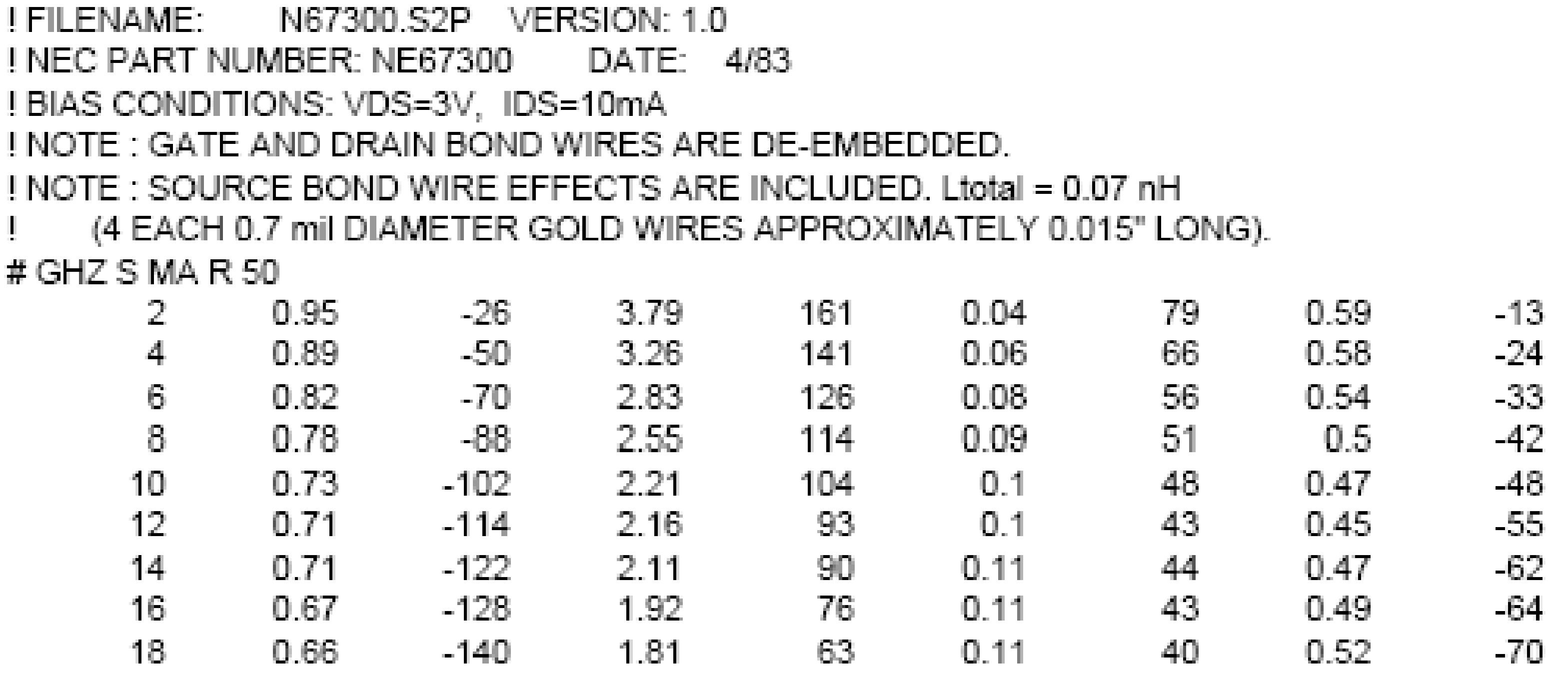
MMIC Design and Technology
Amplifier Design

Instructor Dr. Ali Medi

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
```

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.

