IMPEDANCE MATCHING CIRCUITS

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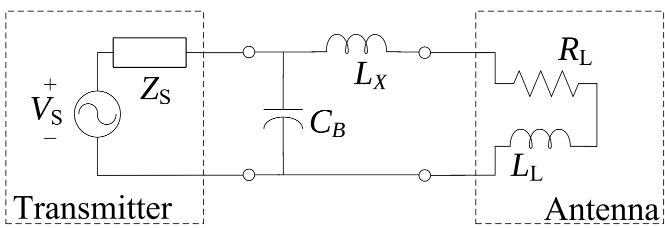
PROBLEMS

1. Using an L-section, find the two possible solutions to match a 75-Ω transmission line to a load impedance $Z_L = (10 + j30)\ \Omega$.

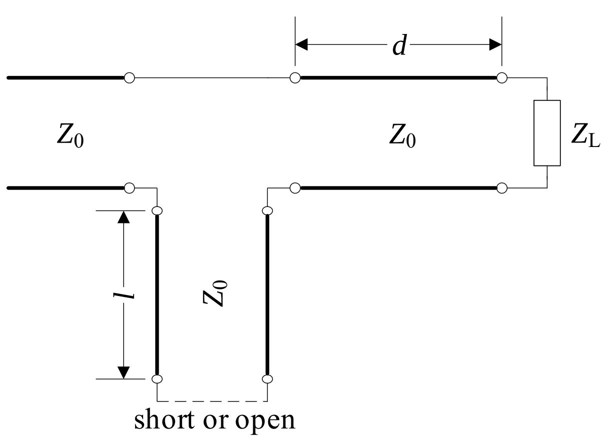
2. Using an L-section, find the two possible solutions to match a 50-Ω line at 100 MHz to a load impedance Z_L consisting of a 100-Ω resistor in parallel with a 10-pF capacitor.

3. Using an L-section, find the two possible solutions to match a 50-Ω line at 380 MHz to a load impedance Z_L consisting of a 35-Ω resistor in series with a 6-nH inductor. Implement in Keysight ADS both solutions and confirm the correct performance of the matching circuits by plotting $|S_{11}|$ from 10 MHz to 800 MHz

4. The transmitter illustrated below is operating at 1 GHz on a 75-Ω system and has an output impedance $Z_S = (90 + j30)\ \Omega$. The transmitter must be directly connected to an antenna whose input impedance is equivalent to the series combination of a resistor R_L = 75 Ω and an inductor L_L = 3nH. Using the L-Section matching network indicated below, find the values of L_X and C_B such that maximum power is delivered to the antenna.

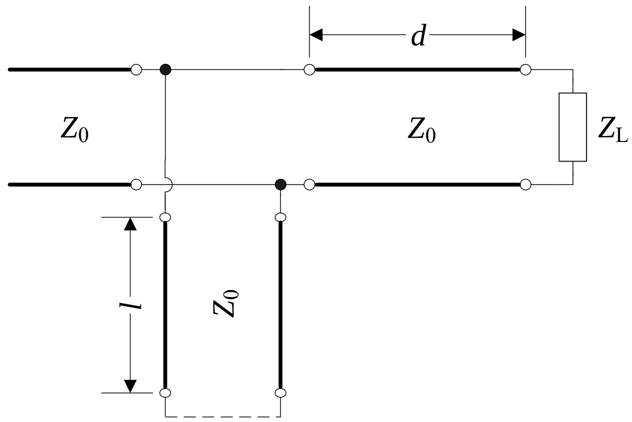


5. A load impedance Z_L consisting of a 100-Ω resistor in parallel with a 1-pF capacitor is to be match at 5 GHz to a transmission line whose characteristic impedance is Z_0 = 50 Ω. Using a single-stub series tuning network as illustrated below: a) find the first two distances d_1 and d_2 from the load where the stub could be connected; b) connecting the stub at the minimum distance from the load, find the length l_{oc} for an open-circuited stub, and the length l_{sc} for a short-circuited stub; c) assuming transmission lines on air (or free-space), implement in Keysight ADS the solution for d minimum and l_{oc}.



6. Repeat problem 5 using a single-stub shunt tuning network.

7. A load impedance at 5 GHz is $Z_L = (30 + j90)\ \Omega$. A single-stub shunt tuning network, as illustrated below, is used to match Z_L to $Z_0 = 50\ \Omega$. a) Find the first two distances d_1 and d_2 from the load where the stub could be connected; b) Connecting the stub at the minimum distance from the load, find the length l_{oc} for an open-circuited stub, and the length l_{sc} for a short-circuited stub.



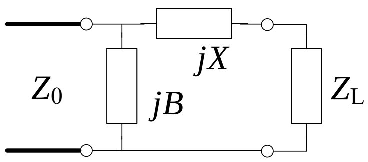
8. Design a 3-section binomial impedance transformer to match at 1 GHz a load impedance $Z_L = 100\ \Omega$ to a transmission line with characteristic impedance $Z_0 = 50\ \Omega$. Calculate the theoretical bandwidth Δf at $\Gamma_m = -20$ dB. Calculate the corresponding lengths of the three sections assuming ideal transmission lines on air. Implement your design in Keysight ADS and confirm the theoretical results.

9. Design a 5-section Butterworth impedance transformer to match a load impedance $Z_L = 200\ \Omega$ to a transmission line whose characteristic impedance is $Z_0 = 50\ \Omega$. Calculate the theoretical fractional bandwidth for a maximum reflection of -60 dB. Calculate the corresponding lengths of the five sections to achieve a perfect match at 15 GHz, assuming ideal transmission lines with effective relative dielectric constant $\varepsilon_e = 3.2$.

