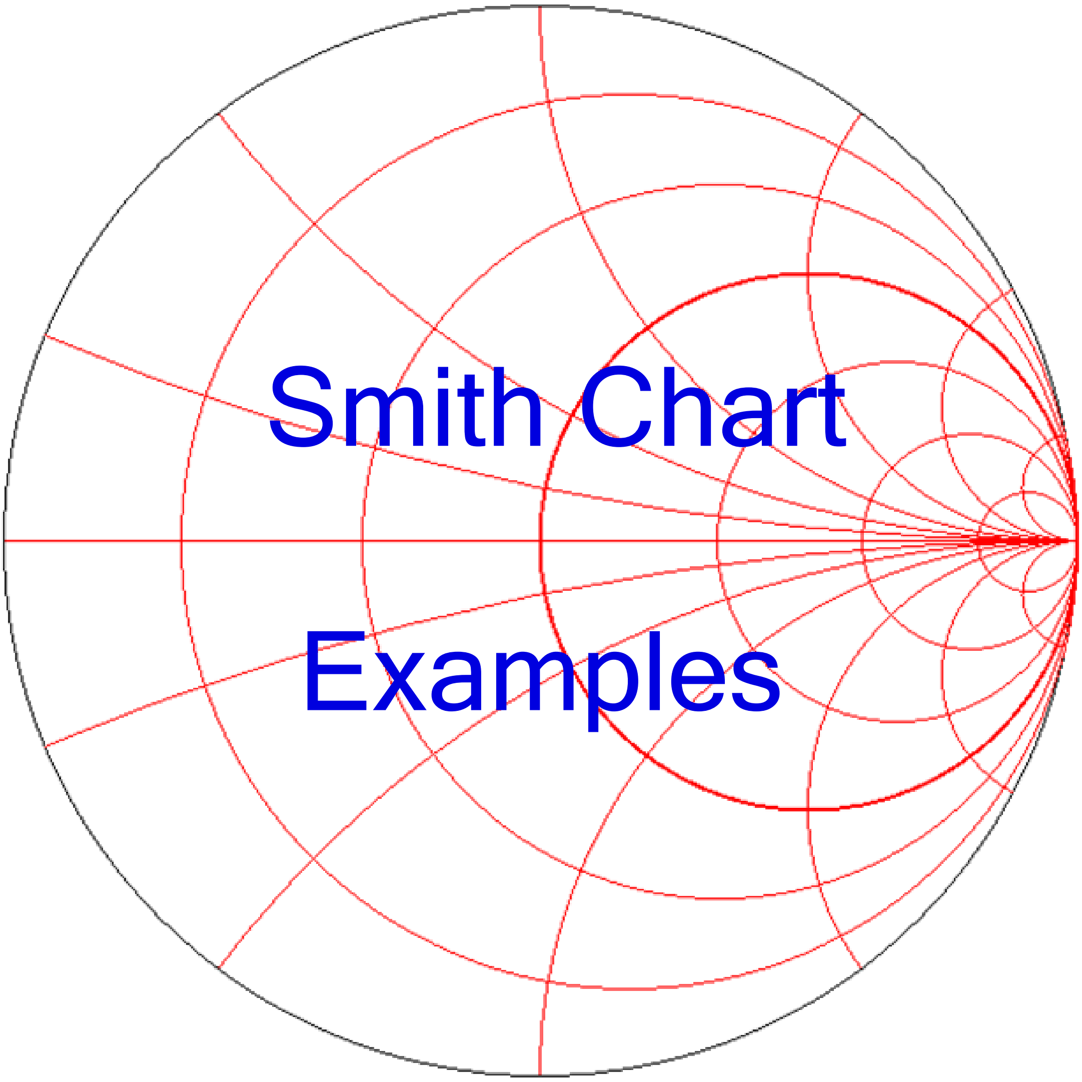
Bern University of Applied Sciences
Engineering and Information Technology

Division of Electrical and Communication Technology

Smith Chart Examples



Smith V3.10

Prof. Fritz Dellsperger 5.2010

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Impedance Matching

Impedance, Admittance, Reflection Coefficient, VSWR and Return Loss

Impedance: $Z = R + jX$ R: Resistance X: Reactance

$$Z = Z_0 \frac{1+\Gamma}{1-\Gamma}$$

Admittance: $Y = G + jB$ G: Conductance B: Susceptance

$$Z = \frac{1}{Y} \qquad Y = \frac{1}{Z}$$

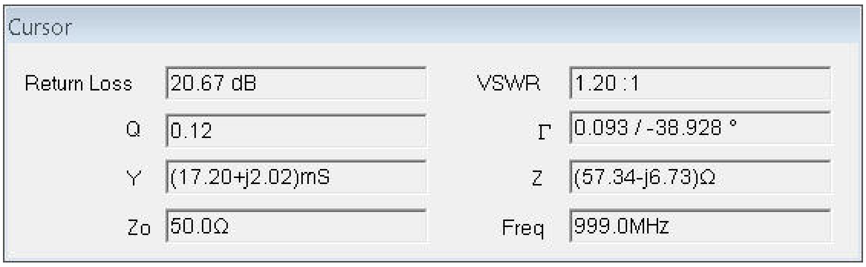
Reflection Coefficient: $\Gamma = \frac{Z - Z_0}{Z + Z_0} = \frac{Y_0 - Y}{Y_0 + Y} = |\Gamma| \angle \varphi$ Z_0 : Reference Impedance

$$|\Gamma| = \frac{VSWR - 1}{VSWR + 1} = 10^{-\frac{RL}{20}} = \frac{|Z - Z_0|}{|Z + Z_0|}$$

Voltage Standing Wave Ratio: $VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} = \frac{1+10^{-\frac{RL}{20}}}{1-10^{-\frac{RL}{20}}} = \left.\frac{|Z_0|}{|Z|}\right|_{Z<Z_0} = \left.\frac{|Z|}{|Z_0|}\right|_{Z>Z_0}$

Return Loss: $RL = -20 \cdot \log|\Gamma| = -20 \cdot \log\frac{VSWR - 1}{VSWR + 1} = -20 \cdot \log\frac{|Z - Z_0|}{|Z + Z_0|}$

All values for cursor position in Smith-Chart are displayed in window “Cursor”.

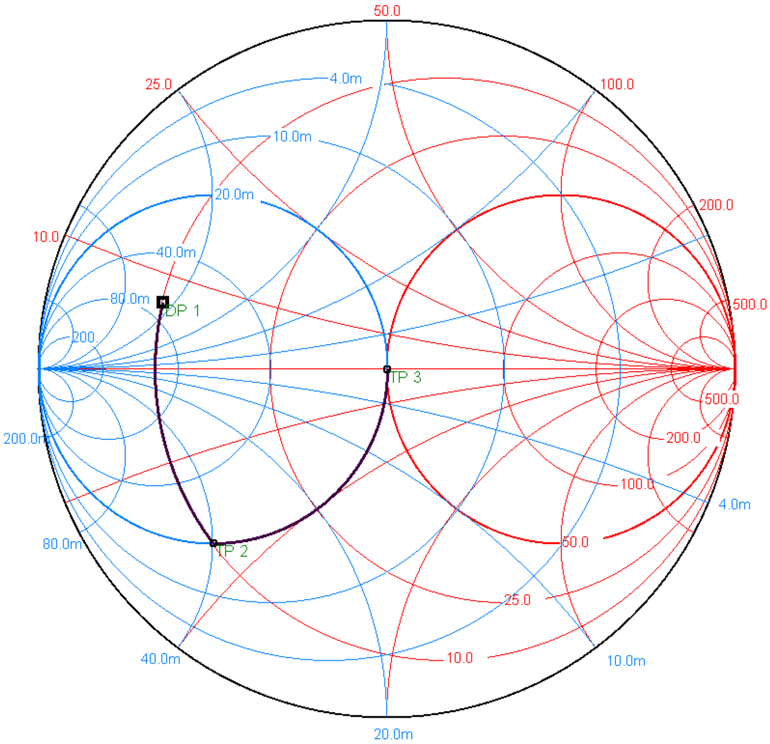


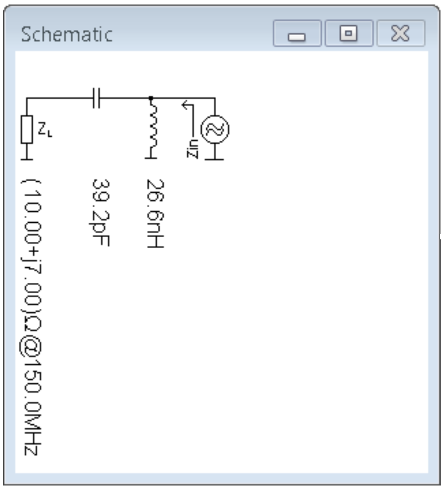
Matching arbitrary impedances to 50 Ohm

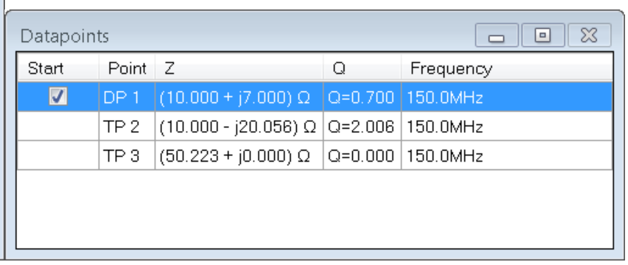
Example 1: Use 2 reactance elements, Highpass

Problem: Match an impedance of $(10+j7)\Omega$ to 50Ω. Use 2 reactance (L,C) in a circuit topology with highpass characteristic. Frequency: 150 MHz.

Smith project file: Example1.xmlsc







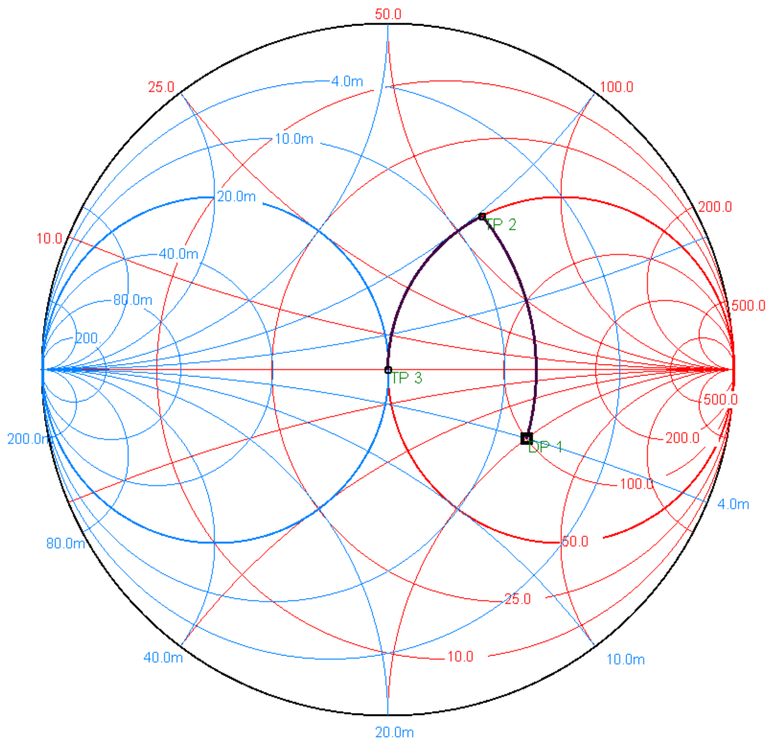
Datapoints

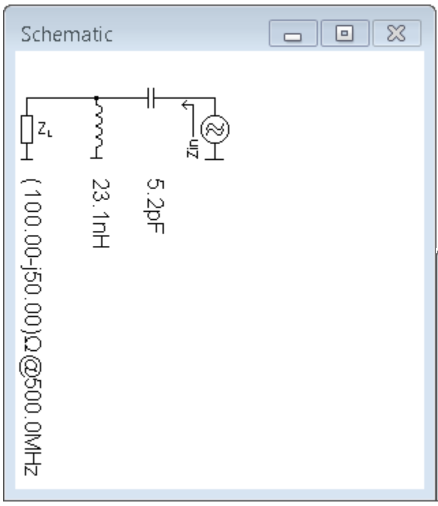
Start	Point	Z	Q	Frequency
☑	DP 1	(10.000 + j7.000) Ω	Q=0.700	150.0MHz
	TP 2	(10.000 - j20.056) Ω	Q=2.006	150.0MHz
	TP 3	(50.223 + j0.000) Ω	Q=0.000	150.0MHz

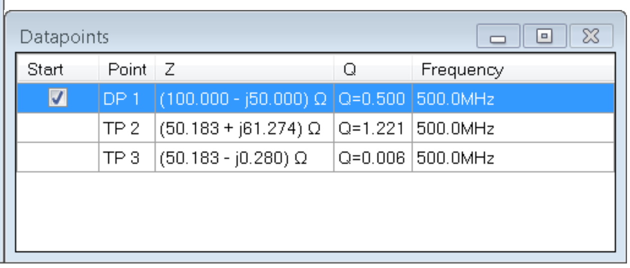
Example 2: Use 2 reactance elements, Highpass

Problem: Match an impedance of $(100 - j50)\Omega$ to 50Ω. Use 2 reactance (L,C) in a circuit topology with highpass characteristic. Frequency: 500 MHz.

