MMIC Design and Technology
Active Devices

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Lecture 5 Active Devices

MESFET Operation

$$I_{ds} = qN_d(h-a)wv$$

$$v = \mu E$$

$$E = \frac{V_{ds}}{s}$$

$$a = \left(\frac{2\varepsilon_0 \varepsilon_r (V_{bi} - V_{gs})}{qN_d} \right)^{\frac{1}{2}}$$

$$g_m = \left. \frac{\partial I_{ds}}{\partial V_{gs}} \right|_{V_{ds}=Const}$$

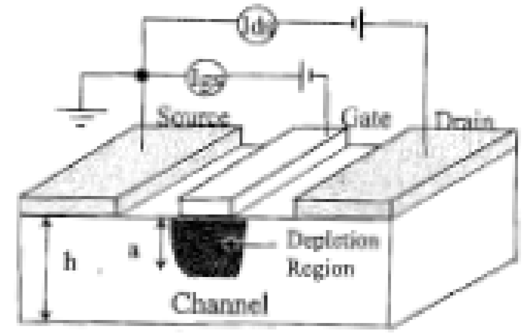


Figure 2.31 Schematic of a MESFET

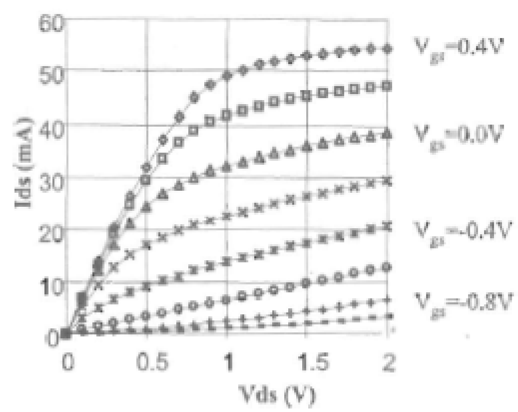


Figure 2.33 Output characteristics of a MESFET

MESFET Equivalent Circuit

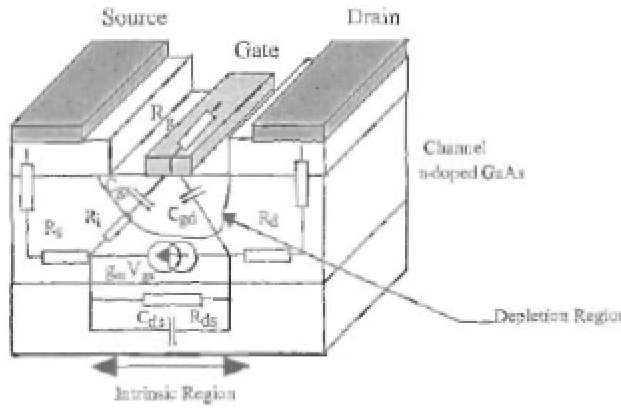


Figure 2.34 Cross-section of MESFET with superimposed lumped-element equivalent circuit

