Diseño de Amplificadores de Microondas

Parte 2
Estabilidad y Métodos de Diseño

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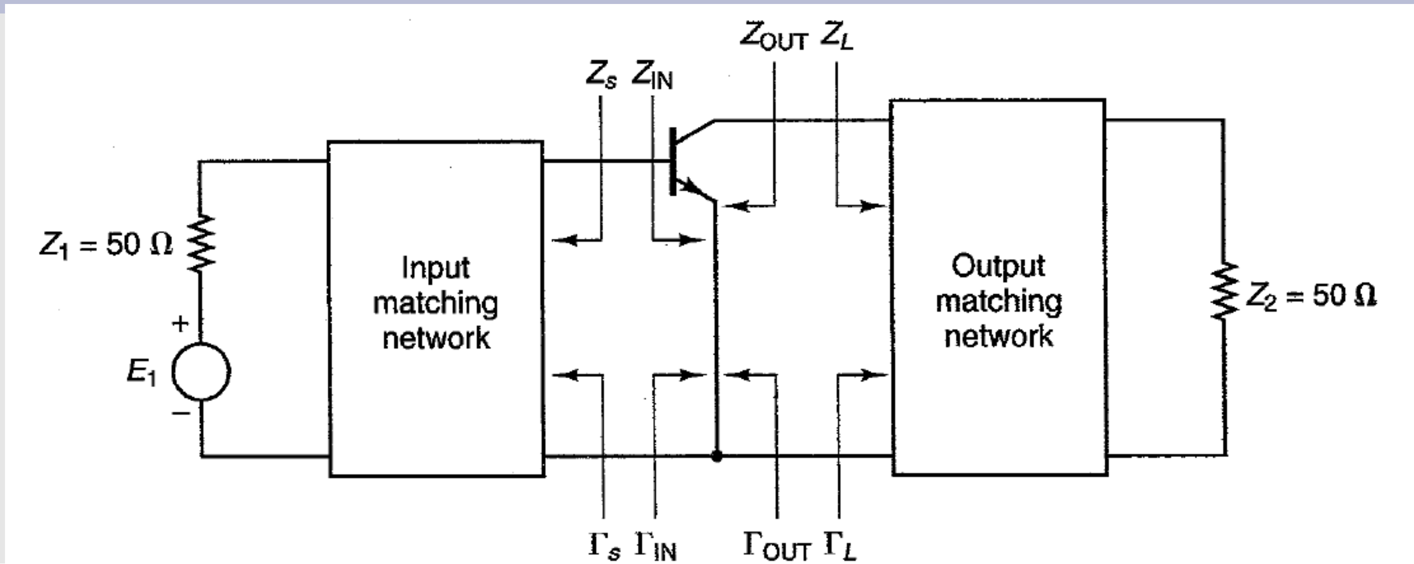
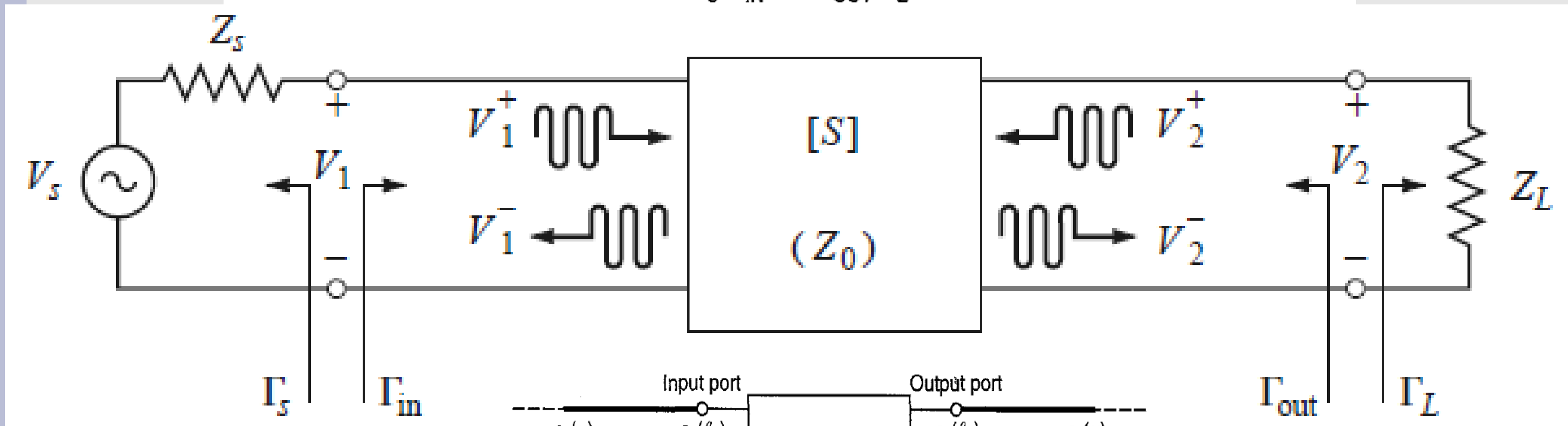
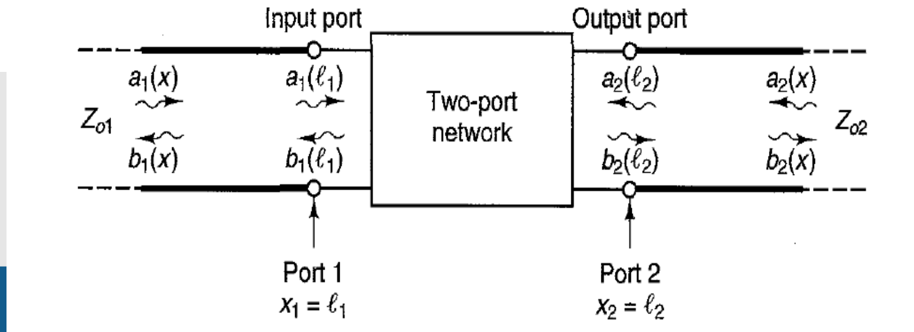
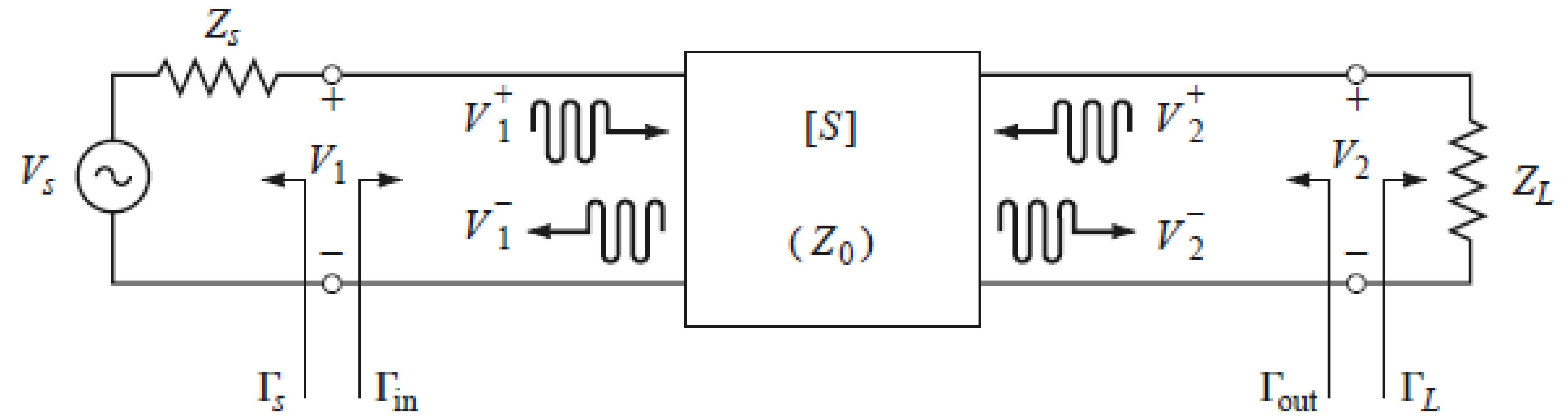
Estructura Basica Amplificador de Microondas







