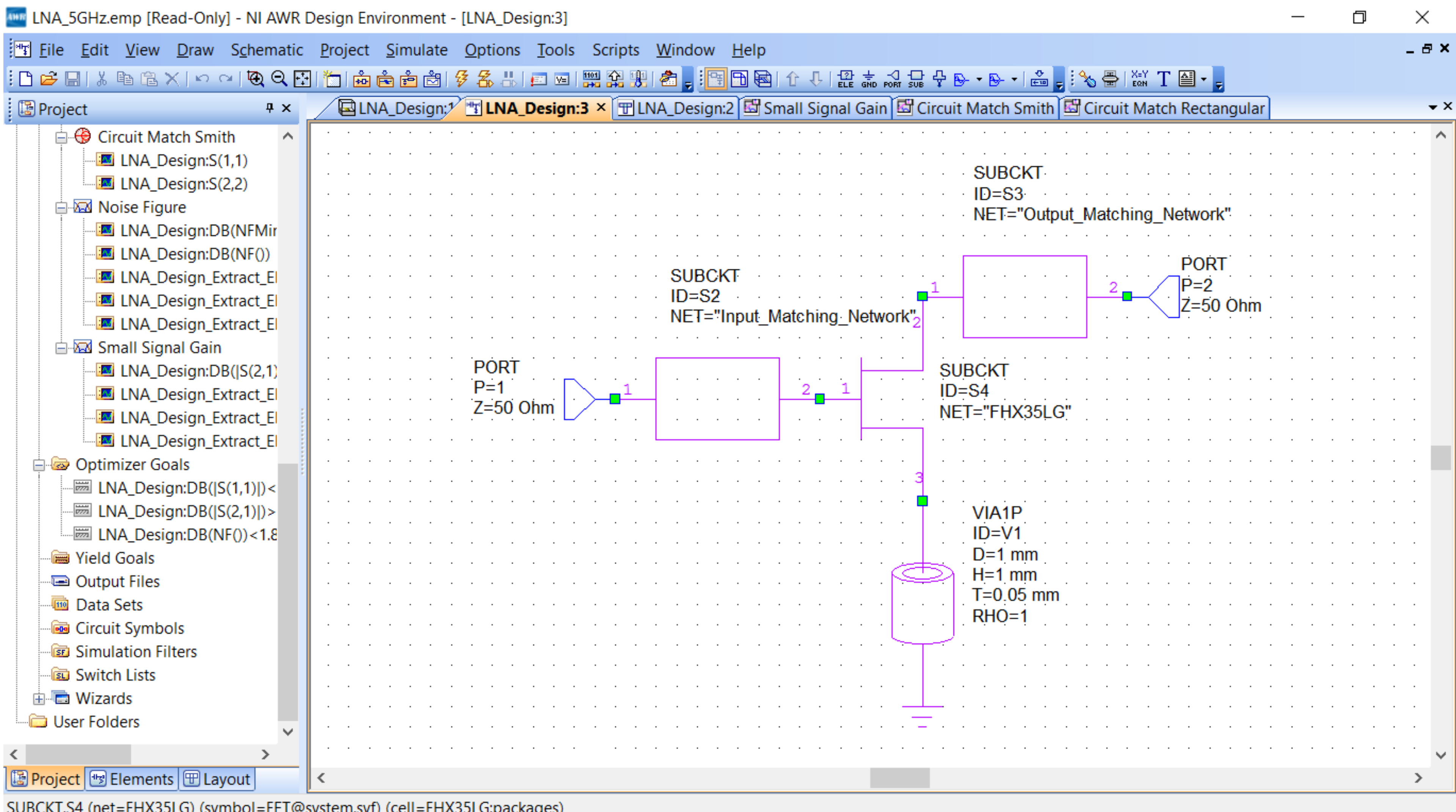
Diseño amplificador RF de pequeña señal para máxima ganancia usando AWR



- Diseño de amplificadores de RF
    - Diseño para máxima ganancia
        - Caso unilateral
        - Caso bilateral
    - Estabilidad
        - Estabilización del transistor
    - Diseño para una ganancia específica
    - Diseño para bajo ruido
    - Redes de polarización
    - RF chokes

Referencias

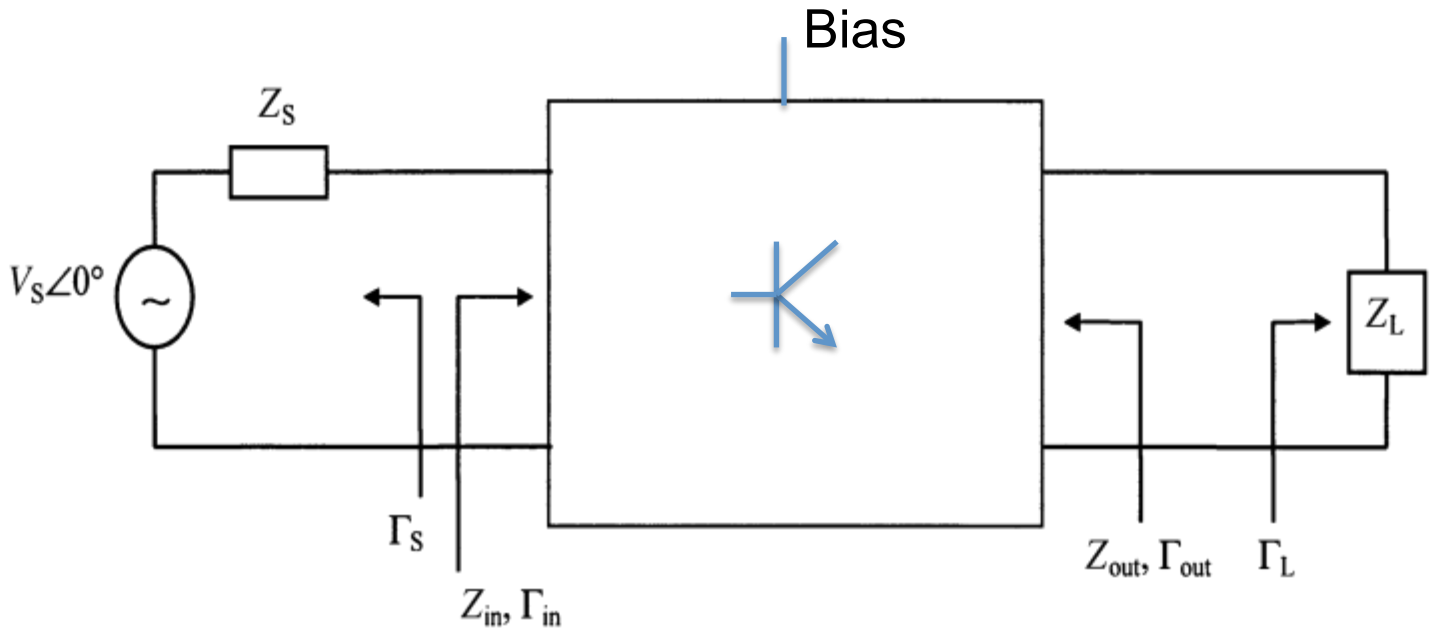
- [1] Guillermo Gonzalez, *Microwave Transistor Amplifiers, Analysis and Design, 2nd ed.*; Prentice Hall, 1996.

- [2] Devendra K. Misra, *Radio-Frequency and Microwave Communication Circuits*; John Wiley & Sons Inc., 2001

- [3] Cornelis J. Kikkert, RF Electronics. Design and Simulation, James Cook University, Australia, 2013

- [4] Sören Peik, Amplifier Design for MG using MWO, 2016.

Estabilidad



Condiciones necesarias y suficientes de estabilidad incondicional

$$|\Delta| = |S_{11}S_{22} - S_{12}S_{21}| < 1 \tag{1}$$

$$k = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}S_{21}|} > 1 \tag{2}$$

Estabilidad

Círculos de estabilidad de salida de Γ_L para $\left|\Gamma_{IN}\right| = 1$

$$r_L = \left| \frac{S_{12}S_{21}}{\left|S_{22}\right|^2 - \left|\Delta\right|^2} \right| \qquad (3)$$

$$C_L = \frac{\left(S_{22} - \Delta S_{11}^*\right)^*}{\left|S_{22}\right|^2 - \left|\Delta\right|^2} \qquad (4)$$