Smith project file: Example2.xmlsc





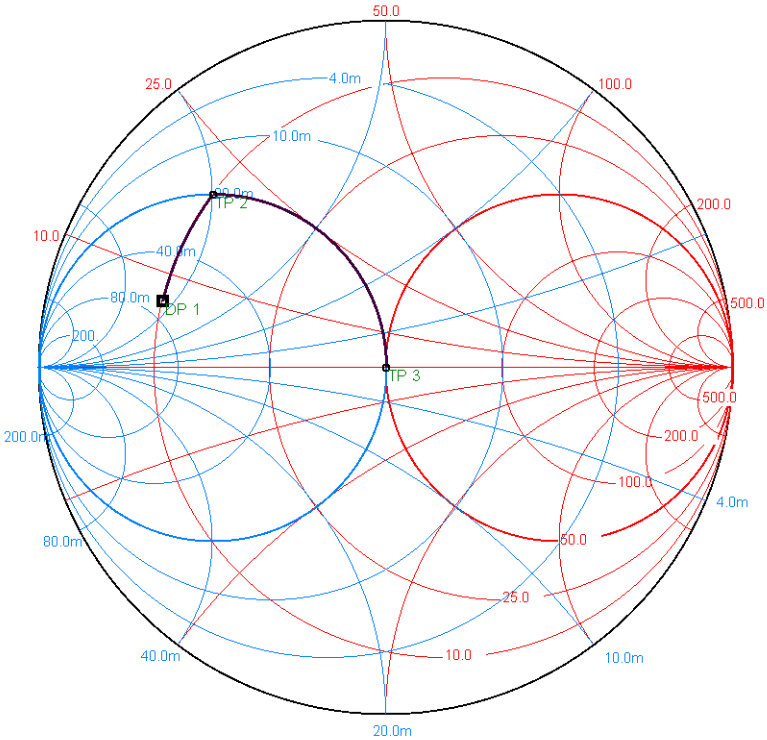

Datapoints

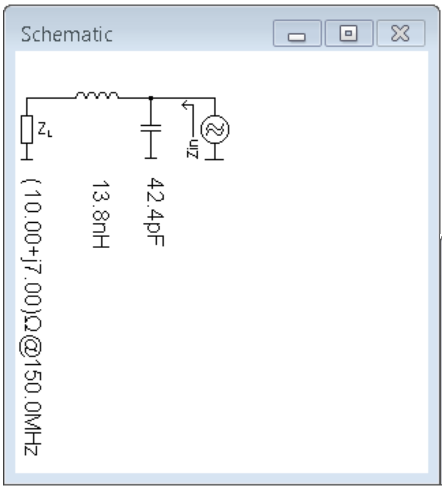
Start	Point	Z	Q	Frequency
☑	DP 1	(100.000 - j50.000) Ω	Q=0.500	500.0MHz
	TP 2	(50.183 + j61.274) Ω	Q=1.221	500.0MHz
	TP 3	(50.183 - j0.280) Ω	Q=0.006	500.0MHz

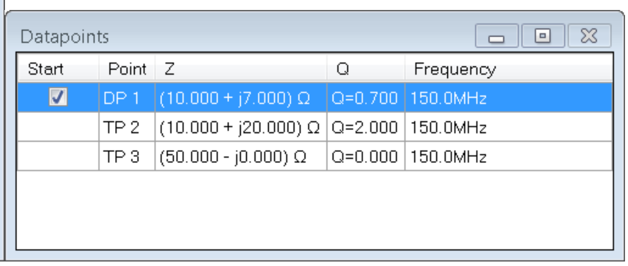
Example 3: Use 2 reactance elements, Lowpass

Problem: Match an impedance of $(10 + j7)\Omega$ to 50Ω. Use 2 reactance (L,C) in a circuit topology with lowpass characteristic. Frequency: 150 MHz.

Smith project file: Example3.xmlsc





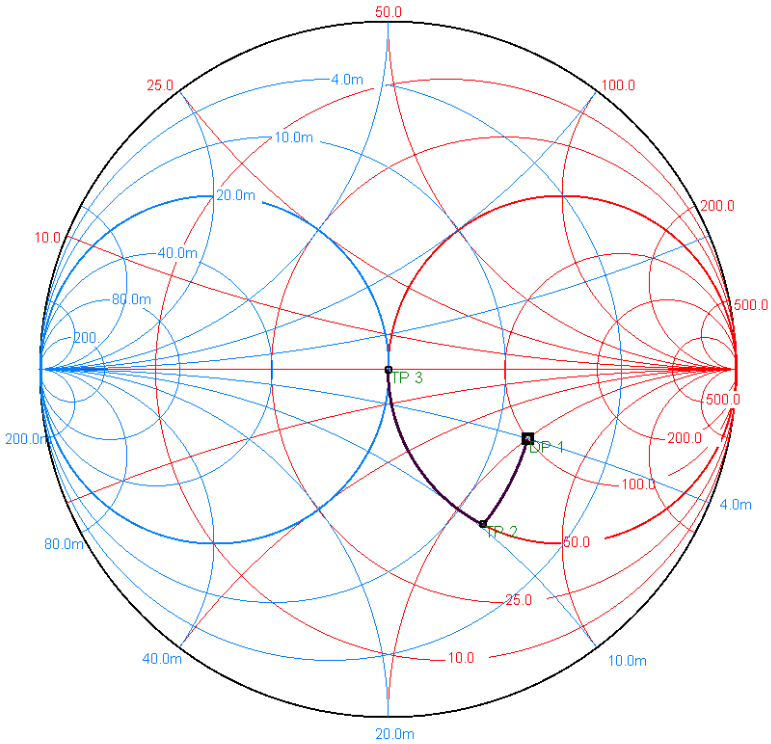

Datapoints

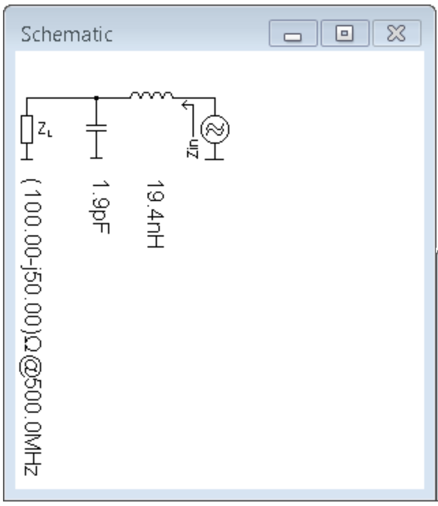
Start	Point	Z	Q	Frequency
☑	DP 1	(10.000 + j7.000) Ω	Q=0.700	150.0MHz
	TP 2	(10.000 + j20.000) Ω	Q=2.000	150.0MHz
	TP 3	(50.000 - j0.000) Ω	Q=0.000	150.0MHz

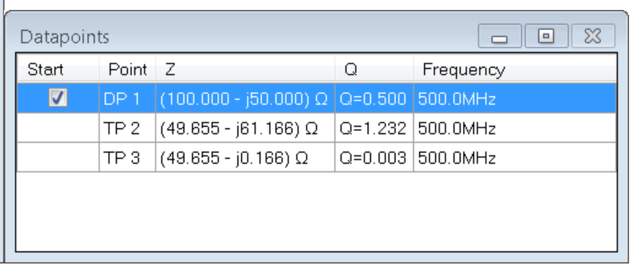
Example 4: Use 2 reactance elements, Lowpass

Problem: Match an impedance of $(100 - j50)\Omega$ to 50Ω. Use 2 reactance (L,C) in a circuit topology with lowpass characteristic. Frequency: 500 MHz.

Smith project file: Example4.xmlsc







Datapoints

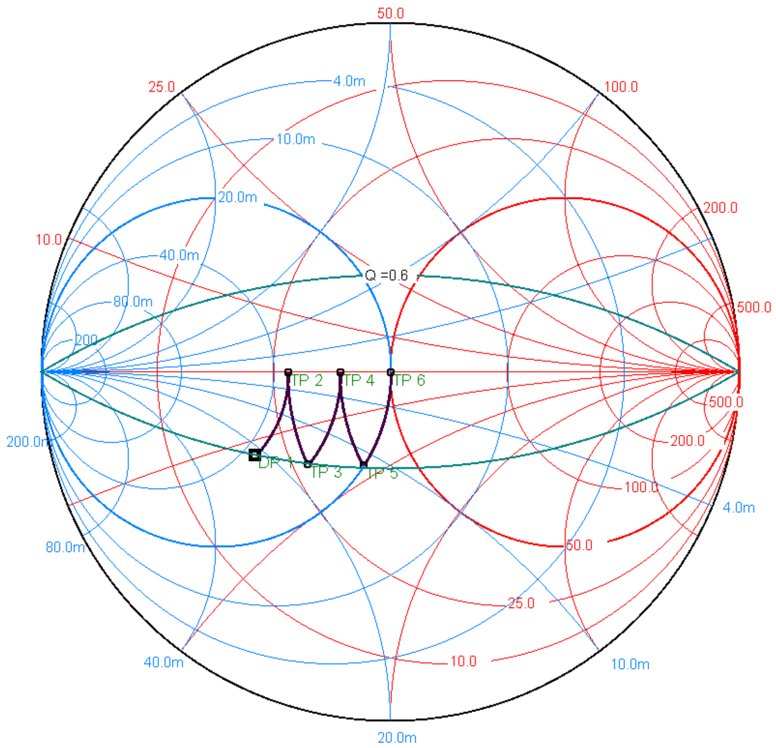
Start	Point	Z	Q	Frequency
☑	DP 1	(100.000 - j50.000) Ω	Q=0.500	500.0MHz
	TP 2	(49.655 - j61.166) Ω	Q=1.232	500.0MHz
	TP 3	(49.655 - j0.166) Ω	Q=0.003	500.0MHz

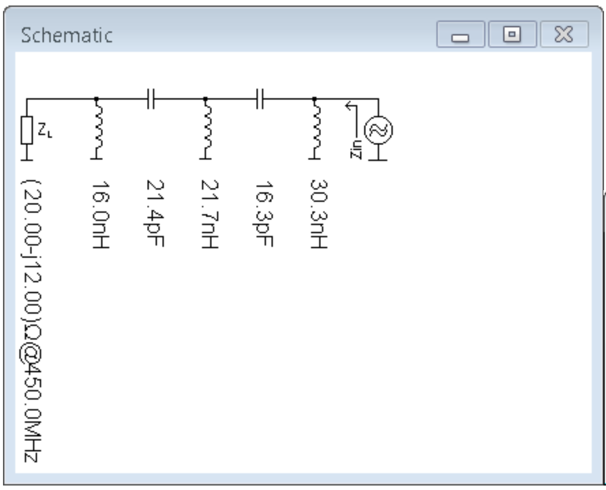
Example 5: Antenna Match with 3 or more reactance elements, Low Q, Highpass

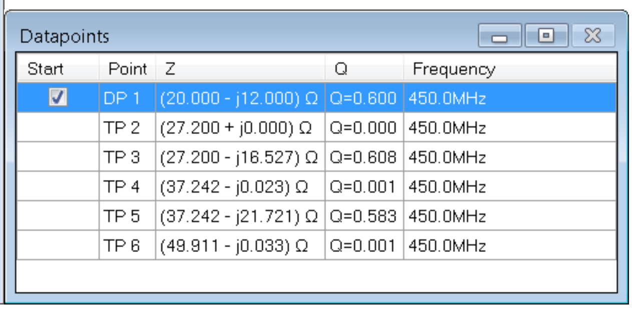
Problem: Match an antenna impedance of $(20 - j12)\Omega$ to 50Ω. Use L and C in a circuit topology with highpass characteristic and do not exceed a $Q_{max} = \frac{X}{R} = \frac{12}{20} = 0.6$ (for maximum bandwidth).

Frequency: 450 MHz.

Smith project file: Example5.xmlsc






Datapoints

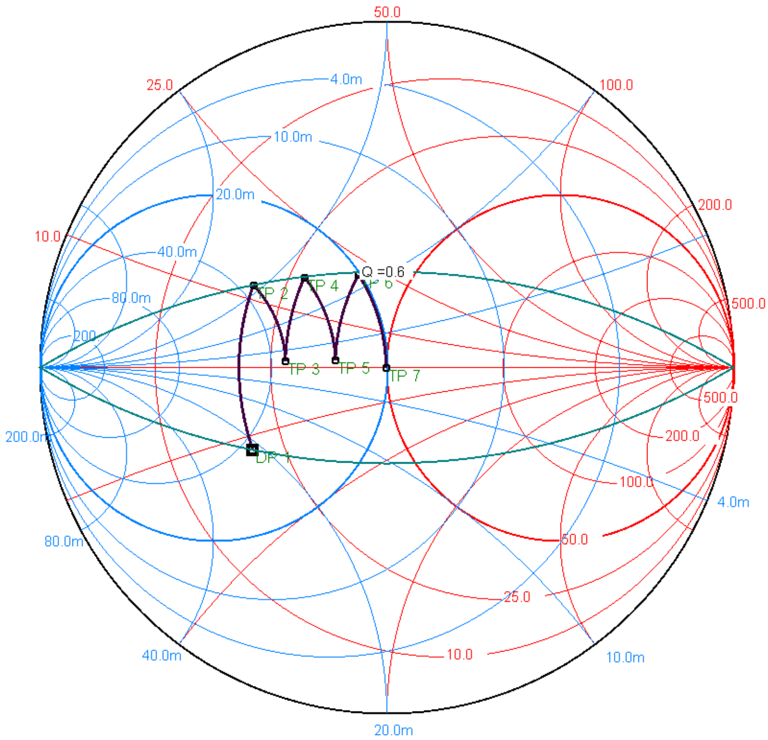
Start	Point	Z	Q	Frequency
☑	DP 1	(20.000 - j12.000) Ω	Q=0.600	450.0MHz
	TP 2	(27.200 + j0.000) Ω	Q=0.000	450.0MHz
	TP 3	(27.200 - j16.527) Ω	Q=0.608	450.0MHz
	TP 4	(37.242 - j0.023) Ω	Q=0.001	450.0MHz
	TP 5	(37.242 - j21.721) Ω	Q=0.583	450.0MHz
	TP 6	(49.911 - j0.033) Ω	Q=0.001	450.0MHz

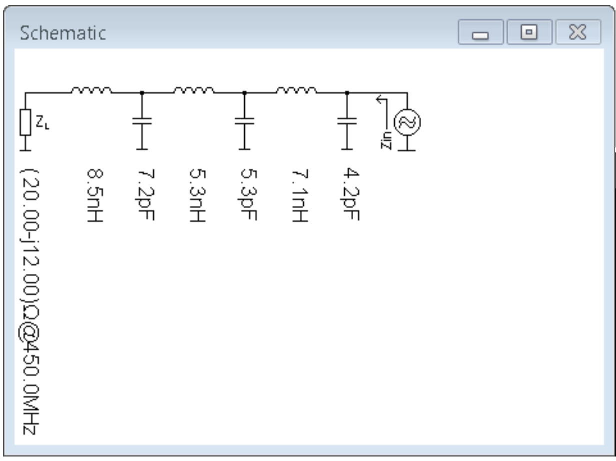
Example 6: Antenna Match with 3 or more reactance elements, Low Q, Lowpass

Problem: Match an antenna impedance of $(20-j12)\Omega$ to 50Ω. Use L and C in a circuit topology with lowpass characteristic and do not exceed a $Q_{max} = \frac{X}{R} = \frac{12}{20} = 0.6$ (for maximum bandwidth).

