8장 LNA 설계

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- Gain and Circles
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Gain & Circles

Thevenin Equivalent Circuit

Z_o; **Reference Impedance**

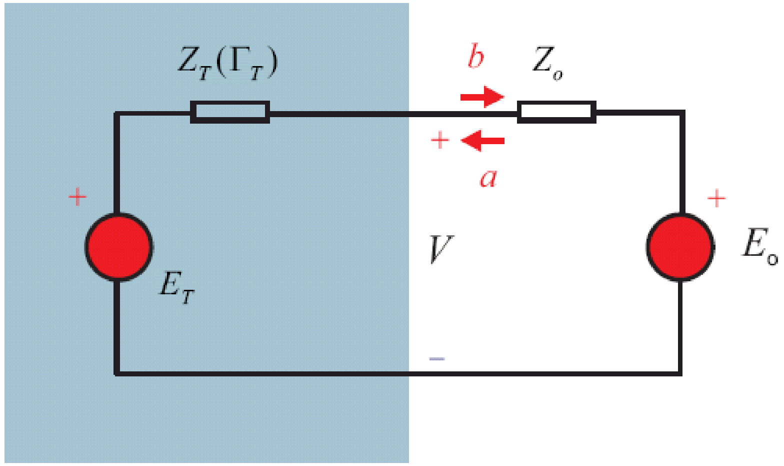
Superposition

$$V = E_o \frac{Z_T}{Z_o + Z_T} + E_T \frac{Z_o}{Z_o + Z_T} = V^+ + V^-$$

and $V^+ = \dfrac{E_o}{2}$

$$V^- = \frac{E_o}{2} \cdot \frac{Z_T - Z_o}{Z_T + Z_o} + E_T \frac{Z_o}{Z_o + Z_T}$$

$$= V^+ \Gamma_T + E_T \frac{Z_o}{Z_o + Z_T}$$



Hence

$$b = \frac{V^-}{\sqrt{2Z_o}} = \frac{V^+}{\sqrt{2Z_o}} \Gamma_T + \frac{E_T}{\sqrt{2Z_o}} \frac{Z_o}{Z_o + Z_T} = \Gamma_T a + b_T$$

where

$b_T = \dfrac{E_T}{\sqrt{2}} \dfrac{\sqrt{Z_o}}{Z_o + Z_T}$; **The normalized reflected voltage at the termination** Z_o

Γ_T; **The reflection coefficient with inner source killed**

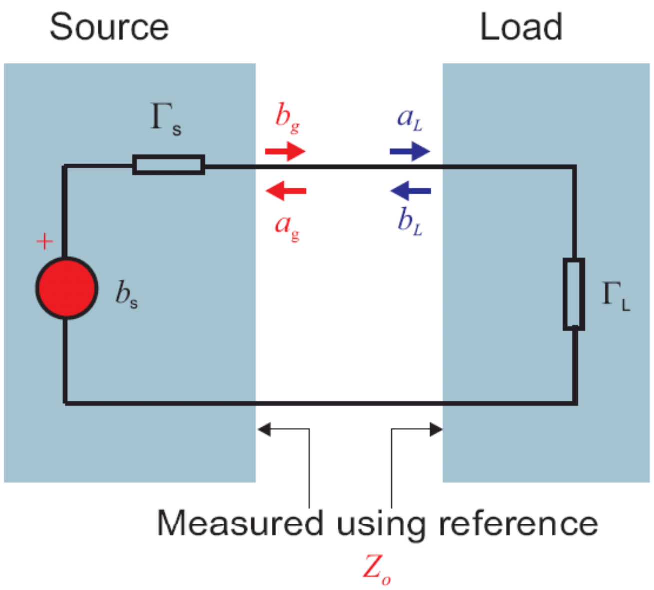
Power Relation

Q1; P_L **Delivered Power to load** Γ_L ?

$$P_L = |a_L|^2 - |b_L|^2 = |a_L|^2 (1 - |\Gamma_L|^2) \rightarrow a_L \ ?$$

Q2; P_A **Available Power from the source** ?

$$P_A = P_L\big|_{\Gamma_L = \Gamma_s^*}$$



From the circuit

$$b_L = \Gamma_L a_L; \qquad b_g = b_s + \Gamma_s a_g$$

and

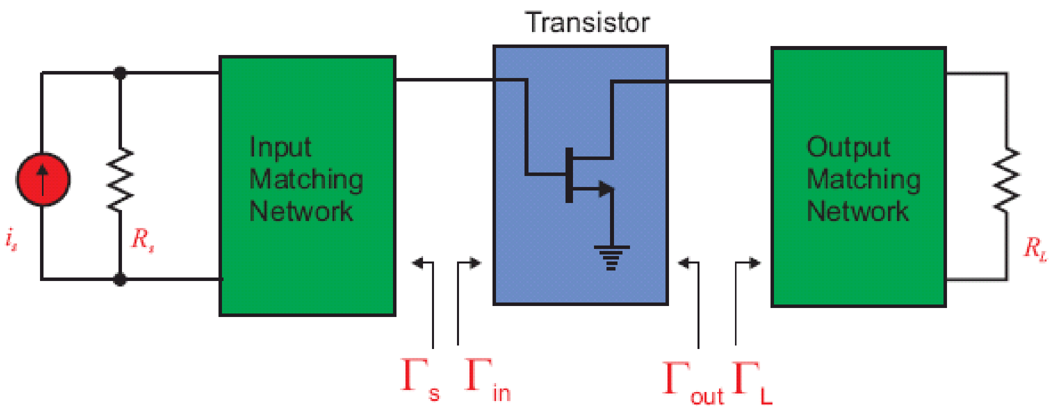
$$a_L = b_g = b_s + \Gamma_s a_g = b_s + \Gamma_s b_L = b_s + \Gamma_s \Gamma_L a_L$$

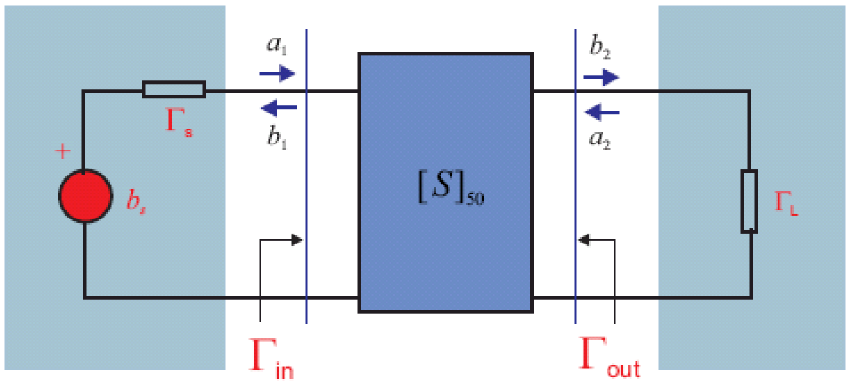
$$\rightarrow a_L = \frac{b_s}{1 - \Gamma_s \Gamma_L}$$

The Delivered Power; $\quad P_L = |a_L|^2 - |b_L|^2 = \dfrac{|b_s|^2 (1 - |\Gamma_L|^2)}{|1 - \Gamma_s \Gamma_L|^2}$

The Available Power by substituting $\Gamma_s = \Gamma_L^*$; $\quad P_A = \dfrac{|b_s|^2}{1 - |\Gamma_s|^2}$

Definitions of Reflection Coefficients





Γ_s; **Source (Impedance)**

Γ_L; **Load (Impedance)**

Γ_{in}; **Input (Impedance)**

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

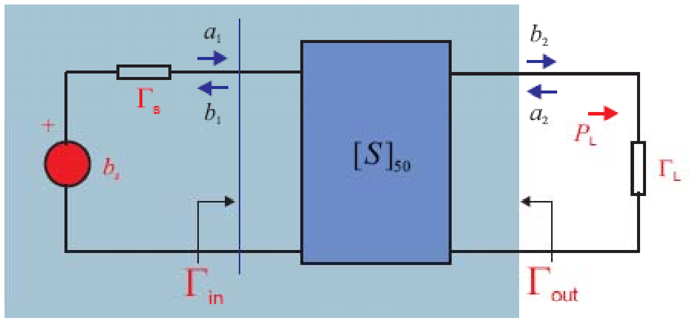
Γ_{out}; **Source (Impedance)**

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

Note; Input & Output matching networks are lossless

Transducer Power Gain

$$G_T = \frac{\textbf{Delivered Power to Load}}{\textbf{Available Power from source}} = \frac{P_L}{P_A}$$



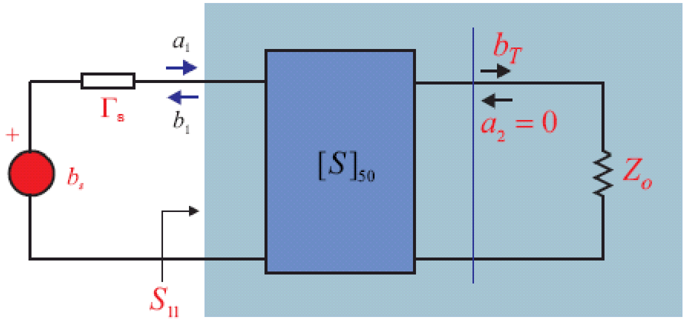
Note that

$$P_A = \frac{|b_s|^2}{1-|\Gamma_s|^2},$$

and Thevenin equivalent at the load

$$\Gamma_T = \Gamma_{out}$$

$$b_T = b_2|_{a_2=0} = S_{21}a_1 + S_{22}a_2 = S_{21}a_1 = S_{21}\frac{b_s}{1-S_{11}\Gamma_s}$$



G_T Continued

$$G_T = \frac{\textbf{Delivered Power to Load}}{\textbf{Available Power at Input}} = \frac{P_L}{P_A}$$

Available Power

$$P_A = \frac{|b_s|^2}{1-|\Gamma_s|^2},$$

Delivered Power

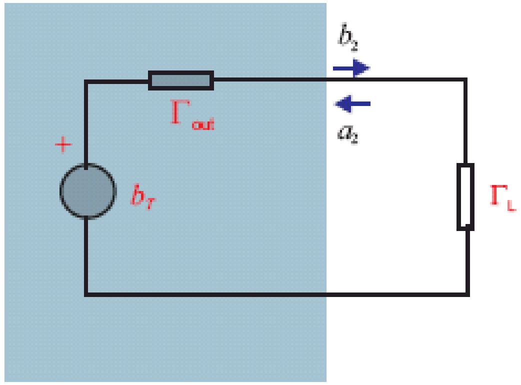
$$P_L = |b_2|^2 (1-|\Gamma_L|^2) = \frac{|b_T|^2 (1-|\Gamma_L|^2)}{|1-\Gamma_{out}\Gamma_L|^2}$$

$$= \frac{|b_s|^2 |S_{21}|^2 (1-|\Gamma_L|^2)}{|1-S_{11}\Gamma_s|^2 |1-\Gamma_{out}\Gamma_L|^2}$$

Therefore

$$G_T = \frac{P_L}{P_A} = \frac{(1-|\Gamma_s|^2)|S_{21}|^2 (1-|\Gamma_L|^2)}{|1-\Gamma_{out}\Gamma_L|^2 |1-S_{11}\Gamma_s|^2}$$

Thevenin Equivalent Circuit
at Load plane



Alternative Form of G_T

Note that

$$a_1 = \frac{b_s}{1-\Gamma_{in}\Gamma_s}, \; a_2 = \Gamma_L b_2$$

and

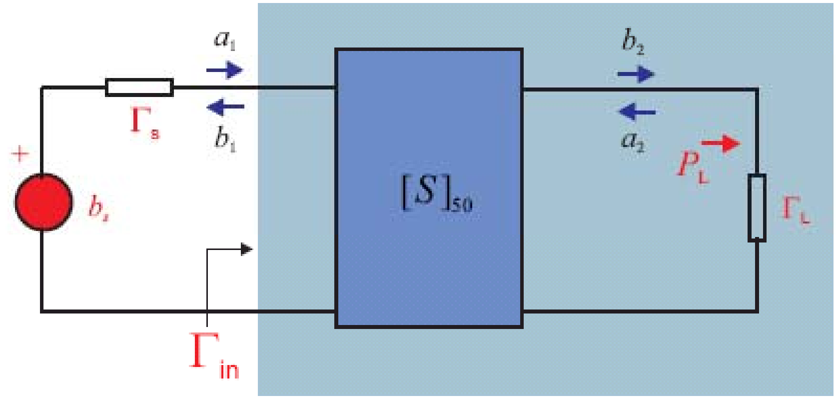
$$b_2 = S_{21}a_1 + S_{22}a_2 = S_{21}\frac{b_s}{1-\Gamma_{in}\Gamma_s} + S_{22}\Gamma_L b_2$$

Hence

$$b_2 = \frac{S_{21}b_s}{(1-\Gamma_{in}\Gamma_s)(1-S_{22}\Gamma_L)}$$

Therefore

$$G_T = \frac{P_L}{P_A} = \frac{|b_2|^2 - |a_2|^2}{\dfrac{|b_s|^2}{1-|\Gamma_s|^2}} = \frac{|b_2|^2(1-|\Gamma_L|^2)}{\dfrac{|b_s|^2}{1-|\Gamma_s|^2}} = \frac{(1-|\Gamma_s|^2)|S_{21}|^2(1-|\Gamma_L|^2)}{|1-\Gamma_{in}\Gamma_s|^2|1-S_{22}\Gamma_L|^2}$$



Available Power Gain

$$G_A \equiv \frac{\text{AvailablePower from load}}{\text{Available Power from source}} = \frac{P_{L,\max}}{P_A}$$

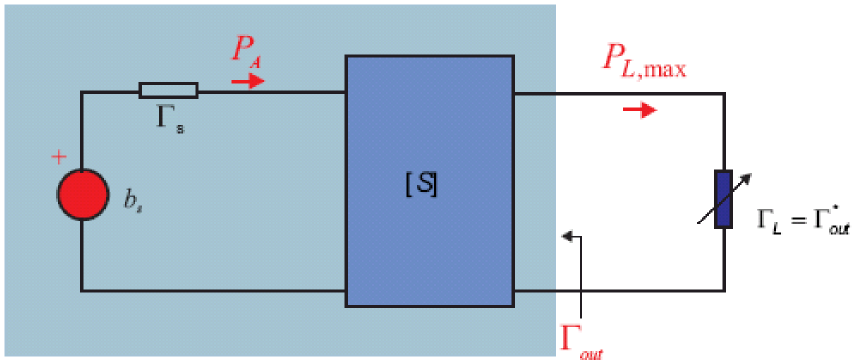
So from the Transducer Power Gain G_T, Available Power Gain when $\Gamma_L = \Gamma_{out}^*$

$$G_A = G_T\Big|_{\Gamma_L=\Gamma_{out}^*} = \frac{(1-|\Gamma_s|^2)|S_{21}|^2(1-|\Gamma_L|^2)}{|1-\Gamma_{out}\Gamma_L|^2|1-S_{11}\Gamma_s|^2}\Bigg|_{\Gamma_L=\Gamma_{out}^*} = \frac{(1-|\Gamma_s|^2)|S_{21}|^2}{|1-S_{11}\Gamma_s|^2(1-|\Gamma_{out}|^2)}$$

Therefore

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

It represents input mismatch by Γ_s



Available Power Gain Derivation

(Another Derivation of Available Power Gain)

Thevenin Representation at the output side

$$\frac{a_1}{b_s} = \frac{1}{1 - S_{11}\Gamma_s}$$

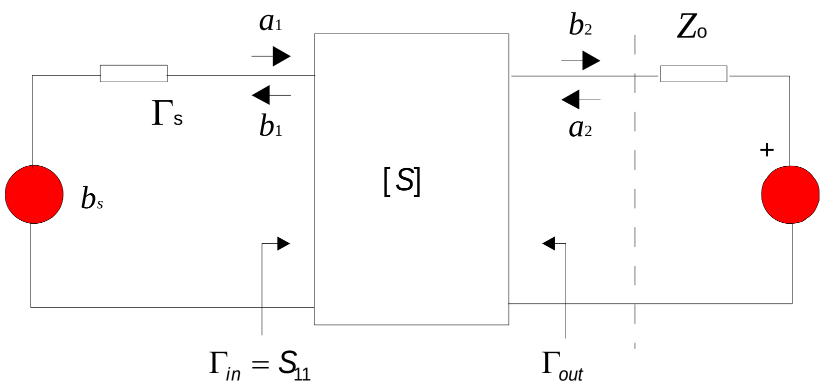
$$b_2 = S_{21}a_1 + \Gamma_{out}a_2 = S_{21}\frac{b_s}{1 - S_{11}\Gamma_s} + \Gamma_{out}a_2 = b_G + S_{22}a_2$$

Hence

$$P_{Ao} = \frac{|b_s|^2 |S_{21}|^2}{|1 - S_{11}\Gamma_s|^2 \,(1 - |\Gamma_{out}|^2)}, \text{ and } P_{Ai} = \frac{|b_s|^2}{1 - |\Gamma_s|^2}$$

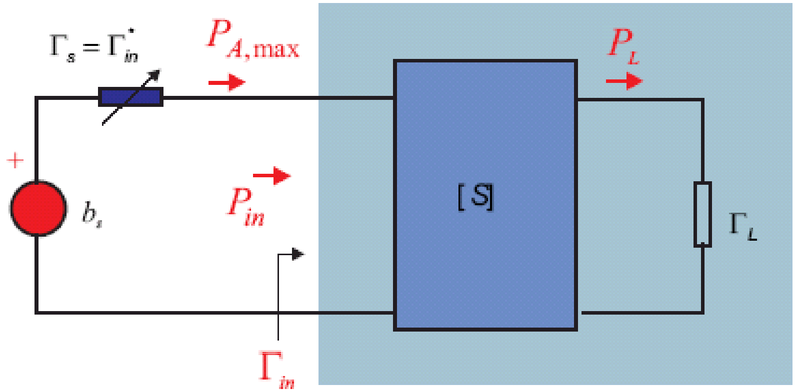
Therefore

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



Power Gain

$$G_p \equiv \frac{\textbf{Delivered Power to the Load}}{\textbf{Input Power at the Device Input}}$$



Input power

$$P_{in} = |a_1|^2 (1-|\Gamma_{in}|)^2 = \frac{|b_s|^2 (1-|\Gamma_{in}|)^2}{|1-\Gamma_{in}\Gamma_s|^2}$$

$$P_L = \frac{|b_s|^2 |S_{21}|^2 (1-|\Gamma_L|^2)}{|1-\Gamma_{in}\Gamma_s|^2 |1-S_{22}\Gamma_L|^2}$$

Hence

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

This is the Power gain from Transducer Power gain when $\Gamma_s = \Gamma_{in}^*$

$$G_p = G_T\big|_{\Gamma_s=\Gamma_{in}^*} = \left.\frac{(1-|\Gamma_s|^2)|S_{21}|^2 (1-|\Gamma_L|^2)}{|1-\Gamma_{in}\Gamma_s|^2 |1-S_{22}\Gamma_L|^2}\right|_{\Gamma_s=\Gamma_{in}^*} = \frac{|S_{21}|^2 (1-|\Gamma_L|^2)}{(1-|\Gamma_{in}|)^2 |1-S_{22}\Gamma_L|^2}$$

Therefore

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

It represent the output mismatch by Γ_L

Unilateral Gains

In Unilateral Case , ie $S_{12} = 0$, Transducer Power Gain becomes

$$G_{TU} = G_T\big|_{S_{12}=0} = \left.\frac{(1-|\Gamma_s|^2)|S_{21}|^2(1-|\Gamma_L|^2)}{|1-S_{11}\Gamma_s|^2|1-\Gamma_{out}\Gamma_L|^2}\right|_{S_{12}=0} = \frac{(1-|\Gamma_s|^2)|S_{21}|^2(1-|\Gamma_L|^2)}{|1-S_{11}\Gamma_s|^2|1-S_{22}\Gamma_L|^2}$$

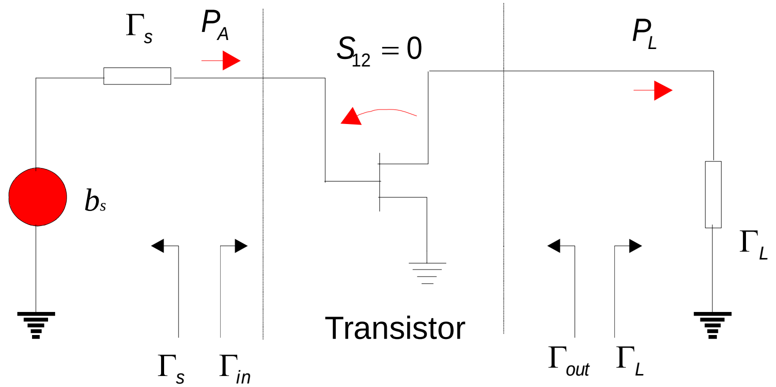
When conjugate match both the input and output

$$G_{TU,\max} = \frac{|S_{21}|^2}{(1-|S_{11}|^2)(1-|S_{22}|^2)}$$

In general, $S_{12} \neq 0$, $G_{TU,\max}$ becomes Mason's Gain U

$$U = \frac{\left|\frac{S_{21}}{S_{12}} - 1\right|^2}{2k\left|\frac{S_{21}}{S_{12}}\right| - 2\,\mathrm{Re}\left(\frac{S_{21}}{S_{12}}\right)}$$

This is used as the device Passivity and Activity



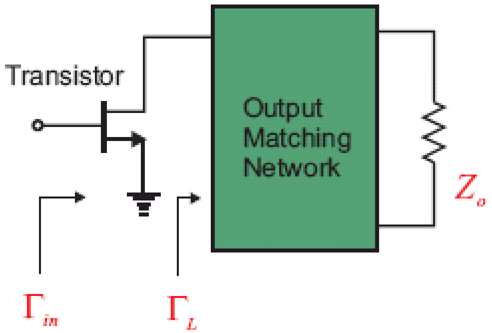
Load Stability Circle

Q; Input impedance $\rightarrow$ negative for some $\Gamma_L \rightarrow |\Gamma_{in}| > 1$

The region of Γ_L ? $\rightarrow |\Gamma_{in}| < 1$

Load Stability Circle;

the locus of Γ_L which makes $|\Gamma_{in}| = 1$



From $\Gamma_{in} = S_{11} + \dfrac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L}$

$$\Gamma_L = \frac{\Gamma_{in} - S_{11}}{S_{22}\Gamma_{in} - D} = \frac{1}{S_{22}} + \frac{D/S_{22} - S_{11}}{S_{22}\Gamma_{in} - D}$$

where

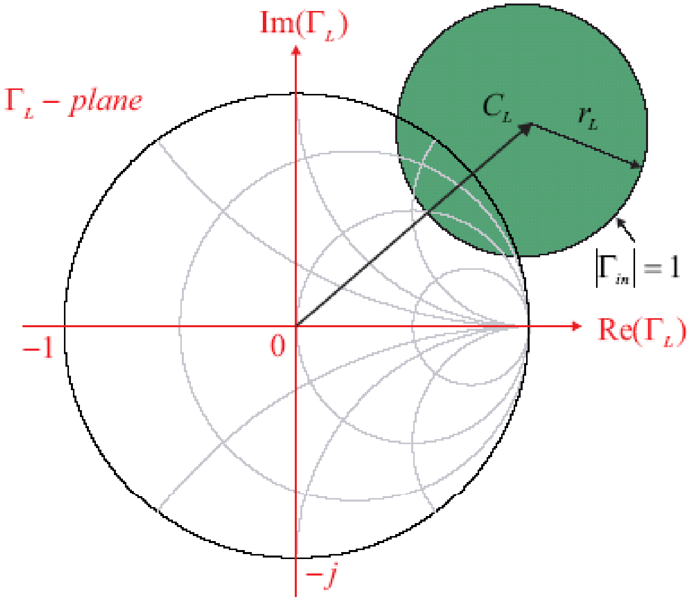
$$D = S_{11}S_{22} - S_{21}S_{12}$$

Center C_L and Radius r_L

$$C_L = \frac{S_{22}^* - D^* S_{11}}{|S_{22}|^2 - |D|^2}, \text{ and } \quad r_L = \frac{|S_{12}S_{21}|}{\left||S_{22}|^2 - |D|^2\right|}$$

Stable Region

$\begin{cases} |S_{11}| < 1 \\ \text{Outside the Circle} \end{cases}$ **or** $\begin{cases} |S_{11}| > 1 \\ \text{Inside the Circle} \end{cases}$



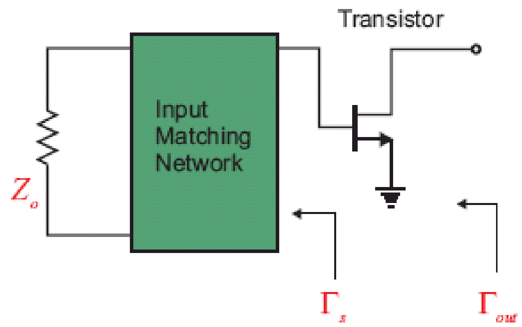
Source Stability Circle

Q; Output impedance $\rightarrow$ negative for some $\Gamma_s \rightarrow |\Gamma_{out}| > 1$

