NOTABLE 29 - VI - 2005

Apuntes de Fundamentos de Microondas 2
4º ETSI Telecomunicación
Universidad de Málaga

Carlos García Argos (carlos@garciaargos.com)
http://www.garciaargos.com

Curso 2004/2005

(IÑIGO)

FUNDAMENTOS DE MICROONDAS 2

$$M = \frac{4 R_g R_L}{|Z_g + Z_L|^2} = \frac{(1-|\Gamma_g|^2)(1-|\Gamma_L|^2)}{|1-\Gamma_g \Gamma_L|^2} = 1 - \left(\frac{COE_{in}-1}{COE_{in}+1}\right)^2$$

$\Gamma_{zg} = 0$

$$COE_{in} = \frac{1+|\Gamma_x|}{1-|\Gamma_x|} = \frac{1+\sqrt{1-M_x}}{1-\sqrt{1-M_x}}$$

$\Gamma_{zg} = 0$

$$G_t = M_L G_d = M_g G_p \qquad G_d = \frac{M_g}{M_L} G_p$$

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

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

$$G_{tu} = \frac{1-|\Gamma_g|^2}{|1-S_{11}\Gamma_g|^2} |S_{21}|^2 \frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \qquad G_{tu,max} = \frac{1}{1-|S_{11}|^2} |S_{21}|^2 \frac{1}{1-|S_{22}|^2}$$

$$K = \frac{1+|\Delta|^2 - |S_{11}|^2 - |S_{22}|^2}{2|S_{12}||S_{21}|} \qquad MAG = \frac{|S_{21}|}{|S_{12}|}\left(K \pm \sqrt{K^2-1}\right) \qquad MSG = \left|\frac{S_{21}}{S_{12}}\right|$$

$$FM = \frac{F-1}{1-1/G_d} \qquad F = F_1 + \frac{F_2-1}{G_1} + \frac{F_3-1}{G_1G_2} + \dots \qquad G_{1dB} = G_0 - 1$$

$$M_{L1} = M_{g2} \rightarrow G_p = G_{p1} G_{p2},\ G_d = G_{d1} G_{d2},\ G_t = M_{g1} G_{p1} G_{p2}$$

$$i(t) = i(v_{OL}(t)) + g(v_{OL}(t))\, v_{RF}(t) \qquad g(t) = \sum G_n e^{j\omega_{OL} n t}$$

$$\begin{bmatrix} I^*_{IMAG} \\ I_{FI} \\ I_{RF} \end{bmatrix} = \begin{bmatrix} G_0 & G_1^* & G_2^* \\ G_1 & G_0 & G_1^* \\ G_2 & G_1 & G_0 \end{bmatrix} \begin{bmatrix} V^*_{IMAG} \\ V_{FI} \\ V_{RF} \end{bmatrix} \qquad \bar{V} = \left(\bar{\bar{R}} + \left(\bar{\bar{G}} + \bar{\bar{C}}\right)^{-1}\right) \bar{I} \qquad f_c = \frac{1}{2\pi C_j \sqrt{R_S R_j}}$$

$$Z_{IMAG} \Rightarrow \begin{bmatrix} I_{FI} \\ I_{RF} \end{bmatrix} = \begin{bmatrix} G_0 + \frac{|G_1|^2}{Y^*_{IMAG} - G_0} & G_1 + \frac{G_1^* G_2}{Y^*_{IMAG} - G_0} \\ G_1^* + \frac{G_1 G_2^*}{Y^*_{IMAG} - G_0} & G_0 + \frac{|G_2|^2}{Y^*_{IMAG} - G_0} \end{bmatrix} \begin{bmatrix} V_{FI} \\ V_{RF} \end{bmatrix}$$

$$f_{CS} = \frac{1}{2\pi C_j \sqrt{R_f R_r}}$$

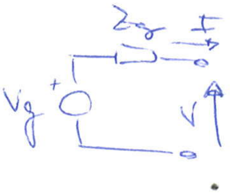
Paralelo: $S_{21} = \frac{2}{2+\bar{Y}}$, $A = \left(1 + \frac{Z_0}{2R_f}\right)^2$, $L_I = 1 + \left(\frac{\omega C_j Z_0}{2}\right)^2$

Serie: $S_{21} = \frac{2}{2+\bar{Z}}$, $A = 1 + \left(\frac{1}{2\omega C_j Z_0}\right)^2$, $L_I = \left(1 + \frac{R_f}{2Z_0}\right)^2$

$$[S] = \frac{1}{2+\bar{Y}} \begin{bmatrix} -\bar{Y} & 2 \\ 2 & -\bar{Y} \end{bmatrix}$$

$$[S] = \frac{1}{2+\bar{Z}} \begin{bmatrix} \bar{Z} & 2 \\ 2 & \bar{Z} \end{bmatrix}$$

TEMA 1



$$a = a_g \Big|_{Z_L = Z_0} = \frac{V_g}{\sqrt{8 Z_0}} (1 - \Gamma_g)$$

$$|a_g|^2 = P_{dg} (1 - |\Gamma_g|^2)$$

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

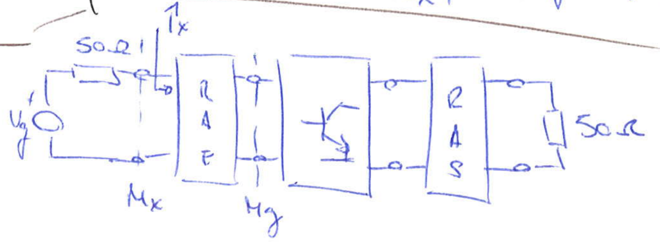
TEMA 2

$$M = \frac{4 R_g R_L}{|Z_g + Z_L|^2} = \frac{(1 - |\Gamma_g|^2)(1 - |\Gamma_L|^2)}{|1 - \Gamma_g \Gamma_L|^2}$$

$$COE_{in} = \frac{1 + |\Gamma_x|}{1 - |\Gamma_x|} = \frac{1 + \sqrt{1 - M_x}}{1 - \sqrt{1 - M_x}}$$

$$M_x = 1 - |\Gamma_x|^2 = 1 - \left(\frac{COE_{in} - 1}{COE_{in} + 1} \right)^2$$

$\Gamma_g = 0$ (Z_0)



$$G_p = \frac{P_{eL}}{P_{in}} \qquad G_d = \frac{P_{dsal}}{P_{dg}} \qquad G_t = \frac{P_{eL}}{P_{dg}}$$

$$G_t = M_L G_d = M_g G_p$$

$$G_d = \frac{M_g}{M_L} G_p$$

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

$$G_{tu,max} = \frac{1}{1 - |S_{11}|^2} |S_{21}|^2 \frac{1}{1 - |S_{22}|^2} \qquad G_{tu} = M_g \cdot G_{tu,max} \cdot M_L$$

CEE: $C_{go} = \dfrac{S_{22} \Delta^* - S_{11}^*}{|\Delta|^2 - |S_{11}|^2}$ $\quad R_{go} = \dfrac{|S_{21} S_{12}|}{\left| |\Delta|^2 - |S_{11}|^2 \right|}$

CES: $C_{Lo} = \dfrac{S_{11} \Delta^* - S_{22}^*}{|\Delta|^2 - |S_{22}|^2}$ $\quad R_{Lo} = \dfrac{S_{21} S_{12}}{\left| |\Delta|^2 - |S_{22}|^2 \right|}$

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

$$MAG = \left|\frac{S_{21}}{S_{12}}\right| \left(k \pm \sqrt{k^2-1}\right)$$

$$MSG = \left|\frac{S_{21}}{S_{12}}\right|$$

G_p = cte:

$$C_{Lp} = \frac{g_p (S_{22}^* - \Delta^* S_{11})}{1 + g_p (|S_{22}|^2 - |\Delta|^2)} \qquad R_{Lp} = \frac{\sqrt{1 - 2k g_p |S_{12}S_{21}| + g_p^2 |S_{12}S_{21}|^2}}{\left|1 + g_p(|S_{22}|^2 - |\Delta|^2)\right|}$$

$$g_p = \frac{G_p}{|S_{21}|^2}$$

G_d = cte:

$$C_{gd} = \frac{g_d (S_{11}^* - \Delta^* S_{22})}{1 + g_d (|S_{11}|^2 - |\Delta|^2)} \qquad R_{gd} = \frac{\sqrt{1 - 2k g_d |S_{12}S_{21}| + g_d^2 |S_{12}S_{21}|^2}}{\left|1 + g_d(|S_{11}|^2 - |\Delta|^2)\right|}$$

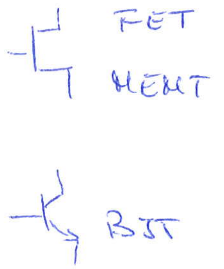
M = cte:

$$C_M = \frac{M \Gamma_L^*}{1 + (M-1)|\Gamma_L|^2} \qquad R_M = \sqrt{|C_M|^2 - \frac{M - 1 + |\Gamma_L|^2}{1 + (M-1)|\Gamma_L|^2}}$$

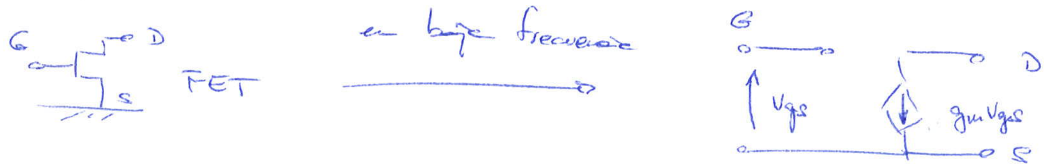
TEMA 1: CARACTERIZACIÓN DE DISPOSITIVOS DE ESTADO SÓLIDO DE RADIOFRECUENCIA Y MICROONDAS

1.- INTRODUCCIÓN AL PROBLEMA DE LA CARACTERIZACIÓN

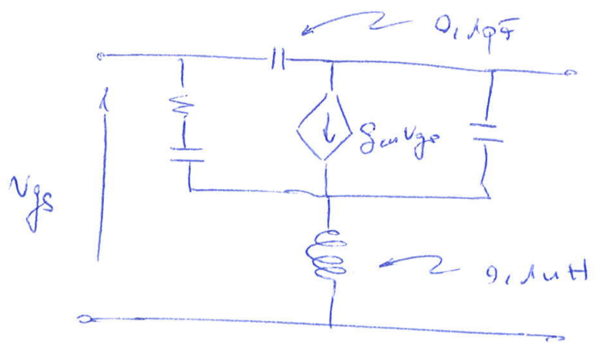
Nos encontraremos dispositivos como:



Básicamente como en baja frecuencia, pero con unos efectos debidos a la alta frecuencia



Este modelo no vale para altas frecuencias. Un modelo más real en la nueva situación que se plantea sería:



$\omega L = 6{,}28\,\Omega$

$(\omega C)^{-1} = 158\,\Omega$ } $f = 10\,GHz$

Respecto a la impedancia característica típica de 50 Ω son comparables, por lo que hay que tener en cuenta sus efectos.

Otro problema es la construcción de estos dispositivos, ya que hace falta una tecnología muy precisa y costosa (fotolitografía)

¿Cómo caracterizar un dispositivo?

a) Tipo caja negra:

Se suelen dar diferentes S(f) para diferentes frecuencias y polarizaciones (sólo válidos en pequeña señal o aproximación lineal)

$$S(f) = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$$

Como ventaja, no tenemos que preocuparnos de lo que hay en su interior.

¿Qué ocurre si queremos un dispositivo que trabaje en régimen no lineal? Por ejemplo, amplificadores de potencia.

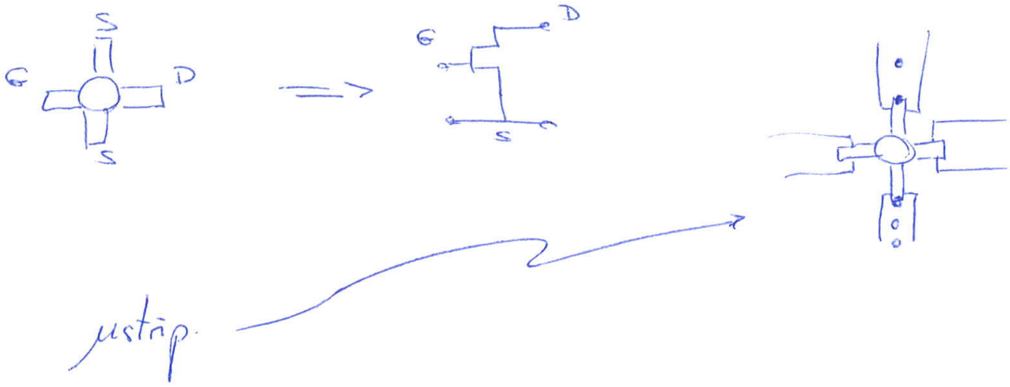
Nos tendrían que dar S(f,A) (no se usa frecuentemente)

Para el modelo lineal necesitamos saber:

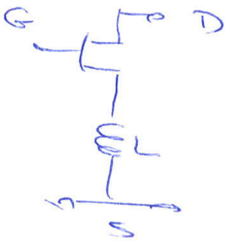
1.- Dónde están los planos de referencia

2.- El test-fixture del dispositivo

1.-



En realidad, debido a los agujeros que conectan el dispositivo al plano de masa, hace falta saber cómo están los agujeros porque en realidad tendrán una pequeña inductancia.