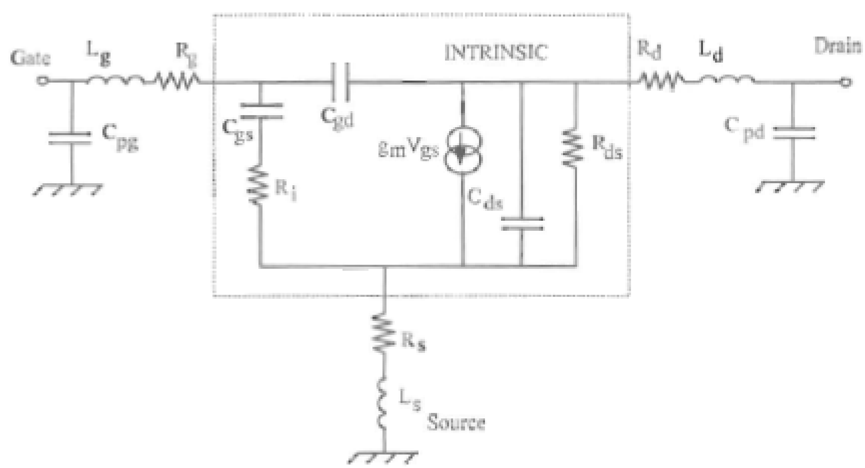


Figure 2.35 Lumped-element equivalent circuit of a MESFET

:es

$$g_m = \left.\frac{\partial I_{ds}}{\partial V_{gs}}\right|_{V_{ds}=Const}$$

Frequency

$$f_T = \frac{g_m}{2\pi\left(C_{gs} + C_{gd}\right)}$$

Cut off Frequency where $I_{ds}=I_{gs}$

$$f_T = \frac{v_{eff}}{2\pi L_g}$$

For High frequency
Increase effective velocity
and reduce gate lengths

$$f_T = \frac{g_m}{2\pi\left[\left(C_{gs} + C_{gd}\right)\left(1 + \frac{R_s + R_d}{R_{ds}}\right) + g_m C_{gd}\left(R_s + R_d\right)\right]}$$

