High-Frequency Filters

(Part 2)

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Outline

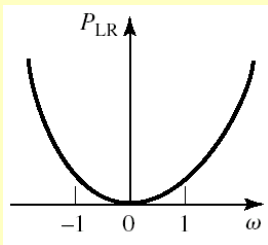
- Low-pass to high-pass transformations
- De-normalized element values high-pass prototypes
- Low-pass to band-pass transformations
- De-normalized element values band-pass prototypes
- Example of a band-pass prototype filter design
- Low-pass to band-stop transformations
- De-normalized element values band-stop prototypes

Low-Pass to High-Pass Transformation

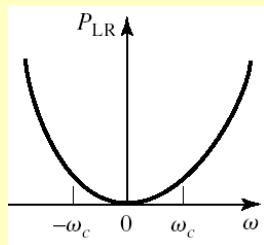
- From the low-pass prototype, we apply the following transformation:

$$\omega \leftarrow -\frac{\omega_c}{\omega}$$

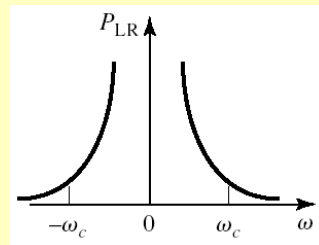
Low-pass Scaled



Low-pass



High-pass



(D. M. Pozar, Microwave Engineering, Wiley, 2005)

Low-Pass to High-Pass Transformation (cont.)

To transform the low-pass prototype into a high-pass filter:

- Series inductors are replaced with capacitors, and
- Shunt capacitors are replaced with inductors:

$$jX = j\omega L = -j\frac{\omega_c L}{\omega} = \frac{\omega_c L}{j\omega} = \frac{1}{j\omega C} \quad \text{then } C = \frac{1}{\omega_c L}$$

$$jB = j\omega C = -j\frac{\omega_c C}{\omega} = \frac{\omega_c C}{j\omega} = \frac{1}{j\omega L} \quad \text{then } L = \frac{1}{\omega_c C}$$

De-Normalized Element Values H-P Prototypes

- The final element values for a high-pass prototype are obtained from (R_0 is the actual source resistance):

$$L_k = \frac{R_0}{\omega_c g_k} \quad (g_k \text{ corresponds to a capacitor in the LP prototype})$$

$$C_k = \frac{1}{R_0 \omega_c g_k} \quad (g_k \text{ corresponds to an inductor in the LP prototype})$$

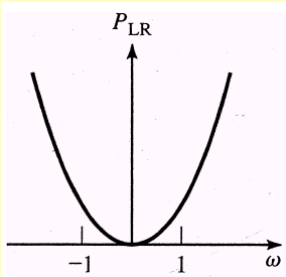
$$R_L = \begin{cases} R_0 / g_{N+1} & \text{if } g_{N+1} \text{ corresponds to a load conductance} \\ R_0 g_{N+1} & \text{if } g_{N+1} \text{ corresponds to a load resistance} \end{cases}$$

Low-Pass to Pass-Band Transformation

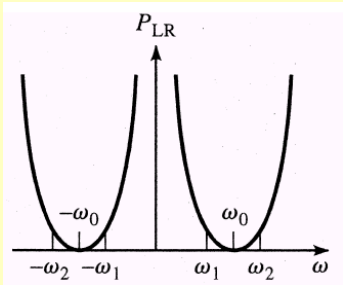
- We apply the following transformation:

$$\omega \leftarrow \frac{\omega_0}{\omega_2 - \omega_1}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right) \qquad \omega_0 = \sqrt{\omega_1 \omega_2}$$

Low-pass Scaled



Band-pass



(D. M. Pozar, Microwave Engineering, Wiley, 2005)

Low-Pass to Band-Pass Transformation (cont.)

To transform the low-pass prototype into a band-pass filter:

- Series inductors are replaced with a series LC circuit, and
- Shunt capacitors are replaced with a shunt LC circuit:

Let $\Delta = \dfrac{\omega_2 - \omega_1}{\omega_0}$ $\qquad \omega \leftarrow \dfrac{1}{\Delta}\left(\dfrac{\omega}{\omega_0} - \dfrac{\omega_0}{\omega}\right)$

$$jX = j\omega L = j\frac{1}{\Delta}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)L = j\frac{\omega L}{\omega_0 \Delta} + \frac{\omega_0 L}{j\omega\Delta}$$

$$jB = j\omega C = j\frac{1}{\Delta}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)C = j\frac{\omega C}{\omega_0 \Delta} + \frac{\omega_0 C}{j\omega\Delta}$$

De-Normalized Element Values B-P Prototypes

- The final element values for a band-pass prototype are obtained from (R_0 is the actual source resistance):

If g_k corresponds to an inductor in the low-pass prototype:

$$L_k = \frac{R_0 g_k}{\omega_0 \Delta} \quad \text{in series with} \quad C_k = \frac{\Delta}{R_0 \omega_0 g_k}$$

