{18.1} \right)^3 \right] \right]$$

$$b_e = 0.564 \left(\frac{\epsilon_r - 0.9}{\epsilon_r + 3} \right)^{0.053}$$

$u = W/h$ and $g = s/h$, where W is width of the strip, h is height of the substrate and s is spacing between the strips. The error in

ϵ_{re_eff} is within 0.7% over the ranges of

$0.1 \leq u \leq 10$, $0.1 \leq g \leq 10$, and $1 \leq \epsilon_r \leq 18$.

$$\epsilon_{ro_eff} = \epsilon_{re} + (0.5(\epsilon_r + 1) - \epsilon_{re} + a_o) \cdot \exp(-c_o \cdot g^{d_o}) \quad (3)$$

where ϵ_{ro_eff} is odd mode effective dielectric

constant

$$a_o = 0.7287(\epsilon_{re} - 0.5(\epsilon_r + 1)) \cdot (1 - \exp(-0.179u))$$

$$b_o = (0.747 \cdot \epsilon_r) / (0.15 + \epsilon_r)$$

$$c_o = b_o - (b_o - 0.207) \cdot \exp(-0.414u)$$

$$d_o = 0.593 + 0.694 \cdot \exp(-0.526u)$$

where ϵ_{re} is the effective dielectric constant of a single microstrip line of width W .

$$Z_{ce} = \frac{Z_c \cdot \sqrt{\frac{\epsilon_{re}}{\epsilon_{re_eff}}}}{1 - Q_1 \cdot \sqrt{\epsilon_{re}} \cdot \frac{Z_c}{377}} \quad (4)$$

$$Q_1 = 0.8685u^{0.194}$$

$$Q_2 = 1 + 0.7519g + 0.189g^{2.31}$$

$$Q_3 = 0.1975 \left[166 + \left(\frac{8.4}{g} \right)^6 \right]^{-0.387} + \frac{1}{241} \ln \left[\frac{g^{10}}{1 + \left(\frac{g}{3.4} \right)^{10}} \right]$$

$$Q_4 = 2 \frac{Q_1}{Q_2} \cdot \frac{1}{u^{Q_3} \cdot \exp(-g) + (2 - \exp(-g)) \cdot u^{-Q_3}}$$

$$Q_5 = 1.794 + 1.14 \ln \left(1 + \frac{0.638}{g + 0.517g^{2.43}} \right)$$

$$Q_6 = 0.2305 \frac{1}{2813} \ln \left[\frac{g^{10}}{1 + \left(\frac{g}{5.8}\right)^{10}} \right] + \frac{1}{5.1} \ln(1 + 0.598g^{1.154})$$

$$Q_7 = \frac{10 + 190g^2}{1 + 82.3g^3}$$

$$Q_8 = \exp \left[-6.5 - 0.95 \ln(g) - \left(\frac{g}{0.15}\right)^5 \right]$$

$$Q_9 = \ln(Q_7) \cdot \left(Q_8 + \frac{1}{16.5} \right)$$

$$Q_{10} = Q_4 - \frac{Q_5}{Q_2} \exp \left(\frac{Q_6 \ln(u)}{u^{Q_9}} \right)$$

$$Z_{co} = \frac{Z_c \cdot \sqrt{\frac{\epsilon_{re}}{\epsilon_{ro_eff}}}}{1 - Q_{10} \cdot \sqrt{\epsilon_{re}} \cdot \frac{Z_c}{377}} \quad (5)$$

Where Z_{ce} and Z_{co} are even and odd mode characteristic impedances.

4. Filter Design Method

The first step in designing a filter is to determine the order of the filter, n required. The order of the filter can be determined from (6), (7) and (8) [4] [6]. From the result of (8), the order of the filter can be determined from Figure 3.

Fractional bandwidth,

$$FBW = \frac{\omega_2 - \omega_1}{\omega_0} \quad (6)$$

Bandpass transformation,

$$\frac{\omega}{\omega_1} = \frac{2}{FBW} \left(\frac{\omega - \omega_0}{\omega_0} \right) \quad (7)$$

Normalized frequency,

$$\left| \frac{\omega}{\omega_1} \right| - 1 \quad (8)$$

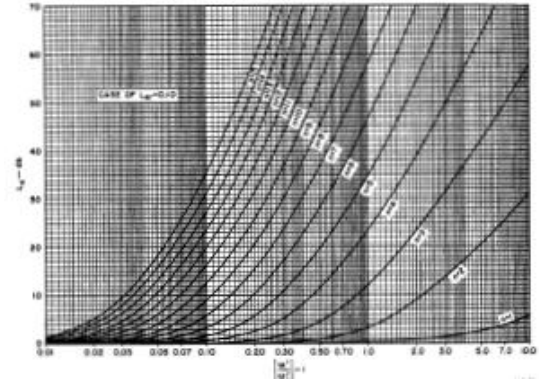


Figure 3 : Attenuation versus normalised frequency for 0.1dB ripple low-pass filter prototype [4]

