Stub Tuner Matched RF Amplifiers

- Stub tuners can be used to match sources and load to S_{11}* and S_{22}* of the RF BJT or FET
- Either open or short circuit stubs may be used
- When using short circuit stubs, place a capacitor between the stub and ground to produce RF path to ground – Do not short directly to ground as this will affect transistor DC biasing
- High resistance $\lambda/4$ transformers or RFC's may be used to provide DC path to transistor for biasing without affecting the RF signal path

Stub Tuner Matched RF Amplifier

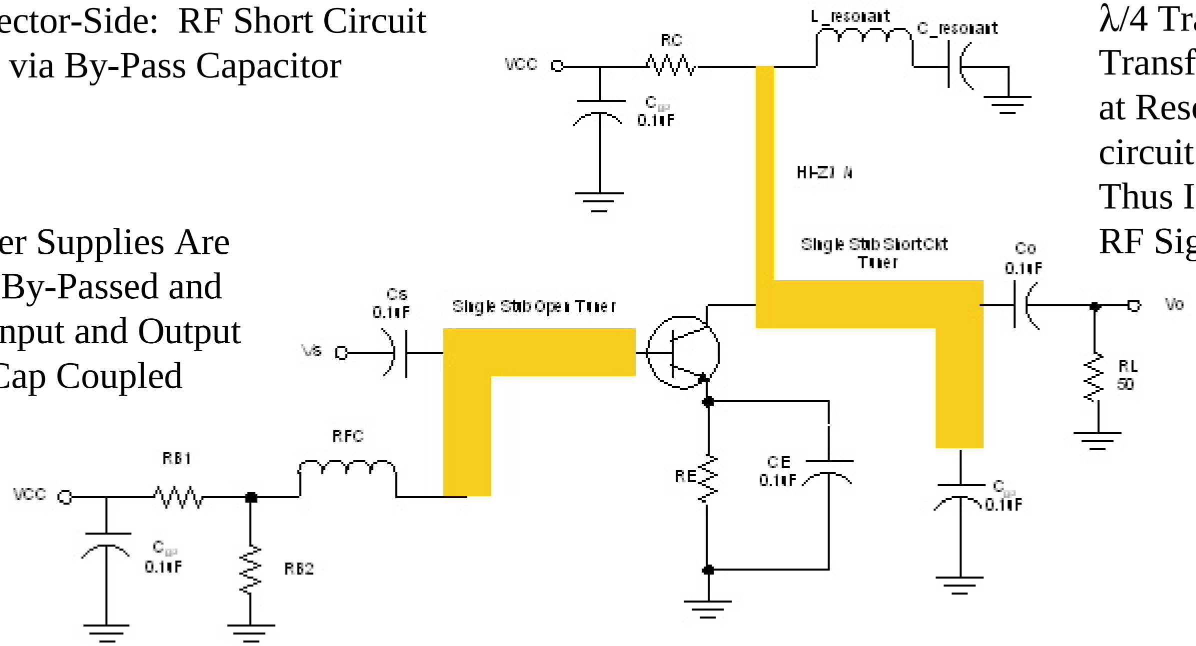
Stub tuners of two types:
Base-Side: Open Circuit Stub w/ Isolation from DC Bias Circuit Using RFC.
Collector-Side: RF Short Circuit Stub via By-Pass Capacitor

Series Resonant Ckt at Operating Frequency:
Short Ckt at Resonance, Open Circuit at DC

$$\omega_0 = \frac{1}{\sqrt{L_{resonant} C_{resonant}}}$$

$\lambda/4$ Transformer:
Transforms Short Circuit at Resonance to Open circuit at BJT Collector Thus Isolating RC from RF Signal Path