If g_k corresponds to a capacitor in the low-pass prototype:

$$C_k = \frac{g_k}{R_0 \omega_0 \Delta} \quad \text{in parallel with} \quad L_k = \frac{R_0 \Delta}{\omega_0 g_k}$$

$$R_L = \begin{cases} R_0 / g_{N+1} & \text{if } g_{N+1} \text{ corresponds to a load conductance} \\ R_0 g_{N+1} & \text{if } g_{N+1} \text{ corresponds to a load resistance} \end{cases}$$

Example: Band-Pass Filter Prototype

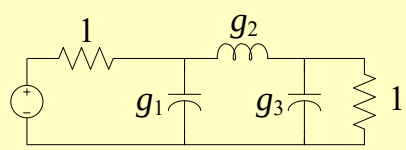
Design a band-pass filter with the following specifications:

- Sixth-order Chebyshev response with 0.5dB ripple level
- Center frequency at 1 GHz
- Relative bandwidth of 10%
- For a 50-Ω system

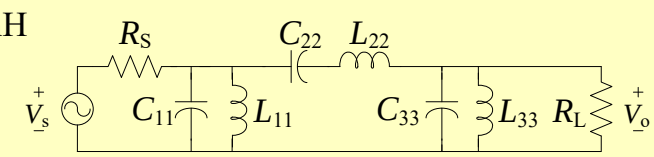
Example: Band-Pass Filter Prototype (cont.)

Solution:

$g_1 = g_3 = 1.5963$
$g_2 = 1.0967$
$g_4 = 1$
$R_0 = 50\ \Omega$, $f_0 = 1$ GHz, $\Delta = 0.1$

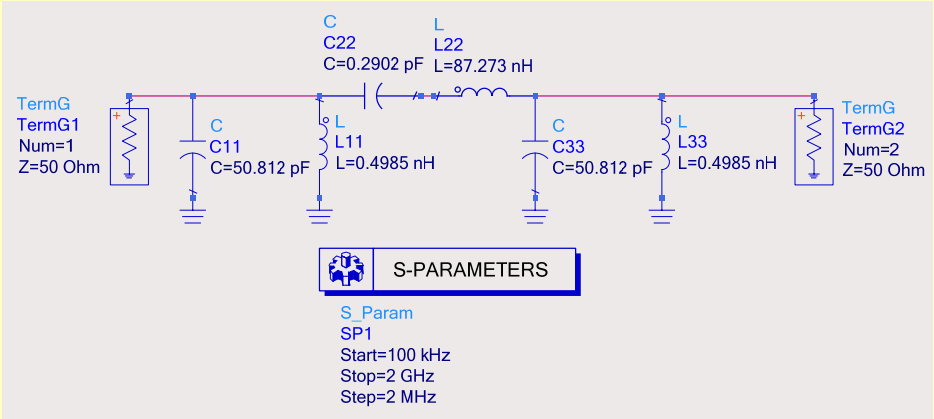


$R_S = R_L = 50\Omega$
$C_{11} = C_{33} = 50.812$pF
$L_{11} = L_{33} = 0.4985$nH
$L_{22} = 87.273$nH
$C_{22} = 0.2902$pF



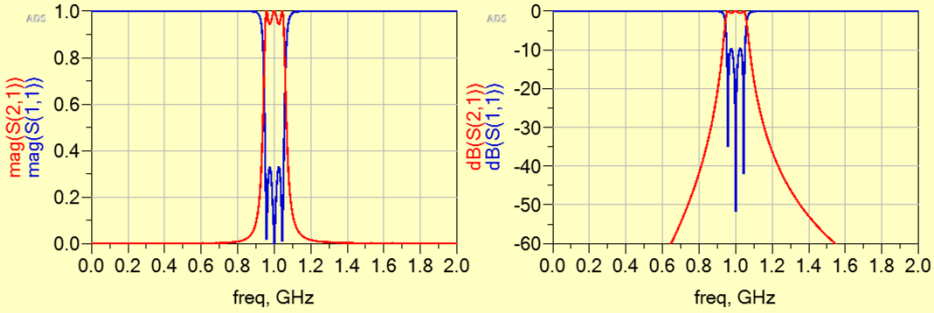
Example: Band-Pass Filter Prototype (cont.)

ADS simulation:



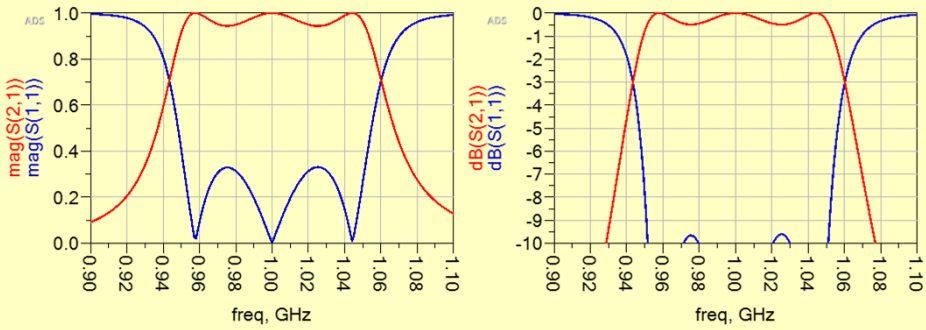
Example: Band-Pass Filter Prototype (cont.)

