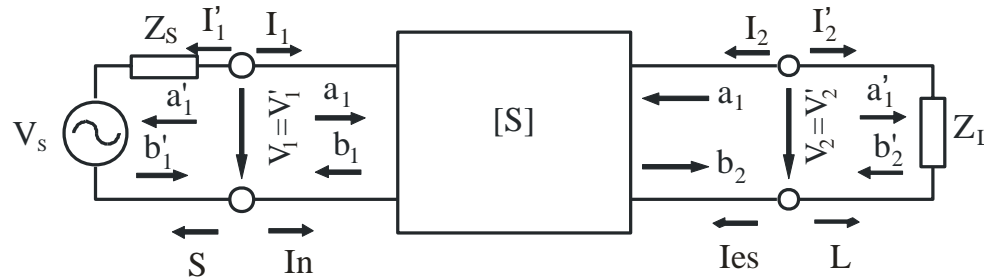


Amplificatoare de Microunde

Proiectarea unui singur etaj

Cîştigurile în putere ale unui diport



$$G = \frac{P_L}{P_{in}} = \frac{|S_{21}|^2 (1 - |\Gamma_L|^2)}{(1 - |\Gamma_{in}|^2) |1 - S_{22}\Gamma_L|^2}$$

$$G_A = \frac{P_{avL}}{P_{avS}} = \frac{P_L |_{\Gamma_L = \Gamma_{ies}^*}}{P_{in} |_{\Gamma_{in} = \Gamma_S^*}} = \frac{|S_{21}|^2 (1 - |\Gamma_S|^2)}{|1 - S_{11}\Gamma_S|^2 (1 - |\Gamma_L|^2)}$$

$$G_T = \frac{P_L}{P_{avS}} = \frac{|S_{21}|^2 (1 - |\Gamma_S|^2) (1 - |\Gamma_L|^2)}{|1 - \Gamma_S \Gamma_{in}|^2 |1 - S_{22}\Gamma_L|^2}$$

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} \quad \Gamma_S = \frac{Z_S - Z_0}{Z_S + Z_0}$$

$$\Gamma_{in} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L}$$

$$\Gamma_{ies} = \frac{Z_{ies} - Z_0}{Z_{ies} + Z_0} = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - S_{11}\Gamma_S}$$

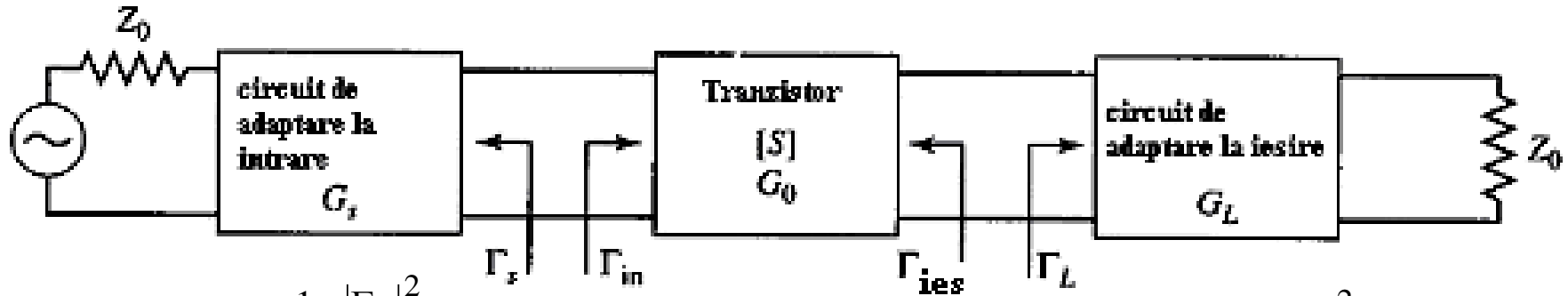
➤ Reflexii nule $\Gamma_L = \Gamma_S = 0$

$$G_T = |S_{21}|^2$$

Dispozitiv unilateral $S_{12} = 0$

$$G_{TU} = \frac{|S_{21}|^2 (1 - |\Gamma_S|^2) (1 - |\Gamma_L|^2)}{|1 - \Gamma_S S_{11}|^2 |1 - S_{22}\Gamma_L|^2}$$