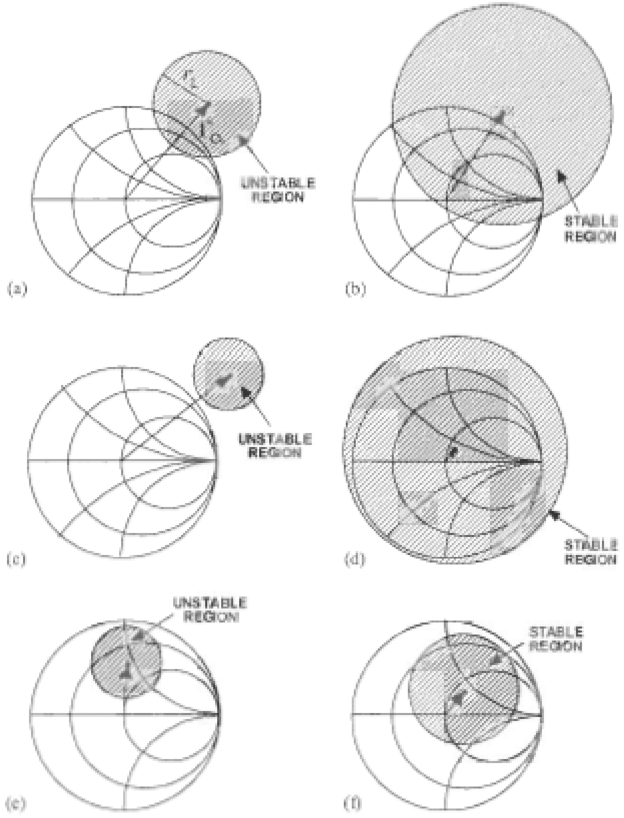


Figure 5.2 Stability circles on the Smith chart: (a) stability circle partially inside the Smith chart, (b) partially inside and encompassing the 50 Ω point, (c) completely outside, (d) completely encompassing the Smith chart, (e) completely inside but not encompassing the 50 Ω point and (f) completely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

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

Constant Gain Circles

G_T= Power delivered to load / Power available from source

$$G_T = \frac{|S_{21}|^2 \left(1 - |\Gamma_s|^2\right)\left(1 - |\Gamma_L|^2\right)}{|1 - S_{11}\Gamma_s - S_{22}\Gamma_L + \Delta\Gamma_s\Gamma_L|^2}$$

G_{TU}

When S_{12}=0, $G_{TU}=G_sG_oG_L$

$$G_s = \frac{1-\left|\Gamma_s\right|^2}{\left|1-S_{11}\Gamma_s\right|^2}$$

$$G_0 = \left|S_{21}\right|^2$$

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

MAG

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

$$K < 1$$

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

$$K > 1$$

Noise Figure

