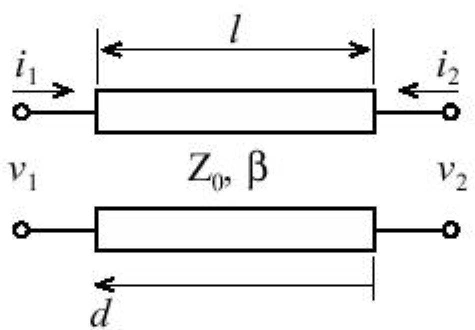
Stepped Impedance Low-Pass Filter

- Relatively easy (believe that?) low-pass implementation
- Uses alternating very high and very low characteristic impedance lines
- Commonly called Hi-Z, Low-Z Filters
- Electrical performance inferior to other implementations so often used for filtering unwanted out-of-band signals

Approximate Equivalent Circuits for Short Transmission line Sections

- Using Table 4-1, approximate equivalent circuits for a short length of transmission line with Hi-Z or Low-Z are found

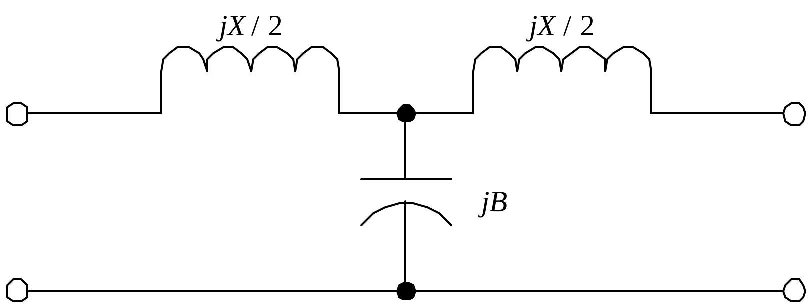


$$A = \cos\beta l \qquad B = jZ_0 \sin\beta l$$

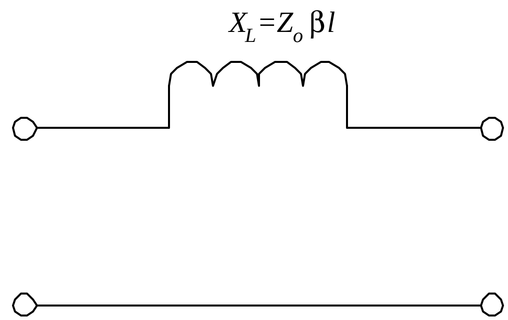
$$C = \frac{j\sin\beta l}{Z_0} \qquad D = \cos\beta l$$

Approximate Equivalent Circuits for Short Transmission line Sections

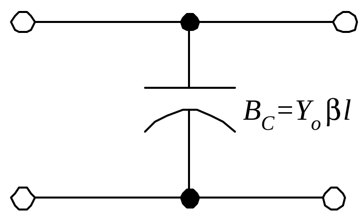
- The equivalent circuits are:



T-Equialent circuit for transmission line section
$b\ l << \pi / 2$



Equialent circuit for small $b\ l$ and large Z_o



Equialent circuit for small $b\ l$ and small Z_o

Approximate Equivalent Circuits for Short Transmission line Sections

- Series inductors of a low-pass prototype replaced with Hi-Z line sections ($Z_o = Z_h$)
- Shunt capacitors replaced with Low-Z line sections ($Z_o = Z_l$)
- Ratio Z_h/Z_l should be as high as possible

$$\beta l = \frac{LR_g}{Z_h} \quad (\text{inductor})$$

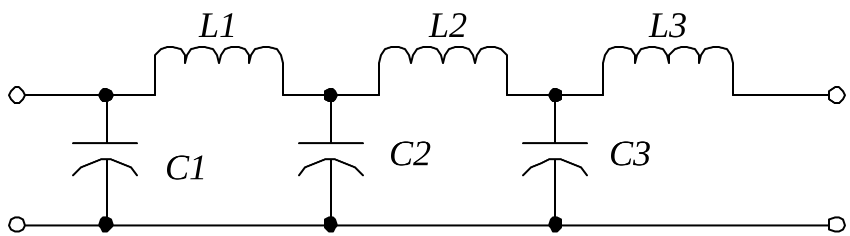
$$\beta l = \frac{CZ_l}{R_g} \quad (\text{capacitor})$$