Schema bloc a unui amplificator cu un tranzistor



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

$$G_0 = |S_{21}|^2$$

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

$$G_T = G_S G_0 G_L$$

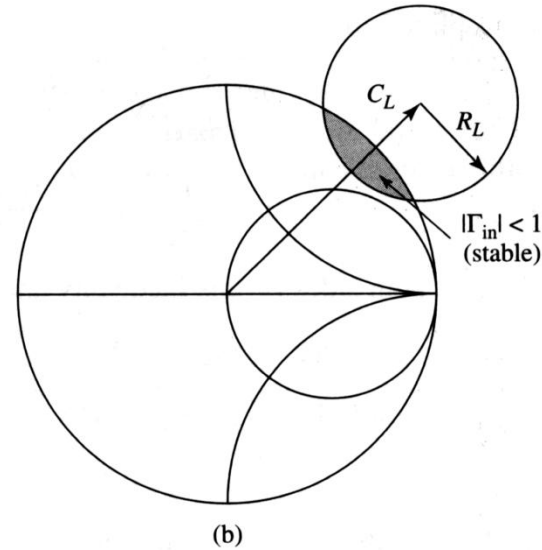
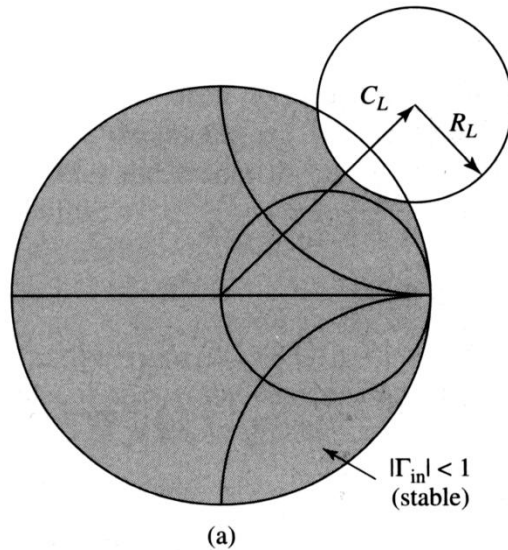
Stabilitatea

- **Stabilitatea necondiționată:** circuitul este necondiționat stabil dacă $|\Gamma_{in}| < 1$ și $|\Gamma_{ies}| < 1$ pentru orice impedanță pasivă a sarcinii și sursei.
- **Stabilitatea condiționată:** circuitul este condiționat stabil dacă $|\Gamma_{in}| < 1$ și $|\Gamma_{ies}| < 1$ doar pentru un anumit interval de valori pentru impedanța pasivă a sarcinii și sursei.

Cercurile de stabilitate

cercul de stabilitate la ieşire : $|\Gamma_{in}| = 1$ cercul de stabilitate la intrare $|\Gamma_{ies}| = 1$

$$C_L = \frac{(S_{22} - \Delta S_{11}^*)^*}{|S_{22}|^2 - |\Delta|^2} \quad R_L = \frac{|S_{12}S_{21}|}{\left| |S_{22}|^2 - |\Delta|^2 \right|} \quad C_S = \frac{(S_{11} - \Delta S_{22}^*)^*}{|S_{11}|^2 - |\Delta|^2} \quad R_S = \frac{|S_{12}S_{21}|}{\left| |S_{11}|^2 - |\Delta|^2 \right|}$$



$$|\Delta| < 1$$

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

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

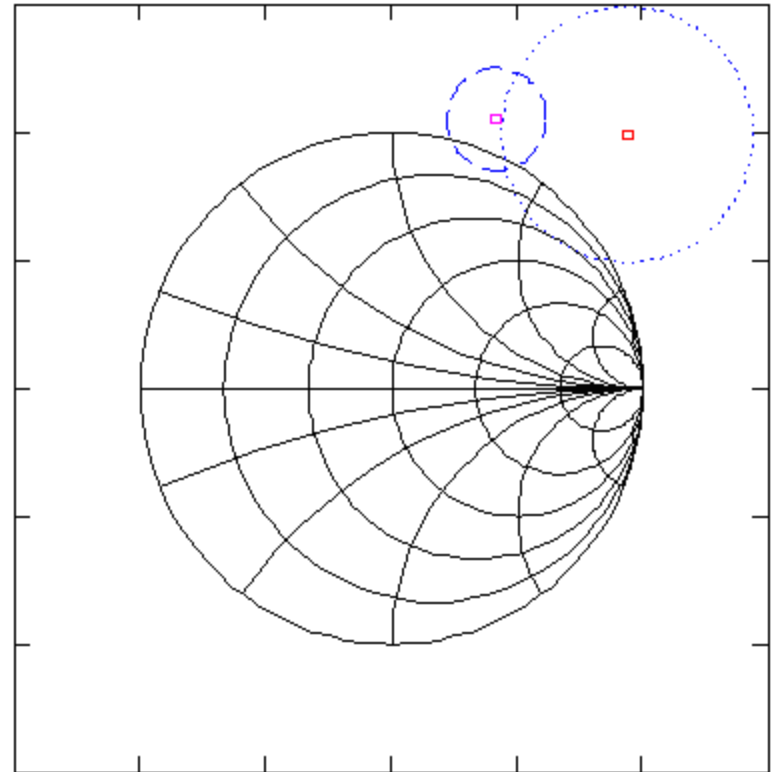
Exemplu

$$S = \begin{bmatrix} 0.894e^{-j60.6^\circ} & 0.02e^{j62.4^\circ} \\ 3.122e^{j123.6^\circ} & 0.781e^{-j27.6^\circ} \end{bmatrix}$$

