Design and Analysis of Stepped Impedance Microstrip Low Pass Filter for Wireless Applications

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Abstract: There is an increasing demand for microwave systems to meet the emerging telecommunication challenges with respect to size, performance and cost. This project describes a general design technique for micro strip low pass filters and there optimization that are used to convey microwave frequency signals. The ADS simulation tool is used to design an stepped impedance low pass filter of range 10-14GHz. This simulation results show that the filter works on 10GHz at the center frequency and achieves attenuation of 28dB, which effectively suppresses the parasitic bands. To attain the filter with these characteristics, Insertion Loss Method is performed. Compared to other filter types, this design works very well with excellent harmonic suppression performance.

Keywords: ADS, Attenuation, Harmonic suppression Insertion loss, Micro strip, Stepped impedance, Optimization.

1. Introduction

Micro strip is a type of electrical transmission line, which can be fabricated using printed circuit board [PCB] technology, and is used to convey microwave-frequency signal. It consists of a conducting strip separated from a ground plane dielectric layer known as the substrate. Micro strip is much less expensive than traditional waveguide technology, as well as being far lighter and more compact. The disadvantages of micro strip compared with waveguide are the generally lower power handling capacity, and higher losses. Also, unlike waveguide, microstrip is not enclosed, and is therefore susceptible to cross talk and unintentional radiation. For lowest cost, microstrip devices may be built on an ordinary FR-4 (standard PCB) substrate. However it is often found that the dielectric losses in FR-4 are too high at microwave frequencies, and that the dielectric constant is not sufficiently tightly controlled. For these reasons, an Epoxy_E_Fiberglass substrate is used. On a smaller scale, micro strip transmission lines are also built into monolithic microwave integrated circuits [MMIC] s. Micro strip lines are also used in high-speed digital PCB designs, where signals need to be routed from one part of the assembly to another with minimal distortion, and avoiding high cross talk and radiation. A strip line circuit uses a flat strip of metal, which is sandwiched between two parallel ground planes. The insulating material of the substrate forms a dielectric.

The width of the strip, the thickness of the substrate and the relative permittivity of the substrate determine the characteristic impedance of the strip, which is a transmission line. In the general case, the dielectric material may be different above and below the central conductor to prevent the propagation of unwanted modes; the two ground planes must be shorted together. Most communication systems require an RF front end, where RF filters and low noise amplifiers perform analog signal processing. Micro strip RF filters are commonly used in receivers and transmitters operating in 800 MHz to 30 GHz frequency range. In this project, a design of prototype low pass filter and its implementation to microstrip line is done and responses are analysed. Joining together two micro strip transmission lines with different characteristic impedances forms fundamental micro strip low pass filter. The design is performed in Advanced Design System software.

2. DESIGN AND MATHEMATICAL CALCULATION

In microwave filters, lumped elements of the of filter circuit sections are simulated by means of waveguides, coaxial lines, strip (or) micro strip lines, cavity resonators, etc. [2].The equivalent lumped elements values of the microwave components are themselves functions of the frequency [2].

There are two design techniques properly used.
1) Image parameter method.
2) Insertion loss method

A. Advantage of Insertion Loss Method

The Insertion Loss method allows high degree of control over the pass band and stop band amplitude and phase characteristics, with a systematic way to synthesize a desired response. Among various practical filter responses we have chosen maximally flat filter response. This characteristic is also called the binomial or Butterworth response, and is optimum in the sense that it provides the flattest possible pass band response for a given filter order.

B. Low-Pass Design

Basic design of microwave filters of type's low-pass, band-pass and band-stop, operating at arbitrary frequency bands and between arbitrary resistive loads, are made from a prototype low-pass design through:
1) Some frequency transformer,
2) Element normalization and Simulation of these elements by means of sections of microwave transmission line**,**
3) Design of a prototype low-pass filter with the desired pass band characteristics,
4) Transformation of this prototype network to the required type (low-pass, high-pass, band-pass) filter with the specified centre and band-edge frequencies.
5) Realization of the network in microwave form by using sections of microwave transmission lines.

C. Flow Diagram to Design a Filter

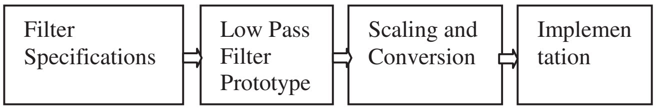

Fig 1 Design flow diagram

D. Filter Specifications

Response Type	**Butterworth (or) maximally flat**
Centre frequency	10GHz
Stop band attenuation	-28db
Source and load Impedance	50 ohm
Substrate Thickness	1.58mm
Dielectric constant	4.2
Metal Thickness	0.02128mil

3. DESIGNING STEPS FOR LOW PASS FILTER IN ADS

STEP.1
We choose order of the filter to be 10, N = 10.
There are two responses to assign prototype values for designing.
1) Butter worth (maximally flat) filter,
2) Chebyshev filter.