Stepped Impedance Low-Pass Filter

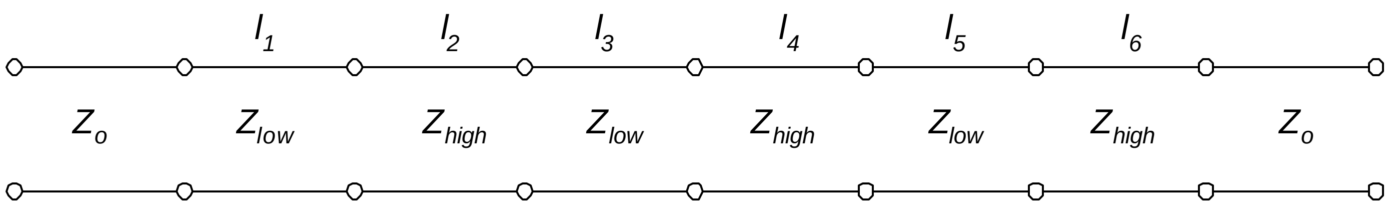
- Select the highest and lowest practical line impedance; e.g. the highest and lowest line impedances could be 150 and 10 Ω, respectively
- For example, given the low-pass filter prototype, solve for the lengths of the microstriplines:

$$l_{Ln} = g_n \frac{Z_{low}}{R_g \, \boldsymbol{b}} \quad ; \quad l_{Cn} = g_n \frac{R_g}{\boldsymbol{b} \, Z_{high}}$$

Stepped Impedance Low-Pass Filter - Implementation



6^{th} Order Low-Pass Filter Prototype



Stepped Impedance Implementation

Microstripline Layout of Filter

Bandstop Filter

- Require either maximum or minimal impedance at center frequency f_o
- Let line lengths $l = l_{\mathrm{o}}/4$
- Let Ω = 1 cut-off frequency of the low-pass prototype transformed into upper and lower cut-off frequencies of bandstop filter via **bandwidth factor** :

$$bf = cot\left(\frac{p}{2}\frac{w_L}{w_o}\right) = cot\left[\frac{p}{2}\left(1 - \frac{sbw}{2}\right)\right] \quad ; \quad sbw = \frac{(w_U - w_L)}{w_o}$$

Bandstop Filter: Implementation

1. Find the low-pass filter prototype
2. The L's and C's replaced by open and short circuit stubs, respectively as in Low-Pass filter design with

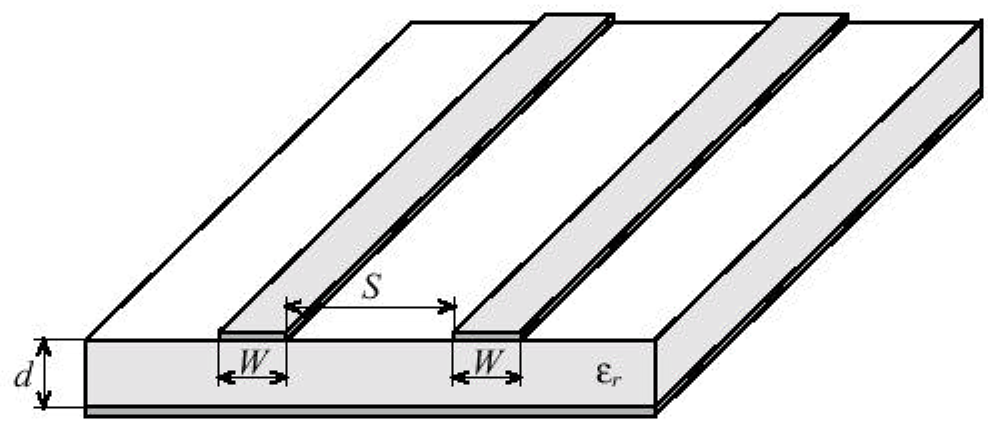
   $$Z_{Ln} = (bf)\, g_n \text{ and } Y_{Cn} = (bf)\, g_n$$

3. Unit lengths of $l_o/4$ are inserted and Kuroda's Identities are used to convert all series stubs into shunt stubs
4. Denormalize the unit elements