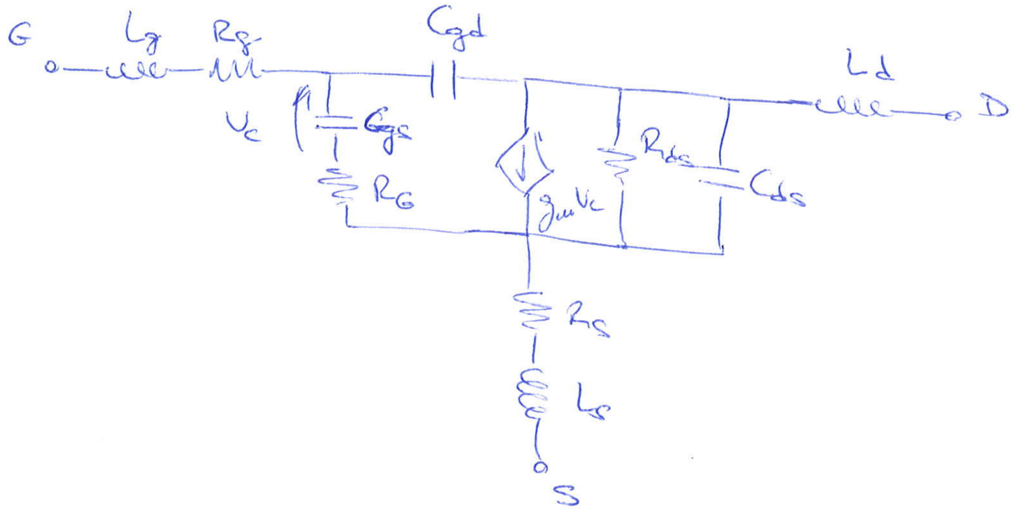


El fabricante debe especificar el plano de referencia.

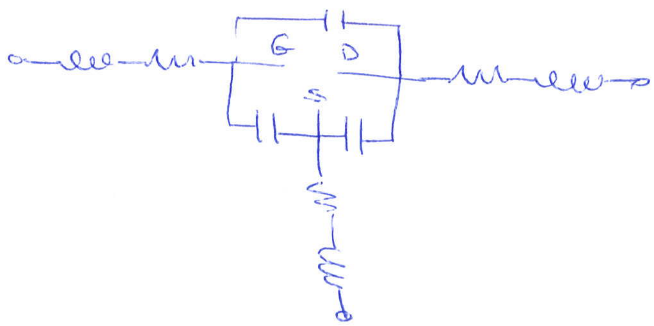
2.- Nos referimos al circuito de medida empleado por el fabricante para darnos los parámetros que da (disposición física, etc.)

Los parámetros deben tomarse tanto en corte como en saturación.

b) Circuito equivalente lineal (en bornas del chip):



Tengamos en cuenta que esto va encapsulado por lo que tendremos más efectos parásitos:



Tenemos muchos parámetros (por tanto precisión), pero son complicados de obtener.

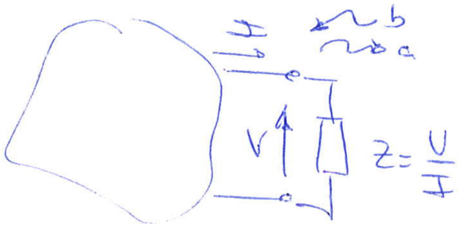
Permite simulaciones y un análisis lineal (de ahí su nombre). Salvo que interese realmente saber cómo funciona internamente, es mejor quedarse con el modelo de caja negra.

c) Circuito equivalente no lineal

Es un refinamiento mayor, pero más complejo y difícil de encontrar para un dispositivo.

2.- REPASO DE PARÁMETROS S

Aparecen de modo natural cuando hay líneas de transmisión, pero se pueden usar cuando no hay líneas ni dispositivos que presenten efectos de propagación.



Pero en una guía de ondas no se puede identificar V ni I, ya que sólo hay un conductor.

Se definen 2 ondas a, b, respecto de una impedancia de referencia Z_0. Si no se dice nada, $Z_0 = 50\ \Omega$

$$V = \sqrt{2Z_0}\,(a+b) \qquad \longleftrightarrow \qquad a = \frac{V + Z_0 I}{\sqrt{8Z_0}}$$

$$I = \sqrt{\frac{2}{Z_0}}\,(a-b) \qquad\qquad b = \frac{V - Z_0 I}{\sqrt{8Z_0}}$$

↑ nuevas magnitudes observables

Surge también el concepto de coeficiente de reflexión:

$$\Gamma = \frac{b}{a}$$

quedando Z:

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

Por lo que dará igual usar Z o Γ (aunque hace falta conocer Z_0 para definir Γ)

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

Si descomponemos V en V^+ y V^-:

$$V^+ = \sqrt{2 Z_0}\, a \qquad V^- = \sqrt{2 Z_0}\, b$$

Estos parámetros sólo tienen sentido físico en dispositivos de parámetros distribuidos.

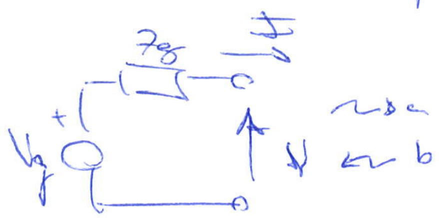
La potencia quedará:

$$Pot = \frac{1}{2} Re(V I^*) = \frac{1}{2} Re\left(\sqrt{2 Z_0}(a+b)\sqrt{\frac{2}{Z_0}}(a^* - b^*)\right) =$$

$$= Re\left(|a|^2 - a b^* + b a^* - |b|^2\right) = |a|^2 - |b|^2$$

En una guía de ondas lo que se puede medir es a y b.

Respecto del generador tenemos:



$V = V_g - Z_g I \qquad P_{dg} = \dfrac{|V_g|^2}{8 Re(Z_g)}$

Dadas las expresiones anteriores y la ya conocida:

$$a = a_g + \Gamma_g b$$

$$a = a_g \Big|_{Z_L = Z_0} = \frac{V}{\sqrt{2 Z_0}} = \frac{\frac{Z_0}{Z_g + Z_0} V_g}{\sqrt{2 Z_0}} = \frac{V_g}{\sqrt{8 Z_0}} (1 - \Gamma_g)$$

¿Cómo se relaciona con la potencia disponible?

Cargamos el generador con Z_g^*:

$$P_{dg} = |a|^2 - |b|^2 = |a|^2 (1 - |\Gamma_g^*|^2) = |a|^2 (1 - |\Gamma_g|^2)$$

De $\begin{cases} a = a_g + \Gamma_g b \\ \Gamma = \frac{b}{a} \end{cases} \longrightarrow a = \dfrac{a_g}{1 - |\Gamma_g|^2}$ y si la llevamos a la anterior:

$$P_{dg} = \frac{|a_g|^2}{1 - |\Gamma_g|^2} \qquad \boxed{|a_g|^2 = P_{dg} (1 - |\Gamma_g|^2)}$$

El generador entrega toda su potencia a la carga, pero a es mayor, por lo que $b \neq 0$. No es lo mismo onda incidente que potencia disponible

3: TRANSFORMACIÓN ENTRE PARÁMETROS

Una vez definida la impedancia de referencia:

$S|_{Z_0} \longrightarrow Z, Y, T$

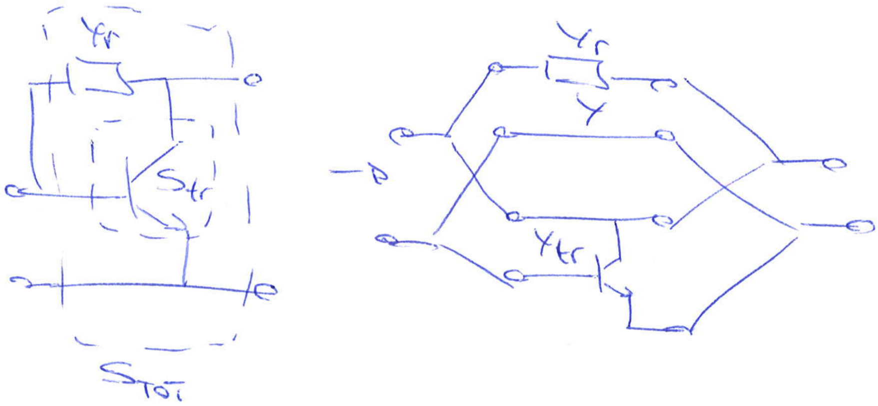
$$\bar{\bar{S}} = [\bar{\bar{Z}} - Z_0 \bar{\bar{I}}][\bar{\bar{Z}} + Z_0 \bar{\bar{I}}]^{-1}$$

$$\bar{\bar{Z}} = Z_0 [\bar{\bar{I}} - \bar{\bar{S}}]^{-1} [\bar{\bar{I}} + \bar{\bar{S}}]$$

Se asemejan a coeficientes de reflexión porque son relaciones entre a's y b's

Referencia → (* 1.13, 1.14 *)

Ejemplo de uso de esas tablas:



$Y_T = Y_{tr} + Y_r$

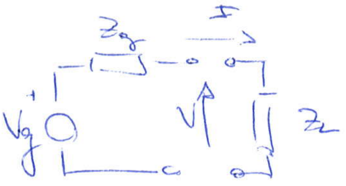
Paralelo → S → Y → Σ → S

Serie → S → Z → Σ → S

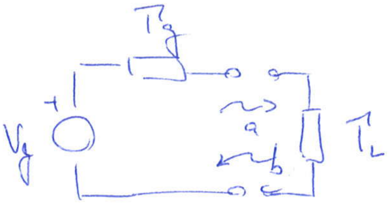
Cascada → S → T → Σ → S

Hemos dicho que los fabricantes dan S' en emisor común y fuente común.

$S'_E \rightarrow Y_E \rightarrow Y_B \rightarrow S'_B$



Dado Z_0 ref



$$\begin{cases} V = V_g - Z_g I \\ V = Z_L I \end{cases}$$

$$\begin{cases} a = a_g + \Gamma_g b \\ b = \Gamma_L a \end{cases}$$

$$a_g = \frac{V_g}{\sqrt{8 Z_0}}(1-\Gamma_g)$$

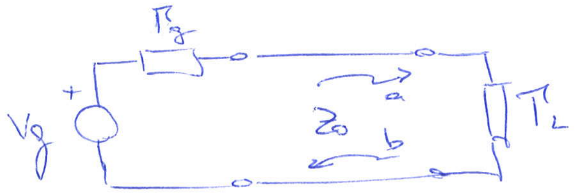
$$\Updownarrow$$

$$|a_g|^2 = P_{dg}(1 - |\Gamma_g|^2)$$

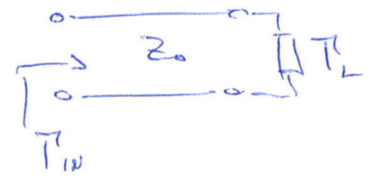
- ¿Por qué se usan los parámetros S en microondas?

Donde dice "parámetros S" puede ir "ondas de potencia", como magnitudes observables.

1.- Son los parámetros naturales de las líneas de transmisión.