A 2nd pole parallel-coupled microstrip bandpass filter is designed at a center frequency of 5.2 GHz with 3.84 % bandwidth. Chebyshev response with 0.1 dB passband ripple is used in the design. Element values of a 2nd order lowpass prototype with 0.1dB passband ripple are calculated by means of the formulas for Chebyshev response. The resulting values are:

$$g_0 = 1, \quad g_1 = 0.8430, \quad g_2 = 0.6220,$$

$$g_3 = g_{n+1} = 1.3554$$

The low-pass prototype elements values obtained can be represented as shown in Figure 4.

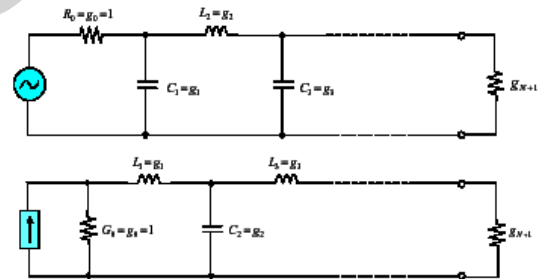


Figure 4 : Low-pass filter prototype

The low-pass filter consists of series and parallel branch, J-inverter is used to convert low-pass filter to bandpass filter with only shunt branch as shown in Figure 5.

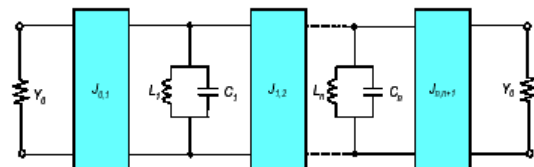


Figure 5 : Bandpass filter prototype

Formulas to calculate characteristic admittance of J-inverters are given in [2] [4] [1] [7].

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi \cdot FBW}{2 \cdot g_0 g_1}} \quad (9)$$

$$\frac{J_{j,j+1}}{Y_0} = \frac{\pi FBW}{2} \cdot \frac{1}{\sqrt{g_j g_{j+1}}} \quad j=1 \text{ to } n-1 \quad (10)$$

$$\frac{J_{n,n+1}}{Y_0} = \sqrt{\frac{\pi FBW}{2 g_n g_{n+1}}} \quad (11)$$

where $g_0, g_1, g_2, \dots, g_n$ are the elements of the lowpass prototype and FBW is the fractional bandwidth of the bandpass filter, $J_{j,j+1}$ are the characteristic admittances of the J ó inverters and Y_0 is the characteristic admittance of the terminating lines.

The even and odd characteristic impedances for parallel lines, Z_{0e} and Z_{0o} Can be obtained from (12) and (13). The calculated results are compiled in Table 1.

$$(Z_{0e})_{j,j+1} = \frac{1}{Y_0} \left[1 + \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0} \right)^2 \right] \quad (12)$$

$$(Z_{0o})_{j,j+1} = \frac{1}{Y_0} \left[1 - \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0} \right)^2 \right] \quad (13)$$

where $j = 0$ to n

Table 1
Parameters of parallel-coupled filter

n	$J_{i,i+1}/Y_0$	Z_{0e} (ohms)	Z_{0o} (ohms)
1	0.2672	66.925	40.205
2	0.0831	54.500	46.19
3	0.2672	66.925	40.205

The physical dimensions of the parallel coupled microstrip lines that exhibit the desired even and odd mode impedances are computed. Equations (1) through (5) are used to find the desired dimensions of the filter (width & space). The calculated results are given in Table 2.

Table 2
Physical dimension of coupled line

Line Description	Width (mm)	Length (mm)	Space (mm)
50 ohm line	1.8564	6.7602	-
Coupled lines 1 and 3	1.5427	6.9347	0.5996
Coupled lines 2	1.7968	6.7839	2.1847

The lengths of coupled line sections are computed by [2] [4] [1].

$$l_j = \frac{\lambda_0}{4 \sqrt{(\epsilon_{re})_j \cdot (\epsilon_{ro})_j}} - \Delta l_j$$

where $\hat{\epsilon}l_j$ are the resonator length corrections to account for the fringing effects at the open ends of the resonators and are given by

$$\Delta l = h * \xi_1 \xi_3 \xi_5 / \xi_4$$

where

$$\xi_1 = 0.434907 \frac{\left[(\epsilon_{re})^{0.81} + 0.26 \left(\frac{W}{h} \right)^{0.8544} \right] + 0.236}{\left[(\epsilon_{re})^{0.81} - 0.189 \left(\frac{W}{h} \right)^{0.8544} \right] + 0.87}$$

$$\xi_2 = 1 + \frac{\left(\frac{W}{h} \right)^{0.371}}{2.35 \cdot \epsilon_r + 1}$$

$$\xi_3 = 1 + \frac{0.5274 a \tan \left[0.084 \left(\frac{W}{h} \right)^{\frac{1.9413}{\xi_2}} \right]}{(\epsilon_{re})^{0.9236}}$$

$$\xi_5 = 1 - 0.218 \cdot \exp \left(-7.5 \frac{W}{h} \right)$$

5. Results

A 2nd order parallel-coupled bandpass filter as shown in Figure 6 is stup using ADS to study the effect of optimizing the different parameters of coupled line. The circuit dimensions are based on Table 2.