$$F = F_{\min} + 4R_n \frac{\left|\Gamma_s - \Gamma_{opt}\right|^2}{\left(1 - \left|\Gamma_s\right|^2\right)\left|1 + \Gamma_{opt}\right|^2}$$

F_{min} is noise figure at Γ_{opt}
R_n is normalized “noise resistance”
Circles of constant noise figure in Γ_s Plane

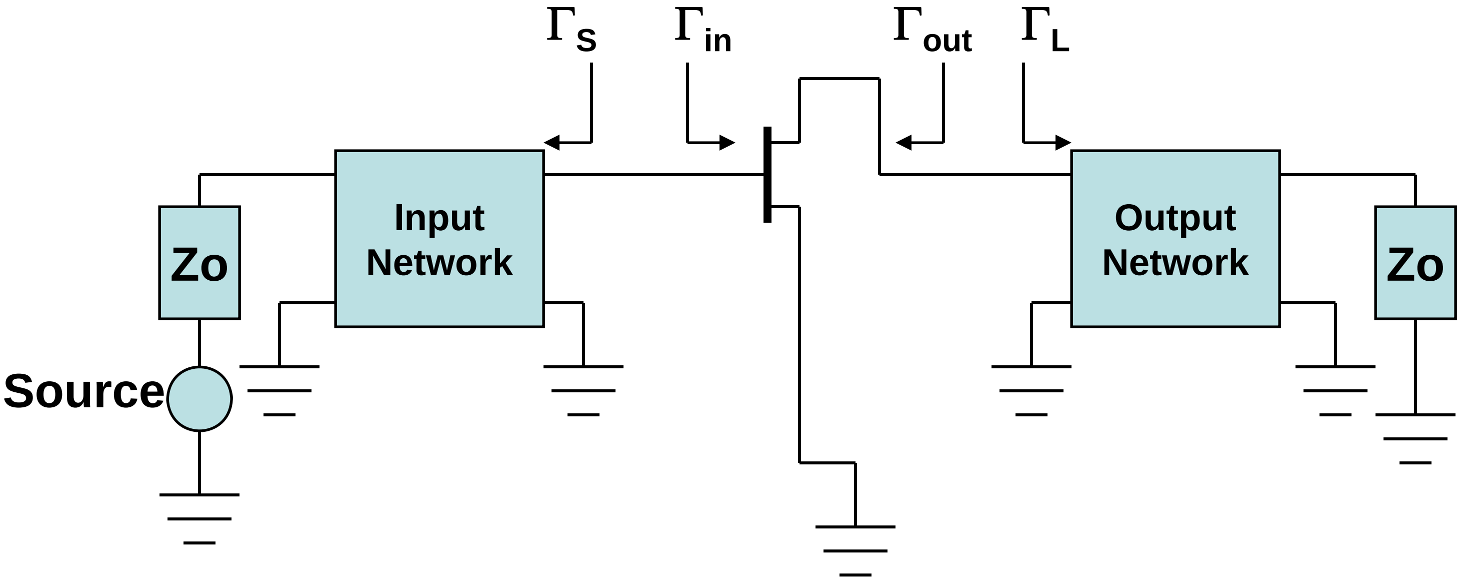
Device Data File

```
! NEC PART NUMBER: NE67300       DATE:    4/83
! BIAS CONDITIONS: VDS=3V,  IDS=10mA
! NOISE PARAMETERS
! 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).
 1  0.40  .90   12  .57
 2  0.40  .85   21  .51
 4  0.40  .75   40  .44
 6  0.60  .69   55  .38
 8  0.80  .62   70  .33
10  1.10  .56   85  .28
12  1.40  .52   99  .24
14  1.70  .49  114  .20
16  2.00  .47  127  .18
18  2.25  .45  140  .16
```

FORMAT

GHz	NF_{min}dB	Γ_{opt} Mag	Γ_{opt} angle	normalized Rn

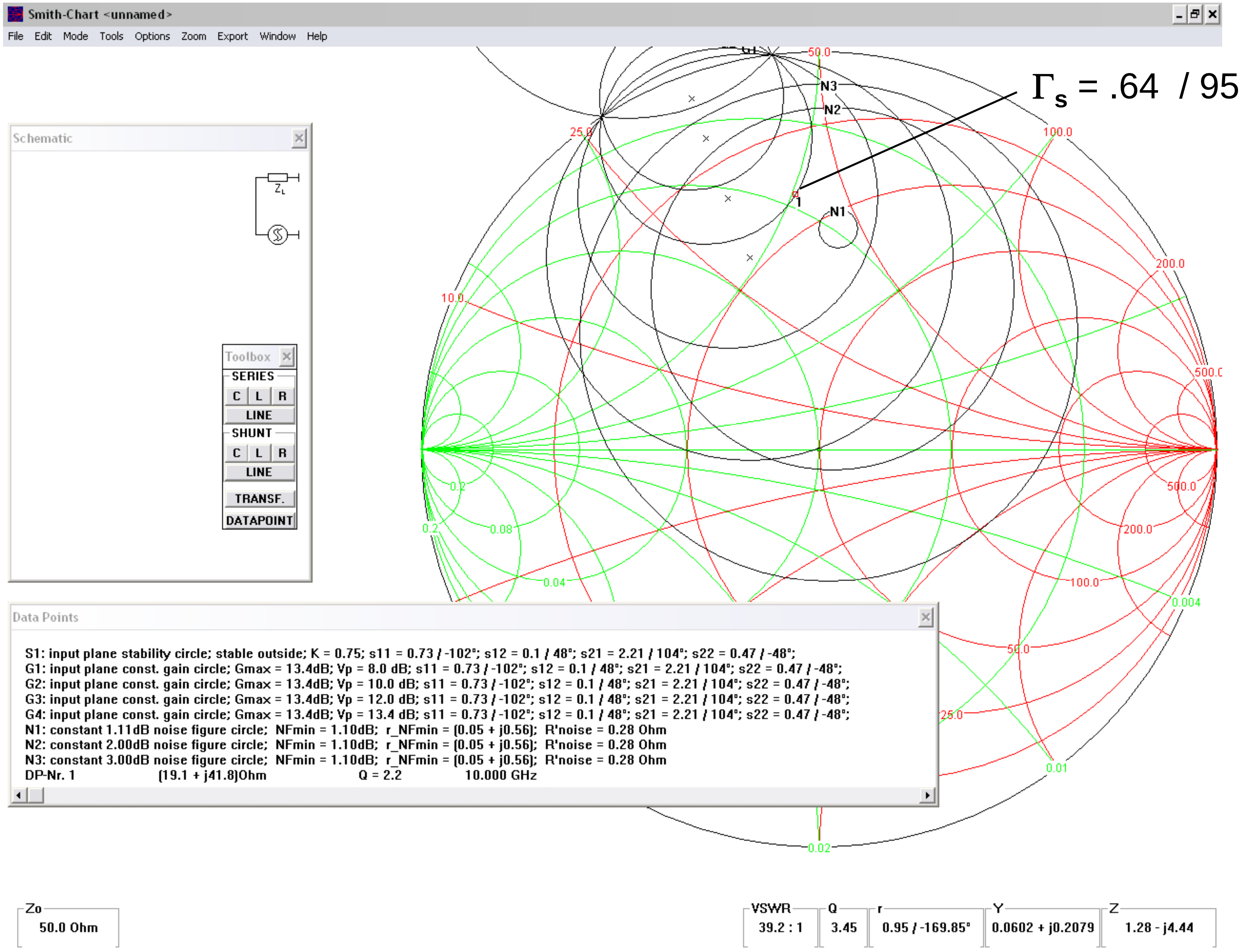
Design Process



Design Γ_s and Γ_L to provide the desired performance
May be a trade with stability, gain, noise figure
Then design matching networks

Design Process

- Plot on Γ_s plane
  - – Source stability circle
