# Basics of RF Amplifier Design

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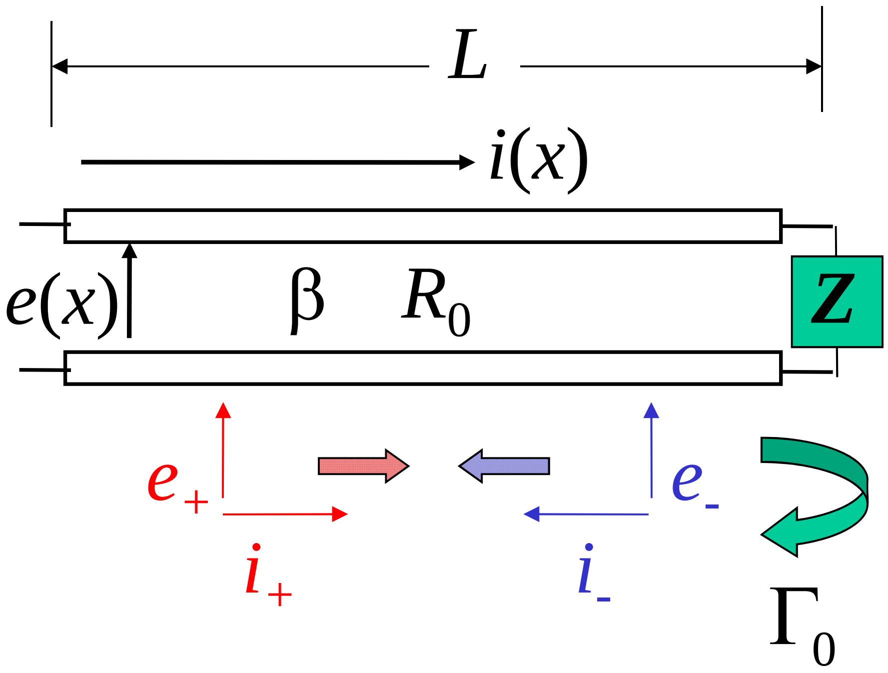
# Voltage Reflection Coefficient




$$\Gamma_0 = \frac{e_-}{e_+} = \frac{Z - R_0}{Z + R_0} = \frac{G_0 - Y}{G_0 + Y}$$