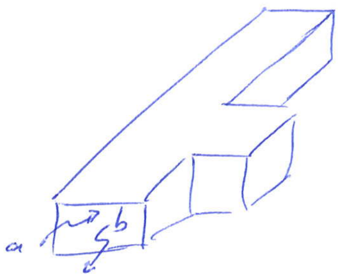


Al moverse por una línea de transmisión de impedancia característica Z_0, los parámetros S sólo cambian en la fase, no en el módulo. (línea sin pérdidas)

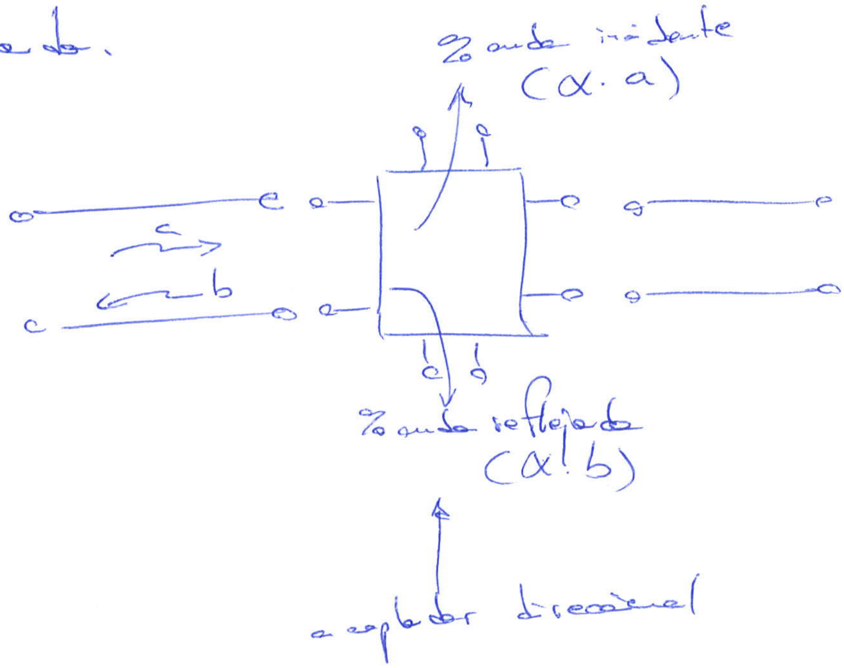


$$|\Gamma_{IN}| = |\Gamma_L|$$

2.- Cuando tenemos un circuito construido con guías de onda, no podemos caracterizarlo con tensiones y corrientes, ya que no hay modos TEM.



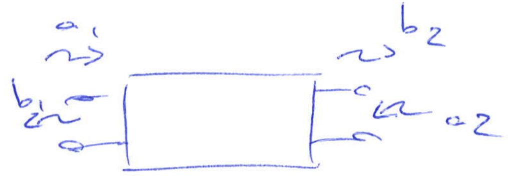
3.- En otros casos, es muy difícil medir tensiones y corrientes a altas frecuencias, pero existe un dispositivo, el acoplador direccional, que discrimina muy bien las ondas incidente y reflejada.



4.- Para medir los parámetros Y o Z hay que hacer cortocircuitos y circuitos abiertos.

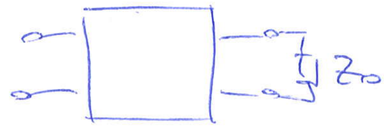
En muchas ocasiones no se puede hacer un circuito abierto. Por ejemplo, una guía abierta radia, por lo que no puede hacerse. Los cortos sí se pueden hacer, pero son "regulinex".

Para medir un bipuerto con parámetros S, sin embargo, basta con cargar con Z_0



$$\begin{cases} b_1 = S_{11} a_1 + S_{12} a_2 \\ b_2 = S_{21} a_1 + S_{22} a_2 \end{cases} \qquad S_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0}$$

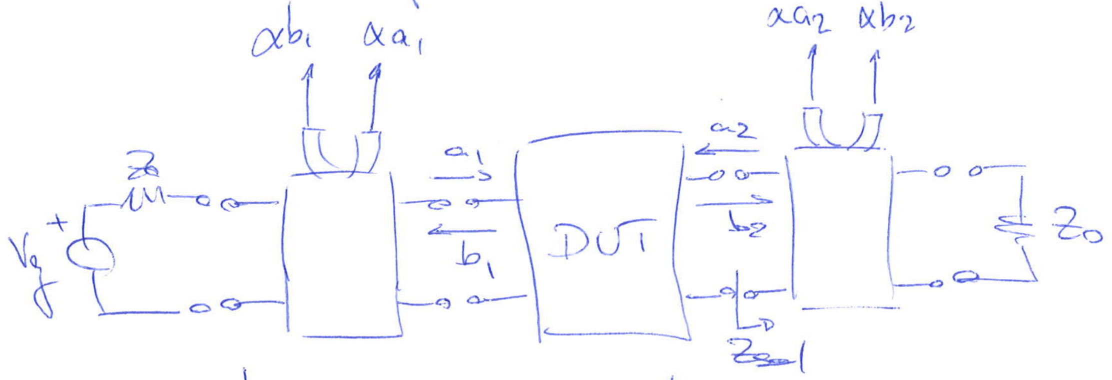
Las cargas terminales son mucho más fáciles de hacer para los parámetros S que para los demás parámetros.



Además, los cortocircuitos o circuitos abiertos pueden generar oscilaciones. Esto es así porque los transistores de ondas ya de por sí tienden a oscilar con mucha facilidad.

(ex 1.9*) → analizador de redes.

Explica el esquema teórico necesario para medir parámetros S.



$$S_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0} \qquad S_{21} = \left.\frac{b_2}{a_1}\right|_{a_2=0} \rightarrow Z_{sal} = Z_0$$

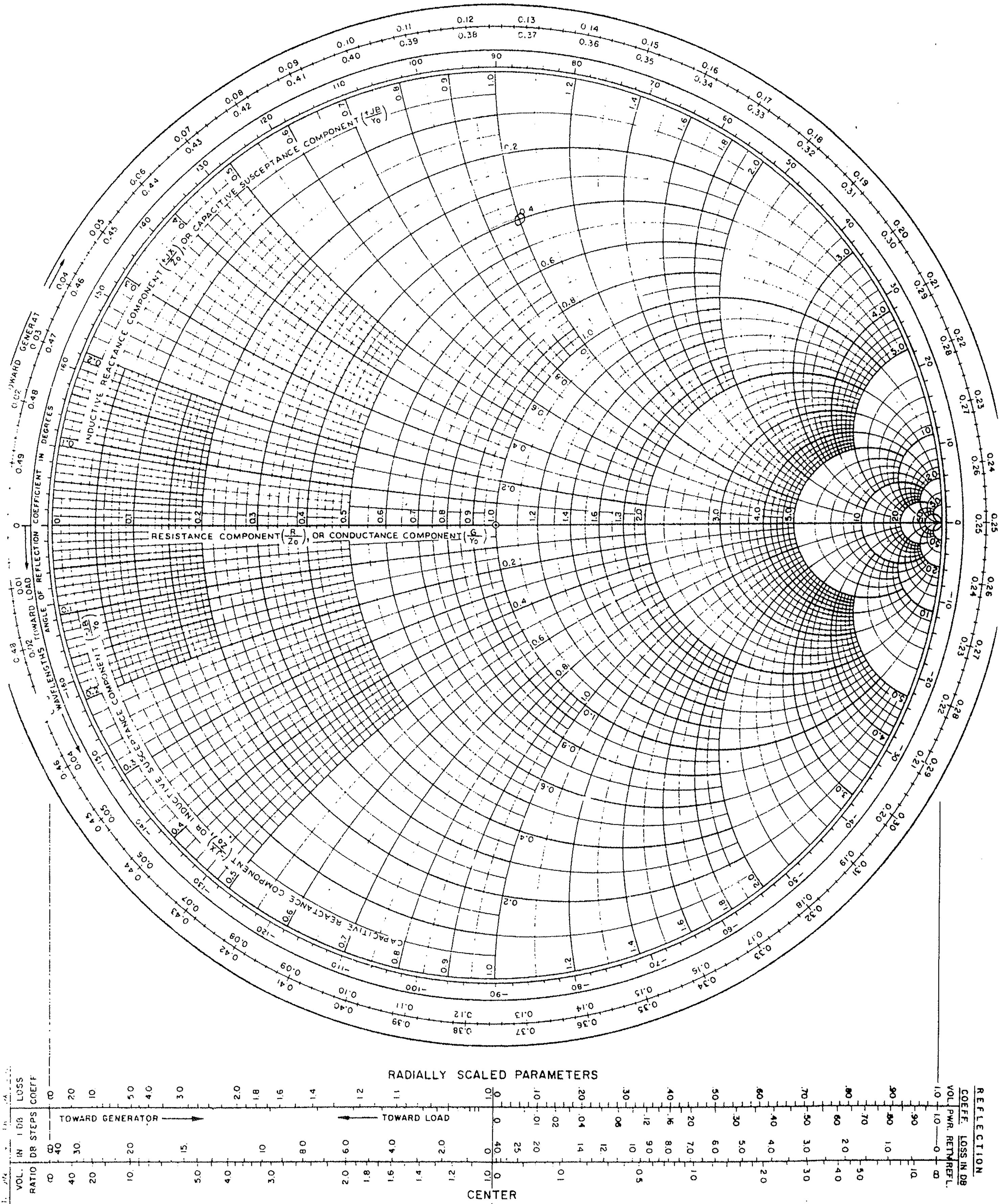
Hay que medir módulo y fase relativos de a_1, b_1 y b_2

Para medir los S_{12} y S_{22} se le da la vuelta al tema.