$$\Delta = S_{11}S_{22} - S_{21}S_{12} = 0.696 \angle -83^\circ$$

$$K = \frac{1 + |\Delta|^2 - |S_{11}|^2 - |S_{22}|^2}{2|S_{12}S_{21}|} = 0.607$$

$$\mu = 0.86$$



$$C_L = \frac{(S_{22} - \Delta S_{11}^*)^*}{|S_{22}|^2 - |\Delta|^2} = 1.361 \angle 47^\circ$$

$$C_S = \frac{(S_{11} - \Delta S_{22}^*)^*}{|S_{11}|^2 - |\Delta|^2} = 1.132 \angle 68^\circ$$

$$R_L = \frac{|S_{12}S_{21}|}{|S_{22}|^2 - |\Delta|^2} = 0.5$$

$$R_S = \frac{|S_{12}S_{21}|}{|S_{11}|^2 - |\Delta|^2} = 0.199$$

Adaptarea simultana - tranzistorul bilateral

$$\begin{aligned}\Gamma_{\text{in}} &= \Gamma_S^* \\ \Gamma_{\text{ies}} &= \Gamma_L^*\end{aligned} \quad G_{T \text{ max}} = \frac{1}{1 - |\Gamma_S|^2} |S_{21}|^2 \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2}$$

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

$$\Gamma_L^* = S_{22} + \frac{S_{12}S_{21}}{\frac{1}{\Gamma_g} - S_{11}}$$

$$\Gamma_S = \frac{B_1 \pm \sqrt{B_1^2 - 4|C_1|^2}}{2C_1}$$

$$\Gamma_L = \frac{B_2 \pm \sqrt{B_2^2 - 4|C_2|^2}}{2C_2}$$

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

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

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

$$C_2 = S_{22} - \Delta S_{11}^*$$

$$B_1^2 - 4|C_1|^2 = B_2^2 - 4|C_2|^2 = 4(K^2 - 1)|S_{12}|^2|S_{21}|^2$$

Exemplu

- *Să proiectăm un amplificator pentru un câștig maxim la 4 GHz utilizând un circuit de adaptare cu un singur stub. Să se calculeze și să se reprezinte grafic pierderile de întoarcere la intrare și câștigul între 3 și 5 GHz.*

f(GHz)	S_{11}	S_{21}	S_{12}	S_{22}
3.0	$0.80 \angle -89^\circ$	$2.86 \angle 99^\circ$	$0.03 \angle 56^\circ$	$0.76 \angle -41^\circ$
4.0	$0.72 \angle -116^\circ$	$2.60 \angle 76^\circ$	$0.03 \angle 57^\circ$	$0.73 \angle -54^\circ$
5.0	$0.66 \angle -142^\circ$	$2.39 \angle 54^\circ$	$0.03 \angle 62^\circ$	$0.72 \angle -68^\circ$

Solutie

$$\Delta = S_{11}S_{22} - S_{12}S_{21} = 0.488 \angle -162.289^\circ$$

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}S_{21}|} = 1.195$$

$$\Gamma_S = \frac{B_1 \pm \sqrt{B_1^2 - 4|C_1|^2}}{2C_1} = 0.872 \angle 123.407^\circ$$

$$\Gamma_L = \frac{B_2 \pm \sqrt{B_2^2 - 4|C_2|^2}}{2C_2} = 0.876 \angle 61.026^\circ$$

$$G_S = \frac{1}{1 - |\Gamma_S|^2} = 4.17 = 6.201 \text{ dB} \quad G_0 = |S_{21}|^2 = 6.76 = 8.299 \text{ dB} \quad G_L = \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2} = 1.67 = 2.227 \text{ dB}$$

$$G_{T \max} = 6.201 + 8.229 + 2.227 = 16.657 \text{ dB}$$

$$y_S = \frac{Y_S}{Y_0} = Y_S Z_0 = Y_S \cdot 50 = \frac{1 - \Gamma_S}{1 + \Gamma_S} = 0.3 - j \cdot 1.819$$