Resumiendo Ganancias



$$G = \frac{P_L}{P_{IN}} = f(\Gamma_L, [S])$$

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

Power Gain

$$G_T = \frac{P_L}{P_{AVS}} = f(\Gamma_S, \Gamma_L, [S])$$

$$G_T = \frac{1 - |\Gamma_s|^2}{|1 - \Gamma_{IN}\Gamma_s|^2}\,|S_{21}|^2\,\frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2}$$

Transducer Gain

$$G_A = \frac{P_{AVN}}{P_{AVS}} = f(\Gamma_S, [S])$$

$$G_A = \frac{1 - |\Gamma_s|^2}{|1 - S_{11}\Gamma_s|^2}\,|S_{21}|^2\,\frac{1}{1 - |\Gamma_{OUT}|^2}$$

Available Power Gain

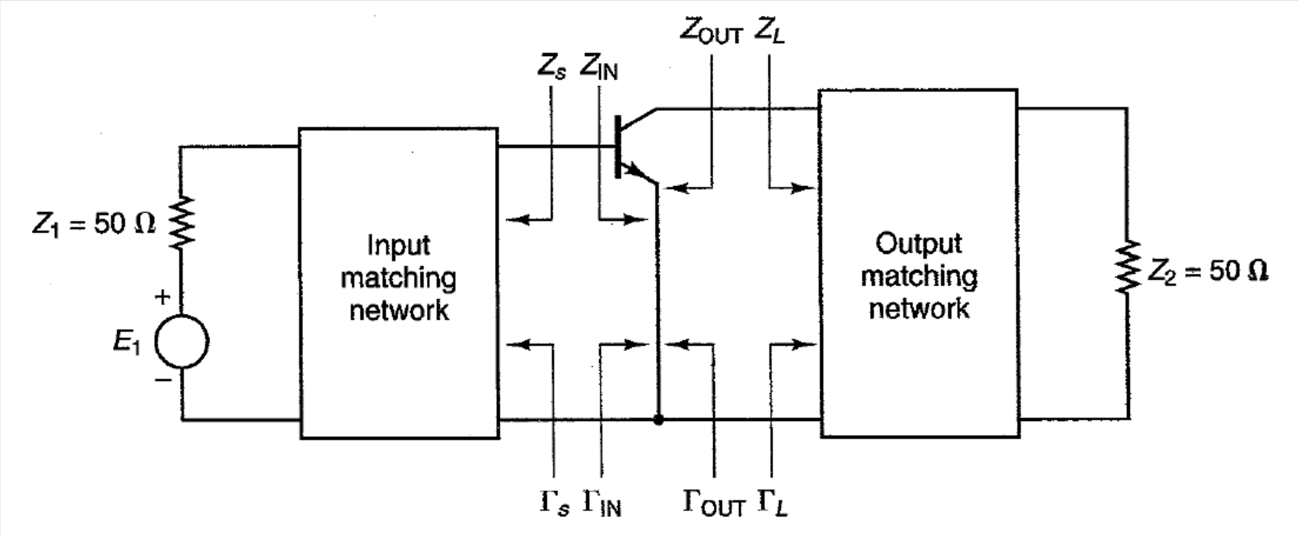
$$\Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$$

