Microwave Filter Design

Chp6. Highpass Filters

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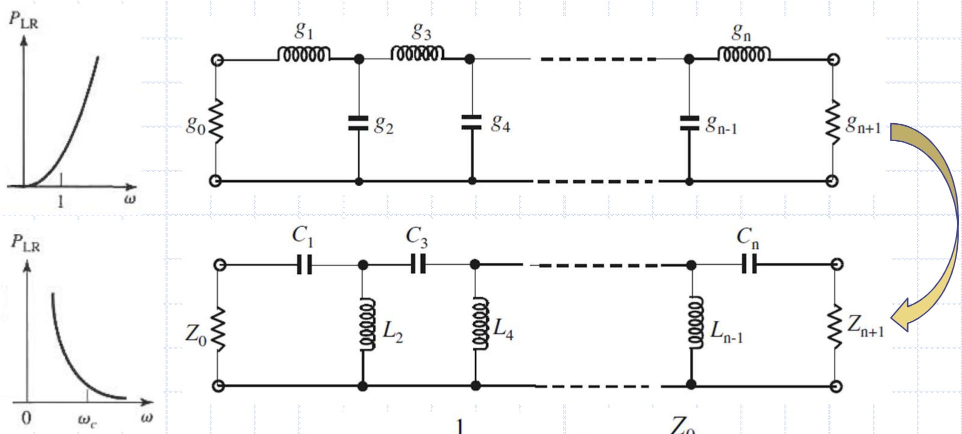
Highpass Filters

- Highpass filter prototype



Highpass Transformation

$$\Omega = -\frac{\omega_c \Omega_c}{\omega}$$

$$C_i = \frac{1}{Z_0 \omega_c \Omega_c g_i} \qquad L_i = \frac{Z_0}{\omega_c \Omega_c g_i}$$

- Find an appropriate microstrip realization
  - Quasilumped HPF
  - Optimum Distributed HPF

Example
- Quasilumped Highpass Filters

- Design a three-order HPF with 0.1 dB ripple and cutoff frequency of 1.5 GHz. The source/load impedance of the filter is 50 Ω.
  - Step 1 – Find out the required L/C element values

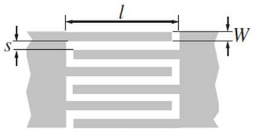
For passband ripple $L_{Ar} = 0.1$ dB

n	g_1	g_2	g_3	g_4	g_5	g_6
1	0.3052	1.0				
2	0.8431	0.6220	1.3554			
3	1.0316	1.1474	1.0316	1.0		
4	1.1088	1.3062	1.7704	0.8181	1.3554	
5	1.1468	1.3712	1.9750	1.3712	1.1468	1.0

$$C_1 = C_3 = \frac{1}{Z_0 \omega_c \Omega_c g_1} = 2.0571 \times 10^{-12}\ \text{F}$$

$$L_2 = \frac{Z_0}{\omega_c \Omega_c g_2} = 4.6236 \times 10^{-9}\ \text{H}$$

  - Step 2 – Choose the adequate structures to implement the required L/C
    - C1 and C3 are realized by interdigital capacitor

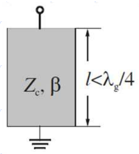


$$C(\text{pF}) = 3.937 \times 10^{-5}\, l(\varepsilon_r + 1)[0.11(n-3) + 0.252] \qquad \text{for } l \text{ in } \mu\text{m}$$

or

Y-parameters from EM simulator

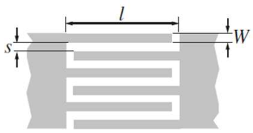
    - L2 is realized by short-circuited stub



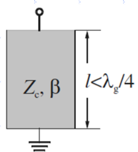
$$jZ_c \tan\left(\frac{2\pi}{\lambda_{gc}} l\right) = j\omega_c L_2$$