And minimize resistance

HEMT and pHEMT

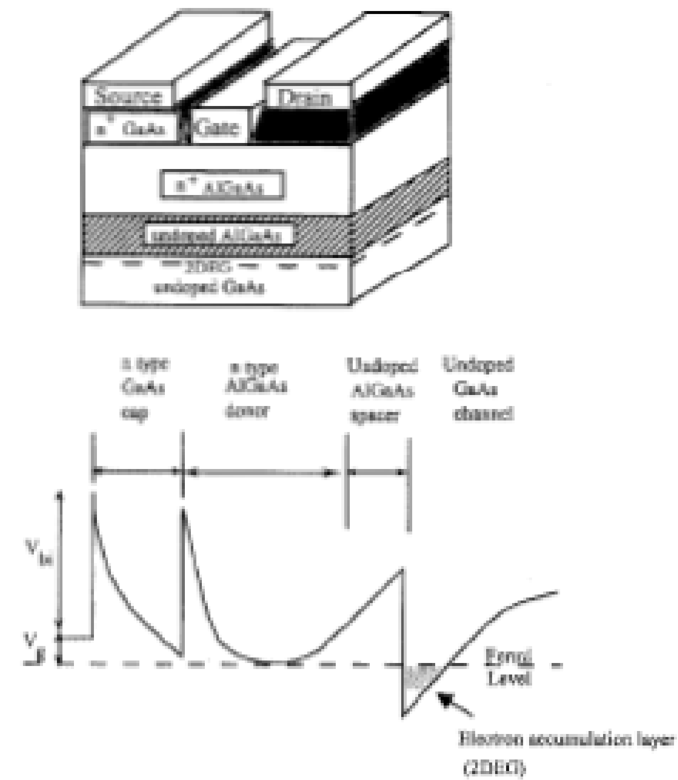


Figure 2.37 Cross-section of AlGaAs/GaAs HEMT and its conduction band diagram

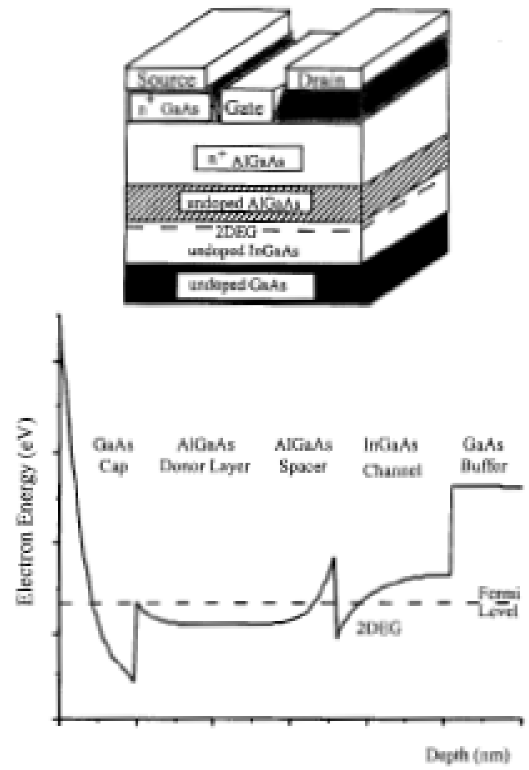


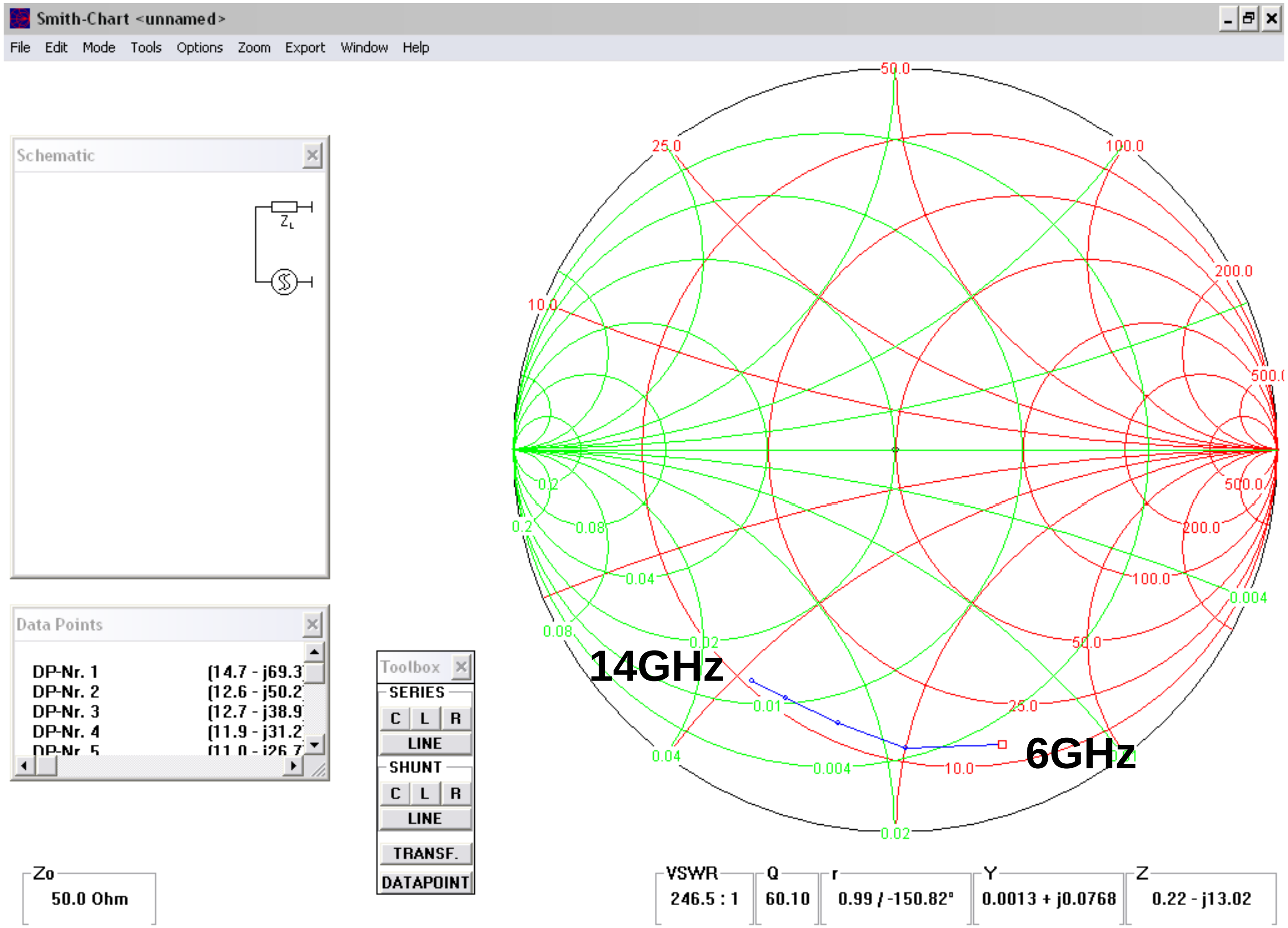
Figure 2.39 Cross-section of a GaAs pHEMT grown on a GaAs substrate and its conduction band diagram