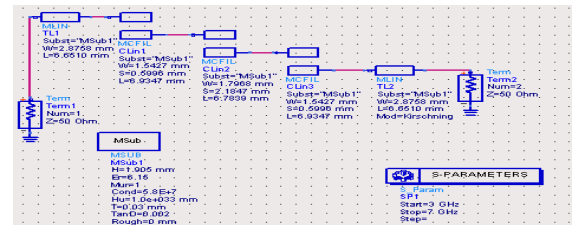


Figure 6 : Circuit of investigating coupled line parameters

The result of the microstrip filter simulation is shown in Figure 7. In the plot, we can find out that the centre frequency of the filter has deviated from

the specified frequency 5.2 GHz. So the design cannot be used in practice.

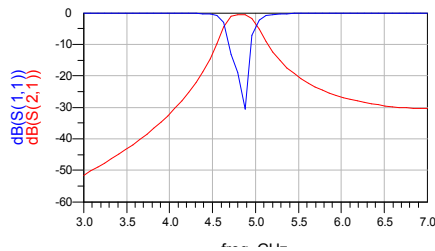


Figure 7 : Amplitude versus frequency curve of the filter by conventional method

6. Optimal design of coupled microstrip filter [8] [7]

To reach the specified request, we adopt the optimal design ability owning by ADS to reach the goal. We put the OPTIM controller in the schematic as well as three GOAL controllers to specify the optimal goals which we want to get after optimization. The paper sets three GOAL controllers which define the band-pass insert loss, alias attenuation and reflect ratio respectively. To make the insert loss in band as least as possible, a 3dB loss is set when the frequency between 5.1 GHz and 5.3GHz.

We use VAR components to set the tunable parameters such as microstrip width, gap and length. In this design, the filter is symmetrical geometrically, indeed only two group different values are needed to determined during the optimization which are set to be (w1,s1,l1) and (w2,s2,l2) in the schematic. The parameters in the VAR component should set around the values which we have calculated with conventional method. As the coupled microstrip filter is sensitive to the increment and decrease of its dimension, the value should not deflect the centre too much to lessen the time exhausted in the optimization.

The plot of the amplitude versus frequency after optimization is shown in Figure 8. In the plot, we can get that the centre frequency of the filter has adjusted to 5.2 GHz and the corresponding insert loss is less than 1dB.

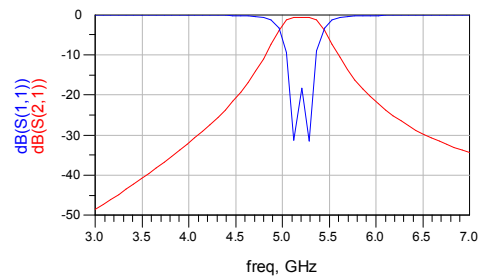


Figure 8 : Amplitude versus frequency graphic after optimization

After the optimization, we update the dimensions of the microstrip with the new parameters which are derived from the optimization. The refined parameters of the dimension are listed in Table 3

Table 3
Physical dimension of coupled line

Line Description	Width (mm)	Length (mm)	Space (mm)
50 ohm line	2.8758	6.6510	-
Coupled lines 1 and 3	0.5957	8.4377	1.0012
Coupled lines 2	0.8716	4.8283	1.5471

The layout of the parallel-coupled bandpass filter in ADS is shown in Figure 8. ADS use numerical techniques based on method of moments.

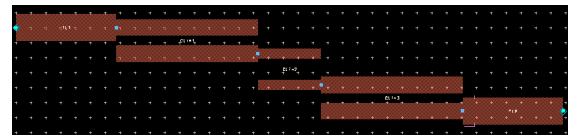


Figure 9 : Layout of parallel-coupled bandpass filter

7. Conclusion

In this paper, the detail procedures for designing a parallel-coupled bandpass filter has been presented. This filter is designed at a center frequency of 5.2 GHz with 3.84 %. Half wavelength long resonators and admittance inverters are used to realize the filter. The optimization function owning by ADS is an efficient tool to amend the drawback of conventional method with theoretic formulas.

8. Reference

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