Example
- Stepped-impedance LPF

- Step 3 – find out the required physical length for element values

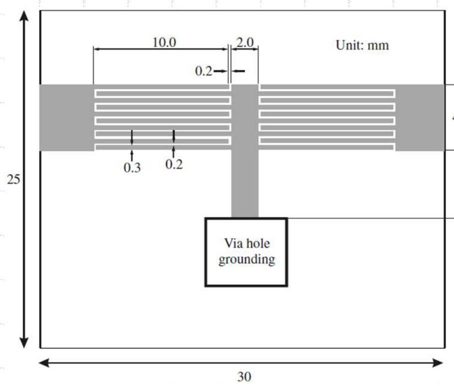


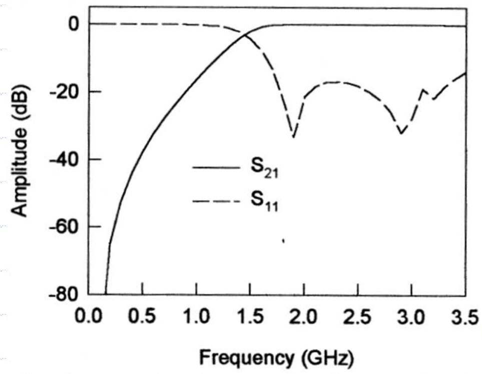
Number of fingers: 10
Length of fingers: 10 mm
Width of fingers: 0.3 mm
Space of fingers: 0.2 mm



Width of the line: 2 mm (Z_c = 84.62 Ω)
Length of the line: 11.327 mm

The microstrip is designed on a substrate with a dielectric constant of 2.2 and a thickness of 1.57 mm

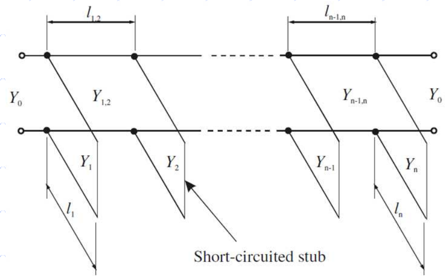




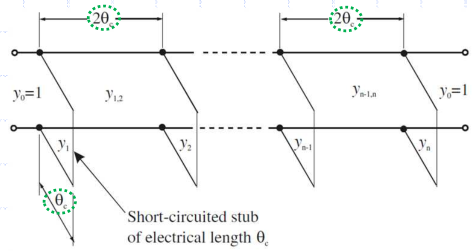
Optimum Distributed Highpass Filters

- General structure – equal electrical length connecting line with shorting stubs

Pseudohighpass filter

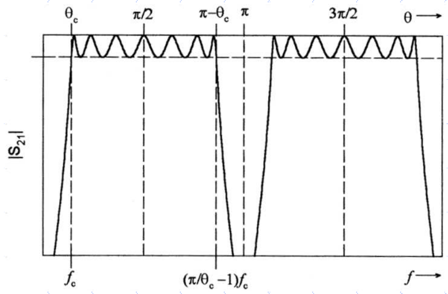


Optimum highpass filter (commensurate elements)



n stubs imply 2n-1 order filter response

- Optimum filtering characteristics



$$|S_{21}(\theta)|^2 = \frac{1}{1+\varepsilon^2 F_N^2(\theta)}$$

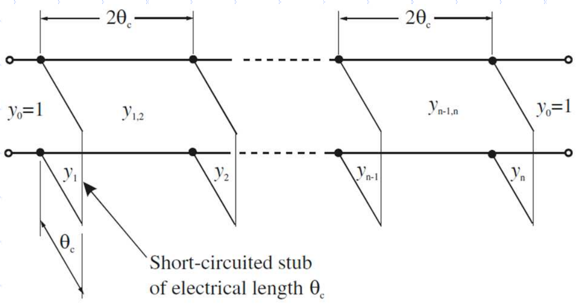
$$F_N(\theta) = \frac{(1+\sqrt{1-x_c^2})T_{2n-1}\left(\frac{x}{x_c}\right) - (1-\sqrt{1-x_c^2})T_{2n-3}\left(\frac{x}{x_c}\right)}{2\cos\left(\frac{\pi}{2}-\theta\right)}$$