Data file for actual device

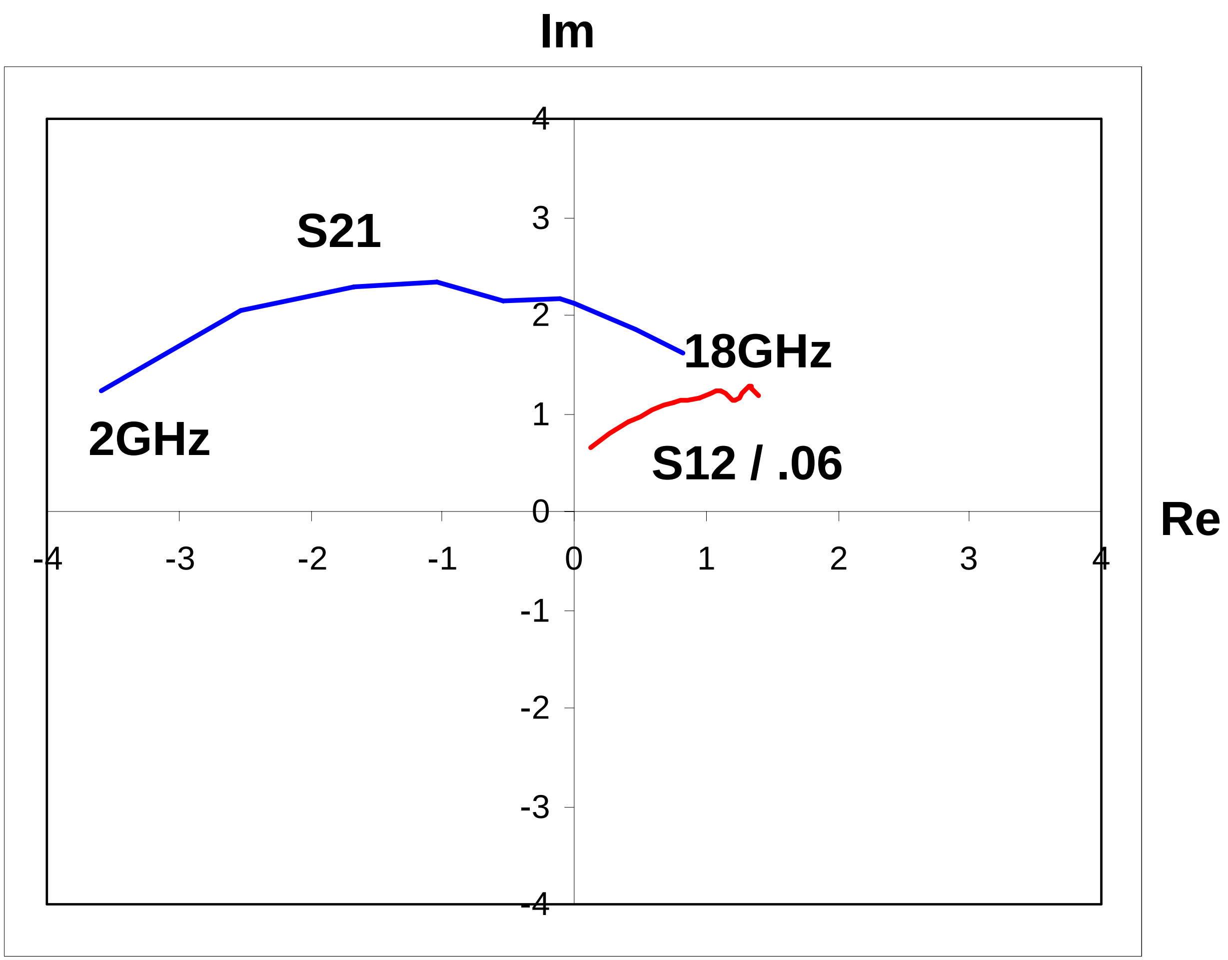
! FILENAME: N67300.S2P VERSION: 1.0
! NEC PART NUMBER: NE67300 DATE: 4/83
! BIAS CONDITIONS: VDS=3V, IDS=10mA
! NOTE : GATE AND DRAIN BOND WIRES ARE DE-EMBEDDED.
! NOTE : SOURCE BOND WIRE EFFECTS ARE INCLUDED. Ltotal = 0.07 nH
! (4 EACH 0.7 mil DIAMETER GOLD WIRES APPROXIMATELY 0.015" LONG).
GHZ S MA R 50