Frequency: 450 MHz.

Smith project file: Example6.xmlsc





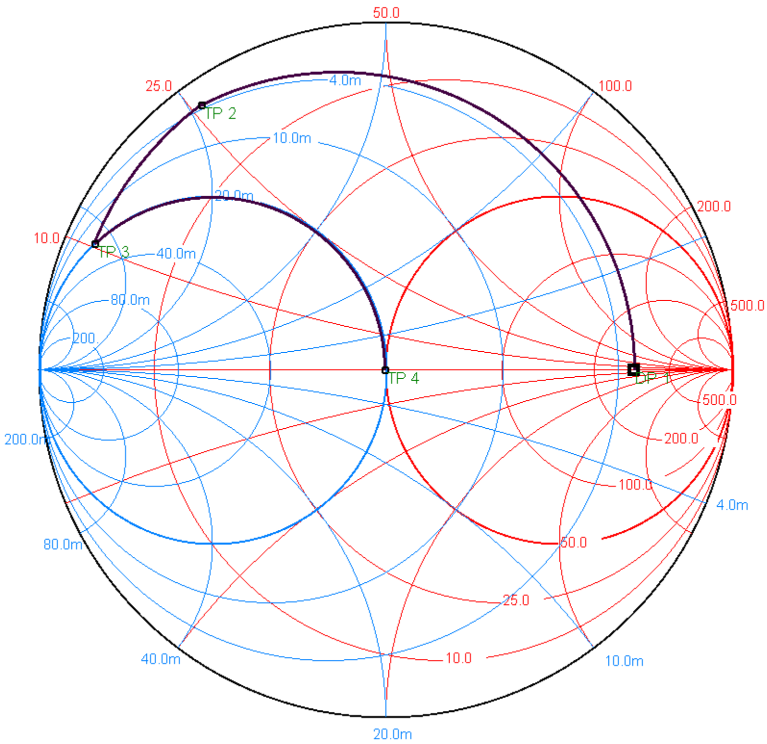
Datapoints

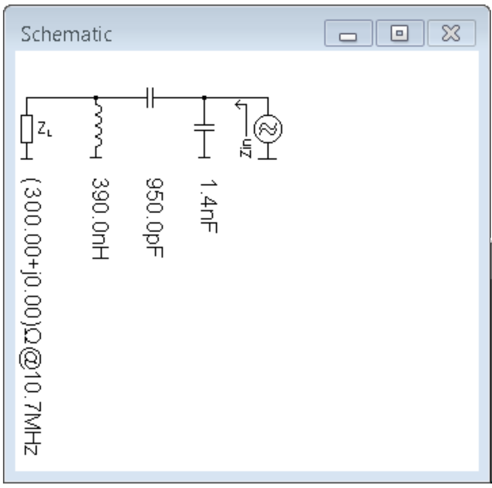
Start	Point	Z	Q	Frequency
☑	DP 1	(20.000 - j12.000) Ω	Q=0.600	450.0MHz
	TP 2	(20.000 + j12.033) Ω	Q=0.602	450.0MHz
	TP 3	(27.180 + j1.281) Ω	Q=0.047	450.0MHz
	TP 4	(27.180 + j16.280) Ω	Q=0.599	450.0MHz
	TP 5	(36.855 + j1.679) Ω	Q=0.046	450.0MHz
	TP 6	(36.855 + j21.754) Ω	Q=0.590	450.0MHz
	TP 7	(49.695 + j0.006) Ω	Q=0.000	450.0MHz

Example 7: Match Ceramic Filter to 50 Ohm

Problem: For measurement purposes match a 10.7 MHz 300 Ohm Ceramic filter to 50 Ohm using a parallel resonance circuit with capacitive voltage divider and L = 330 nH.
Frequency: 10.7 MHz.

Smith project file: Example7.xmlsc



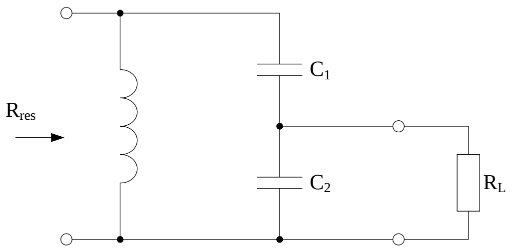


Datapoints

Start	Point	Z	Q	Frequency
☑	DP 1	(300.000 + j0.000) Ω	Q=0.000	10.7MHz
	TP 2	(2.274 + j26.021) Ω	Q=11.442	10.7MHz
	TP 3	(2.274 + j10.364) Ω	Q=4.557	10.7MHz
	TP 4	(49.503 - j0.119) Ω	Q=0.002	10.7MHz

$f_0 := 10.7 \cdot \text{MHz} \quad R_1 := 300 \cdot \Omega \quad L := 390 \cdot \text{nH}$

$$B := \frac{2 \cdot \pi \cdot L \cdot f_0^{\,2}}{R_1} = 791.298 \cdot \text{kHz}$$



For Q ≥ 10 following approximations can be used:

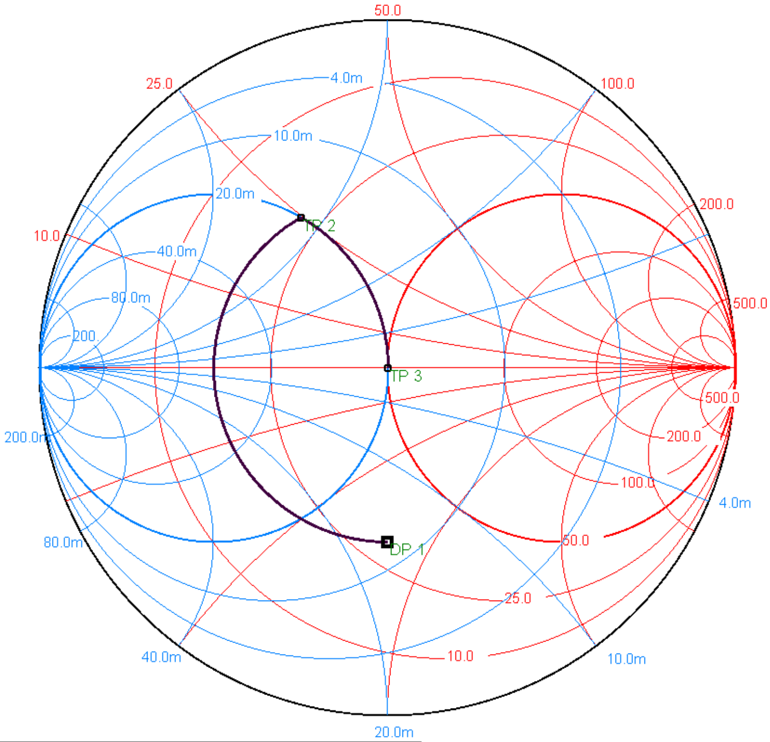
$$Q \approx \frac{f_o}{B} \quad C \approx \frac{1}{2\pi B R_{res}} \quad L \approx \frac{1}{\omega_o^{2} C} \quad N = \sqrt{\frac{R_{res}}{R_L}}$$

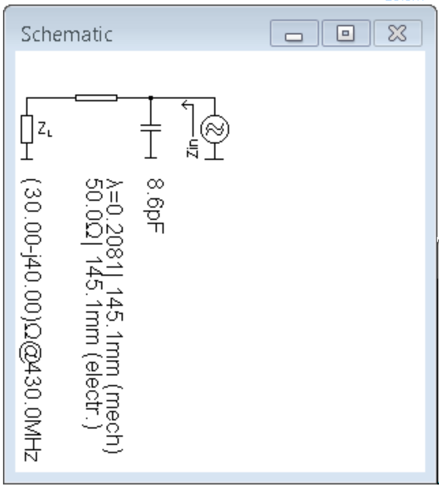
$$Q_p \approx \frac{Q}{N} \quad C_1 \approx \frac{C_2}{N-1} \quad C_2 \approx NC$$

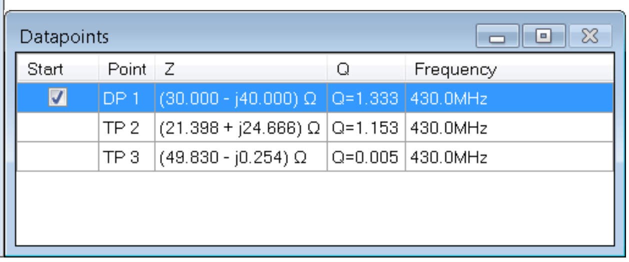
Example 8: Antenna match using reactance and serie line element

Problem: Match an antenna impedance of $(30 - j40)\Omega$ to 50Ω. Use one reactance and one serie line. Frequency: 430 MHz.

Smith project file: Example8.xmlsc





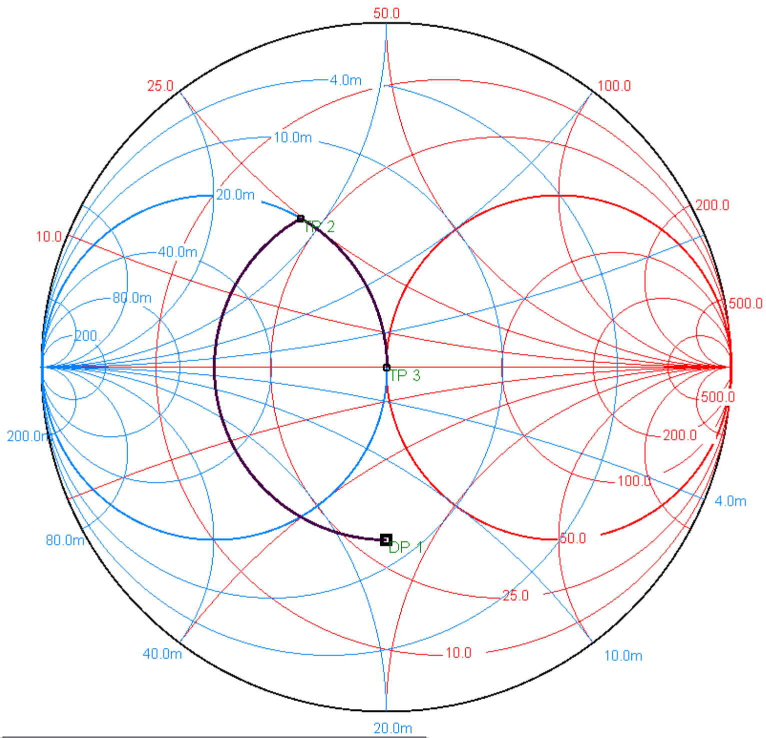


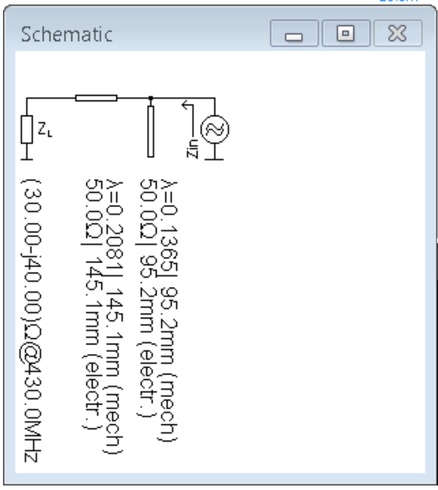
Start	Point	Z	Q	Frequency
☑	DP 1	(30.000 - j40.000) Ω	Q=1.333	430.0MHz
	TP 2	(21.398 + j24.666) Ω	Q=1.153	430.0MHz
	TP 3	(49.830 - j0.254) Ω	Q=0.005	430.0MHz

Example 9: Antenna match using serie line and open stub

Problem: Match an antenna impedance of $(30 - j40)\Omega$ to 50Ω. Use one serie line and an open stub. Frequency: 430 MHz.

