CHAPTER 5

Lowpass and Bandpass Filters

Conventional microstrip lowpass and bandpass filters such as stepped-impedance filters, open-stub filters, semilumped element filters, end- and parallel-coupled half-wavelength resonator filters, hairpin-line filters, interdigital and combline filters, pseudocombline filters, and stub-line filters are widely used in many RF/microwave applications. It is the purpose of this chapter to present the designs of these filters with instructive design examples.

5.1 LOWPASS FILTERS

In general, the design of microstrip lowpass filters involves two main steps. The first one is to select an appropriate lowpass prototype, such as one as described in Chapter 3. The choice of the type of response, including passband ripple and the number of reactive elements, will depend on the required specifications. The element values of the lowpass prototype filter, which are usually normalized to make a source impedance $g_0 = 1$ and a cutoff frequency $\Omega_c = 1.0$, are then transformed to the L-C elements for the desired cutoff frequency and the desired source impedance, which is normally 50 ohms for microstrip filters. Having obtained a suitable lumped-element filter design, the next main step in the design of microstrip lowpass filters is to find an appropriate microstrip realization that approximates the lumped-element filter. In this section, we concentrate on the second step. Several microstrip realizations will be described.

5.1.1 Stepped-Impedance, L-C Ladder Type Lowpass Filters

Figure 5.1(a) shows a general structure of the stepped-impedance lowpass microstrip filters, which use a cascaded structure of alternating high- and low-impedance transmission lines. These are much shorter than the associated guided-

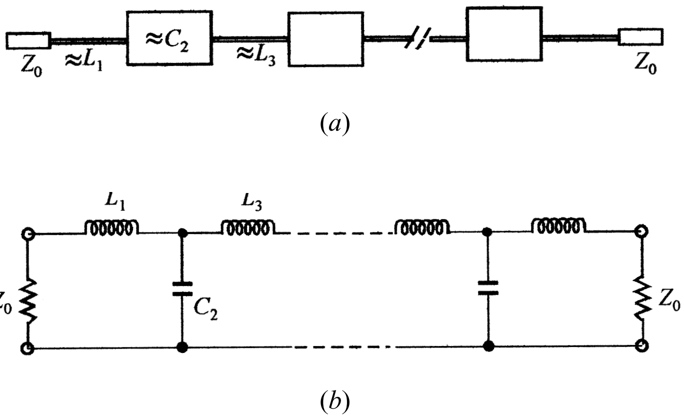


FIGURE 5.1 (*a*) General structure of the stepped-impedance lowpass microstrip filters. (*b*) L-C ladder type of lowpass filters to be approximated.

wavelength, so as to act as semilumped elements. The high-impedance lines act as series inductors and the low-impedance lines act as shunt capacitors. Therefore, this filter structure is directly realizing the L-C ladder type of lowpass filters of Figure 5.1(*b*).

Some *a priori* design information must be provided about the microstrip lines, because expressions for inductance and capacitance depend upon both characteristic impedance and length. It would be practical to initially fix the characteristic impedances of high- and low-impedance lines by consideration of

- $Z_{0C} < Z_0 < Z_{0L}$, where Z_{0C} and Z_{0L} denote the characteristic impedances of the low and high impedance lines, respectively, and Z_0 is the source impedance, which is usually 50 ohms for microstrip filters.
- A lowerZ_{0C} results in a better approximation of a lumped-element capacitor, but the resulting line width W_C must not allow any transverse resonance to occur at operation frequencies.
- A higher Z_{0L} leads to a better approximation of a lumped-element inductor, but Z_{0L} must not be so high that its fabrication becomes inordinately difficult as a narrow line, or its current-carrying capability becomes a limitation.

In order to illustrate the design procedure for this type of filter, the design of a three-pole lowpass filter is described in follows.

The specifications for the filter under consideration are

Cutoff frequency f_c = 1 GHz

Passband ripple 0.1 dB (or return loss ≤ –16.42 dB)

Source/load impedance Z_0 = 50 ohms

A lowpass prototype with Chebyshev response is chosen, whose element values are

$$g_0 = g_4 = 1$$
$$g_1 = g_3 = 1.0316$$
$$g_2 = 1.1474$$

for the normalized cutoff $\Omega_c = 1.0$. Using the element transformations described in Chapter 3, we have

$$\begin{aligned} L_1 = L_3 &= \left(\frac{Z_0}{g_0}\right)\left(\frac{\Omega_c}{2\pi f_c}\right) g_1 = 8.209 \times 10^{-9}\text{ H} \\ C_2 &= \left(\frac{g_0}{Z_0}\right)\left(\frac{\Omega_c}{2\pi f_c}\right) g_2 = 3.652 \times 10^{-12}\text{ F} \end{aligned} \tag{5.1}$$

The filter is to be fabricated on a substrate with a relative dielectric constant of 10.8 and a thickness of 1.27 mm. Following the above-mentioned considerations, the characteristic impedances of the high- and low-impedance lines are chosen as Z_{0L} = 93 ohms and Z_{0C} = 24 ohms. The relevant design parameters of microstrip lines, which are determined using the formulas given in Chapter 4, are listed in Table 5.1, where the guided wavelengths are calculated at the cutoff frequency f_c = 1.0 GHz.