The region of Γ_s ? $\rightarrow |\Gamma_{out}| < 1$

Source Stability Circle;

the locus of Γ_s which makes $|\Gamma_{out}| = 1$



From $\Gamma_{out} = S_{22} + \dfrac{S_{12}S_{21}\Gamma_s}{1 - S_{22}\Gamma_s}$

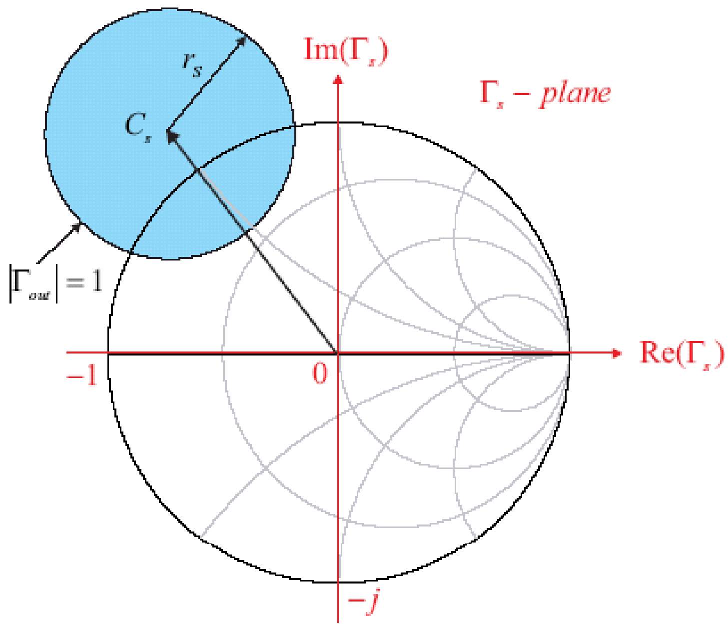
Changing 1$\rightarrow$2; Source stability circle

Center C_L and Radius r_L

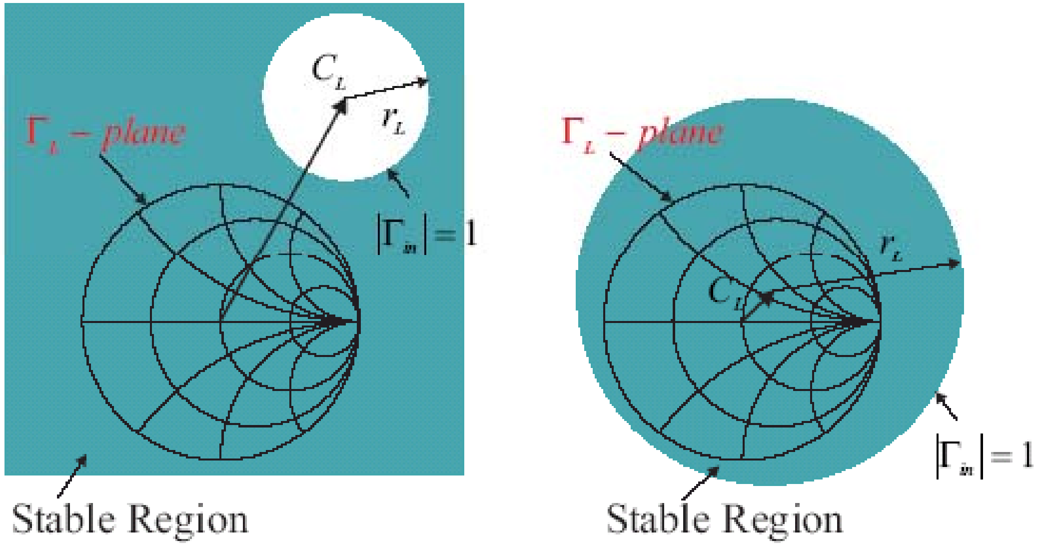
$$C_s = \frac{S_{11}^* - D^* S_{22}}{|S_{11}|^2 - |D|^2}, \quad \textbf{and} \quad r_s = \frac{|S_{12}S_{21}|}{\left||S_{11}|^2 - |D|^2\right|}$$

Stable Region

$\begin{cases} |S_{22}| < 1 \\ \textbf{Outside the Circle} \end{cases}$ **or** $\begin{cases} |S_{22}| > 1 \\ \textbf{Inside the Circle} \end{cases}$



Unconditional Stability Condition



The Necessary and Sufficient Condition for Stability

$$|S_{11}| < 1, \quad \begin{cases} |C_L| - r_L > 1 \\ or \\ r_L - |C_L| > 1 \end{cases}, \quad \textbf{and} \quad |S_{22}| < 1, \quad \begin{cases} |C_s| - r_s > 1 \\ or \\ r_s - |C_s| > 1 \end{cases}$$

Then

Stability Factor; $k = \dfrac{1 - |S_{22}|^2 - |S_{11}|^2 + |D|^2}{2|S_{12}S_{21}|} > 1, \quad |S_{12}S_{21}| < 1 - |S_{22}|^2$, **and** $|S_{12}S_{21}| < 1 - |S_{11}|^2$

Conjugate Match & MAG (Maximum Available Gain)

In Stable Case, Maximum Gain occurs at Simultaneous Conjugate Match

$$\Gamma_s^* = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L}, \quad \Gamma_L^* = S_{22} + \frac{S_{12}S_{21}\Gamma_s}{1 - S_{11}\Gamma_s}$$

These are Simulatneous Equations and Meaningful solutions

$$\Gamma_{sM} = \frac{C_1^*}{|C_1|}\left[\frac{B_1}{2|C_1|} - \sqrt{\frac{B_1^2}{4|C_1|^2} - 1}\right], \quad \textbf{and} \quad \Gamma_{LM} = \frac{C_2^*}{|C_2|}\left[\frac{B_2}{2|C_2|} - \sqrt{\frac{B_2^2}{4|C_2|^2} - 1}\right]$$

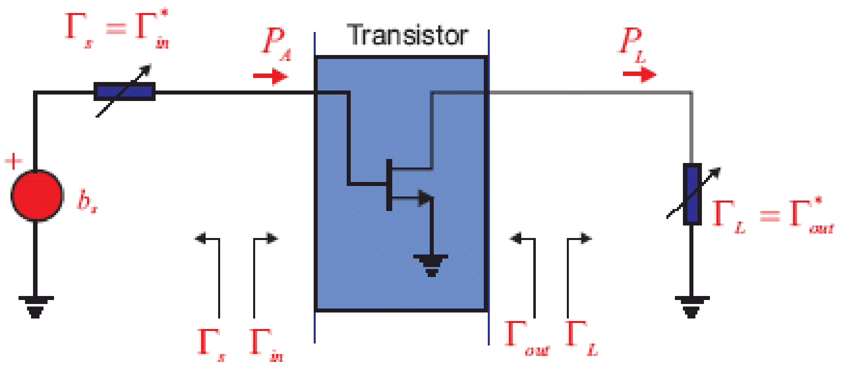
where

$$C_1 = S_{11} - DS_{22}^*, \quad C_2 = S_{22} - DS_{11}^*, \quad B_1 = 1 - |S_{22}|^2 + |S_{11}|^2 - |D|^2, \quad B_2 = 1 - |S_{11}|^2 + |S_{22}|^2 - |D|^2$$

$$D = S_{11}S_{22} - S_{12}S_{21}$$

and the gain becomes maximum

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



MSG (Maximum Stable Gain)

For stable condition

$$MAG(\textbf{Maximum Available Gain}) = G_{\max} = \left|\frac{S_{21}}{S_{12}}\right|(k - \sqrt{k^2 - 1})$$

When the device is unstable, the power Gain attainable is equal to

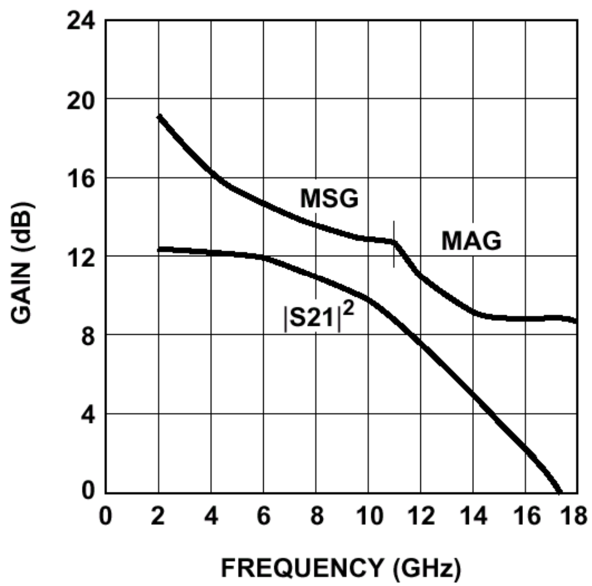
$$MSG(\textbf{Maximum Stable Gain}) = MAG\big|_{k=1} = \left|\frac{S_{21}}{S_{12}}\right|$$

Note

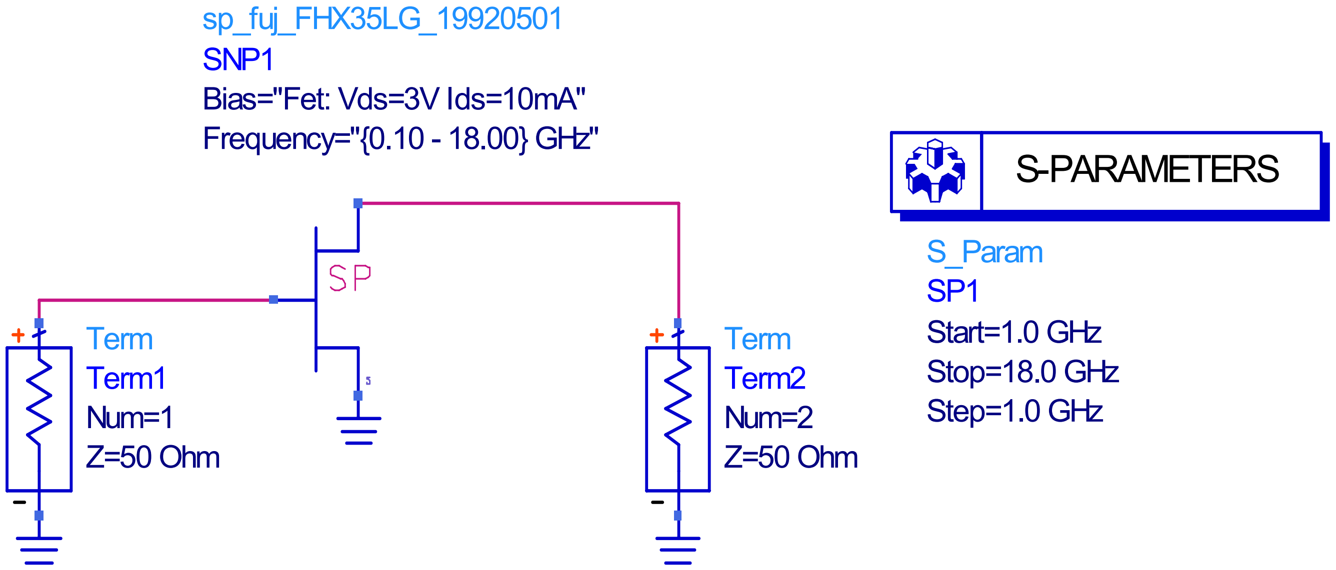
1. MSG and MAG is Power Gains

2. MSG or MAG are maximum Power Gain obtainable from devices

3. MSG can be obtained when $k = 1$



ADS Example(Ex 8.3)

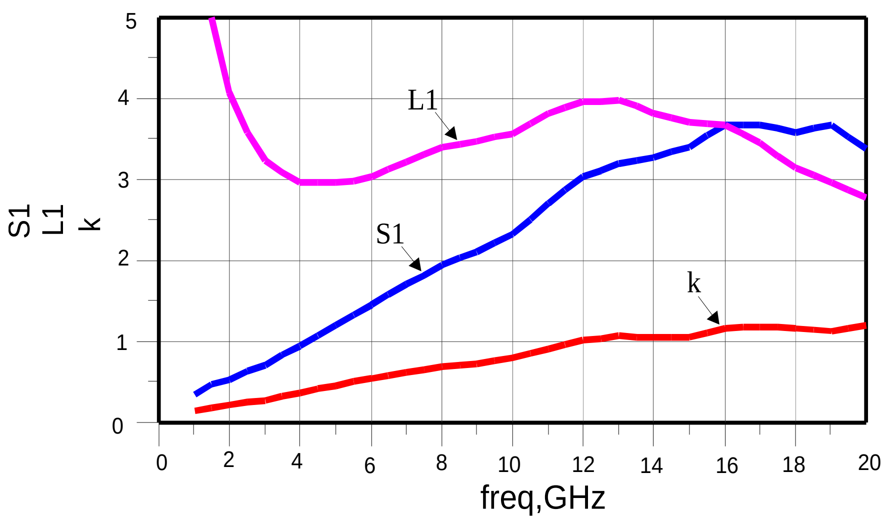


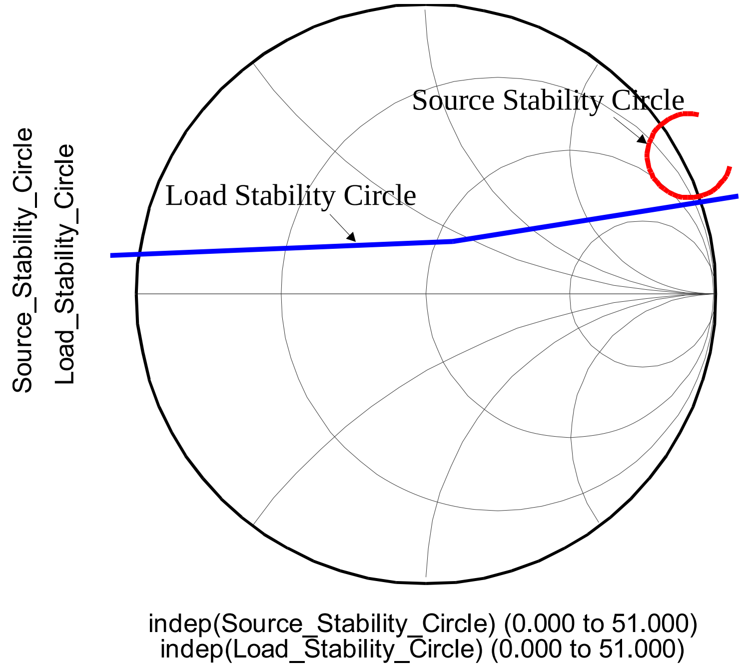
Plot $\frac{1-|S_{11}|^2}{|S_{12}S_{21}|}, \frac{1-|S_{22}|^2}{|S_{12}S_{21}|}$, and k. Draw Load and Source stability circles at 1GHz

ADS Example(Ex 8.3)

K=stab_fact(S), S1=(1-mag(S11))**2/mag(S12*S21), S1=(1-mag(S11))**2/mag(S12*S21)

Source_stability_Circle=s_stab_circle(S[0],51)
Load_stability_Circle=l_stab_circle(S[0],51)





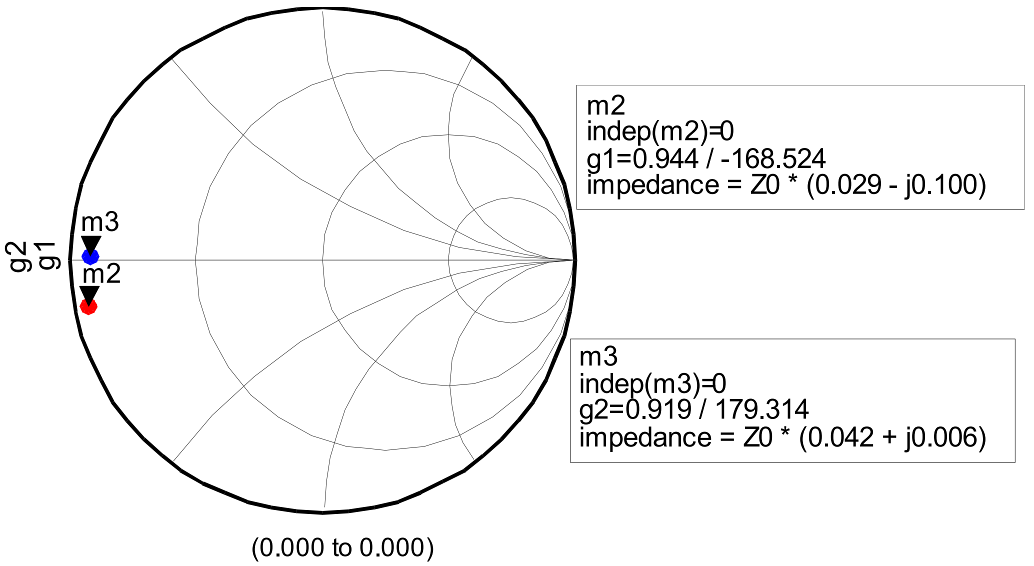
ADS Example(Ex 8.4)

For the S-parameters in ex8-2 Plot max gain and conjugate matching points at 12 GHz

Eqn m=find_index(freq, 12G)

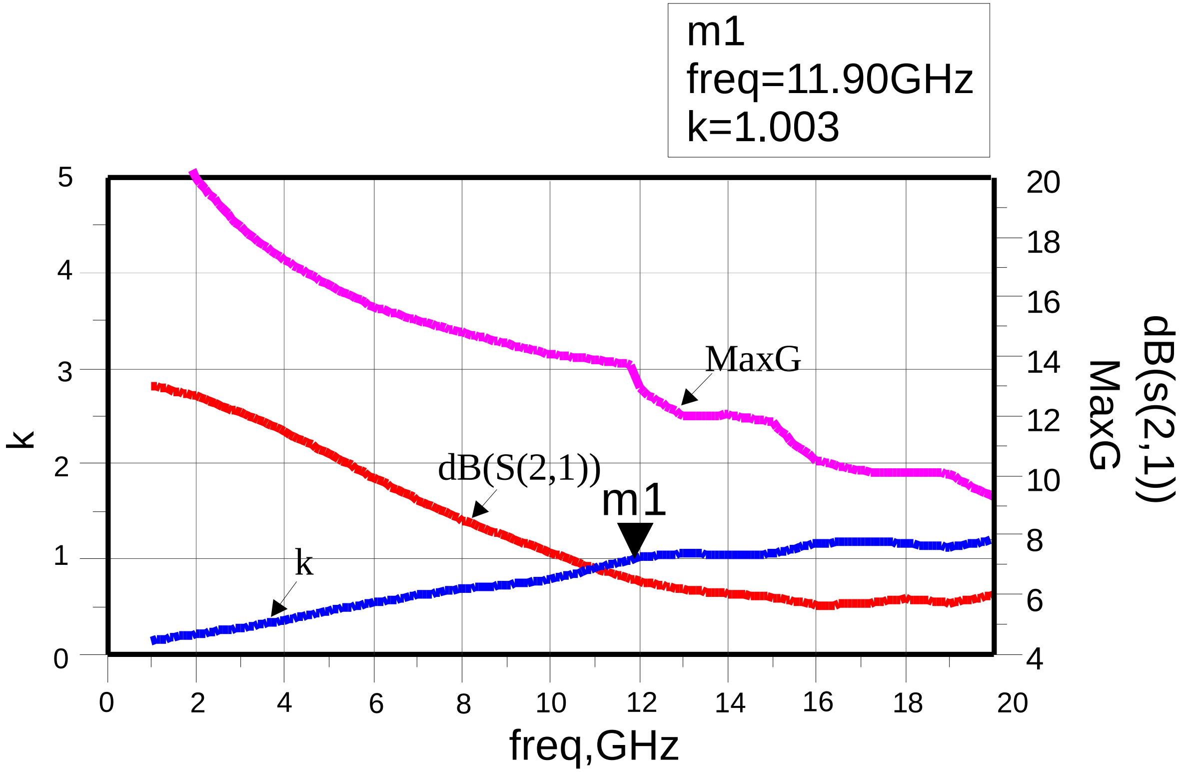
Eqn g1=sm_gamma1(S[m])

Eqn g2=sm_gamma2(S[m])



ADS Example(Ex 8.4)

Eqn MaxG=max_gain(S)



Available Gain Circles

Q: Choice of Γ_s $\rightarrow$ Not Γ_{sM} $\rightarrow$ But $\Gamma_L = (\Gamma_{out})^*$ $\rightarrow$ Gain Degradation?
$\rightarrow$ The locus of Γ_s giving the equal gain degradation

From Available Gain

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

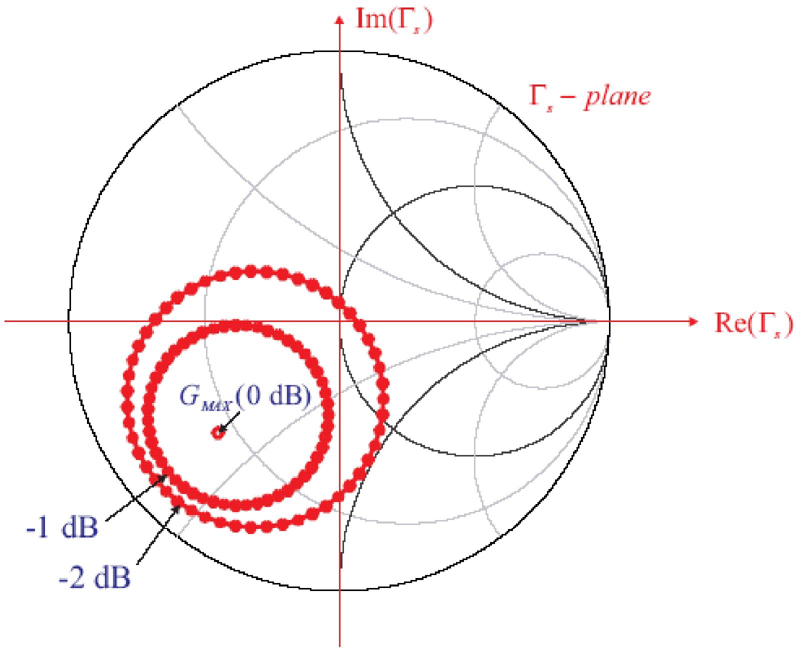
where g_a normalized gain by $|S_{21}|^2$ and

$$g_{a,\max} = \frac{k-\sqrt{k^2-1}}{|S_{21}S_{12}|}$$

The Center and Radius

$$C_A = \frac{g_a(S_{11}^* - D^*S_{22})}{1+g_a(|S_{11}|^2 - |D|^2)}$$

$$r_A = \frac{\sqrt{1-2k\,|S_{12}S_{21}|\,g_a + |S_{12}S_{21}|^2 g_a^2}}{|1+g_a(|S_{11}|^2-|D|^2)|}$$



Note: **It represents the gain degradation by the Source Mismatch**

Power Gain Circles

Q: Choice of Γ_L $\rightarrow$ Not Γ_{LM} $\rightarrow$ But $\Gamma_s = (\Gamma_{in})^*$ $\rightarrow$ Gain Degradation?
$\rightarrow$ The locus of Γ_L giving the equal gain degradation

From Power Gain

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

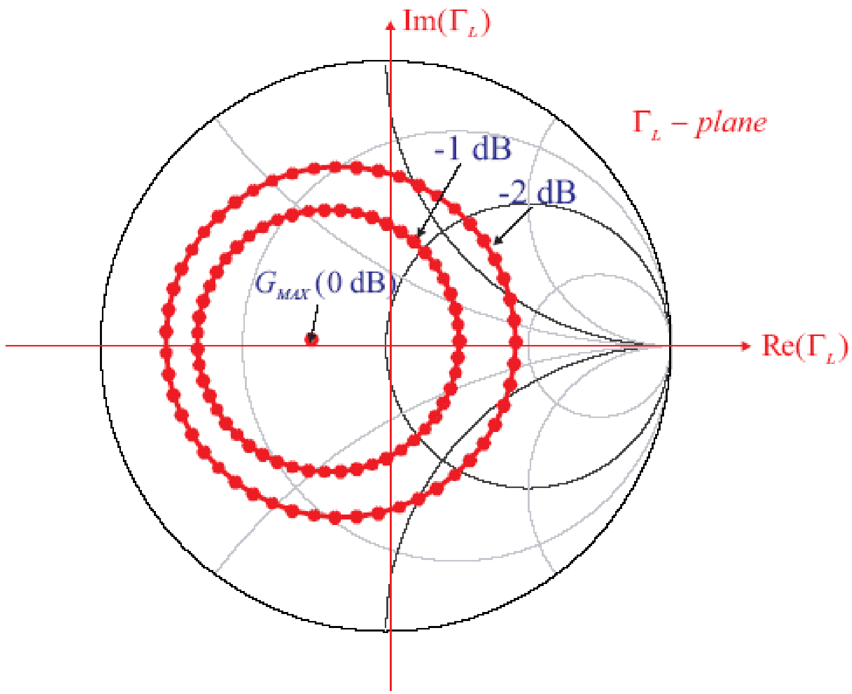
as g_a, where g_p normalized gain by $|S_{21}|^2$ and

$$g_{p,\max} = \frac{k-\sqrt{k^2-1}}{|S_{21}S_{12}|}$$

The Center and Radius by changing C_A, r_A 1→2

$$C_p = \frac{g_p(S_{22}^* - D^* S_{11})}{1+g_p(|S_{22}|^2-|D|^2)}$$

$$r_p = \frac{\sqrt{1-2k\,|S_{12}S_{21}|\,g_p + |S_{12}S_{21}|^2 g_p^2}}{|1+g_p(|S_{22}|^2-|D|^2)|}$$