Smith project file: Example9.xmlsc





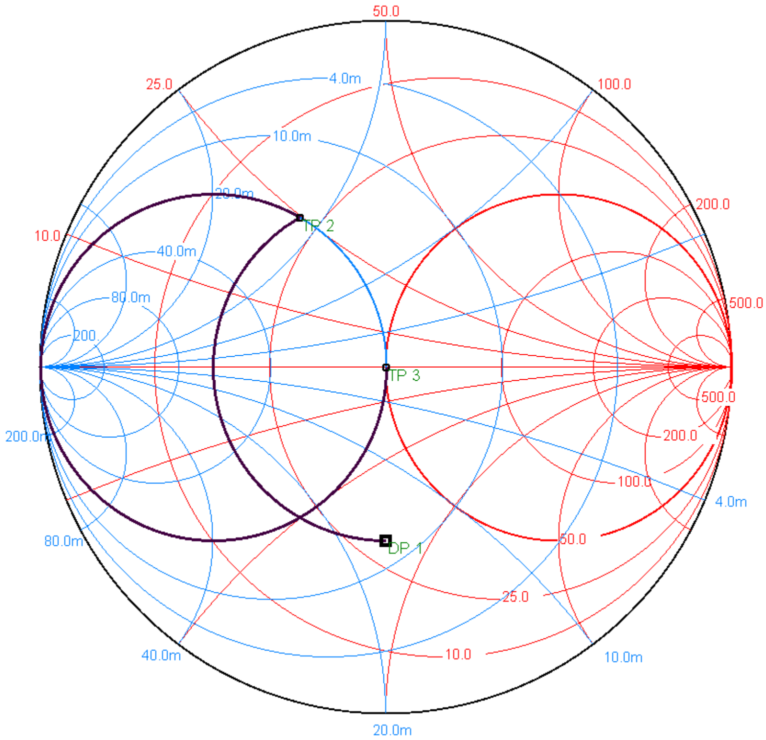
Datapoints

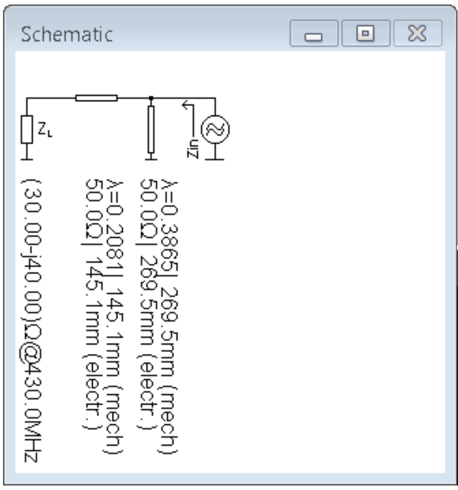
Start	Point	Z	Q	Frequency
☑	DP 1	(30.000 - j40.000) Ω	Q=1.333	430.0MHz
	TP 2	(21.398 + j24.666) Ω	Q=1.153	430.0MHz
	TP 3	(49.831 + j0.000) Ω	Q=0.000	430.0MHz

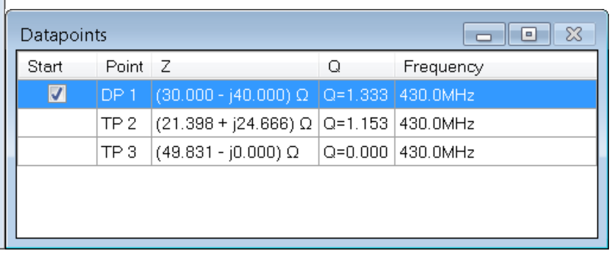
Example 10: Antenna match using serie line and shorted stub

Problem: Match an antenna impedance of $(30 - j40)\Omega$ to 50Ω. Use one serie line and a shorted stub. Frequency: 430 MHz.

Smith project file: Example10.xmlsc







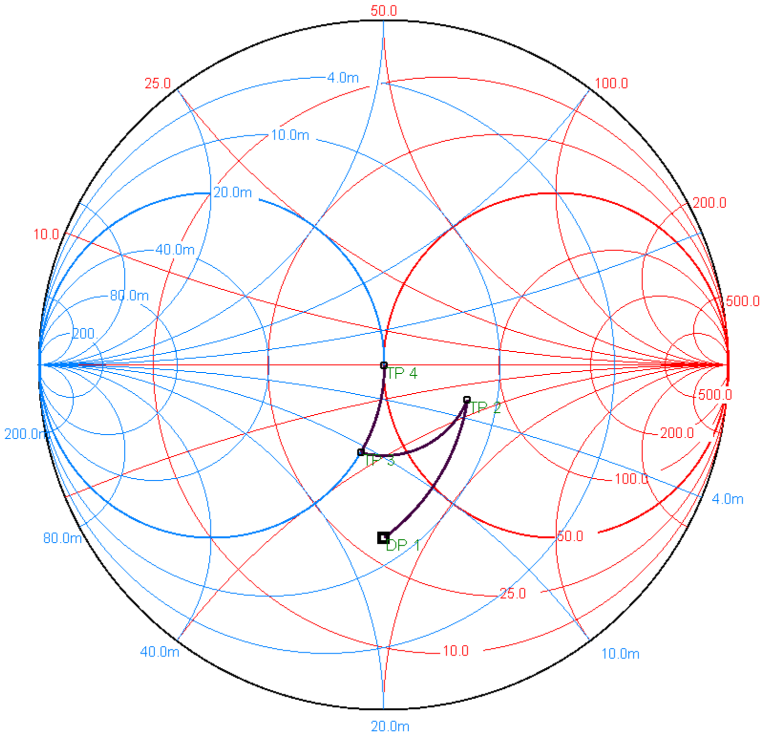
Datapoints

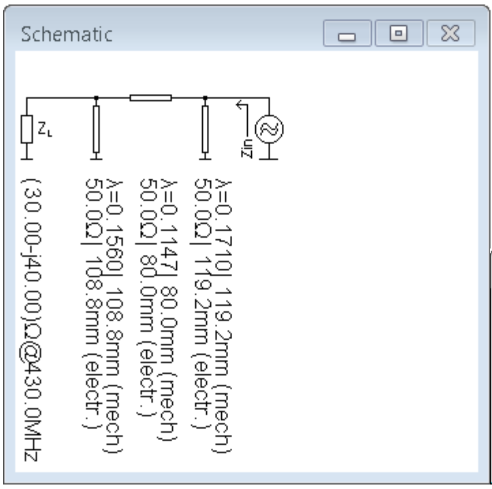
Start	Point	Z	Q	Frequency
☑	DP 1	(30.000 - j40.000) Ω	Q=1.333	430.0MHz
	TP 2	(21.398 + j24.666) Ω	Q=1.153	430.0MHz
	TP 3	(49.831 - j0.000) Ω	Q=0.000	430.0MHz

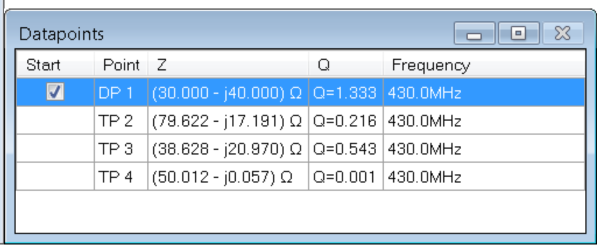
Example 11: Antenna match using double stub tuner

Problem: Match an antenna impedance of $(30 - j40)\Omega$ to 50Ω. Use a double stub tuner with serie line length of 80 mm and $\varepsilon_r = 1$. Frequency: 430 MHz.

Smith project file: Example11.xmlsc

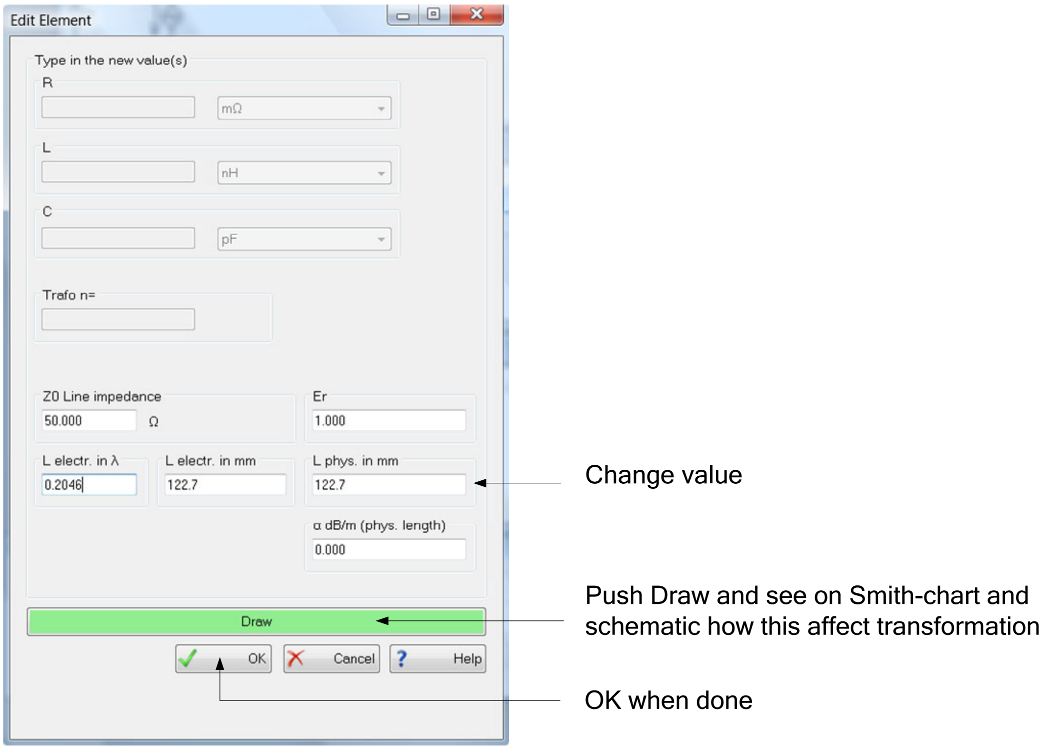





Datapoints

Start	Point	Z	Q	Frequency
☑	DP 1	(30.000 - j40.000) Ω	Q=1.333	430.0MHz
	TP 2	(79.622 - j17.191) Ω	Q=0.216	430.0MHz
	TP 3	(38.628 - j20.970) Ω	Q=0.543	430.0MHz
	TP 4	(50.012 - j0.057) Ω	Q=0.001	430.0MHz

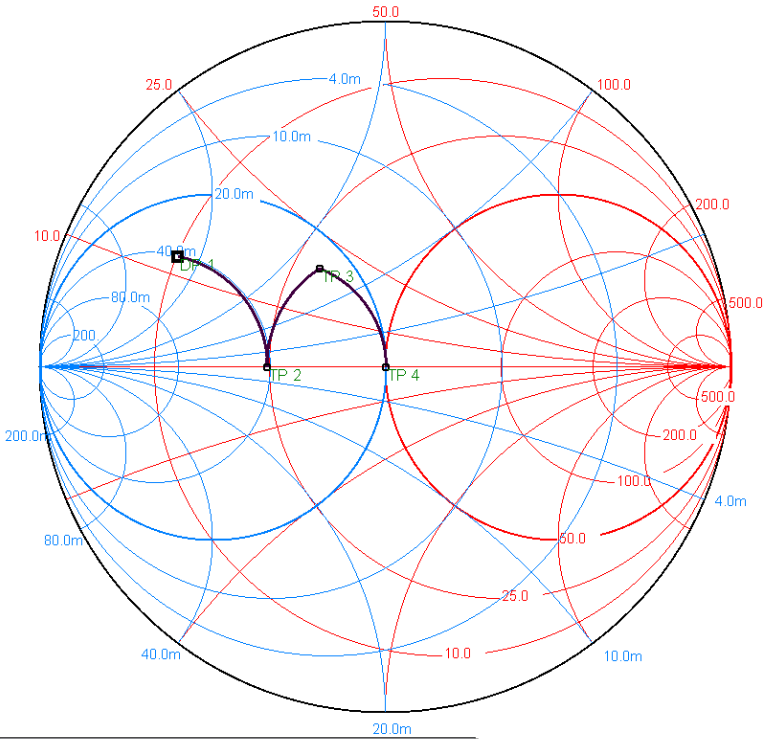
Use Edit Element (doubleclick on element in schematic) to adjust for desired line length.

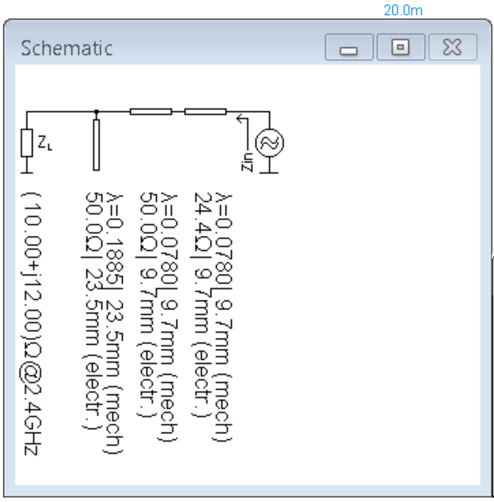


Example 12: Nonsynchronous Transformer

Problem: Match an impedance of $(10 + j12)\Omega$ to 50Ω. Use an open stub and a nonsynchronous transformer. Frequency: 2.4 GHz.