$$y_L = \frac{1 - \Gamma_L}{1 + \Gamma_L} = 0.089 - j \cdot 0.586$$

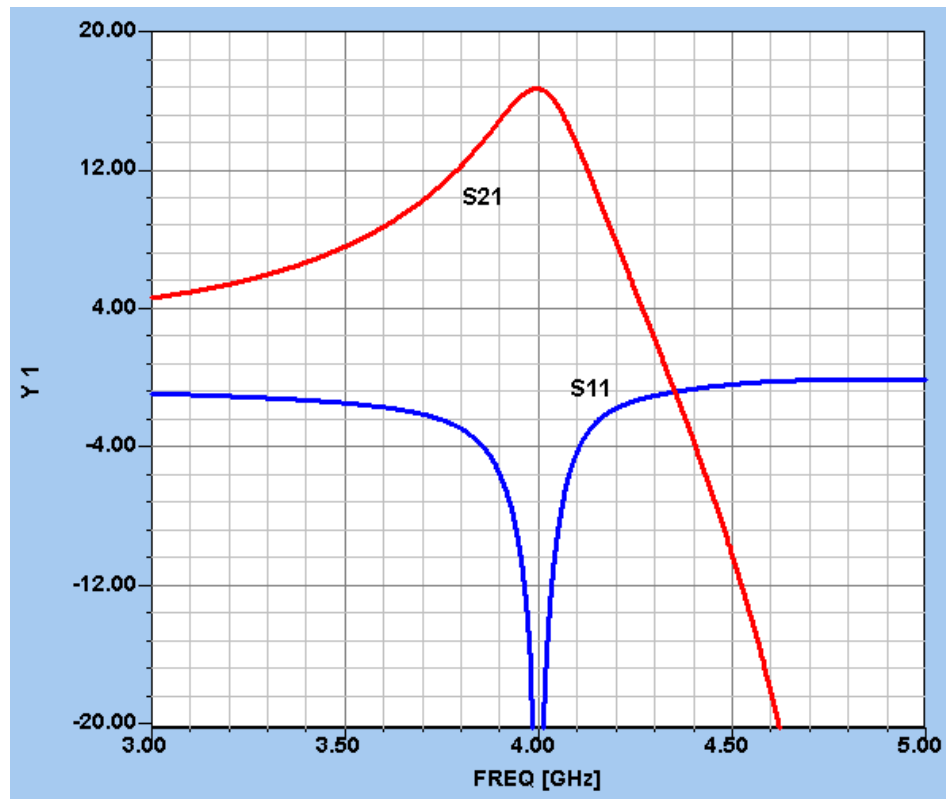
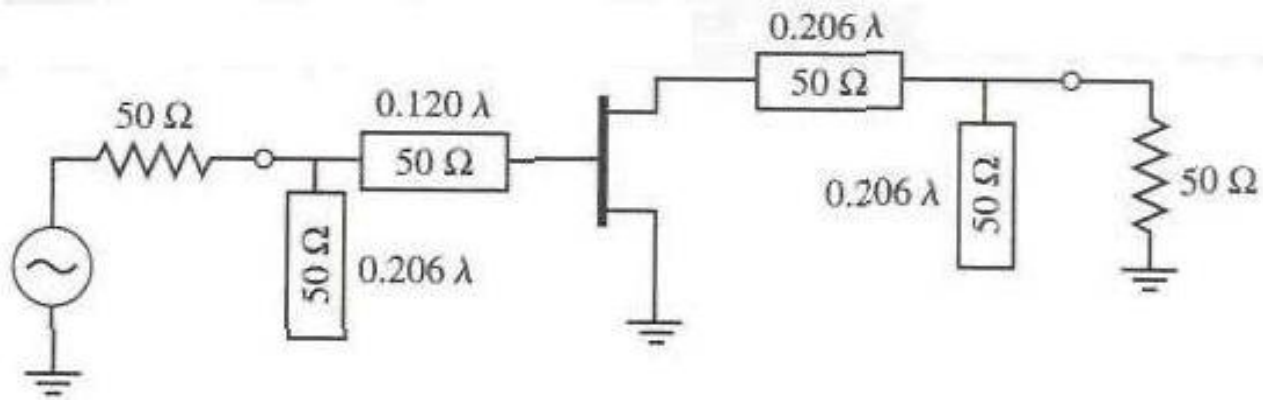
$$y_S(\theta) = \frac{1 - \Gamma_S \cdot e^{2j\theta}}{1 + \Gamma_S \cdot e^{2j\theta}} \quad \Re[y_S(\theta)] = 1 \quad \theta = 0.75$$

$$l_{L1} = 0.206\lambda$$

$$l_1 = \frac{\theta}{2\pi} = 0.119\lambda \quad y_S(0.75) = 1 + j \cdot 3.559$$

$$l_{Lstub} = 0.206\lambda$$

$$l_{stub} = \frac{1}{2\pi} a \tan(\Im m(y_S(0.75))) = 0.206\lambda$$



Proiectarea pentru un câștig specificat

$$\frac{1}{(1+U)^2} < \frac{G_T}{G_{TU}} < \frac{1}{(1-U)^2} \quad U = \frac{|S_{12}||S_{21}||S_{11}||S_{22}|}{(1-|S_{11}|^2)(1-|S_{22}|^2)}$$