$$x = \sin\left(\frac{\pi}{2}-\theta\right), \quad x_c = \sin\left(\frac{\pi}{2}-\theta_c\right)$$

where ε is the passband rippl, θ is the electrical length, n is the number of short-circuted stubs, and $T_N(x) = \cos(n\cos^{-1}x)$ is the chebyshev function of the first kind of degree n.

Optimum Distributed Highpass Filters

- Design equations for optimum highpass filters



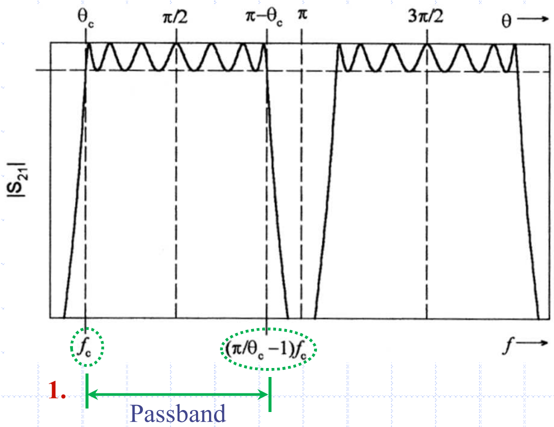


TABLE 6.1 Element values of optimum distributed highpass filters with 0.1 dB ripple

n	θ_c	y_1 / y_n	$y_{1,2}$ / $y_{n-1,n}$	y_2 / y_{n-1}	$y_{2,3}$ / $y_{n-2,n-1}$	y_3 / y_{n-2}	$y_{3,4}$
2	25°	0.15436	1.13482				
	30°	0.22070	1.11597				
	35°	0.30755	1.08967				
3	25°	0.19690	1.12075	0.18176			
	30°	0.28620	1.09220	0.30726			
	35°	0.40104	1.05378	0.48294			
4	25°	0.22441	1.11113	0.23732	1.10361		
	30°	0.32300	1.07842	0.39443	1.06488		
	35°	0.44670	1.03622	0.60527	1.01536		
5	25°	0.24068	1.10540	0.27110	1.09317	0.29659	
	30°	0.34252	1.07119	0.43985	1.05095	0.48284	
	35°	0.46895	1.02790	0.66089	0.99884	0.72424	
6	25°	0.25038	1.10199	0.29073	1.08725	0.33031	1.08302
	30°	0.35346	1.06720	0.46383	1.04395	0.52615	1.03794
	35°	0.48096	1.02354	0.68833	0.99126	0.77546	0.98381

Normalized characteristic admittance

2. Shorting stub: $Z_i = Z_0 / y_i$

3. Connecting line: $Z_{i,i+1} = Z_0 / y_{i,i+1}$

Example
- Optimum Distributed Highpass Filters

- Design an optimum distributed HPF at cutoff frequency of 1.5 GHz and 0.1 dB ripple passband up to 6.5 GHz using 6 stubs. The source/load impedance of the filter is 50 Ω.
  - Step 1 – Find out the required electrical length θ_c

$$\left(\frac{\pi}{\theta_c} - 1\right) f_c = 6.5 \quad \Rightarrow \quad \theta_c = 33.75°$$

  - Step 2 – look up table to find the required characteristic impedances of the element values