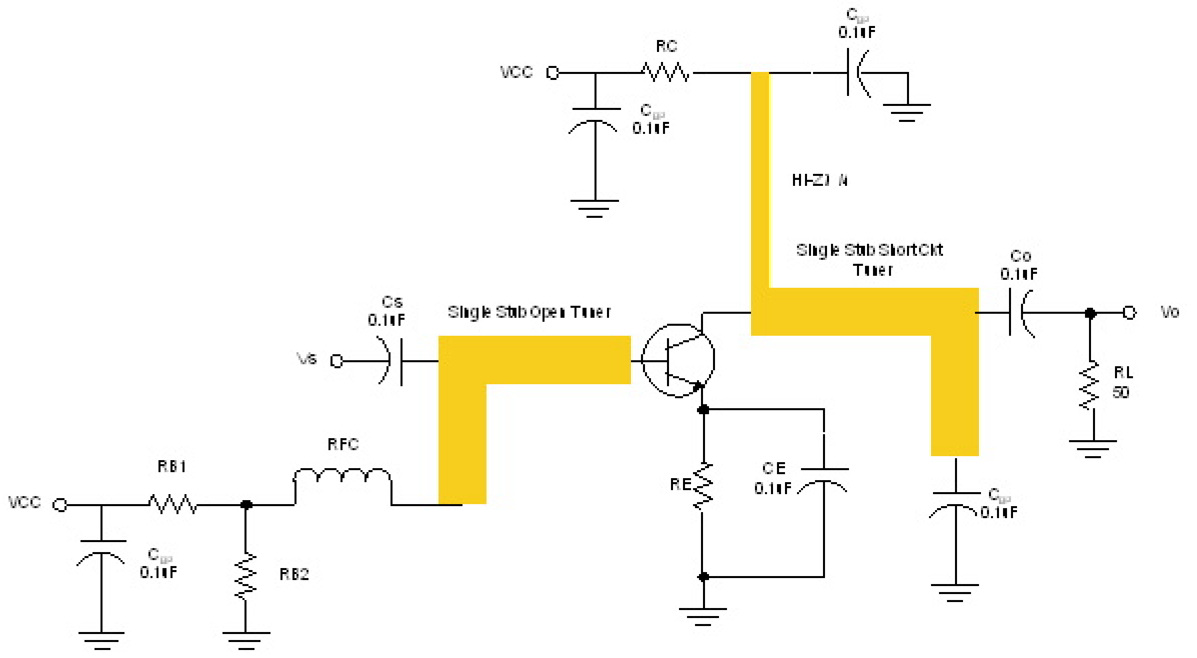
Power Supplies Are Cap By-Passed and RF Input and Output are Cap Coupled



The BJT “Self-Bias” Configuration Is Shown Which Produces Excellent Quiescent Point Stability

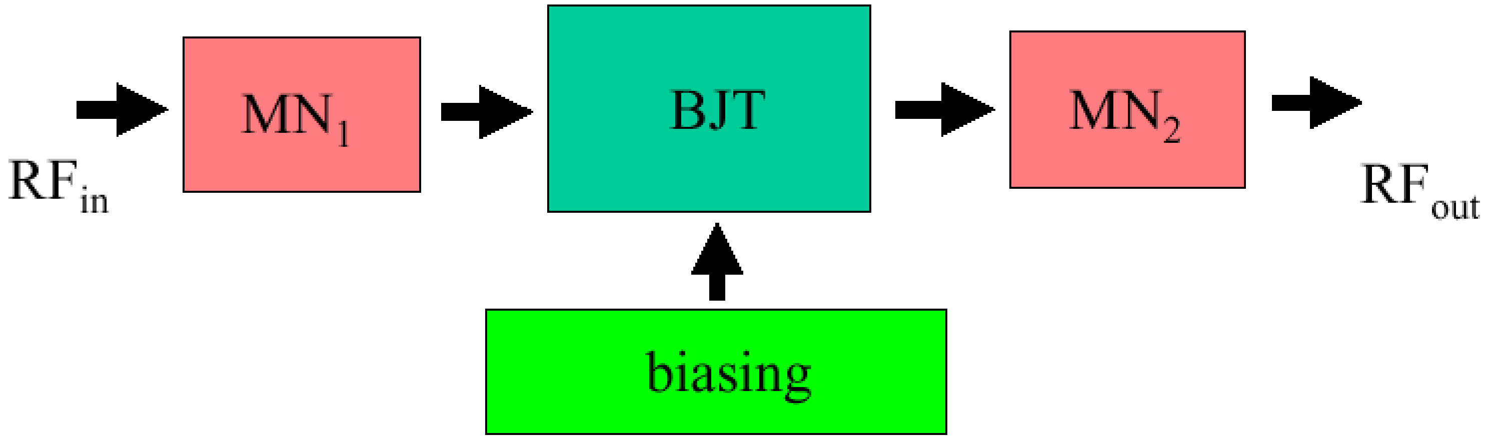
Stub Tuner Matched RF Amplifier

Simpler method of bias isolation at BJT collector: C_{BP} is RF short-circuit which when transformed by the Quarter-Wave Transformer is open circuit at the Single Stub Tuner and provides DC path for the Bias Network



