Application of Microstrip Discontinuities to Design a Low Pass Filter

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Abstract

In this paper discontinuities in microstrip line are critically discussed and these discontinuities are used to design compact microstrip low pass filters, which show a very good performance. The design methods are clearly explained with one example. Simulations were done to obtain results and it was seen that the simulated results have a very good match with the calculated results.

Key words- Return loss, Insertion Loss, Microstrip Discontinuities

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1. Introduction

Microstrip filters are very important components of wireless communication. Amongst the four basic filter responses, viz., low pass, high pass, band pass and band reject, the role of low pass filter (LPF) is immeasurable in communication at both the transmitter and receiver sides. The design of microstrip LPF has several challenges because of the various losses such as radiation losses, dielectric losses etc.

Microstrip discontinuities include open ends, gaps, steps, bends and T-junctions. Most of the discontinuities occur because of the routing requirement of microstrip lines. The effect of an open end in a microstrip line is to create extra fringe electric field at the location of the open circuit. Therefore, an open end in a microstrip line does not present an ideal open circuit at the physical reference plane. The open end can be modeled by a small extension in the physical length of the line assuming that no fringe field exists [1]. The microstrip series gap can be useful in microstrip resonators where it is used to couple RF energy from the input line to the resonator. It can also be used in dc blocking circuits if the frequency is high enough to cause sufficiently low impedance in the small series capacitance. The single gap does not produce sufficient coupling as seen at the design stage, therefore, one needs to utilize an interdigital structure to boost the coupling [2].

In a microstrip circuit, it is sometimes necessary to change the width of the line to alter the characteristic impedance of the line. This is typically required in designing impedance matching circuits and filters. The change in the width can be symmetrical or asymmetrical. Having bends in a complex microstrip circuit is almost unavoidable. Without bending the lines, it would be nearly impossible to reduce the circuit dimensions. In fact, it is one of the biggest advantages of microstrip lines that they can be shaped relatively easily. However, microstrip bends affect the VSWR and therefore must be properly compensated [1-2].

Microstrip T-junction occurs when a line interacts with another line at a right angle and terminates. Perhaps the most common use of a T-junction is in the microstrip stubs. Other common application is in the power dividers and branch-line application [2].

In this paper the design of LPF has been elaborated using the Chebyshev low pass prototype technique [3]. In the design, a low pass prototype circuit for cut-off frequency 3-GHz has been considered and the elemental values are calculated for Chebyshev response. The prototype filter is then transformed into the desired low-pass filter with the elemental values for the considered cut-off frequency. The source impedance is taken as 50 Ω for the proposed design. After getting the suitable lumped elements for filter design it is then transformed to the appropriate microstrip realization.

2. Low Pass Filter Design Using Stepped Impedance

General conditions:

The general structure of the stepped impedance low pass Microstrip filters is shown in figure (1), where a cascaded structure of alternating high and low impedance transmission lines has been used. The high impedance line acts as a series inductor and the low impedance line acts as a shunt capacitor. Thus this method is used to realize the LC ladder type low pass filter. In the microstrip lines the expression of inductance and capacitance depend upon the characteristic impedance as well as the length of microstrip line. For the practical design initially the high and low characteristic impedances of the lines must be fixed by the following consideration:

(1) The value of characteristic impedance of source must be greater than the characteristic impedance of the line with broader width but smaller than that of a small width line.

(2) The lower characteristic impedance of the broader width of line gives the better approximation of a lumped element capacitor with the condition that the broader width must not allow any transverse resonance to occur at operation frequencies.

(3) The higher characteristic impedance of smaller width of line leads to a better approximation of a lumped element inductor but it should not be so high that its fabrication is impractical.

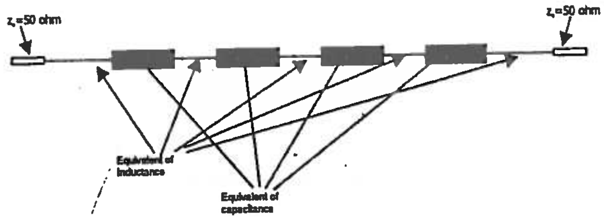


Fig: 1. General structure of stepped low pass microstrip filter

Design Specification of Prototype Filter:

Cut-off frequency fc = 3.0 GHz, Passband ripple =0.01 dB, Source and Load Impedance Zo = 50Ω, Stop-Band Attenuation L_{AS} is greater than 50 dB at Ω_S>3 GHz. The structure of prototype filter with the element values are taken as in [4]. To design the LPF using stepped impedance the values of the highest and the lowest impedance have been assumed. And the length of each component can be calculated from the following expressions

$$\beta l = \left\{ \frac{Z_{high}}{Z_0} \right\} g_k$$

$$\beta l = \left\{ \frac{Z_0}{Z_{low}} \right\} g_k$$

Where each term has their conventional meaning that is 'l' is the length of resonator, the phase constants β are different for lines with different widths. Z_{low} and Z_{high} are the assumed lowest and highest impedances of the microstrip lines with highest and lowest width respectively and g_k are elemental values of the prototype structure. This is one of the easiest methods to design the microstrip LPF. The lengths of the lines can be evaluated more accurately, as shown in the following section.