TABLE 6.1 Element values of optimum distributed highpass filters with 0.1 dB ripple

n	θ_c	y_1 / y_n	$y_{1,2}$ / $y_{n-1,n}$	y_2 / y_{n-1}	$y_{2,3}$ / $y_{n-2,n-1}$	y_3 / y_{n-2}	$y_{3,4}$
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- Intepolation method to find θ_c= 33.75°

$$y_1 = 0.35346 + \frac{(0.48096 - 0.35346)}{5} \times 3.75$$
$$= 0.44909$$
$$y_{1,2} = 1.03446$$
$$y_2 = 0.63221$$
$$y_{2,3} = 1.00443$$
$$y_3 = 0.71313$$
$$y_{3,4} = 0.99734$$

Prof. T. L. Wu

Example
- Optimum Distributed Highpass Filters

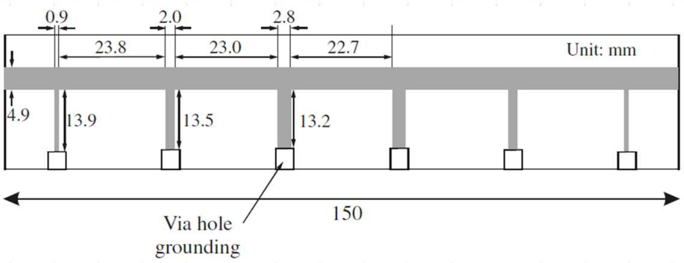
- Find the characteristic impedances for the line elements (Z_0 = 50)

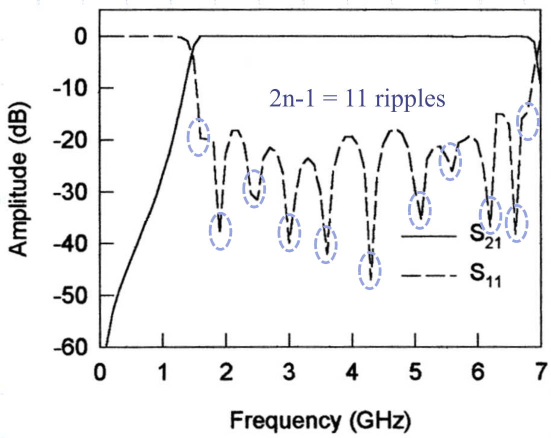
$$Z_1 = Z_6 = \frac{Z_0}{y_1} = \frac{Z_0}{y_6} = \frac{50}{0.44909} = 111.34\ \Omega \qquad Z_{1,2} = Z_{5,6} = \frac{Z_0}{y_{1,2}} = \frac{Z_0}{y_{5,6}} = \frac{50}{1.03446} = 48.33\ \Omega$$

$$Z_2 = Z_5 = \frac{Z_0}{y_2} = \frac{Z_0}{y_5} = \frac{50}{0.63221} = 79.09\ \Omega \qquad Z_{2,3} = Z_{4,5} = \frac{Z_0}{y_{2,3}} = \frac{Z_0}{y_{4,5}} = \frac{50}{1.00443} = 49.78\ \Omega$$

$$Z_3 = Z_4 = \frac{Z_0}{y_3} = \frac{Z_0}{y_4} = \frac{50}{0.71313} = 70.11\ \Omega \qquad Z_{3,4} = \frac{Z_0}{y_{3,4}} = \frac{50}{0.99734} = 50.13\ \Omega$$

The microstrip is designed on a substrate with a dielectric constant of 2.2 and a thickness of 1.57 mm





HW V

Please design a HPF based on Butterworth prototype with the following specifications using interdigital capacitors and short-circuited stubs:

1. Cutoff frequency : 3 GHz
2. Insertion loss > 25 dB at 1 GHz

The properties of the substrate is $\varepsilon_r = 4.4$ and loss tangent of 0. The substrate thickness is 1.6 mm.

a. Please determine the order of the HPF.
b. Find out the required series capacitances and shunt inductance.
c. Plot the return loss and insertion loss for the designed HPF using ADS.
d. Utilize 6, 8, and 10 fingers to realize this HPF and discuss the frequency response for the three structures in EM solver.
e. Discuss the frequency responses from the circuit simulator (ADS) and EM solver.