  - – Constant Gain circles
  - – Constant Noise Figure circles
- Choose a suitable value of Γ_s



S1: input plane stability circle; stable outside; K = 0.75; s11 = 0.73 / -102°; s12 = 0.1 / 48°; s21 = 2.21 / 104°; s22 = 0.47 / -48°;
G1: input plane const. gain circle; Gmax = 13.4dB; Vp = 8.0 dB; s11 = 0.73 / -102°; s12 = 0.1 / 48°; s21 = 2.21 / 104°; s22 = 0.47 / -48°;
G2: input plane const. gain circle; Gmax = 13.4dB; Vp = 10.0 dB; s11 = 0.73 / -102°; s12 = 0.1 / 48°; s21 = 2.21 / 104°; s22 = 0.47 / -48°;
G3: input plane const. gain circle; Gmax = 13.4dB; Vp = 12.0 dB; s11 = 0.73 / -102°; s12 = 0.1 / 48°; s21 = 2.21 / 104°; s22 = 0.47 / -48°;
G4: input plane const. gain circle; Gmax = 13.4dB; Vp = 13.4 dB; s11 = 0.73 / -102°; s12 = 0.1 / 48°; s21 = 2.21 / 104°; s22 = 0.47 / -48°;
N1: constant 1.11dB noise figure circle; NFmin = 1.10dB; r_NFmin = (0.05 + j0.56); R'noise = 0.28 Ohm
N2: constant 2.00dB noise figure circle; NFmin = 1.10dB; r_NFmin = (0.05 + j0.56); R'noise = 0.28 Ohm
N3: constant 3.00dB noise figure circle; NFmin = 1.10dB; r_NFmin = (0.05 + j0.56); R'noise = 0.28 Ohm