Design Strategy: RF Amplifiers

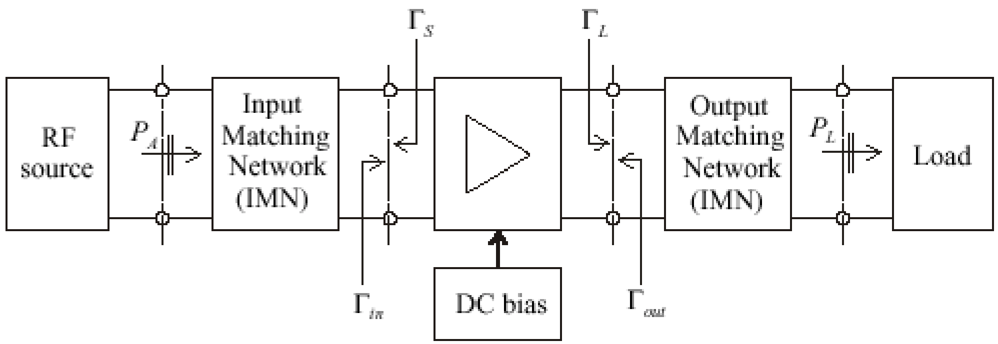
- Objective: Design a complete class A, single-stage RF amplifier operated at 1 GHz which includes biasing, matching networks, and RF/DC isolation.



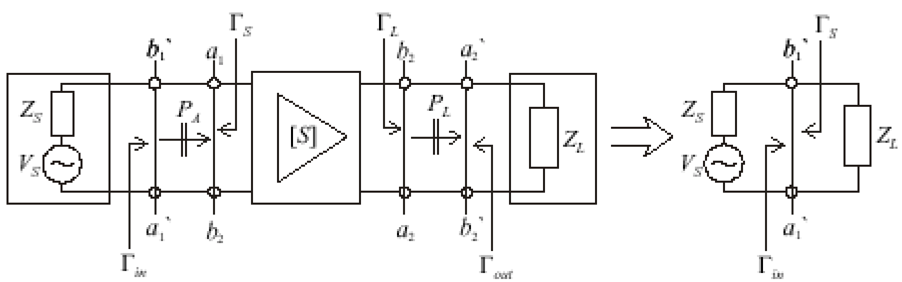
Design Strategy: RF Amplifier

- Design DC biasing conditions
- Select S-parameters for operating frequency
- Build input and output matching networks for desired frequency response
- Include RF/DC isolation
- simulate amplifier performance on the computer

Design Strategy: Approach



For power considerations, matching networks are assumed lossless



Power Relationships

Transducer Power Gain

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

Available Power Gain ($\Gamma_L = \Gamma_{out}^*$)

$$G_A = \frac{(1-|\Gamma_S|^2)\,|S_{21}|^2}{|1-|\Gamma_{out}|^2|\,|1-S_{11}\Gamma_S|^2}$$

Operating Power Gain ($\Gamma_S = \Gamma_{in}^*$)

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

Stability of Active Device

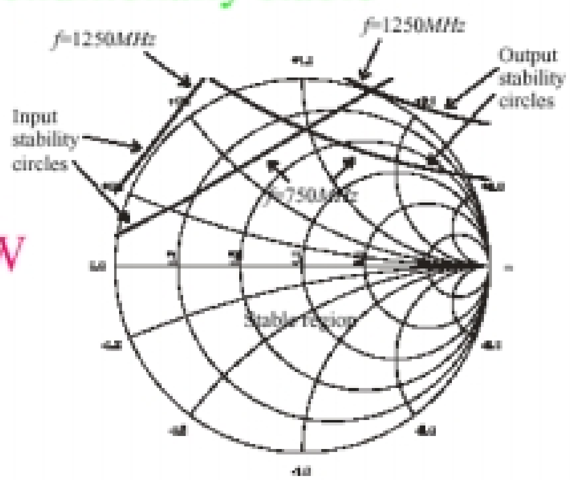
$$\left.\begin{array}{l} |\Gamma_L|<1, |\Gamma_S|<1 \\ |\Gamma_{in}|<1, |\Gamma_{out}|<1 \end{array}\right\}$$

Stability factor

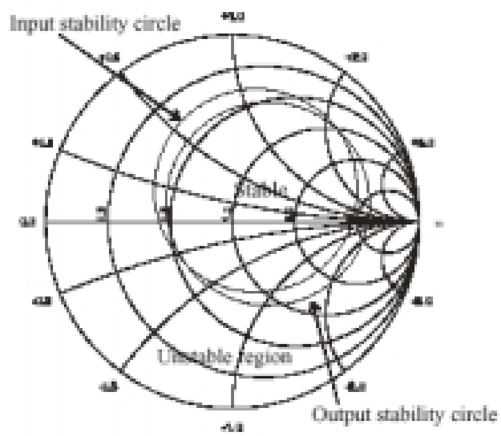
$$\boxed{k = \frac{1-|S_{11}|^2-|S_{22}|^2+|S_{11}S_{22}-S_{12}S_{21}|^2}{2|S_{12}||S_{21}|}}$$

If not unconditionally stable

BFG505W



or



Stability of Amplifiers

- In a two-port network, oscillations are possible if the magnitude of either the input or output reflection coefficient is greater than unity, which is equivalent to presenting a negative resistance at the port. This instability is characterized by

$$|\Gamma_{in}| > 1 \text{ or } |\Gamma_{out}| > 1$$

which for a unilateral device implies $|S_{11}| > 1$ or $|S_{22}| > 1$.