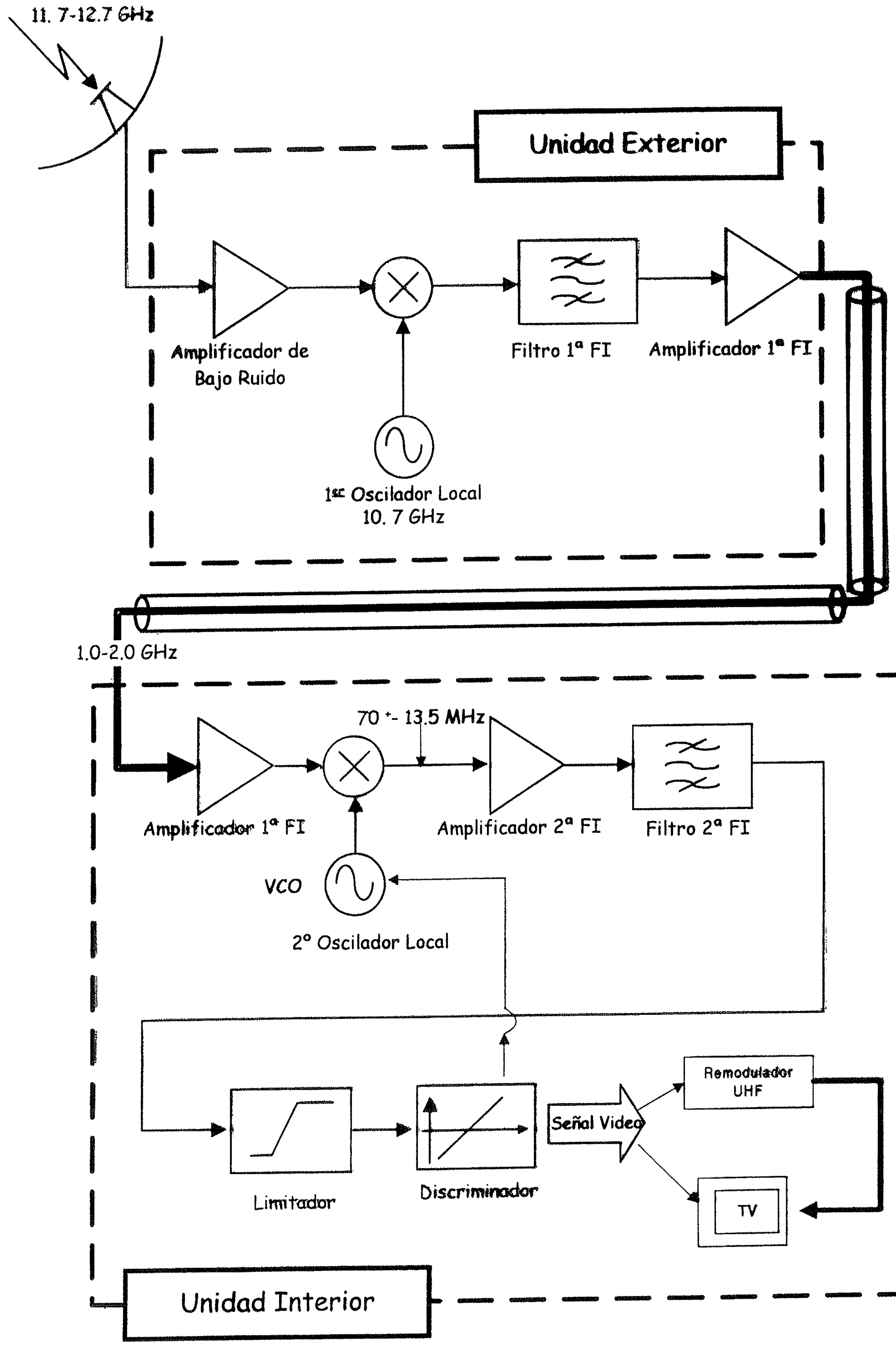
(9) 4º TEC. SUP. 2'91 €

NAME	TITLE	DWG. NO.
SMITH CHART FORM 5301-7560-N	GENERAL RADIO COMPANY, WEST CONCORD, MASSACHUSETTS	DATE

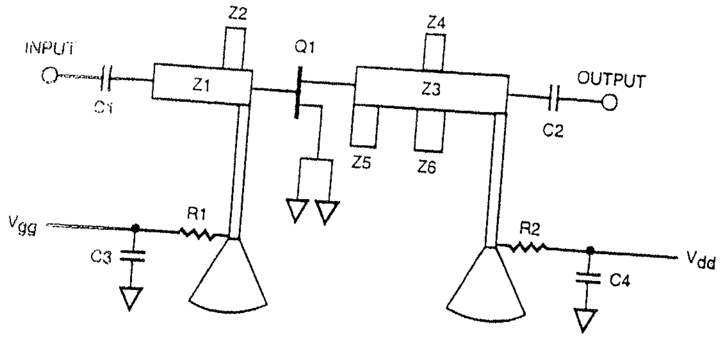
IMPEDANCE OR ADMITTANCE COORDINATES



Electronics- Vol. 17, No. 1, PP. 130–133, 318–325, Jan. 1944



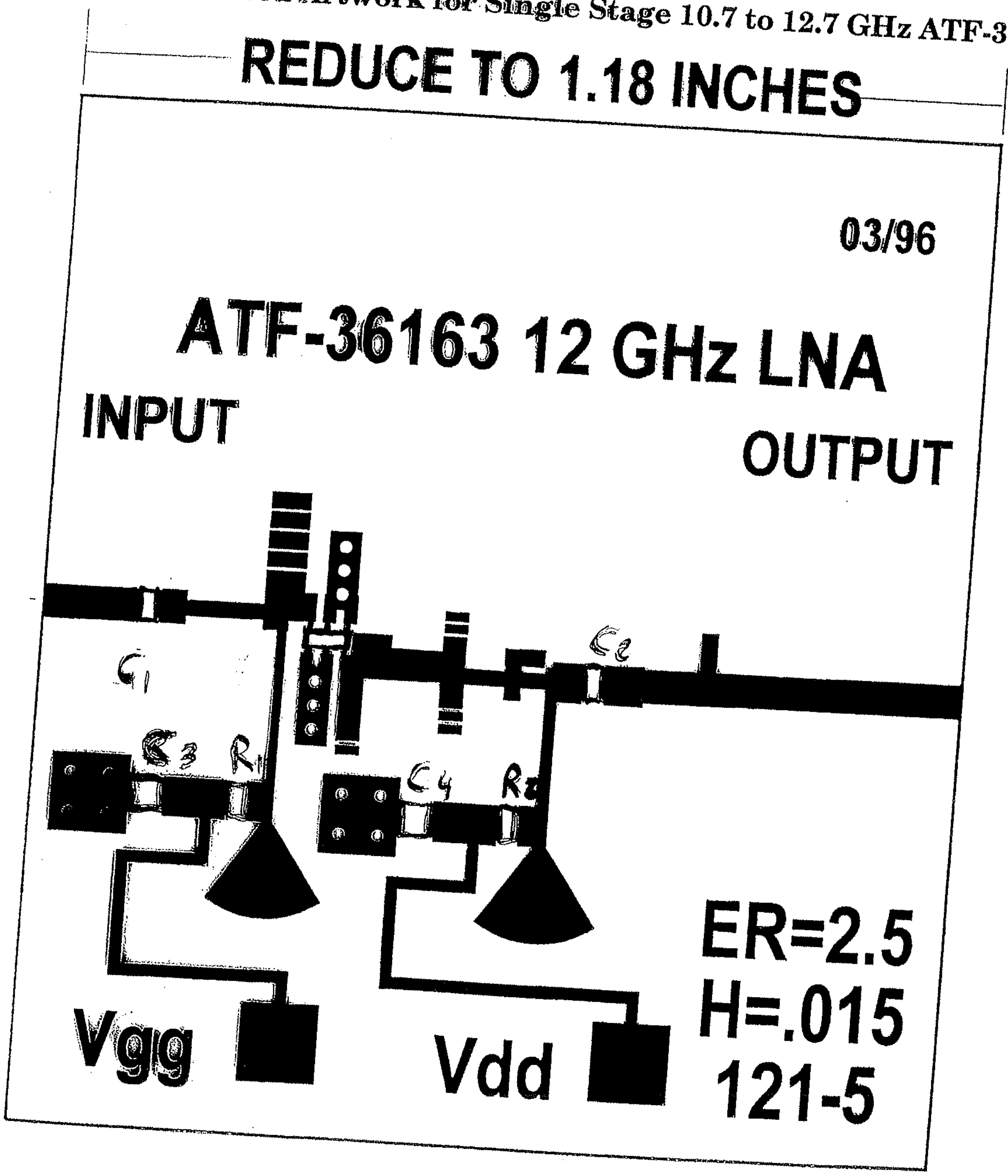
11. 7-12.7 GHz
Unidad Exterior
Amplificador de Bajo Ruido
Filtro 1ª FI
Amplificador 1ª FI
1er Oscilador Local
10. 7 GHz
1.0-2.0 GHz
70 +- 13.5 MHz
Amplificador 1ª FI
Amplificador 2ª FI
Filtro 2ª FI
VCO
2º Oscilador Local
Remodulador UHF
Señal Video
TV
Limitador
Discriminador
Unidad Interior

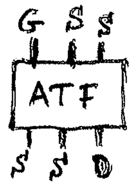


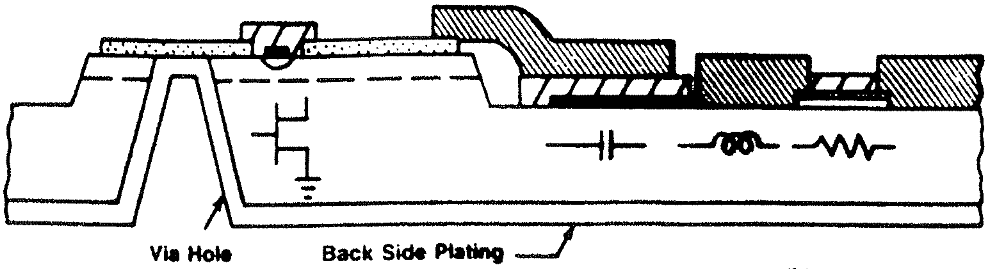
C1 = 2.7 pF CHIP CAPACITOR
C2 = 1 pF CHIP CAPACITOR
C3, C4 = 1000 pF CHIP CAPACITOR
Q1 = AGILENT TECHNOLOGIES ATF-36163 PHEMT
R1, R2 = 50 OHM CHIP RESISTOR
Z1, Z2 = INPUT MATCHING NETWORK
Z3, Z4, Z5, Z6 = OUTPUT MATCHING NETWORK

Figure 6. Schematic Diagram of One Stage ATF-36163 amplifier.

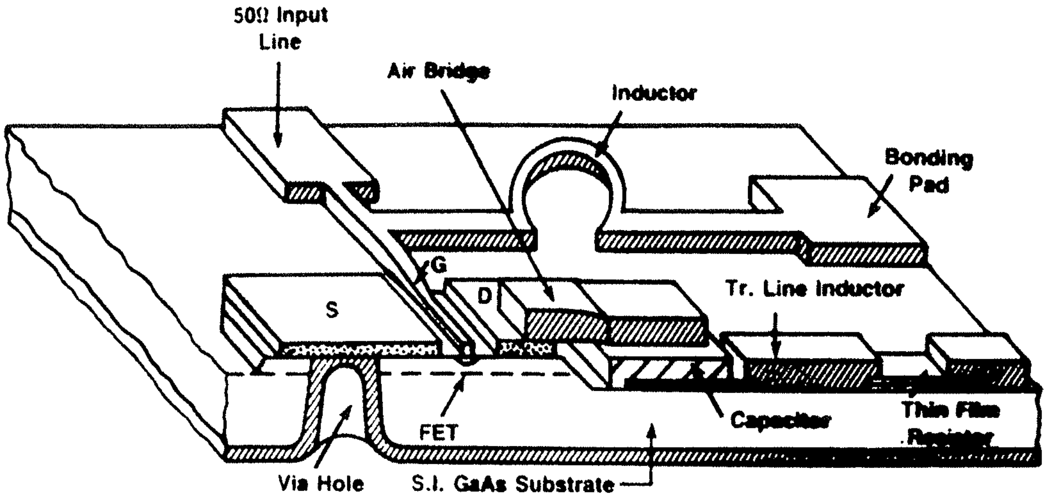
Appendix I. Revised Artwork for Single Stage 10.7 to 12.7 GHz ATF-36163 LNA.







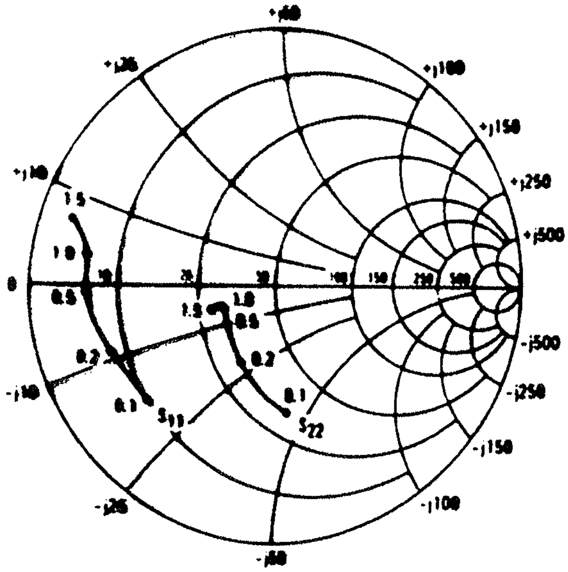
(h)



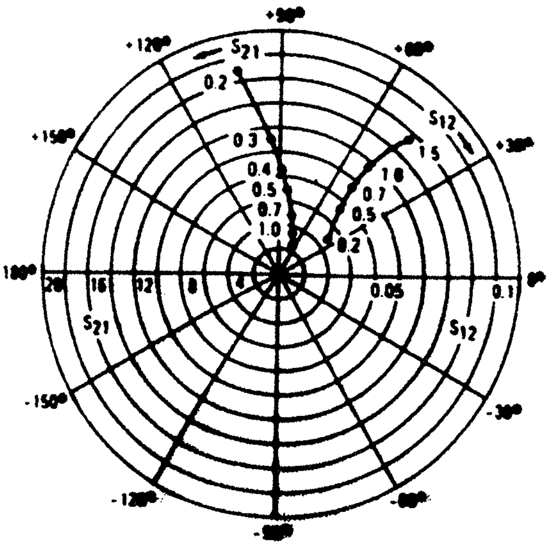
(i)

Figure 15.15 Small-signal microwave ICs process levels. (*a*) Ion implantation. (*b*) Mesa isolation. (*c*) Ohmic contact. (*d*) Gate formation. (*e*) Resistor evaporation. (*f*) Dielectric deposition. (*g*) Metal 2. (*h*) Via-hole etching and backside plating. (*i*) Completed MMIC.