Note: **It represents the gain degradation by the Load Mismatch**

Noise Figure & Noise Parameters

Ref) G. Gonzalez, *Microwave Transistor Amplifier*, **2nd Edition, Prentice Hall**

$$F = \frac{\text{Actual noise power output}}{\text{Power output due to source noise}} = \frac{P_{no}}{P_{ns}}$$

$$= F_{\min} + \frac{R_n}{G_s}\left|Y_s - Y_{opt}\right|^2$$

where

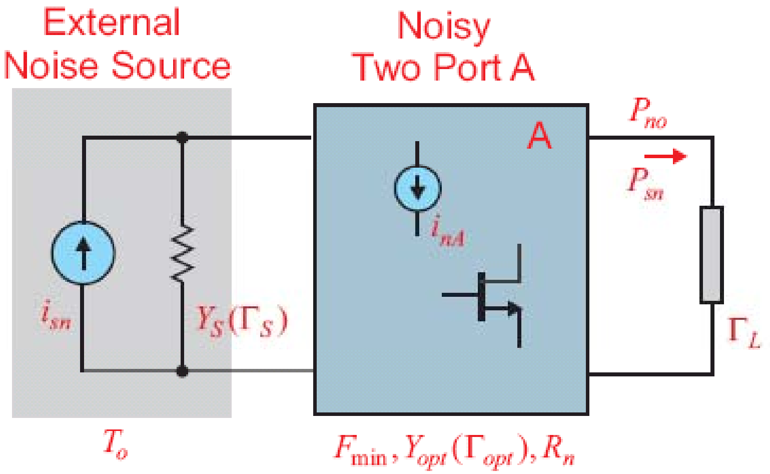
$Y_s = G_s + jB_s$, **and** $Y_{opt} = G_{opt} + jB_{opt}$

Noise parameters

$R_n(\omega)$; **Noise resistance**

$Y_{opt}(\omega)$; **Optimum Source Admittance**

$F_{\min}$; **Min. Noise Figure**



Rearranging

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

$$\leftarrow Y_s = \frac{1}{Z_o}\cdot\frac{1-\Gamma_s}{1+\Gamma_s},\quad Y_{opt} = \frac{1}{Z_o}\cdot\frac{1-\Gamma_{opt}}{1+\Gamma_{opt}},\quad \text{and } r_n = \frac{R_n}{Z_o},$$

Noise Circles

Q; Choice of $\Gamma_s \rightarrow$ Not $\Gamma_{opt} \rightarrow$ NF degradation from $F_{\min}$

$\rightarrow$ The locus of Γ_s giving the equal degradation of NF

From

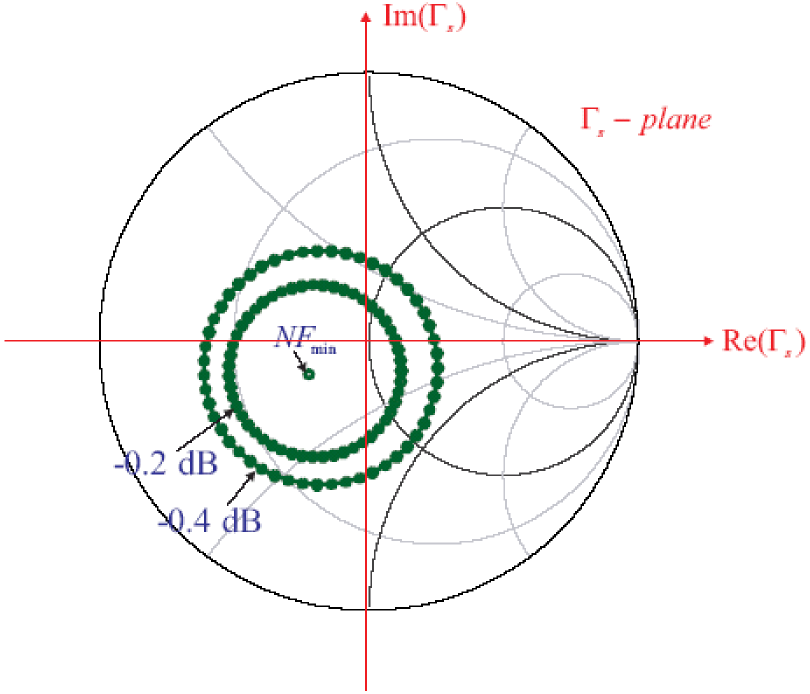
$$F = F_{\min} + \frac{4r_n \left|\Gamma_s - \Gamma_{opt}\right|^2}{(1-\left|\Gamma_s\right|^2)\left|1+\Gamma_{opt}\right|^2}$$

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

The center & Radius

$$C_F = \frac{\Gamma_{opt}}{1+N_i},$$

$$R_F = \frac{1}{N_i+1}\sqrt{N_i^2 + N_i(1-\left|\Gamma_{opt}\right|^2)}$$



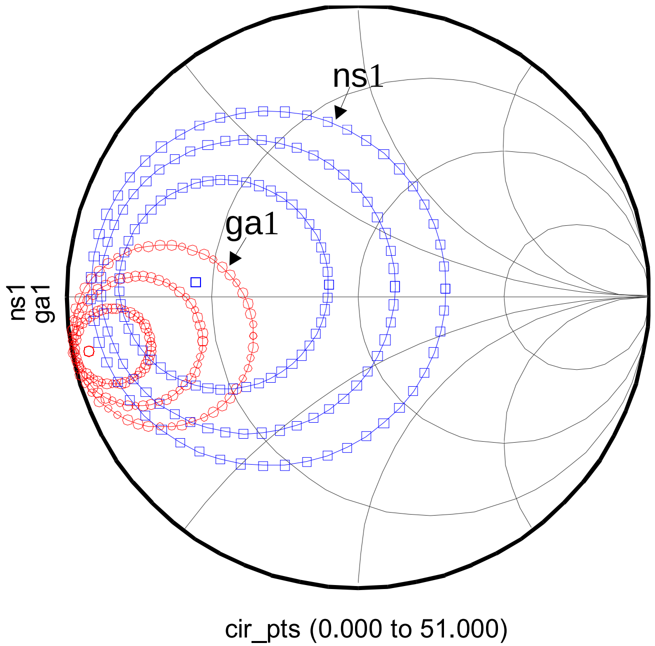
It represents the NF degradation caused by Γ_s

ADS Example(Ex 8.4)

For the S-parameters in ex8-2 Plot Available gain and noise circles at 12 GHz

Eqn ga1=ga_circle(S[m])

Eqn ns1=ns_circle({0, 1,2,3}+NFmin[m], NFmin[m], Sopt[m], Rn[m]/50, 51)



Gain Summary

Transducer power gain in 50-ohm	$G_T = \|S_{21}\|^2$
Transducer power Gain	$G_T = \dfrac{(1-\|\Gamma_L\|^2)\|S_{21}\|^2(1-\|\Gamma_s\|^2)}{\|(1-S_{22}\Gamma_L)(1-S_{11}\Gamma_s)-S_{12}S_{21}\Gamma_L\Gamma_s\|^2}$
Power Gain(Output mismatch)	$G_p = \dfrac{(1-\|\Gamma_L\|^2)\|S_{21}\|^2}{\|1-S_{22}\Gamma_L\|^2(1-\|\Gamma_{in}\|^2)}$
Available power Gain (Input Mismatch)	$G_A = \dfrac{P_{Ao}}{P_{Ai}} = \dfrac{(1-\|\Gamma_s\|^2)\|S_{21}\|^2}{\|1-S_{11}\Gamma_s\|^2(1-\|\Gamma_{out}\|^2)}$
Mason's unilateral Gain (Passivity and Activity)	$U = \dfrac{\|S_{21}/S_{12}-1\|^2}{2k\|S_{21}/S_{12}\|-2\,\mathrm{Re}(S_{21}/S_{12})}$
Maximum Unilateral Power gain (Approximation)	$G_{TUmax} = \dfrac{\|S_{21}\|^2}{(1-\|S_{22}\|^2)(1-\|S_{11}\|^2)}$
Maximum Stable gain	$G_{ms} = \left\|\dfrac{S_{21}}{S_{12}}\right\|$
Maximum Available gain	$G_{ma} = \left\|\dfrac{S_{21}}{S_{12}}\right\|(k-\sqrt{k^2-1})$

Circles Summary

Circles	Center	Radius
Available Gain	$C_A = \frac{g_a(S_{11}^* - D^* S_{22})}{1 + g_a(\|S_{11}\|^2 - \|D\|^2)}$	$r_A = \frac{\sqrt{1 - 2k\|S_{12}S_{21}\|g_a + \|S_{12}S_{21}\|^2 g_a^2}}{\|1 + g_a(\|S_{11}\|^2 - \|D\|^2)\|}$
Power Gain	$C_p = \frac{g_p(S_{22}^* - D^* S_{11})}{1 + g_p(\|S_{22}\|^2 - \|D\|^2)}$	$r_p = \frac{\sqrt{1 - 2k\|S_{12}S_{21}\|g_p + \|S_{12}S_{21}\|^2 g_p^2}}{\|1 + g_p(\|S_{22}\|^2 - \|D\|^2)\|}$
Noise Mismatch	$C_F = \frac{\Gamma_{opt}}{1 + N_i}$	$r_F = \frac{\sqrt{N_i^2 + N_i(1 - \|\Gamma_{opt}\|^2)}}{(1 + N_i)}$
Input Stability	$C_s = \frac{S_{11}^* - D^* S_{22}}{\|S_{11}\|^2 - \|D\|^2}$	$r_s = \frac{\|S_{12}S_{21}\|}{\|\|S_{11}\|^2 - \|D\|^2\|}$
Output Stability	$C_L = \frac{S_{22}^* - D^* S_{11}}{\|S_{22}\|^2 - \|D\|^2}$	$r_L = \frac{\|S_{12}S_{21}\|}{\|\|S_{22}\|^2 - \|D\|^2\|}$

$$g_a = \frac{G_A}{|S_{21}|^2}, \quad g_p = \frac{G_p}{|S_{21}|^2}, \text{ and } \quad k = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |D|^2}{2|S_{12}S_{21}|}$$

Summary & Reference

- Gains→Transducer Power Gain, Available Power Gain, Power Gain

  Circles →Available Gain Circle, Power Gain Circle

  Load and Source Stability Circles

- NF, Noise Circles

- Reference

G. Gonzalez, *Microwave Transistor Amplifier*, 2nd Edition, Prentice Hall

Lab 7-2

- 2SC4226의 S-parameter를 측정하고(100MHz-1GHz) Stability를 확인한 후 이의 Input, output conjugate Matching impedance 및 MSG, MAG를 plot 하시오

Lab 7-3

- 2SC4226의 Available Gain Circle 및 noise Circle Stability circle을 그리시오

Lab 7-4

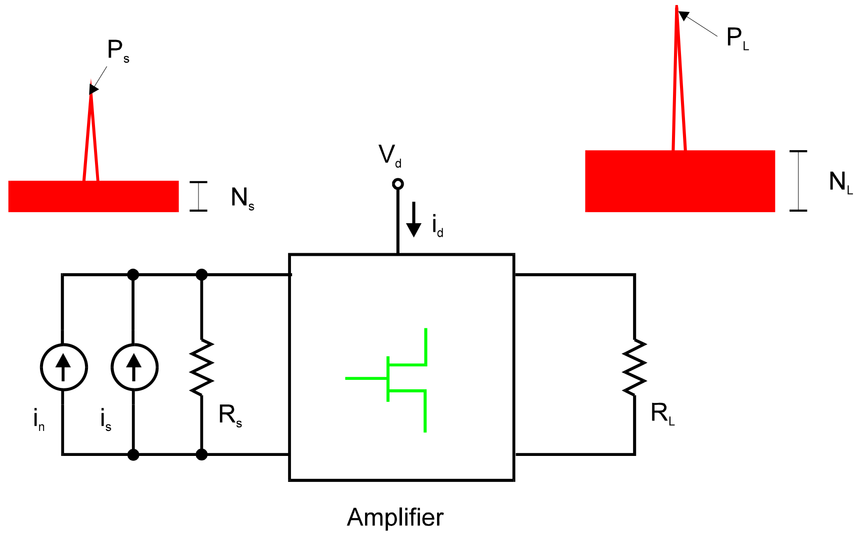
- 강의에 보인 2SC4226의 5V, 30mA bias를 15V 전원을 이용한 active bias 회로를 설계하고 이를 ADS를 이용 확인하시오.
- (pnp TR 2N2907)

LNA Design

Contents

- Problem
- Design with ADS
  - Lumped Design
  - Distributed Design Examples
- Conclusion and reference

Amplifier in Noisy Environment



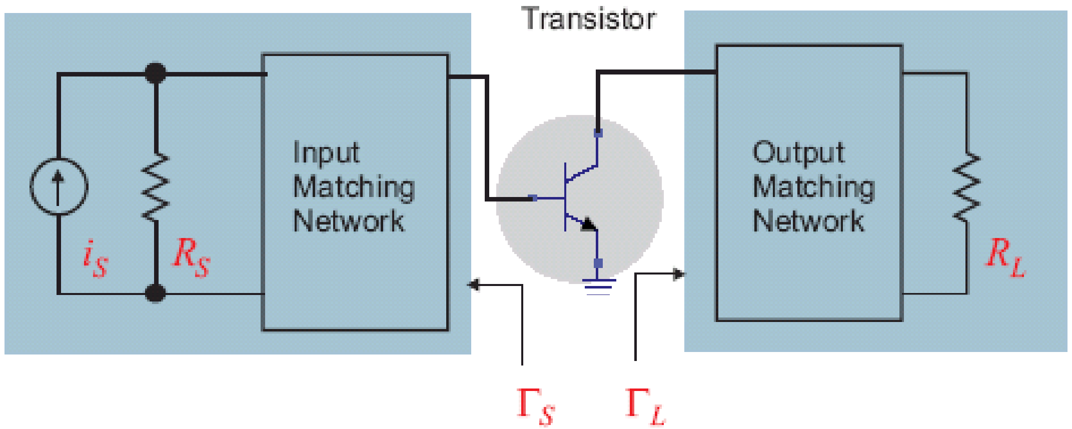
Problem
--Minimize the Noise figure

$$\text{Noise Factor: } F' = \frac{P_L / N_L}{P_S / N_S} = 1 + \frac{N_a}{N_S G}$$

$$\text{Noise Figure: } F = 10\log(F') \text{ [dB]}$$

Design Procedure for LNA

- **Active Device Selection ←(MAG > G, Nfmin < NF @ Design frequency)**
- **Pick up the optimum Source & Load impedances (Circles Drawing)**
- **Matching network design**
- **Bias Circuit Adding**
- **Stability Check @ other frequencies**
- **Layout**



Lumped LNA Example

Active Device Preparation for ADS

- S-parameter inputting to ADS
  - S-parameter Check
  - Minimum Noise Check
- Large Signal Model
  - Curve Tracing
  - S-parameter Check
  - Minimum Noise Check

S-Parameter Inputting

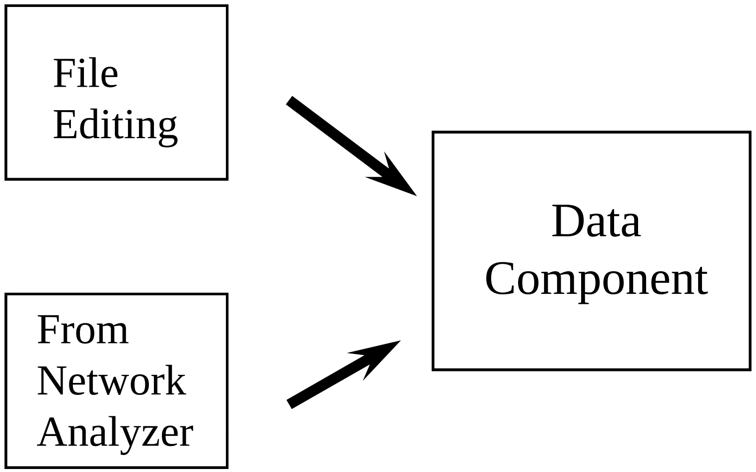
TouchStone Format

```
! NEC710
# GHZ S MA R 50
2  .95   -26  3.57  157  .04  76  .66  -14
22  .60  -144  1.30   40  .14  40  .56  -85
! NOISE PARAMETERS
 4  .7    .64   69  .38
18   2.7  .46  -33  .40
(Freq  NFmin  Sopt  Rn/Zo)
```

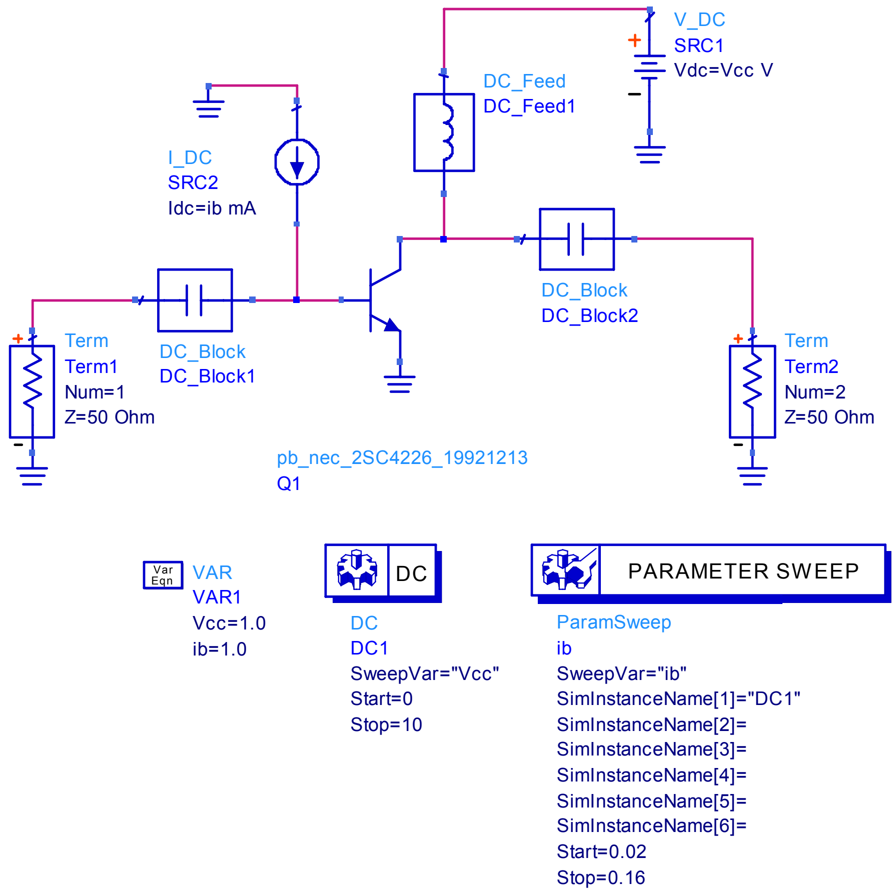
CitiFile Format

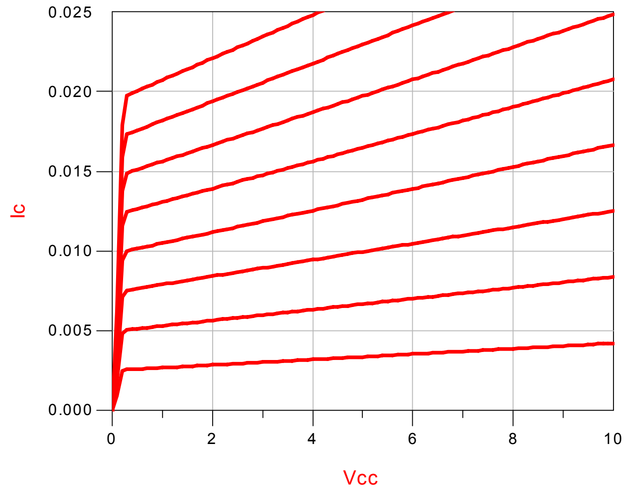
```
CITIFILE A.01.00
#NA VERSION HP8510B.05.00
NAME MEMORY
#NA REGISTER 1
VAR FREQ MAG 5
DATA S RI
        VAR_LIST_BEGIN
        1000000000
        2000000000
        2500000000
        3000000000
        VAR_LIST_END
BEGIN
-1.31189E-3,-1.47980E-3
-3.67867E-3,-0.67782E-3
-3.43990E-3,0.58746E-3
-2.70664E-4,-9.76175E-4
0.65892E-4,-9.61571E-4
END
```

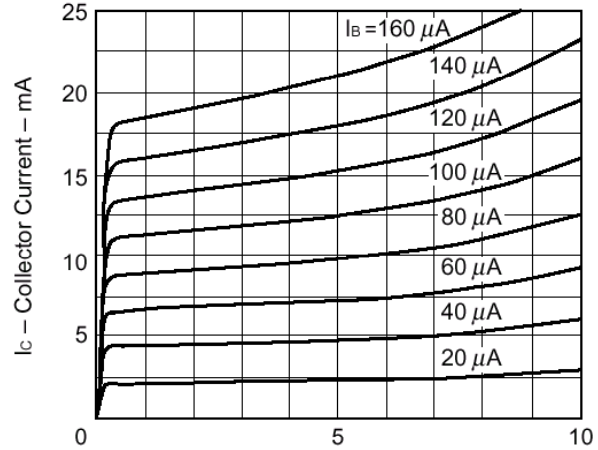
- Text-editor



Large Signal Model Check

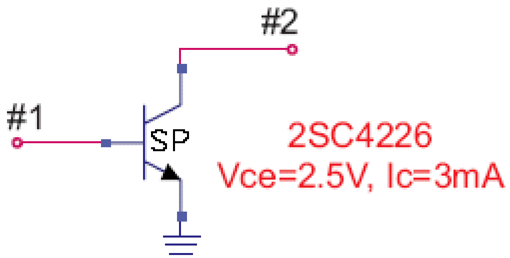


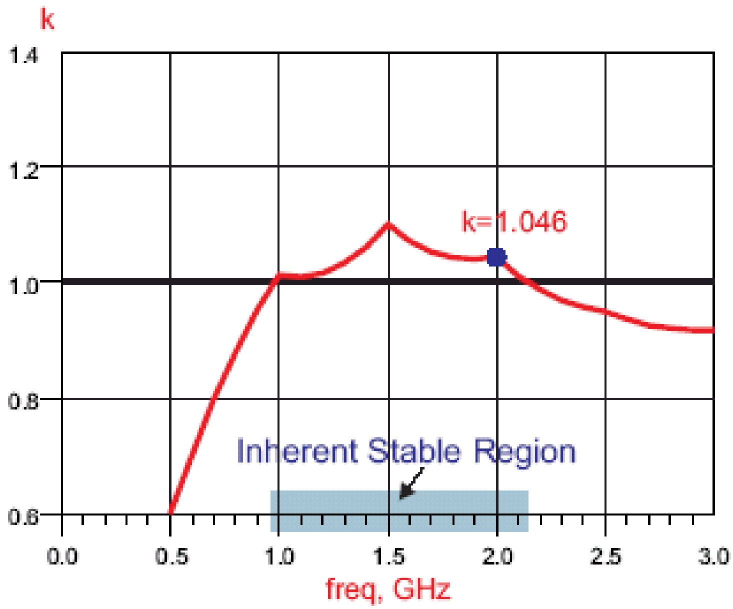


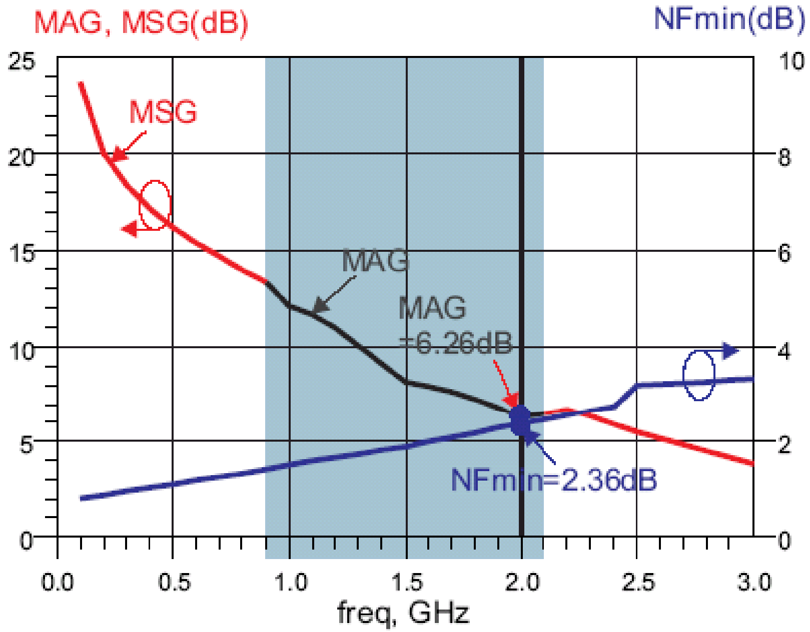


Device for LNA (@ 2GHz, *G* >5dB, *NF* <3dB)