For Butterworth response we use the specific formula to determine prototype values. The formula is

Butterworth Prototype Element Values

$g_o = 1$

$g_k = 2\sin[(2k-1)\pi/2n]$, k=1,2,…..,N

$g_{n+1} = 1$, for all N

STEP.2: Filter Transformations from Prototype

In order to design actual low pass filters, the transformations of the low pass prototype filters with normalized cut off frequency, w_c=1 and having the source and load resistances of 50ohm are made into the desired type with Required source and load impedances using frequency and impedance transformations.

Formula to calculate L_K and C_K

Prototype Element	**Low Pass Filter**
Shunt Arm g_k	$C_k = g_k/Z_l w_c$
Series Arm g_k	$L_k = g_k Z_h/w_c$

The values are shown in table below

Prototype element values	**Corresponding L and C Values**
g1= 0.3129	C1=0.099599pF
g2=0.9080	L1=0.7255nH
g3=1.4142	C3=0.45015pF
g4= 1.7820	L4=1.4180nH
g5= 1.9754	C5=0.628pF
g6= 1.9754	L6=1.571nH
g7= 1.7820	C7=0.567pF
g8=1.4142	L8=1.12nH
g9=0.9080	C9=0.289pF
g10=0.3129	L10=0.248nH

STEP 3: By Substituting all these L and C values in the network design, we have; and “display window” is being created.

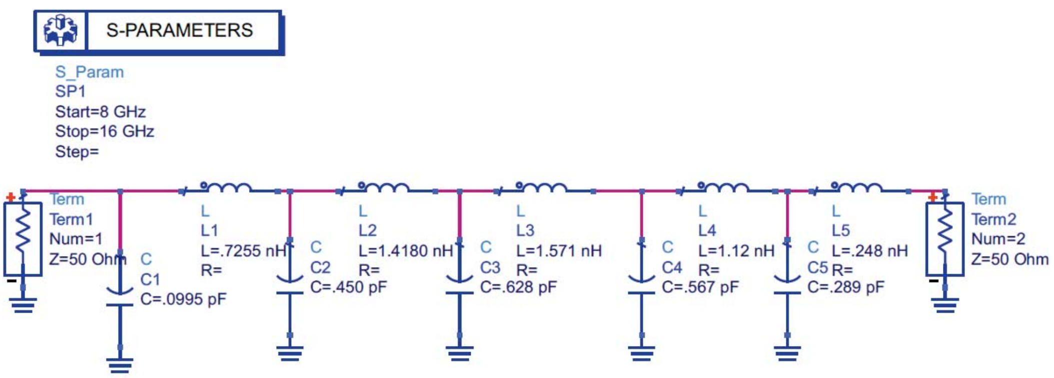

Fig 2: Schematic diagram of LPF with S parameters

Output waveform of LPF using lumped elements

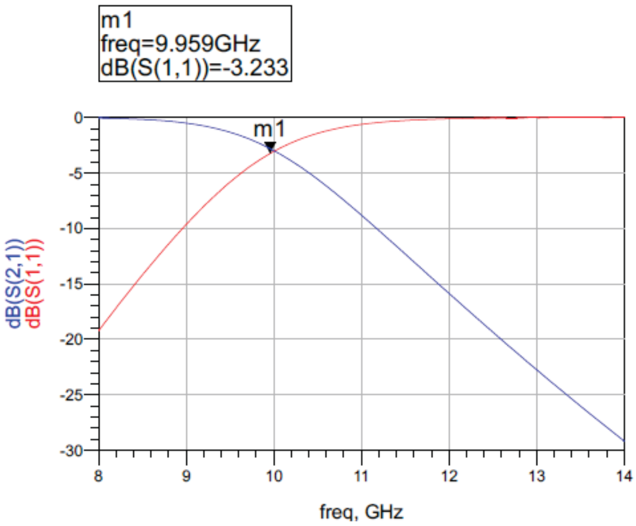

Fig 3: Output Wave form S parameters vs Frequency

This is the prototype low pass filter response where the attenuation property is not satisfied here. Hence we go for micro strip implementation.

STEP 4:

Filter designs beyond 500MHz are difficult to realize with discrete components because the wavelength becomes comparable with the physical filter element dimensions, resulting in various losses severely degrading the circuit performance. Thus to arrive at practical filters, the lumped component filters must be converted into distribution element realizations.