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

$$\Gamma_S = \frac{Z_S - Z_0}{Z_S + Z_0}$$

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0}$$

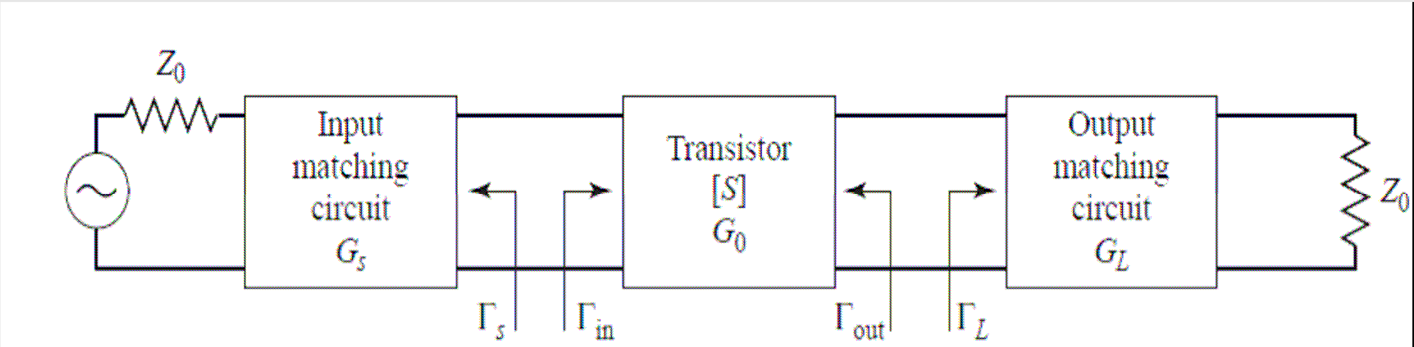
Ganancias en estructura de amplificador



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

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

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



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

$$G_T = G_S G_0 G_L$$

G_S, G_L pueden ser >1 al reducir las pérdidas que habría debido a desadaptación

Si transistor “unilateral” (S12=0 o despreciable)

$$\Gamma_{in} = S_{11}$$

Estabilidad: Previo

Previo:

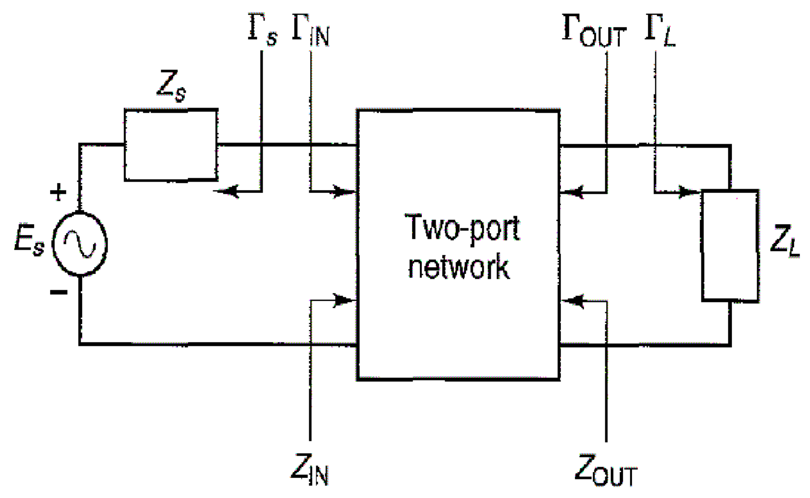
$$\Gamma = \underbrace{\frac{Z - Z_0}{Z + Z_0}}_{Z_0 \text{ real}} \Rightarrow |\Gamma| < 1 \Leftrightarrow \mathrm{Re}(Z) > 0$$

Estabilidad: Incondicional y Condicional

Estabilidad **Incondicional** =

Estable para todo Z_S, Z_L pasivo

(es decir para todo Γ_S, Γ_L que cumple $|\Gamma_S|<1$, $|\Gamma_L|<1$) ⇔



$$|\Gamma_{IN}| = \left| S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \right| < 1$$

$$|\Gamma_{OUT}| = \left| S_{22} + \frac{S_{12}S_{21}\Gamma_s}{1 - S_{11}\Gamma_s} \right| < 1$$

y parámetros S no tienen polos en el semiplano derecho ("Rollett proviso"). Asegurado al poderse medir por ej.

R. Jackson, Rollett Proviso in the Stability of Linear Microwave Circuits—A Tutorial, IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 54, NO. 3, MARCH 2006

Estabilidad **Condicional** = **"Potencialmente inestable"** si estable solo para cierto rango de valores Z_S, Z_L pasivos

Círculos de Estabilidad (1)

$|\Gamma_{in}|<1, \; |\Gamma_{out}|<1$

Centro C_L Radio R_L

$$|\Gamma_{in}| = \left| S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \right| = 1 \Leftrightarrow \left| \Gamma_L - \frac{(S_{22} - \Delta S_{11}^*)^*}{|S_{22}|^2 - |\Delta|^2} \right| = \left| \frac{S_{12}S_{21}}{|S_{22}|^2 - |\Delta|^2} \right|$$