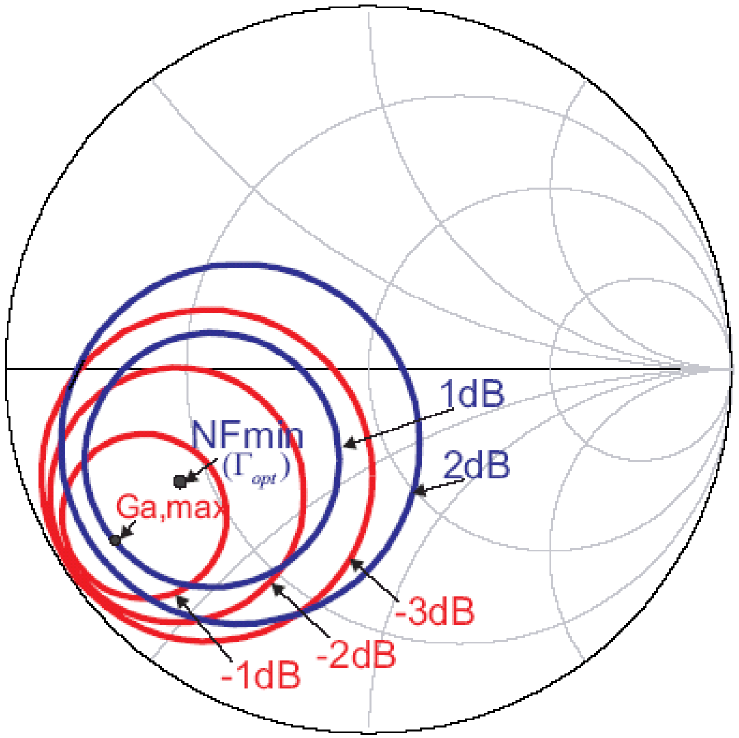
- BJT: 2SC4226 (2.5V, Ic=3mA),
- Stable at 2GHz
- Gain: 6.26dB max, NF; 2.36dB min
- Unstable case→Stabilizing



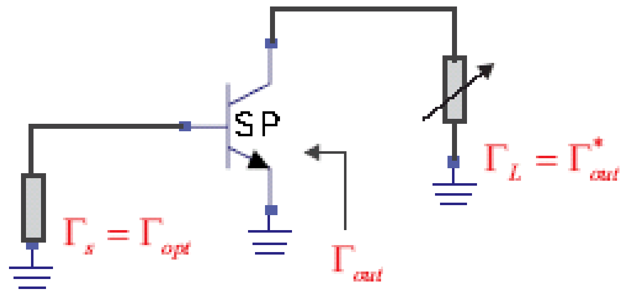




Input & Output Impedance Selection



Ga Circles & Noise Circles @2GHz



Impedance for Min NF

$$\Gamma_S = \Gamma_{opt} = 0.6\angle 150^o$$

$$Z_S = Z_{opt} = 13.4 - j13.0$$

Associated Gain $G_A > 5.26$ **dB**

Associated Output Impedance

$$\Gamma_L = \Gamma_{out}^* = \left(S_{22} + \frac{S_{12}S_{21}\Gamma_{opt}}{1 - S_{11}\Gamma_{opt}} \right)^*$$

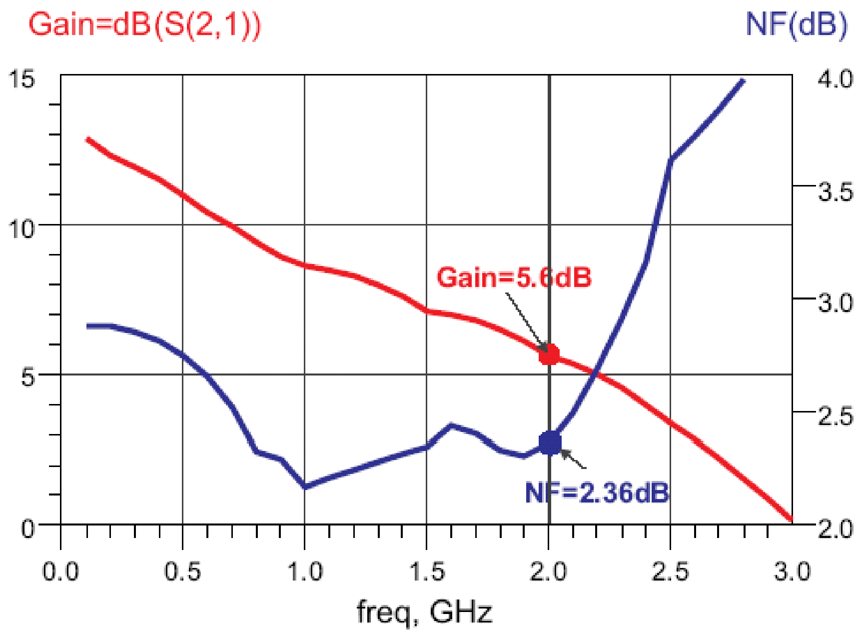
$$= 0.661\angle 67.7^o$$

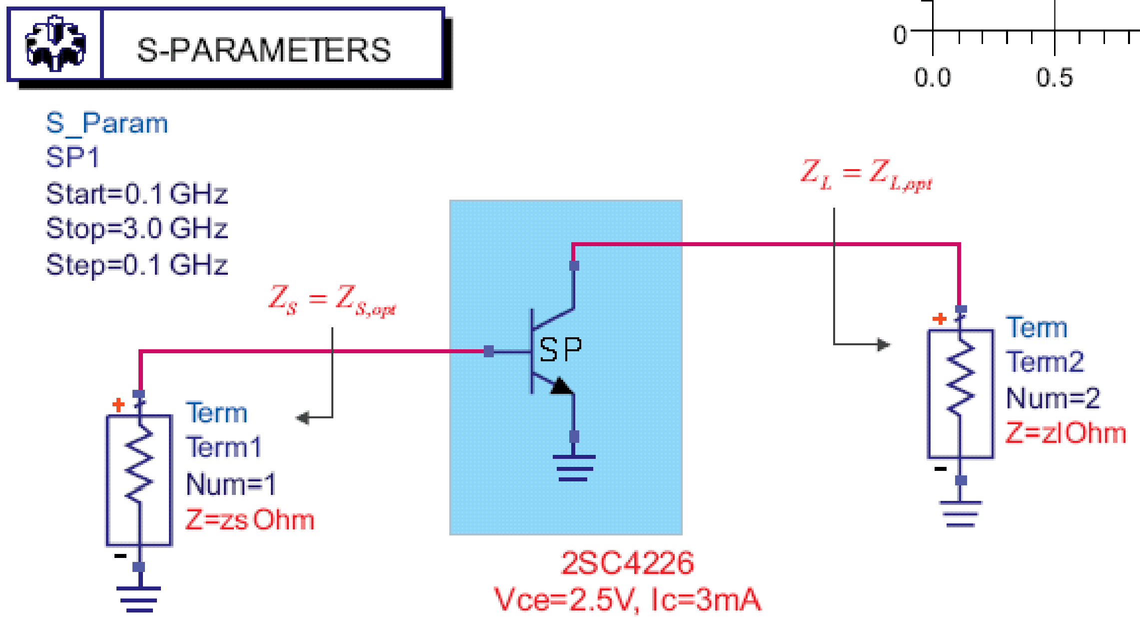
$$Z_L = 30.1 + j65.3$$

Selected Impedance Verification

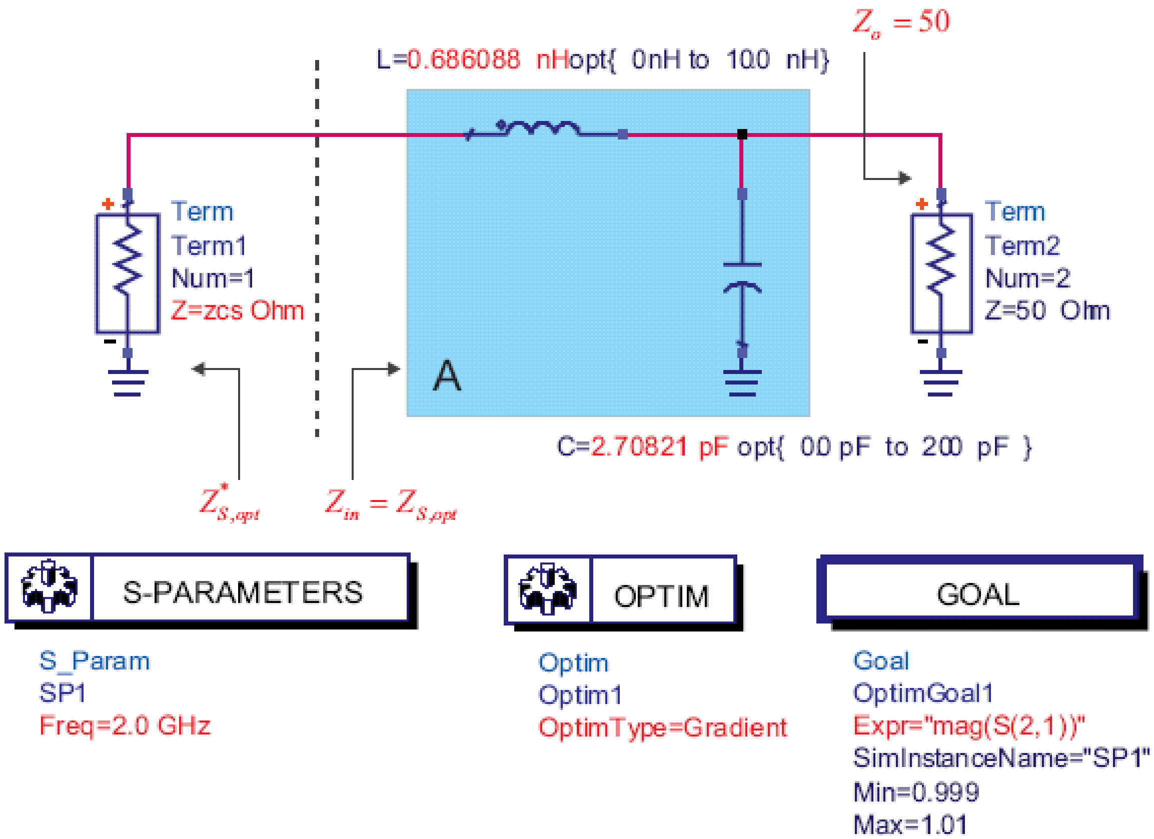
$$Z_S = Z_{S,opt} = 13.4 - j13.0,$$
$$Z_L = Z_{L,opt} = 30.1 + j65.3$$

Gain=5.6dB>5.26dB, NF=2.36dB





Matching Network Design (Input)



Matching Network by C, L

(Ch. 5)

$Z_o = 50$

$\rightarrow Z_{in} = Z_{S,opt} = 13.4 - j13.0$

Set port #1 Impedance

$Z_1 = Z_{S,opt}^*$

Maximum Power Transfer

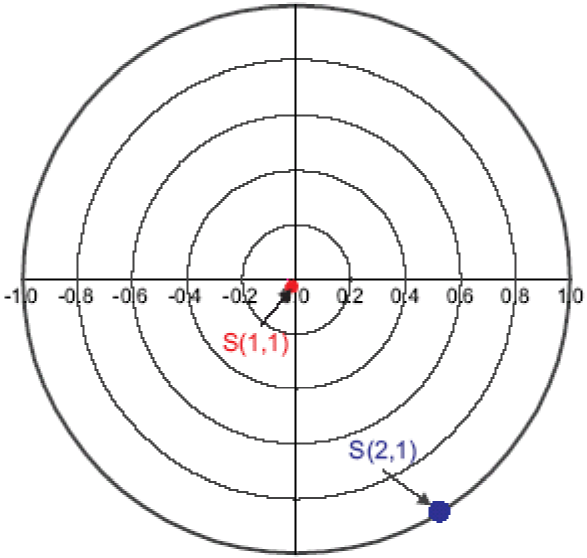
$Z_{in} = Z_{S,opt}$

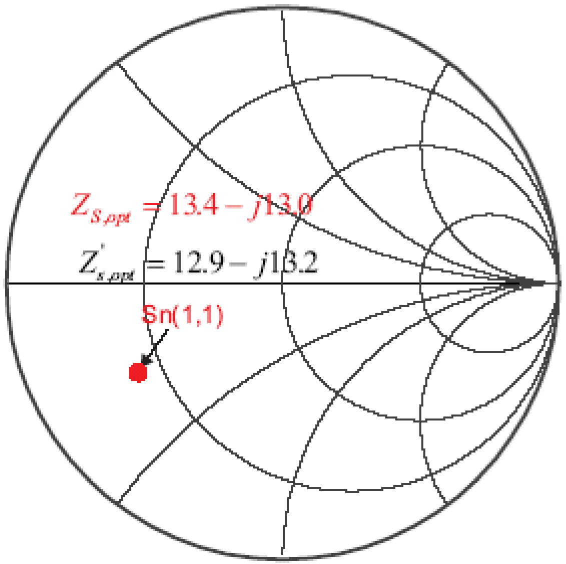
Matching Network Results (Input)

For the S-parameters ($Z^*_{S,opt}$,50) **at matched condition**

$$S_{11} = \frac{Z_{in} - \left(Z^*_{S,opt}\right)^*}{Z_{in} + \left(Z^*_{S,opt}\right)} = \frac{Z_{in} - Z_{S,opt}}{Z_{in} + Z^*_{S,opt}} = 0$$ **(** $\because Z_{in} = Z_{S,opt}$ **for match) and** $|S_{21}|^2 = \frac{|b_2|^2}{|a_1|^2} = 1 \rightarrow |S_{21}| = 1$

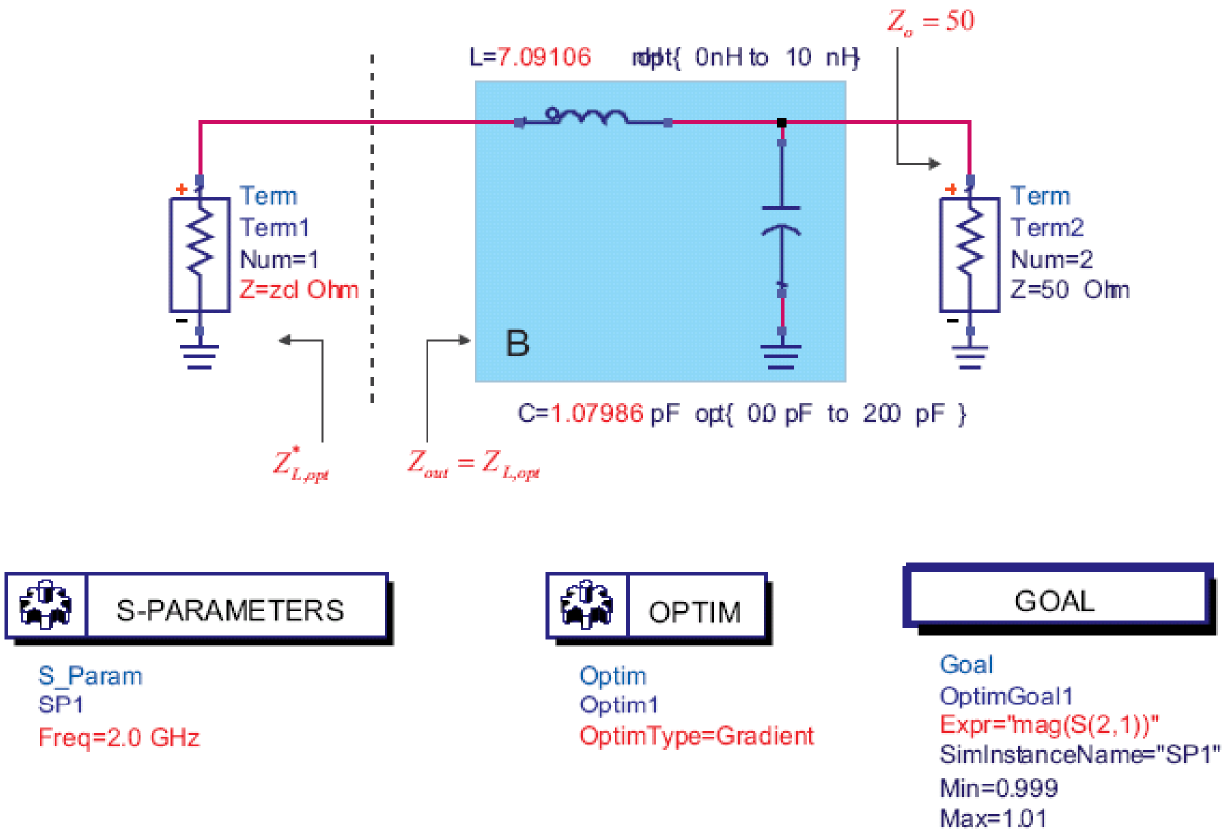
$\rightarrow |a_1|^2$ **; delivered power to 2-port input and** **2-port lossless**





Reference ($Z^*_{S,opt}$, 50) Reference (50,50)

Matching Network Design(Output)



Matching Network by C, L

$Z_o = 50$

$\rightarrow Z_{out} = Z_{L,opt} = 30.1 + j65.3$

Set port #1 Impedance

$Z_1 = Z^*_{L,opt}$

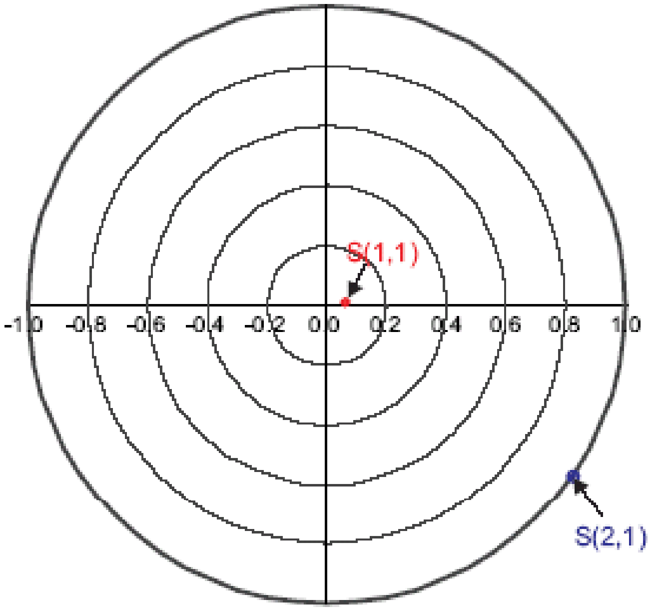
Maximum Power Transfer

$Z_{out} = Z_{L,opt}$

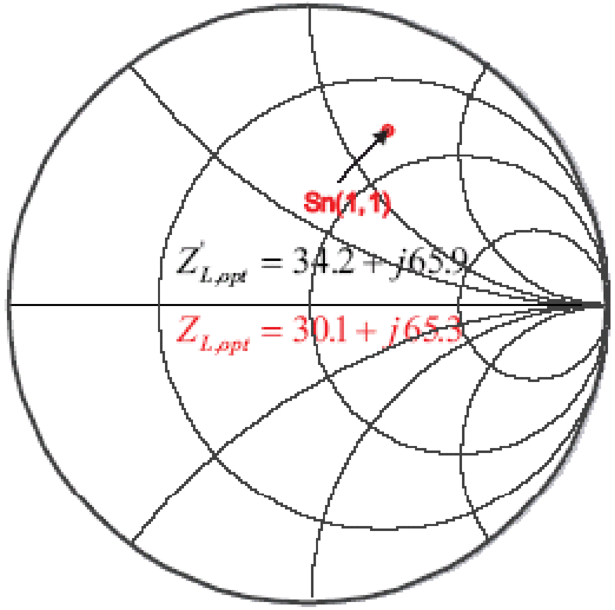
Matching Network Results (Output)

For the S-parameters ($Z^*_{L,opt}$,50) at matched condition;

Similar to Input match; $S_{11} = 0$ **and** $|S_{21}| = 1$



Reference ($Z^*_{L,opt}$, 50)

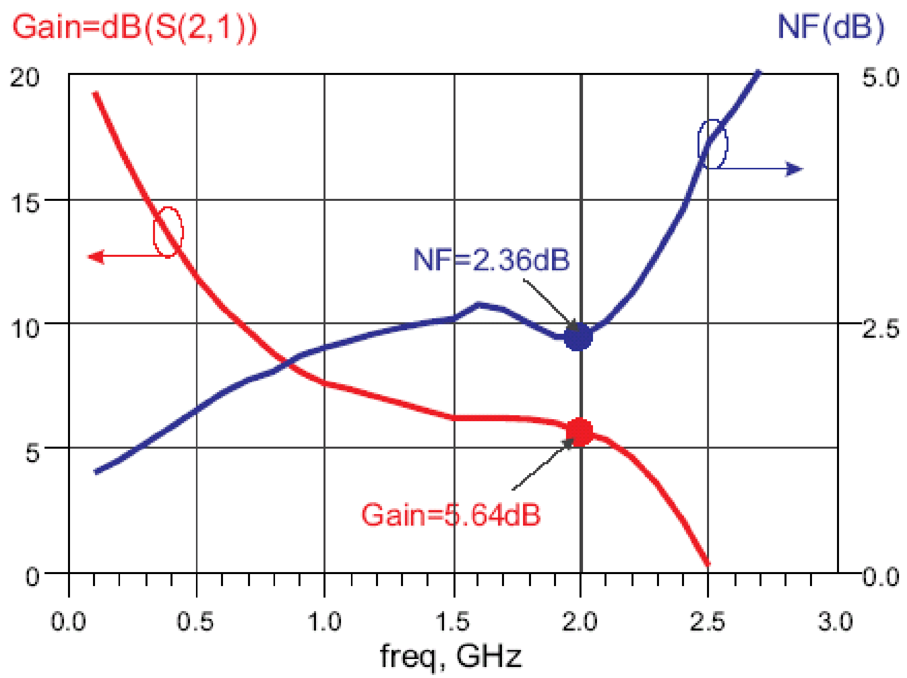


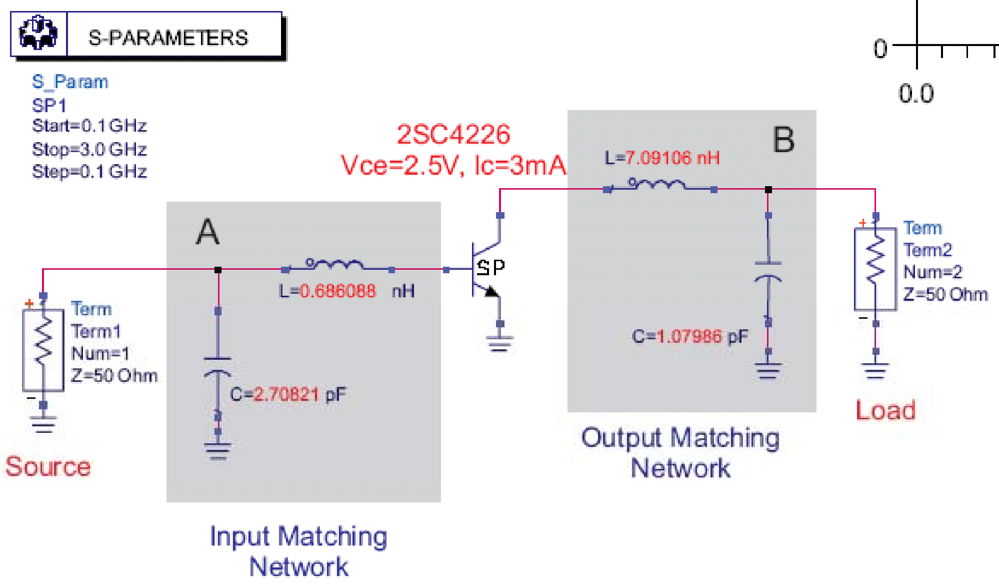
Reference (50,50)