In order to convert lumped components to micro strip lines of various impedances we used Richards Transformation and Kuroda Identities can be used to separate filter elements by using microstrip lines.

RICHARDS TRANSFORMATION:

To accomplish the conversion from lumped and distributed circuit designs, Richards proposed a special transformation that allows open and short circuit transmission line segments to emulate the inductive and capacitive behaviour of the discrete components.

Richards transformation allows us to replace lumped inductors with short circuit stubs and capacitors with open circuit stubs of characteristic impedance Zo= 1/ C. Thus from prototype series inductance are the same and shunt capacitance is replaced by 1/ C values.

Formula for Electrical Lengths

$$\beta l_{l} = g_{x} * R_0 / Z_{h}$$
$$\beta l_{c} = g_{x} * Z_L / R_{0}$$

After substitution the Results after Richards Transformation and Kuroda Identity we get the length of inductors and capacitors.

Step 5: LINE CALC

With having the impedance and electrical length of the stub lines, dielectric constant, substrate width, the width of the line can be calculated using linecalc tool in schematic window as shown in Fig 5.

Impedance(ohm)	Width(W)(mm)	Length(L)(mm)
Z_l =20	12.759	0.426
Z_h =120	0.557	1.29
Z_l =20	12.759	1. 92
Z_h =120	0.557	2.53
Z_l =20	12.759	2.694
Z_h =120	0.557	2.80
Z_l =20	12.759	2.43
Z_h =120	0.557	2.009
Z_l =20	12.759	1.238
Z_h =120	0.557	0.444
Z_0 =50	3.701	0. 950

Finally the transformation from prototype to micro strip look likes

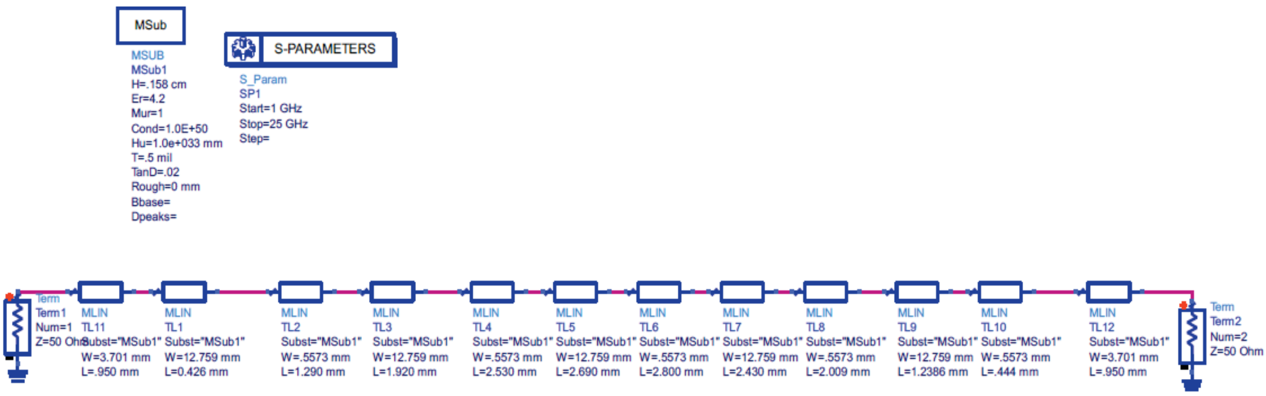

Fig 4: schematic diagram of untuned LPF with substrate specifications

For the above low pass filter prototype we have obtained the result which is not the desired result which is shown in figure 5

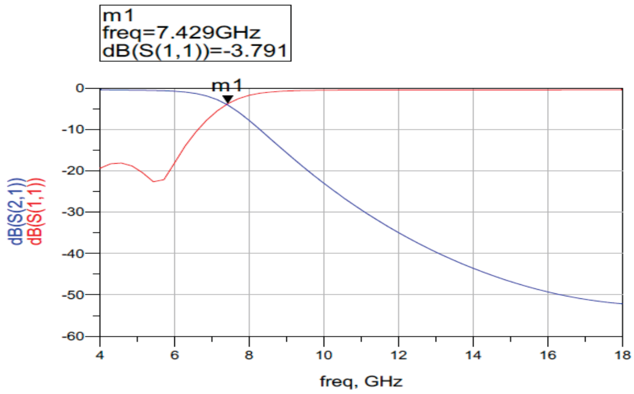

Fig 5: Output Wave form S parameters vs Frequency (untuned)

Graph shows the attenuation of -55dB at 7.48GHz cut off frequency, but we are designing a low pass filter for 10GHz cut off frequency.