Stability Requirements

- Thus the requirements for stability are

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

and $\quad | \Gamma_{out} | = |S_{22} + l| < 1$

- These are defined by circles, called stability circles, that delimit $|\Gamma_{in}| = 1$ and $|\Gamma_L| = 1$ on the Smith chart.

Stability Regions: Stability Circles

- Regions of amplifier stability can be depicted using stability circles using the following:

  Output stability circle:

$$r_{out} = \frac{\left|S_{12}S_{21}\right|}{\left|\left|S_{22}{}^{2}\right| - \left|\Delta\right|^{2}\right|}, \quad C_{out} = \frac{\left(S_{22} - S_{11}^{*}\Delta\right)^{*}}{\left|S_{22}\right|^{2} - \left|\Delta\right|^{2}}$$

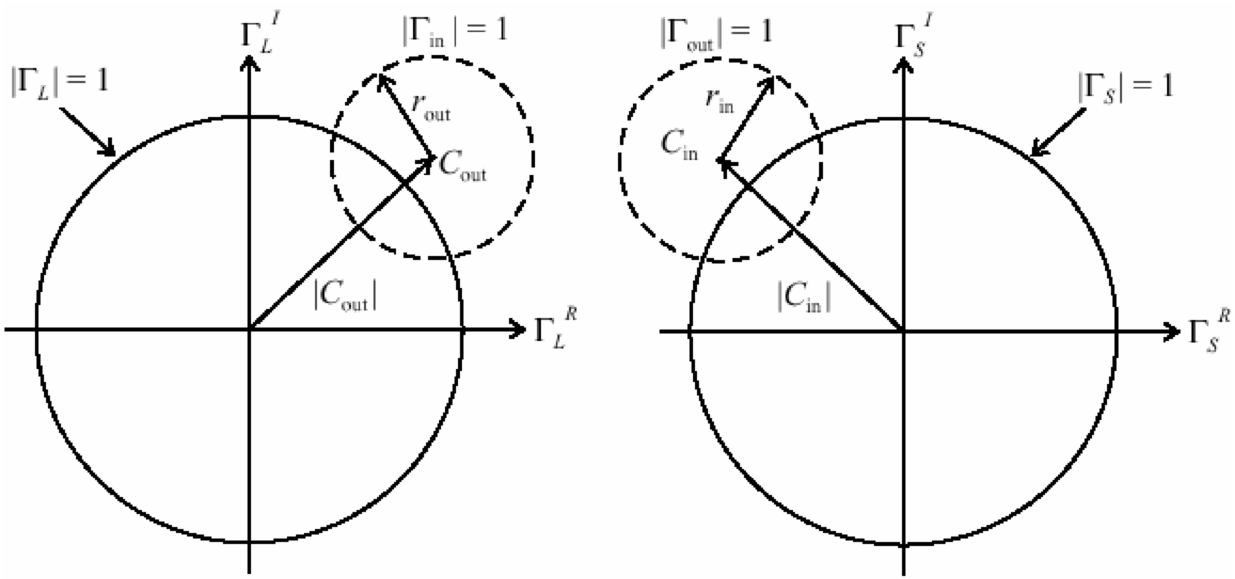
Input stability circle:

$$r_{in} = \frac{\left|S_{12}S_{21}\right|}{\left|\left|S_{11}{}^{2}\right| - \left|\Delta\right|^{2}\right|}, \quad C_{in} = \frac{\left(S_{11} - S_{22}^{*}\Delta\right)^{*}}{\left|S_{11}\right|^{2} - \left|\Delta\right|^{2}}$$

Stability Regions: Stability Circles

Where:

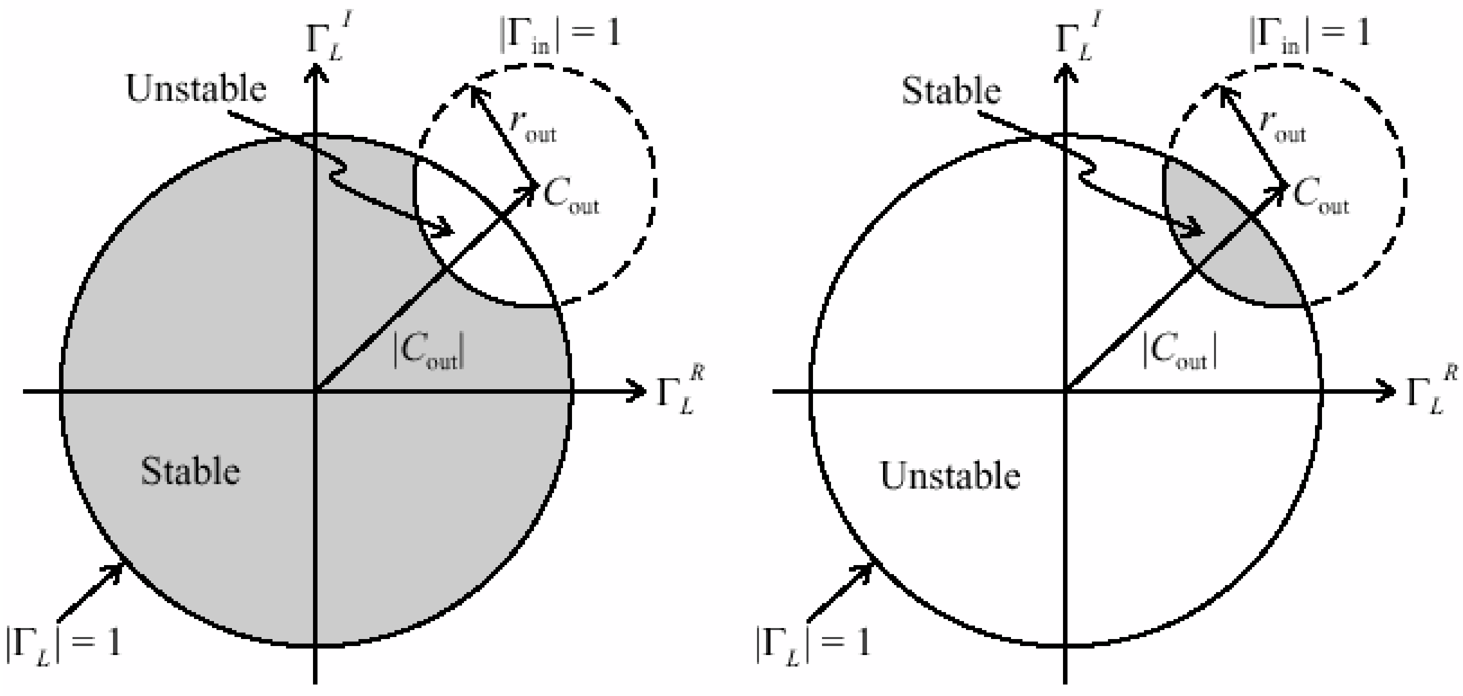
$$\Delta = S_{11}S_{22} - S_{12}S_{21}$$



(a) Output stability circle

(b) Input stability circle

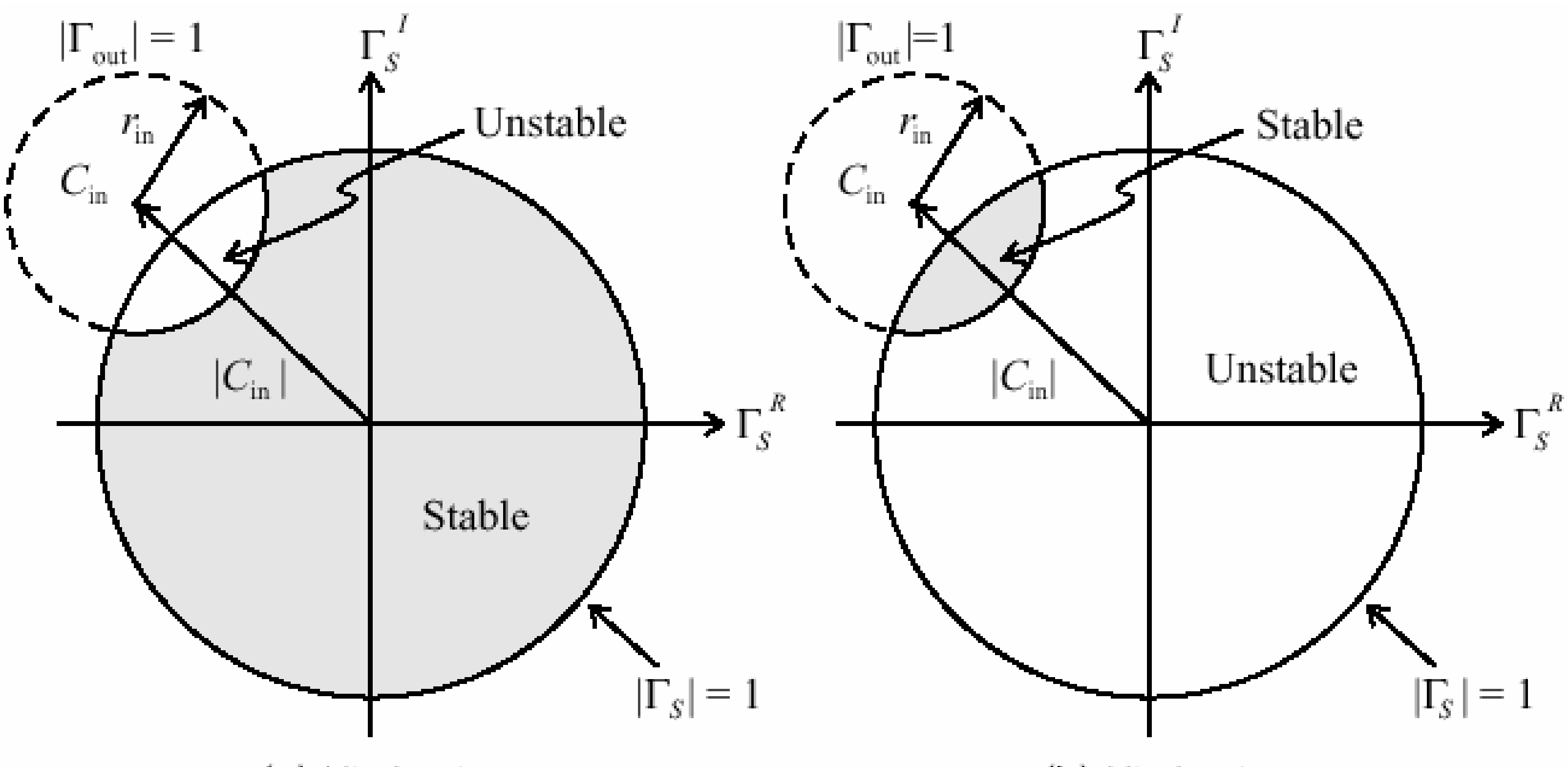
Stability Regions: Output Stability Circles