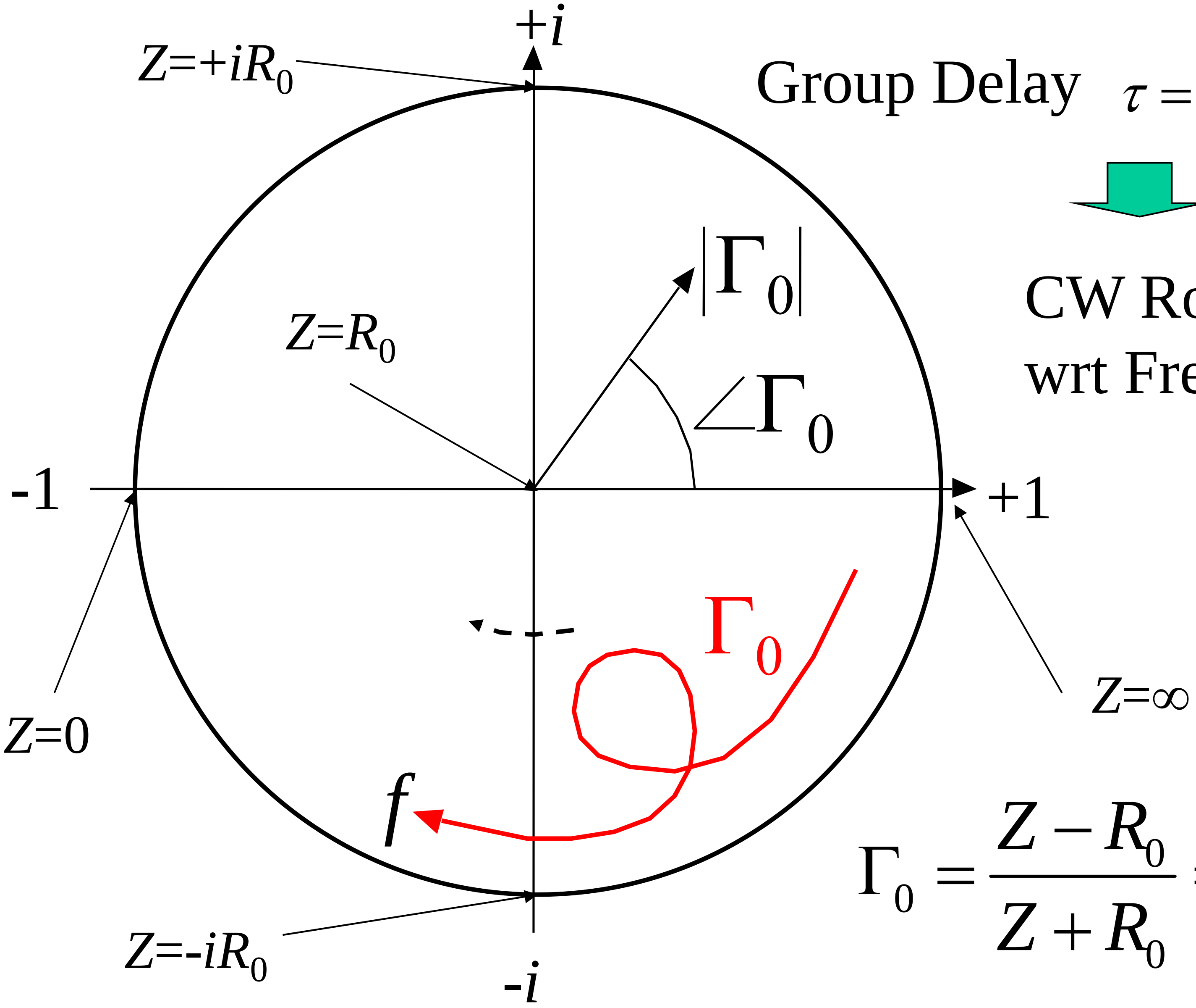
where $Y = Z^{-1}$

Measurable by Vector Network Analyzer

(Usually $R_0$=50 Ω)