ADS simulation results:



Example: Band-Pass Filter Prototype (cont.)

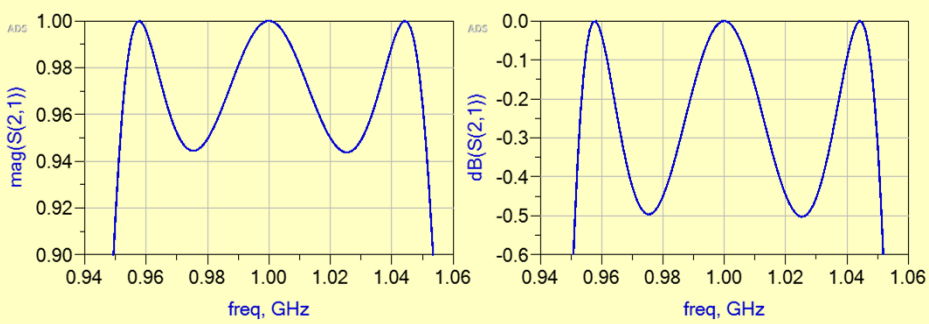
ADS simulation results (zoom in):



$$|S_{11}|^2 + |S_{21}|^2 = 1$$

Example: Band-Pass Filter Prototype (cont.)

ADS simulation results ($|S_{21}|$ zoom in):

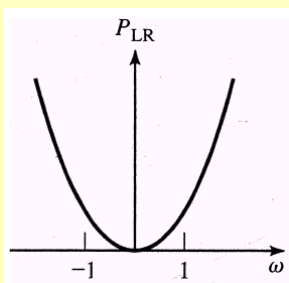


Low-Pass to Band-Stop Transformation

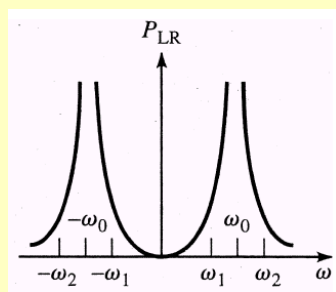
- We apply the following transformation:

$$\omega \leftarrow -\Delta\left(\frac{\omega}{\omega_0}-\frac{\omega_0}{\omega}\right)^{-1} \qquad \omega_0=\sqrt{\omega_1\omega_2} \qquad \Delta=\frac{\omega_2-\omega_1}{\omega_0}$$

Low-pass Scaled



Band-stop



(D. M. Pozar, Microwave Engineering, Wiley, 2005)

Low-Pass to Band-Stop Transformation (cont.)

To transform the low-pass prototype into a band-stop filter:

- Series inductors are replaced with a shunt LC circuit, and
- Shunt capacitors are replaced with a series LC circuit:

$$\omega \leftarrow -\Delta\left(\frac{\omega}{\omega_0}-\frac{\omega_0}{\omega}\right)^{-1}$$

$$jX = j\omega L = \frac{-jL\Delta}{\left(\frac{\omega}{\omega_0}-\frac{\omega_0}{\omega}\right)} = \frac{1}{\frac{\omega}{-j\omega_0 L\Delta}+\frac{\omega_0}{j\omega L\Delta}} = \frac{1}{\frac{j\omega}{\omega_0 L\Delta}+\frac{\omega_0}{j\omega L\Delta}}$$

$$jB = j\omega C = \frac{-jC\Delta}{\left(\frac{\omega}{\omega_0}-\frac{\omega_0}{\omega}\right)} = \frac{1}{\frac{\omega}{-j\omega_0 C\Delta}+\frac{\omega_0}{j\omega C\Delta}} = \frac{1}{\frac{j\omega}{\omega_0 C\Delta}+\frac{\omega_0}{j\omega C\Delta}}$$

De-Normalized Element Values B-S Prototypes

- The final element values for a band-stop prototype are obtained from (R_0 is the actual source resistance):

If g_k corresponds to an inductor in the low-pass prototype:

$$C_k = \frac{1}{R_0 \omega_0 g_k \Delta} \quad \text{in parallel with} \quad L_k = \frac{R_0 g_k \Delta}{\omega_0}$$

If g_k corresponds to a capacitor in the low-pass prototype:

$$L_k = \frac{R_0}{\omega_0 g_k \Delta} \quad \text{in series with} \quad C_k = \frac{g_k \Delta}{R_0 \omega_0}$$

$$R_L = \begin{cases} R_0 / g_{N+1} & \text{if } g_{N+1} \text{ corresponds to a load conductance} \\ R_0 g_{N+1} & \text{if } g_{N+1} \text{ corresponds to a load resistance} \end{cases}$$

Dr. J. E. Rayas-Sánchez 17