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

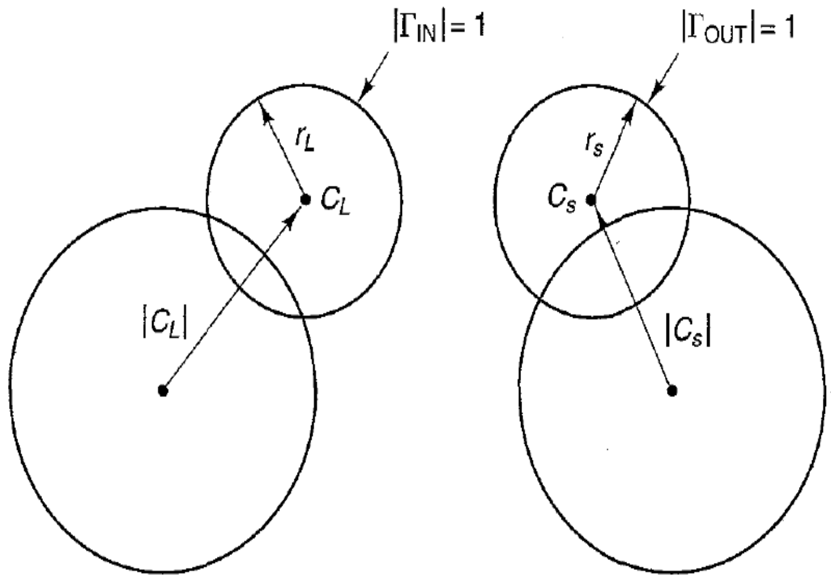
$S_{11} \Leftrightarrow S_{22}$

$$|\Gamma_{out}| = \left| S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - S_{11}\Gamma_S} \right| = 1 \Leftrightarrow$$

Γ_S en círculo de centro C_S y radio R_S

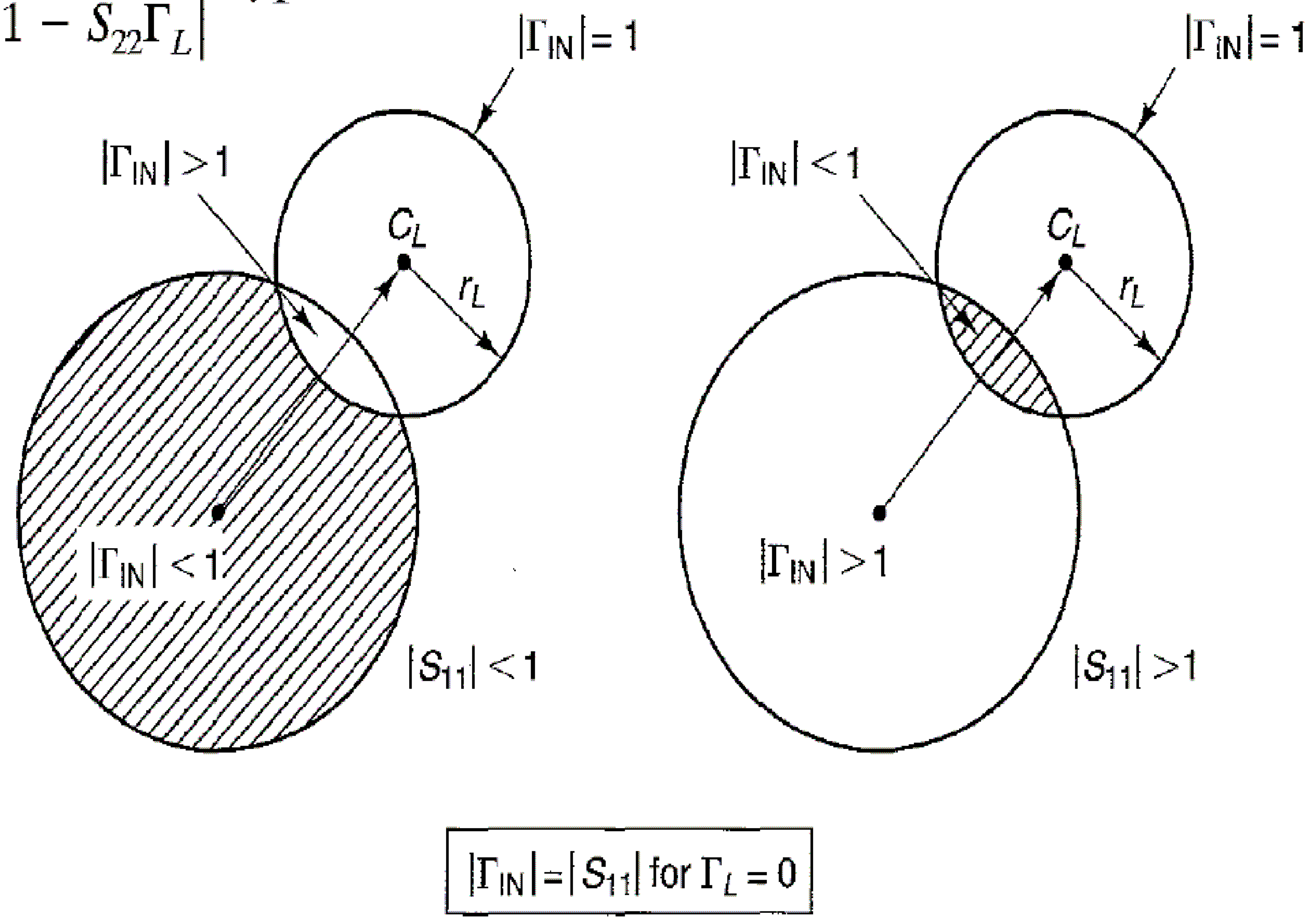
$$C_S = \frac{(S_{11} - \Delta S_{22}^*)^*}{|S_{11}|^2 - |\Delta|^2}$$