$$\Rightarrow \quad Z = R_0 \frac{1+\Gamma_0}{1-\Gamma_0}$$

# Variation of Reflection Coefficient $\Gamma_0$

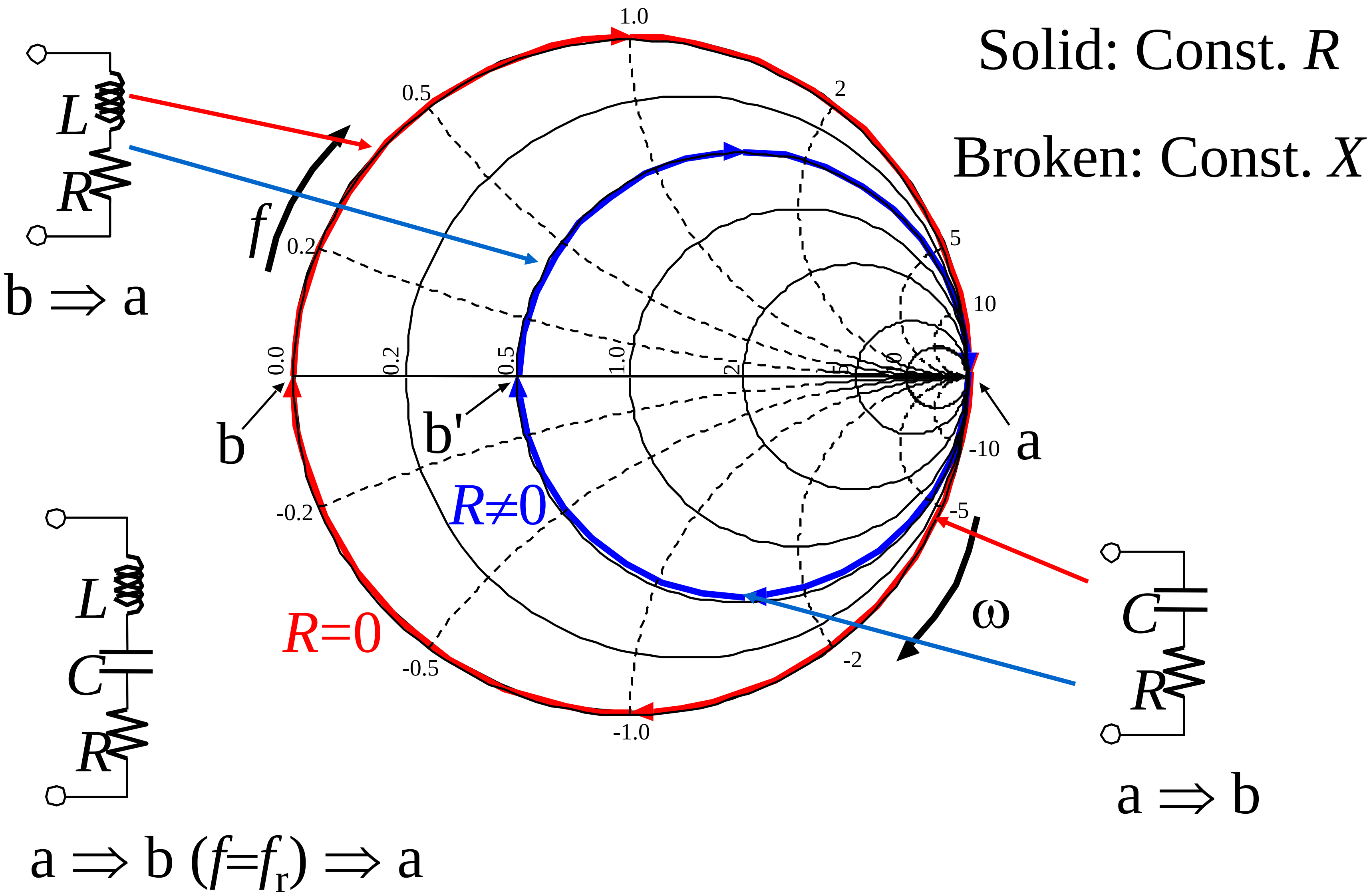