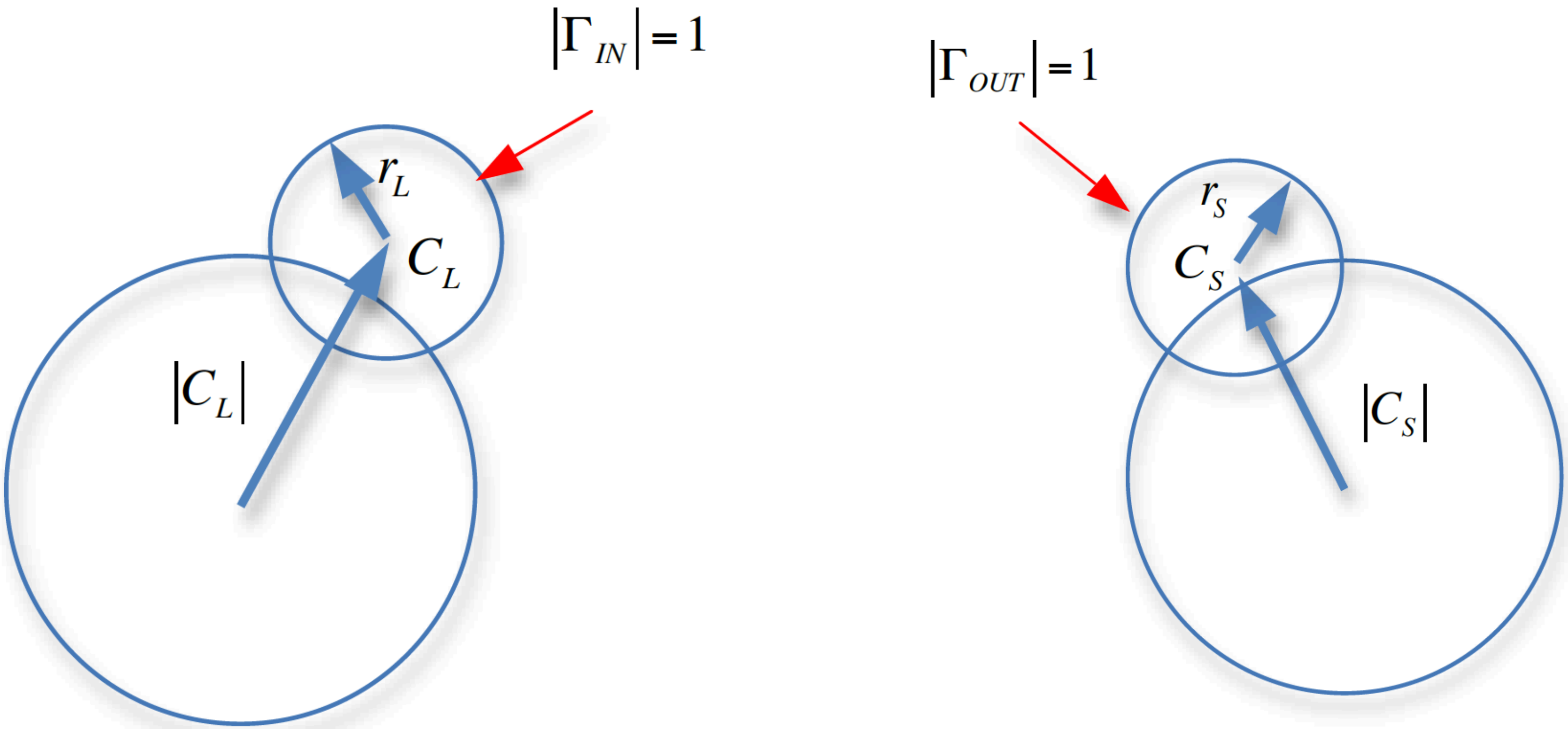
Estabilidad

Círculos de estabilidad de salida de Γ_S para $\left|\Gamma_{OUT}\right| = 1$

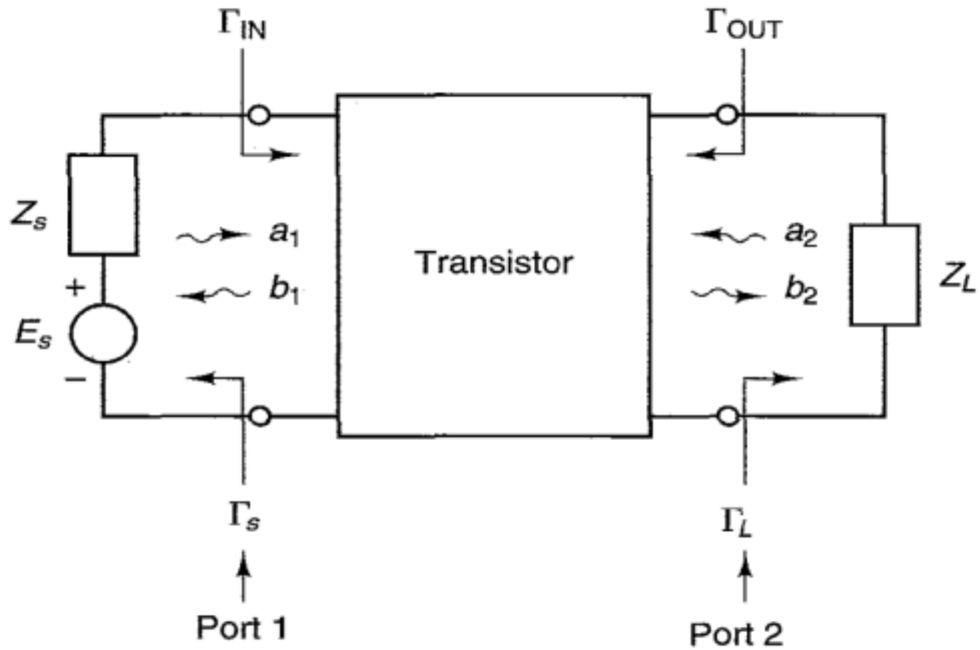
$$r_S = \left| \frac{S_{12} S_{21}}{\left|S_{11}\right|^2 - \left|\Delta\right|^2} \right| \tag{5}$$

$$C_S = \frac{\left(S_{11} - \Delta S_{22}^*\right)^*}{\left|S_{11}\right|^2 - \left|\Delta\right|^2} \tag{6}$$

Estabilidad



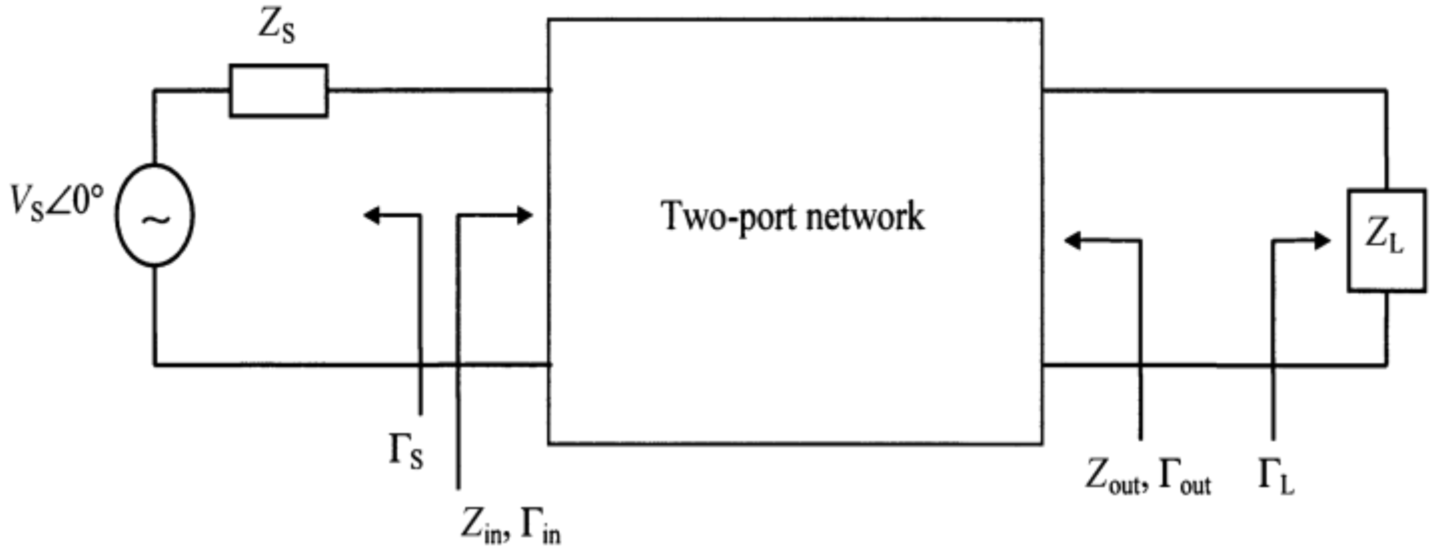
Maximización de la ganancia



$$\Gamma_{in} = \frac{b_1}{a_1} = S_{11} + \frac{\Gamma_L S_{21} S_{12}}{1 - \Gamma_L S_{22}} \tag{7}$$

$$\Gamma_{out} = \frac{b_2}{a_2} = S_{22} + \frac{\Gamma_S S_{21} S_{12}}{1 - \Gamma_S S_{11}} \tag{8}$$

Maximización de la ganancia



$$G_S = \frac{1-|\Gamma_S|^2}{|1-\Gamma_{in}\Gamma_S|^2}, \qquad G_0 = |S_{21}|^2, \qquad G_L = \frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2}$$

Ganancia del transductor

$$G_T = G_S G_0 G_L \tag{9}$$

Diseño para máxima ganancia (adapt. conjugada)

- Dado un transistor, se fija la ganancia G_0
- La ganancia total del amplificador se determina por G_S y G_L
- La máxima ganancia está dada por

$$\Gamma_{in} = \Gamma_S^*, \tag{10}$$

$$\Gamma_{out} = \Gamma_L^*, \tag{11}$$

Asumiendo adaptaciones sin pérdidas

$$G_{T\,\max} = \frac{1}{\left|1-\Gamma_S\right|^2}\left|S_{21}\right|^2 \frac{1-\left|\Gamma_L\right|^2}{\left|1-S_{22}\Gamma_L\right|^2} \tag{12}$$

- Diseño de amplificadores de RF
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  - Diseño para bajo ruido
  - Redes de polarización
  - RF chokes

Diseño para máxima ganancia (adapt. conjugada)

- Dado un transistor, se fija la ganancia G_0
- La ganancia total del amplificador se determina por G_S y G_L
- La máxima ganancia está dada por

$$\Gamma_S^* = \Gamma_{in} = S_{11} \tag{13}$$

$$\Gamma_L^* = \Gamma_{out} = S_{22} \tag{14}$$

Asumiendo adaptaciones sin pérdidas

$$G_{T\max} = \frac{1}{\left|1 - S_{11}\right|^2} \left|S_{21}\right|^2 \frac{1}{\left|1 - S_{22}\right|^2} \tag{15}$$

- Diseño de amplificadores de RF
  - Estabilidad
    - Estabilización del transistor
  - Diseño para máxima ganancia
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  - Redes de polarización
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Máxima ganancia – caso bilateral

En el caso de un transistor bilateral, Γ_{in} es afectada por Γ_{out} y viseversa. Las ecuaciones son

$$\Gamma_S^* = \Gamma_{in} = S_{11} + \frac{\Gamma_L S_{21} S_{12}}{1 - \Gamma_L S_{22}} \tag{16}$$

$$\Gamma_L^* = \Gamma_{out} = S_{22} + \frac{\Gamma_S S_{21} S_{12}}{1 - \Gamma_S S_{11}} \tag{17}$$

Máxima ganancia – caso bilateral

$$\Gamma_S = \Gamma_{MS} = \frac{B_1 \pm \sqrt{B_1^2 - 4\left|C_1\right|^2}}{2C_1} \tag{18}$$

$$\Gamma_L = \Gamma_{ML} = \frac{B_2 \pm \sqrt{B_2^2 - 4\left|C_2\right|^2}}{2C_2} \tag{19}$$

Donde B1, C1, B2 y C2 son

$$\Delta = S_{11}S_{22} - S_{12}S_{21}$$

$$B_1 = 1 + \left|S_{11}\right|^2 - \left|S_{22}\right|^2 - \left|\Delta\right|^2 \tag{20}$$

$$B_2 = 1 + \left|S_{22}\right|^2 - \left|S_{11}\right|^2 - \left|\Delta\right|^2 \tag{21}$$

$$C_1 = S_{11} - S_{22}^*\Delta \tag{22}$$

$$C_2 = S_2 - S_{11}^*\Delta \tag{23}$$

Máxima ganancia – caso bilateral

$$G_S = \frac{1-|\Gamma_S|^2}{|1-\Gamma_{in}\Gamma_S|^2} = \frac{1-|\Gamma_S|^2}{|1-\Gamma_S^*\Gamma_S|^2} = \frac{1}{1-|\Gamma_S|^2} \tag{24}$$