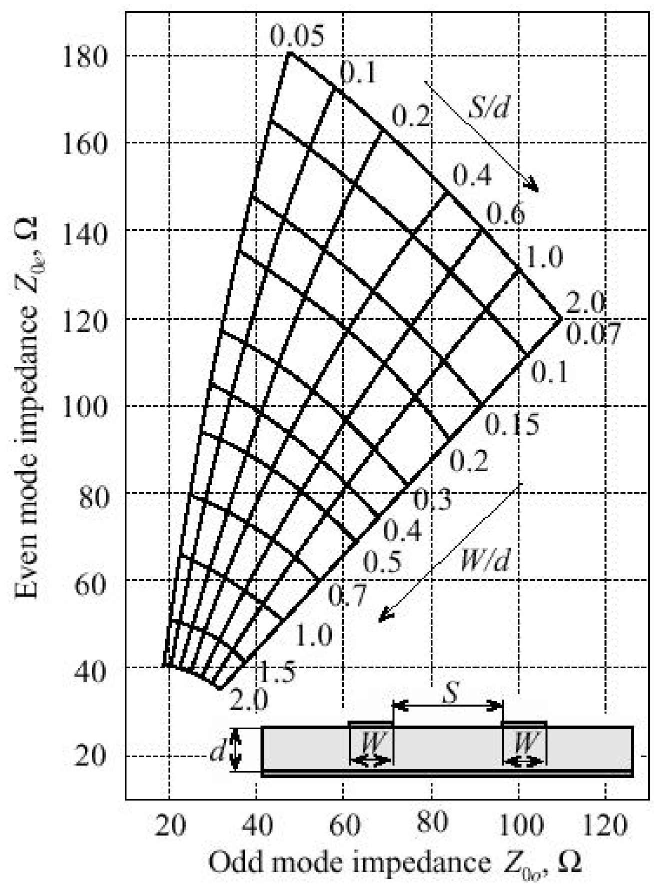
Coupled Filters: Bandpass

- Even and Odd mode excitations resulting in

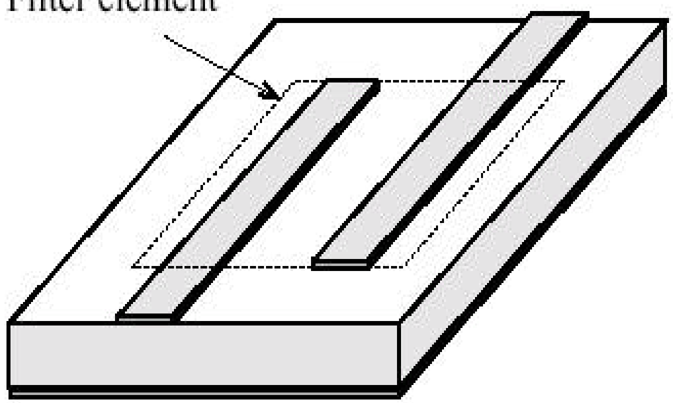
$$Z_{Oe} = \frac{1}{v_{pe} C_e} \quad ; \quad Z_{Oo} = \frac{1}{v_{po} C_{od}}$$



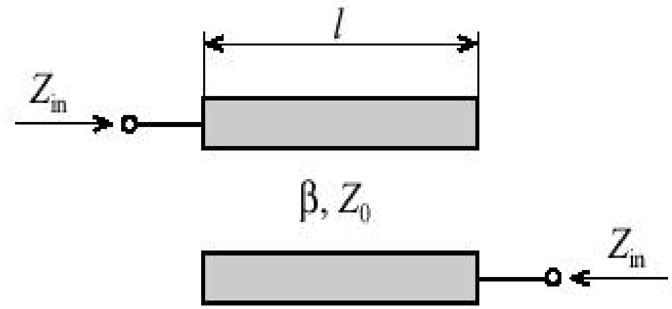
Coupled Filters: Even & Odd Impedances



Bandpass Filter Section



(a) Arrangement of two microstrip lines



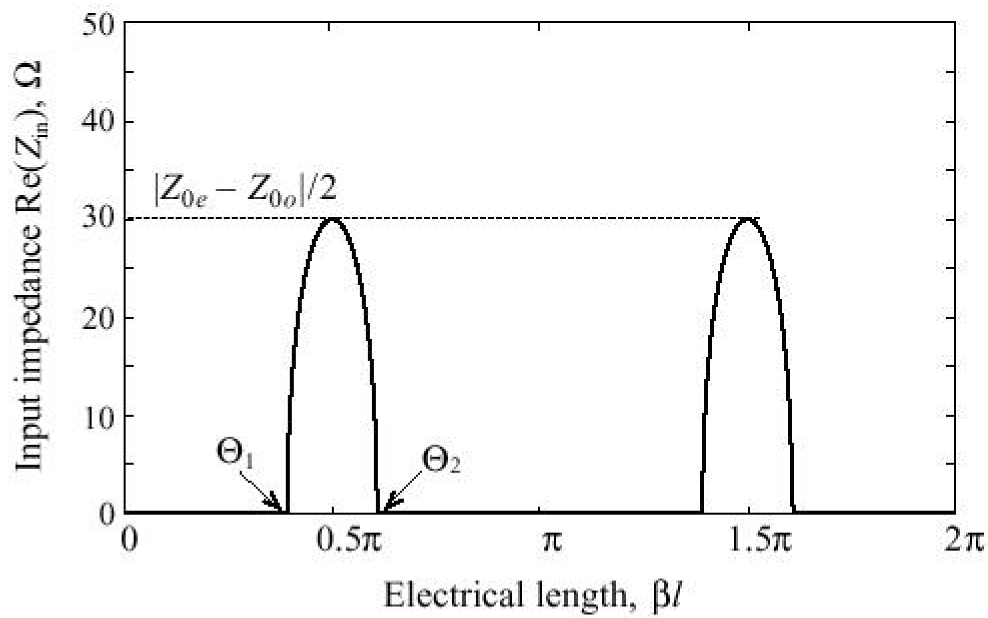
(b) Transmission line representation

$$Z_{in} = \frac{1}{2\,sin(b\,l)}\sqrt{(Z_{Oe} - Z_{Oo})^2 - (Z_{Oe} + Z_{Oo})^2\,cos^2(b\,l)}$$