DP-Nr. 1 (19.1 + j41.8)Ohm Q = 2.2 10.000 GHz

Zo: 50.0 Ohm
VSWR: 39.2 : 1
Q: 3.45
r: 0.95 / -169.85°
Y: 0.0602 + j0.2079
Z: 1.28 - j4.44

Γ_s = .64 / 95.3 deg

Lecture 6 Amplifier Design

Design Process

- Calculate Γ_{out}

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

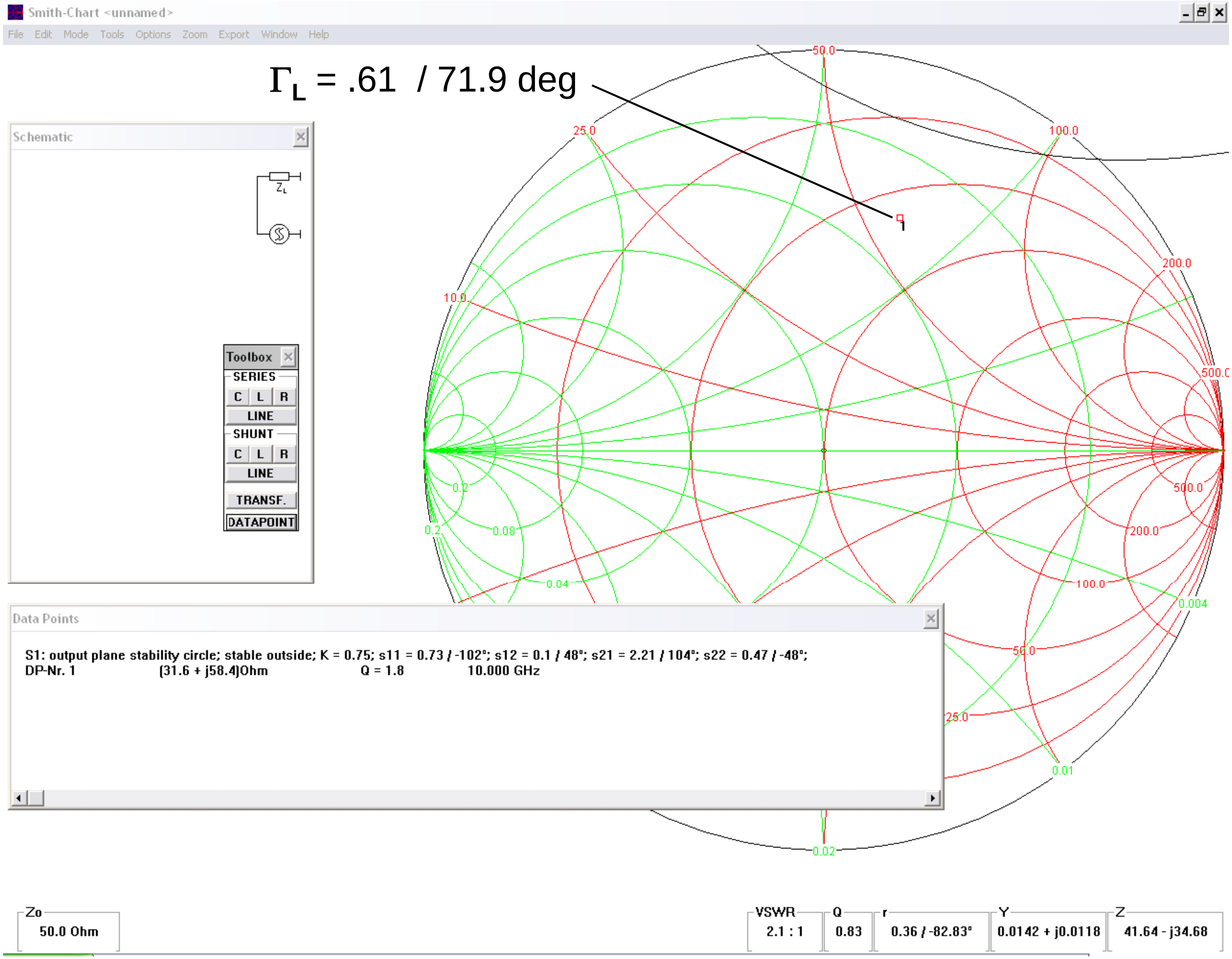
For example data

When Γ_s = .64 / 95.3 deg

Γ_{out} = 0.61 / -71.9 deg

Design Process

- Plot on Γ_L plane
  - Load stability circle
  - Conjugate of $\Gamma_{out} = \Gamma^*_{out}$
- If Γ^*_{out} is an allowed value for Γ_L
  - Choose $\Gamma_L = \Gamma^*_{out}$
- Else
  - Plot Constant Gain circle on Γ_L plane
  - Select a suitable value of Γ_L



$\Gamma_L = .61 \ / \ 71.9$ deg

S1: output plane stability circle; stable outside; K = 0.75; s11 = 0.73 / -102°; s12 = 0.1 / 48°; s21 = 2.21 / 104°; s22 = 0.47 / -48°;

DP-Nr. 1 [31.6 + j58.4]Ohm Q = 1.8 10.000 GHz

Zo: 50.0 Ohm

VSWR: 2.1 : 1

Q: 0.83

r: 0.36 / -82.83°

Y: 0.0142 + j0.0118

Z: 41.64 - j34.68

Calculate Gain