$$G_S = \frac{1-|\Gamma_S|^2}{|1-S_{11}\Gamma_S|^2}$$

$$G_0 = |S_{21}|^2$$

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

$$\Gamma_S = S_{11}^* \quad G_{S\max} = \frac{1}{1-|S_{11}|^2}$$

$$\Gamma_L = S_{22}^* \quad G_{L\max} = \frac{1}{1-|S_{22}|^2}$$

$$g_S = \frac{G_S}{G_{S\max}} = \frac{1-|\Gamma_S|^2}{1-|S_{11}\Gamma_S|^2} (1-|S_{11}|^2)$$

$$g_L = \frac{1-|\Gamma_L|^2}{1-|S_{22}\Gamma_L|^2} (1-|S_{22}|^2)$$

$$C_S = \frac{g_S S_{11}^*}{1-(1-g_S)|S_{11}|^2}$$

$$C_L = \frac{g_L S_{22}^*}{1-(1-g_L)|S_{22}|^2}$$

$$R_S = \frac{\sqrt{1-g_S} (1-|S_{11}|^2)}{1-(1-g_S)|S_{11}|^2}$$

$$R_L = \frac{\sqrt{1-g_L} (1-|S_{22}|^2)}{1-(1-g_L)|S_{22}|^2}$$

Exemplu

Să proiectăm un amplificator care să aibă un câștig de 11 dB la 4 GHz. Desenați cercurile de câștig constant pentru 11 dB și 3 dB, și 1 dB și 1 dB. Calculați și desenați pierderile de întoarcere și câștigul global al amplificatorului între 3 și 5 GHz. Tranzistorul TEC are următorii parametri S

f(GHz)	S_{11}	S_{21}	S_{12}	S_{22}
3.0	$0.80 \angle -90^\circ$	$2.8 \angle 100^\circ$	0	$0.66 \angle -50^\circ$
4.0	$0.75 \angle -120^\circ$	$2.5 \angle 80^\circ$	0	$0.60 \angle -70^\circ$
5.0	$0.71 \angle -140^\circ$	$2.3 \angle 60^\circ$	0	$0.58 \angle -85^\circ$

Solutie

$$G_{S \max} = \frac{1}{1 - |S_{11}|^2} = 2.29 = 3.59 \text{ dB}$$

$$G_0 = |S_{21}|^2 = 6.25 = 7.959 \text{ dB}$$

$$G_{L \max} = \frac{1}{1 - |S_{22}|^2} = 1.56 = 1.938 \text{ dB}$$

$$G_{TU \max} = 3.59 + 1.938 + 7.959 = 13.487 \text{ dB}$$

$$G_{SdB3} = 3 \text{ dB}$$

$$G_{SdB2} = 2 \text{ dB}$$

$$G_{LdB1} = 1 \text{ dB}$$

$$G_{LdB0} = 0 \text{ dB}$$

$$G_{S3} = 10^{G_{SdB3}/10} = 1.995$$

$$G_{S2} = 10^{G_{SdB2}/10} = 1.585$$

$$G_{L1} = 10^{G_{LdB1}/10} = 1.259$$

$$G_{L0} = 10^{G_{LdB0}/10} = 1$$

$$g_S(G_{S3}) = G_{S3} [1 - |S_{11}|^2] = 0.873 \quad g_S(G_{S2}) = G_{S2} [1 - |S_{11}|^2] = 0.693 \quad g_L(G_{L1}) = G_{L1} [1 - |S_{22}|^2] = 0.806 \quad g_L(G_{L0}) = G_{L0} [1 - |S_{22}|^2] = 0.64$$