Bandpass Filter Section

- According to Figure 5-47, the characteristic bandpass filter performance attained when

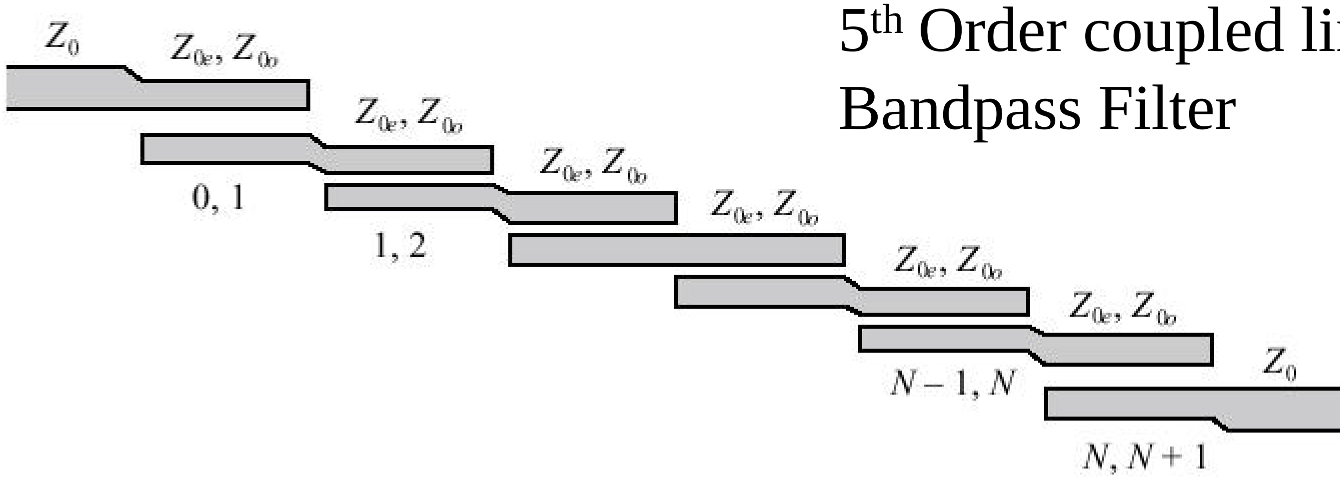
$$l = l\,/4 \text{ or } b\, l = p\,/2\,.$$



Bandpass Filter Section

- The upper and lower frequencies are

$$(b\,l)_{1,2} = q_{1,2} = \pm cos^{-1}\left[\frac{Z_{Oe} - Z_{Oo}}{Z_{Oe} + Z_{Oo}}\right]$$



5th Order coupled line Bandpass Filter

Bandpass Filter: Implementation

1. Find the low-pass filter prototype
2. Identify normalized bandwidth, uper, and lower frequencies

$$BW = \frac{w_U - w_L}{w_O}$$

- Allowing:

$$J_{0,1} = \frac{1}{Z_O}\sqrt{\frac{p\,BW}{2g_O g_1}}; \quad J_{i,i+1} = \frac{1}{Z_O}\frac{p\,BW}{2\sqrt{g_i g_{i+1}}}; \quad J_{N,N+1} = \frac{1}{Z_O}\sqrt{\frac{p\,BW}{2g_N g_{N+1}}}$$

Bandpass Filter: Implementation

- This allows determination of the odd and even characteristic line impedances:

$$Z_{Oo}\Big|_{i,i+1} = Z_O\left[1 - Z_O J_{i,i+1} + \left(Z_O J_{i,i+1}\right)^2\right]$$

and

$$Z_{Oe}\Big|_{i,i+1} = Z_O\left[1 + Z_O J_{i,i+1} + \left(Z_O J_{i,i+1}\right)^2\right]$$

- Indices i, $i+1$ refer to the overlapping elements and Z_O is impedance at ends of the filter structure

Bandpass Filter: Implementation

- Determine line dimensions and *S* and *W* of the coupled lines from the graph on Figure 5-45 p256.
- Length of each coupled line segment at the center frequency is l /4.
- Normalized frequency is

$$\Omega = \frac{w_c}{w_U - w_L}\left(\frac{w}{w_c} - \frac{w_c}{w}\right)$$