$$G_T = \frac{|S_{21}|^2 \left(1-|\Gamma_s|^2\right)\left(1-|\Gamma_L|^2\right)}{\left|1-S_{11}\Gamma_s - S_{22}\Gamma_L + \Delta\Gamma_s\Gamma_L\right|^2}$$

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

For our example $\boldsymbol{G_T}$ = 15.8
10Log G_T = 12.0 **dB**

Calculate Noise Figure

$$F = F_{\min} + 4R_n \frac{\left|\Gamma_s - \Gamma_{opt}\right|^2}{\left(1 - \left|\Gamma_s\right|^2\right)\left|1 + \Gamma_{opt}\right|^2}$$

Some useful Excel functions (must install Analysis ToolPak)

IMABS	**Returns the absolute value (modulus) of a complex number**
IMAGINARY	**Returns the imaginary coefficient of a complex number**
IMARGUMENT	**Returns the argument theta, an angle expressed in radians**
IMCONJUGATE	**Returns the complex conjugate of a complex number**
IMCOS	**Returns the cosine of a complex number**
IMDIV	**Returns the quotient of two complex numbers**
IMEXP	**Returns the exponential of a complex number**
IMLN	**Returns the natural logarithm of a complex number**
IMLOG10	**Returns the base-10 logarithm of a complex number**