2	0.95	-26	3.79	161	0.04	79	0.59	-13
4	0.89	-50	3.26	141	0.06	66	0.58	-24
6	0.82	-70	2.83	126	0.08	56	0.54	-33
8	0.78	-88	2.55	114	0.09	51	0.5	-42
10	0.73	-102	2.21	104	0.1	48	0.47	-48
12	0.71	-114	2.16	93	0.1	43	0.45	-55
14	0.71	-122	2.11	90	0.11	44	0.47	-62
16	0.67	-128	1.92	76	0.11	43	0.49	-64
18	0.66	-140	1.81	63	0.11	40	0.52	-70
f1	ReS11	ImS11	ReS21	ImS21	ReS12	ImS12	ReS22	ImS22

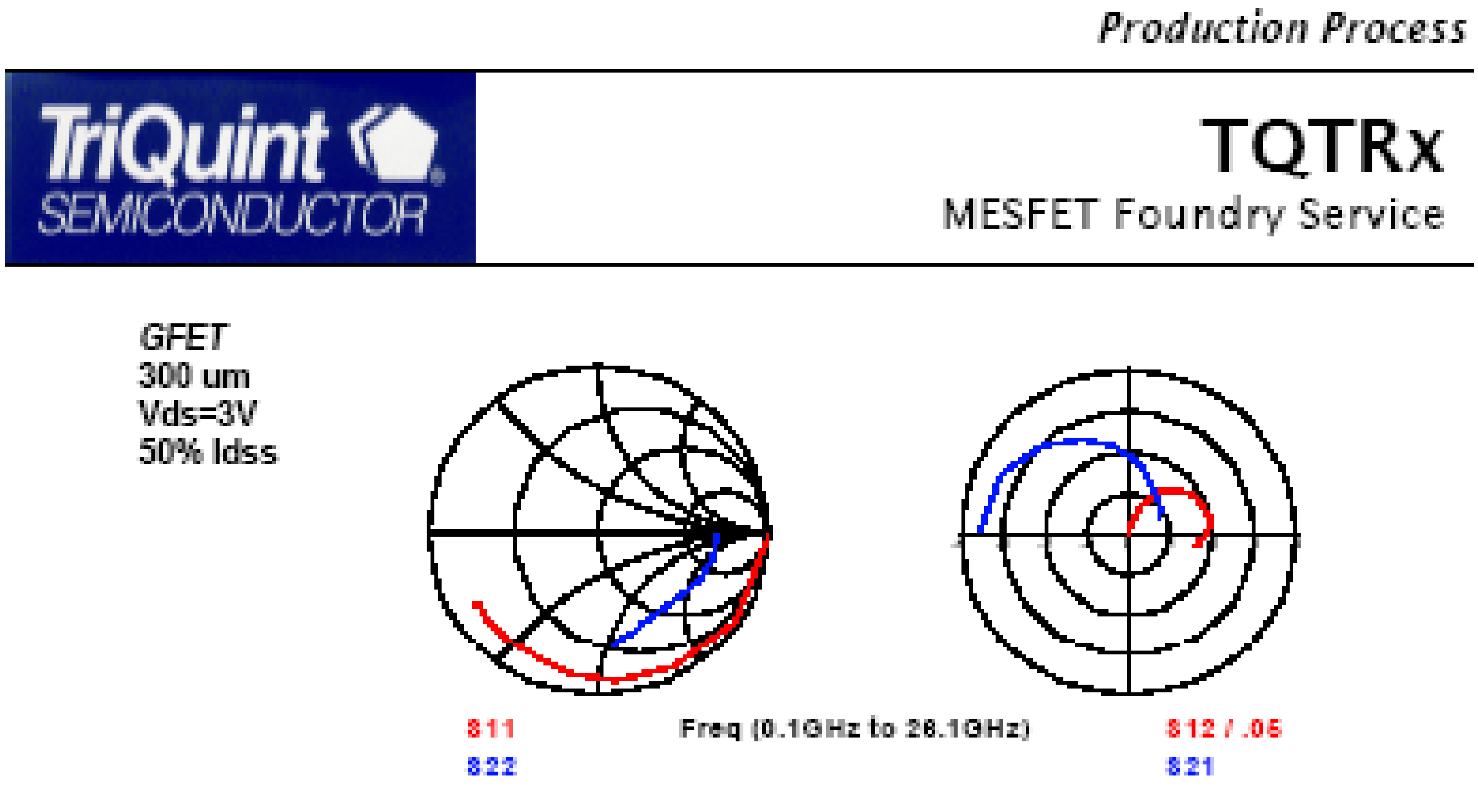
S11 on Smith Chart



S21 and S12



FET Example

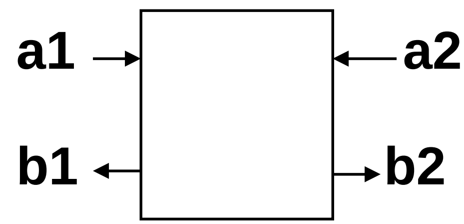

Production Process
TriQuint
SEMICONDUCTOR
TQTRx
MESFET Foundry Service
GFET
300 um
Vds=3V
50% Idss
S11
S22
Freq (0.1GHz to 26.1GHz)
S12 / .05
S21

Input Reflection Coefficient

- S11 is reflection coefficient only when port 2 is terminated in a matched load

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

Γ_{in}



Γ_L

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

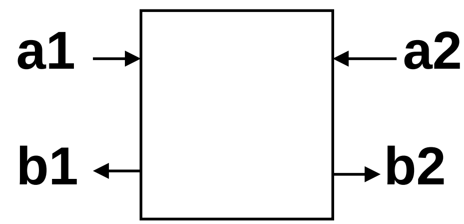
=S_{11} when S12 = 0

Output Reflection Coefficient

- S22 is reflection coefficient only when port 1 is terminated in a matched load

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

Γ_s



Γ_{out}

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

$=S_{22}$ when S12 = 0

Stability

- Transistor is unstable when $|\Gamma_{in}| > 1$

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