10. Implement in microstrip technology the impedance transformer of Problem 8. Assume that the substrate height is $H = 2$ mm, with a relative dielectric constant $\varepsilon_r = 4$. For the dielectric losses, use a loss tangent $\tan(\delta) = 0.01$. For the metallic losses, assume that all metal traces (including the ground plane) are made of copper with conductivity $\sigma = 5.8\times10^7$ S/m and thickness $t = 0.6$ mil = 15.24 µm (half-once copper). Simulate the corresponding circuit in Keysight ADS.

Solutions

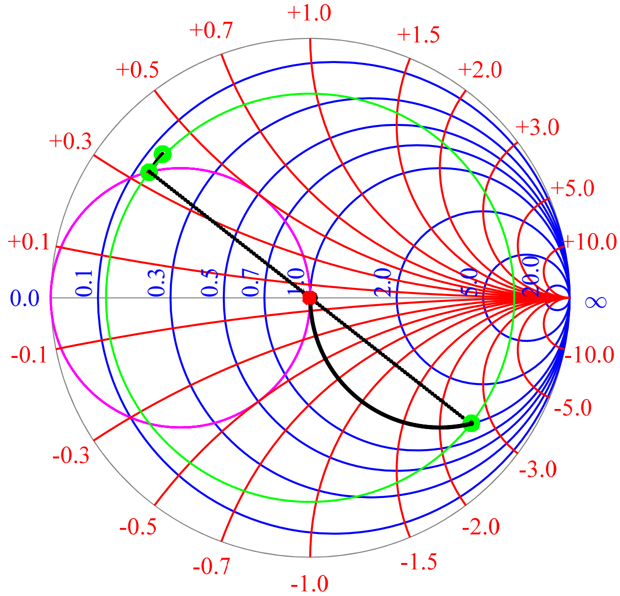
1.



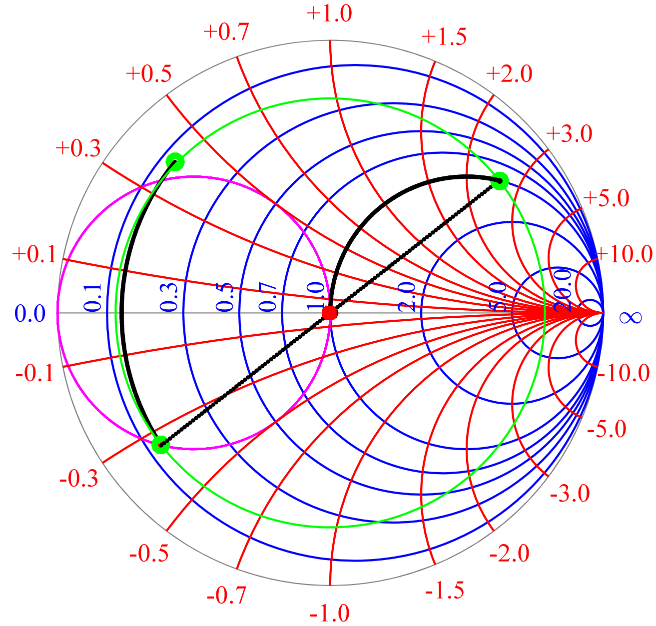
Solution A:
$X = -4.5049\ \Omega$
$B = 0.033993$ S

Solution B:
$X = -55.4951\ \Omega$
$B = -0.033993$ S

Solution A:

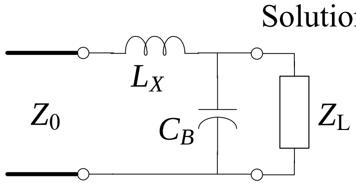


Solution B:



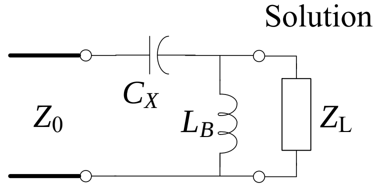
2.

Solution A:

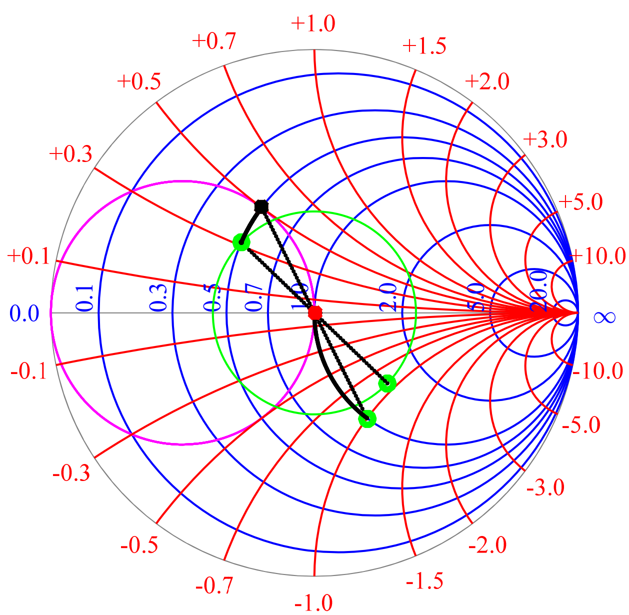


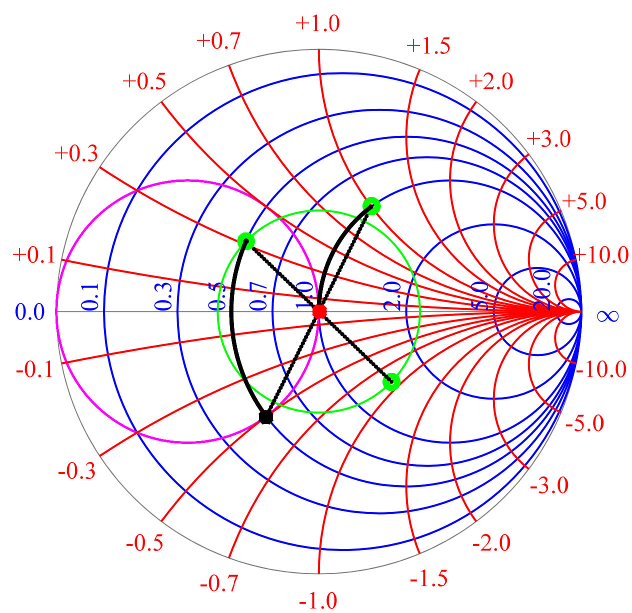
$L_X = 79.5775$ nH
$C_B = 5.9155$ pF

Solution B:



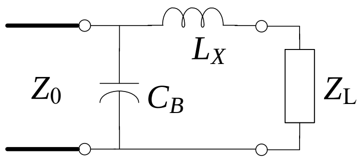
$C_X = 31.831$ pF
$L_B = 97.7419$ nH



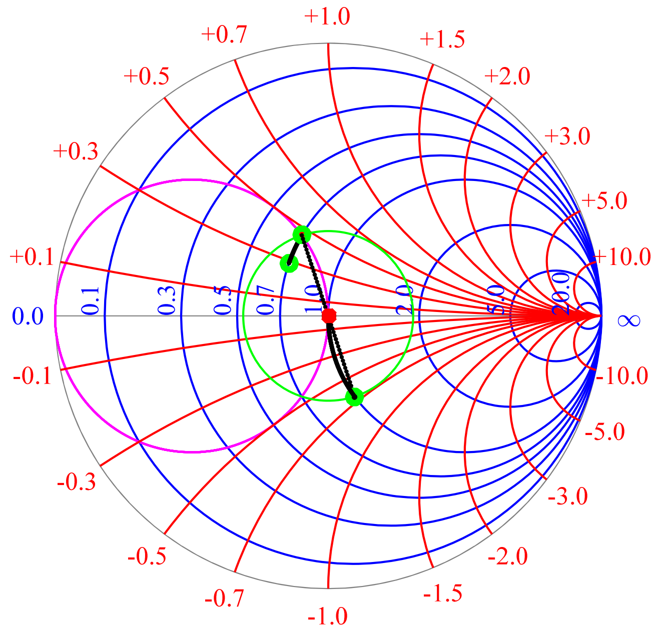


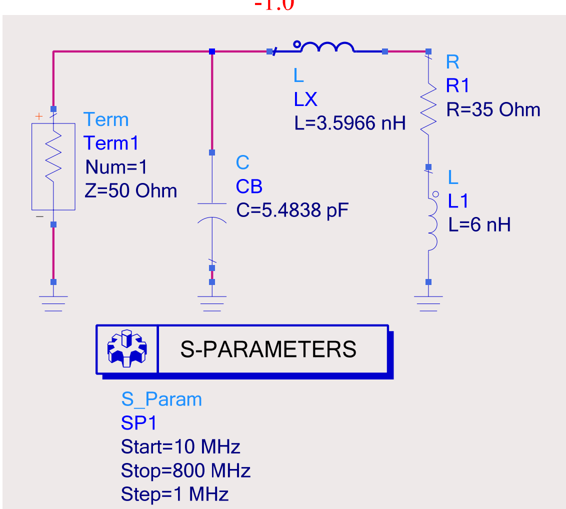
3.

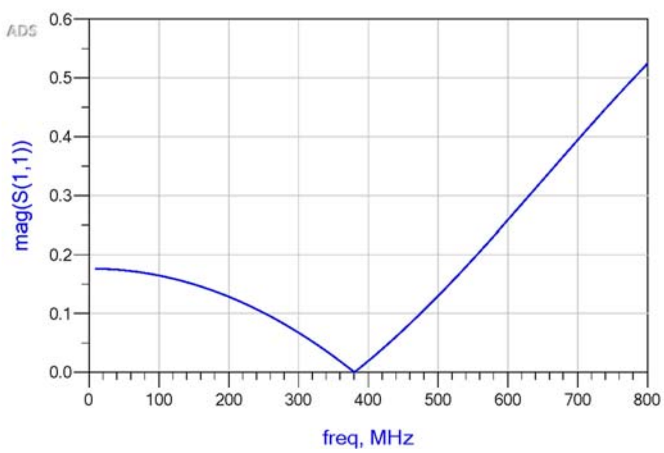
Solution A:



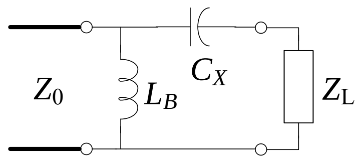
C_B = 5.4838 pF
L_X = 3.5966 nH



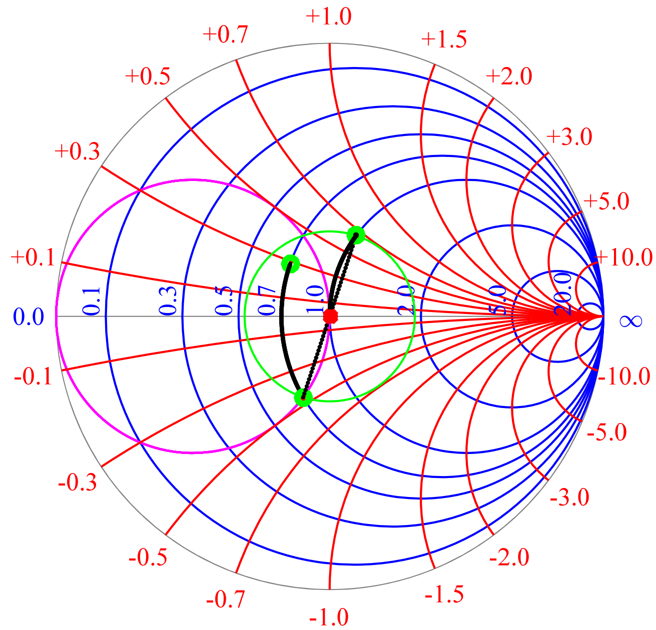


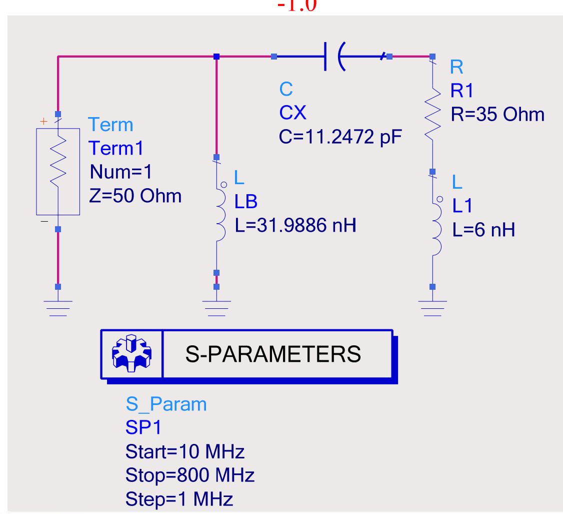


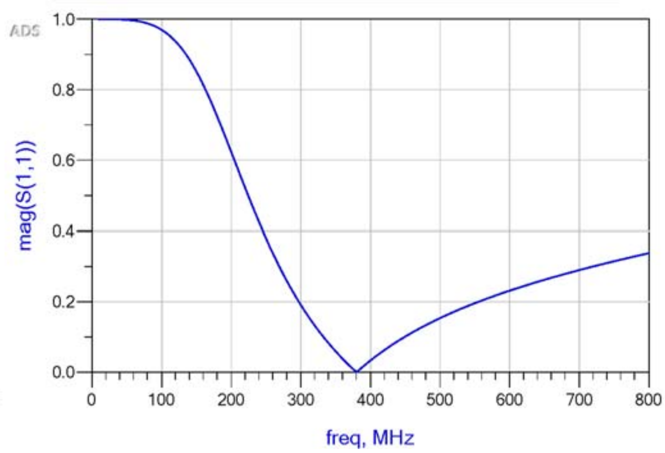
Solution B:



L_B = 31.9886 nH
C_X = 11.2472 pF

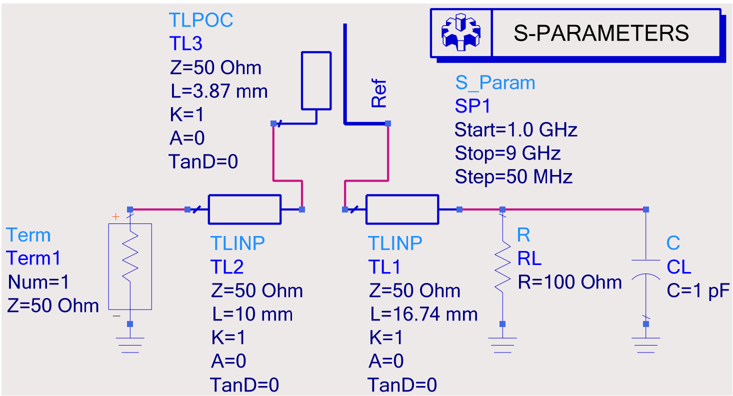


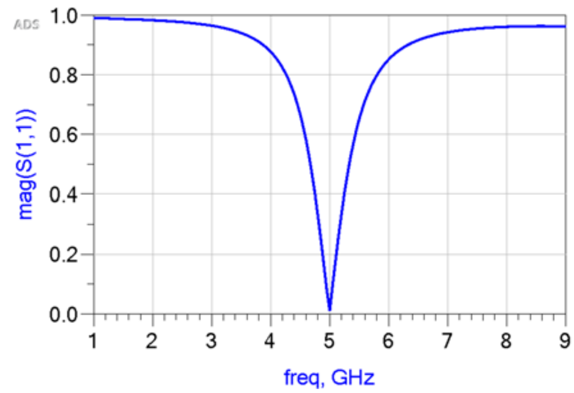




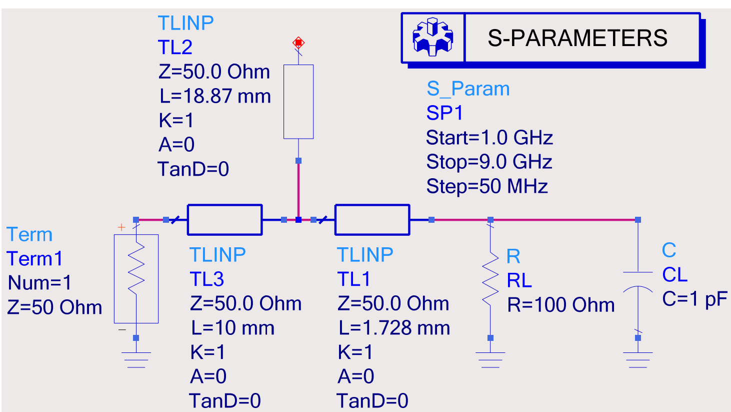
4. $L_X = 3.89$ nH; $C_B = 1.45$ pF.