IMLOG2	**Returns the base-2 logarithm of a complex number**
IMPOWER	**Returns a complex number raised to an integer power**
IMPRODUCT	**Returns the product of from 2 to 29 complex numbers**
IMREAL	**Returns the real coefficient of a complex number**
IMSIN	**Returns the sine of a complex number**
IMSQRT	**Returns the square root of a complex number**
IMSUB	**Returns the difference between two complex numbers**
IMSUM	**Returns the sum of complex numbers**

Design Input and Output Network

- Input network transforms the source impedance such that Γ_s is presented to the transistor
- Output network transforms the load impedance such that Γ_L is presented to the transistor

Biasing

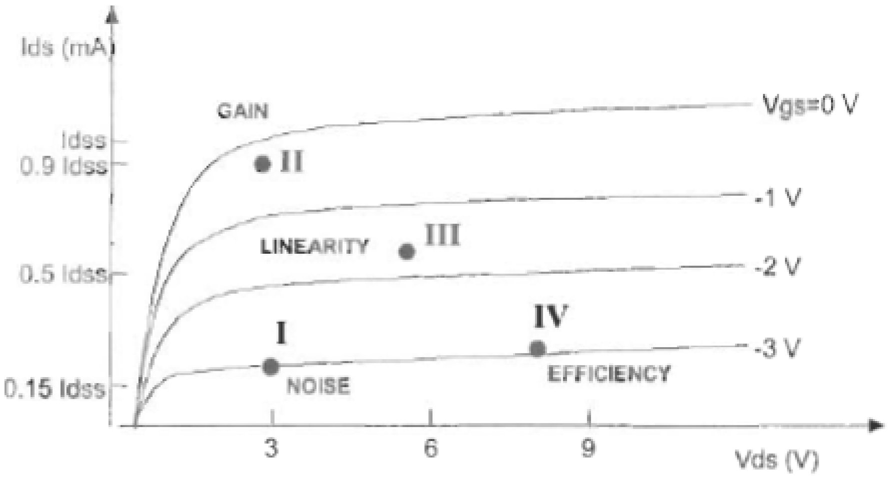


Figure 5.12 Typical FET I-V curves and operating bias points

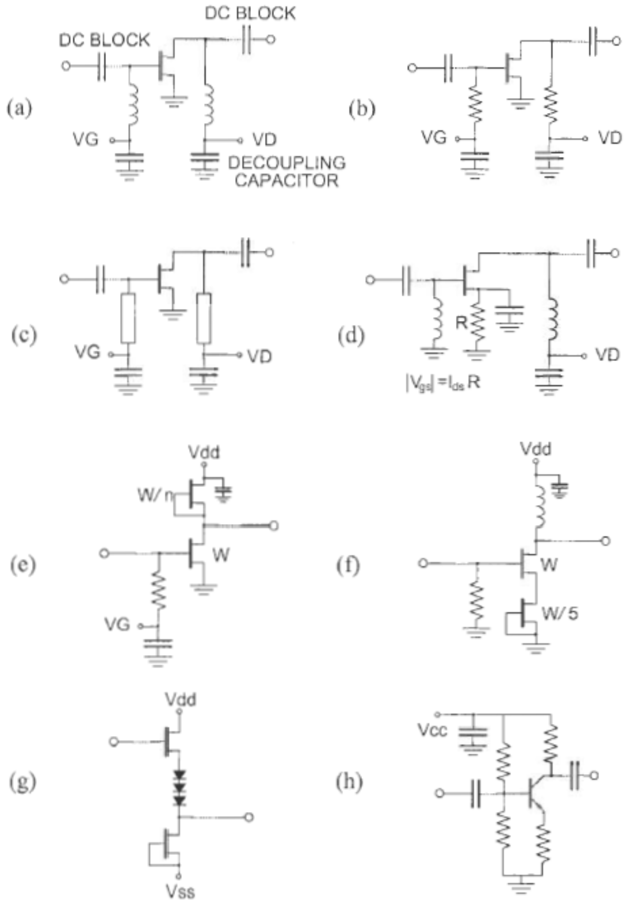


Figure 5.13 DC bias networks: (a) inductors as bias chokes, (b) high value resistors, (c) microstrip stubs, (d) self-biasing, (e) active load, (f) constant-current source self-biasing, (g) DC coupling and (h) bipolar transistor biasing