3. Frequency & Impedance Transformation

To design the desired LPF the frequency as well as the impedance of the prototype structure is to be transformed to the required values. For the impedance transformation the scaling factor $_0$ is considered as Z_0/g_0, $Z_0 = 50\Omega$. In principle, the impedance scaling factor is applied upon a filter network in such a way that

$L \rightarrow \gamma_0 L$

$C \rightarrow C/\gamma_0$

$R \rightarrow \gamma_0 R$

$G \rightarrow G/\gamma_0$

This transformation has no effect on the shape of the response.

Low pass transformation of prototype to actual

$\Omega = (\Omega_c/\omega_c)\ \omega$, $L = (\Omega_c/\omega_c)\gamma_0 * g$, $g \rightarrow$ inductance

$C = (\Omega_c/\omega_c)\ \gamma_0/g_0$ $g \rightarrow$ capacitance

By considering source and load impedance as 50 Ω,

$C_1 = 0.802$ pF, $C_3 = 1.673$ pF, $C_5 = 0.802$ pF

$L_2 = 3.4613$ nH , $L_4 = 3.4613$ nH

The transformed values of several elements are then required to transform to the desire microstrip structure using the Richard transformation.

To get the Richards Transform values the following mapping is required

$t = \tanh (l*p)/v_p$

$p = \sigma + j\omega$

l/v_p is the ratio of the length of basic commensurate length to the phase velocity.

't' is the new complex frequency variable also known as the Richards variable. The new complex plane where t is defined is called the t plane.

For lossless passive network,

$p = j\omega$ and hence $t = j \tan\theta$,

where $\theta = (\omega * l) / v_p$ = electrical length.

For $\theta_0 = \pi/2$ and $\Omega = \tan\theta = \tan [\theta_0 (\omega/\omega_0)]$

The value of $\Omega = \tan \{(\pi / 2) (\omega/\omega_0)\}$,

for $\omega = 0$ the value of $\Omega = 0$ and for $\omega = \omega_0$ the value of $\Omega = \infty$.

The frequency mapping of real frequency and distributed frequency Ω is shown in figure (2). From the figure (2) it is clear that at about ω=3, the value of Ω approaches infinity.

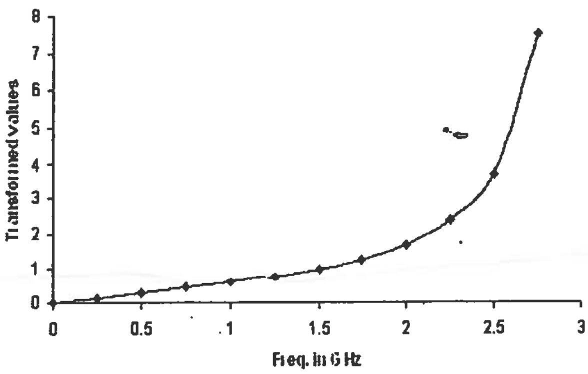


Fig: 2. Frequency mapping, ω vs. Ω.

The passive networks for the design has been considered lossless and the above equation transformed to $j \tan \beta l$, where $\beta l = \theta$.

$\theta = (\omega * l) / v_p$ is the electrical length,

where $\theta_0 = \beta_0 l = 2\pi/\lambda_0 * l$.

For the impedance transformation the mapping is given as $Z = tZc = jZc\tan\theta$, where Zc is the characteristic impedance of line. Similarly the lumped capacitance $Y=p^*C$ corresponds to open circuited admittance $Y = tYc = jYc\tan\theta$ where Yc is the characteristic admittance.