Verification of Lumped Matching Networks

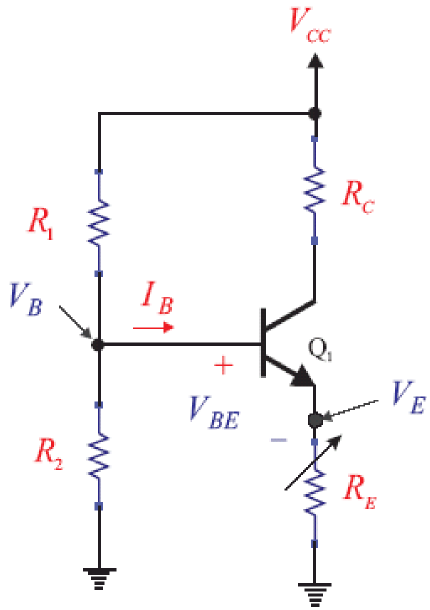
Gain @ 2GHz $= 5.6dB$

NF@2GHz $= 2.36dB$





DC Bias Circuit for BJT



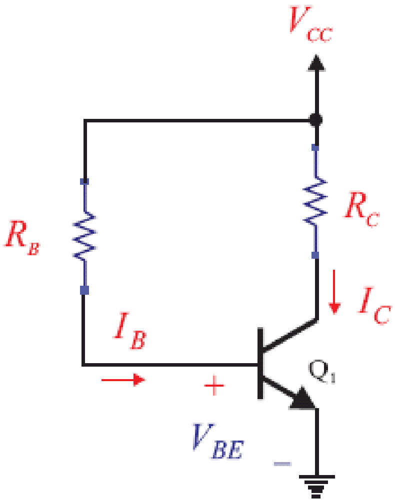
(1) Bias Circuit using Emitter Resistor

Neglecting I_B

$$V_B = \frac{R_2}{R_1 + R_2} V_{CC} \rightarrow$$

$$I_E = \frac{V_B - V_{BE}}{R_E} \cong I_C$$

- **Stable Bias,**
- **but Imperfect Emiter GND**



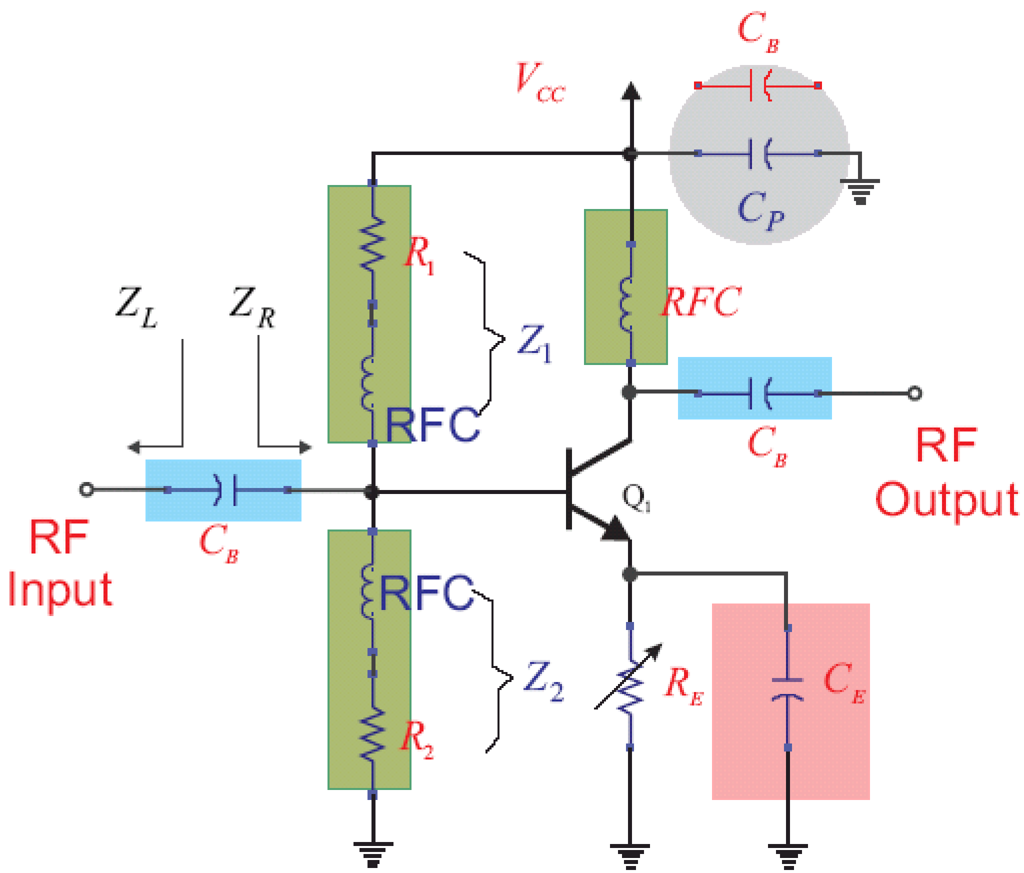
(2) Grounded Emitter Bias Circuit

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} \rightarrow$$

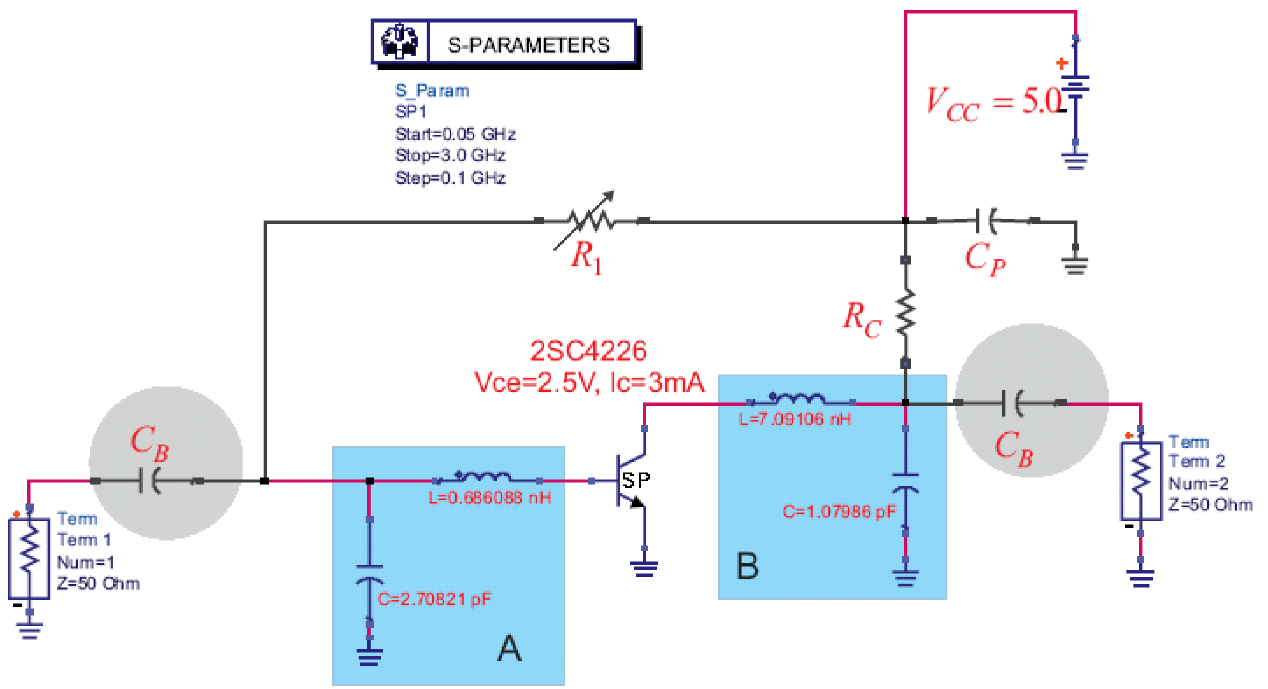
$$I_C = \beta I_B$$

- **Unstable Bias** $\leftarrow \beta$
- **Perfect Emiiter GND**

Decoupling and DC Blocking



Amplifier Circuit with DC Bias



Capacitors

$C_B = 10\,pF$

$(\approx 1\Omega \;\; @\, 2GHz)$

$C_p = 100\,pF$

Resistors

$$R_1 = \frac{V_{CC} - V_{BE}}{I_B} = 143K$$

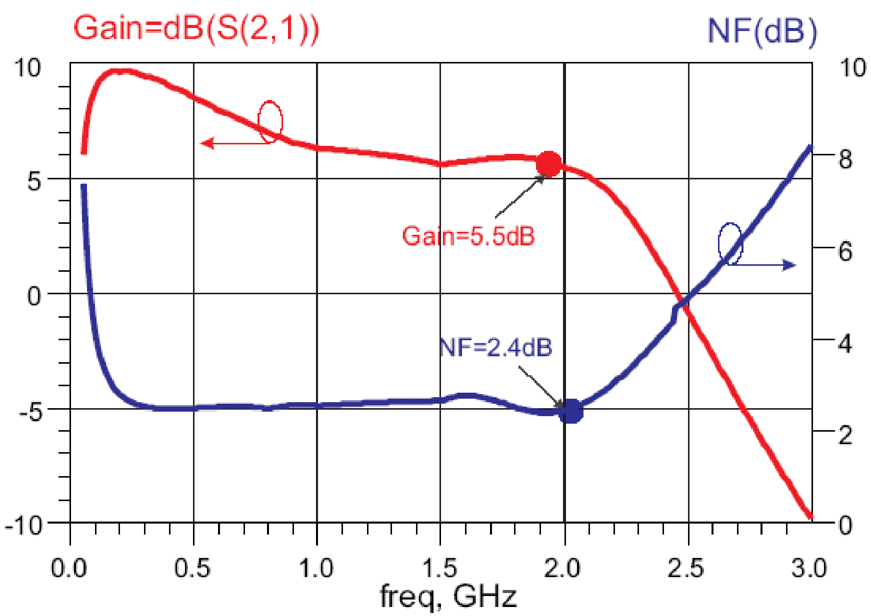
$V_{CE} = 2.5$

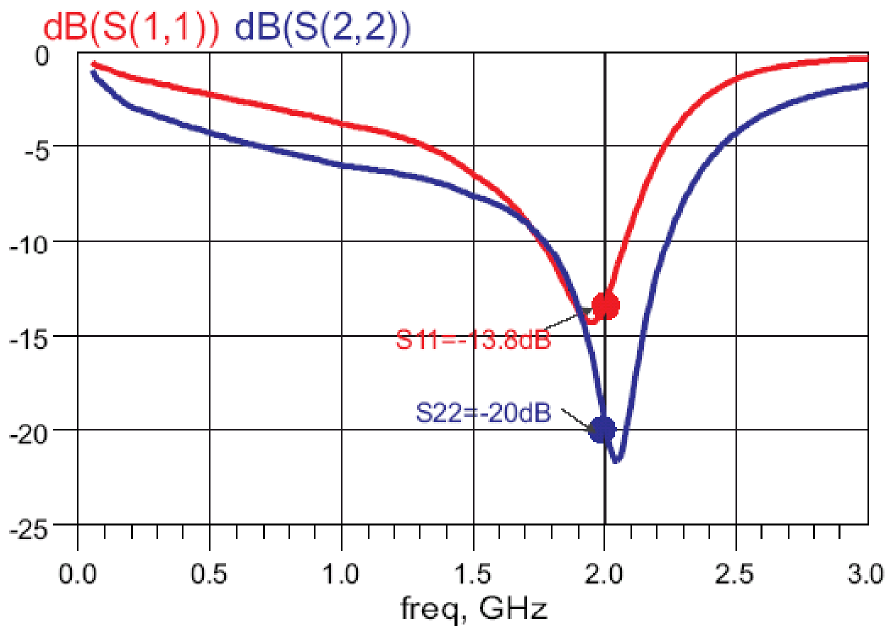
$$R_C = \frac{V_{CC} - V_{CE}}{I_C} = 833\Omega$$

$(R_C >> 50 \,||\, 50 = 25)$

Performance of Designed Amplifier

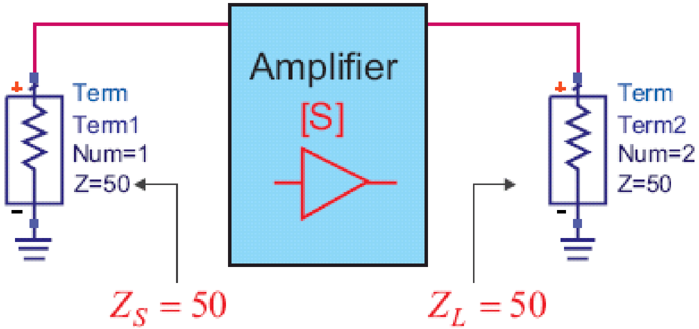
- Gain=5.5dB>5dB, NF=2.4dB<3dB @2GHz
- Input RL=13.8dB, Output RL= 20dB

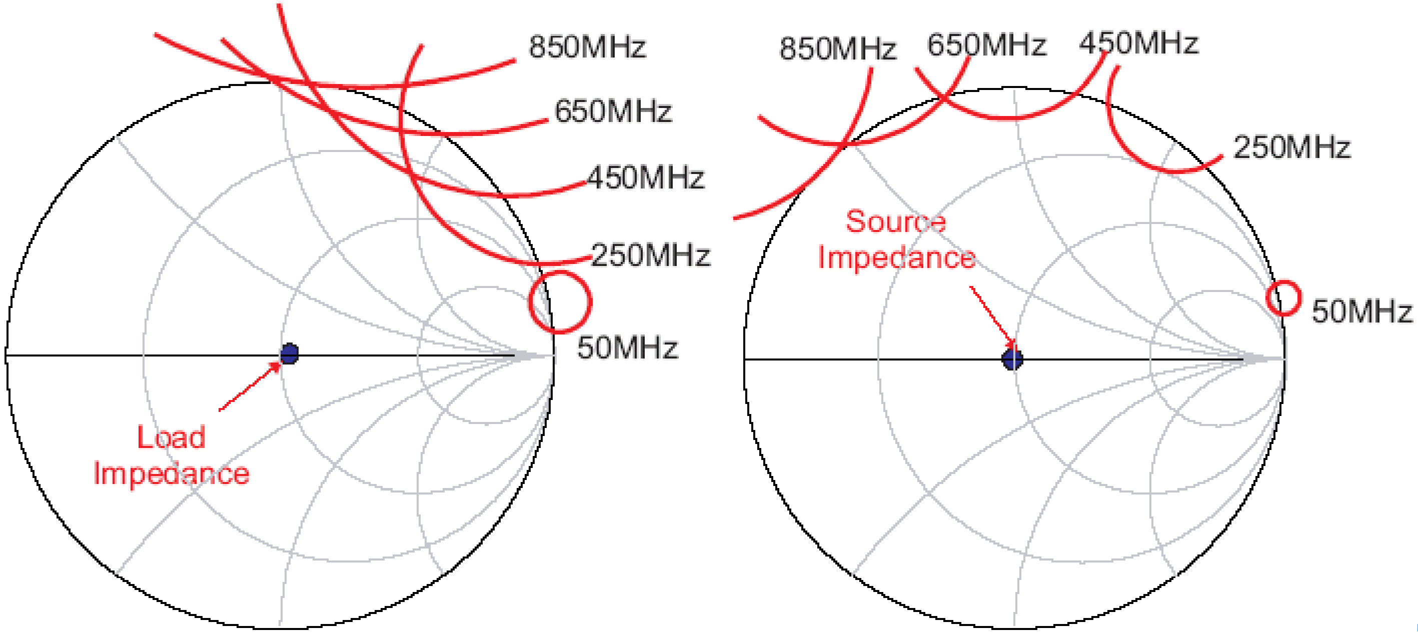




Source & load Stability in Low Frequency

- Stable @ low frequency

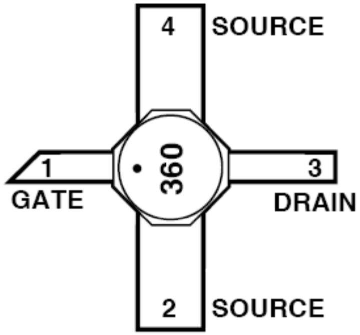


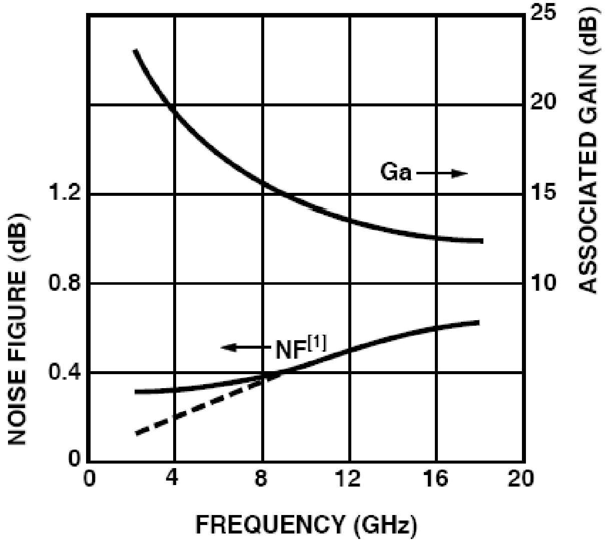


Distributed LNA Example

Transistor (ATF36077)

NO.	Spec Item	Value
1	Frequency Range	9.7~10.3 GHz
2	DC Supply Voltage	3.3 V
3	DC Current Consumption	< 30 mA
4	Gain	> 10 dB
5	Noise Figure	< 1.5 dB



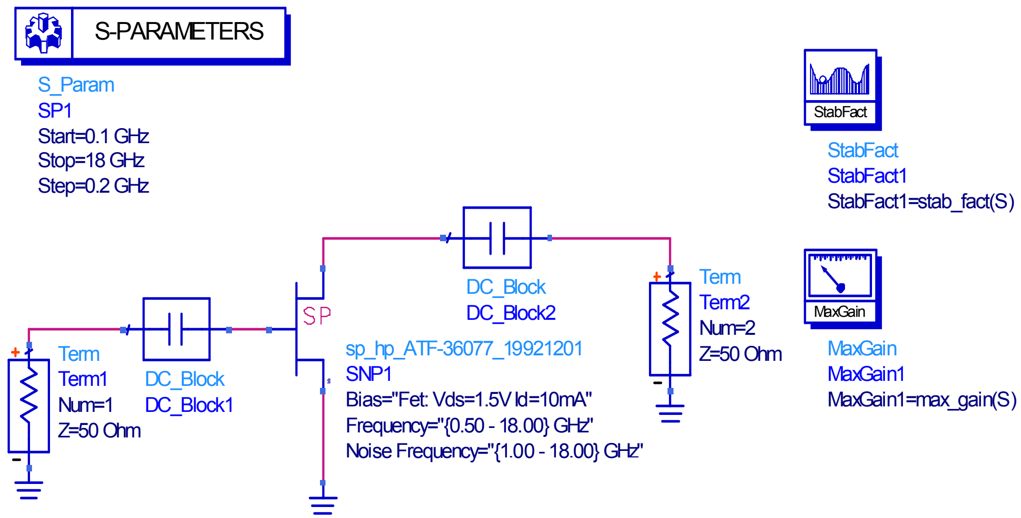


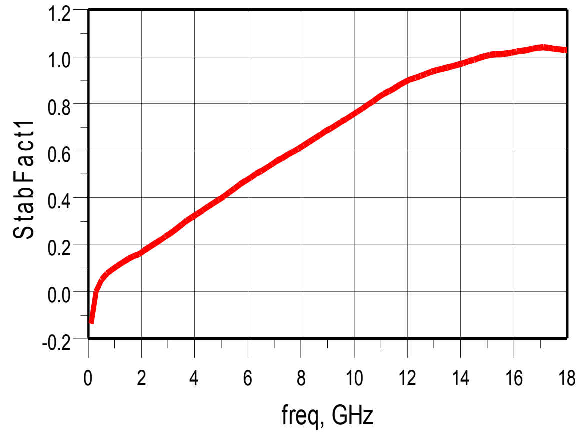
Substrate

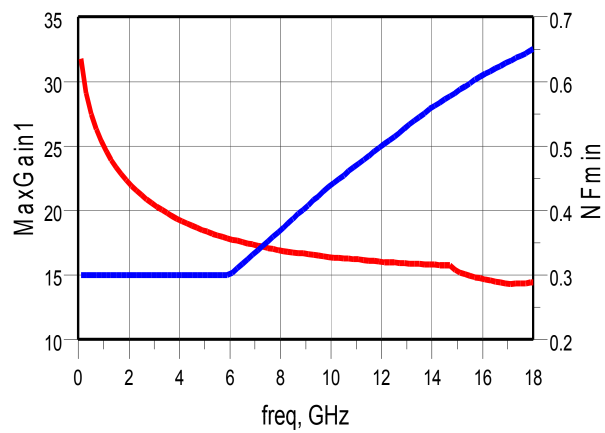
- UL2000
  - Permittivity;2.5
  - Thickness;0.25mm(10 mil)
  - Conductor Thickness; 17um
  - Loss Tangent;0.0022

[1] Rogers corporation, ULTRALAM2000 HF laminate, Available at http;//www.rogerscoporation.com