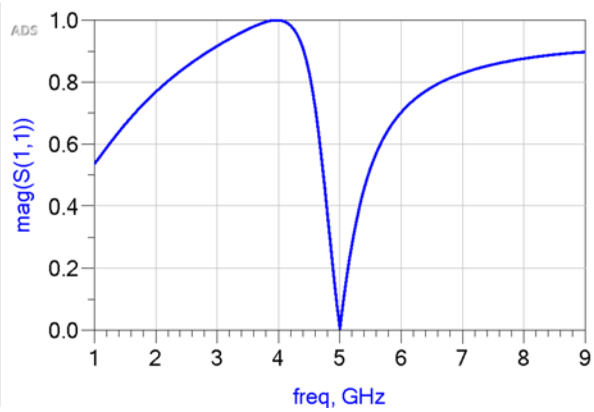
5. $d_1 = 0.279\lambda$, $d_2 = 0.392\lambda$. Using $d = 0.279\lambda$, then $l_{oc} = 0.0645\lambda$ and $l_{sc} = 0.3145\lambda$. Since $\varepsilon_e = 1$ (air or free-space) and $f = 5$ GHz, $\lambda = 60$ mm. Hence $d = 16.74$ mm and $l_{oc} = 3.87$ mm. ADS simulation:





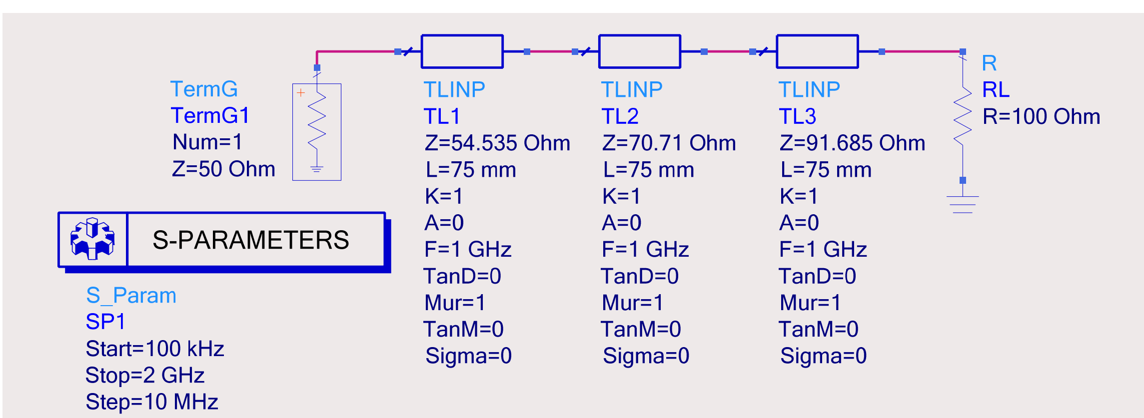
6. $d_1 = 0.0288\lambda$, $d_2 = 0.1416\lambda$. Using $d = 0.0288\lambda$, then $l_{oc} = 0.3145\lambda$ and $l_{sc} = 0.0645\lambda$. Since $\varepsilon_e = 1$ and $f = 5$ GHz, $\lambda = 60$ mm. Hence $d = 1.728$ mm and $l_{oc} = 18.87$ mm. ADS simulation:

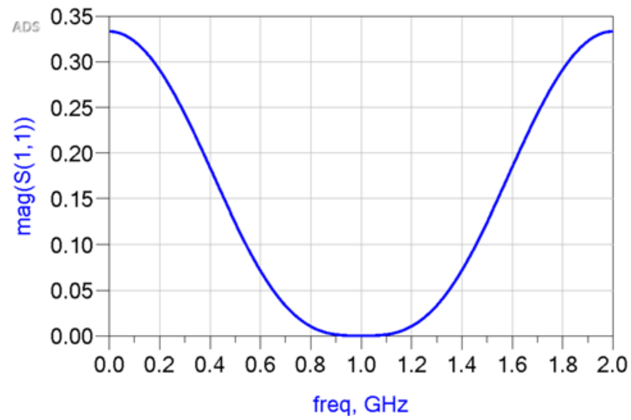


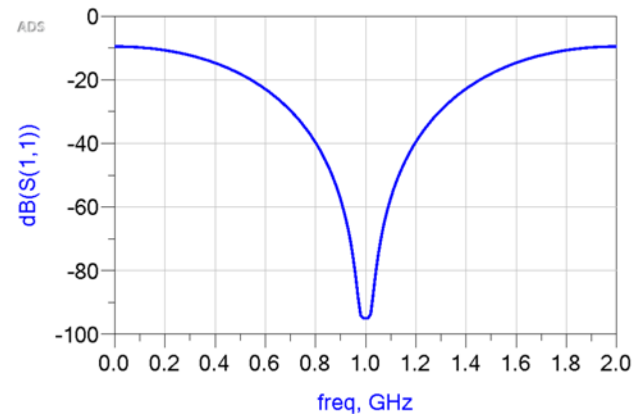


7. $d_1 = 0.2696\lambda$, $d_2 = 0.3808\lambda$. Using $d = 0.2696\lambda$, then $l_{oc} = 0.3133\lambda$ and $l_{sc} = 0.0633\lambda$.

