

# Comparative Analysis of Low-pass Microstrip Filter Performances for Two Different Dielectric Materials

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## Abstract

The dielectric material is a basic element which impacts considerably on a microstrip structure performances. This project demonstrates how filter performances such as gain, bandwidth, return loss and insertion loss change proportionally with substrate material variation. The RT/Duroid 5880 and the FR-4 are two dielectric materials proposed as substrates of a low pass microstrip filter. The design and simulation are done on ADS software. The transmission and reflection characteristics show that the RT/ Duroid 5880 as a dielectric substrate permits to obtain better performance as compared to the FR-4 substrate.

## Keywords:

*Microstrip low pass filter, dielectric material, substrate, return and insertion loss, performances.*

## 1. Introduction

During recent years, there is an accelerated development of communication systems such as radar, mobile, satellite, wireless sensor, Bluetooth, WI-FI.

One of the indispensable building blocks in a communication system is the filter. Main purpose of filter is to pass frequencies in desired range and reject all others. There are four types of filter which are the high pass filter, the low pass filter, the band stop filter and the band pass filter. Each one can pass or reject frequencies in different way. High pass filter passes the frequencies higher than cutoff frequency.

Low pass filter allows passing only the frequencies below the cut-off frequency. Band stop filter passes the frequencies which are outside two cutoff frequencies and Band pass filter allows to pass the frequencies located between two cut-off frequencies.

Depending on the application, the filters can be designed either by lumped or microstrip components [1]. Microstrip filter consists of a conducting strip separated from a ground plane by a dielectric material known as substrate. Such filter is formed, from a series connection of high and low impedance microstrip lines [2].

Depending on its position, microstrip filter is used as transmitter or receiver component of RF signal, at

frequencies ranging from 800 MHz to 30 GHz. Microstrip filters have gained more attention than traditional waveguides due to their high performance, small size, light weight, low cost, robust design and easy integration in printed circuit [3]. On the other hand, they present some disadvantages such as their high losses and narrow bandwidth [4]. During conception of microstrip filter, selection of an appropriate dielectric material is very important to achieve maximum efficiency [5].

This work consists of a comparative study of a low pass filter performances for two different dielectric materials, which are the RT/Duroid 5880 and the FR-4 dielectrics. The design and simulation results are performed by ADS software.

## 2. Design of Microstrip Low-pass Filter for Two Different Substrate Materials

A low pass filter is a filter, which passes signal lower than cutoff frequency and eliminates signal higher than cutoff frequency. The general structure of low-pass filter is formed by an alternation of series inductors and shunt capacitors [6,7].

In high frequency applications, Low pass filter is designed from distributed elements such as transmission lines. The common form of microstrip low pass filter is shown in Figure1. It consists of a cascaded of high and low impedance transmission lines [9]. A high-impedance line is obtained by a narrow microstrip line and acts similar to a series inductor and a low- impedance line is obtained by a large microstrip line and acts like a shunt capacitor.

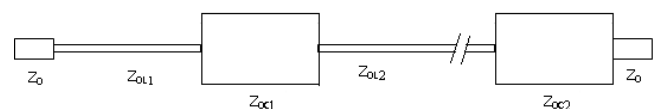


Fig. 1 Low pass microstrip filter

$Z_{0Li}$  and  $Z_{0ci}$  represent respectively the characteristic impedances of inductors and capacitors

A high  $Z_{0L}$  line constitutes a better approximation of lumped inductor.

A low  $Z_{0c}$  line constitutes a better approximation of a lumped capacitor.

The design of a microstrip filter imposes two essential steps; the first one is to select a suitable prototype and deduce the lumped filter design. In this step the choice of the order and type of filter are necessary.

The second step is to determine an appropriate microstrip structure that approximates the lumped element filter. The substrate characteristic influences on the final lumped design and its performances.

For the current project, Chebyshev prototype is exploited to design a fourth order low pass filter having the following characteristics:

The inductor impedance  $Z_{0L}=100\Omega$

The capacitor impedance  $Z_{0C}=10\Omega$

The source and load impedance  $Z_0=50\Omega$

The Cut-off frequency  $f_c=2\text{GHz}$

Chebyshev formula are used to find the normalized lumped values[10]

$$g_0=1 \tag{1}$$

$$g_k=2\sin\{(2k-1)\pi/2N\} \tag{2}$$

for  $k=1,2,\dots,N$

$$g_{N+1}=1 \tag{3}$$

$N$  is the order of filter

The obtained results are:

$$g_1=0.7654$$

$$g_2=1.8478$$

$$g_3=1.8478$$

$$g_4=0.7654$$

Now inductors and capacitors values can be deduced [1].