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



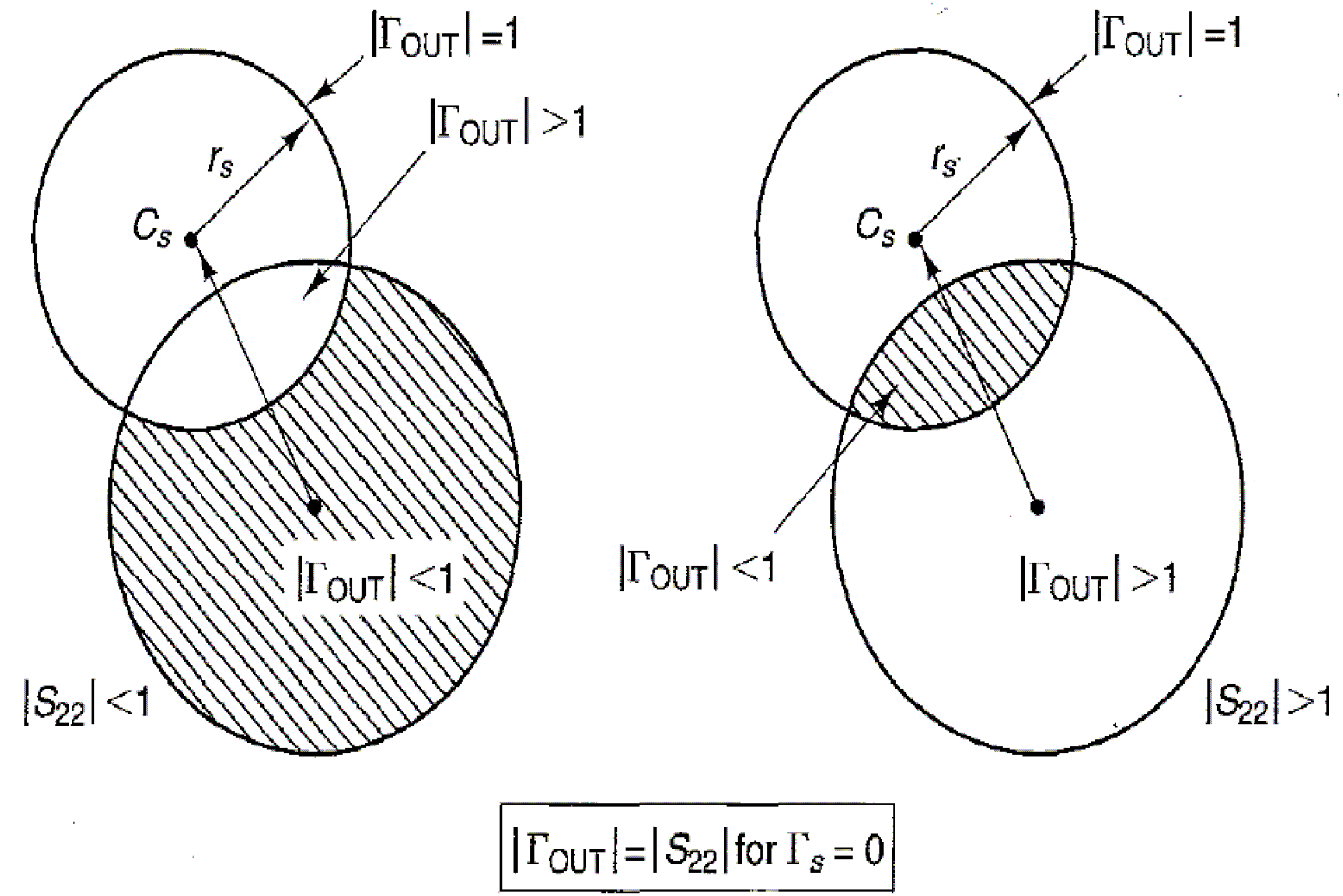
Círculos de Estabilidad (2)

$$|\Gamma_{IN}| = \left| S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \right| < 1$$