Boundary Condition for Stability

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

Stability

- Transistor is unstable when $|\Gamma_{out}| > 1$

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

Boundary Condition for Stability

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

Stability Circles on Smith Chart

- Load or Source stability circle is the locus of points in the Γ_L or Γ_s plane, for which Γ_{in} or Γ_{out} = 1. If the center of the smith chart is enclosed by the stability circle then all points inside the circle are stable. If the center is not enclosed then all points inside the circle are unstable.

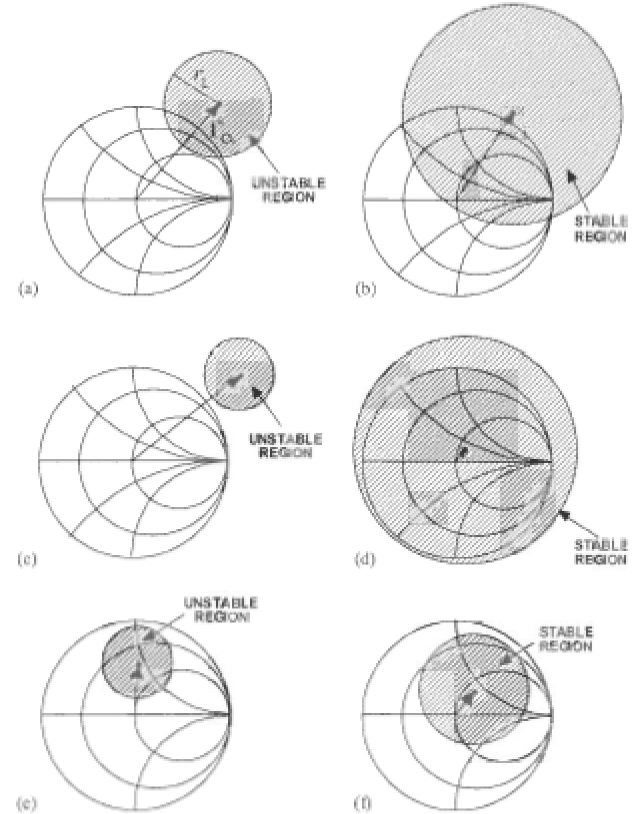


Figure 5.2 Stability circles on the Smith chart: (a) stability circle partially inside the Smith chart, (b) partially inside and encompassing the 50 Ω point, (c) completely outside, (d) completely encompassing the Smith chart, (e) completely inside but not encompassing the 50 Ω point and (f) completely inside and encompassing the 50 Ω point

Unconditional Stability

- If all of the smith chart is in a stable region then the transistor is said to be unconditionally stable.
  - Γ_{in} or Γ_{out} <1 for all values of Γ_L or Γ_S

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

Unconditionally Stable for K>1

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