$$C_S(G_{S3}) = 0.706 \angle 120^\circ$$

$$C_S(G_{S2}) = 0.628 \angle 120^\circ$$

$$C_L(G_{L1}) = 0.520 \angle 70^\circ$$

$$C_L(G_{L0}) = 0.440 \angle 70^\circ$$

$$R_S(G_{S3}) = 0.168$$

$$R_S(G_{S2}) = 0.293$$

$$R_L(G_{L1}) = 0.303$$

$$R_L(G_{L0}) = 0.441$$

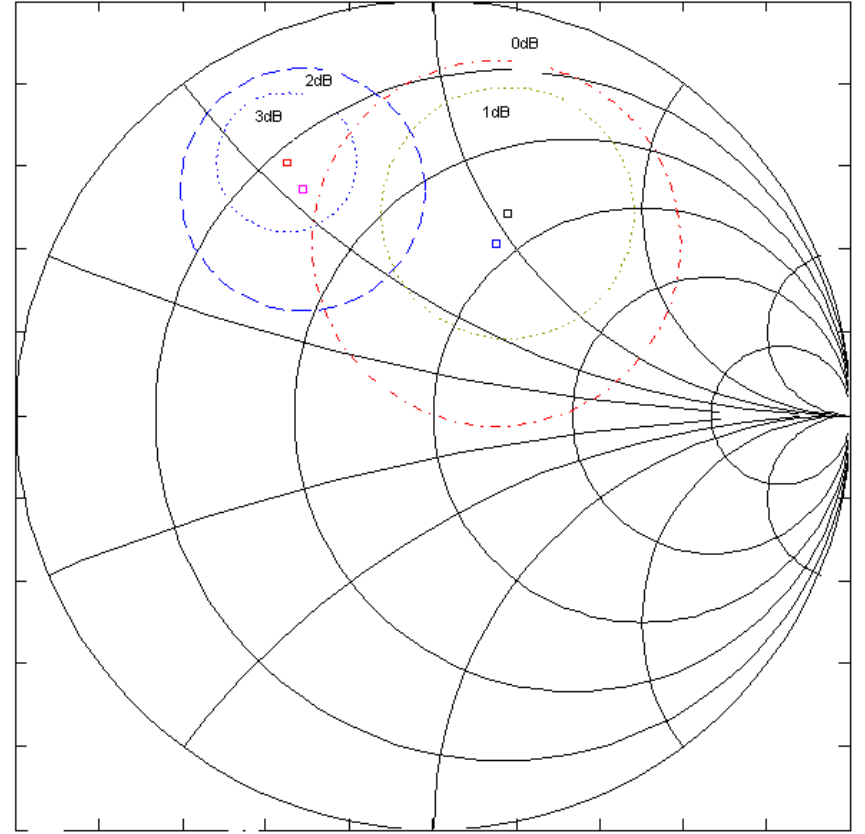
$$G_S = 2 \text{ dB}$$

$$G_L = 1 \text{ dB}$$

$$G_T = 10.9 \text{ dB}$$

$$\Gamma_S = \left(|C_S(G_{S2})| - R_S(G_{S2}) \right) \cdot e^{j \cdot \arg(C_S(G_{S2}))} = 0.336 \angle 120^\circ$$

$$\Gamma_L = \left(|C_L(G_{L1})| - R_L(G_{L1}) \right) \cdot e^{j \cdot \arg(C_L(G_{L1}))} = 0.216 \angle 70^\circ$$



$$y_S = \frac{1 - \Gamma_S}{1 + \Gamma_S} = 1.142 - j \cdot 0.748$$

$$\Re(y_S(\theta)) = \Re\left(\frac{1 - \Gamma_S \cdot e^{2j\theta}}{1 + \Gamma_S \cdot e^{2j\theta}}\right) = 1 \quad \theta = 1.138 \quad l_{S1} = \frac{\theta}{2\pi} = 0.181\lambda$$