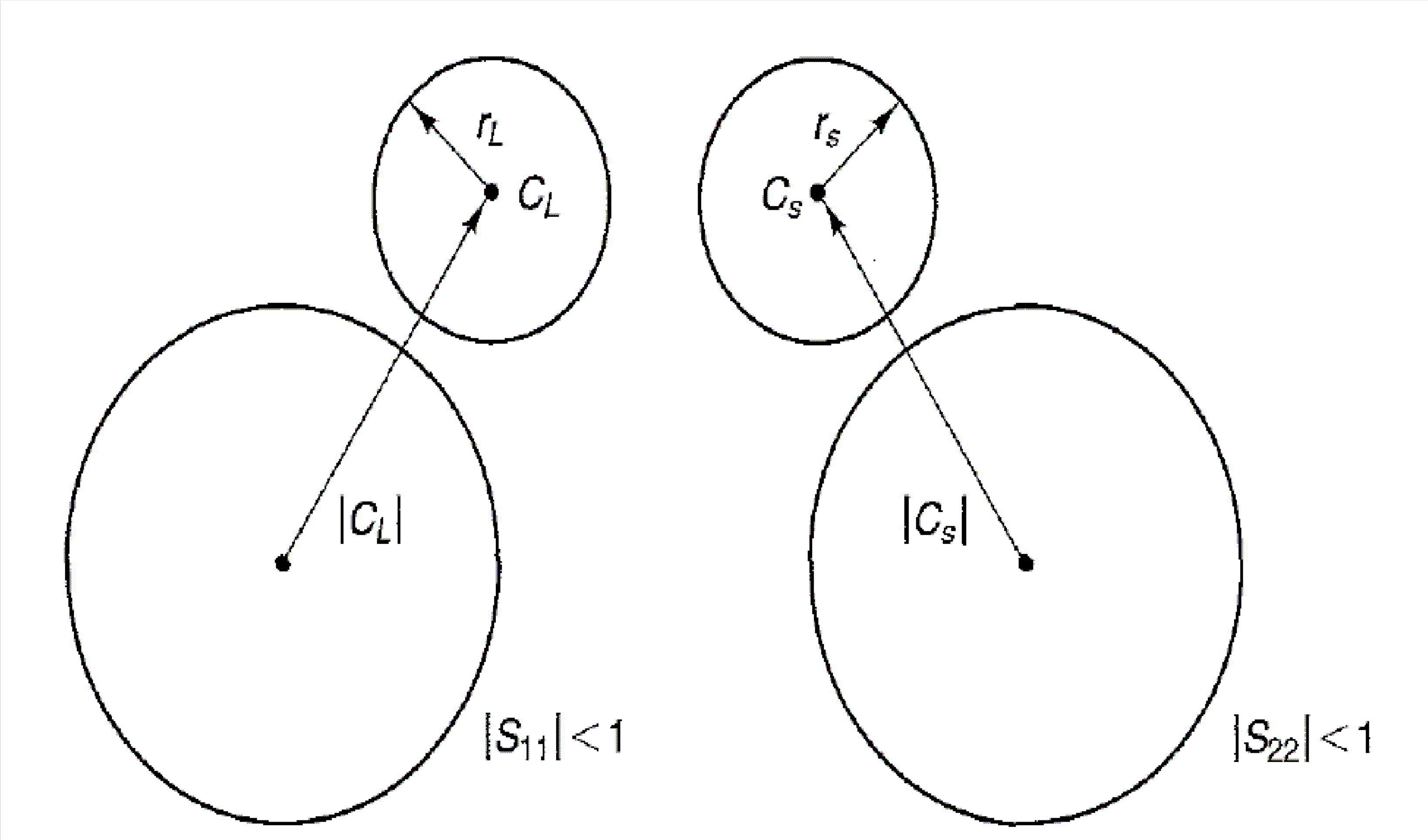


Círculos de Estabilidad (3)

$$|\Gamma_{OUT}| = \left| S_{22} + \frac{S_{12}S_{21}\Gamma_s}{1 - S_{11}\Gamma_s} \right| < 1$$



Círculos de Estabilidad: Estabilidad Incondicional



$$||C_L| - R_L| > 1 \quad \text{for} \quad |S_{11}| < 1$$

$$||C_S| - R_S| > 1 \quad \text{for} \quad |S_{22}| < 1$$

Tests para estabilidad incondicional:

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

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

Para todo w, (Woods, 1976)

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

Para todo w, (Edwards y Sinksy, 1992)

y parámetros S no tienen polos en el semiplano derecho ("Rollett proviso"). Asegurado al poderse medir por ej.

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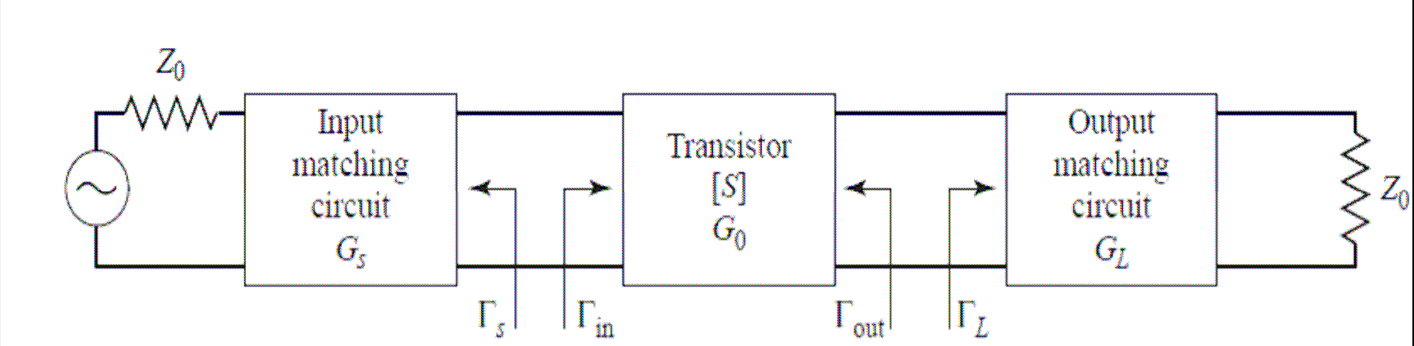
Diseño para máxima ganancia (Adaptación Conjugada)



$$G_T = G_S G_0 G_L$$

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

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

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

$$\Gamma_{in} = \Gamma_S^*$$

$$\Gamma_{out} = \Gamma_L^*$$

$$G_{T\max} = \frac{1}{1 - |\Gamma_S|^2} |S_{21}|^2 \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2}$$

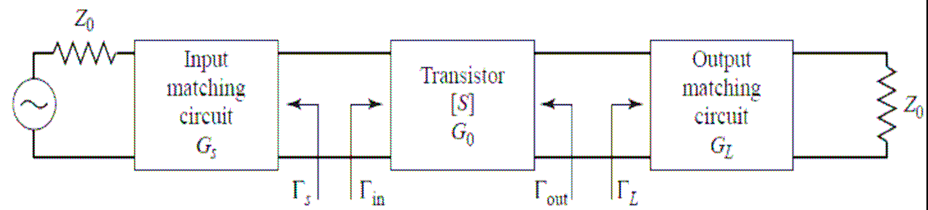
$$\Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$$

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

Además: $G_{Tmax} = G_{pmax} = G_{Amax}$

Diseño para máxima ganancia (Adaptación Conjugada): Γ_S, Γ_L

$$\Gamma_{in} = \Gamma_S^* \qquad \Gamma_{out} = \Gamma_L^*$$



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

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

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

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

$$\Gamma_L^* = \frac{S_{22} - \Delta\Gamma_S}{1 - S_{11}\Gamma_S},$$

Sustituyendo y haciendo cuentas, usando que:

$$\Delta\left(S_{11}^* S_{22}^* - S_{12}^* S_{21}^*\right) = |\Delta|^2$$

$$\Rightarrow \quad (S_{11} - \Delta S_{22}^*)\Gamma_S^2 + \left(|\Delta|^2 - |S_{11}|^2 + |S_{22}|^2 - 1\right)\Gamma_S + \left(S_{11}^* - \Delta^* S_{22}\right) = 0$$