$$G_0 = |S_{21}|^2 \tag{25}$$

$$G_L = \frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \tag{26}$$

Ejemplo. Especificaciones

BFP540

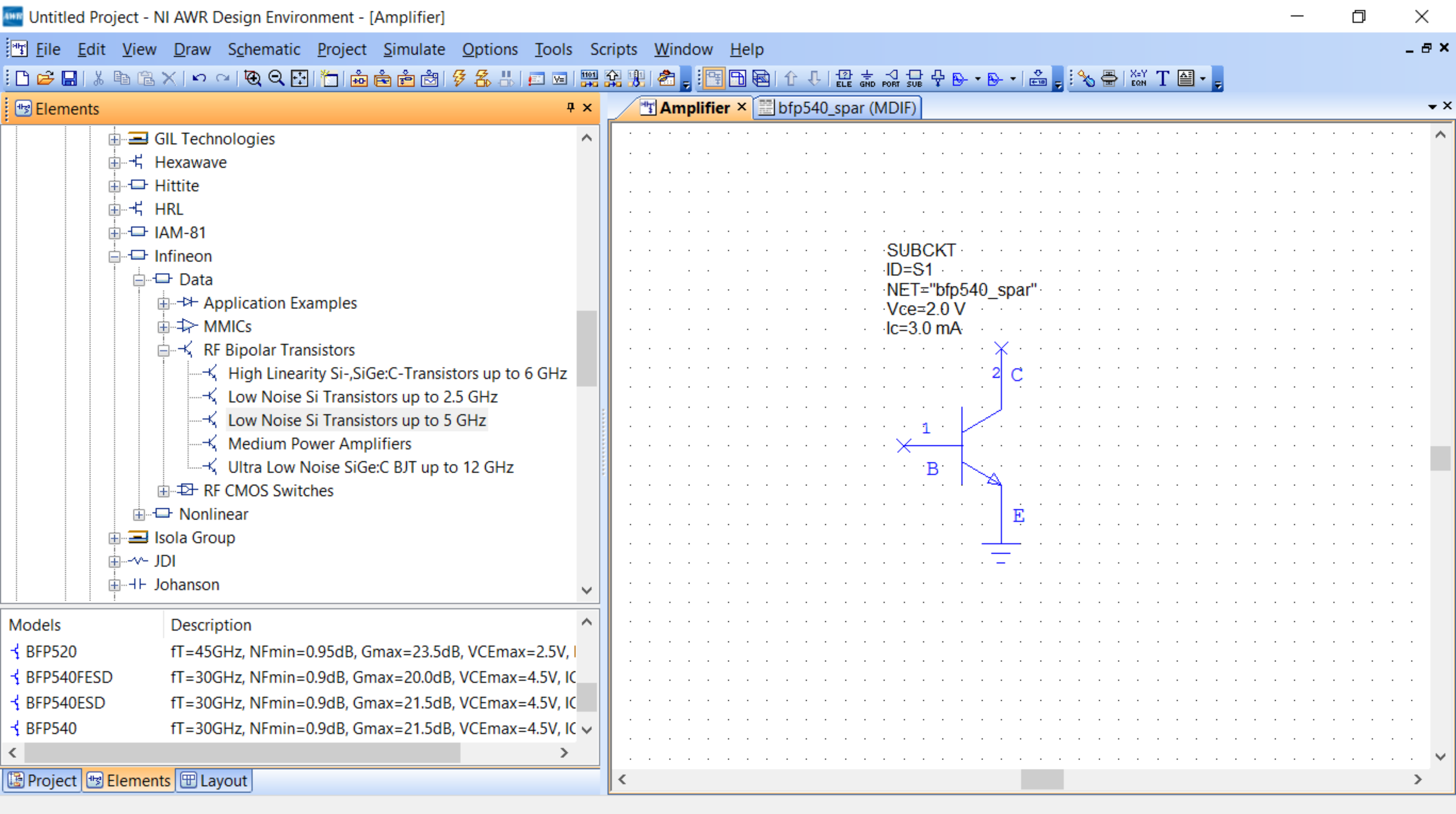
Low Noise Silicon Bipolar RF Transistor

- For highest gain and low noise amplifier
- Outstanding G_{ms} = 21.5 dB at 1.8 GHz
  Minimum noise figure NF_{min} = 0.9 dB at 1.8 GHz
- Pb-free (RoHS compliant) and halogen-free package
  with visible leads
- Qualification report according to AEC-Q101 available

Ejemplo. Especificaciones

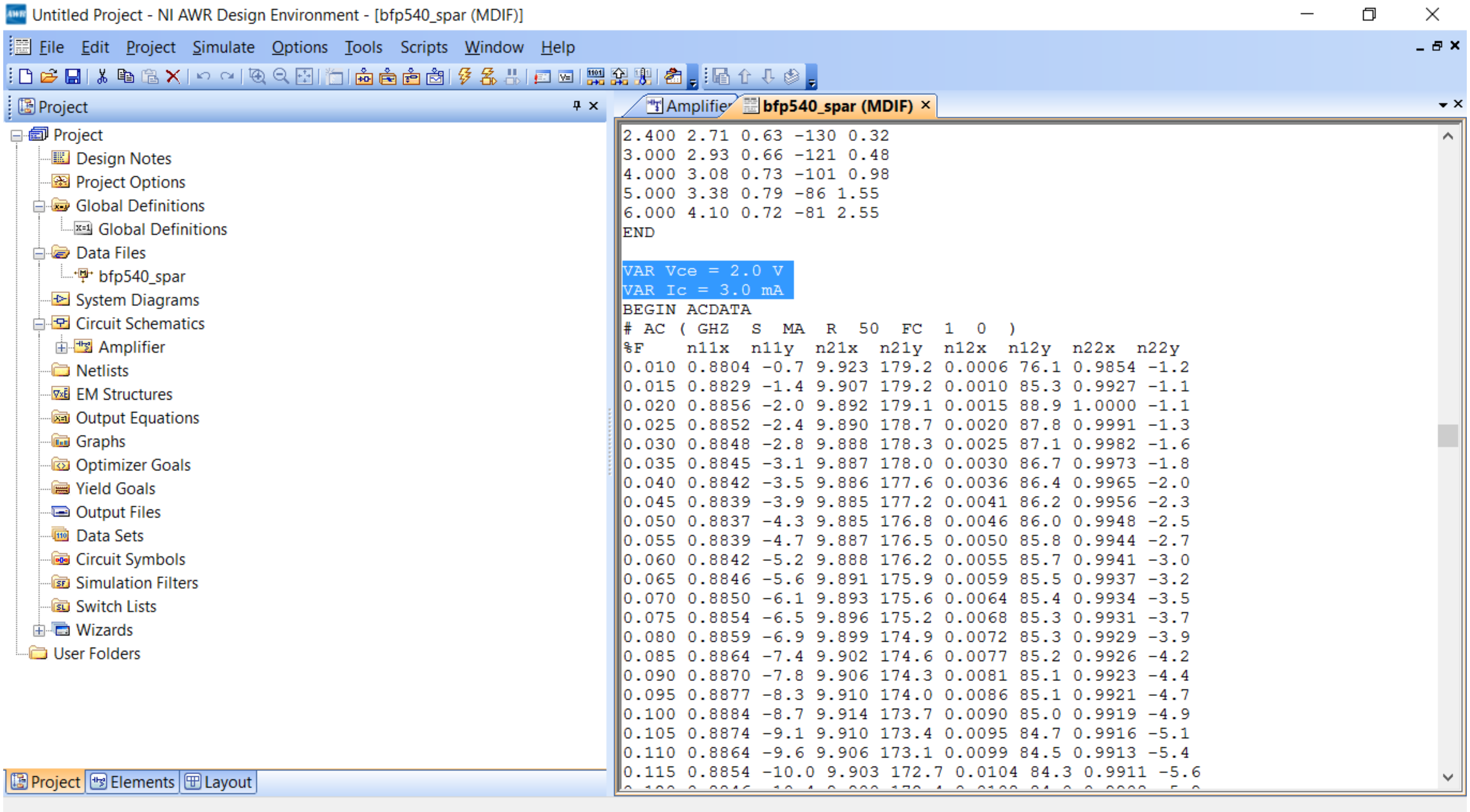
- Transistor Infineon BPF540
- Diseño de máxima ganancia
- Frecuencia, 5GHz
- Punto de polarización VCE=2V, Ic=3mA

Ejemplo. AWR



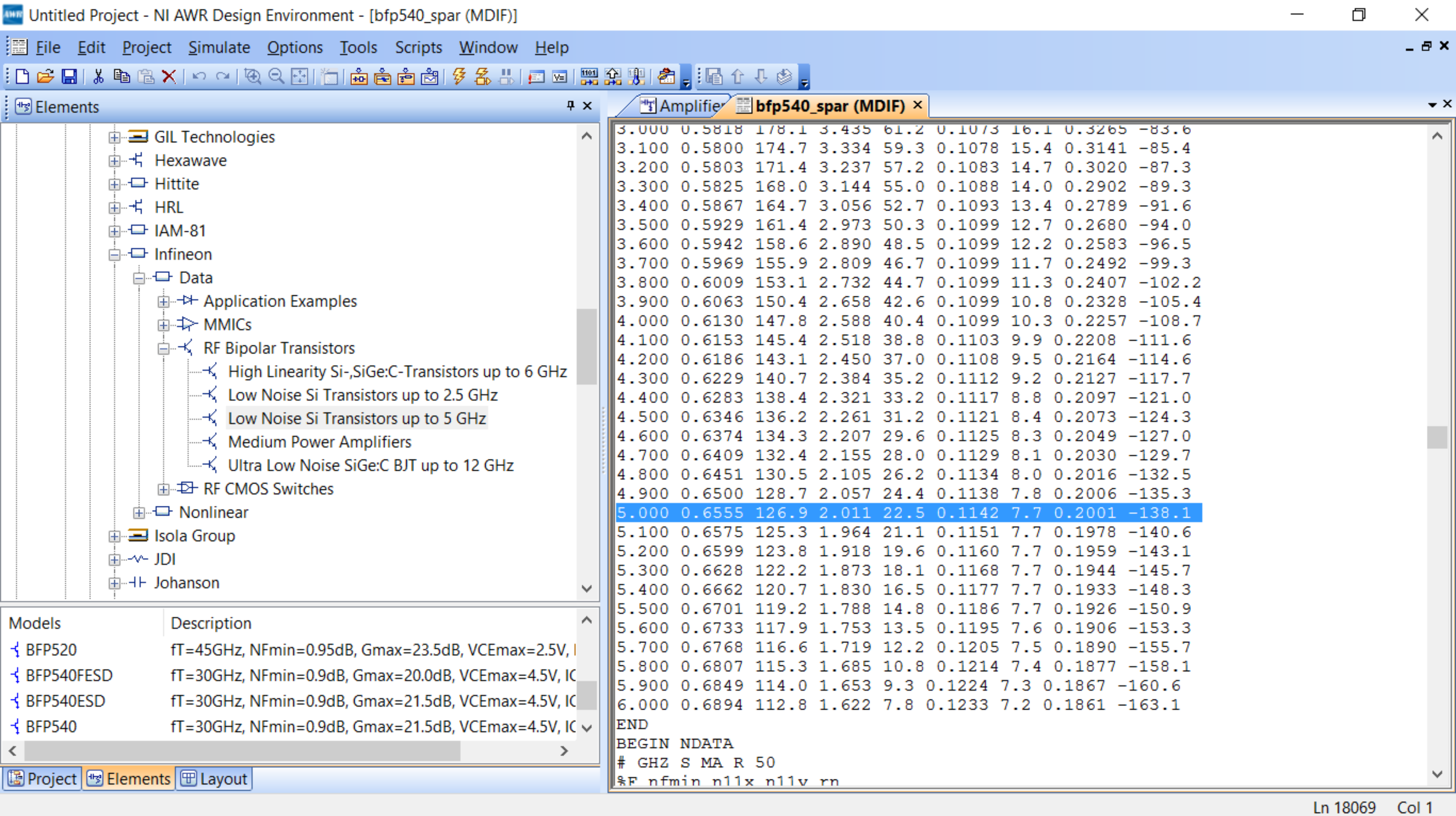
Untitled Project - NI AWR Design Environment - [Amplifier]
File Edit View Draw Schematic Project Simulate Options Tools Scripts Window Help
Elements
GIL Technologies
Hexawave
Hittite
HRL
IAM-81
Infineon
Data
Application Examples
MMICs
RF Bipolar Transistors
High Linearity Si-,SiGe:C-Transistors up to 6 GHz
Low Noise Si Transistors up to 2.5 GHz
Low Noise Si Transistors up to 5 GHz
Medium Power Amplifiers
Ultra Low Noise SiGe:C BJT up to 12 GHz
RF CMOS Switches
Nonlinear
Isola Group
JDI
Johanson
Models
Description
BFP520
fT=45GHz, NFmin=0.95dB, Gmax=23.5dB, VCEmax=2.5V,
BFP540FESD
fT=30GHz, NFmin=0.9dB, Gmax=20.0dB, VCEmax=4.5V,
BFP540ESD
fT=30GHz, NFmin=0.9dB, Gmax=21.5dB, VCEmax=4.5V,
BFP540
fT=30GHz, NFmin=0.9dB, Gmax=21.5dB, VCEmax=4.5V,
Project
Elements
Layout
Amplifier
bfp540_spar (MDIF)
SUBCKT
ID=S1
NET="bfp540_spar"
Vce=2.0 V
Ic=3.0 mA
2
C
1
B
E