8. $Z_1 = 54.535\ \Omega$, $Z_2 = 70.71\ \Omega$, $Z_3 = 91.685\ \Omega$, $l_1 = l_2 = l_3 = 75$ mm. The theoretical bandwidth is $\Delta f = 919.13$ MHz. Implementation in Keysight ADS with ideal transmission lines:

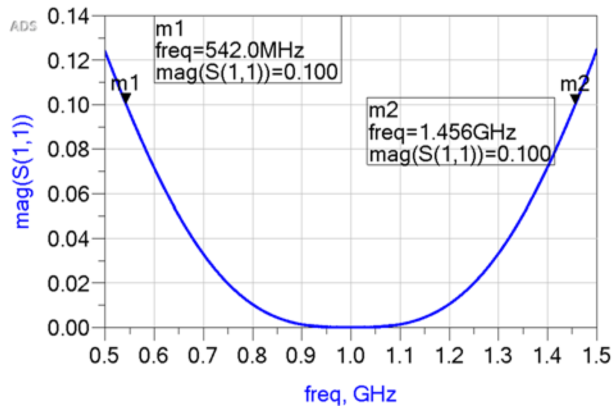


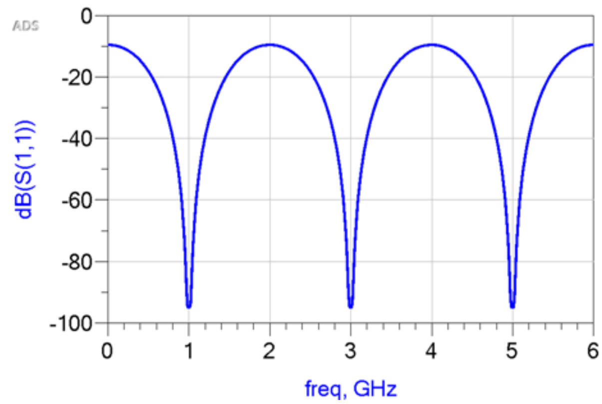




It is confirmed a Butterworth response centered at 1 GHz, with $|\Gamma| = 0.333 = -9.54$ dB at low frequencies.

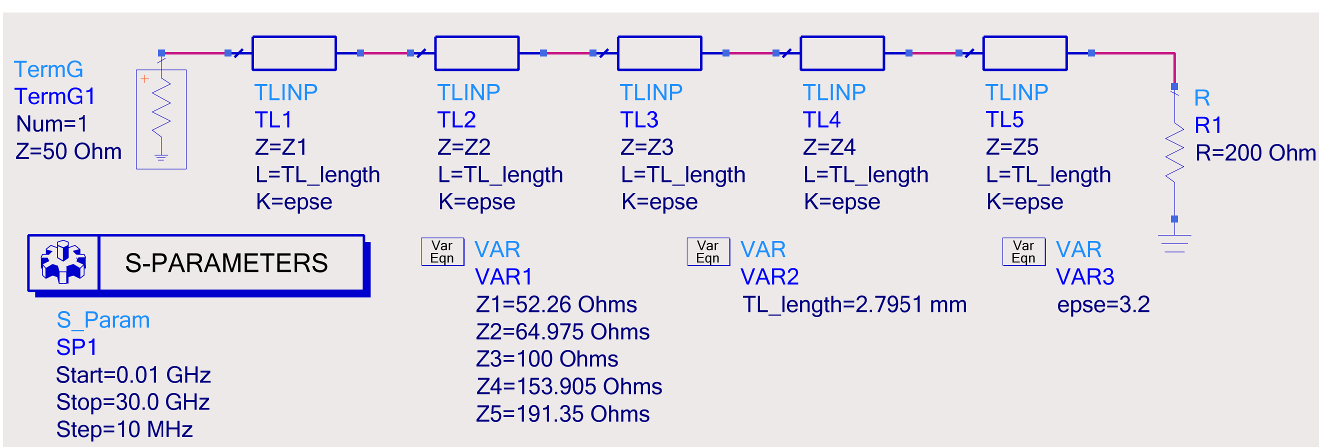
Zooming-in to measure the bandwidth at $\Gamma_m = 0.1 = -20$ dB, and simulating up to 6 GHz:

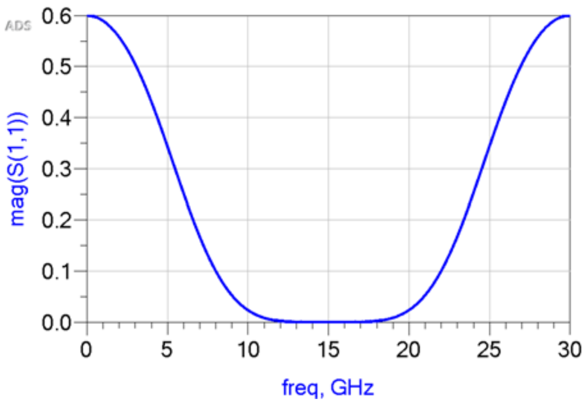


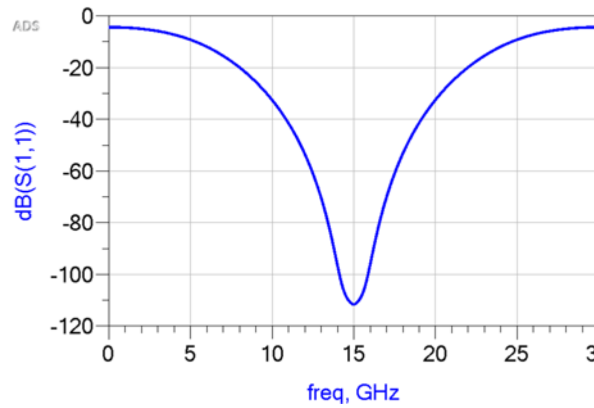


It is seen that $\Delta f = (1{,}456 - 542)$ MHz = 914 MHz at $\Gamma_m = 0.1$, which is very close to the theoretical prediction (919.13 MHz). It is also confirmed a periodic impedance matching at 1 GHz, 3 GHz, 5 GHz, etc.

9. $Z_1 = 52.26\ \Omega$, $Z_2 = 64.975\ \Omega$, $Z_3 = 100\ \Omega$, $Z_4 = 153.905\ \Omega$, $Z_5 = 191.35\ \Omega$. The expected relative bandwidth for maximum reflection $\Gamma_m = 0.001 = -60$ dB is 34.85%. Centering the impedance transformer at $f_0 = 15$ GHz, the expected theoretical bandwidth is $\Delta f = 5.227$ GHz. The five TL lengths are $l_1 = \ldots = l_5 = 2.7951$ mm. Implementation in Keysight ADS with ideal transmission lines:

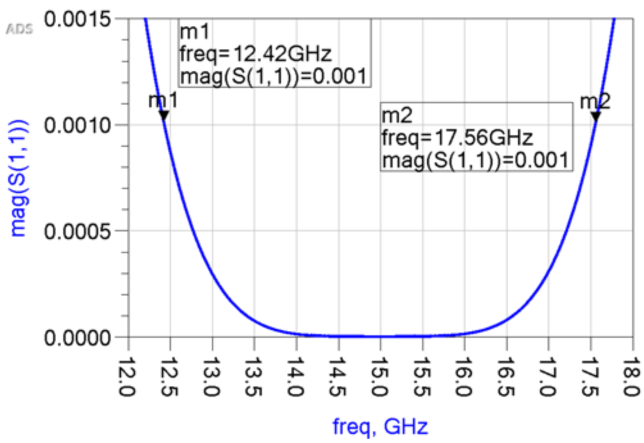






It is confirmed a Butterworth response centered at 15 GHz, with $|\Gamma| = 0.6 = -4.44$ dB at low frequencies.

Zooming-in at $|\Gamma| = -60$ dB $= 0.001$:



It is seen that the actual bandwidth Δf is equal to (17.56 – 12.42) GHz = 5.14 GHz at Γ_m, which is close to the theoretical expected bandwidth (5.227 GHz).

10. Using Gupta's formulas:

$W_1/H = 1.767$ for $Z_0 = 54.535\ \Omega$ and $\varepsilon_r = 4$
$W_2/H = 1.0829$ for $Z_0 = 70.71\ \Omega$ and $\varepsilon_r = 4$
$W_3/H = 0.61071$ for $Z_0 = 91.685\ \Omega$ and $\varepsilon_r = 4$

Since $H = 2$mm, then $W_1 = 3.534$mm, $W_2 = 2.1659$mm, $W_3 = 1.2214$mm.

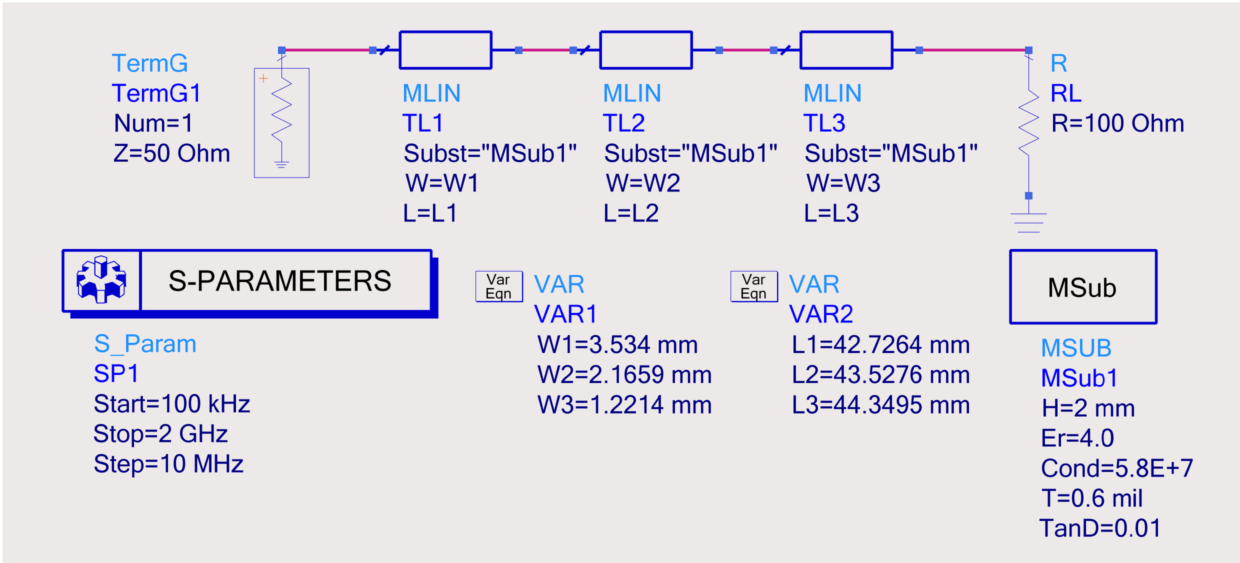
The effective dielectric constant for each segment of microstrip line is:

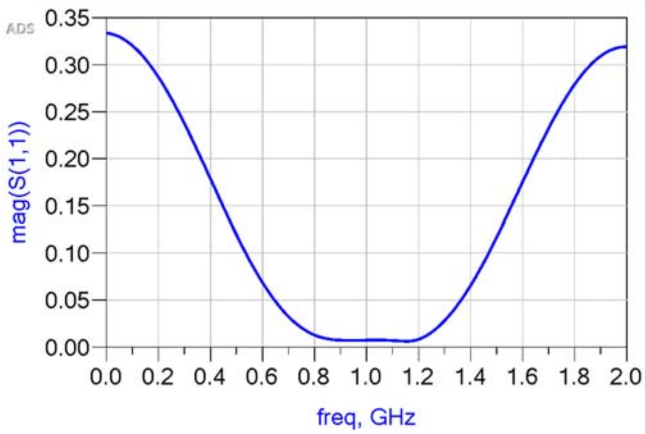
$\varepsilon_{e1} = 3.0813$ for $W_1/H = 1.767$ and $\varepsilon_r = 4$
$\varepsilon_{e2} = 2.9689$ for $W_2/H = 1.0829$ and $\varepsilon_r = 4$
$\varepsilon_{e3} = 2.8599$ for $W_3/H = 0.61071$ and $\varepsilon_r = 4$

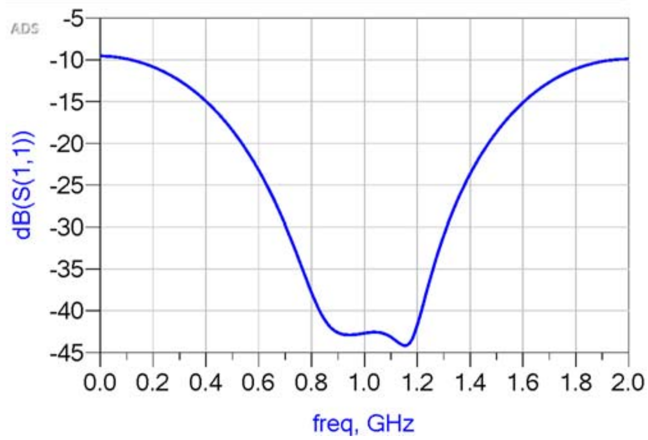
The corresponding physical lengths are ($f_0 = 1$GHz):

$l_1 = \lambda_1/4 = 42.7264$ mm, $l_2 = \lambda_2/4 = 43.5276$ mm, $l_3 = \lambda_3/4 = 44.3495$ mm

Implementing the circuit in Keysight ADS:

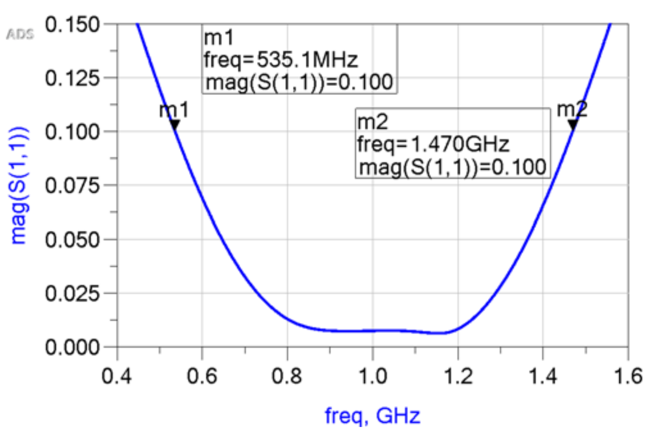


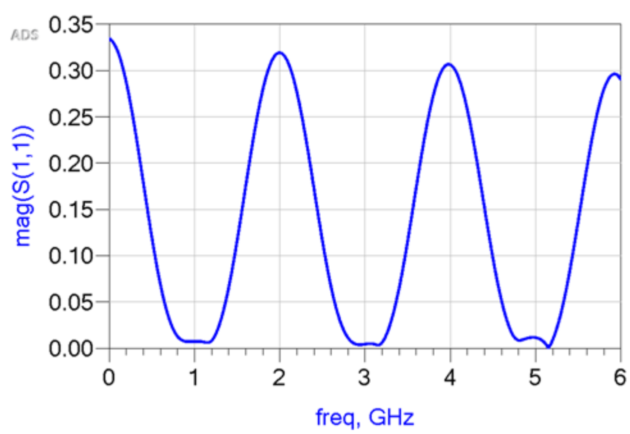




It is seen that the impedance matching is centered at 1 GHz, with $|\Gamma| = 0.333 = -9.54$ dB at low frequencies, as expected. However, the response is strictly no longer a Butterworth response (maximally flat).

Zooming-in to measure the bandwidth at $\Gamma_m = 0.1 = -20$ dB, and simulating up to 6 GHz:





It is seen that $\Delta f = (1{,}470 - 535.1)$ MHz $= 934.9$ MHz at $\Gamma_m = 0.1$, which is still close to the theoretical prediction (919.13 MHz). It is also seen that the periodic impedance matching at 1 GHz, 3 GHz, 5 GHz, etc. is affected by the microstrip losses.