(a) Shaded region is stable, since $|S_{11}| < 1$

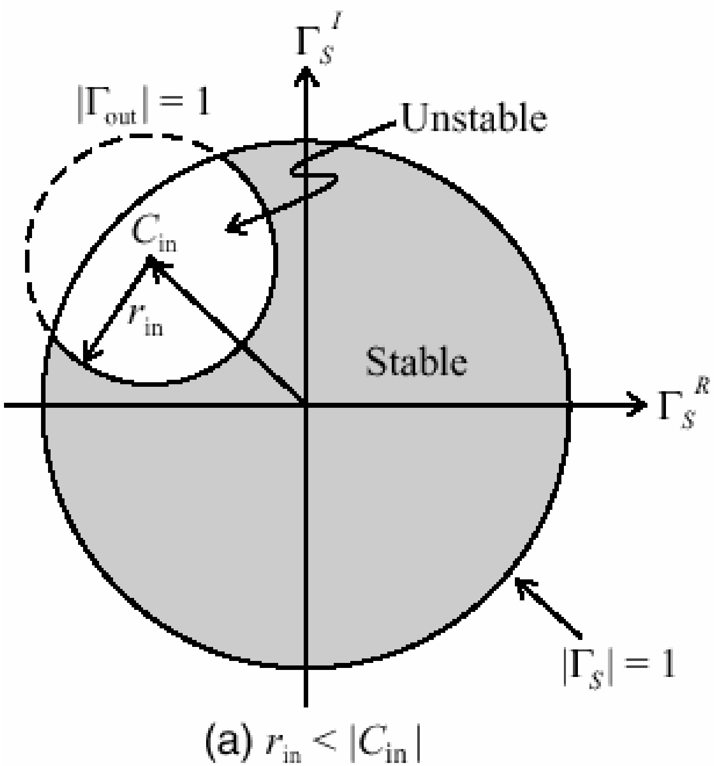
(a) Stable region excludes the origin, $\Gamma_L = 0$, since $|S_{11}| > 1$