COEFFICIENTS versus FREQUENCY
(V_{CE} = 10 V, I_C = 50 mA)



COEFFICIENTS versus FREQUENCY
(V_{CE} = 10 V, I_C = 50 mA)



V_{CE} (Volts)	I_C (mA)	f (MHz)	S_{11}		S_{21}		S_{12}		S_{22}	
			$\lvert S_{11}\rvert$	∠φ	$\lvert S_{21}\rvert$	∠φ	$\lvert S_{12}\rvert$	∠φ	$\lvert S_{22}\rvert$	∠φ
5.0	10	100	0.70	-102	17.42	128	0.044	43	[illegible]	-57
		300	0.75	-156	7.11	98	0.068	24	0.32	-97
		500	0.78	-170	4.38	88	0.064	25	0.26	-110
		700	0.78	-176	3.16	77	0.071	26	0.23	-117
		1000	0.78	176	2.26	67	0.078	27	0.24	-126
		1500	0.79	167	1.51	54	0.082	29	[illegible]	-133
	25	100	[illegible]	-131	24.24	118	0.029	38	[illegible]	-87
		300	0.77	-167	8.76	95	[illegible]	32	[illegible]	-137
		500	0.79	-176	5.26	86	0.046	38	[illegible]	-150
		700	0.80	178	3.82	78	[illegible]	40	0.31	-158
		1000	0.79	173	2.72	70	0.067	42	0.32	-164
		1500	0.81	164	1.82	58	[illegible]	42	0.34	-167
	50	100	0.71	-147	27.72	113	0.021	37	[illegible]	-107
		300	0.78	-173	9.59	94	0.030	40	[illegible]	-152
		500	0.81	179	5.72	85	0.038	46	[illegible]	-163
		700	0.81	176	4.09	78	0.046	50	[illegible]	-169
		1000	0.81	171	2.89	71	0.061	51	[illegible]	-175
		1500	0.82	163	1.96	62	0.082	48	[illegible]	-177
10	10	100	0.71	-92	18.77	131	0.037	47	[illegible]	-44
		300	0.74	-150	8.09	100	0.061	28	0.36	-69
		500	0.75	-166	5.01	87	0.068	28	0.27	-75
		700	0.76	-174	3.62	78	0.064	28	0.24	-79
		1000	0.76	179	2.58	69	0.071	30	0.24	-88
		1500	0.77	168	1.72	56	0.086	31	0.31	-104
	25	100	0.67	-120	27.10	122	0.027	42	0.57	-88
		300	0.73	-163	10.27	97	0.036	36	0.27	-110
		500	0.76	-174	6.21	86	0.043	39	0.22	-124
		700	0.77	-179	4.48	78	0.061	41	0.20	-132
		1000	0.77	175	3.19	71	0.062	43	0.20	-139
		1500	0.78	166	2.13	59	0.080	42	0.25	-142
	50	100	0.66	-137	31.53	116	0.020	37	0.48	-86
		300	0.74	-169	11.17	95	0.028	40	0.27	-131
		500	0.77	-177	6.69	85	0.037	46	0.24	-144
		700	0.77	178	4.82	78	0.047	48	0.23	-152
		1000	0.77	173	3.42	71	0.069	50	0.23	-158
		1500	0.79	165	2.30	61	0.078	47	0.27	-159

Figure 1.9.8 *S*-parameter data for the Motorola MRF962 transistor. (From **Motorola RF Data Manual**; reproduced with permission of Motorola, Inc.)

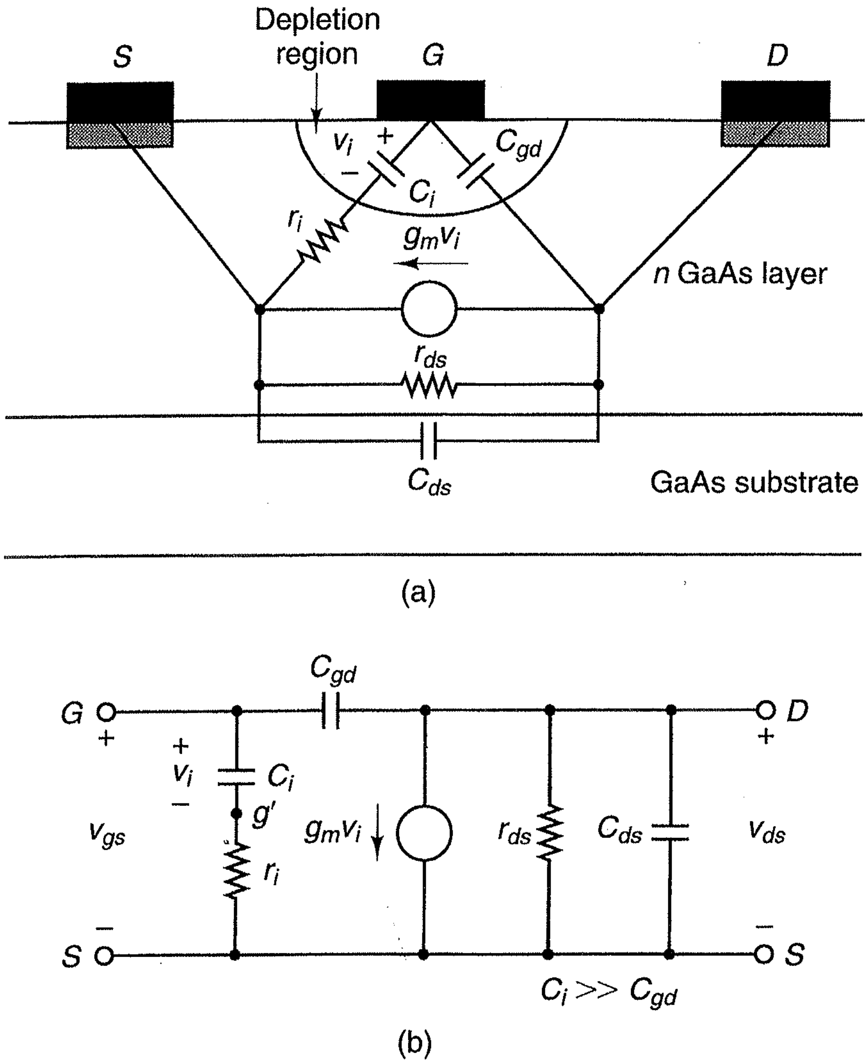


Figure 1.11.13 (a) Cross-sectional geometry of a GaAs FET; (b) GaAs FET high-frequency model for the common-source configuration.

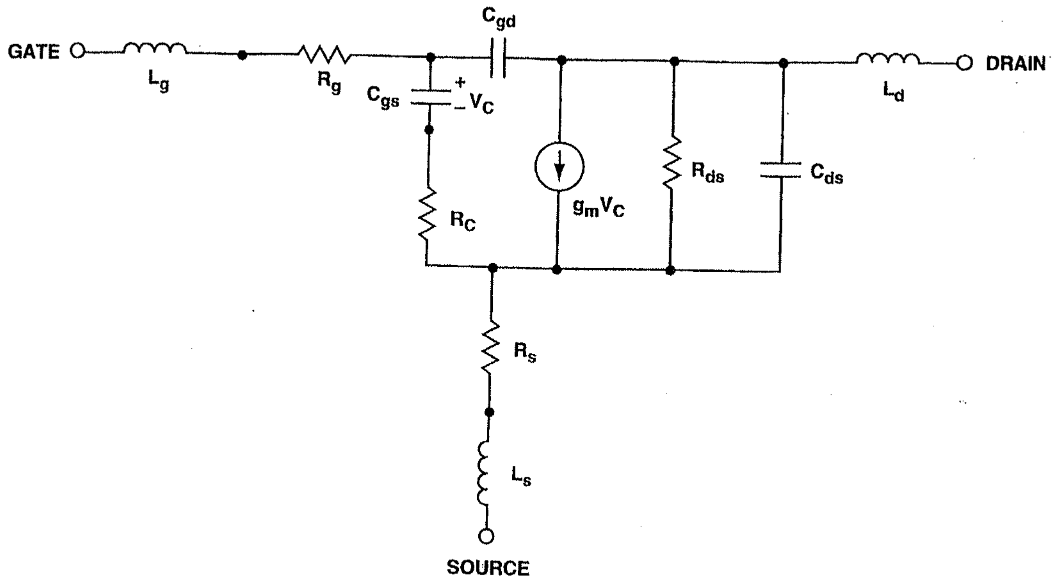


Figure 1. Equivalent Circuit for Linear GaAs FET Models.

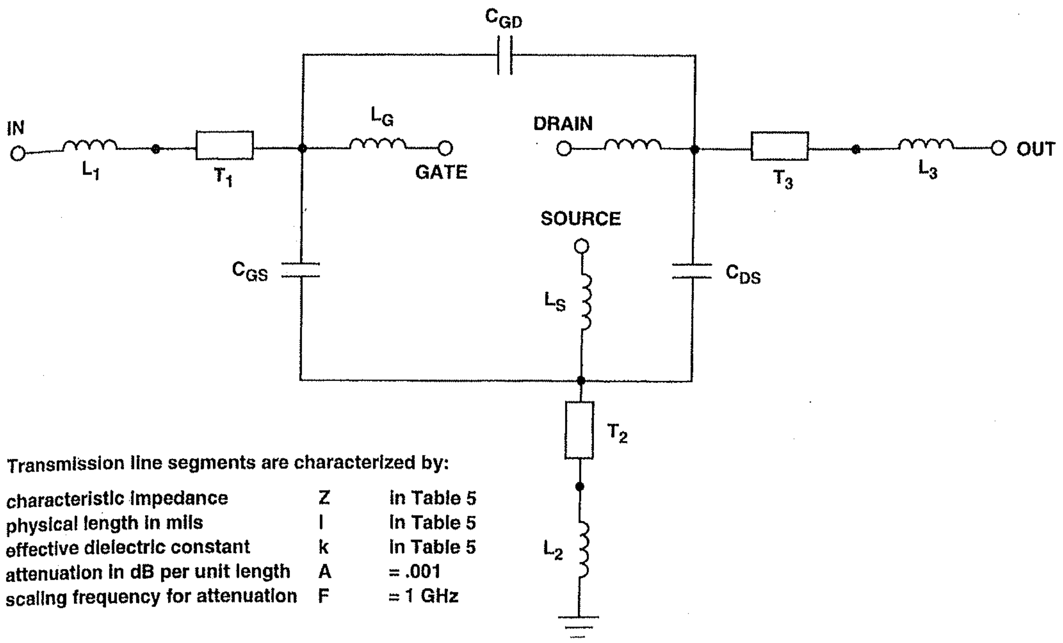


Figure 2. FET Transistor Package Equivalent Circuit.

Table 1. Circuit Element Values for Linear GaAs FET Models.

	Components											
Part No., Bias	Lg nH	Ld nH	Ls nH	Rd Ω	Rg Ω	Rs Ω	Cgs pF	Cgd pF	Cde pF	gm mS	TF ps	Rds Ω
ATF-101XX 2 V, 20 mA	0.9	0.6	0.15	2.0	2.5	2.0	0.25	0.1	0.1	70	0.001	200
ATF-102XX 2 V, 20 mA	0.9	0.6	0.15	2.0	2.5	2.0	0.40	0.1	0.1	60	0.001	200
ATF-107XX 2 V, 20 mA 4 V, 70 mA	0.9 0.9	0.6 0.6	0.15 0.15	2.0 4.0	3.0 6.0	2.0 2.0	0.40 0.80	0.15 0.1	0.1 0.2	60 130	0.001 0.001	200 200
ATF-131/132XX 3 V, 20 mA	0.9	0.6	0.15	2.0	3.0	0.5	0.14	0.05	0.03	60	0.001	250
ATF-133/134XX 3 V, 20 mA	0.9	0.6	0.15	2.0	3.0	0.5	0.20	0.05	0.03	40	0.001	250
ATF-137XX 3 V, 20 mA 4 V, 20 mA	0.9 0.9	0.6 0.6	0.15 0.15	2.0 4.0	3.0 3.0	2.0 2.0	0.20 0.24	0.05 0.05	0.03 0.03	40 50	0.001 0.001	250 250
ATF-211XX 3 V, 30 mA 6 V, 80 mA	0.4 0.4	0.5 0.5	0.15 0.15	1.5 1.0	1.5 1.0	1.0 0.5	0.70 1.2	0.10 0.08	0.14 0.15	68 115	0.001 0.001	180 180
ATF-251XX 3 V, 20 mA 5 V, 50 mA	0.4 0.4	0.7 0.7	0.15 0.15	2.0 1.0	2.5 2.0	1.0 0.5	0.36 0.60	0.07 0.06	0.16 0.08	48 75	0.001 0.001	150 180
ATF-261XX 3 V, 10 mA 5 V, 30 mA	0.6 0.6	0.7 0.7	0.15 0.15	2.0 2.0	5.0 5.0	5.0 5.0	0.16 0.26	0.03 0.015	0.06 0.06	27 42	0.001 0.001	275 275
ATF-35XXX 1.5 V, 10 mA	29.4 pH	26.6 pH	5 pH	5.0	1.0	0.5	0.088	0.0459	0.0527	53.7	0.47	105.1
ATF-441XX 9 V, 500 mA	0.20	0.20	0.03	0.15	0.02	0.16	3.0	0.3	1.35	350	5	15
ATF-451XX 9 V, 250 mA	0.20	0.20	0.06	0.30	0.75	0.32	1.5	0.2	0.70	175	5	.0
ATF-461XX 9 V, 125 mA	0.20	0.20	0.1	0.60	1.60	0.60	0.8	0.1	0.35	80	5	55

Table 2. Circuit Element Values for FET Package Models.

element	units	35/36	70	77	84	86
LG	nH	0.9	0.5	0.9	0.5	0.5
LD	nH	0.6	0.5	0.6	0.5	0.5
LS	nH	0.15	0.15	0.15	0.15	0.15
L1	nH	.01	.01	.01	.01	.5
L2	nH	.005	.005	.005	.005	.05
L3	nH	.01	.01	.01	.01	.2
T1: Z	W	65	40	65	65	65
T1: l	mils	35	25	35	25	25
T1: k	-	7	7	7	9	9
T2: Z	W	30	20	30	30	30
T2: l	mils	15	5	15	7	7
T2: k	-	7	7	7	9	9
T3: Z	W	65	40	65	65	65
T3: l	mils	35	25	35	25	25
T3: k	-	7	7	7	9	9
CGS	pF	.05	.05	.05	.03	.03
CDS	pF	.05	.05	.05	.05	.05
CGD	pF	.005	.005	.005	.01	.01

Note: Both the die and package models include inductance values for the gate, drain, and source bond wires (Ld, Lg, Ls). When placing the die model in a package model, use the bond wire value given in the package description and omit the values given in the die model.