Group Delay $\tau = -\dfrac{\partial[\angle\Gamma_0]}{\partial\omega}$

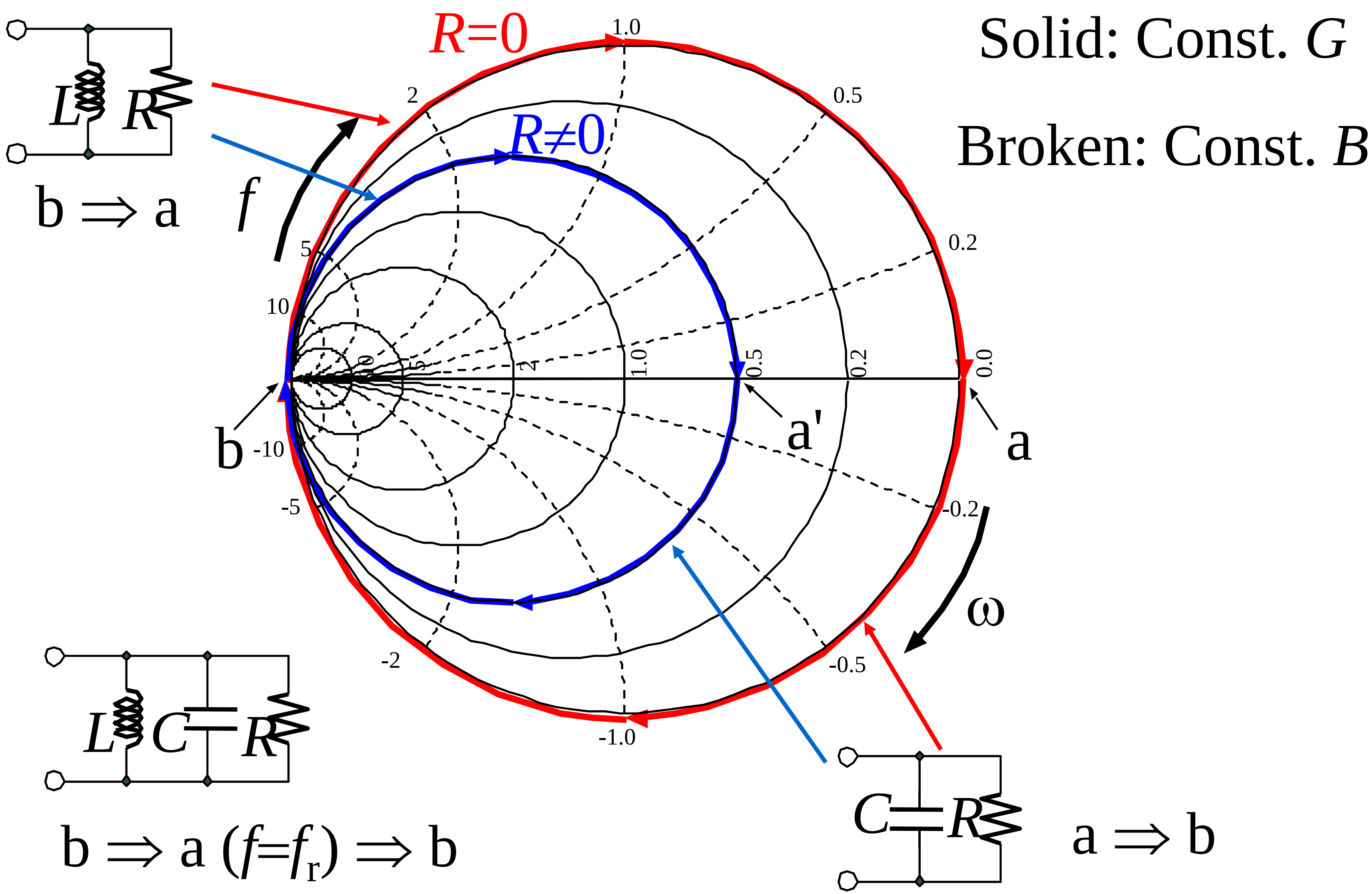
CW Rotation wrt Frequency