Smith project file: Example12.xmlsc

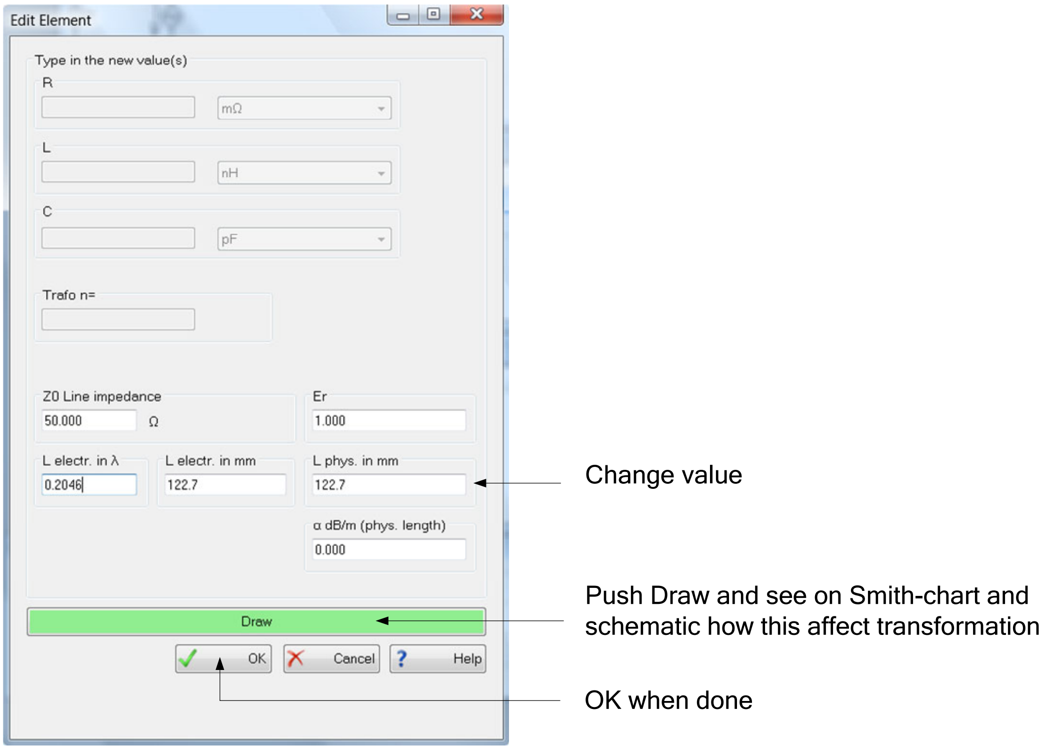




Datapoints

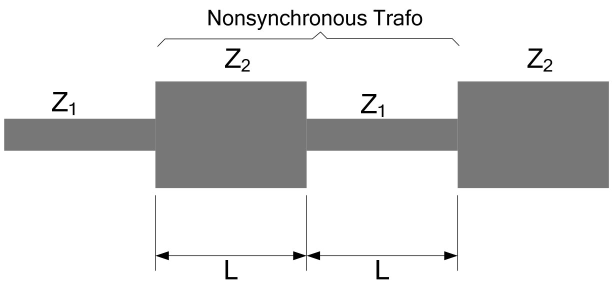
Start	Point	Z	Q	Frequency
☑	DP 1	(10.000 + j12.000) Ω	Q=1.200	2.4GHz
	TP 2	(24.400 + j0.000) Ω	Q=0.000	2.4GHz
	TP 3	(29.482 + j19.259) Ω	Q=0.653	2.4GHz
	TP 4	(50.453 - j0.427) Ω	Q=0.008	2.4GHz

Use Edit Element (doubleclick on element in schematic) to adjust for desired line length.



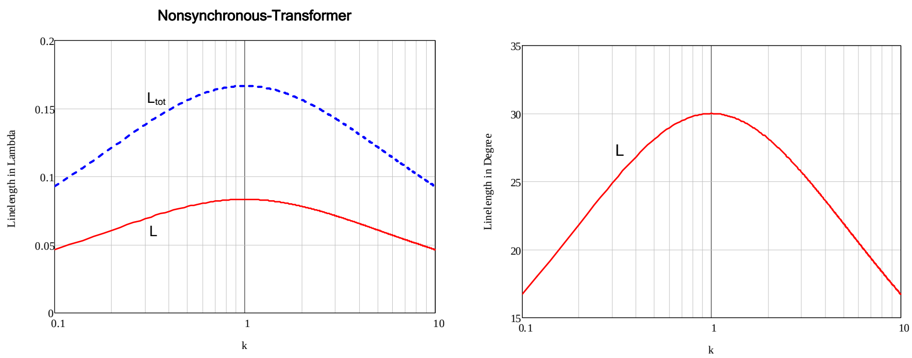
Properties of Nonsynchronous Trafo:

It uses two pieces of line with the same length. One line must have the line impedance of the source and the other line the impedance of the load. The total length depends on impedance ratio and is much shorter than $\lambda / 4$.



L = Length of one line section

$$k = Z_1 / Z_2 \qquad L = \frac{\lambda}{2\pi\sqrt{\varepsilon_r}} \operatorname{a\,tan}\left(\frac{1}{\sqrt{k + \frac{1}{k} + 1}}\right)$$



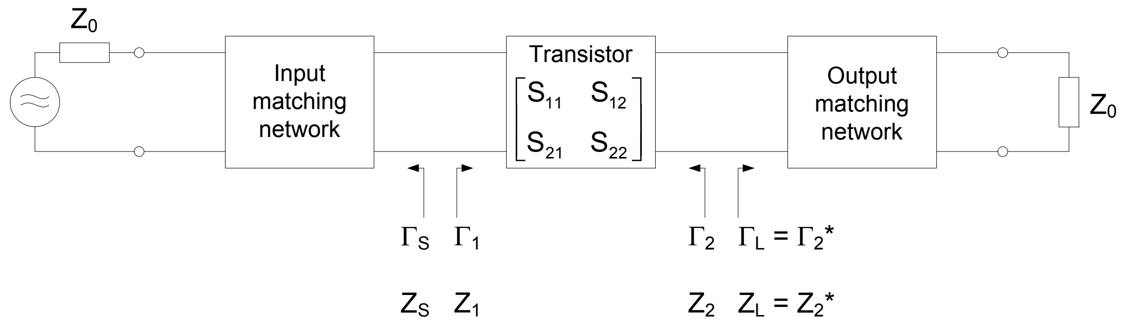
Line length as function of impedance ratio k

Low Noise Amplifier Design

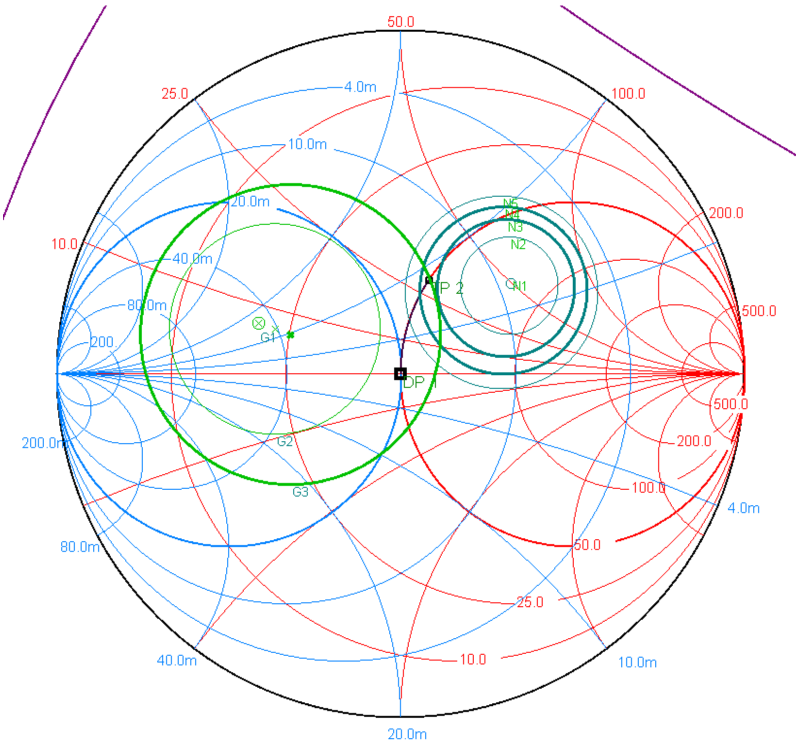
Example 13: Low Noise Amplifier, 2.0 GHz

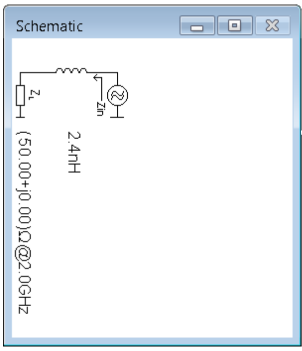
Problem: Design input and output matching network for a LNA using BFG33G.
Frequency: 2 GHz

Smith project file: Example13-input.xmlsc



If we choose a source impedance of Z_S = (50+j30)Ohm we get a gain of approx. 12 dB and a NF of approx. 3.85 dB with only a serie inductor as input matching network.





Datapoints

Start	Point	Z	Q	Frequency
☑	DP 1	(50.000 + j0.000) Ω	Q=0.000	2.0GHz
	TP 2	(50.000 + j30.000) Ω	Q=0.600	2.0GHz

Circles

Visible	Highlighted	Details
☑	☐	G1: input plane const. gain circle ;Vp=12.94dB ;Gmax=12.94dB ;S11=0.12 < -149.00°; S12=0.11 < 59.40°; S21=3.76 < 78.90°; S22=0.41 < -54.50°; 2.0GHz
☑	☐	G2: input plane const. gain circle ;Vp=12.50dB ;Gmax=12.94dB ;S11=0.12 < -149.00°; S12=0.11 < 59.40°; S21=3.76 < 78.90°; S22=0.41 < -54.50°; 2.0GHz
☑	☑	G3: input plane const. gain circle ;Vp=12.00dB ;Gmax=12.94dB ;S11=0.12 < -149.00°; S12=0.11 < 59.40°; S21=3.76 < 78.90°; S22=0.41 < -54.50°; 2.0GHz
☑	☐	S1: Input plane stability circle; stable inside; K=1.17; S11=0.12 < -149.00°; S12=0.11 < 59.40°; S21=3.76 < 78.90°; S22=0.41 < -54.50°; 2.0GHz
☑	☐	S2: Output plane stability circle; stable outside; K=1.17; S11=0.12 < -149.00°; S12=0.11 < 59.40°; S21=3.76 < 78.90°; S22=0.41 < -54.50°; 2.0GHz
☑	☐	N1: Constant 3.60dB noise figure circle; NFmin = 3.60dB; Γ_NFmin = 0.42 < 39.10; r'noise = 0.98;2.0GHz
☑	☐	N2: Constant 3.70dB noise figure circle; NFmin = 3.60dB; Γ_NFmin = 0.42 < 39.10; r'noise = 0.98;2.0GHz
☑	☑	N3: Constant 3.80dB noise figure circle; NFmin = 3.60dB; Γ_NFmin = 0.42 < 39.10; r'noise = 0.98;2.0GHz
☑	☑	N4: Constant 3.90dB noise figure circle; NFmin = 3.60dB; Γ_NFmin = 0.42 < 39.10; r'noise = 0.98;2.0GHz
☑	☐	N5: Constant 4.00dB noise figure circle; NFmin = 3.60dB; Γ_NFmin = 0.42 < 39.10; r'noise = 0.98;2.0GHz

With a few calculations we get:

S-parameters at 2000 MHz:

$$S := \begin{pmatrix} 0.121 \cdot e^{j \cdot -149 \cdot deg} & 0.108\, e^{j \cdot 59.4 \cdot deg} \\ 3.756\, e^{j \cdot 78.9 \cdot deg} & 0.41 \cdot e^{j \cdot -54.5 \cdot deg} \end{pmatrix}$$

Source impedance at 2000 MHz:

$$Z_S := (50 + j \cdot 30) \cdot \Omega$$

$$Z_0 := 50 \cdot \Omega$$

$$\Gamma_S := \frac{Z_S - Z_0}{Z_S + Z_0} = 0.083 + 0.275j$$

$$|\Gamma_S| = 0.287$$

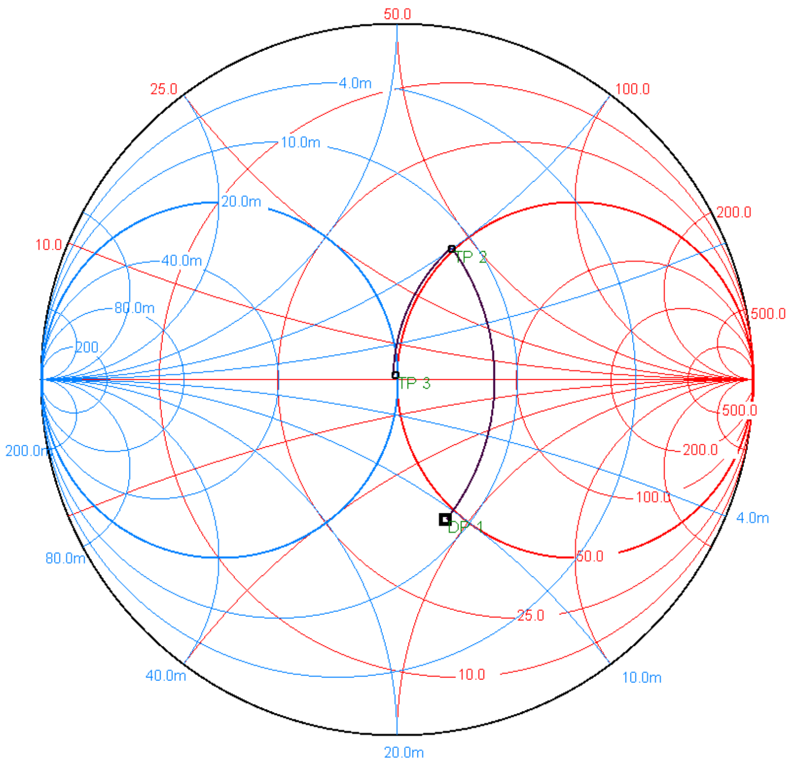
$$\arg(\Gamma_S) = 73.301deg$$

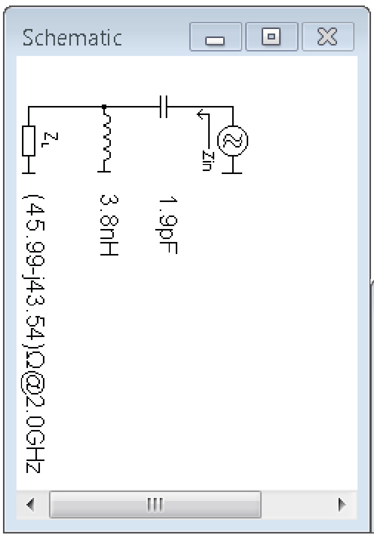
$$\Gamma_2 := S_{2,2} + \frac{S_{1,2} \cdot S_{2,1} \cdot \Gamma_S}{1 - S_{1,1} \cdot \Gamma_S} = 0.136 - 0.392j$$

$$Z_2 := Z_0 \cdot \frac{1 + \Gamma_2}{1 - \Gamma_2} = (45.987 - 43.54j)\,\Omega$$

For the output network we conjugately match Z_2 (or Γ_2) to 50 Ohm.
There are several possibilities to realize the output matching network.