$$y_S(2\pi l_{S1}) = 1 + j \cdot 0.713$$

$$l_{stubb} = \frac{1}{2\pi} \arctan(\Im(y_S(2\pi l_{S1}))) = 0.099\lambda$$

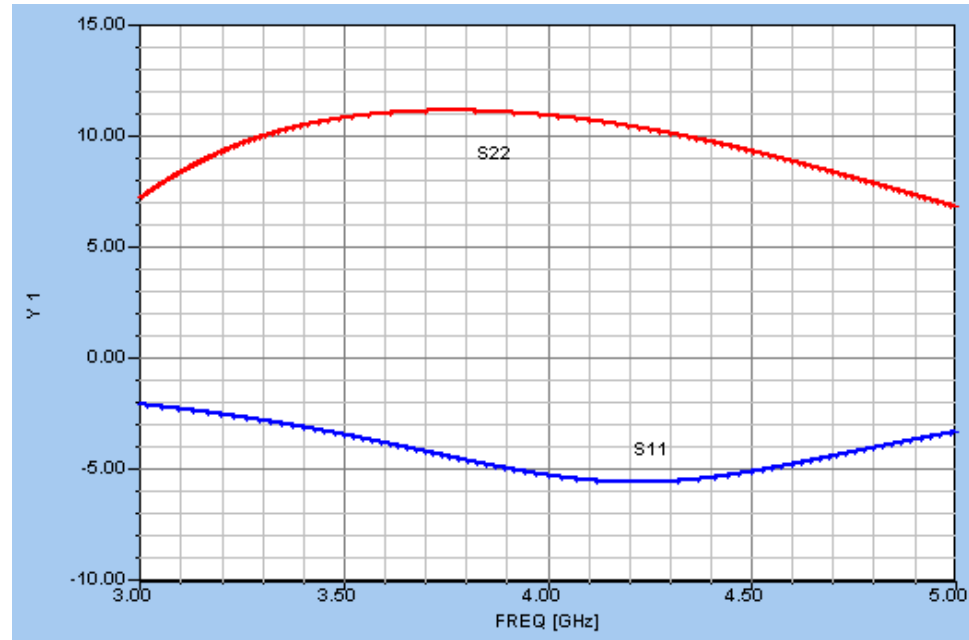
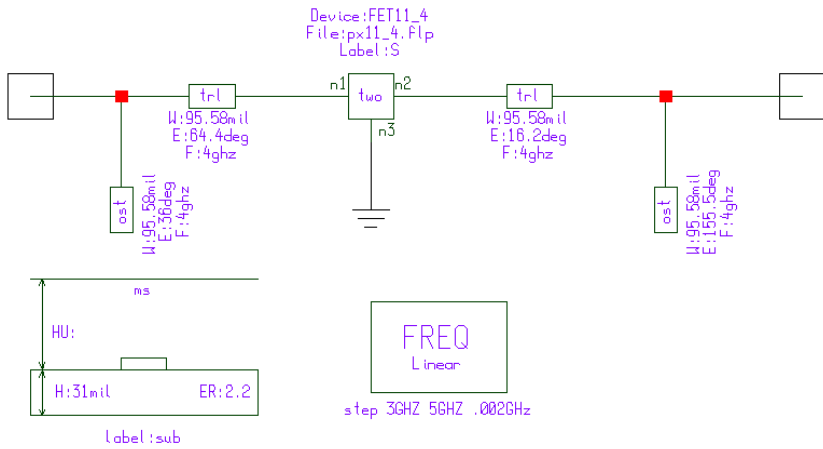
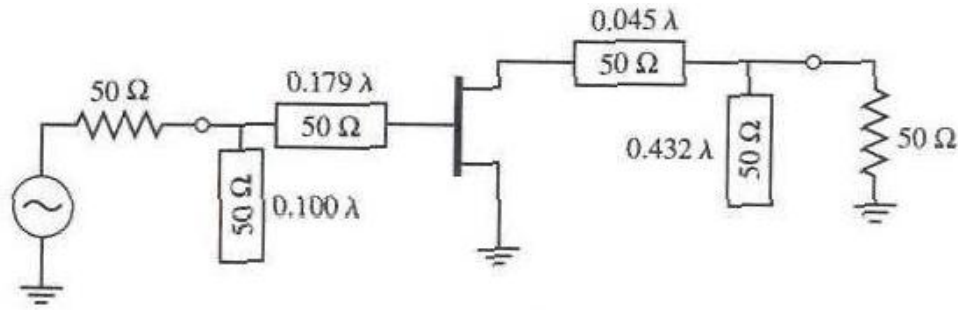
$$y_L = \frac{1 - \Gamma_L}{1 + \Gamma_L} = 0.798 - j \cdot 0.34$$

$$\Re(y_L(\theta)) = 1 \quad \theta = 0.284 \quad l_{L1} = \frac{\theta}{2\pi} = 0.045\lambda$$

$$y_L(2\pi l_{L1}) = 1 - j \cdot 0.443$$

$$l_{stubb} = \frac{1}{2\pi} \arctan(\Im(y_L(2\pi l_{L1}))) = -0.066\lambda$$

$$l_{Lstubb} = l_{stubb} + 0.5\lambda = 0.434\lambda$$



Proiectarea de zgomot mic

$$F = F_{\min} + \frac{R_N}{G_S} |Y_S - Y_{\text{opt}}|^2 \qquad F = F_{\min} + 4r_n \frac{|\Gamma_S - \Gamma_{\text{opt}}|^2}{(1 - |\Gamma_S|^2) |1 + \Gamma_{\text{opt}}|^2}$$

$$R_F = \frac{\sqrt{N(N+1 - |\Gamma_{\text{opt}}|^2)}}{N+1}$$

$$C_F = \frac{\Gamma_{\text{opt}}}{N+1}$$

$$N = \frac{F - F_{\min}}{4R_N/Z_0} |1 + \Gamma_{\text{opt}}|^2$$

EXEMPLU

Un tranzistor TEC pe GaAs este polarizat pentru factorul de zgomot minim și are următorii parametri S și de zgomot la frecvența de 4 GHz