$$\Gamma_0 = \frac{Z - R_0}{Z + R_0} = \frac{G_0 - Y}{G_0 + Y}$$

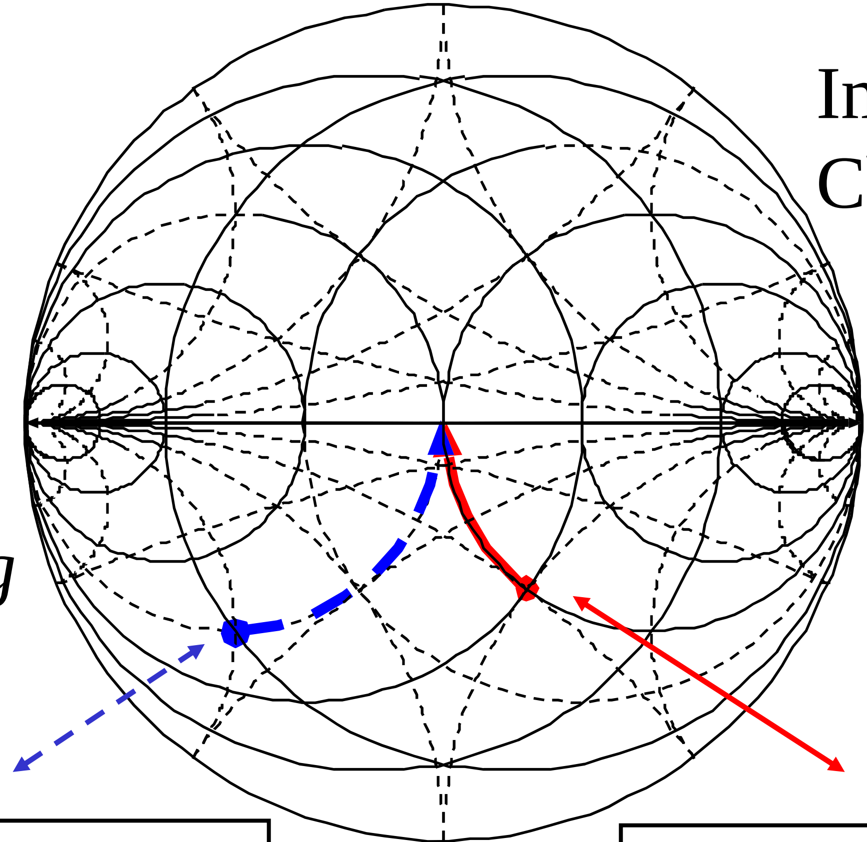
# Smith Chart (Impedance Plot)



