What Does Stability Mean?

- Stability circles determine what load or source impedances should be avoided for stable or non-oscillatory amplifier behavior
- Because reactive loads are being added to amp the conditions for oscillation must be determined
- So the Output Stability Circle determine the Γ_L or load impedance (looking into matching network from output of amp) that may cause oscillation
- Input Stability Circle determine the Γ_S or impedance (looking into matching network from input of amp) that may cause oscillation

Criteria for Unconditional Stability

- Unconditional Stability when amplifier remains stable throughout the entire domain of the Smith Chart at the operating bias and frequency. Applies to input and output ports.
- For $|S_{11}| < 1$ and $|S_{22}| < 1$, the stability circles reside completely outside the $|\Gamma_S| = 1$ and $|\Gamma_L| = 1$ circles.

Unconditional Stability: Rollett Factor

- $||C_{in}| - r_{in}| > 1$ and $||C_{out}| - r_{out}| > 1$
- Stability or Rollett factor k:

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

with $|S_{11}| < 1$ or $|S_{22}| < 1$

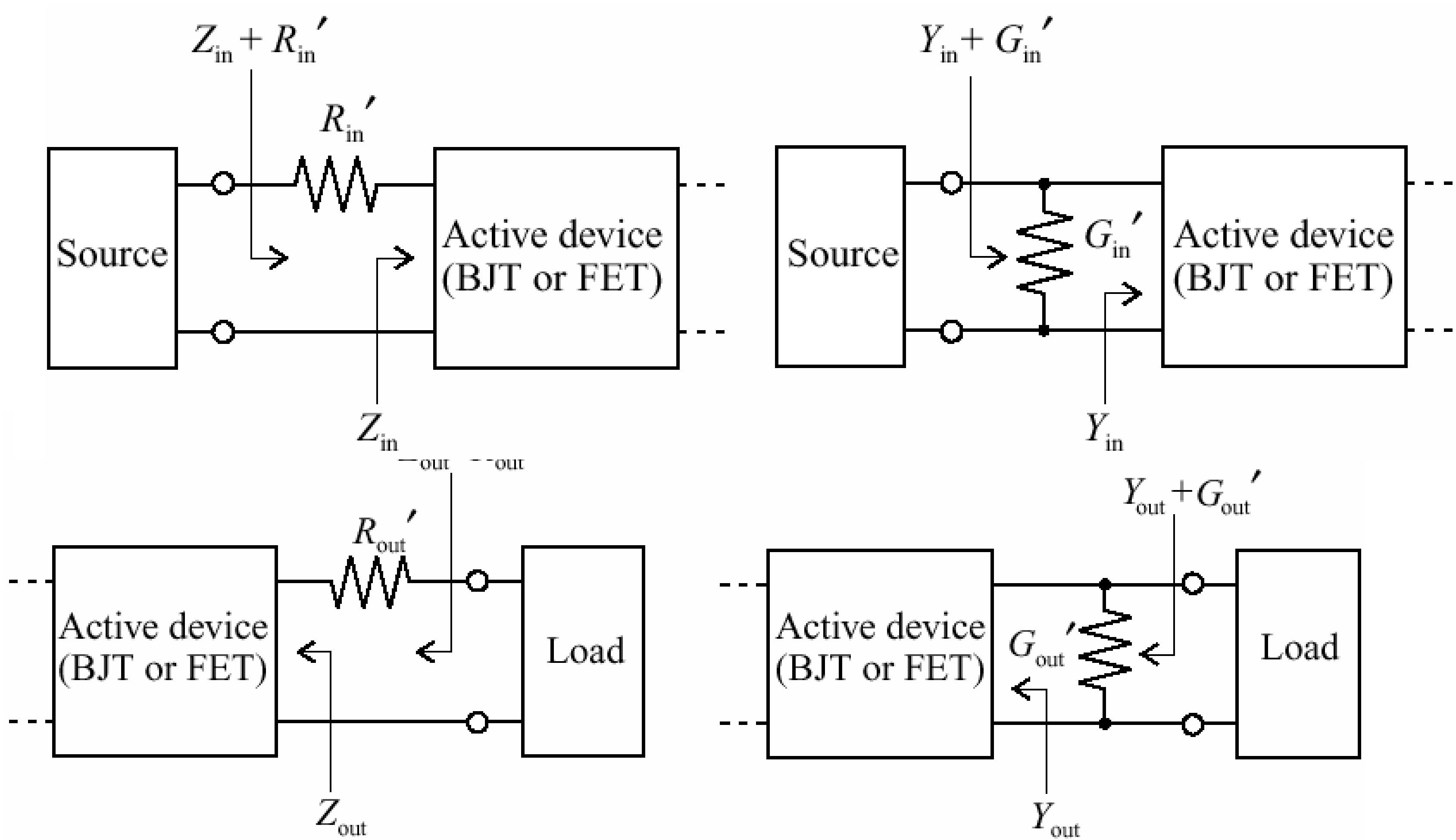
and

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

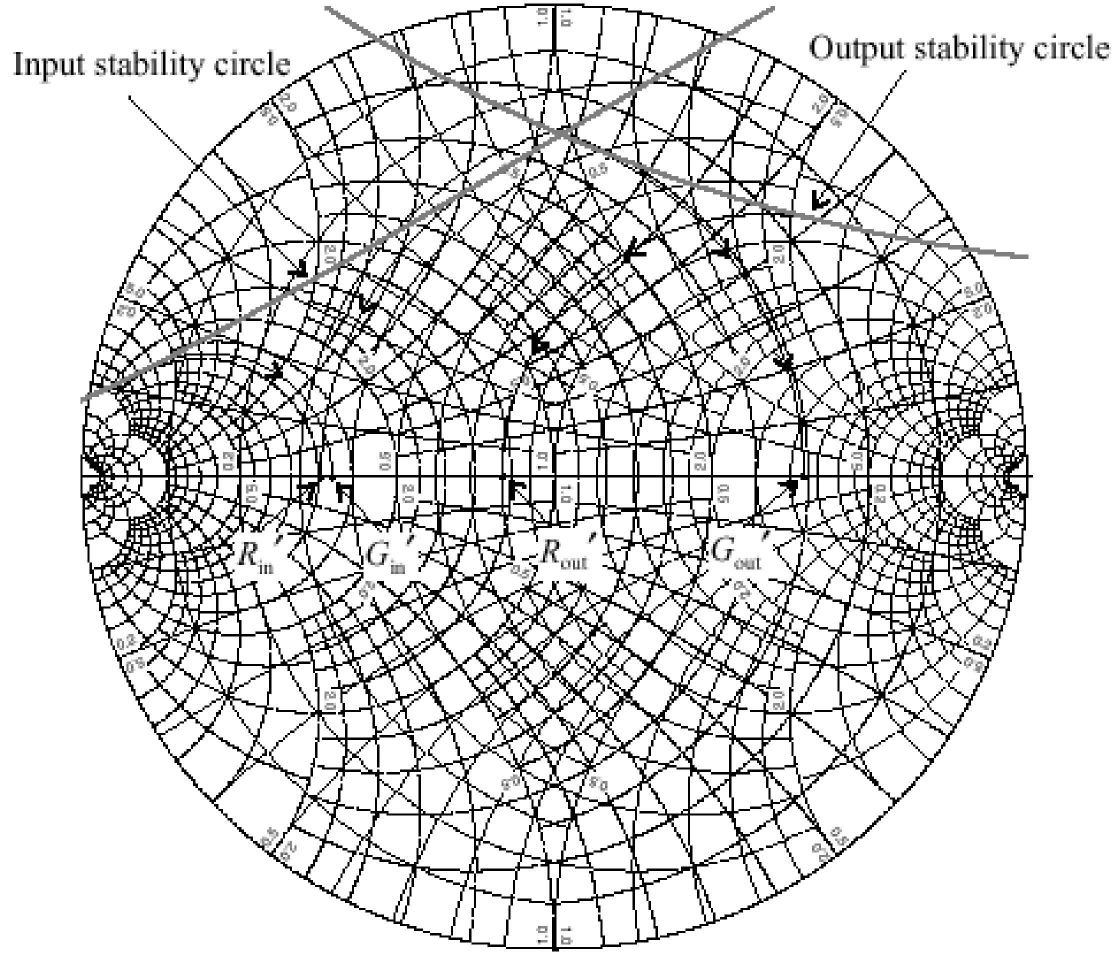
Stabilization Methods

- Stabilization methods can be used to for operation of BJT or FET found to be unstable at operating bias and frequency
- One method is to add series or shunt conductance to the input or output of the active device in the RF signal path to “move” the source or load impedances out of the unstable regions as defined by the Stability Circles