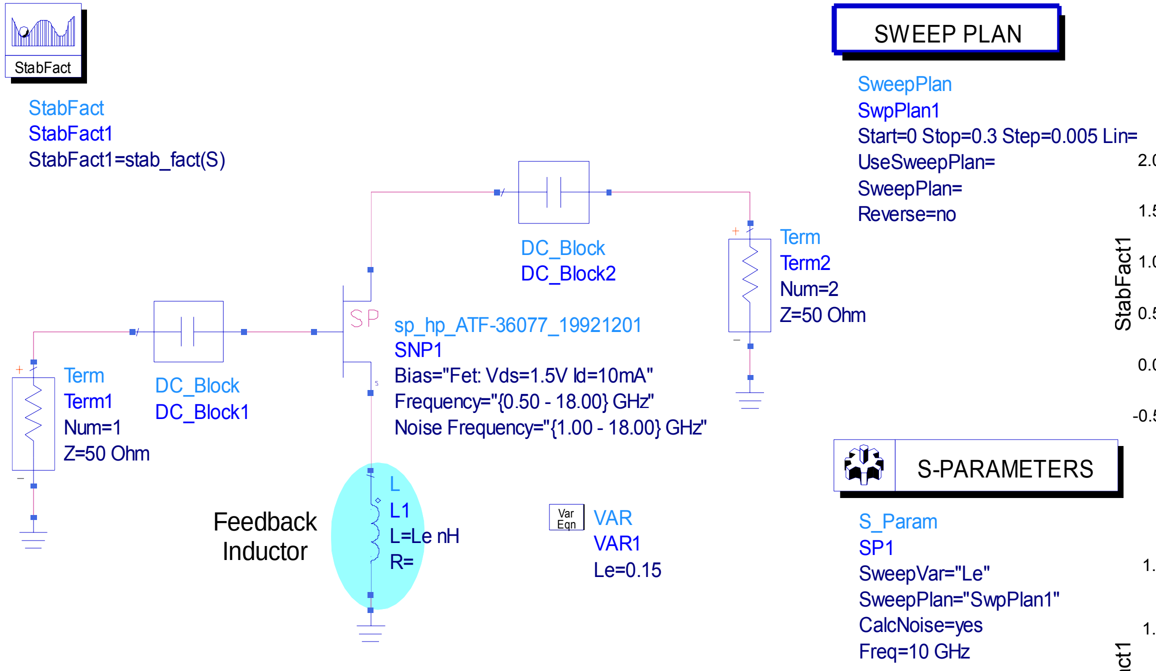
S-parameter input check

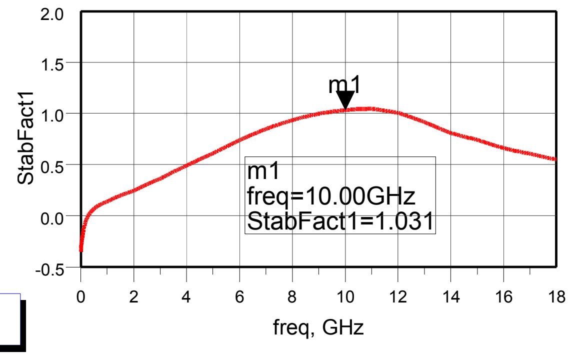


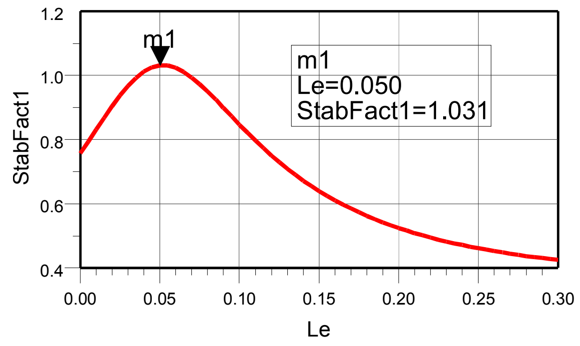




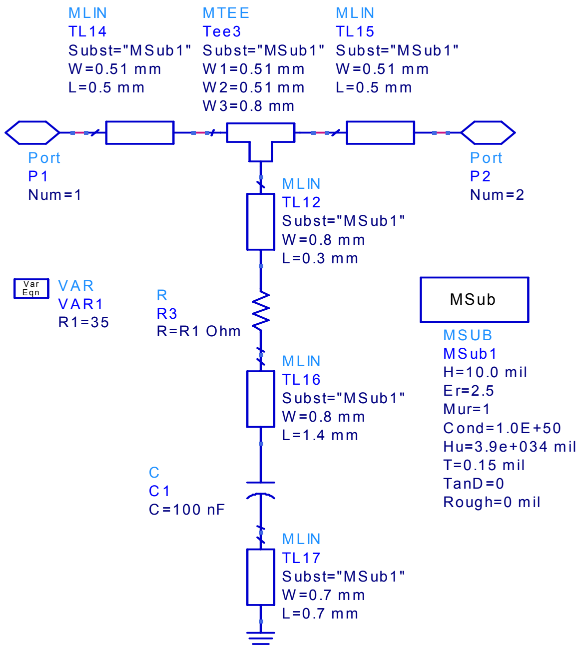
Stabilizing



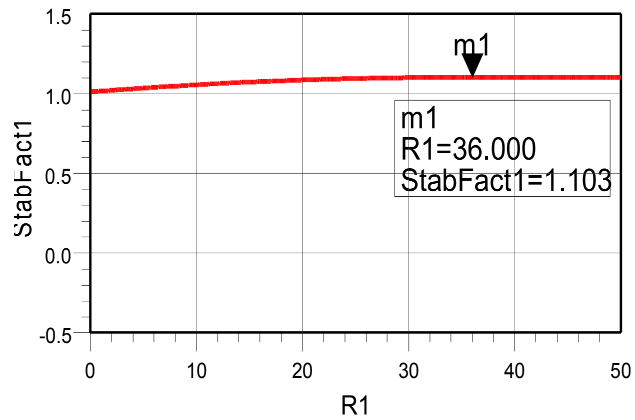


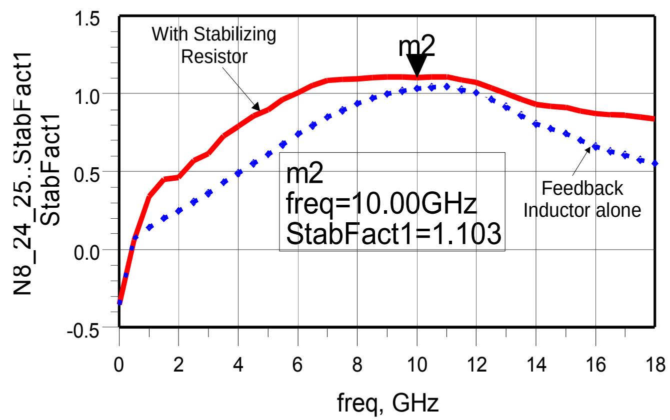


Further stabilization

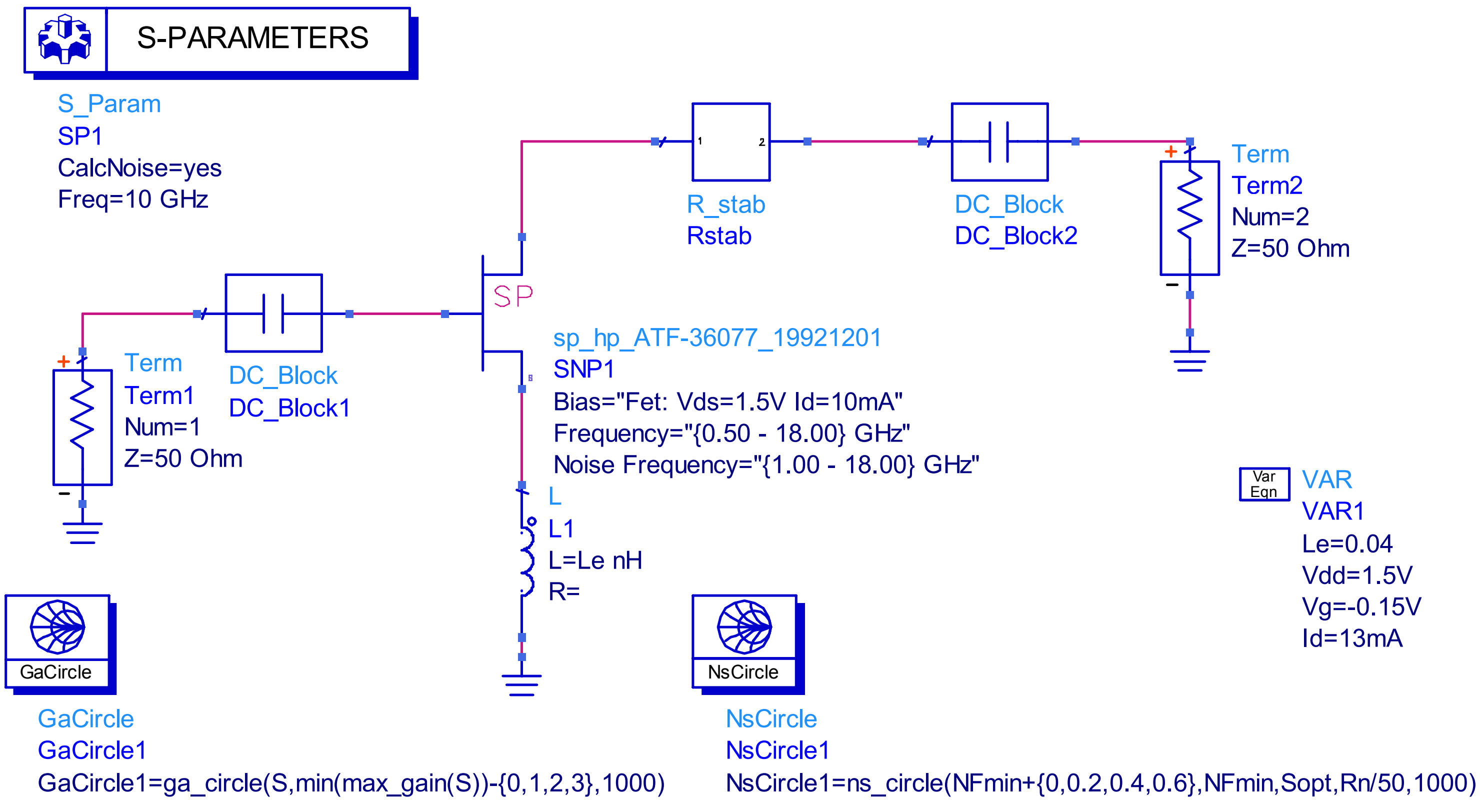


$R = 35$ ohm

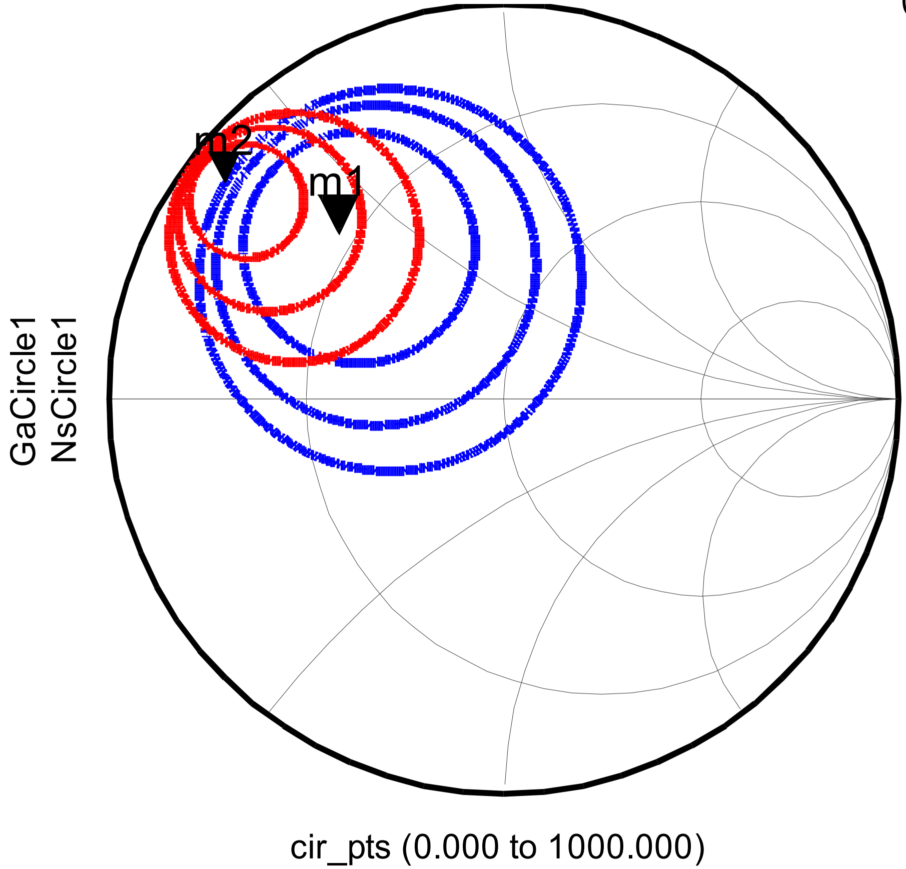




Input and Output Impedance Pick up



Circles



Choice m1

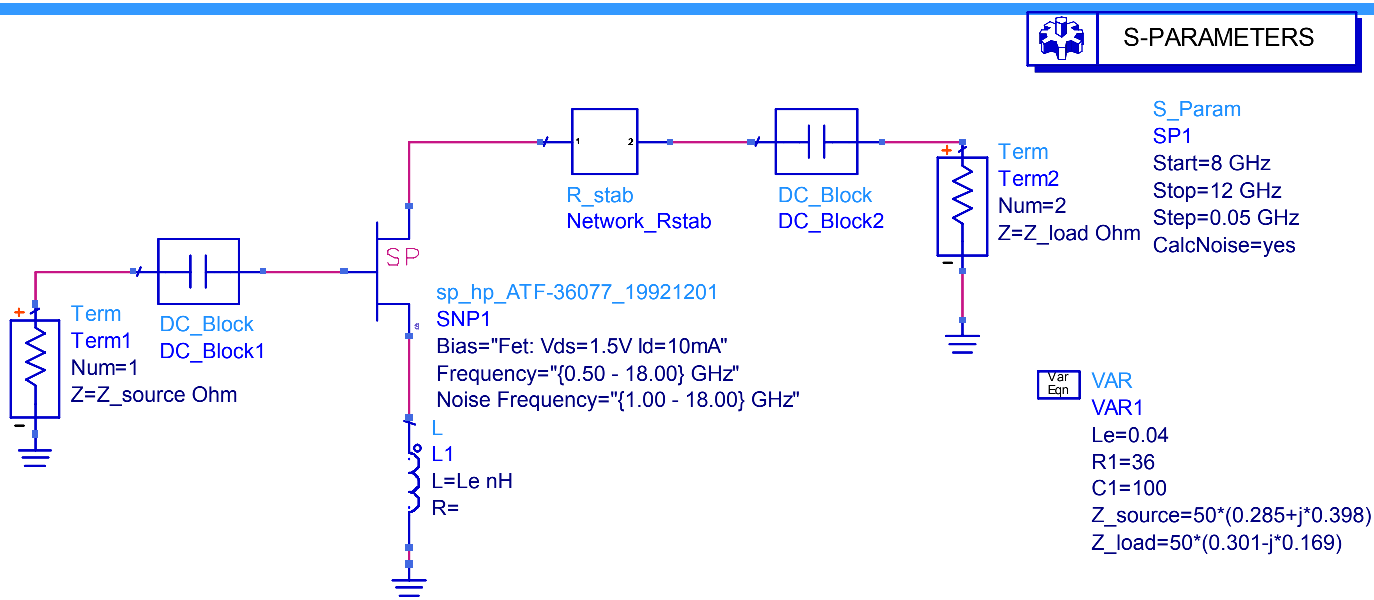
m1
indep(m1)=1000
NsCircle1=0.609 / 133.725
ns figure=0.474788
impedance = Z0 * (0.285 + j0.398)

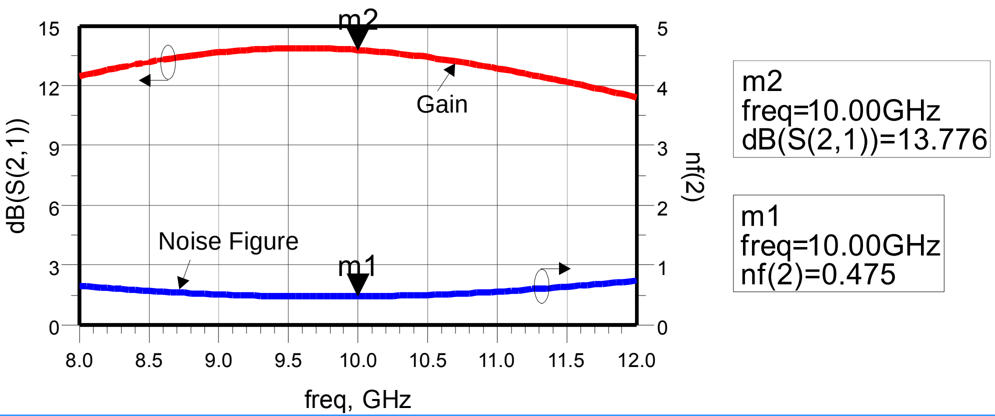
m2
indep(m2)=1000
GaCircle1=0.895 / 142.486
gain=15.380759
impedance = Z0 * (0.062 + j0.338)

$$\Gamma_s = 0.609\angle 133.725^\circ$$

$$\Gamma_L = \left(S_{22} + \frac{S_{12}S_{21}\Gamma_s}{1 - S_{11}\Gamma_s} \right)^* = 0.548\angle -159.04^\circ$$

Verification

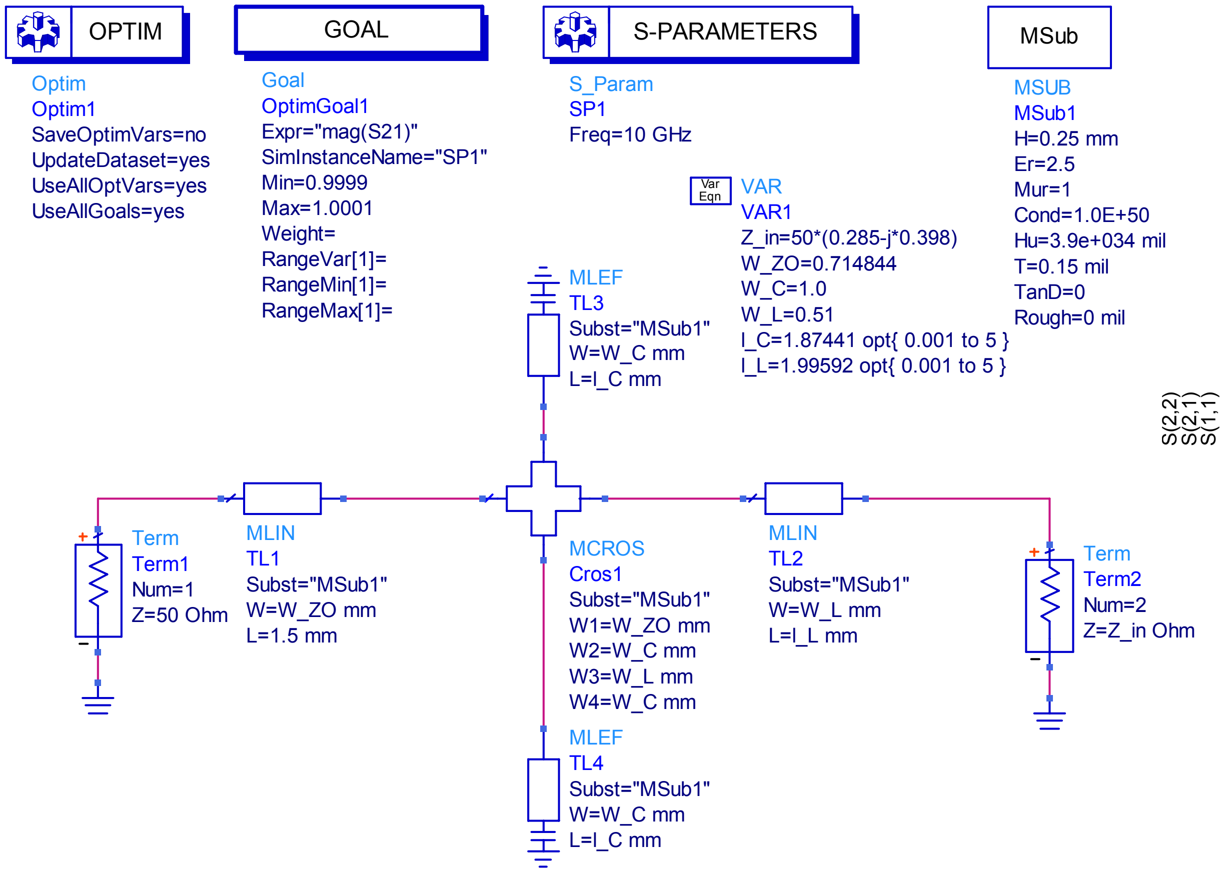


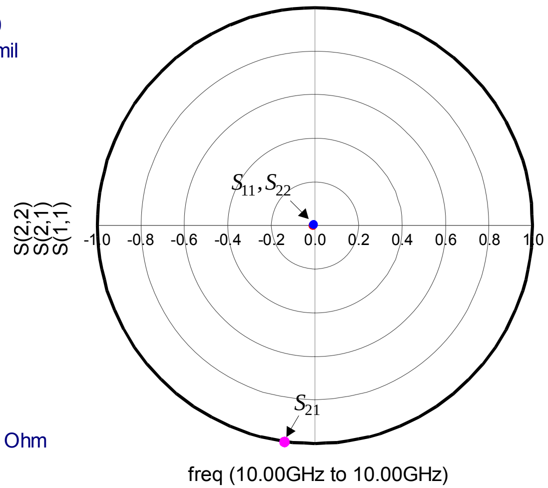


Matching Network Design

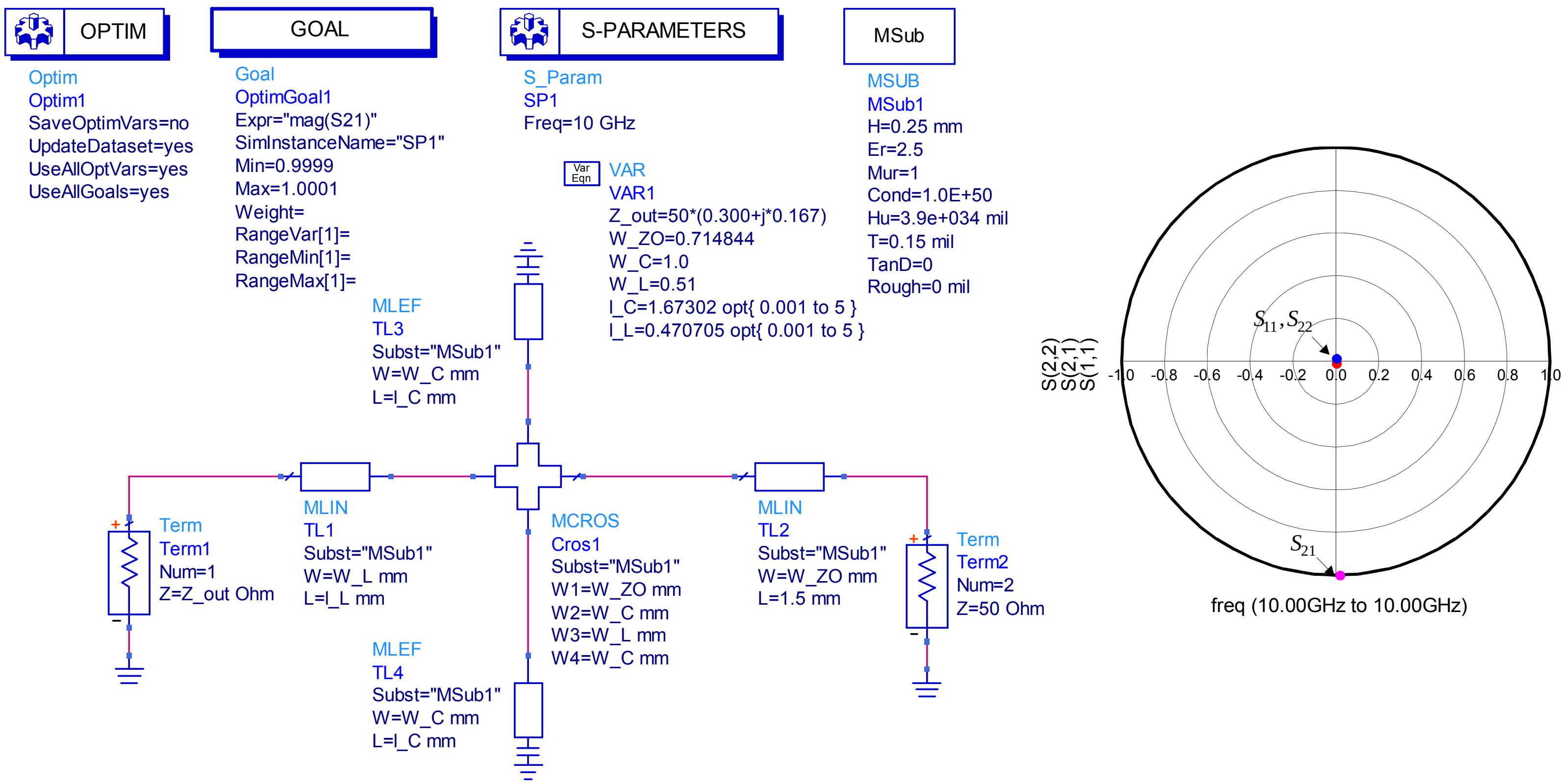
- Distributed Matching Network Design
  - Replacement
  - Verification and Comparison
- Bias Network Adding
  - DC Block
  - RF choke
  - Unstability at Low Frequency

Matching Network Design(Input)

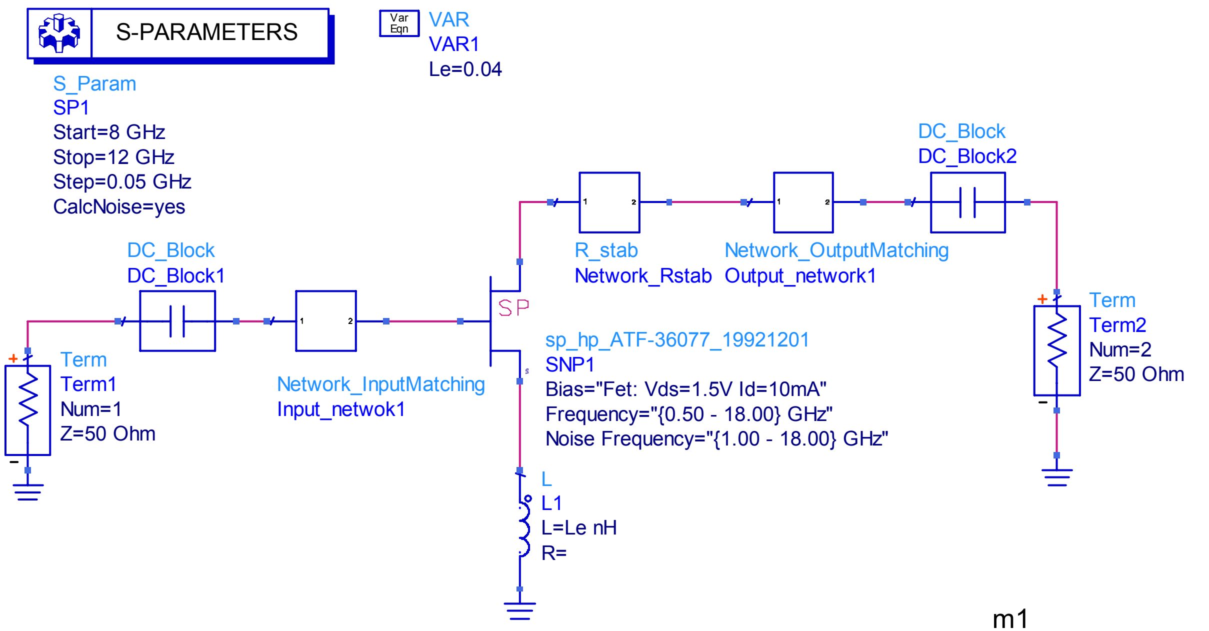


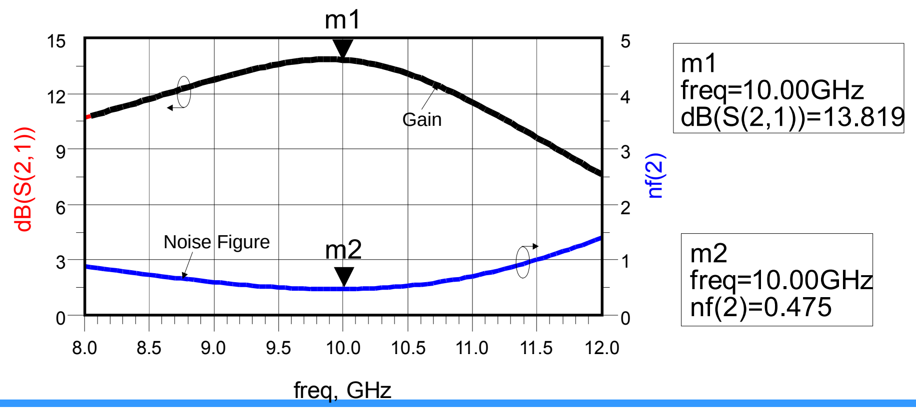


Matching Network Design(Output)

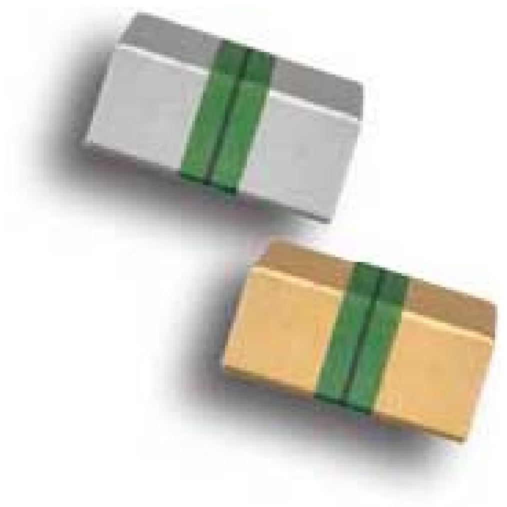


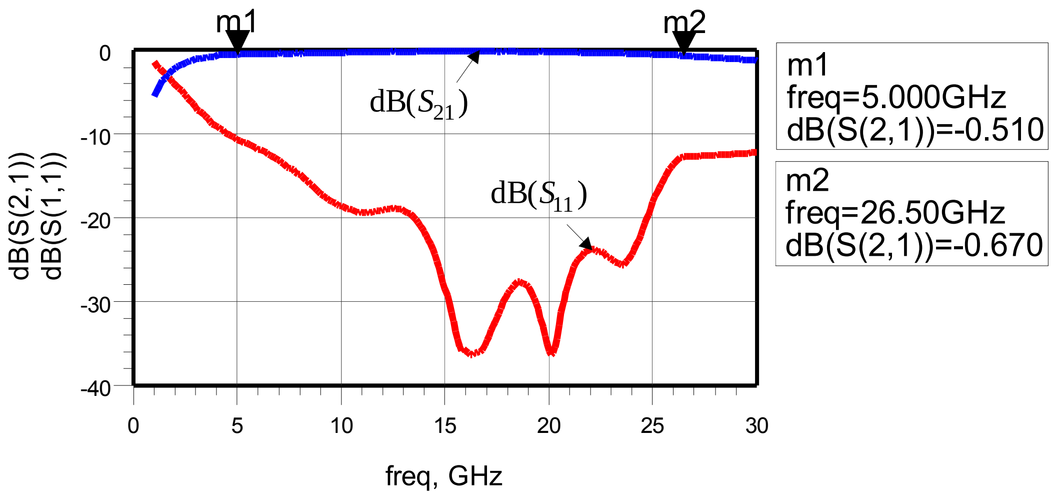
Verification of Lumped Matching Networks