$$L_i = \frac{g_i \cdot Z_0}{\omega_c} \tag{4}$$

$$C_i = \frac{g_i}{Z_0 \cdot \omega_c} \tag{5}$$

From equation (4) and (5) the calculated values for lumped-element network are :

$$L_1=0.47117\text{pF}$$

$$C_1=2.4375\text{nH}$$

$$L_2=6.09394\text{pF}$$

$$C_2=5.88471\text{nH}$$

By inserting all inductors and capacitors values in the fourth order low pass filter, we obtain:

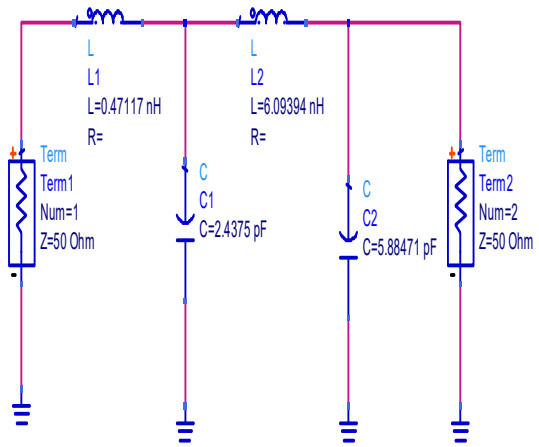


Fig. 2 Lumped low pass filter

To achieve the conversion from lumped to distributed design, Chebyshev proposed a special transformation that allows replacing lumped inductors by high impedance microstrip lines and lumped capacitors by low impedance microstrip lines.

Electrical length of high impedance line:

$$\beta \cdot l_L = (g_i \cdot Z_0) / Z_{0L} \tag{6}$$

Electrical length of low impedance line:

$$\beta \cdot l_C = (g_i \cdot Z_{0C}) / Z_0 \tag{7}$$

We obtain:

$$\beta \cdot l_{L1} = 0.3827$$

$$\beta \cdot l_{C1} = 0.36956$$

$$\beta \cdot l_{L2} = 0.9239$$

$$\beta \cdot l_{C2} = 0.15308$$

$$\beta = 2\pi/\lambda \tag{8}$$

The physical lengths are:

$$l_{L1}=9.141\text{mm}$$

$$l_{C1}=8.827\text{mm}$$

$$l_{L2}=22.068\text{mm}$$

$$l_{C2}=3.6564\text{mm}$$

The substrate characteristics are necessary to calculate the microstrip line width. The RT/ Duroid 5880 and FR4 are respectively used as substrate material of the filter.

A simple calculation on line calc of ADS software permits to obtain the microstrip line width.

2.1 RT/ DUROID 5880

The RT/Duroid 5880 is a Dielectric Material frequently used as microstrip structure substrate.

RT/Duroid 5880 has a standard thickness (h)=1.57 mm, a dielectric constant ( $\epsilon_r$ ) = 2.2, a Loss tangent ( $\delta$ ) =0.0009.

By inserting the value of cut-off frequency and the RT/Duroid 5880 characteristics on the line calc tools of ADS software, we obtained as lines widths:

$W_{C1} = W_{C2} = 35.8761\text{mm}$ , the width of capacitors

$W_{L1} = W_{L2} = 1.39544\text{mm}$ , the width of inductors

The length and width of input and output transmission lines obtained for an impedance characteristic  $50\Omega$  are:

Width=4.64383mm

Length=13.7223mm

Using ADS software, Fig.3 represents the design of microstrip low pass filter for RT/Duroid 5880 as substrate.

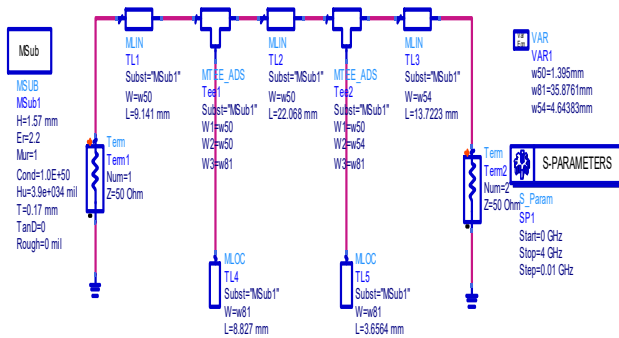


Fig. 3 Microstrip low pass filter design for RT/Duroid 5880 substrate

2.2 FR4

The FR4 Substrate is a dielectric material characterized by a standard thickness  $h=1.6$  mm, a dielectric constant ( $\epsilon_r$ ) =4.4) and a loss tangent ( $\delta$ ) = 0.02.

By using the line calc of ADS software, and taking into account the substrate characteristics and the cut off frequency, we calculated the width values of lines, we obtained

$W_{C1} = W_{C2} = 25.3189\text{mm}$ , the width of capacitors

$W_{L1} = W_{L2} = 0.69873\text{mm}$ , the width of inductors

Fig. 4 represents the microstrip low pass filter structure using FR4 as substrate.

It consists of two high impedance lines acts as inductors and two low impedance lines acts as capacitors.