Stability Regions: Input Stability Circles



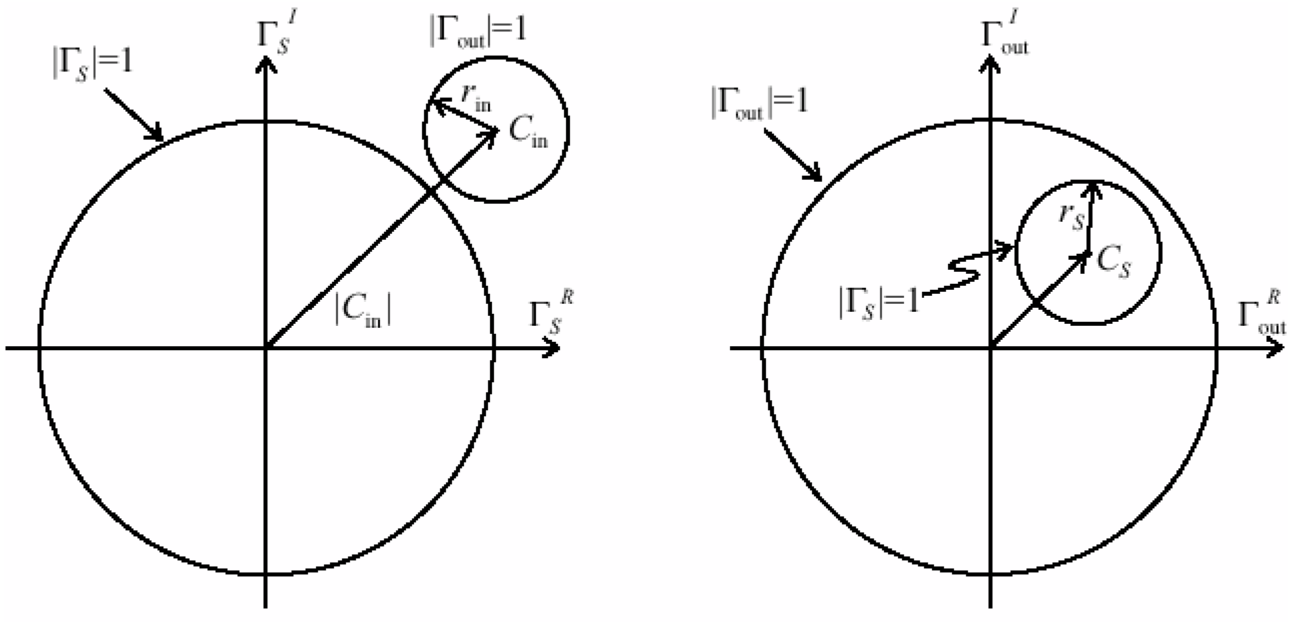
(a) $|S_{22}| < 1$ (b) $|S_{22}| > 1$

Different Input Stability Regions



Dependent on ratio between r_s and $|C_{in}|$

Unconditional Stability



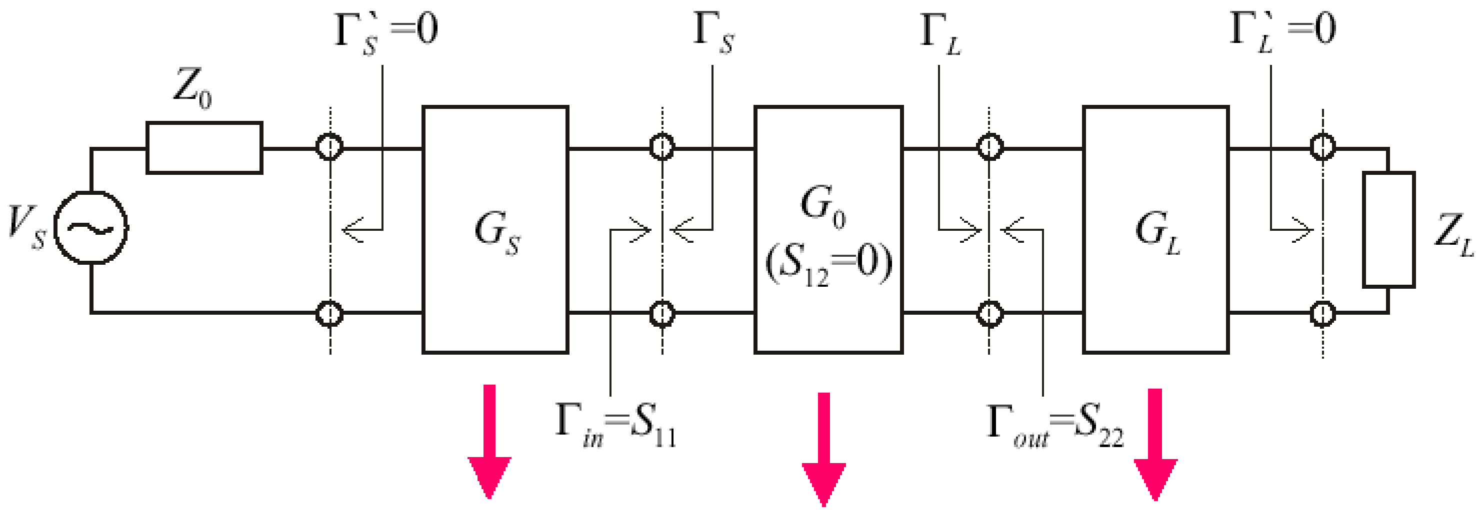
(a) $|\Gamma_{out}|$ = 1 circle must reside outside (b) $|\Gamma_S|$ = 1 circle must reside inside

Stability circles reside completely outside $|\Gamma_S| = 1$ and $|\Gamma_L| = 1$.