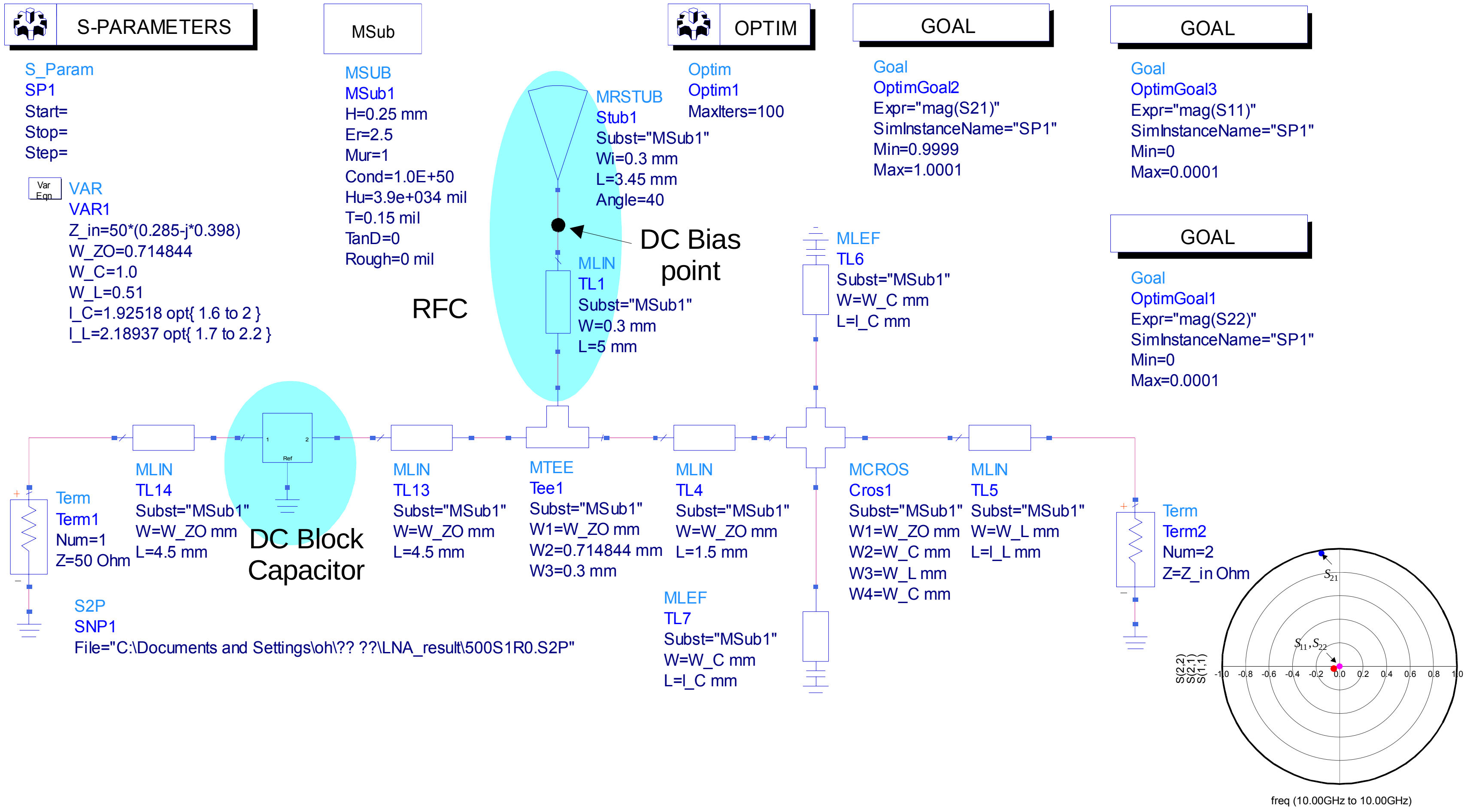
DC Block Capacitor



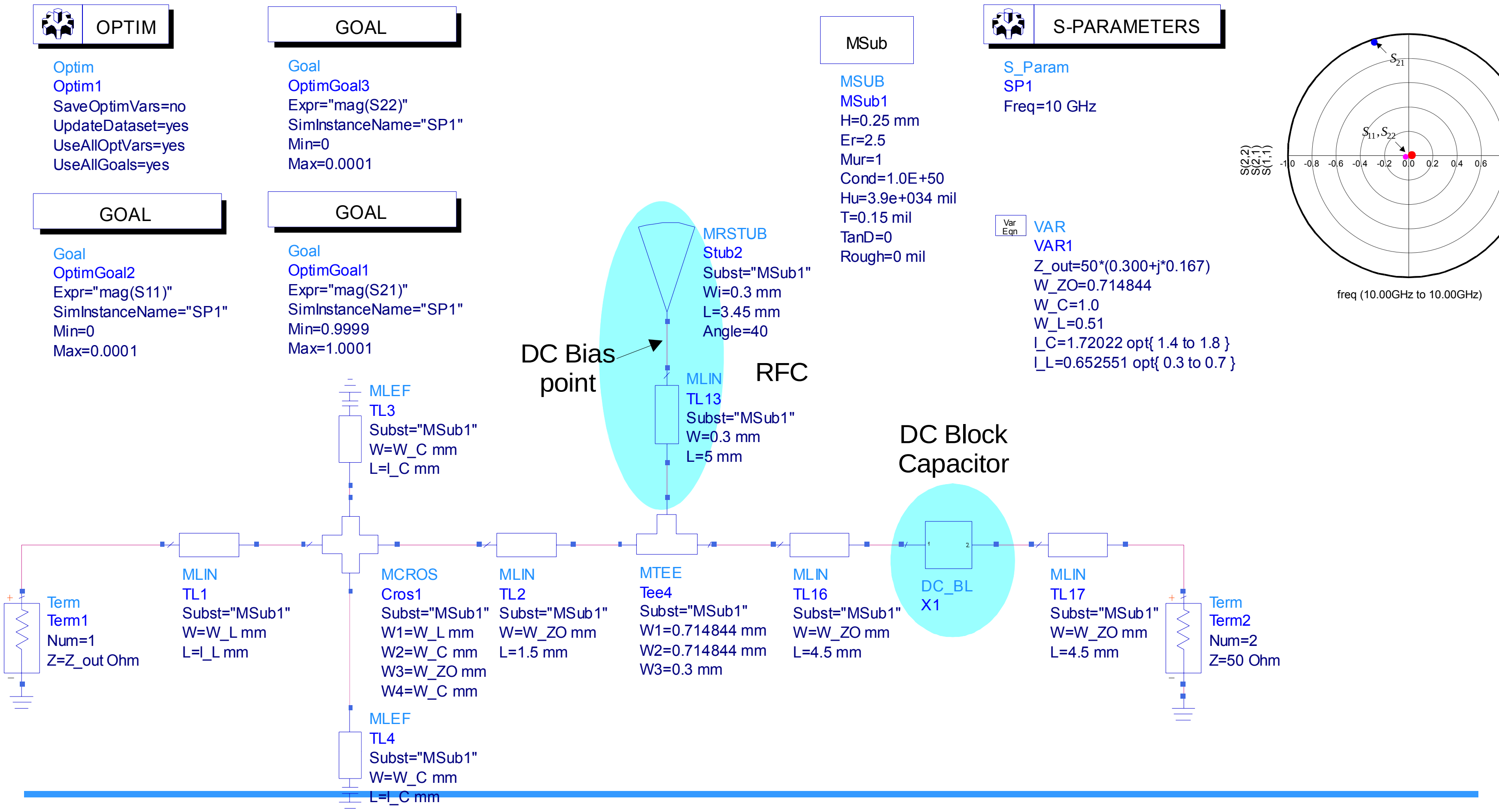


[2] American Technical Ceramics, ATC 545L Series UBC Ultra-Broadband Capacitor, Available at http;//www.atceramics.com

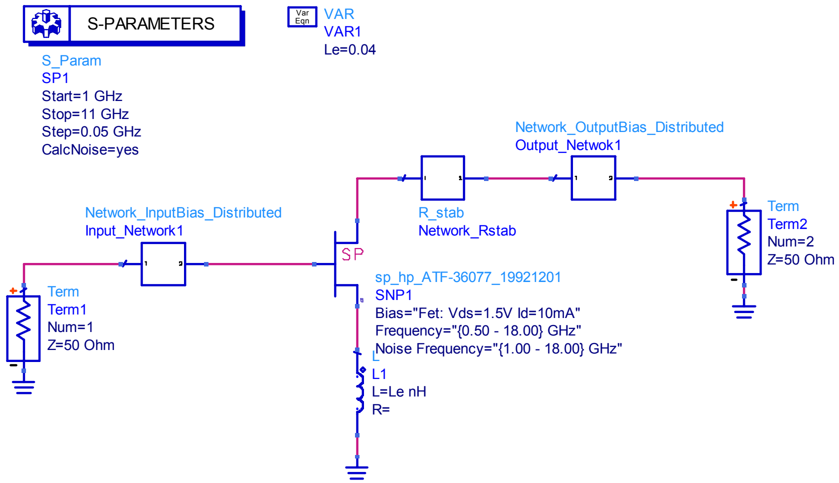
Bias Network Adding(Input)

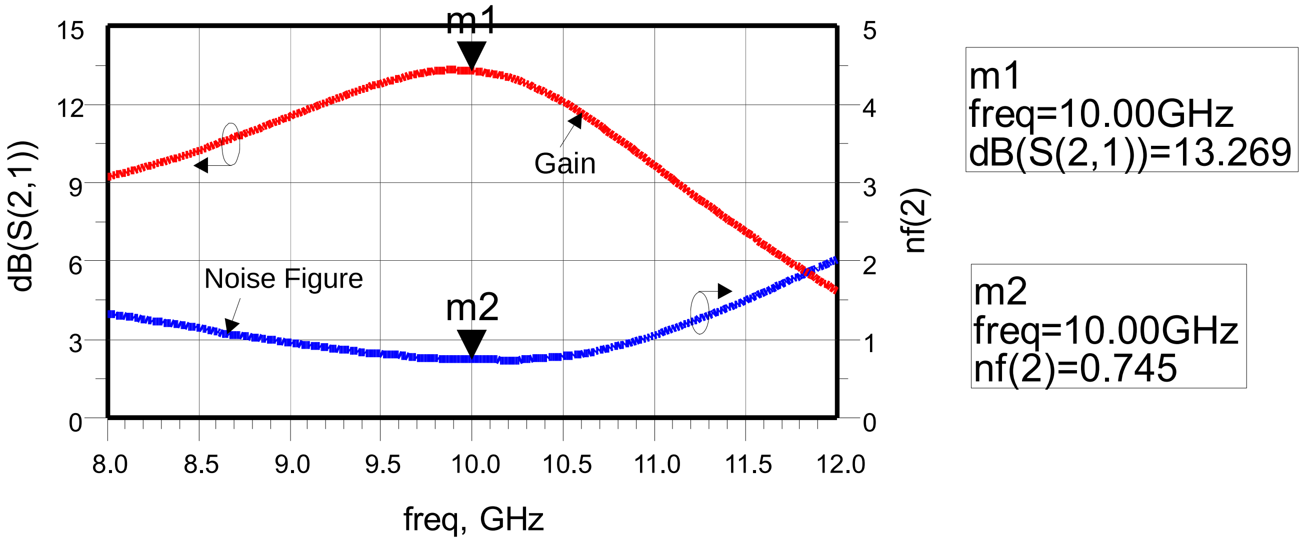


Bias Network Adding(Output)

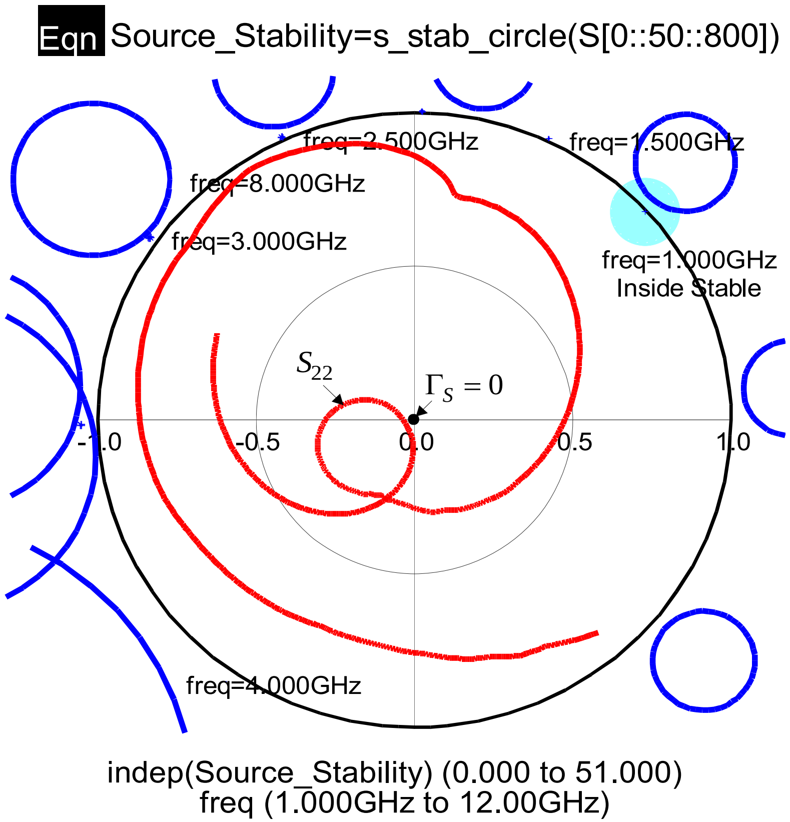


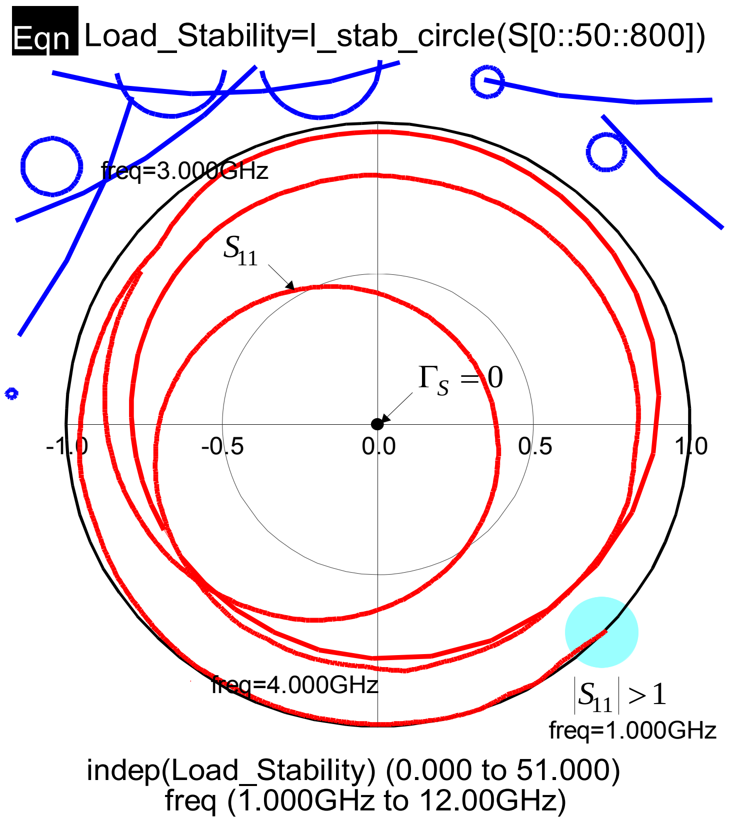
Results


S-PARAMETERS
S_Param
SP1
Start=1 GHz
Stop=11 GHz
Step=0.05 GHz
CalcNoise=yes
VAR
VAR1
Le=0.04
Network_OutputBias_Distributed
Output_Netwok1
R_stab
Network_Rstab
Network_InputBias_Distributed
Input_Network1
Term
Term2
Num=2
Z=50 Ohm
Term
Term1
Num=1
Z=50 Ohm
SP
sp_hp_ATF-36077_19921201
SNP1
Bias="Fet: Vds=1.5V Id=10mA"
Frequency="{0.50 - 18.00} GHz"
Noise Frequency="{1.00 - 18.00} GHz"
L1
L=Le nH
R=

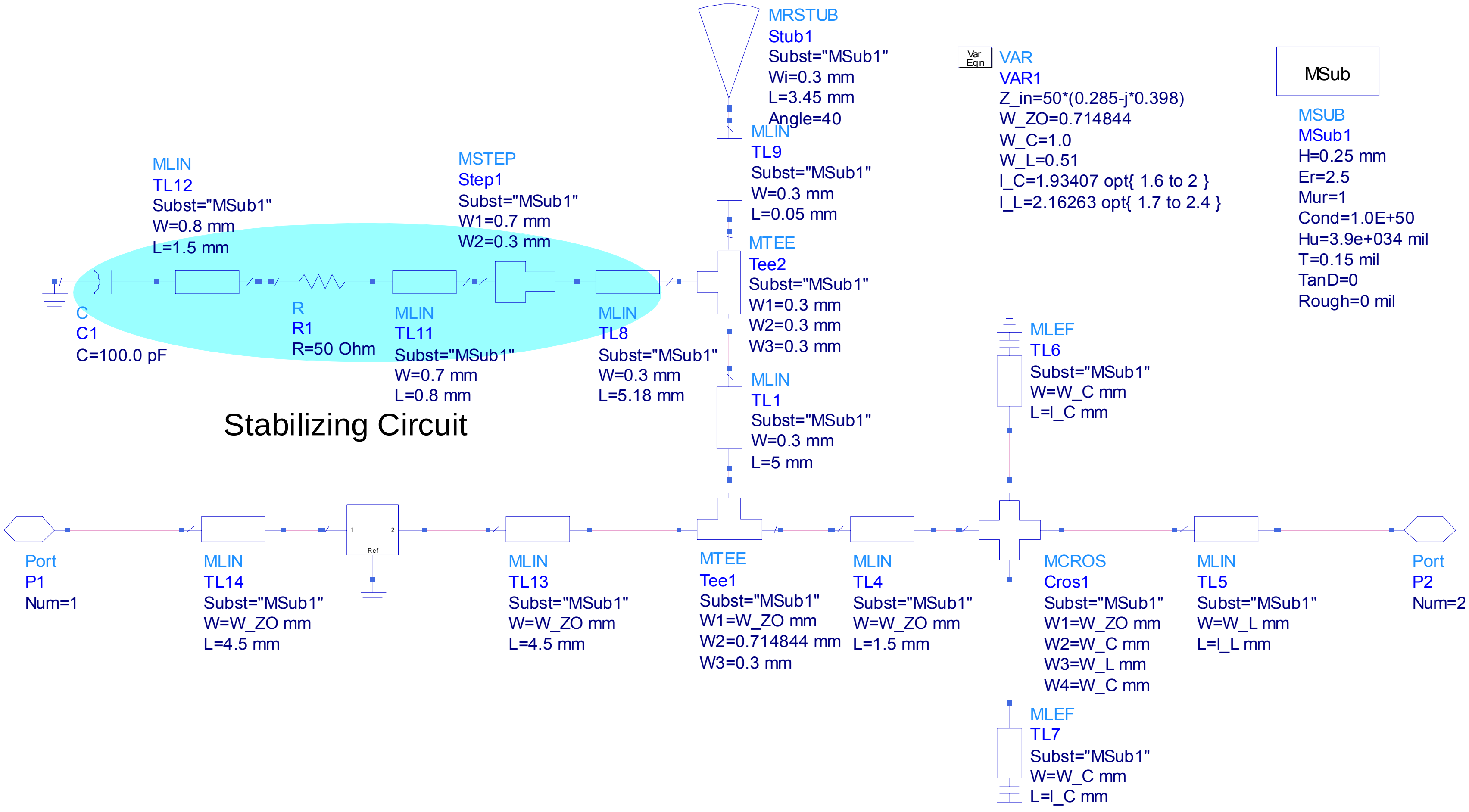

m1
m2
Gain
Noise Figure
dB(S(2,1))
nf(2)
freq, GHz
m1
freq=10.00GHz
dB(S(2,1))=13.269
m2
freq=10.00GHz
nf(2)=0.745

Source and Load Stabilities in Low Frequency



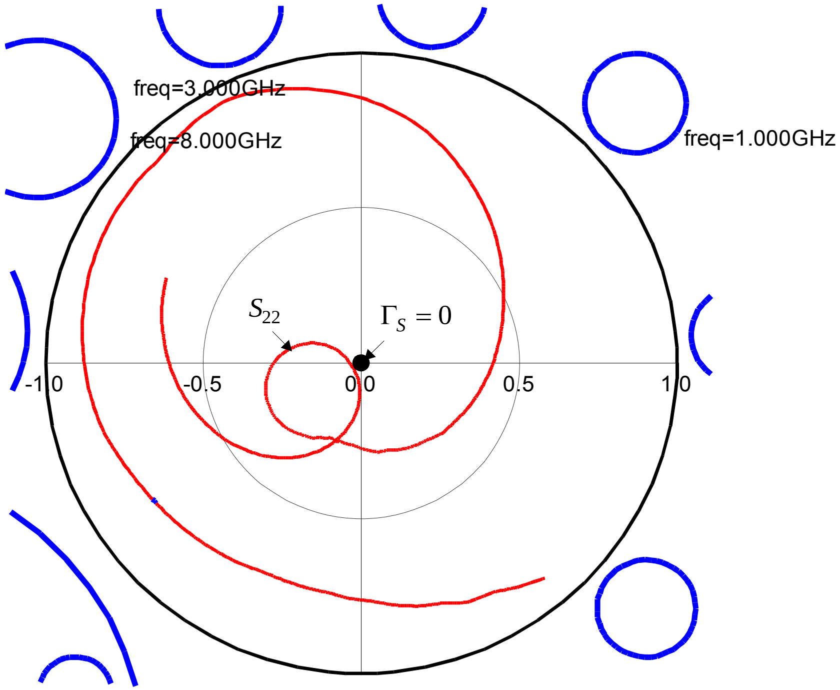


Stability Improvement Circuit(Input)



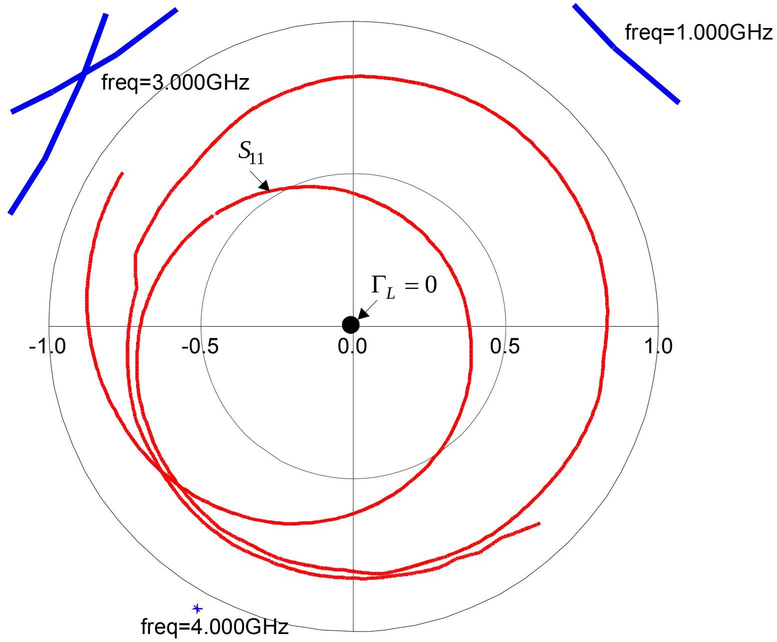
Results

Eqn Source_Stability=s_stab_circle(S[0::50::800])



indep(Source_Stability) (0.000 to 51.000)
freq (1.000GHz to 12.00GHz)

Eqn Load_Stability=l_stab_circle(S[0::50::800])