Stabilization Using Series Resistance or Shunt Conductance

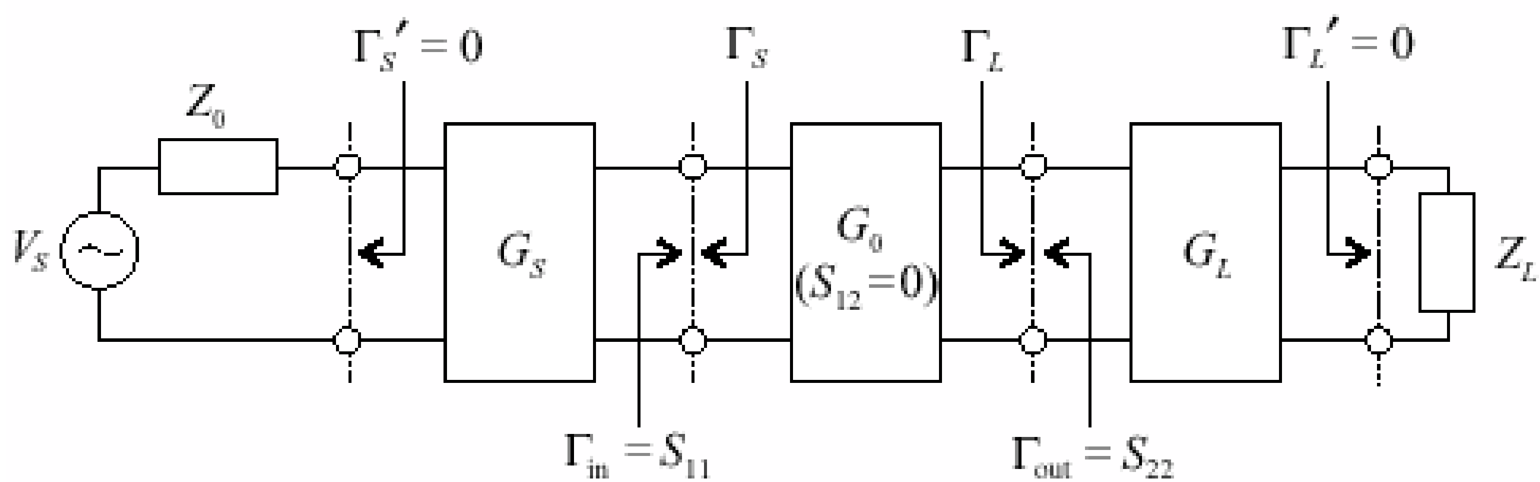


Stabilization Method: Smith Chart



Constant Gain: Unilateral Design (S_{12}= 0)

- Need to obtain desired gain performance
- Basically we can "detune" the amp matching networks for desired gain
- Unilateral power gain G_{TU} implies S_{12} = 0



Unilateral Power Gain Equations

- Unilateral Power gain

$$G_{TU} = \frac{1-|\Gamma_S|^2}{|1-S_{11}\Gamma_S|^2} |S_{21}|^2 \frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} = G_S G_0 G_L$$

- Individual blocks are:

$$G_S = \frac{1-|\Gamma_S|^2}{|1-S_{11}\Gamma_S|^2}\ ; \quad G_0 = |S_{21}|^2\ ; \quad G_L = \frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2}$$

- G_{TU} (dB) = G_S(dB) + G_0(dB) +G_L(dB)

Unilateral Gain Circles

- If $|S_{11}| < 1$ and $|S_{22}| < 1$ maximum unilateral power gain $G_{TU\max}$ when $\Gamma_S = S_{11}^*$ and $\Gamma_L = S_{22}^*$

$$G_{S\max} = \frac{1}{1-|S_{11}|^2}; \quad G_{L\max} = \frac{1}{1-|S_{22}|^2}$$

- Normalized G_S w.r.t. maximum:

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

Unilateral Gain Circles

- Normalized G_L w.r.t. maximums:

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

- Results in circles with center and radii:

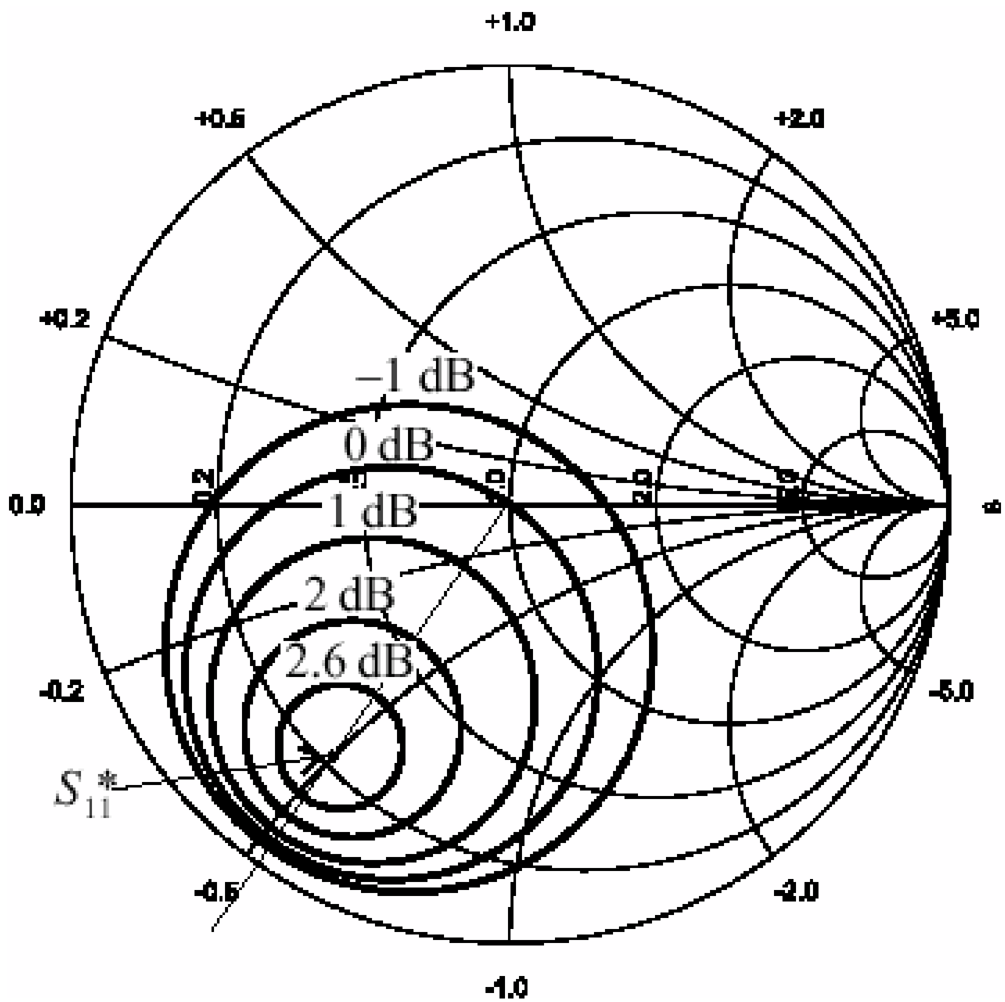
$$d_{g_i} = \frac{g_i S_{ii}}{1-|S_{ii}|^2(1-g_i)}; \quad r_{g_i} = \frac{\sqrt{1-g_i}\left(1-|S_{ii}|^2\right)}{1-|S_{ii}|^2(1-g_i)}$$

ii = 11 or 22 depending on $i = S$ or L

Gain Circle Observations

- $G_{i\,\max}$ when $\Gamma_i = S_{ii}^*$ and $d_{gi} = S_{ii}^*$ of radius $r_{gi} = 0$
- Constant gain circles all have centers on line connecting the origin to S_{ii}^*
- For the special case $\Gamma_i = 0$ the normalized gain is:
  $g_i = 1 - |S_{ii}|^2$ and $d_{gi} = r_{gi} = |S_{ii}|/(1 + |S_{ii}|^2)$
- This implies that $G_i = 1$ (0dB) circle always passes through origin of Γ_i - plane