Table 3. ATF-36 FET Statz Model Parameters for Small Signal Operation.

MODEL=FET

IDS model	Gate model	Parasitics	Breakdown	Noise
NFET=yes	DELTA=0.2	RG=1	GSFWD=1	FNC=01e+(
PFET=	GSCAP=3	RD=0.5	GSREV=0	R=0.17
IDSMOD=3	CGS=0.13 pF	RS=0.5	GDFWD=1	P=0.55
VTO=-0.55	GDCAP=3	LG=0.03 nH	GDREV=0	C=0.2
BETA=0.10	CGD=0.04 pF	LD=0.04 nH	VJR=1	
LAMBDA=0.25		LS=0.01 nH	IS=1 nA	
ALPHA=5.0		CDS=0.05 pF	IR=1 nA	
B=1.5		CRF=0.1	IMAX=0.1	
TNOM=27		RC=350	XTI=	
IDSTC=			N=	
VBI=0.7			EG=	

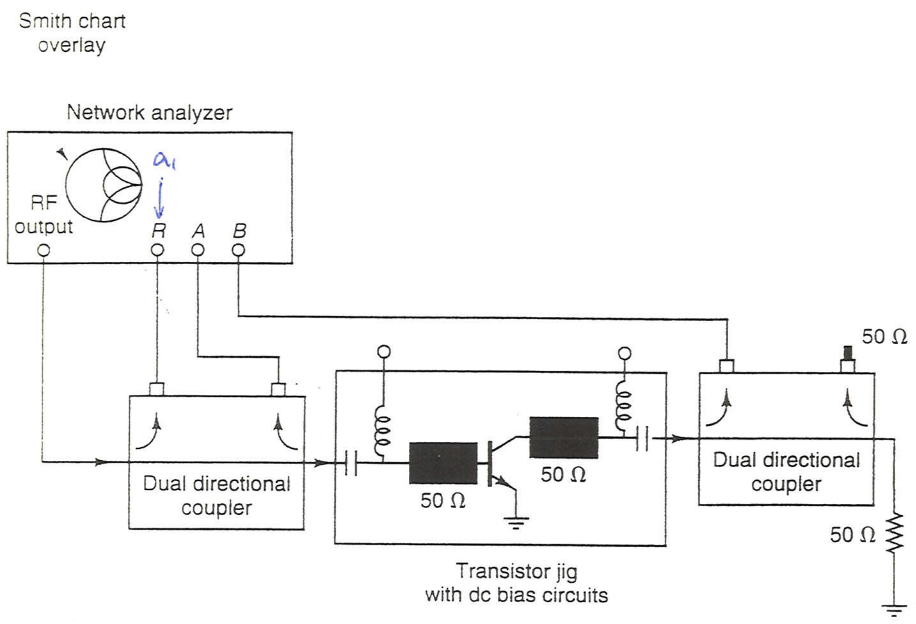


Figure 1.9.3 A measurement set-up for *S* parameters using a network analyzer.

(analizador vectorial)

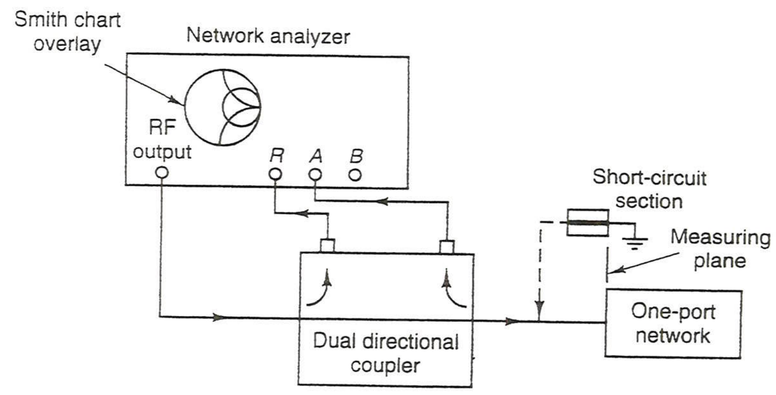
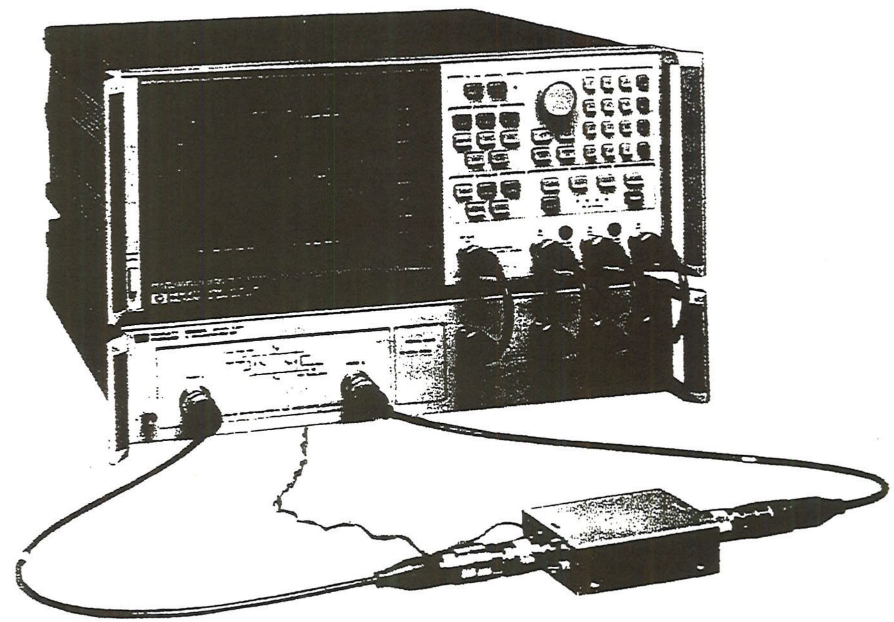


Figure 1.9.2 One-port measurements using a network analyzer.



HP 8753WITH HP 85047A

Figure 1.9.4 The HP8753C network analyzer with an HP85047A *S*-parameter test set. (From HP Test and Measurements Catalog, 1994; courtesy of Hewlett Packard)

HEWLETT PACKARD

LOW NOISE TRANSISTOR

2N6742 (HXTR-6102)

Features

LOW NOISE FIGURE
2.5 dB Typical F_{MIN} AT 4 GHz

HIGH ASSOCIATED GAIN
9.0 dB Typical G_a

HERMETIC PACKAGE

Description

The 2N6742 (HXTR-6102) is an NPN bipolar transistor designed for minimum noise figure. The device utilizes ion implantation techniques in its manufacture and the chip is also provided with scratch protection over its active area. The device is supplied in the HPAC-70GT, a rugged metal/ceramic hermetic package, and is capable of meeting the environmental requirements of MIL-S-19500 and the test requirements of MIL-STD-750/883.

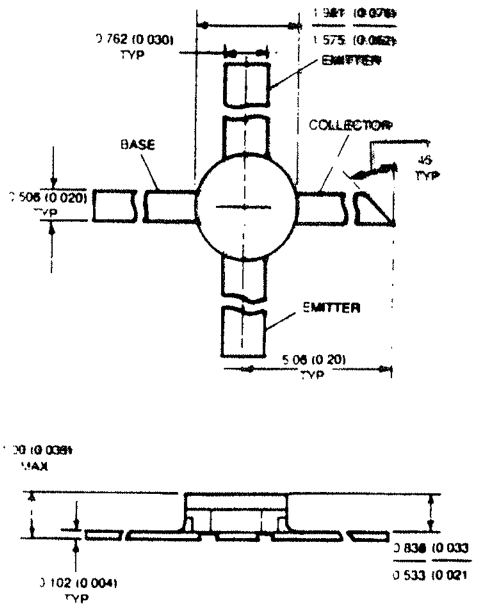
Absolute Maximum Ratings*

(T_{CASE} = 25°C)

Symbol	Parameter	Limit
V_{CBO}	Collector to Base Voltage	35V
V_{CEO}	Collector to Emitter Voltage	20V
V_{EBO}	Emitter to Base Voltage	1.5V
I_C	DC Collector Current	20 mA
P_T	Total Device Dissipation	300 mW
T_J	Junction Temperature	300°C
T_{STG}	Storage Temperature	-65°C to 200°C
—	Lead Temperature (Soldering 10 seconds each lead)	+250°C

*Operation in excess of any one of these conditions may result in permanent damage to this device.

Notes:
1. A θJC maximum of 245°C/W should be used for derating and junction temperature calculations (T_J = P_D × θJC + T_{CASE}).
2. A MTTF of 1.0 × 10⁷ hours will be met or exceeded when the junction temperature is maintained under T_J = 200°C (based on an activation energy of 1.1 eV). For operation above this condition, refer to page 108 "Reliability Performance of Bipolar Transistors".



(DIMENSIONS IN MILLIMETERS AND INCHES)

Outline HPAC-70GT

Fig. 5.5(a) Hewlett Packard low-noise transistor. Copyright of Hewlett Packard. Used by permission.

1.10

Electrical Specifications at $T_{CASE} = 25°C$

Symbol	Parameters And Test Conditions	Test MIL-STD-750	Units	Min.	Typ.	Max.
BV_{CES}	Collector-Emitter Breakdown Voltage at $I_C = 100 \mu A$	3001.1*	V	30		
I_{CEO}	Collector-Emitter Leakage Current at $V_{CE} = 10V$	3041.1	nA			500
I_{CBO}	Collector Cutoff Current at $V_{CB} = 10V$	3036.1	nA			100
h_{FE}	Forward Current Transfer Ratio at $V_{CE} = 10V$, $I_C = 4mA$	3076.1*	—	50	150	250
F_{MIN}	Minimum Noise Figure f = 4 GHz 2 GHz	3246.1	dB		2.8 1.6	3.0
G_a	Associated Gain f = 4 GHz 2 GHz Bias Conditions for Above: $V_{CE} = 10V$, $I_C = 4mA$		dB dB	8.0	9.0 13.5	

*300 μs wide pulse measurement at < 2% duty cycle.

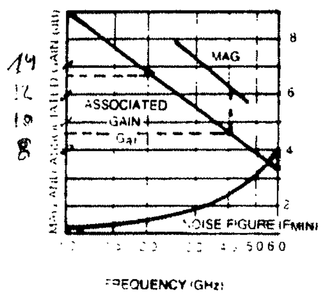


Figure 1. Typical MAG, F_{MIN} and Associated Gain vs. Frequency at $V_{CE} = 10 V$, $I_C = 4 mA$.

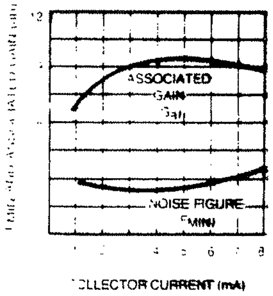


Figure 2. Typical F_{MIN} and Associated Gain vs. I_C at 4 GHz for $V_{CE} = 10 V$ (Tuned for F_{MIN}).

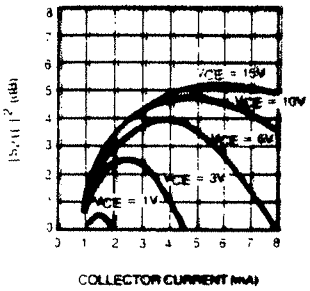


Figure 3. Typical $|S_{21E}|^2$ vs. Bias at 4 GHz.

Typical S-Parameters $V_{CE} = 10 V$, $I_C = 4 mA$

	S_{11}		S_{21}		S_{12}		S_{22}	
Freq. (MHz)	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.
100	0.917	-11	7.149	168	0.007	79	0.991	-4
500	0.782	-54	6.277	135	0.026	54	0.901	-18
1000	0.635	-98	5.037	113	0.037	33	0.787	-30
1500	0.598	-127	3.881	87	0.039	28	0.763	-35
2000	0.589	-149	3.148	[illegible]	0.042	26	0.754	-43
2500	0.570	-163	2.646	59	0.042	25	0.760	-50
3000	0.575	-173	2.209	48	0.043	25	0.773	-58
3500	0.560	180	1.948	37	0.046	25	0.795	-64
4000	0.548	173	1.665	29	0.049	24	0.816	-71
4500	0.530	167	1.450	20	0.053	24	0.850	-78
5000	0.518	160	1.346	[illegible]	0.058	23	0.860	-84
5500	0.500	152	1.210	[illegible]	0.060	22	0.880	-92
6000	0.489	146	1.076	-7	0.063	20	0.877	-99
7000	0.491	132	0.897	-23	0.069	15	0.872	-106

Fig. 5.5(b) Hewlett Packard low-noise transistor.