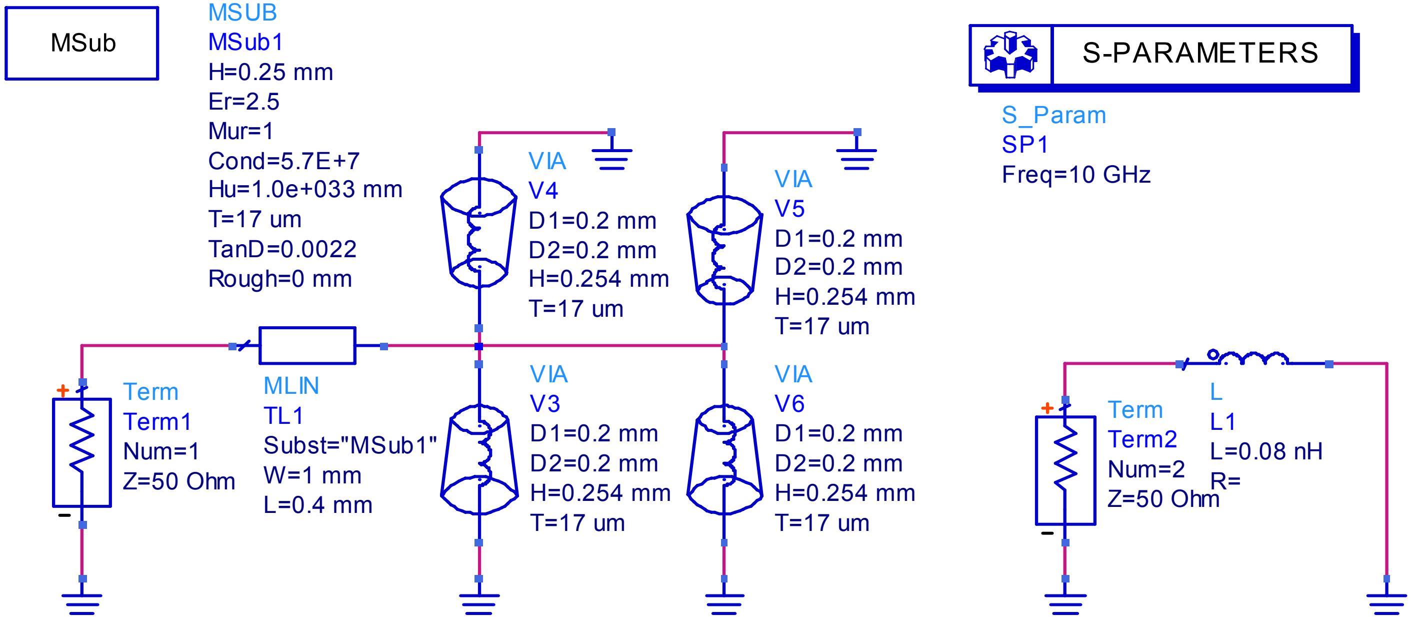


indep(Load_Stability) (0.000 to 51.000)
freq (1.000GHz to 12.00GHz)

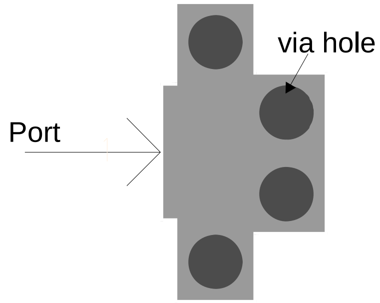
Layout

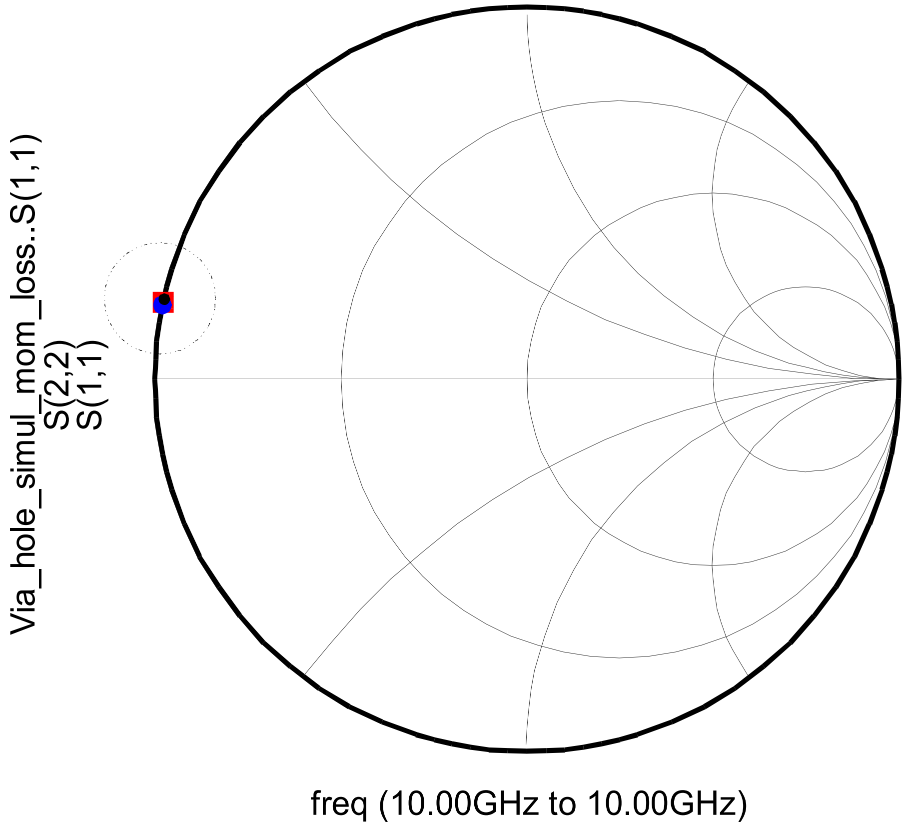
- AutoLayout
- Pattern Simulation
  - EM simulation and Trimming
- Manual Modification

Source Inductance

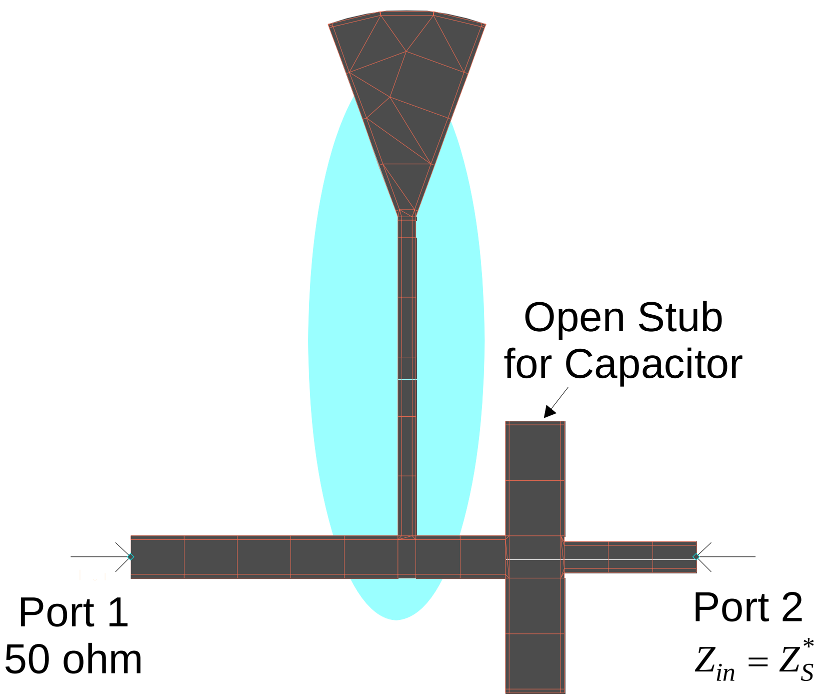


EM Design of Source Inductance





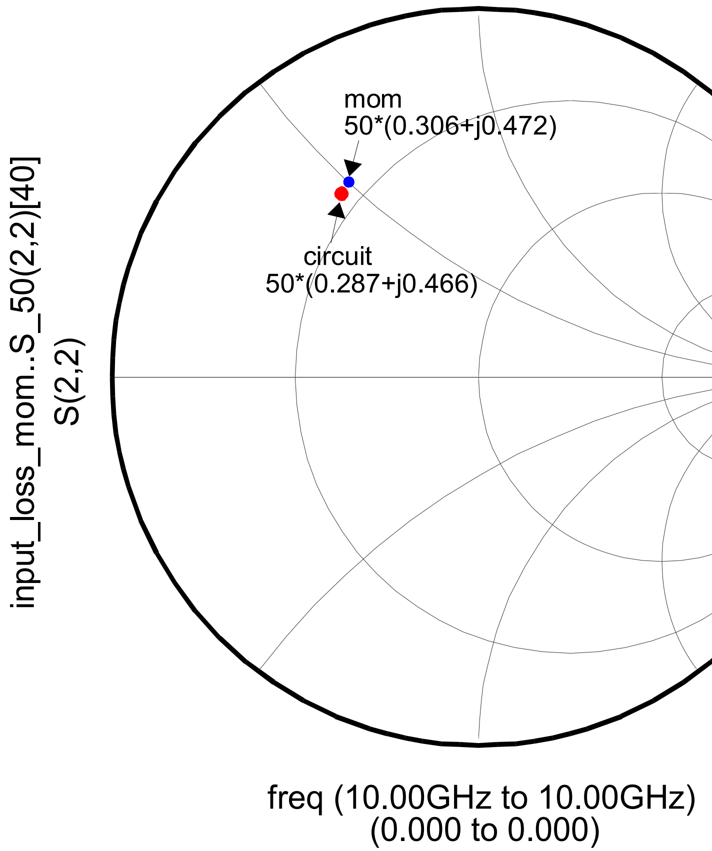
EM Tune of Matching Circuit



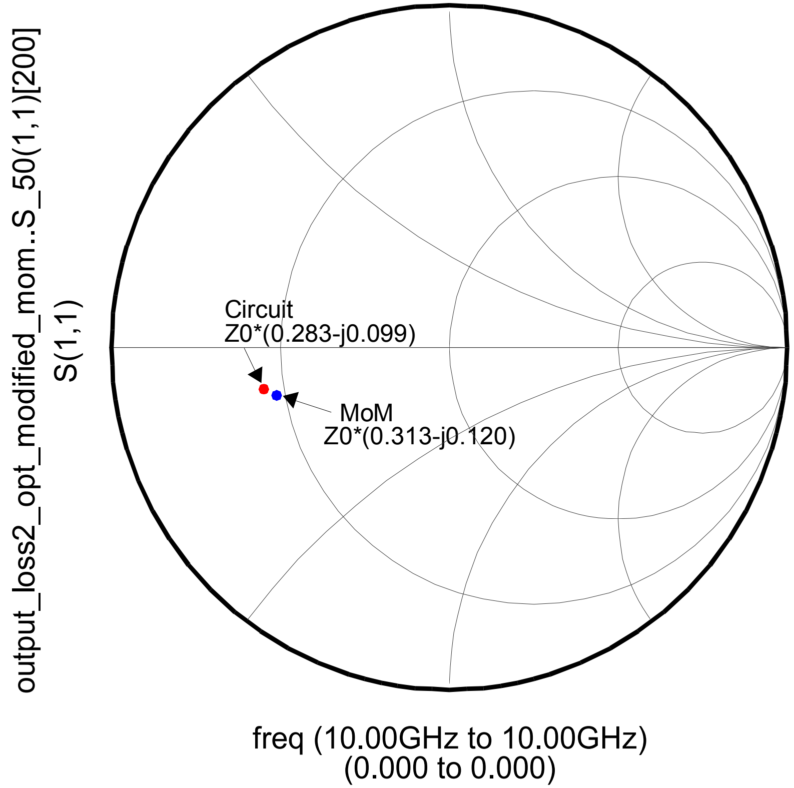
Stub length is tuned

DC Block capacitor excluded

Results

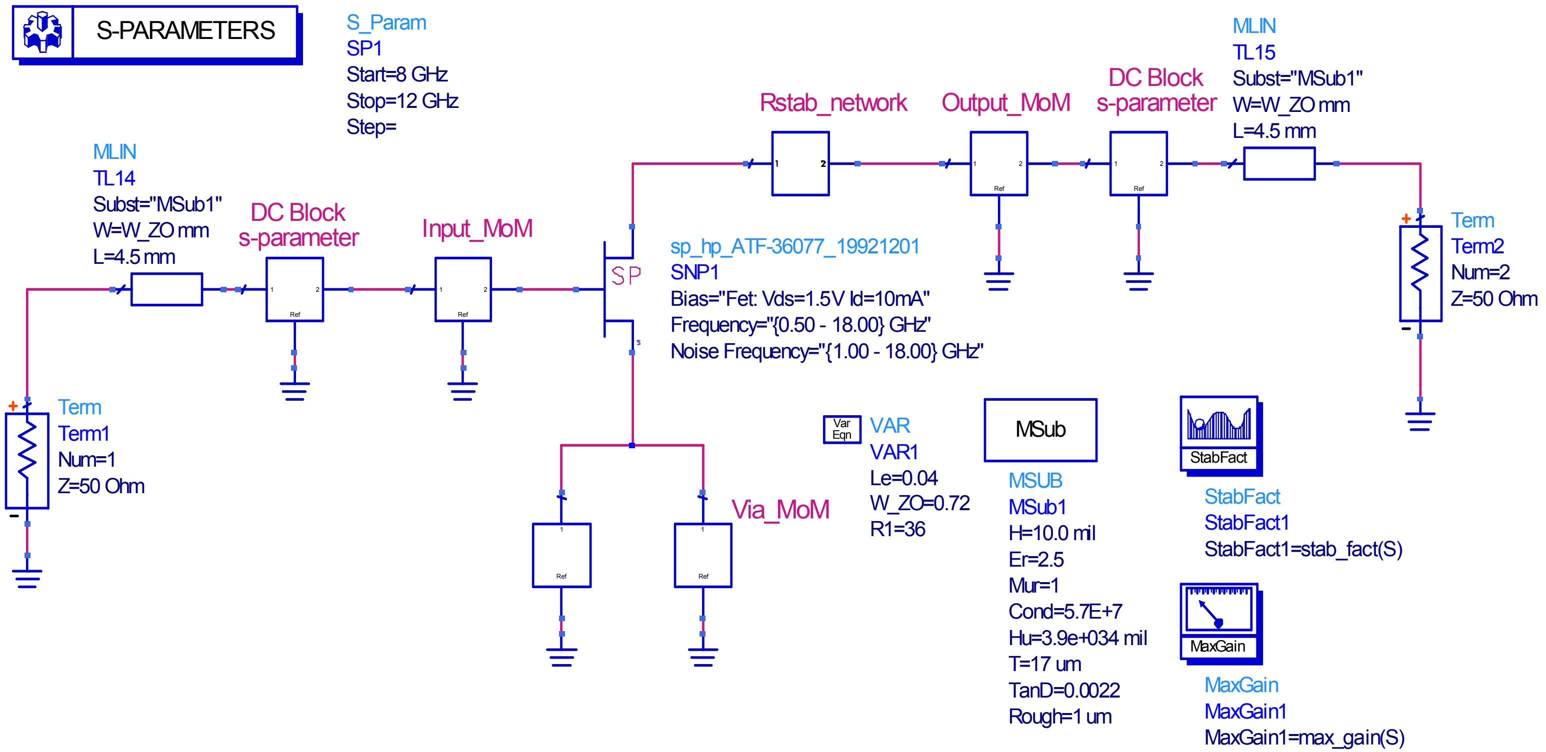


input_loss_mom..S_50(2,2)[40]
S(2,2)
mom
50*(0.306+j0.472)
circuit
50*(0.287+j0.466)
freq (10.00GHz to 10.00GHz)
(0.000 to 0.000)

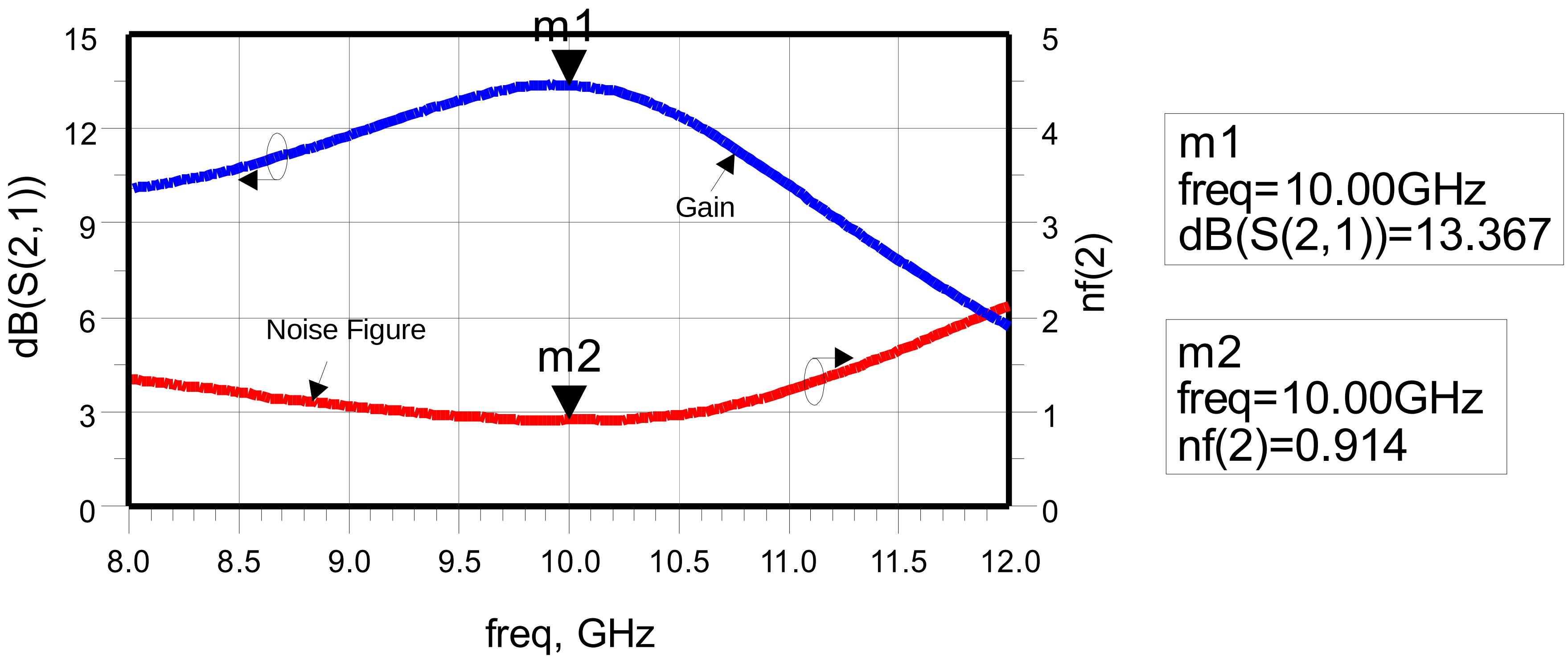


output_loss2_opt_modified_mom..S_50(1,1)[200]
S(1,1)
Circuit
Z0*(0.283-j0.099)
MoM
Z0*(0.313-j0.120)
freq (10.00GHz to 10.00GHz)
(0.000 to 0.000)

EM Verification

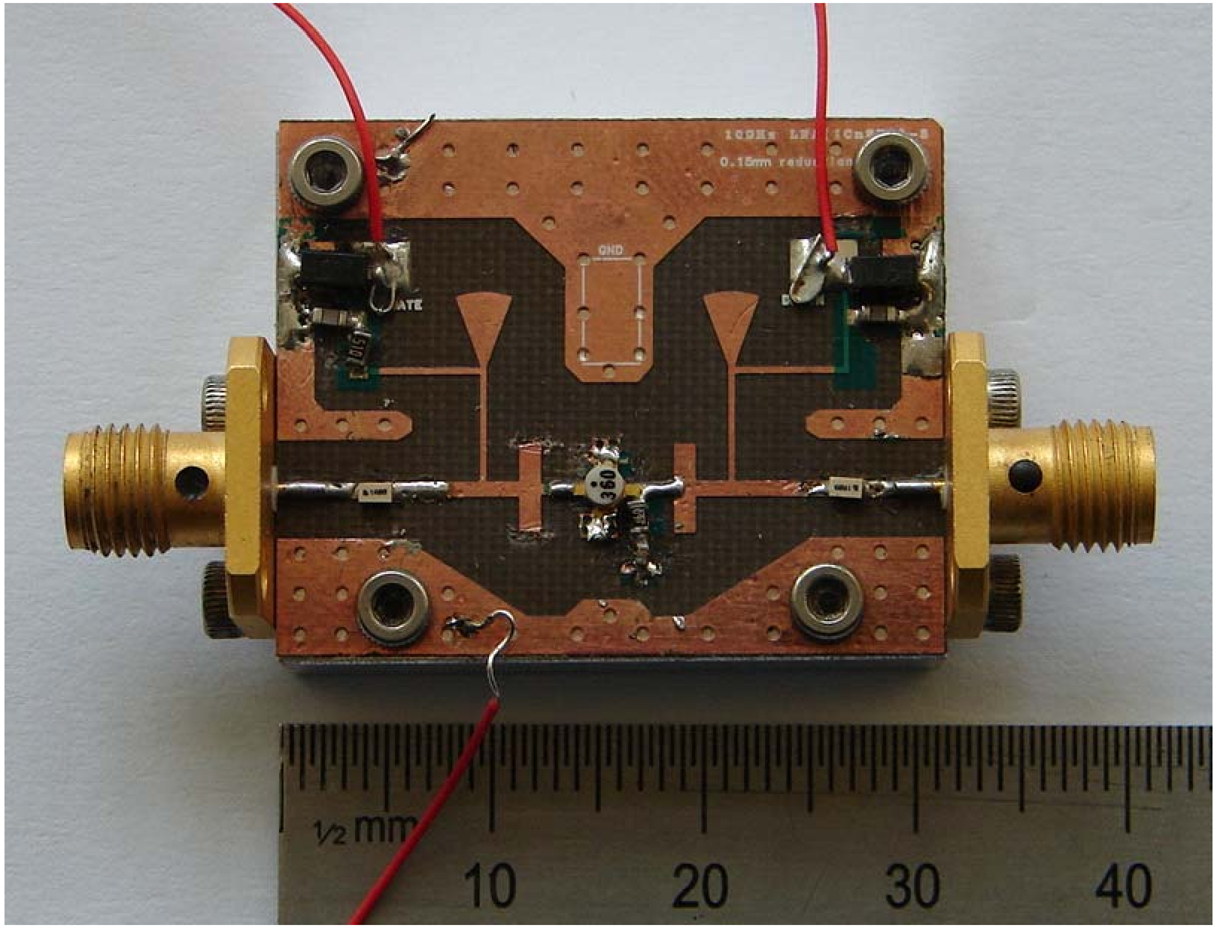


Results

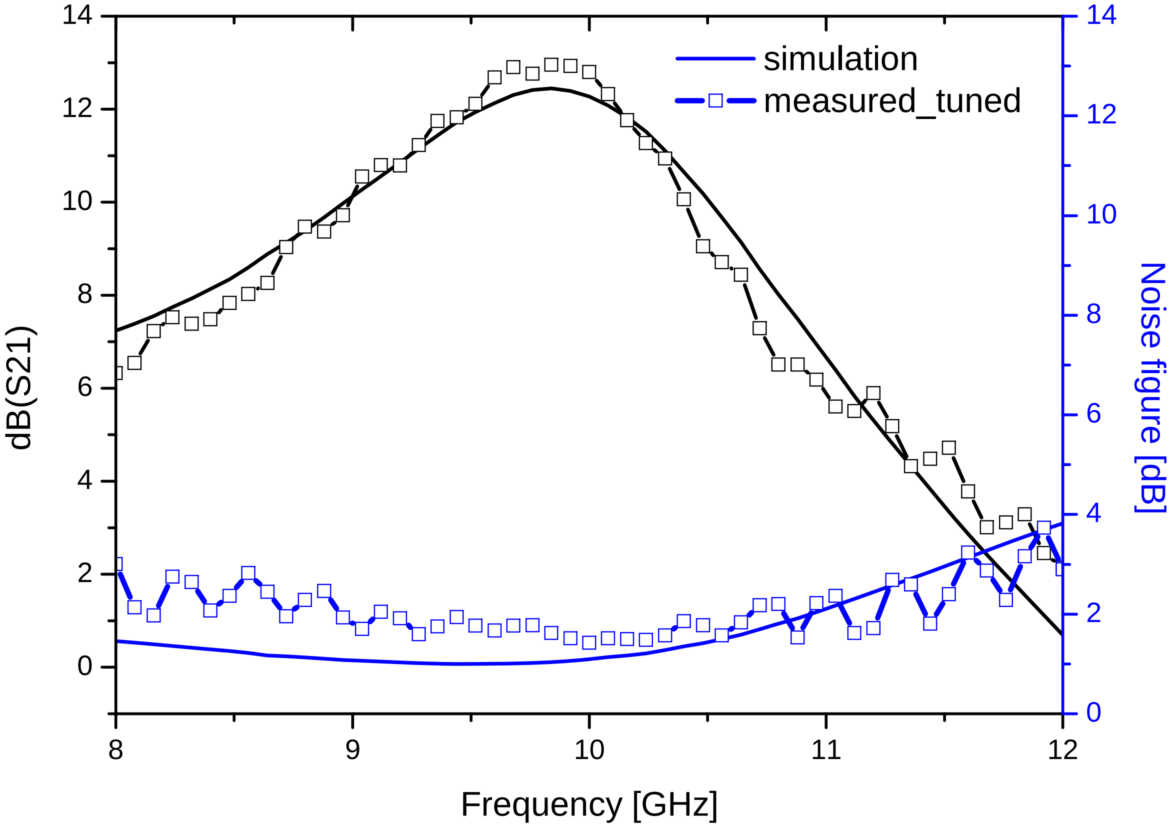


m1
m2
Gain
Noise Figure
15
12
9
6
3
0
5
4
3
2
1
0
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
freq, GHz
dB(S(2,1))
nf(2)
m1
freq=10.00GHz
dB(S(2,1))=13.367
m2
freq=10.00GHz
nf(2)=0.914

Fabrication



Measured Results



Reference

- Reference

[1]. Hewlett Packard, *HP85150B Microwave and RF design system*, 1995

[2]. G.D. Vendelin et al, *Microwave circuit design*, John and Wiley & Sons, 1990.

[3]. H. Fukui, *Low noise microwave transistors & amplifiers*, IEEE Press, 1981