Input Matching Network Gain Circles



Γ_S is detuned implying the matching network is detuned

Bilateral Amplifier Design (S_{12} included)

- Complete equations required taking into account S_{12}: Thus $\Gamma_S{}^* \neq S_{11}$ and $\Gamma_L{}^* \neq S_{22}$

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

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

Bilateral Conjugate Match

- Matched source reflection coefficient

$$\Gamma_{MS} = \frac{B_1}{2C_1} - \frac{1}{2}\sqrt{\left(\frac{B_1}{C_1}\right)^2 - 4\frac{C_1^*}{C_1}}$$

$$C_1 = S_{11} - S_{22}^*\Delta; \quad B_1 = 1 - |S_{22}|^2 - |\Delta|^2 + |S_{11}|^2$$

- Matched load reflection coefficient

$$\Gamma_{ML} = \frac{B_2}{2C_2} - \frac{1}{2}\sqrt{\left(\frac{B_2}{C_2}\right)^2 - 4\frac{C_2^*}{C_2}}$$

$$C_2 = S_{22} - S_{11}^*\Delta; \quad B_2 = 1 - |S_{11}|^2 - |\Delta|^2 + |S_{22}|^2$$

Optimum Bilateral Matching

$$\Gamma_{MS}^{*} = S_{11} + \frac{S_{12}S_{21}\Gamma_{ML}}{1 - S_{22}\Gamma_{ML}}$$

$$\Gamma_{ML}^{*} = S_{22} + \frac{S_{12}S_{21}\Gamma_{MS}}{1 - S_{11}\Gamma_{MS}}$$

Design Procedure for RF BJT Amps

- Bias the circuit as specified by data sheet with available S-Parameters
- Determine S-Parameters at bias conditions and operating frequency
- Calculate stability $|k| > 1$ and $|\Delta| < 1$?
- If unconditionally stable, design for gain
- If $|k| \leq 1$ and $|\Delta| \geq 1$ then draw Stability Circles on Smith Chart by finding r_{out}, C_{out}, r_{in}, and C_{in} radii and distances for the circles

Design Procedure for RF BJT Amps

- Determine if Γ_L (S_{22}* for conjugate match) lies in unstable region – do same for Γ_S
- If stable, no worries.
- If unstable, add small shunt or series resistance to move effective S_{22}* into stable region – use max outer edge real part of circle as resistance or conductance (do same for input side)
- Can adjust gain by detuning Γ_L or Γ_S

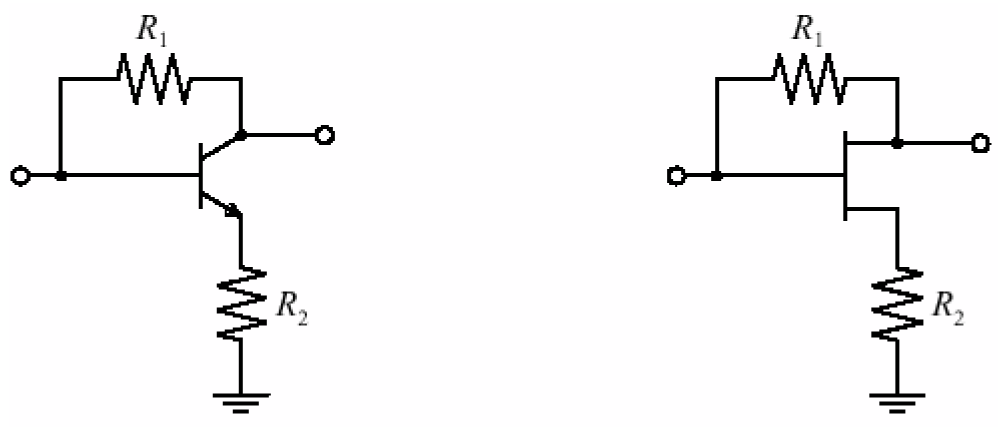
Design Procedure for RF BJT Amps

- To design for specified gain, must be less than $G_{TU\,\mathrm{max}}$ (max unilateral gain small S_{12})
- Recall that (know $G_0 = |S_{21}|^2$)

  G_{TU} [dB] = G_S [dB] + G_0 [dB] + G_L [dB]
- Detune either Γ_S or Γ_L
- Draw gain circles for G_S (or G_L) for detuned Γ_S (or Γ_L) matching network
- Overall gain is reduced when designed for (a) Stability and (b) detuned matching netw0rk