Ejemplo. AWR



Untitled Project - NI AWR Design Environment - [bfp540_spar (MDIF)]
File Edit Project Simulate Options Tools Scripts Window Help
Project
Project
Design Notes
Project Options
Global Definitions
Global Definitions
Data Files
bfp540_spar
System Diagrams
Circuit Schematics
Amplifier
Netlists
EM Structures
Output Equations
Graphs
Optimizer Goals
Yield Goals
Output Files
Data Sets
Circuit Symbols
Simulation Filters
Switch Lists
Wizards
User Folders
Project Elements Layout
Amplifier
bfp540_spar (MDIF)
2.400 2.71 0.63 -130 0.32
3.000 2.93 0.66 -121 0.48
4.000 3.08 0.73 -101 0.98
5.000 3.38 0.79 -86 1.55
6.000 4.10 0.72 -81 2.55
END
VAR Vce = 2.0 V
VAR Ic = 3.0 mA
BEGIN ACDATA
AC (GHZ S MA R 50 FC 1 0)
%F n11x n11y n21x n21y n12x n12y n22x n22y
0.010 0.8804 -0.7 9.923 179.2 0.0006 76.1 0.9854 -1.2
0.015 0.8829 -1.4 9.907 179.2 0.0010 85.3 0.9927 -1.1
0.020 0.8856 -2.0 9.892 179.1 0.0015 88.9 1.0000 -1.1
0.025 0.8852 -2.4 9.890 178.7 0.0020 87.8 0.9991 -1.3
0.030 0.8848 -2.8 9.888 178.3 0.0025 87.1 0.9982 -1.6
0.035 0.8845 -3.1 9.887 178.0 0.0030 86.7 0.9973 -1.8
0.040 0.8842 -3.5 9.886 177.6 0.0036 86.4 0.9965 -2.0
0.045 0.8839 -3.9 9.885 177.2 0.0041 86.2 0.9956 -2.3
0.050 0.8837 -4.3 9.885 176.8 0.0046 86.0 0.9948 -2.5
0.055 0.8839 -4.7 9.887 176.5 0.0050 85.8 0.9944 -2.7
0.060 0.8842 -5.2 9.888 176.2 0.0055 85.7 0.9941 -3.0
0.065 0.8846 -5.6 9.891 175.9 0.0059 85.5 0.9937 -3.2
0.070 0.8850 -6.1 9.893 175.6 0.0064 85.4 0.9934 -3.5
0.075 0.8854 -6.5 9.896 175.2 0.0068 85.3 0.9931 -3.7
0.080 0.8859 -6.9 9.899 174.9 0.0072 85.3 0.9929 -3.9
0.085 0.8864 -7.4 9.902 174.6 0.0077 85.2 0.9926 -4.2
0.090 0.8870 -7.8 9.906 174.3 0.0081 85.1 0.9923 -4.4
0.095 0.8877 -8.3 9.910 174.0 0.0086 85.1 0.9921 -4.7
0.100 0.8884 -8.7 9.914 173.7 0.0090 85.0 0.9919 -4.9
0.105 0.8874 -9.1 9.910 173.4 0.0095 84.7 0.9916 -5.1
0.110 0.8864 -9.6 9.906 173.1 0.0099 84.5 0.9913 -5.4
0.115 0.8854 -10.0 9.903 172.7 0.0104 84.3 0.9911 -5.6

Ejemplo. AWR



Untitled Project - NI AWR Design Environment - [bfp540_spar (MDIF)]
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Elements
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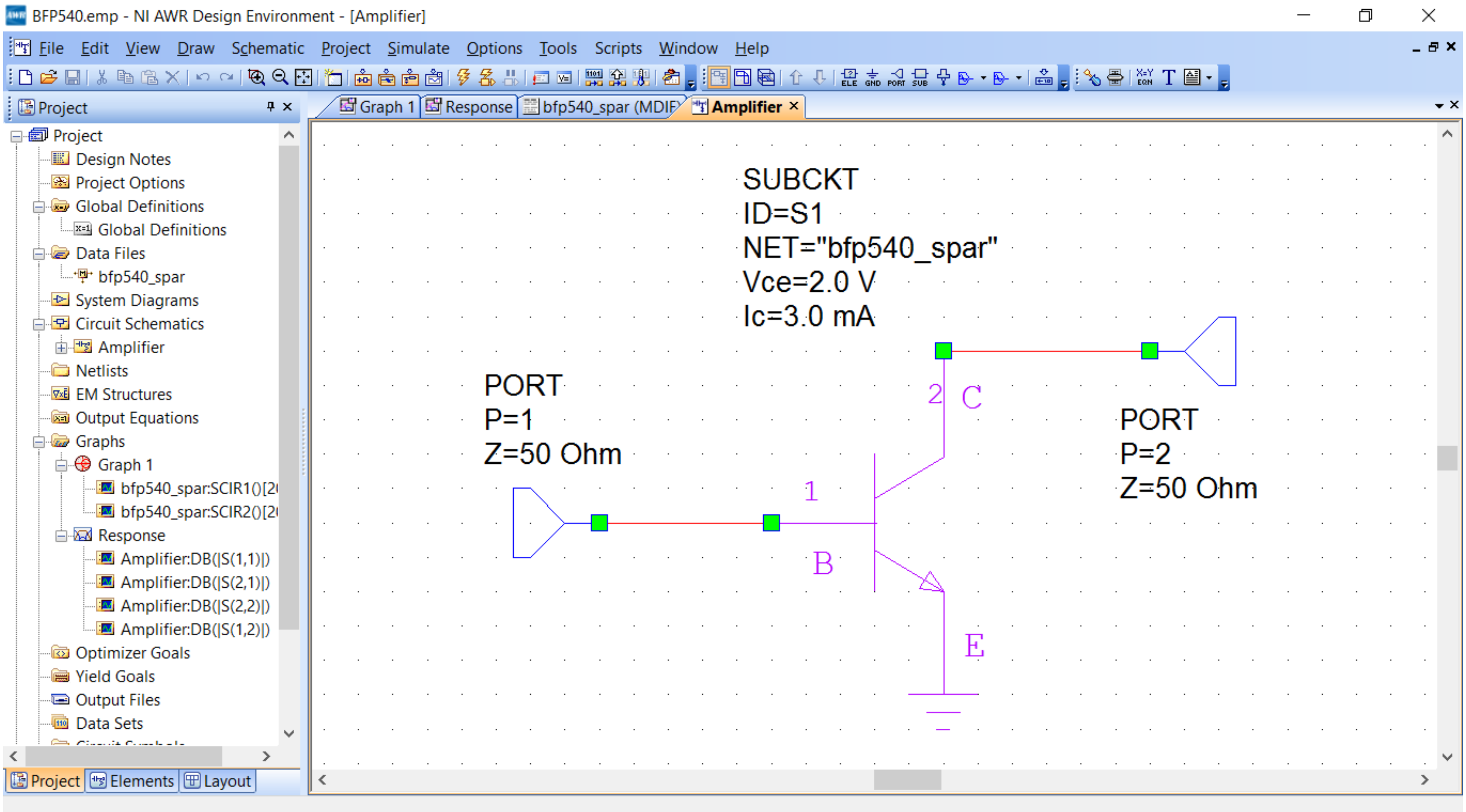
BFP540FESD
fT=30GHz, NFmin=0.9dB, Gmax=20.0dB, VCEmax=4.5V, IC
BFP540ESD
fT=30GHz, NFmin=0.9dB, Gmax=21.5dB, VCEmax=4.5V, IC
BFP540
fT=30GHz, NFmin=0.9dB, Gmax=21.5dB, VCEmax=4.5V, IC
Project
Elements
Layout
Amplifier
bfp540_spar (MDIF)
3.100 0.5800 174.7 3.334 59.3 0.1078 15.4 0.3141 -85.4
3.200 0.5803 171.4 3.237 57.2 0.1083 14.7 0.3020 -87.3
3.300 0.5825 168.0 3.144 55.0 0.1088 14.0 0.2902 -89.3
3.400 0.5867 164.7 3.056 52.7 0.1093 13.4 0.2789 -91.6
3.500 0.5929 161.4 2.973 50.3 0.1099 12.7 0.2680 -94.0
3.600 0.5942 158.6 2.890 48.5 0.1099 12.2 0.2583 -96.5
3.700 0.5969 155.9 2.809 46.7 0.1099 11.7 0.2492 -99.3
3.800 0.6009 153.1 2.732 44.7 0.1099 11.3 0.2407 -102.2
3.900 0.6063 150.4 2.658 42.6 0.1099 10.8 0.2328 -105.4
4.000 0.6130 147.8 2.588 40.4 0.1099 10.3 0.2257 -108.7
4.100 0.6153 145.4 2.518 38.8 0.1103 9.9 0.2208 -111.6
4.200 0.6186 143.1 2.450 37.0 0.1108 9.5 0.2164 -114.6
4.300 0.6229 140.7 2.384 35.2 0.1112 9.2 0.2127 -117.7
4.400 0.6283 138.4 2.321 33.2 0.1117 8.8 0.2097 -121.0
4.500 0.6346 136.2 2.261 31.2 0.1121 8.4 0.2073 -124.3
4.600 0.6374 134.3 2.207 29.6 0.1125 8.3 0.2049 -127.0
4.700 0.6409 132.4 2.155 28.0 0.1129 8.1 0.2030 -129.7
4.800 0.6451 130.5 2.105 26.2 0.1134 8.0 0.2016 -132.5
4.900 0.6500 128.7 2.057 24.4 0.1138 7.8 0.2006 -135.3
5.000 0.6555 126.9 2.011 22.5 0.1142 7.7 0.2001 -138.1
5.100 0.6575 125.3 1.964 21.1 0.1151 7.7 0.1978 -140.6
5.200 0.6599 123.8 1.918 19.6 0.1160 7.7 0.1959 -143.1
5.300 0.6628 122.2 1.873 18.1 0.1168 7.7 0.1944 -145.7
5.400 0.6662 120.7 1.830 16.5 0.1177 7.7 0.1933 -148.3
5.500 0.6701 119.2 1.788 14.8 0.1186 7.7 0.1926 -150.9
5.600 0.6733 117.9 1.753 13.5 0.1195 7.6 0.1906 -153.3
5.700 0.6768 116.6 1.719 12.2 0.1205 7.5 0.1890 -155.7
5.800 0.6807 115.3 1.685 10.8 0.1214 7.4 0.1877 -158.1
5.900 0.6849 114.0 1.653 9.3 0.1224 7.3 0.1867 -160.6
6.000 0.6894 112.8 1.622 7.8 0.1233 7.2 0.1861 -163.1
END
BEGIN NDATA
GHZ S MA R 50
Ln 18069 Col 1