Rollet Factor:

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

Constant Gain Amplifier



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

$$\boxed{G_{TU}(dB) = G_S(dB) + G_0(dB) + G_L(dB)}$$

Constant Gain Circles in the Smith Chart

To obtain desired amplifier gain performance

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

normalize

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

$$\boxed{g_i = \frac{G_i}{G_{i\max}} = \frac{1-|\Gamma_i|^2}{|1-\Gamma_i S_{ii}|^2}(1-|S_{ii}|^2)}$$

This can be written as a circle equation

Circle Equation and Graphical Display

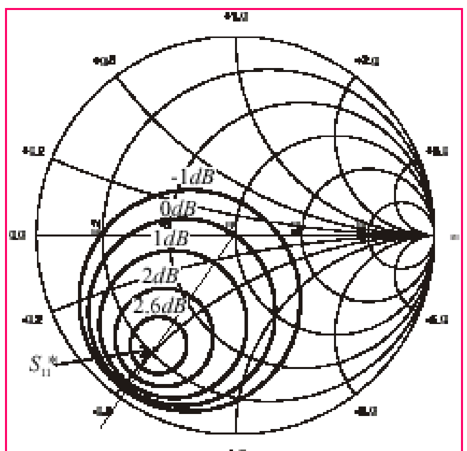
$$(\Gamma_i^R - d_{g_i}^R)^2 + (\Gamma_i^I - d_{g_i}^I)^2 = r_{g_i}^2$$

$$d_{g_i} = \frac{g_i S_{ii}^*}{1-|S_{ii}|^2(1-g_i)}$$

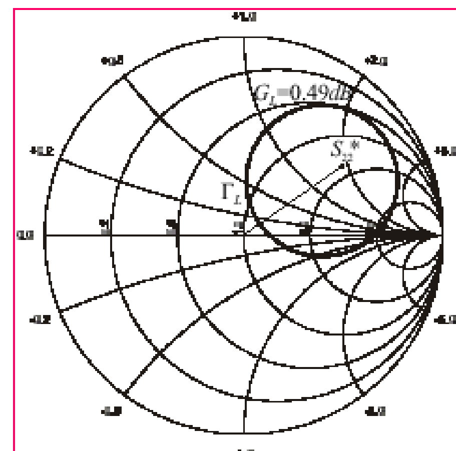
$$r_{g_i} = \frac{\sqrt{1-g_i}\,(1-|S_{ii}|^2)}{1-|S_{ii}|^2(1-g_i)}$$

Constant source gain circles

See Ex. 9.7



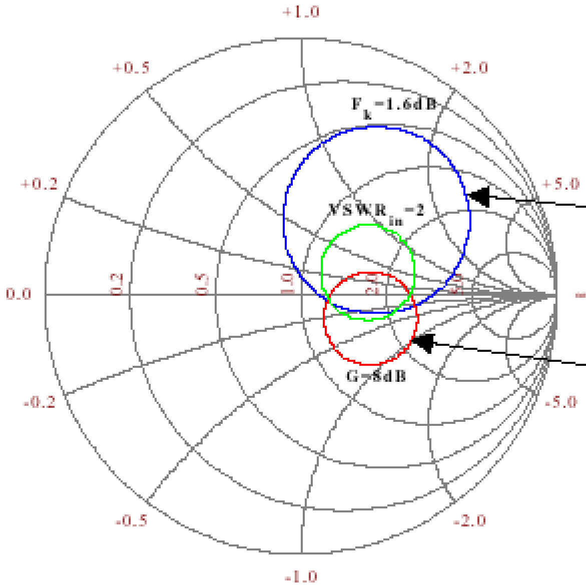
Constant load gain circle



Gain Circles

- Max gain Γ_{imax} =1/(1-$|S_{ii}|^2$) when $\Gamma_{\mathrm{i}} = S_{ii}^*$; gain circle center is at $d_{gi} = S_{ii}^*$ and radius r_{gi} =0
- Constant gain circles have centers on a line connecting origin to S_{ii}^*
- For special case $\Gamma_{\mathrm{i}} = 0$, $g_i = 1-|S_{ii}|^2$ and $d_{gi} = r_{gi} = |S_{ii}|/(1+|S_{ii}|^2)$ implying $\Gamma_{\mathrm{i}} = 1$ (0 dB) circle always passes through origin of Γ_{i} plane

Trade-off Between Gain and Noise



Maximum gain and minimum noise figure are mutually exclusive

Noise figure

Constant gain