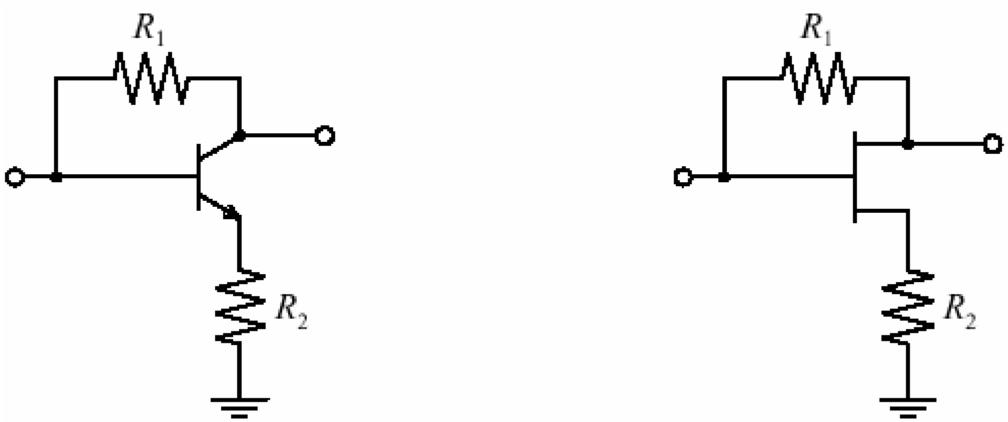
Design Procedure for RF BJT Amps

- Further circles on the Smith Chart include noise circles and constant VSWR circles
- Broadband amps often are feedback amps



(a) Feedback in BJTs (b) Feedback in FETs

RF Shunt-Shunt Feedback Amp Design



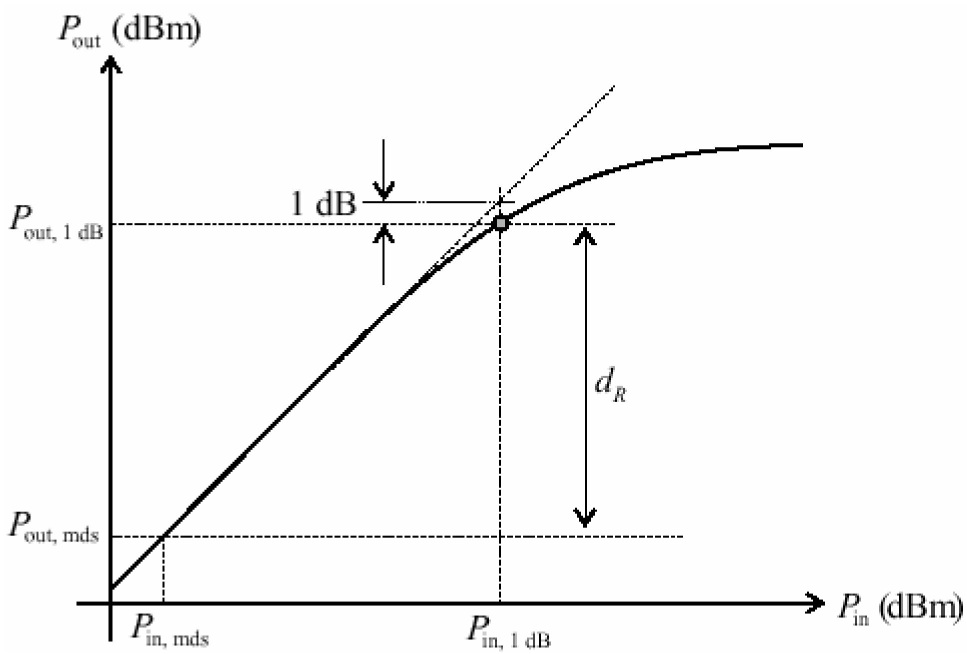
(a) Feedback in BJTs (b) Feedback in FETs

$$R_1 = Z_0\left(1 - S_{21}\right) \qquad R_2 = \frac{Z_0^2}{R_1} - \frac{1}{g_m}$$