Ejemplo Transistor Infineon BPF540

BPF540 a 5GHz, V_{CE}=2V, I_C=3mA (50 Ω)				
F(GHz)	S_{11}	S_{12}	S_{21}	S_{22}
5.0	$0.6556\angle 126.9°$	$0.114\angle 7.7°$	$2.011\angle 22.5°$	$0.200\angle -138.1°$

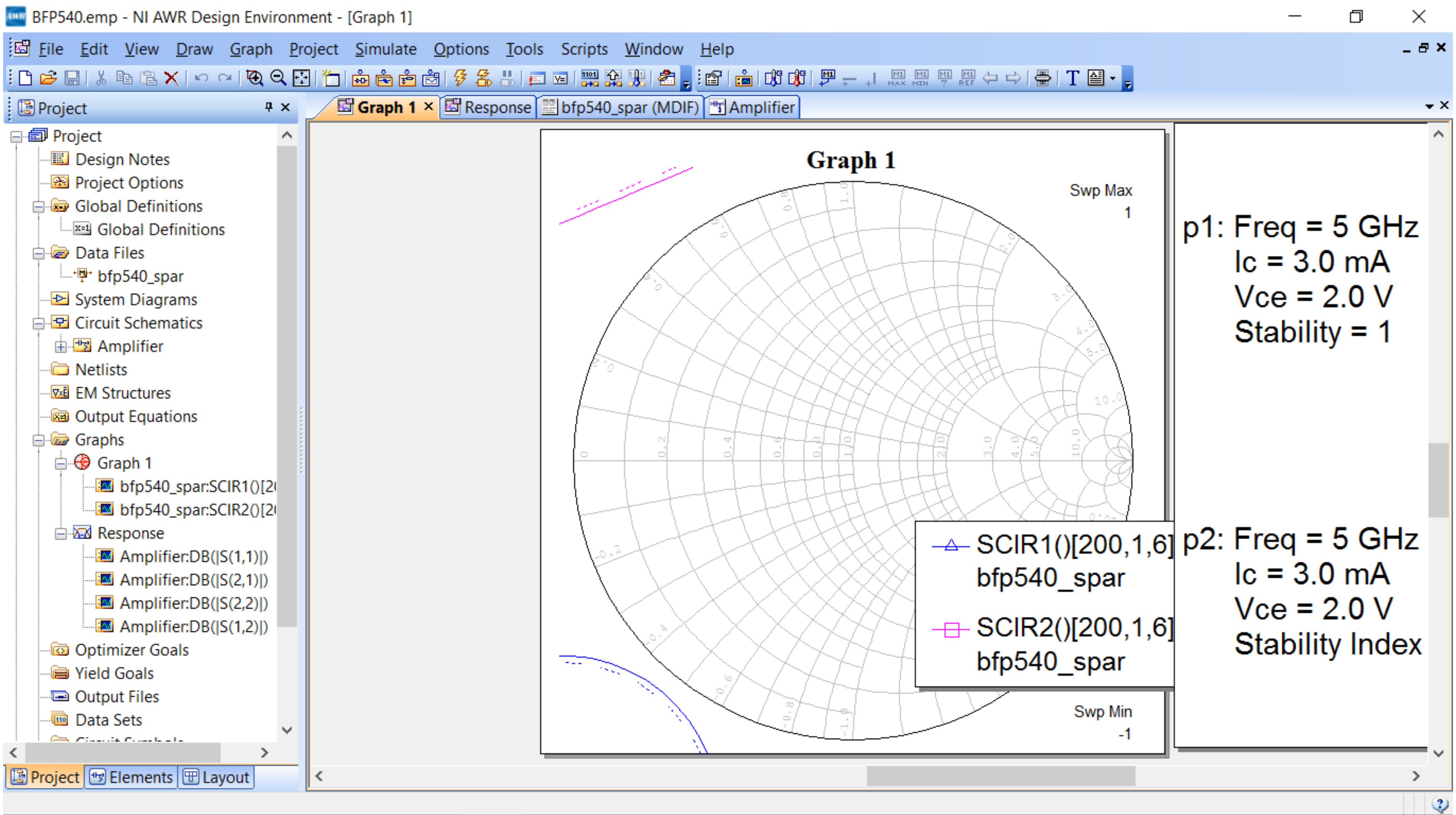
Ejemplo Transistor Infineon BPF540

Estabilidad



Ejemplo Transistor Infineon BPF540

Estabilidad



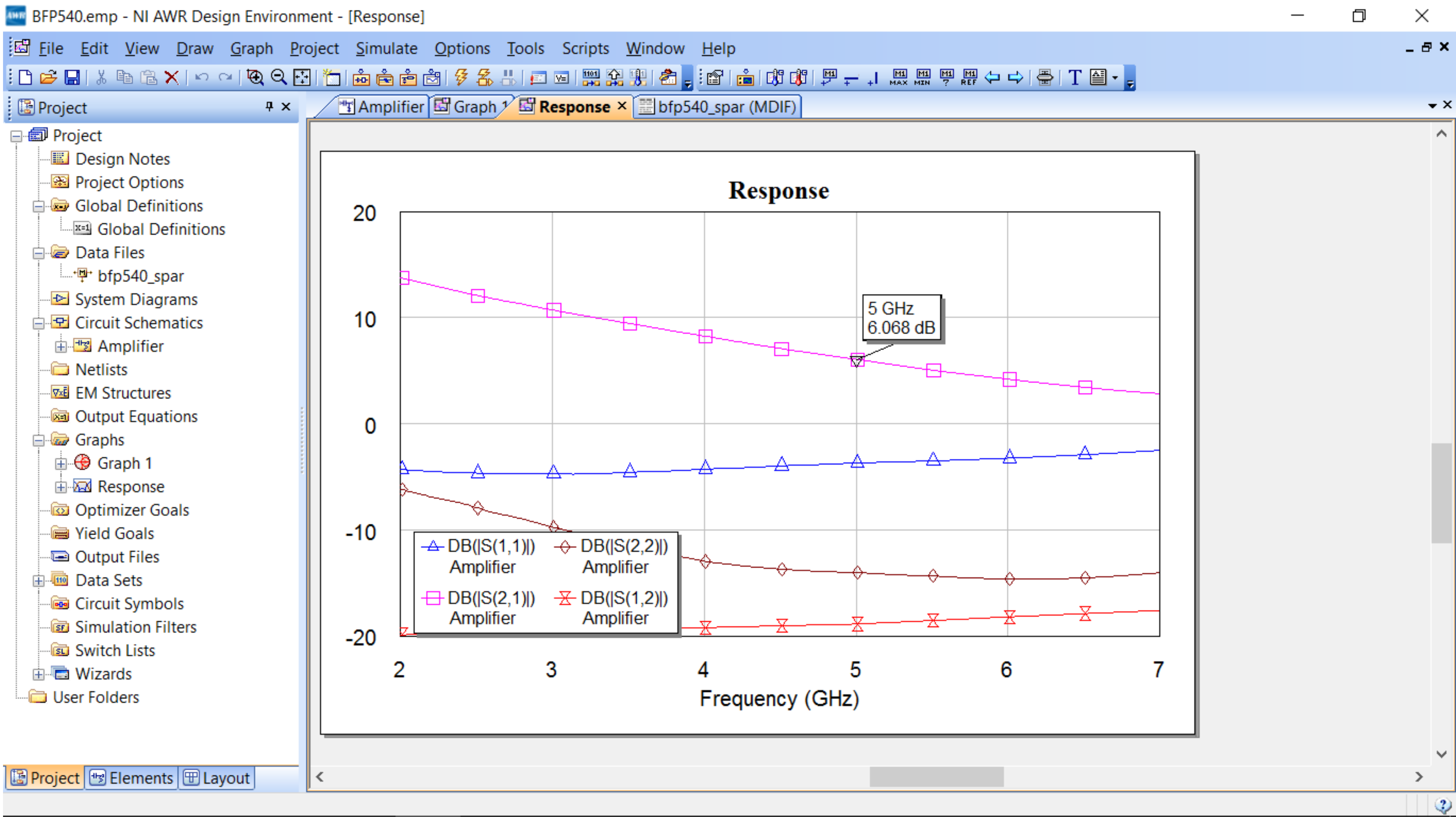
Ejemplo Transistor Infineon BPF540

Estabilidad

El transistor es incondicionalmente estable a la polarización y frecuencia seleccionada

Ejemplo Transistor Infineon BPF540

Ganancia sin adaptar



Ejemplo Cont.

$$\Gamma_S = \frac{B_1 \pm \sqrt{B_1^2 - 4\left|C_1\right|^2}}{2C_1} = 0.793\angle -129°$$

$$\Gamma_L = \frac{B_2 \pm \sqrt{B_2^2 - 4\left|C_2\right|^2}}{2C_2} = 0.553\angle 114°$$

Ejemplo Cont.

Ganancia del transductor

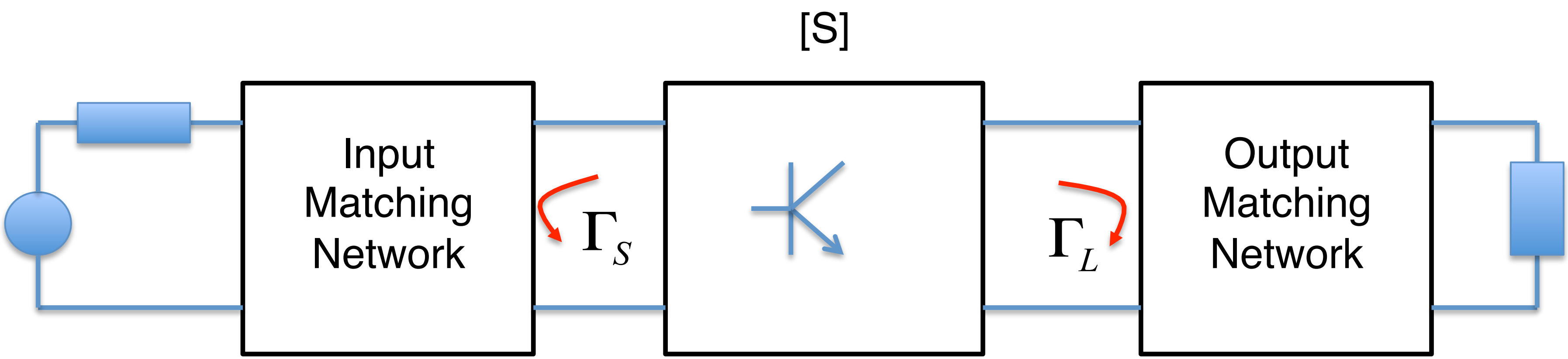
$$G_S = \frac{1}{1 - |\Gamma_S|^2} = 2.694 = 4.3dB$$

$$G_0 = |S_{21}|^2 = 4.044 = 6.07dB$$

$$G_L = \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2} = 0.856 = -0.67dB$$

$$G_T = 4.3dB + 6.07dB - 0.67dB = 9.7dB$$

Ejemplo. Cont.