For getting desired response at 10GHz cut off frequency we are optimizing the low pass filter prototype by tuning the length of inductor and capacitor.

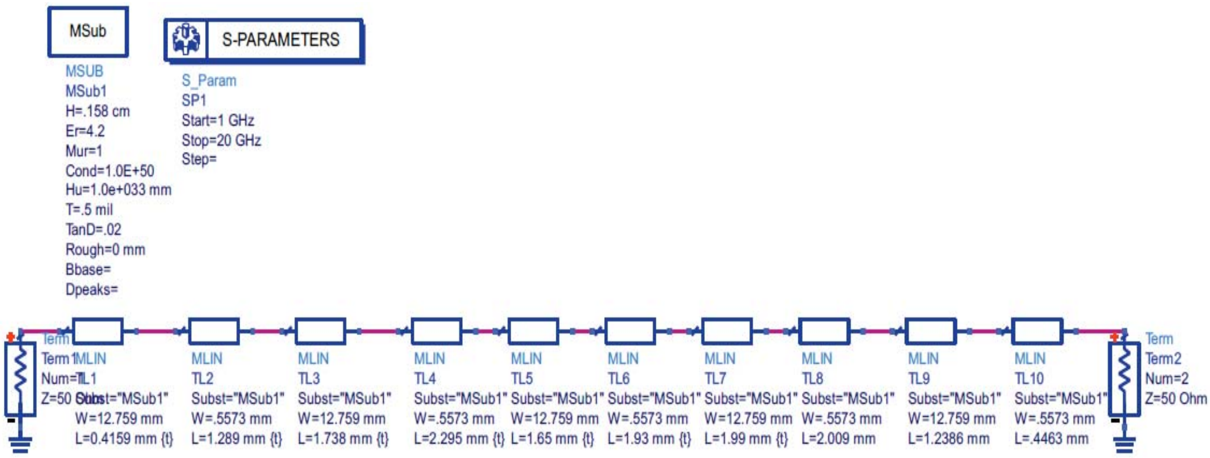

Fig 6: schematic diagram of tuned LPF with substrate specifications

Fig 7: Output Wave form S parameters vs Frequency (tuned)

Above low pass filter prototype is converted into its stepped impedance microstrip model.

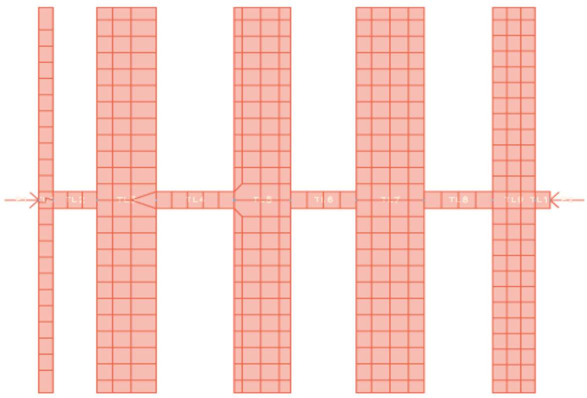

Fig 8: Layout of LPF using Micro strip

4. APPLICATION OF MICROSTRIP LOW PASS FILTER

Wi-Fi is a wireless LAN technology that enables laptop PC's, PDA's, and other devices to connect easily to the Internet. Technically known as IEEE 802.11 a/b/g/n. Wi-Fi is less expensive and nearing the speeds of standard Ethernet and other common wire-based LAN technologies. Several Wi-Fi hot spots have been popular over the past few years. Some business charge customers a monthly fee for service, while others have begun offering it or free in an effort to increase the sales of their goods.

5. CONCLUSION

In this paper, stepped impedance micro strip low pass filter is designed. This filter provides us to achieve better harmonic suppression. This filter not only shows a superior harmonic suppression in stop-band, but also saves as much compact circuit size compared with the conventional one. This design is applied in X-band and Ku band electromagnetic environments. Various steps to design a stepped impedance micro strip filter are described. The special calculator, linecalc of ADS is used for designing. The calculated filter parameters are applied to design a filter. The software platform used in this designing purpose is ADS (Advanced Design System). This software is used especially in leading industries working on MMIC's. A filter of mentioned specifications is designed. The corresponding waveforms are obtained. The range of attenuation achieved can be known from the waveform. Then the layout of the designed stepped impedance micro strip filter is obtained using the software itself. Thus, finally a stepped impedance micro strip filter whose harmonic suppression is -60db is obtained.

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