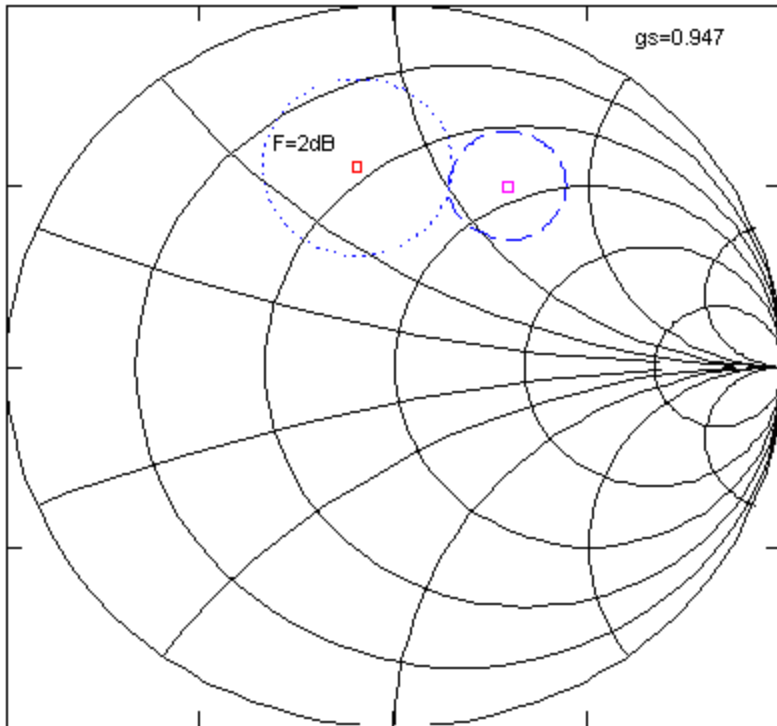
$$S = \begin{bmatrix} 0.6 \angle -60^\circ & 0.05 \angle 26^\circ \\ 1.9 \angle 81^\circ & 0.5 \angle -60^\circ \end{bmatrix} \quad F_{\min} = 1.6 \text{ dB} \quad \Gamma_{\text{opt}} = 0.62 \angle 100^\circ \quad R_N = 20 \Omega$$

Pentru proiectare presupunem tranzistorul unilateral și vom calcula ulterior eroarea maximă în rezultată din această presupunere. Amplificatorul se va proiecta pentru o cifră de zgomot de 2.0 dB cu câștigul maxim compatibil cu această cifră de zgomot.

Solutie

$$U = \frac{|S_{11}S_{22}S_{12}S_{22}|}{(1-|S_{11}|^2)(1-|S_{22}|^2)} = 0.059 \quad \frac{1}{(1+U)^2} < \frac{G_T}{G_{TU}} < \frac{1}{(1-U)^2} \quad 0.891 < \frac{G_T}{G_{TU}} < 1.130 \quad -0.50dB < G_T - G_{TU} < 0.53dB$$

$$F = 10^{\frac{2}{10}} = 1.584 \quad N = \frac{F - F_{\min}}{4R_N/Z_0} |1 + \Gamma_{\text{opt}}|^2 = 0.102 \quad C_F = \frac{\Gamma_{\text{opt}}}{N+1} = 0.563 \angle 100^\circ \quad R_F = \frac{\sqrt{N(N+1-|\Gamma_{\text{opt}}|^2)}}{N+1} = 0.245$$



$$\Gamma_S = 0.141035 + j \cdot 0.522189 = 0.541 \angle 74.886^\circ$$

$$G_S = 10 \log \left[\frac{1 - |\Gamma_S|^2}{|1 - S_{11}\Gamma_S|^2} \right] = 1.702dB$$

$$G_L = 10 \log \left[\frac{1}{1 - |S_{22}|^2} \right] = 1.249dB \quad \Gamma_L = S_{22}^*$$

$$G_0 = 10 \log \left[|S_{21}|^2 \right] = 5.575dB$$

$$G_{TU} = G_S + G_0 + G_L = 8.527dB$$

$$y_S = \frac{1 - \Gamma_S}{1 + \Gamma_S} = 0.449 - j \cdot 0.663 \quad \Gamma_L = \frac{B_2 - \sqrt{B_2^2 - 4|C_2|^2}}{2C_2} = 0.457 \angle 68.435^\circ$$

$$l_{S1} = \frac{\theta}{2\pi} = 0.226\lambda$$

$$y_L = \frac{1 - \Gamma_L}{1 + \Gamma_L} = 0.512 - j \cdot 0.55$$

$$l_{S\text{stub}} = \frac{1}{2 \cdot \pi} a \tan(\Im m(y_S(2 \cdot \pi \cdot l_{S1}))) = 0.145\lambda$$

$$l_{L1} = \frac{\theta}{2 \cdot \pi} = 0.242\lambda$$

$$l_{L\text{stub}} = \frac{1}{2 \cdot \pi} a \tan(\Im m(y_L(2 \cdot \pi \cdot l_{L1}))) = 0.127\lambda$$