Diseño para máxima ganancia (Adaptación Conjugada): Γ_S, Γ_L

$$(S_{11} - \Delta S_{22}^*)\Gamma_S^2 + (|\Delta|^2 - |S_{11}|^2 + |S_{22}|^2 - 1)\Gamma_S + (S_{11}^* - \Delta^* S_{22}) = 0$$

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

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

$$B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2,$$
$$B_2 = 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2,$$
$$C_1 = S_{11} - \Delta S_{22}^*,$$
$$C_2 = S_{22} - \Delta S_{11}^*.$$

Se puede mostrar (Ver libro G. Gonzalez) que:
- si los términos dentro de la raices son positivos => K>1
- si $|\Delta|$<1 => B1>0 y B2 >0

=> si K>1 y $|\Delta|$<1 (incondicionalmente estable) existe una solución para tener Γ_{ML} y Γ_{MS} con $|\Gamma_{ML}|$<1 y $|\Gamma_{MS}|$<1, que es la solución con signo menos

$$G_{T\max} = \frac{1}{1 - |\Gamma_S|^2}|S_{21}|^2 \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2}$$

$$G_{T,\max} = \frac{|S_{21}|}{|S_{12}|}(K - \sqrt{K^2 - 1})$$

Diseño para máxima ganancia (Adaptación Conjugada): Caso unilateral

$$S_{12} = 0$$

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

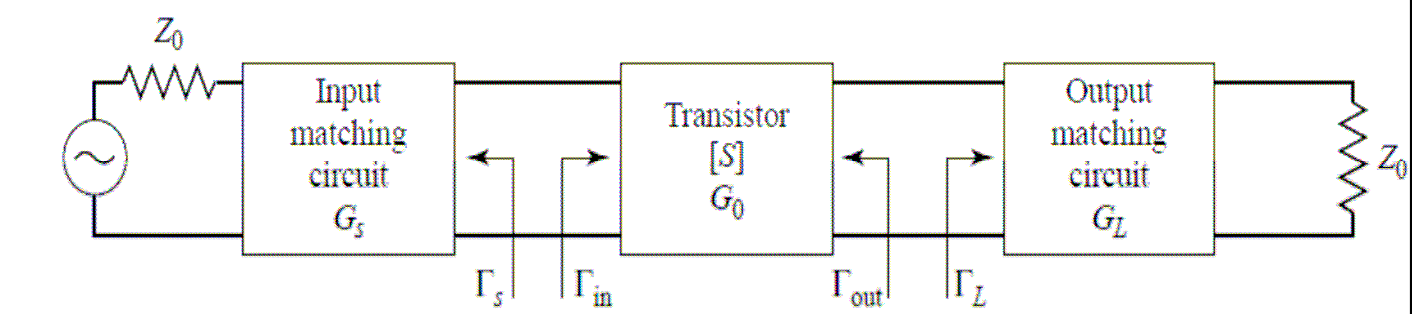
$$\Gamma_S = S_{11}^*$$

$$\Gamma_L = S_{22}^*$$

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

$$G_{TU_{max}} = \frac{1}{1 - |S_{11}|^2}|S_{21}|^2\frac{1}{1 - |S_{22}|^2}.$$

Diseño para Ganancia Específica



$$G_T = G_S G_0 G_L$$

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

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

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

- G_0 dado por transistor => modificar G_S o G_L con adaptación no óptima
- Mejora ancho de banda también.
- Veremos caso **Unilateral (=> S_{12}= 0)**, **incondicionalmente estable**

(Caso Bilateral y caso unilat. Cond estable tratados en libro G. Gonzalez)

Para ver si se puede considerar aprox. unilateral

$$\frac{1}{(1+U)^2} < \frac{G_T}{G_{TU}} < \frac{1}{(1-U)^2}$$

$$U = \frac{|S_{12}||S_{21}||S_{11}||S_{22}|}{\left(1-|S_{11}|^2\right)\left(1-|S_{22}|^2\right)}$$

< 0.2…0.3 dB

U: “unilateral figure of merit”

Diseño para Ganancia Específica
Círculos de Ganancia Constante (1)

S_{12}= 0 => $\Gamma_{in} = S_{11}$ y $\Gamma_{out} = S_{22}$ Incond. estable => $|S_{11}|<1$, $|S_{22}|<1$

$$G_T = G_S G_0 G_L$$

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

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

$$G_{S_{max}} = \frac{1}{1-|S_{11}|^2}$$

$$G_{L_{max}} = \frac{1}{1-|S_{22}|^2}$$

@

$$\Gamma_S = S_{11}^*$$

$$\Gamma_L = S_{22}^*$$

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

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

g_S, g_L constantes:
círculos en plano Γ_S, Γ_L

$$0 \le g_S \le 1 \text{ and } 0 \le g_L \le 1.$$

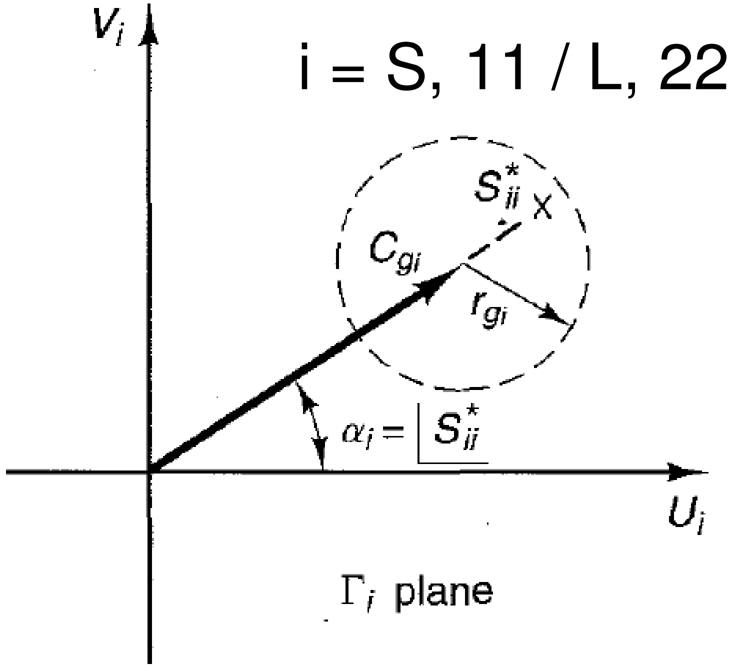
Diseño para Ganancia Específica
Círculos de Ganancia Constante (2)