Problem: Output matching network 1
Smith project file: Example13-output1.xmlsc

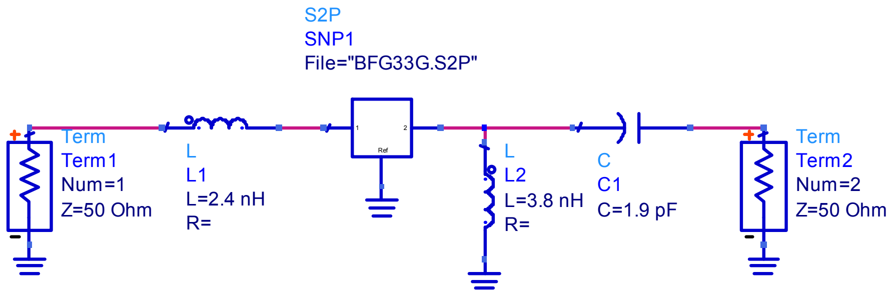


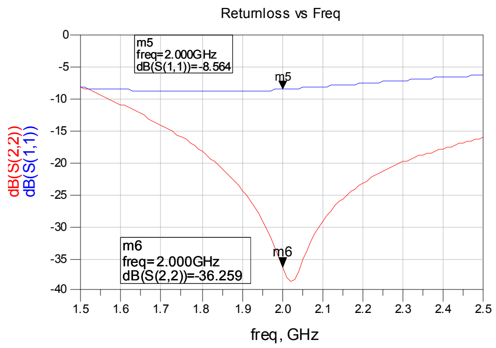


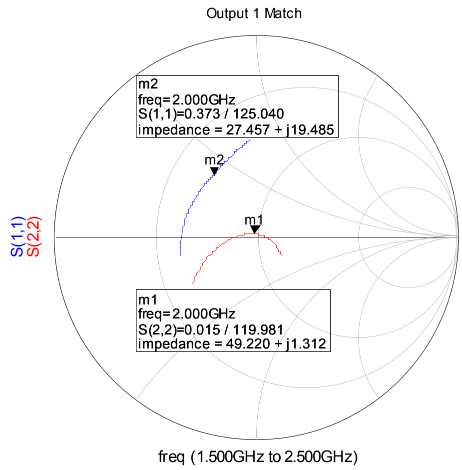
Datapoints

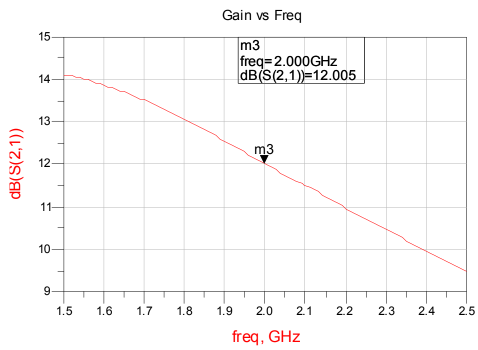
Start	Point	Z	Q	Frequency
☑	DP 1	(45.987 - j43.540) Ω	Q=0.947	2.0GHz
	TP 2	(49.173 + j43.248) Ω	Q=0.880	2.0GHz
	TP 3	(49.173 + j1.365) Ω	Q=0.028	2.0GHz

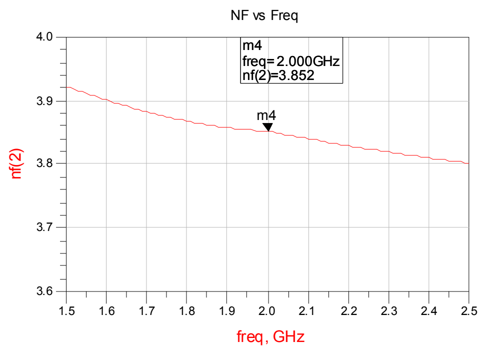
Simulation of LNA with Output matching network 1 versus Frequency in Agilent ADS:





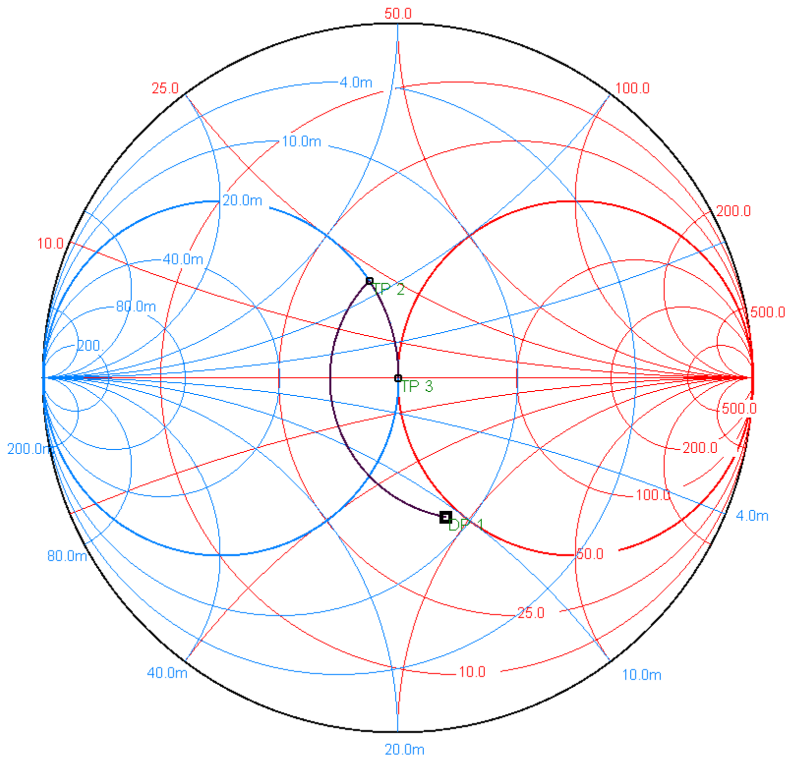


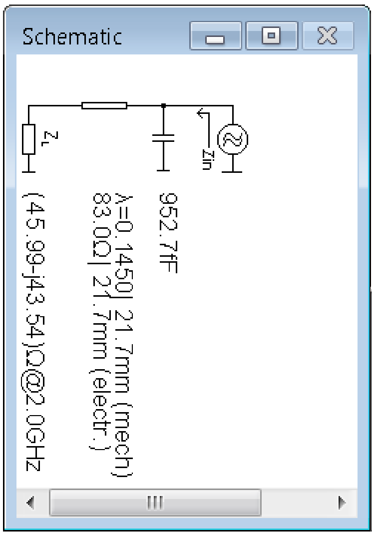


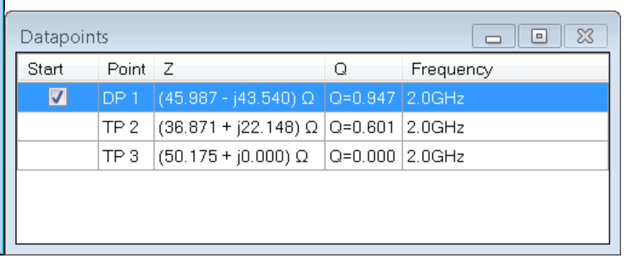


Problem: Output matching network 2

Smith project file: Example13-output2.xmlsc

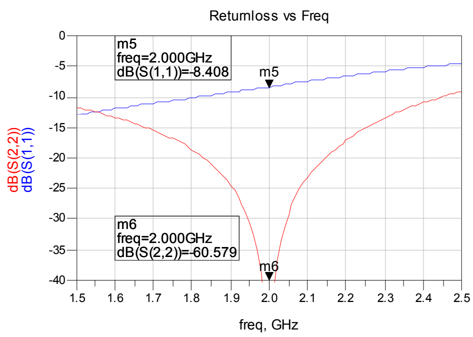


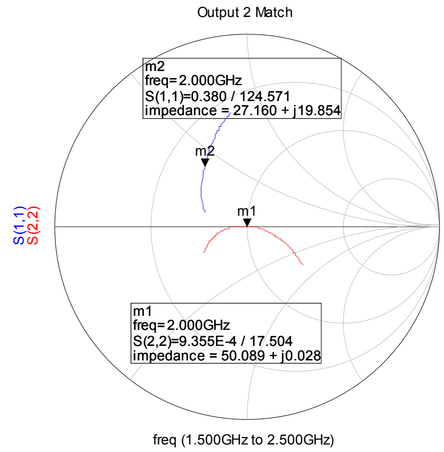


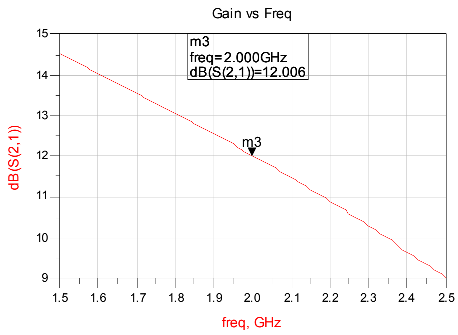


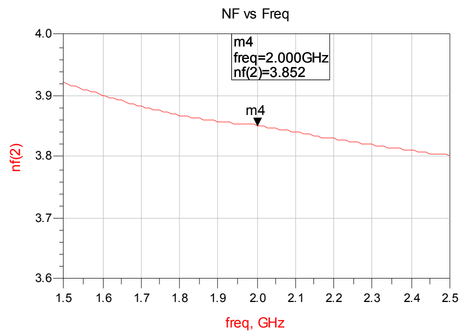
Start	Point	Z	Q	Frequency
☑	DP 1	(45.987 - j43.540) Ω	Q=0.947	2.0GHz
	TP 2	(36.871 + j22.148) Ω	Q=0.601	2.0GHz
	TP 3	(50.175 + j0.000) Ω	Q=0.000	2.0GHz

Simulation of LNA with Output matching network 2 versus Frequency in Agilent ADS:

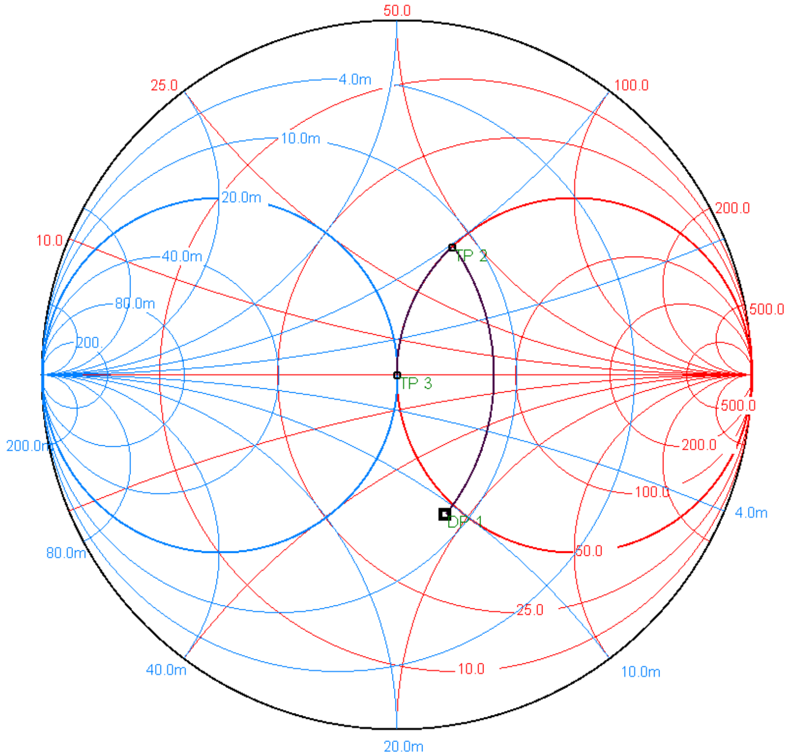


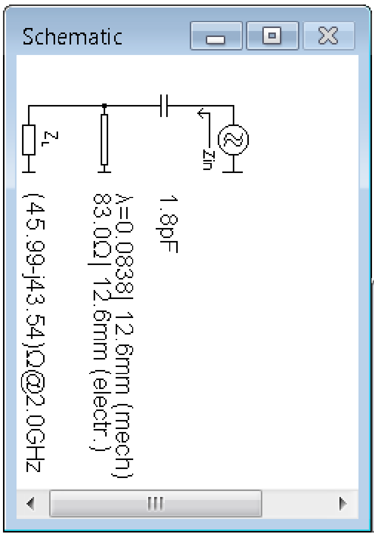


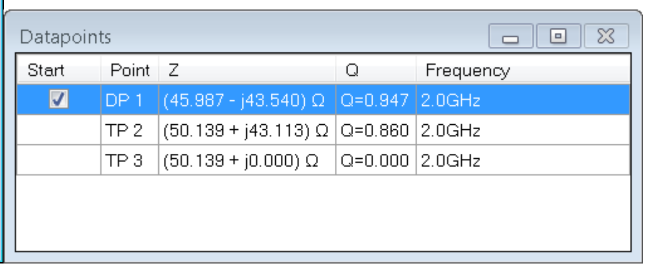




Problem: Output matching network 3
Smith project file: Example13-output3.xmlsc

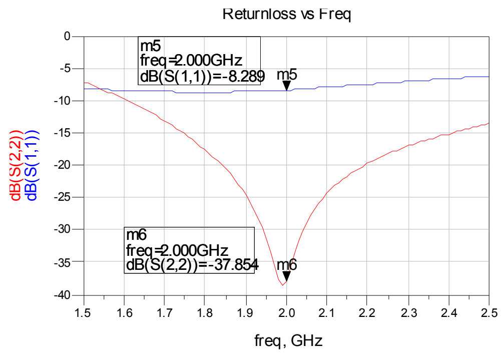


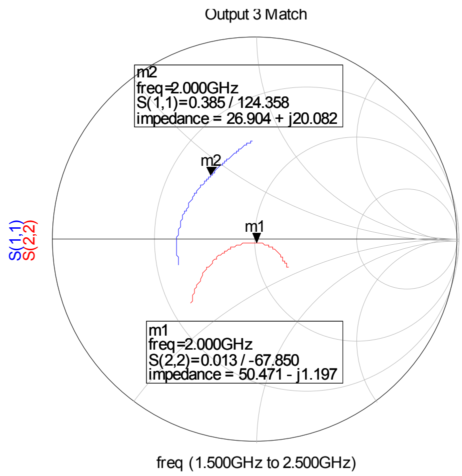


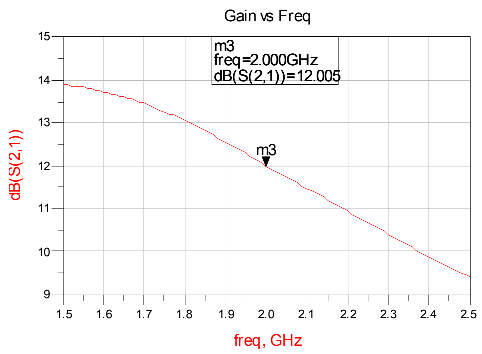

Datapoints

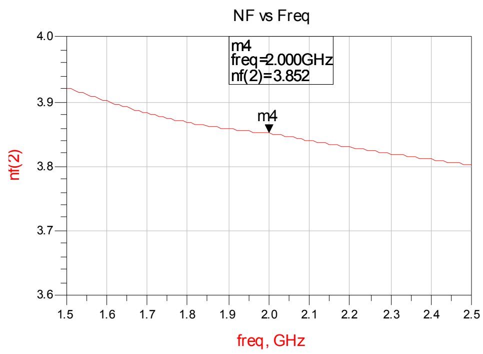
Start	Point	Z	Q	Frequency
☑	DP 1	(45.987 - j43.540) Ω	Q=0.947	2.0GHz
	TP 2	(50.139 + j43.113) Ω	Q=0.860	2.0GHz
	TP 3	(50.139 + j0.000) Ω	Q=0.000	2.0GHz

Simulation of LNA with Output matching network 3 versus Frequency in Agilent ADS:









Conjugate Matching

Example 14: Conjugate Match

Problem: Conjugately match impedance Z_1 (or Gamma Γ_1) to 50 Ohm.

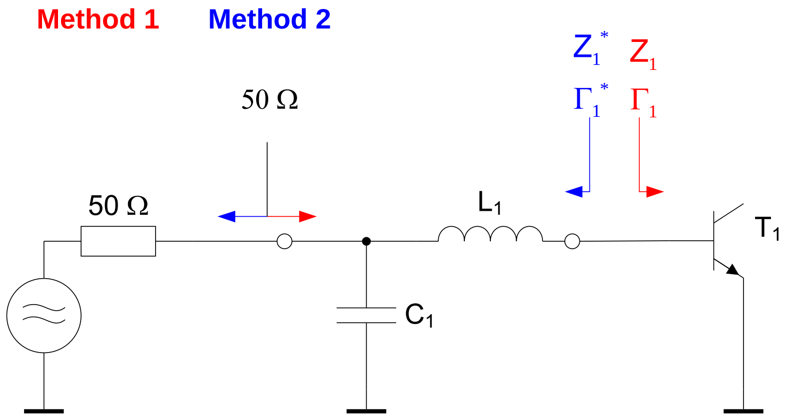
Method 1: Start at Z_1 and transform with network to 50 Ohm.

In this case Z_1 is used as load impedance for the network and after transformation we would like to see 50 Ohm at the input of the network.

Method 2: Start at 50 Ohm and transform with network to
Z_1^* = conjugate Z_1

In this case 50 Ohm is used as load impedance for the network and after transformation we would like to see Z_1^* into the input of the network.

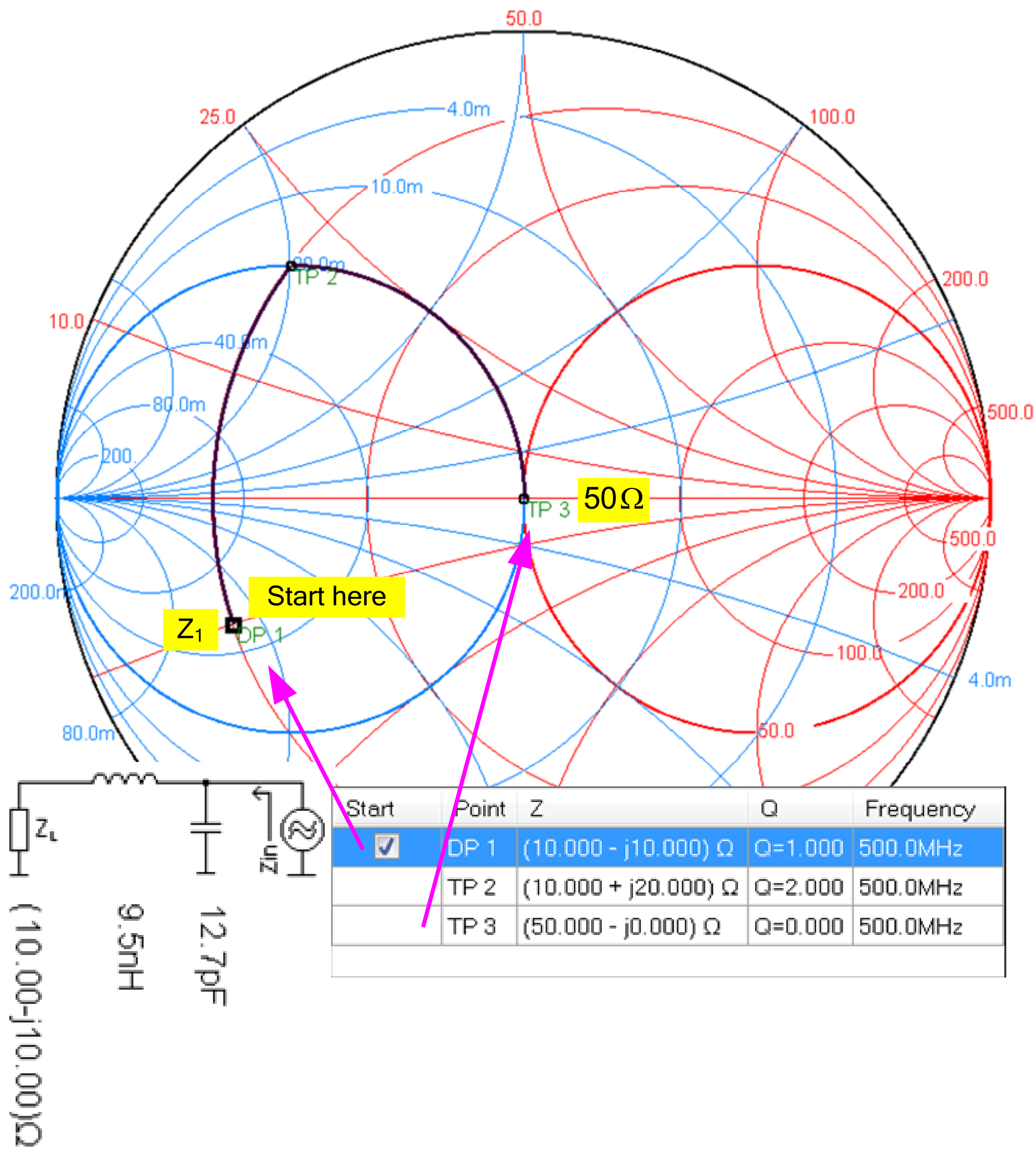
Both method result in the same network.



Example: $Z_1 = (10 - j10)\Omega$

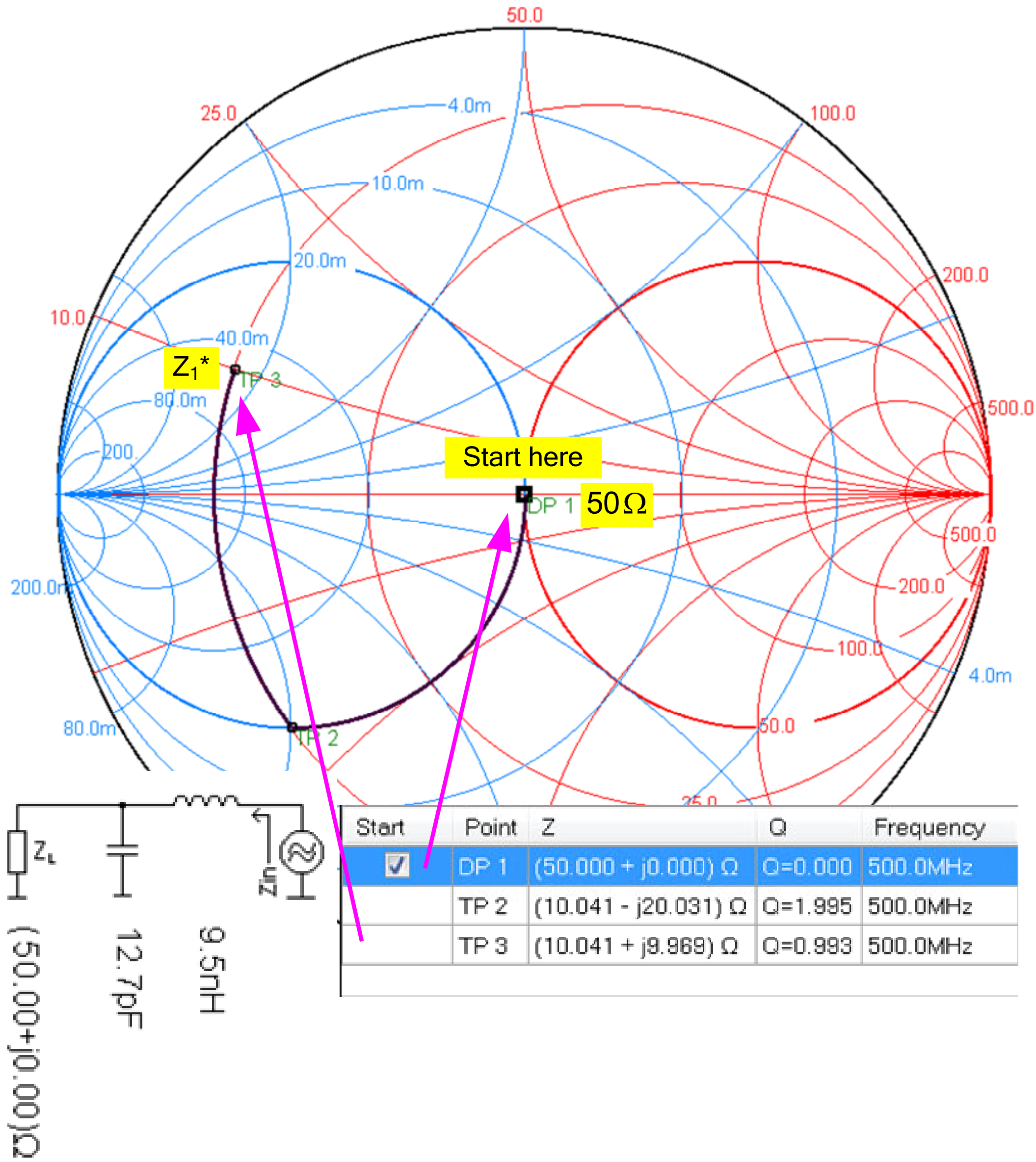
Method 1:

Smith project file: Example14-1.xmlsc



Start	Point	Z	Q	Frequency
☑	DP 1	(10.000 - j10.000) Ω	Q=1.000	500.0MHz
	TP 2	(10.000 + j20.000) Ω	Q=2.000	500.0MHz
	TP 3	(50.000 - j0.000) Ω	Q=0.000	500.0MHz