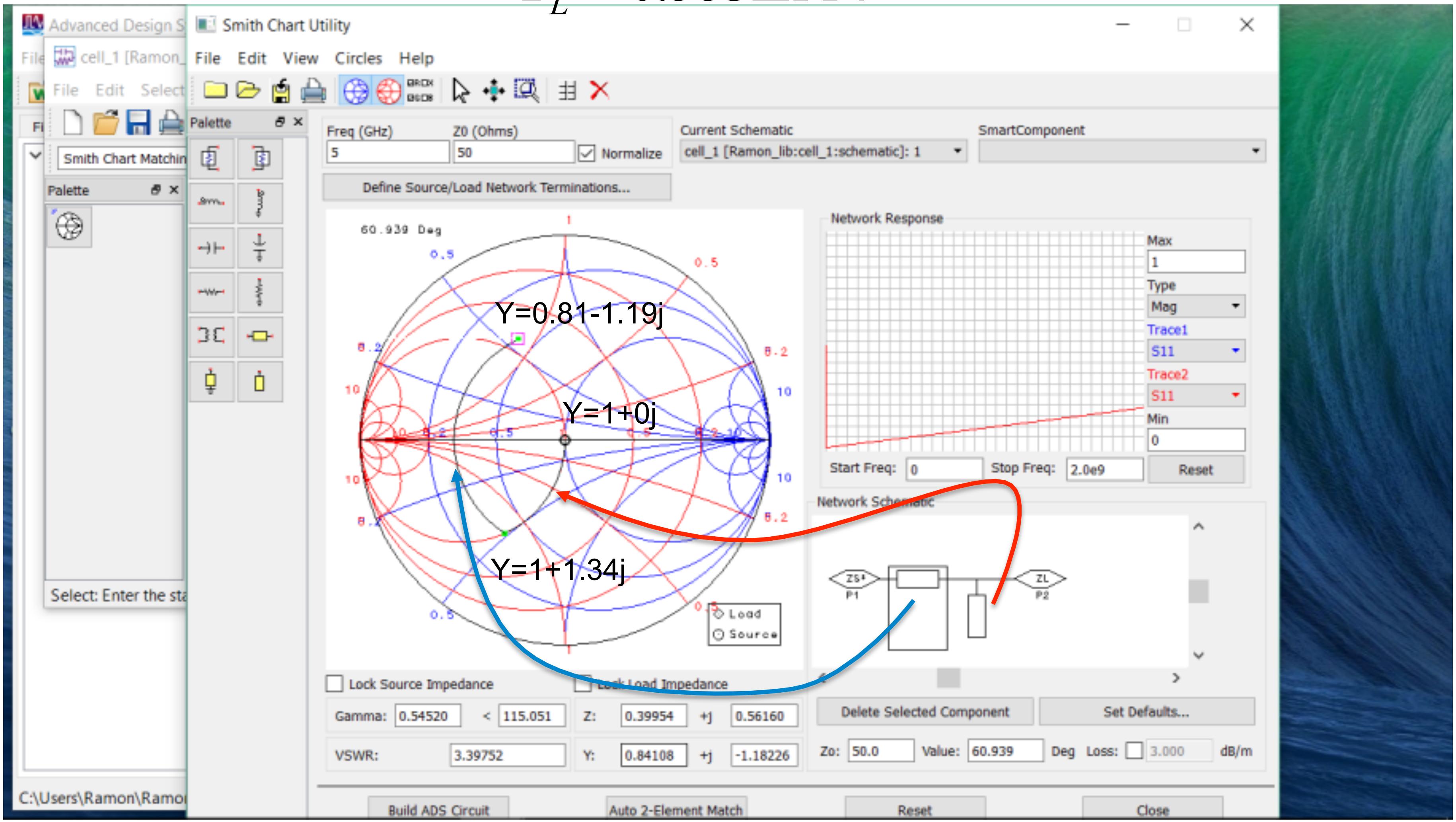


$$\Gamma_S = 0.793\angle -129°$$

$$\Gamma_L = 0.553\angle 114°$$

Output matching Network

$$\Gamma_L = 0.553\angle 114°$$

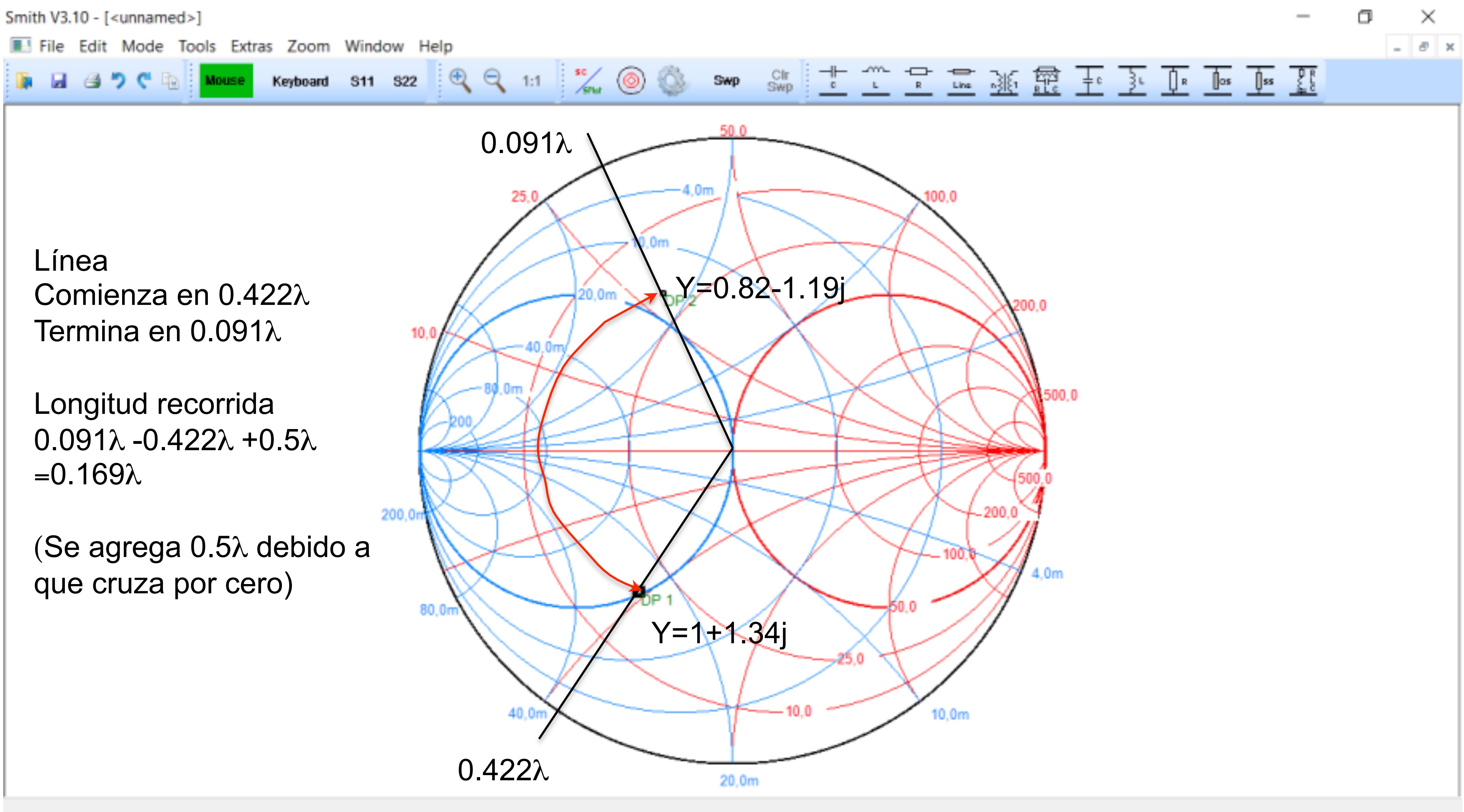


Ejemplo Cont.

Línea
Comienza en 0.422λ
Termina en 0.091λ

Longitud recorrida
0.091λ -0.422λ +0.5λ
=0.169λ

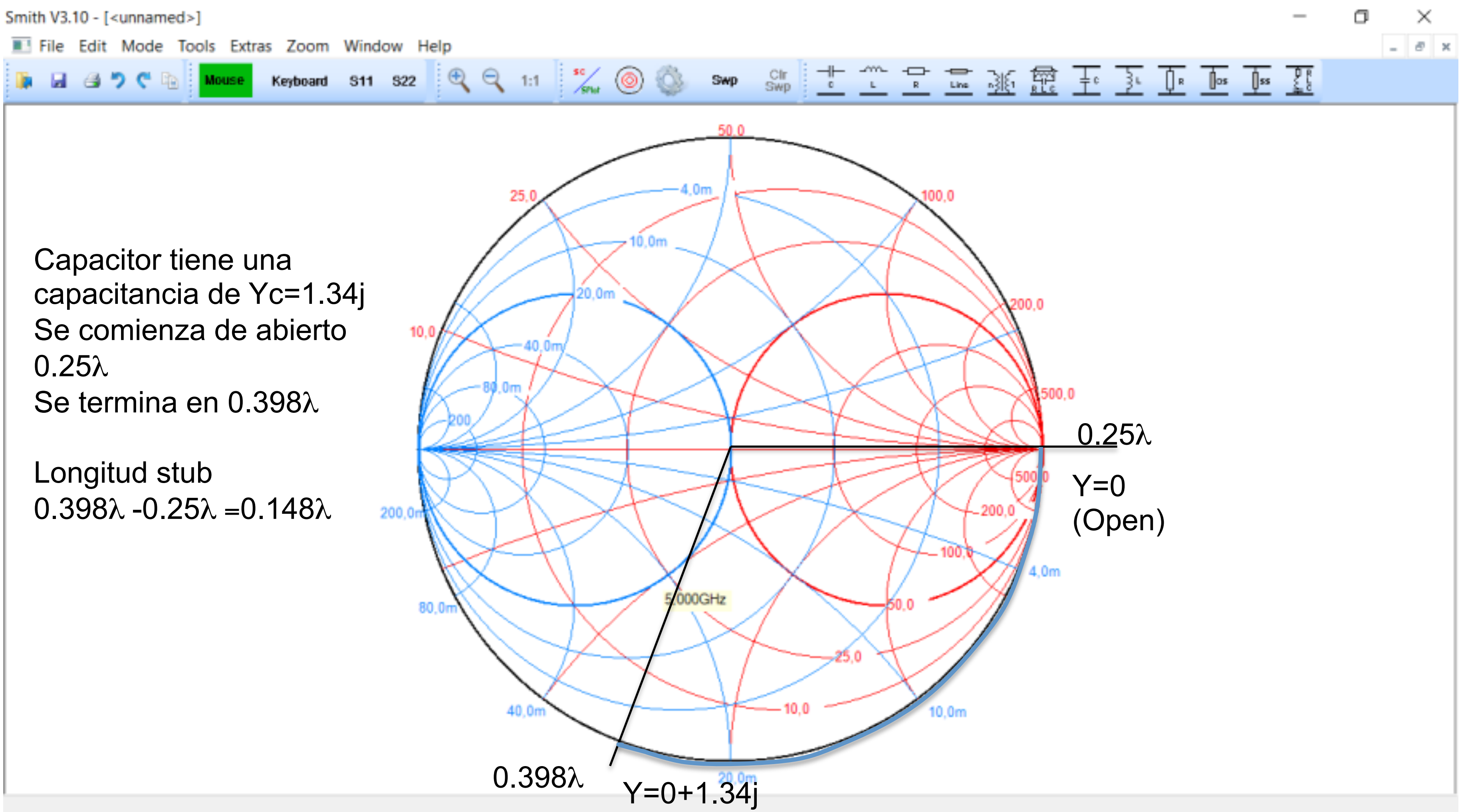
(Se agrega 0.5λ debido a que cruza por cero)