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

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

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

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

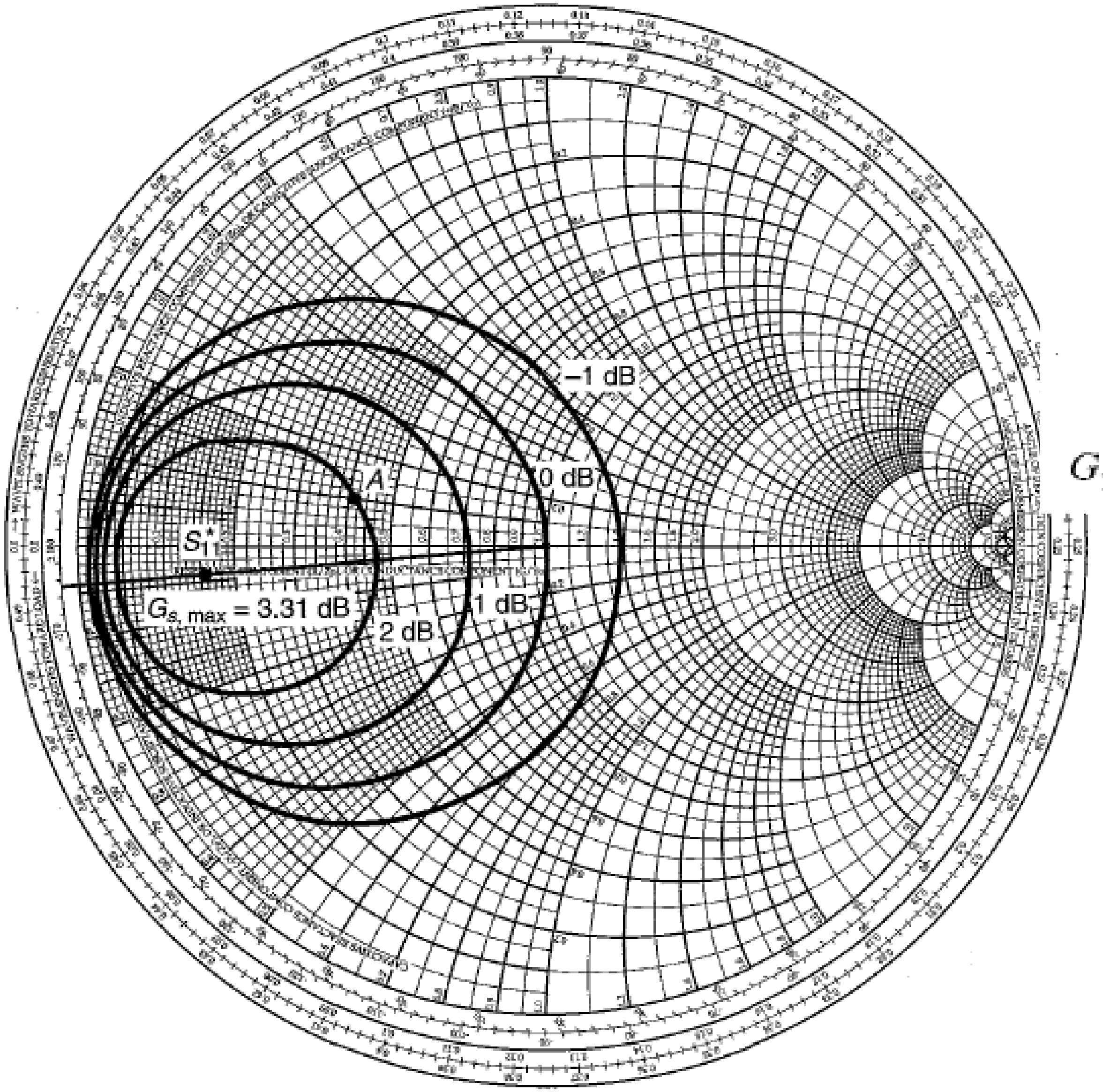


$$g_S = \frac{G_S}{G_{S\max}} = 1 \Leftrightarrow G_S = G_{S\max} \Leftrightarrow \Gamma_S = \Gamma_{in}^* = S_{11}^*$$

$$g_L = \frac{G_L}{G_{L\max}} = 1 \Leftrightarrow G_L = G_{L\max} \Leftrightarrow \Gamma_L = \Gamma_{out}^* = S_{22}^*$$

G_S, G_L =1 (0 dB) => círculos pasan por origen
($\Gamma_S = \Gamma_L = 0$ => $G_T = |S_{21}|^2 = G_0$)

Ej.



$$G_{s,\,\max} = \frac{1}{1 - |S_{11}|^2} = 2.141 \quad \text{or} \quad 3.31\text{ dB}$$

$$G_{L,\,\max} = \frac{1}{1 - |S_{22}|^2} = 1.046 \quad \text{or} \quad 0.195\text{ dB}$$

$$G_o = |S_{21}|^2 = 19.8 \quad \text{or} \quad 12.97\text{ dB}$$

$$G_{TU,\max}(\text{dB}) = 3.31 + 12.97 + 0.195 = 16.47\text{ dB}$$