Typical Noise Parameters

V_{CE} = 10 V, I_C = 4 mA

Freq. (MHz)	Γ_o (Mag./Ang.)	R_N (Ohms)	F_{MIN} (dB)
1000	.480/23°	23.31	1.45
1500	.450/61°	15.57	1.58
2000	.410/88°	15.73	1.72
3000	.425/121°	10.72	2.18
~~4000~~	~~.475/166°~~	~~3.50~~	~~2.75~~
5000	.530/−164°	2.81	3.67
6000	.520/−131°	7.23	4.78

$$F = F_{min} + 4\frac{R_N}{Z_0}\cdot\frac{|\Gamma_g - \Gamma_o|^2}{|1+\Gamma_o|^2\left(1-|\Gamma_g|^2\right)}$$

Low Power Bias Performance

Bias						
V_{CE} V	I_C mA	F_{MIN} dB	G_a dB	R_N Ohms	Γ_o Mag./Ang.	Γ_L Mag./Ang.
3	0.25	2.25	8.5	60.5	.805/31°	.788/25°
3	0.50	1.87	12.7	25.5	.713/38°	.779/29°
3	1.00	1.55	15.7	13.9	.571/39°	.774/29°

Figure 4. Noise Parameters at 1 GHz.

BIAS		Frequency							
		1000 MHz		1500 MHz		2000 MHz		3000 MHz	
V_{CE} V	I_C mA	F_{MIN} dB	G_a dB	F_{MIN} dB	G_a dB	F_{MIN} dB	G_a dB	F_{MIN} dB	G_a dB
3	0.25	2.25	8.5	2.57	5.0	2.83	4.7	3.88	4.1
3	0.50	1.87	12.7	2.06	9.9	2.23	7.9	2.93	6.4
3	1.0	1.55	15.7	1.73	11.7	1.79	10.2	2.38	8.1

Figure 5. Noise Performance vs. Frequency and Bias.

Typical S-Parameters V_{CE} = 3 V, I_C = 0.25 mA

Freq. (MHz)	S_{11} Mag.	S_{11} Ang.	S_{21} (dB)	S_{21} Mag.	S_{21} Ang.	S_{12} (dB)	S_{12} Mag.	S_{12} Ang.	S_{22} Mag.	S_{22} Ang.	K
500	.988	−22	−6.9	.451	152	−28.2	.039	72	.993	−12	.220
1000	.956	−42	−7.2	.438	127	−23.1	.070	55	.975	−22	.464
1500	.929	−65	−7.5	.423	106	−20.6	.093	38	.958	−33	.586
2000	.910	−81	−7.7	[illegible]	89	−19.7	.104	27	.945	−42	.679
3000	.888	−112	−8.1	[illegible]	56	−19.3	.108	6	.938	−59	.821

V_{CE} = 3 V, I_C = 0.50 mA

Freq. (MHz)	S_{11} Mag.	S_{11} Ang.	S_{21} (dB)	S_{21} Mag.	S_{21} Ang.	S_{12} (dB)	S_{12} Mag.	S_{12} Ang.	S_{22} Mag.	S_{22} Ang.	K
500	.976	−24	−0.8	.991	152	−28.4	.038	70	.986	−13	.220
1000	.929	−47	−1.3	.863	128	−23.6	.066	52	.955	−24	.423
1500	.887	−72	−2.0	.792	107	−21.4	.085	35	.920	−34	.583
2000	.856	−89	−2.5	.747	91	−20.6	.093	24	.906	−43	.682
3000	.818	−121	−3.3	.688	60	−20.1	.099	7	.889	−60	.816

V_{CE} = 3 V, I_C = 1.0 mA

Freq. (MHz)	S_{11} Mag.	S_{11} Ang.	S_{21} (dB)	S_{21} Mag.	S_{21} Ang.	S_{12} (dB)	S_{12} Mag.	S_{12} Ang.	S_{22} Mag.	S_{22} Ang.	K
500	.952	−25	4.4	1.67	149	−28.6	.037	66	.972	−14	.328
1000	.884	−54	3.7	1.54	125	−24.3	.061	47	.919	−25	.492
1500	.821	−82	2.7	1.36	104	−23.1	.070	31	.873	−36	.664
2000	.775	−102	1.9	1.25	88	−22.6	.074	23	.854	−43	.793
3000	.738	−133	[illegible]	1.09	59	−22.1	.079	10	.842	−59	.908

Fig. 5.5(c) Hewlett Packard low-noise transistor.

	S	z	y	h	ABCD
S	S_{11} S_{12} S_{21} S_{22}	$S_{11} = \frac{(z'_{11}-1)(z'_{22}+1) - z'_{12}z'_{21}}{\Delta_1}$ $S_{12} = \frac{2z'_{12}}{\Delta_1}$ $S_{21} = \frac{2z'_{21}}{\Delta_1}$ $S_{22} = \frac{(z'_{11}+1)(z'_{22}-1) - z'_{12}z'_{21}}{\Delta_1}$	$S_{11} = \frac{(1-y'_{11})(1+y'_{22}) + y'_{12}y'_{21}}{\Delta_2}$ $S_{12} = \frac{-2y'_{12}}{\Delta_2}$ $S_{21} = \frac{-2y'_{21}}{\Delta_2}$ $S_{22} = \frac{(1+y'_{11})(1-y'_{22}) + y'_{12}y'_{21}}{\Delta_2}$	$S_{11} = \frac{(h'_{11}-1)(h'_{22}+1) - h'_{12}h'_{21}}{\Delta_3}$ $S_{12} = \frac{2h'_{12}}{\Delta_3}$ $S_{21} = \frac{-2h'_{21}}{\Delta_3}$ $S_{22} = \frac{(1+h'_{11})(1-h'_{22}) + h'_{12}h'_{21}}{\Delta_3}$	$\frac{A'+B'-C'-D'}{\Delta_4}$ $\frac{2(A'D'-B'C')}{\Delta_4}$ $\frac{2}{\Delta_4}$ $\frac{-A'+B'-C'+D'}{\Delta_4}$
z	$z'_{11} = \frac{(1+S_{11})(1-S_{22}) + S_{12}S_{21}}{\Delta_5}$ $z'_{12} = \frac{2S_{12}}{\Delta_5}$ $z'_{21} = \frac{2S_{21}}{\Delta_5}$ $z'_{22} = \frac{(1-S_{11})(1+S_{22}) + S_{12}S_{21}}{\Delta_5}$	z_{11} z_{12} z_{21} z_{22}	$\frac{y_{22}}{\lvert y \rvert}$ $\frac{-y_{12}}{\lvert y \rvert}$ $\frac{-y_{21}}{\lvert y \rvert}$ $\frac{y_{11}}{\lvert y \rvert}$	$\frac{\lvert h \rvert}{h_{22}}$ $\frac{h_{12}}{h_{22}}$ $\frac{-h_{21}}{h_{22}}$ $\frac{1}{h_{22}}$	$\frac{A}{C}$ $\frac{\Delta_8}{C}$ $\frac{1}{C}$ $\frac{D}{C}$
y	$y'_{11} = \frac{(1-S_{11})(1+S_{22}) + S_{12}S_{21}}{\Delta_6}$ $y'_{12} = \frac{-2S_{12}}{\Delta_6}$ $y'_{21} = \frac{-2S_{21}}{\Delta_6}$ $y'_{22} = \frac{(1+S_{11})(1-S_{22}) + S_{12}S_{21}}{\Delta_6}$	$\frac{z_{22}}{\lvert z \rvert}$ $\frac{-z_{12}}{\lvert z \rvert}$ $\frac{-z_{21}}{\lvert z \rvert}$ $\frac{z_{11}}{\lvert z \rvert}$	y_{11} y_{12} y_{21} y_{22}	$\frac{1}{h_{11}}$ $\frac{-h_{12}}{h_{11}}$ $\frac{h_{21}}{h_{11}}$ $\frac{\lvert h \rvert}{h_{11}}$	$\frac{D}{B}$ $\frac{-\Delta_8}{B}$ $\frac{-1}{B}$ $\frac{A}{B}$
h	$h'_{11} = \frac{(1+S_{11})(1+S_{22}) - S_{12}S_{21}}{\Delta_7}$ $h'_{12} = \frac{2S_{12}}{\Delta_7}$ $h'_{21} = \frac{-2S_{21}}{\Delta_7}$ $h'_{22} = \frac{(1-S_{11})(1-S_{22}) - S_{12}S_{21}}{\Delta_7}$	$\frac{\lvert z \rvert}{z_{22}}$ $\frac{z_{12}}{z_{22}}$ $\frac{-z_{21}}{z_{22}}$ $\frac{1}{z_{22}}$	$\frac{1}{y_{11}}$ $\frac{-y_{12}}{y_{11}}$ $\frac{y_{21}}{y_{11}}$ $\frac{\lvert y \rvert}{y_{11}}$	h_{11} h_{12} h_{21} h_{22}	$\frac{B}{D}$ $\frac{-\Delta_8}{D}$ $\frac{-1}{D}$ $\frac{C}{D}$
ABCD	$A' = \frac{(1+S_{11})(1-S_{22}) + S_{12}S_{21}}{2S_{21}}$ $B' = \frac{(1+S_{11})(1+S_{22}) - S_{12}S_{21}}{2S_{21}}$ $C' = \frac{(1-S_{11})(1-S_{22}) - S_{12}S_{21}}{2S_{21}}$ $D' = \frac{(1-S_{11})(1+S_{22}) + S_{12}S_{21}}{2S_{21}}$	$\frac{z_{11}}{z_{21}}$ $\frac{\lvert z \rvert}{z_{21}}$ $\frac{1}{z_{21}}$ $\frac{z_{22}}{z_{21}}$	$\frac{-y_{22}}{y_{21}}$ $\frac{-1}{y_{21}}$ $\frac{-\lvert y \rvert}{y_{21}}$ $\frac{-y_{11}}{y_{21}}$	$\frac{-\lvert h \rvert}{h_{21}}$ $\frac{-h_{11}}{h_{21}}$ $\frac{-h_{22}}{h_{21}}$ $\frac{-1}{h_{21}}$	A B C D

$\Delta_1 = (z'_{11}+1)(z'_{22}+1) - z'_{12}z'_{21}$
$\Delta_2 = (1+y'_{11})(1+y'_{22}) - y'_{12}y'_{21}$
$\Delta_3 = (h'_{11}+1)(h'_{22}+1) - h'_{12}h'_{21}$
$\Delta_4 = A'+B'+C'+D'$
$\Delta_5 = (1-S_{11})(1-S_{22}) - S_{12}S_{21}$
$\Delta_6 = (1+S_{11})(1+S_{22}) - S_{12}S_{21}$
$\Delta_7 = (1-S_{11})(1+S_{22}) + S_{12}S_{21}$
$\Delta_8 = AD - BC$

$z'_{11} = z_{11}/Z_o,\ z'_{12} = z_{12}/Z_o,\ z'_{21} = z_{21}/Z_o,\ z'_{22} = z_{22}/Z_o$
$y'_{11} = y_{11}Z_o,\ y'_{12} = y_{12}Z_o,\ y'_{21} = y_{21}Z_o,\ y'_{22} = y_{22}Z_o$
$h'_{11} = h_{11}/Z_o,\ h'_{12} = h_{12},\ h'_{21} = h_{21},\ h'_{22} = h_{22}Z_o$
$A' = A,\ B' = B/Z_o,\ C' = CZ_o,\ D' = D$
$\lvert z \rvert = z_{11}z_{22} - z_{12}z_{21}$
$\lvert y \rvert = y_{11}y_{22} - y_{12}y_{21}$
$\lvert h \rvert = h_{11}h_{22} - h_{12}h_{21}$