# Smith Chart (Admittance Plot)



# Impedance Matching




*Parallel Tuning*

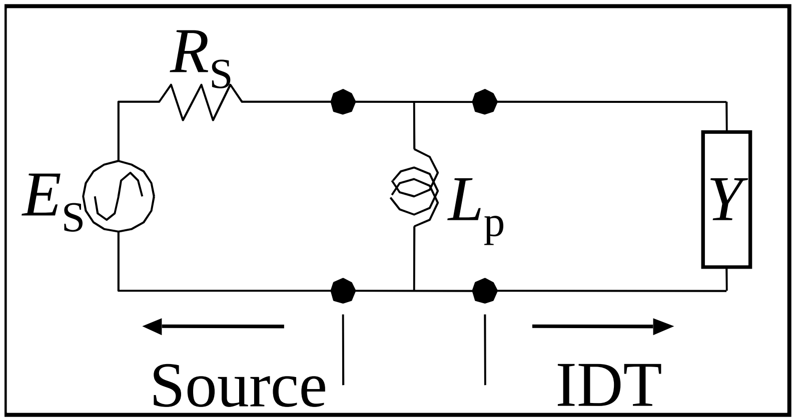
$R_S = \mathrm{Re}[Y]^{-1}$

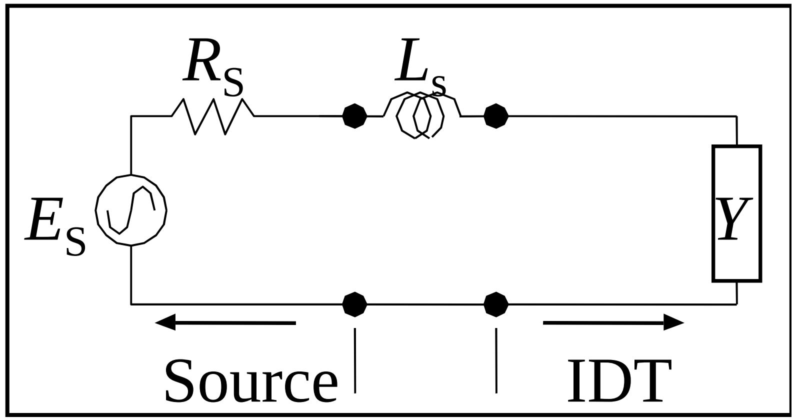
$\omega L_p = -\mathrm{Im}[Y]^{-1}$

*Series Tuning*

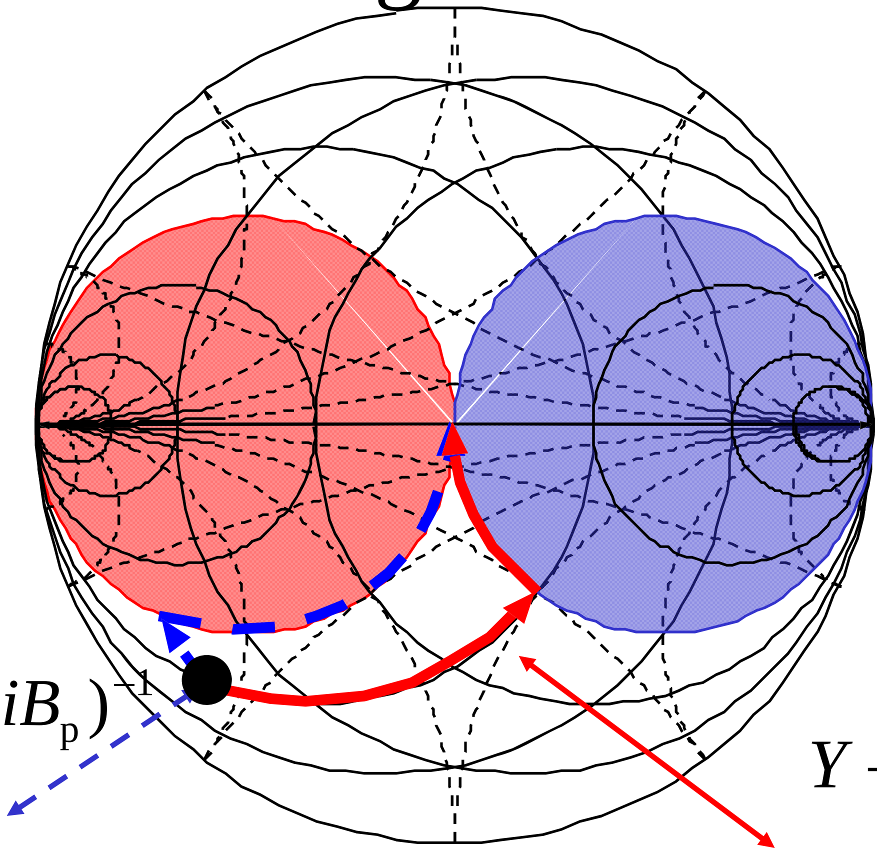