Reemplazamos el capacitor por un open stub

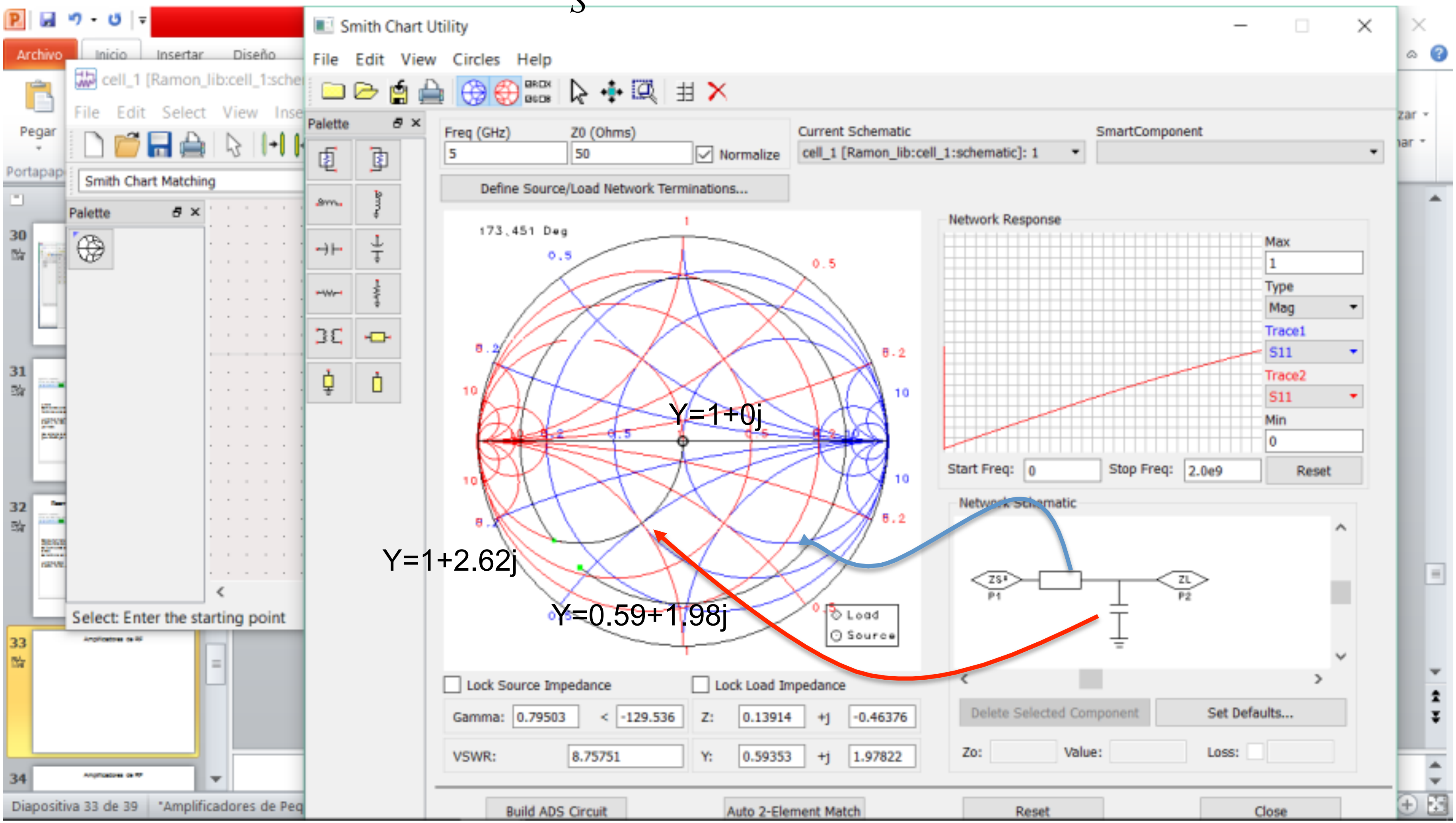
Capacitor tiene una capacitancia de Yc=1.34j
Se comienza de abierto 0.25λ
Se termina en 0.398λ