13

1.13

	S	z	y	h	ABCD
S	S_{11} S_{12} S_{21} S_{22}	$S_{11} = \frac{(z'_{11}-1)(z'_{22}+1)-z'_{12}z'_{21}}{\Delta_1}$ $S_{12} = \frac{2z'_{12}}{\Delta_1}$ $S_{21} = \frac{2z'_{21}}{\Delta_1}$ $S_{22} = \frac{(z'_{11}+1)(z'_{22}-1)-z'_{12}z'_{21}}{\Delta_1}$	$S_{11} = \frac{(1-y'_{11})(1+y'_{22})+y'_{12}y'_{21}}{\Delta_2}$ $S_{12} = \frac{-2y'_{12}}{\Delta_2}$ $S_{21} = \frac{-2y'_{21}}{\Delta_2}$ $S_{22} = \frac{(1+y'_{11})(1-y'_{22})+y'_{12}y'_{21}}{\Delta_2}$	$S_{11} = \frac{(h'_{11}-1)(h'_{22}+1)-h'_{12}h'_{21}}{\Delta_3}$ $S_{12} = \frac{2h'_{12}}{\Delta_3}$ $S_{21} = \frac{-2h'_{21}}{\Delta_3}$ $S_{22} = \frac{(1+h'_{11})(1-h'_{22})+h'_{12}h'_{21}}{\Delta_3}$	$\frac{A'+B'-C'-D'}{\Delta_4}$ $\frac{2(A'D'-B'C')}{\Delta_4}$ $\frac{2}{\Delta_4}$ $\frac{-A'+B'-C'+D'}{\Delta_4}$
z	$z'_{11} = \frac{(1+S_{11})(1-S_{22})+S_{12}S_{21}}{\Delta_5}$ $z'_{12} = \frac{2S_{12}}{\Delta_5}$ $z'_{21} = \frac{2S_{21}}{\Delta_5}$ $z'_{22} = \frac{(1-S_{11})(1+S_{22})+S_{12}S_{21}}{\Delta_5}$	z_{11} z_{12} z_{21} z_{22}	$\frac{y_{22}}{\lvert y\rvert}$ $\frac{-y_{12}}{\lvert y\rvert}$ $\frac{-y_{21}}{\lvert y\rvert}$ $\frac{y_{11}}{\lvert y\rvert}$	$\frac{\lvert h\rvert}{h_{22}}$ $\frac{h_{12}}{h_{22}}$ $\frac{-h_{21}}{h_{22}}$ $\frac{1}{h_{22}}$	$\frac{A}{C}$ $\frac{\Delta_8}{C}$ $\frac{1}{C}$ $\frac{D}{C}$
y	$y'_{11} = \frac{(1-S_{11})(1+S_{22})+S_{12}S_{21}}{\Delta_6}$ $y'_{12} = \frac{-2S_{12}}{\Delta_6}$ $y'_{21} = \frac{-2S_{21}}{\Delta_6}$ $y'_{22} = \frac{(1+S_{11})(1-S_{22})+S_{12}S_{21}}{\Delta_6}$	$\frac{z_{22}}{\lvert z\rvert}$ $\frac{-z_{12}}{\lvert z\rvert}$ $\frac{-z_{21}}{\lvert z\rvert}$ $\frac{z_{11}}{\lvert z\rvert}$	y_{11} y_{12} y_{21} y_{22}	$\frac{1}{h_{11}}$ $\frac{-h_{12}}{h_{11}}$ $\frac{h_{21}}{h_{11}}$ $\frac{\lvert h\rvert}{h_{11}}$	$\frac{D}{B}$ $\frac{-\Delta_8}{B}$ $\frac{-1}{B}$ $\frac{A}{B}$
h	$h'_{11} = \frac{(1+S_{11})(1+S_{22})-S_{12}S_{21}}{\Delta_7}$ $h'_{12} = \frac{2S_{12}}{\Delta_7}$ $h'_{21} = \frac{-2S_{21}}{\Delta_7}$ $h'_{22} = \frac{(1-S_{22})(1-S_{11})-S_{12}S_{21}}{\Delta_7}$	$\frac{\lvert z\rvert}{z_{22}}$ $\frac{z_{12}}{z_{22}}$ $\frac{-z_{21}}{z_{22}}$ $\frac{1}{z_{22}}$	$\frac{1}{y_{11}}$ $\frac{-y_{12}}{y_{11}}$ $\frac{y_{21}}{y_{11}}$ $\frac{\lvert y\rvert}{y_{11}}$	h_{11} h_{12} h_{21} h_{22}	$\frac{B}{D}$ $\frac{\Delta_8}{D}$ $\frac{-1}{D}$ $\frac{C}{D}$
ABCD	$A' = \frac{(1+S_{11})(1-S_{22})+S_{12}S_{21}}{2S_{21}}$ $B' = \frac{(1+S_{11})(1+S_{22})-S_{12}S_{21}}{2S_{21}}$ $C' = \frac{(1-S_{11})(1-S_{22})-S_{12}S_{21}}{2S_{21}}$ $D' = \frac{(1-S_{11})(1+S_{22})+S_{12}S_{21}}{2S_{21}}$	$\frac{z_{11}}{z_{21}}$ $\frac{\lvert z\rvert}{z_{21}}$ $\frac{1}{z_{21}}$ $\frac{z_{22}}{z_{21}}$	$\frac{-y_{22}}{y_{21}}$ $\frac{-1}{y_{21}}$ $\frac{-\lvert y\rvert}{y_{21}}$ $\frac{-y_{11}}{y_{21}}$	$\frac{-\lvert h\rvert}{h_{21}}$ $\frac{-h_{11}}{h_{21}}$ $\frac{-h_{22}}{h_{21}}$ $\frac{-1}{h_{21}}$	A B C D

$\Delta_1 = (z'_{11}+1)(z'_{22}+1) - z'_{12}z'_{21}$
$\Delta_2 = (1+y'_{11})(1+y'_{22}) - y'_{12}y'_{21}$
$\Delta_3 = (h'_{11}+1)(h'_{22}+1) - h'_{12}h'_{21}$
$\Delta_4 = A' + B' + C' + D'$
$\Delta_5 = (1-S_{11})(1-S_{22}) - S_{12}S_{21}$
$\Delta_6 = (1+S_{11})(1+S_{22}) - S_{12}S_{21}$
$\Delta_7 = (1-S_{11})(1+S_{22}) + S_{12}S_{21}$
$\Delta_8 = AD - BC$

$z'_{11} = z_{11}/Z_o,\quad z'_{12} = z_{12}/Z_o,\quad z'_{21} = z_{21}/Z_o,\quad z'_{22} = z_{22}/Z_o$
$y'_{11} = y_{11}Z_o,\quad y'_{12} = y_{12}Z_o,\quad y'_{21} = y_{21}Z_o,\quad y'_{22} = y_{22}Z_o$
$h'_{11} = h_{11}/Z_o,\quad h'_{12} = h_{12},\quad h'_{21} = h_{21},\quad h'_{22} = h_{22}Z_o$
$A' = A,\quad B' = B/Z_o,\quad C' = CZ_o,\quad D' = D$
$\lvert z\rvert = z_{11}z_{22} - z_{12}z_{21}$
$\lvert y\rvert = y_{11}y_{22} - y_{12}y_{21}$
$\lvert h\rvert = h_{11}h_{22} - h_{12}h_{21}$

(a)

Conversion Between Common-Base, Common-Emitter, and Common-Collector y Parameters

$$
\begin{aligned}
y_{11,e} &= y_{11,b} + y_{12,b} + y_{21,b} + y_{22,b} = y_{11,c} \\
y_{12,e} &= -(y_{12,b} + y_{22,b}) = -(y_{11,c} + y_{12,c}) \\
y_{21,e} &= -(y_{21,b} + y_{22,b}) = -(y_{11,c} + y_{21,c}) \\
y_{22,e} &= y_{22,b} = y_{11,c} + y_{12,c} + y_{21,c} + y_{22,c}
\end{aligned}
$$

$$
\begin{aligned}
y_{11,b} &= y_{11,e} + y_{12,e} + y_{21,e} + y_{22,e} = y_{22,c} \\
y_{12,b} &= -(y_{12,e} + y_{22,e}) = -(y_{21,c} + y_{22,c}) \\
y_{21,b} &= -(y_{21,e} + y_{22,e}) = -(y_{12,c} + y_{22,c}) \\
y_{22,b} &= y_{22,e} = y_{11,c} + y_{12,c} + y_{21,c} + y_{22,c}
\end{aligned}
$$

$$
\begin{aligned}
y_{11,c} &= y_{11,e} = y_{11,b} + y_{12,b} + y_{21,b} + y_{22,b} \\
y_{11,c} &= -(y_{11,e} + y_{12,e}) = -(y_{11,b} + y_{21,b}) \\
y_{21,c} &= -(y_{11,e} + y_{21,e}) = -(y_{11,b} + y_{12,b}) \\
y_{22,c} &= y_{11,e} + y_{12,e} + y_{21,e} + y_{22,e} = y_{11,b}
\end{aligned}
$$

(b)

Figure 1.8.1 (a) Conversions among the z, y, h, $ABCD$, and S parameters; **(b)** conversions between y parameters.

Problema :

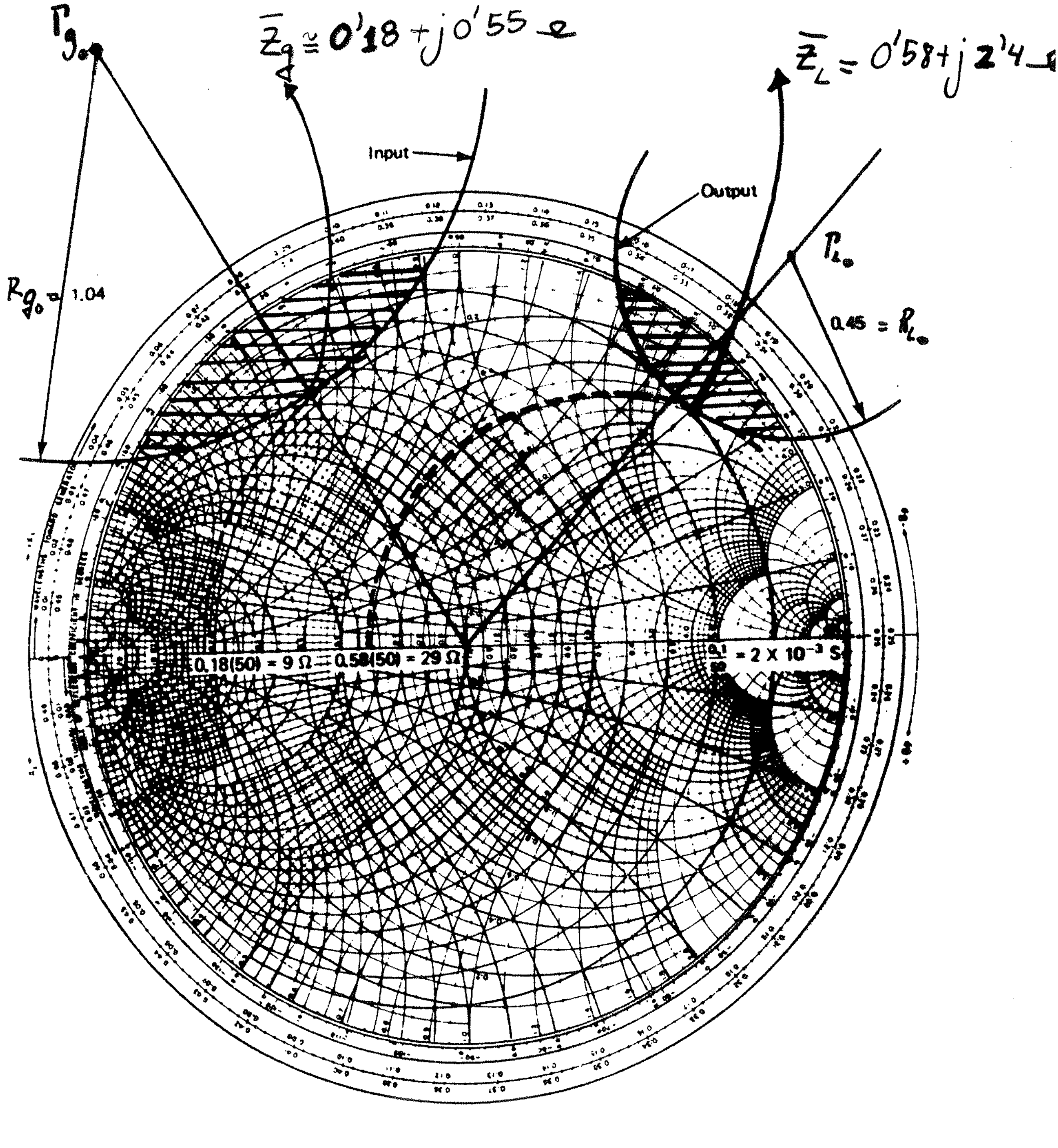


Figure 3.3.6 Input and output stability circles.

2.1