The characteristic impedance may be evaluated from

$$Zc = (2/\pi)[(B-1)-\ln(2B-1)+\{(\varepsilon_r-1)/2\varepsilon_r\}\{\ln(B-1)+0.39-0.61/\varepsilon_r\}]$$

Where $B= 60\ \pi^2/Zc\sqrt{\varepsilon_r}$

$$w/h = (8\ e^A)/(e^{2A}-2)$$

$$A=\frac{Zc}{60}\sqrt{\frac{\varepsilon_r+1}{2}}+\frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23+\frac{\varepsilon_r+1}{2}\right)$$

The physical length of the microstrip line corresponding to inductance and is calculated by using the expression

$$l_L = (\lambda gl/2\pi)\ \sin^{-1}(w_cL/Z_{oL})$$

The physical length for microstrip line corresponding to capacitance and is calculated by the expression

$$l_C = (\lambda gl/2\pi)\ \sin^{-1}(w_cCZ_{oC})$$

4. Results and Discussion

The filter has been designed using a stepped impedance network. To realize the desired circuit the theory of microstrip discontinuities has been applied. The wider portions of strip give the value of capacitances and show the impedances lower than the characteristic impedance of load and source where as the characteristic impedance of inductances are much higher than that of load and source and the strip portions are very thin. The top view of the filter is shown in figure (3). From the simulated results it is observed that the pass-band response is better considering that both the return loss as well as the insertion loss in the pass band are acceptable. The simulated results for parameters S11 and S21 are shown in figure (4), the S11 parameter of the structure is given in figure (5) and the calculated S21 is plotted in the figure (6).

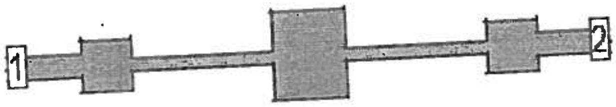


Fig: 3. Top view of stepped impedance LPF

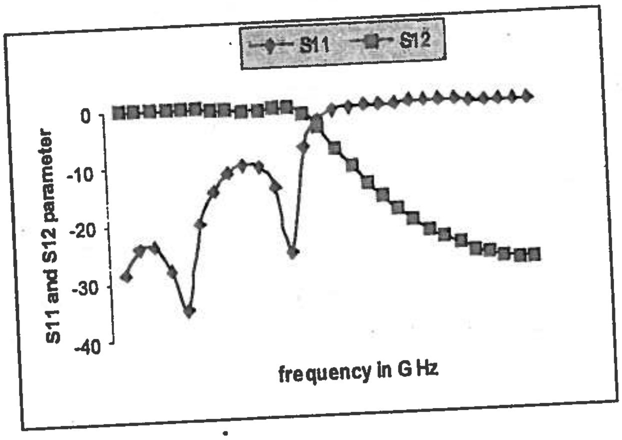


Fig: 4. Simulated S11 and S12 parameters of the designed structure

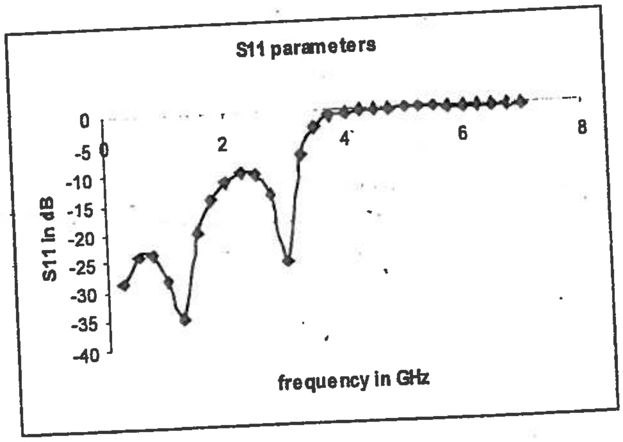
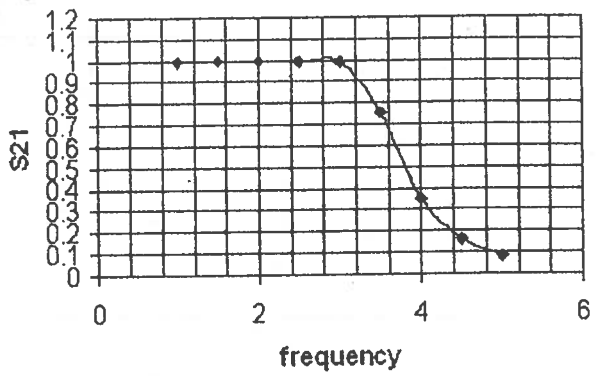


Fig: 5. Calculated S11-parameter of the designed circuits

Fig: 6. Calculated values of S21 parameter



6. Conclusion

This paper presents a method to design the LPF using stepped impedance technique where the discontinuities of the microstrip line have been applied. The stepped impedance method is quite simple to design a microstrip LPF. Another conventional method for microstrip filter design is by using the open stub lines, where the Richard transformation Kuroda Identity is applied. Even though the responses using stepped impedance show an improvement in the pass band response of LPF over the conventional design there are several other suggestions given in the literature [5,6]. Using the defective ground structure (DGS) that sometimes provides the effect of electromagnetic band gap structure at the ground plane of the substrate of the microstrip filter, the performance of the filter can be improved with a reduction in size.

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