Method 2:
Smith project file: Example14-2.xmlsc



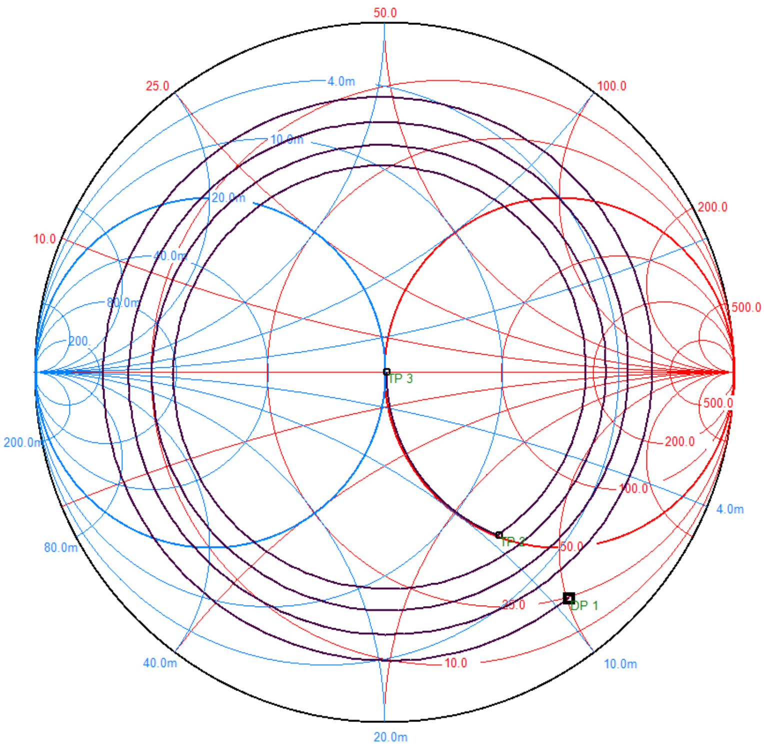
Start	Point	Z	Q	Frequency
☑	DP 1	(50.000 + j0.000) Ω	Q=0.000	500.0MHz
	TP 2	(10.041 - j20.031) Ω	Q=1.995	500.0MHz
	TP 3	(10.041 + j9.969) Ω	Q=0.993	500.0MHz

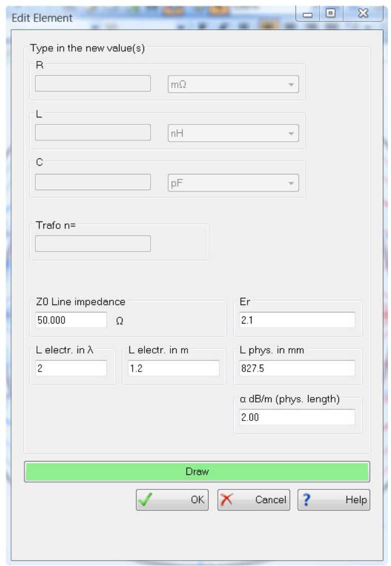
Serial Transmission Line with Attenuation

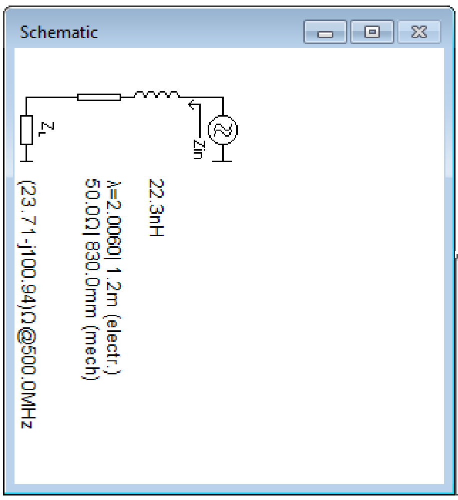
Example 15: Match using transmission line with loss

Problem: Match an impedance of (23.7 + j 101) Ohm to 50 Ohm using a lossy transmission line with an electrical length of about 2 wavelength, attenuation of 2 dB/m and a serial reactance. Frequency: 500 MHz

Smith project file: Example15.xmlsc







Datapoints

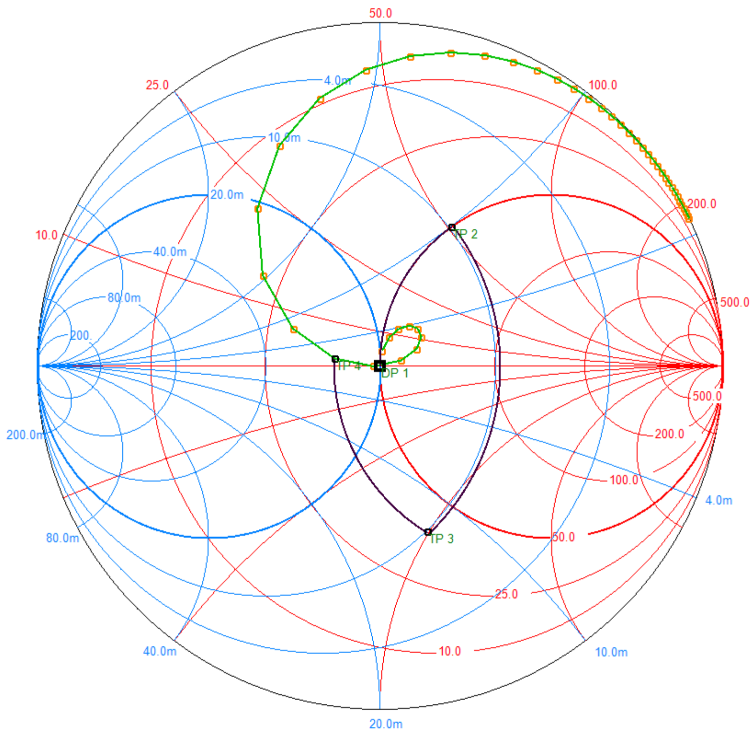
Start	Point	Z	Q	Frequency
☑	DP 1	(23.715 - j100.939) Ω	Q=4.256	500.0MHz
	TP 2	(50.751 - j69.766) Ω	Q=1.375	500.0MHz
	TP 3	(50.751 + j0.291) Ω	Q=0.006	500.0MHz

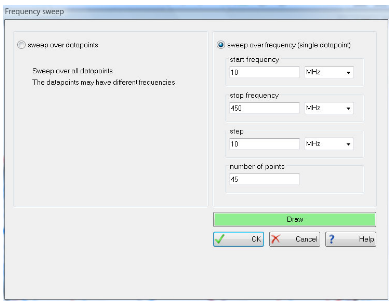
Sweeps

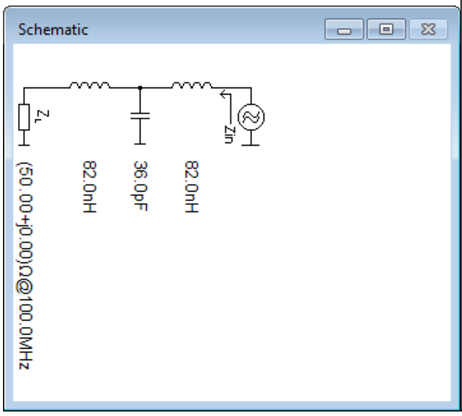
Example 16: Input impedance of a Chebyshev lowpass filter

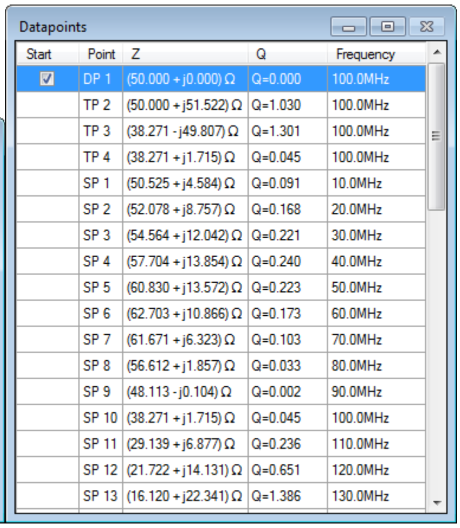
Problem: Plot input impedance of a 50 Ohm Chebyshev lowpass filter with n = 3, Ripple = 0.1 dB and cut-off frequency = 100 MHz
Frequency: 10 MHz to 450 MHz

Smith project file: Example16.xmlsc







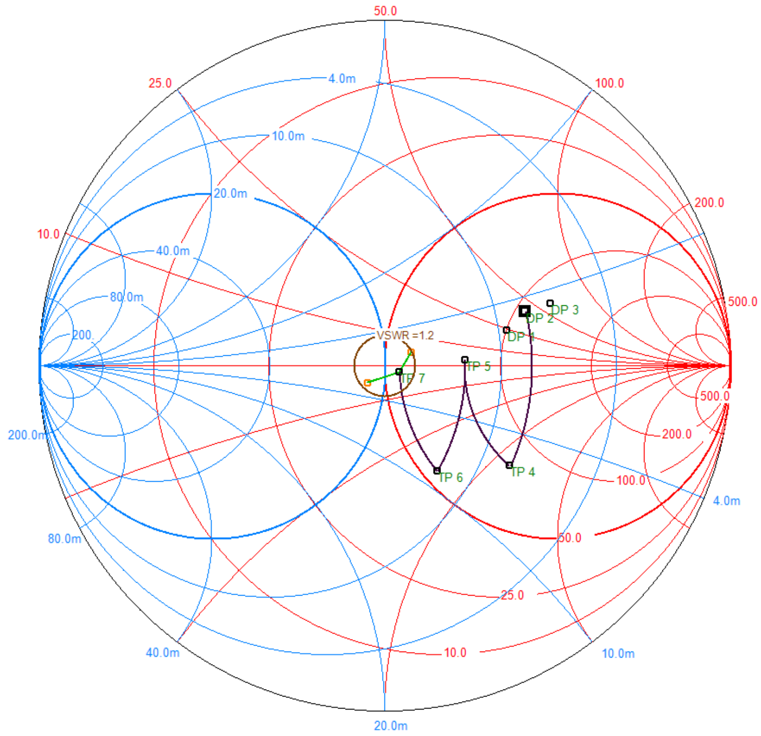

Datapoints

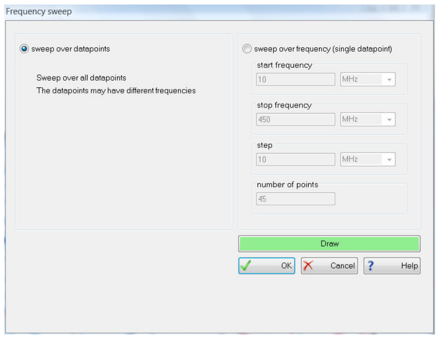
Start	Point	Z	Q	Frequency
☑	DP 1	(50.000 + j0.000) Ω	Q=0.000	100.0MHz
	TP 2	(50.000 + j51.522) Ω	Q=1.030	100.0MHz
	TP 3	(38.271 - j49.807) Ω	Q=1.301	100.0MHz
	TP 4	(38.271 + j1.715) Ω	Q=0.045	100.0MHz
	SP 1	(50.525 + j4.584) Ω	Q=0.091	10.0MHz
	SP 2	(52.078 + j8.757) Ω	Q=0.168	20.0MHz
	SP 3	(54.564 + j12.042) Ω	Q=0.221	30.0MHz
	SP 4	(57.704 + j13.854) Ω	Q=0.240	40.0MHz
	SP 5	(60.830 + j13.572) Ω	Q=0.223	50.0MHz
	SP 6	(62.703 + j10.866) Ω	Q=0.173	60.0MHz
	SP 7	(61.671 + j6.323) Ω	Q=0.103	70.0MHz
	SP 8	(56.612 + j1.857) Ω	Q=0.033	80.0MHz
	SP 9	(48.113 - j0.104) Ω	Q=0.002	90.0MHz
	SP 10	(38.271 + j1.715) Ω	Q=0.045	100.0MHz
	SP 11	(29.139 + j6.877) Ω	Q=0.236	110.0MHz
	SP 12	(21.722 + j14.131) Ω	Q=0.651	120.0MHz
	SP 13	(16.120 + j22.341) Ω	Q=1.386	130.0MHz

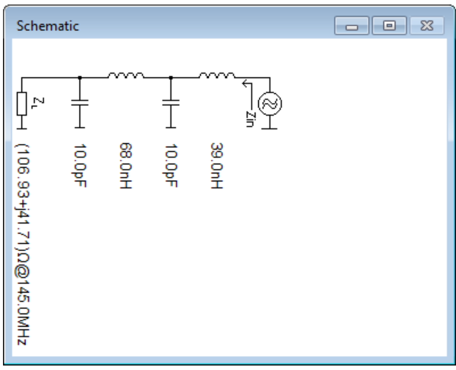
Example 17: Broadband load match

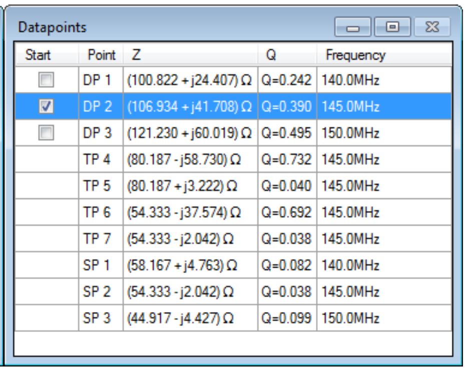
Problem: Given: Load impedance = (100.8+j24.2) Ohm @ 140 MHz, (106.9+j41.7) Ohm @ 145 MHz, (121.2+j60) Ohm @ 150 MHz
Find LC-lowpass network to match within VSWR of 1.2. Use standard component values as possible.
Frequency: 140 MHz to 150 MHz

Smith project file: Example17.xmlsc









Start	Point	Z	Q	Frequency
☐	DP 1	(100.822 + j24.407) Ω	Q=0.242	140.0MHz
☑	DP 2	(106.934 + j41.708) Ω	Q=0.390	145.0MHz
☐	DP 3	(121.230 + j60.019) Ω	Q=0.495	150.0MHz
	TP 4	(80.187 - j58.730) Ω	Q=0.732	145.0MHz
	TP 5	(80.187 + j3.222) Ω	Q=0.040	145.0MHz
	TP 6	(54.333 - j37.574) Ω	Q=0.692	145.0MHz
	TP 7	(54.333 - j2.042) Ω	Q=0.038	145.0MHz
	SP 1	(58.167 + j4.763) Ω	Q=0.082	140.0MHz
	SP 2	(54.333 - j2.042) Ω	Q=0.038	145.0MHz
	SP 3	(44.917 - j4.427) Ω	Q=0.099	150.0MHz