Two connecting microstrip lines are used to link distributed elements between them.

The input and output ports are characterized by an impedance characteristic  $50\text{ ohm}$ .

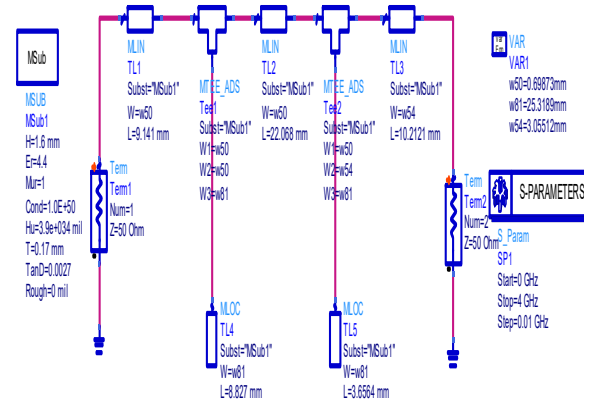


Fig. 4 Microstrip low pass filter design for FR4

3. Results and discussion

Fig. 5 illustrates the response of microstrip low pass filter for the dielectric substrate RT/ Duroid 5880. The performance of the filter is evaluated in terms of gain, bandwidth, insertion-loss  $S_{21}$  and return-loss  $S_{11}$ .

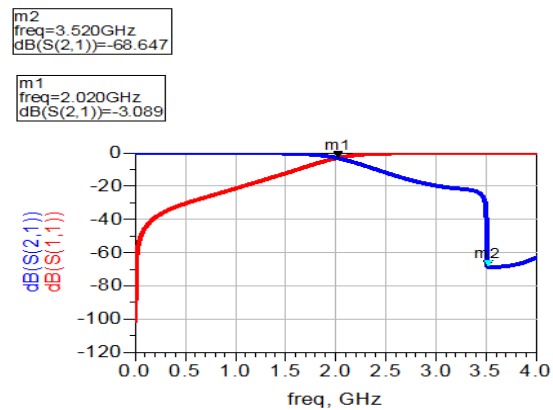


Fig. 5 Microstrip low pass filter response for RT/ Duroid 5880 substrate

The bandwidth of the filter ranges from 0 to 2 GHz. It is lucid from the graph that the ripple in the bandwidth, from 0GHz to 2 GHz is nearly 0 dB,

At 2 GHz the insertion loss is -3.08dB and is sharply increased to -68 dB at 3.5GHz, which gives good response of the low pass filter.

The reflection coefficient S11 achieves -50dB. Therefore the designed filter achieves high performances. The simulation result of the microstrip low pass filter design using ADS software and for a dielectric material FR4 is as shown in Fig. 6.

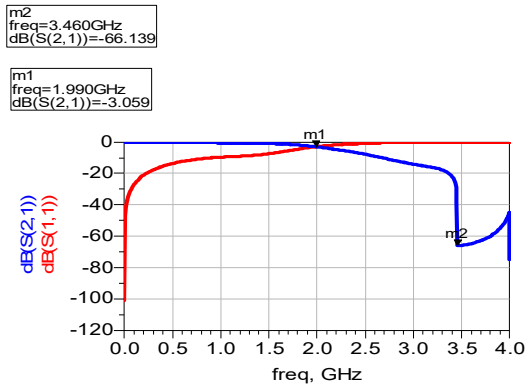


Fig. 6 Microstrip low pass filter response for FR4 substrate

The bandwidth of the filter ranges from 0 to 1.8 GHz. The insertion loss S21 is -3.05dB at cut off frequency 2GHz with 0.2dB ripple in pass-band.

S21 achieves -65 dB at 3.5GHz. The reflection coefficient S11 of the bandwidth range achieves only -40dB. Therefore, the designed filter presents least performances as compared to the filter with RT/Duroid substrate.

The Table1 recapitulates the performances comparison of filter for RT/Duroid and FR4 substrates.

**Table 1:** Performance Comparison of microstrip low pass filter for two different Dielectric substrate

Material/Substrate	Insertion Loss S21 in dB at 2GHz	Return Loss S11 in dB	Band- Pass
RT/ Duroid 5880	-3.08	upto -50	0 to 2GHz
FR4	-3.05	upto -40	0 to 1.8GHz

It is observable from Table 1 that the most appropriate substrate for the microstrip low pass filter design is the RT/Duroid 5880 which provides wider bandwidth, best

gain and more adapted insertion and return loss as compared to the FR4 substrate.

#### 4. Conclusion

In this paper a fourth order microstrip low pass filter is designed based on Chebyshev prototype. A performance study is made for two different dielectric materials which are the RT/Duroid 5880 and the FR-4 dielectrics. The designs and simulations are done on ADS software. From the obtained results of insertion and return loss characteristics, it is observed that the RT/Duroid 5880 substrate permits to obtain best performance as compared to the FR4.

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