Longitud stub
0.398λ -0.25λ =0.148λ

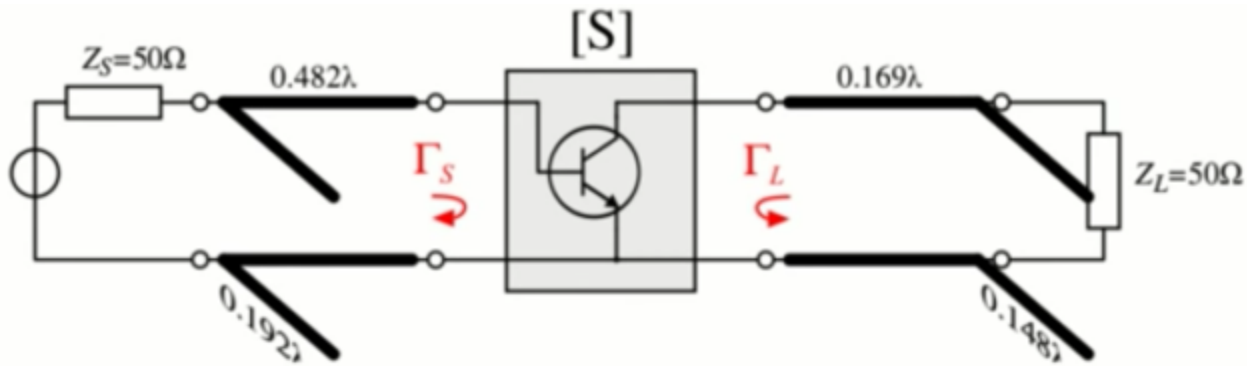


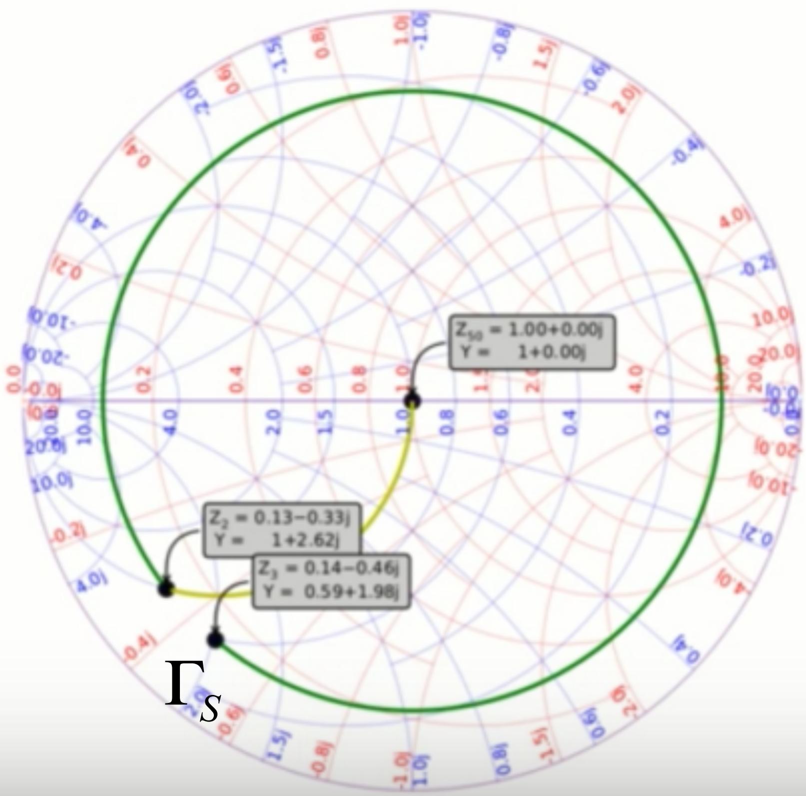
Amplificadores de RF

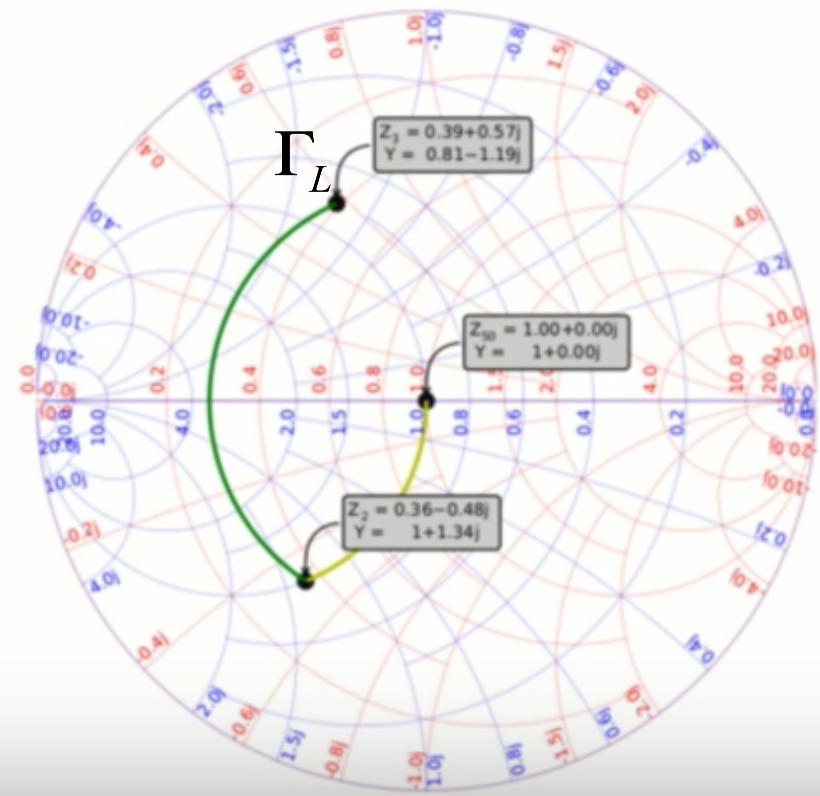
$$\Gamma_S = 0.793\angle -129°$$



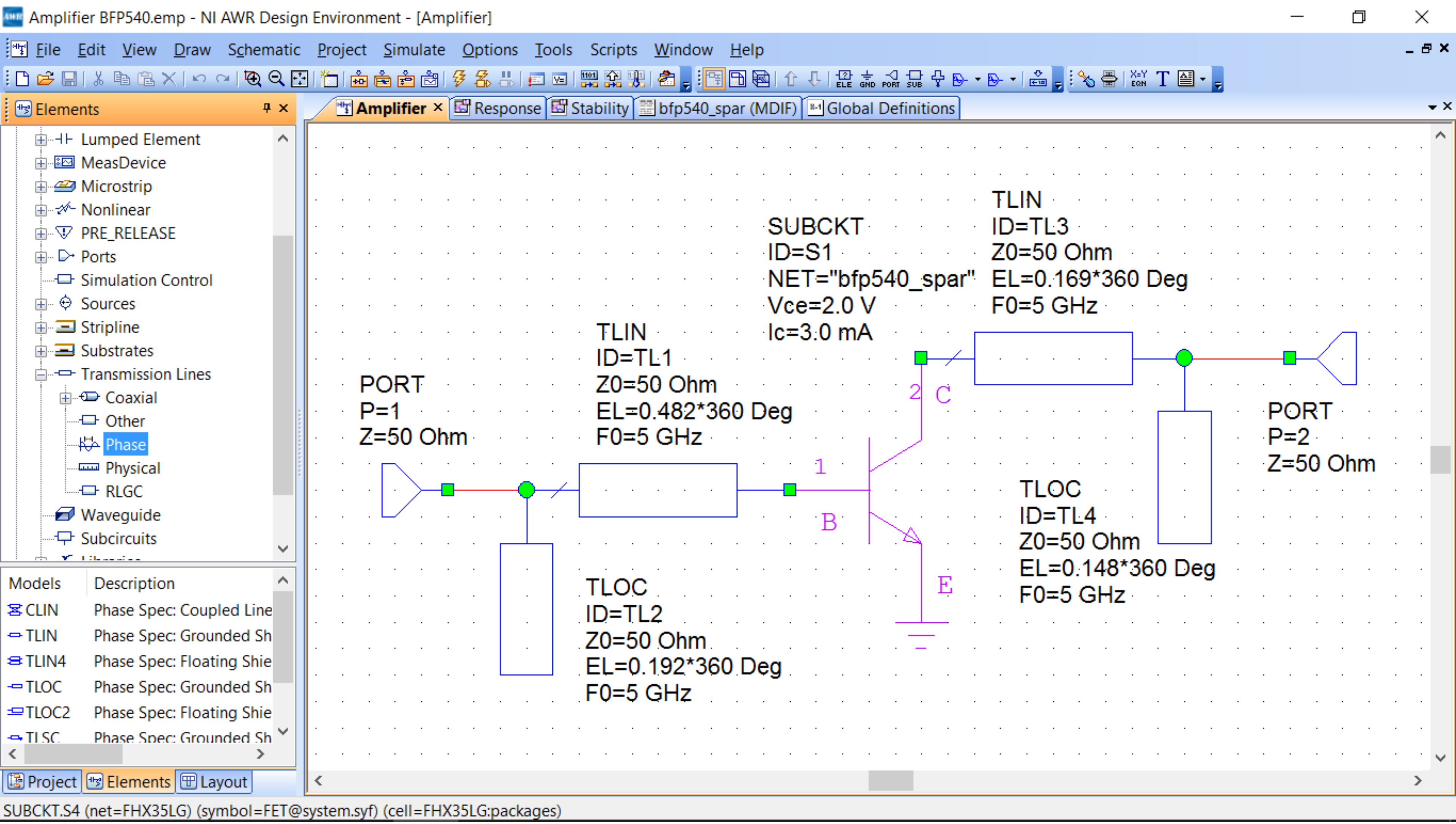
Amplificadores de RF



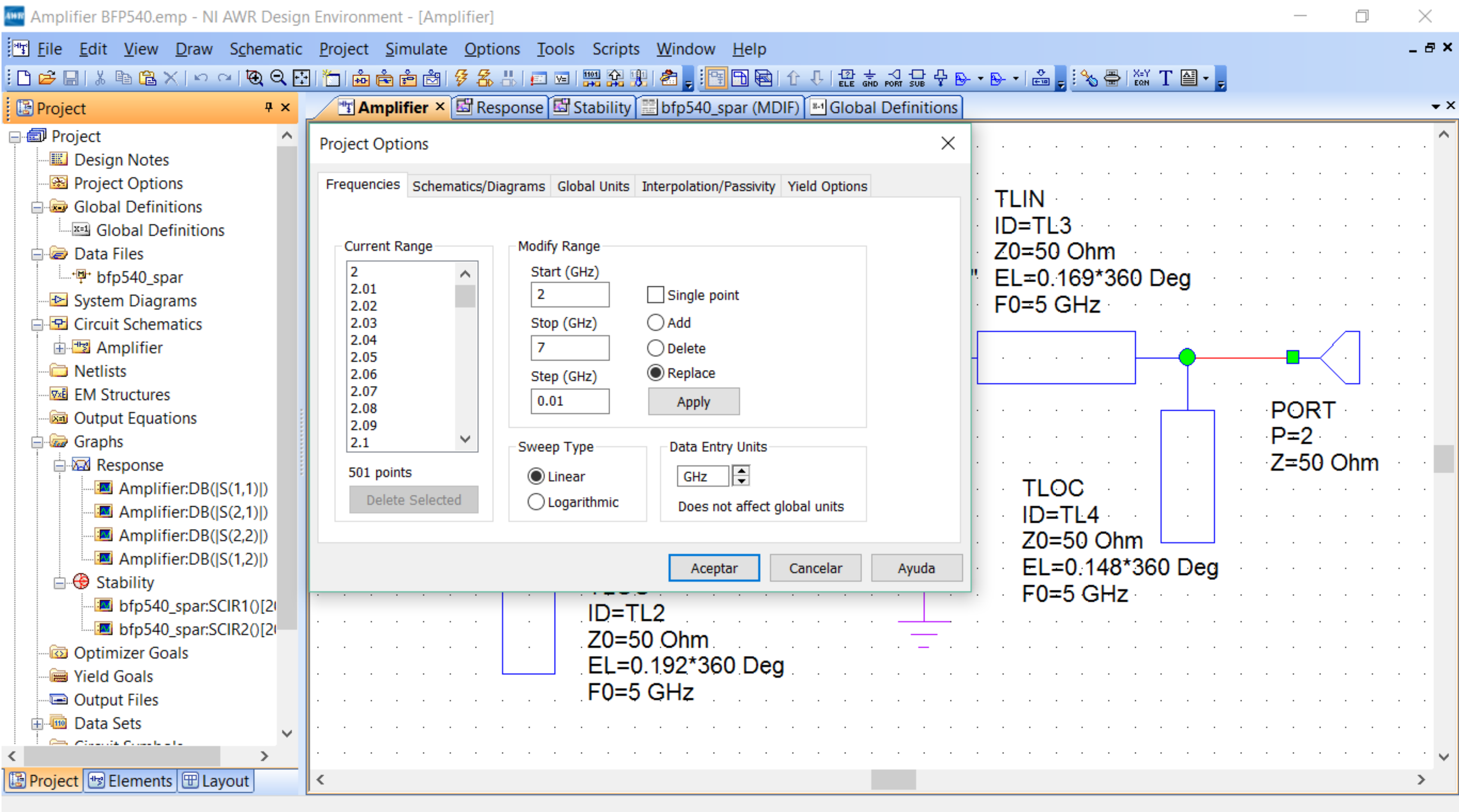




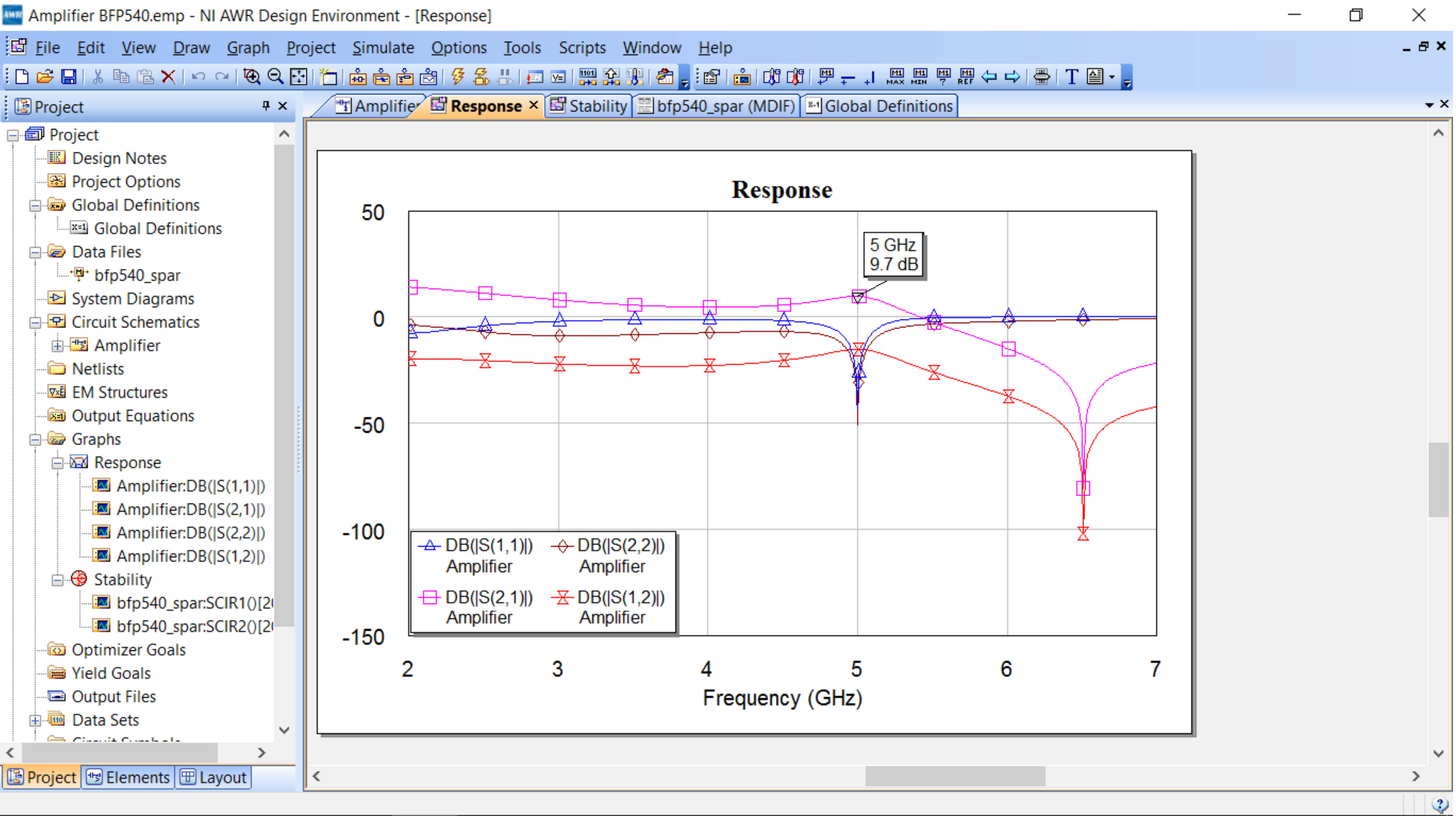
Amplificadores de RF



Amplificadores de RF



Amplificadores de RF



Amplificadores de RF