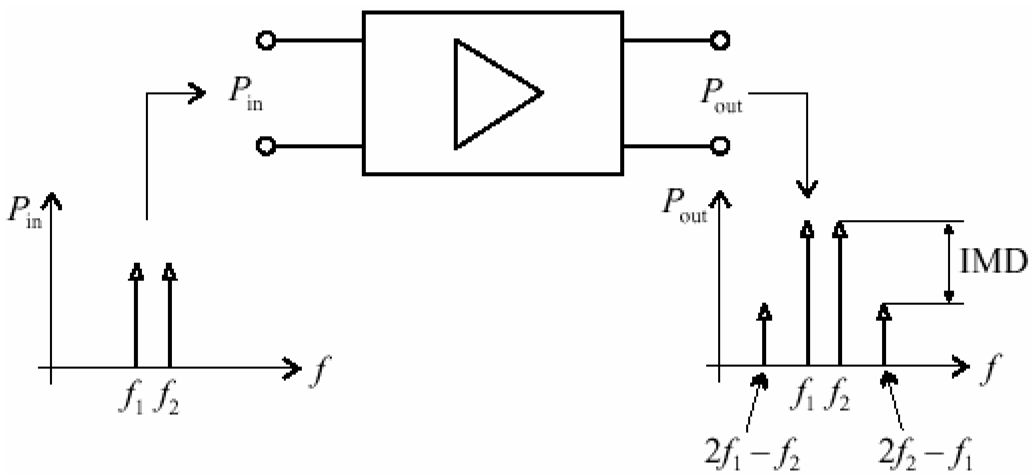
$$g_m = \frac{I_C}{V_T}$$

S_{21} calculated from desired gain G

Distortion: 1 dB Compression

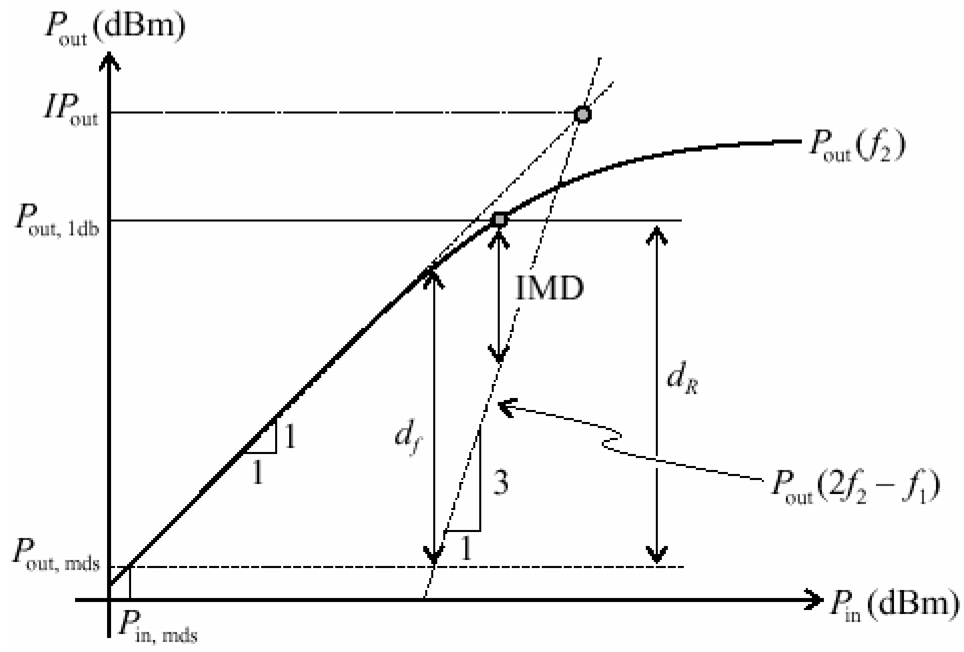


Distortion: 3rd Order Intermodulation Distortion



Distortion: 3rd Order IMD

$$IMD3[\text{dB}] = P_{out}(f_2)[\text{dBm}] - P_{out}(2f_2 - f_1)[\text{dBm}]$$



$$d_f[\text{dB}] = \frac{2}{3}\left(IP[\text{dBm}] - G_0[\text{dB}] - P_{in,mds}[\text{dBm}]\right)$$

Spurious Free Dynamic Range