Initially, the physical lengths of the high- and low-impedance lines may be found by

$$\begin{aligned} l_L &= \frac{\lambda_{gL}}{2\pi} \sin^{-1}\left(\frac{\omega_c L}{Z_{0L}}\right) \\ l_C &= \frac{\lambda_{gC}}{2\pi} \sin^{-1}(\omega_c C Z_{0C}) \end{aligned} \tag{5.2}$$

which give l_L = 11.04 mm and l_C = 9.75 mm for this example. The results of (5.2) do not take into account series reactance of the low-impedance line and shunt susceptance of the high-impedance lines. To include these effects, the lengths of the high- and low-impedance lines should be adjusted to satisfy

$$\begin{aligned} \omega_c L &= Z_{0L} \sin\left(\frac{2\pi l_L}{\lambda_{gL}}\right) + Z_{0C} \tan\left(\frac{\pi l_C}{\lambda_{gC}}\right) \\ \omega_c C &= \frac{1}{Z_{0C}} \sin\left(\frac{2\pi l_C}{\lambda_{gC}}\right) + 2 \times \frac{1}{Z_{0L}} \tan\left(\frac{\pi l_L}{\lambda_{gL}}\right) \end{aligned} \tag{5.3}$$

TABLE 5.1 Design parameters of microstrip lines for a stepped-impedance lowpass filter

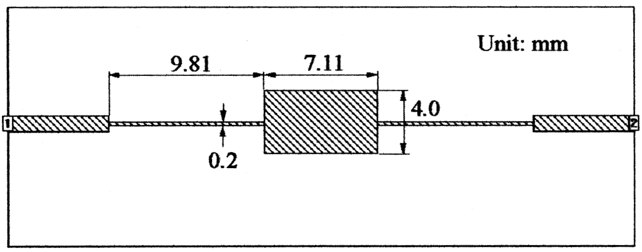
Characteristic impedance (ohms)	$Z_{0C} = 24$	$Z_0 = 50$	$Z_{0L} = 93$
Guided wavelengths (mm)	$\lambda_{gC} = 105$	$\lambda_{g0} = 112$	$\lambda_{gL} = 118$
Microstrip line width (mm)	$W_C = 4.0$	$W_0 = 1.1$	$W_L = 0.2$

where L and C are the required element values of lumped inductors and capacitor given above. This set of equations is solved for l_L and l_C, resulting in $l_L = 9.81$ mm and $l_C = 7.11$ mm.

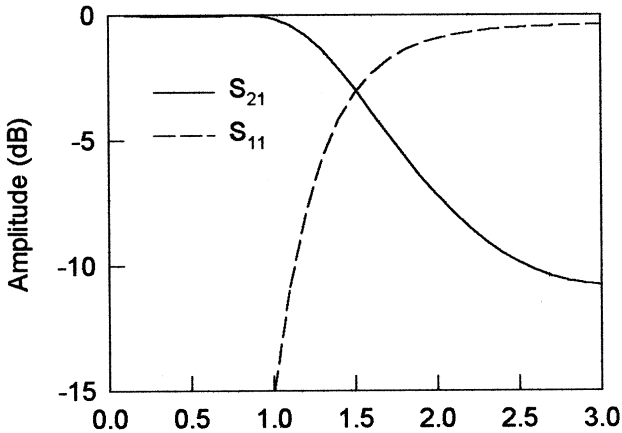
A layout of this designed microstrip filter is illustrated in Figure 5.2(*a*), and its performance obtained by full-wave EM simulation is plotted in Figure 5.2(*b*).

5.1.2 L-C Ladder Type of Lowpass Filters Using Open-Circuited Stubs

The previous stepped-impedance lowpass filter realizes the shunt capacitors of the lowpass prototype as low impedance lines in the transmission path. An alternative realization of a shunt capacitor is to use an open-circuited stub subject to



(*a*)



(*b*)

FIGURE 5.2 (*a*) Layout of a three-pole, stepped-impedance microstrip lowpass filter on a substrate with a relative dielectric constant of 10.8 and a thickness of 1.27 mm. (*b*) Full-wave EM simulated performance of the filter.