$R_S = \mathrm{Re}[Y^{-1}]$

$\omega L_s = -\mathrm{Im}[Y^{-1}]$



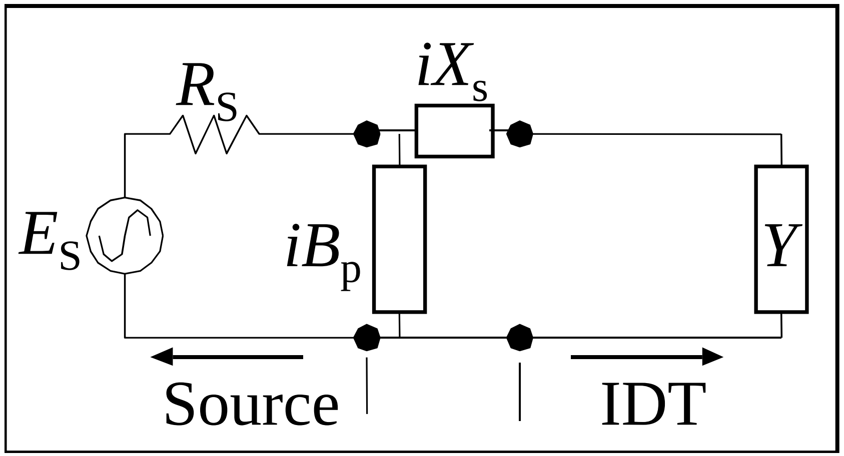



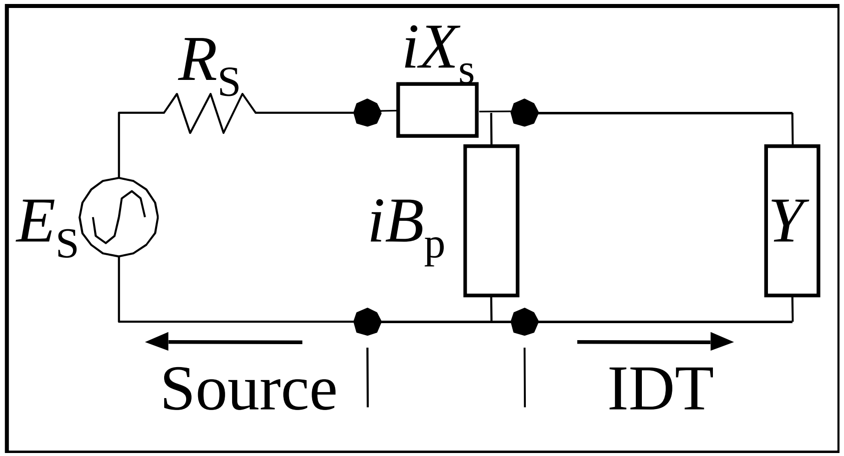
# Series+Parallel Tuning



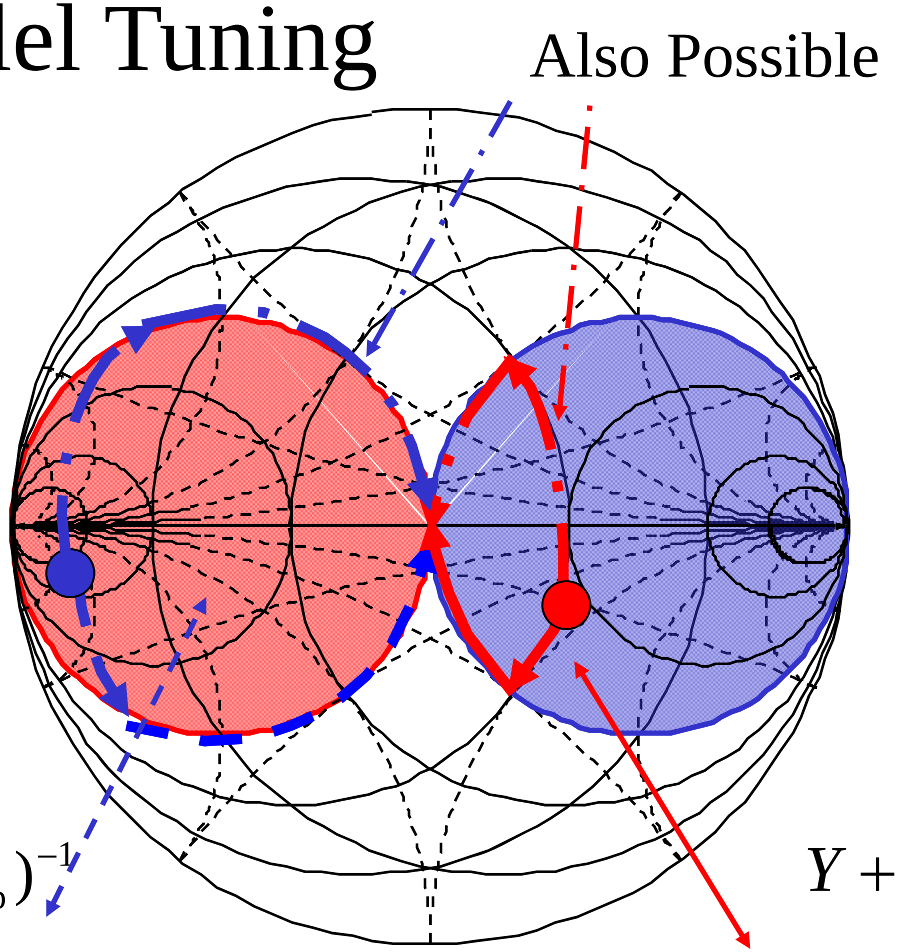
$$Y^{-1} + iX_s = (R_S^{-1} - iB_p)^{-1}$$

$$Y + iB_p = (R_S - iX_s)^{-1}$$



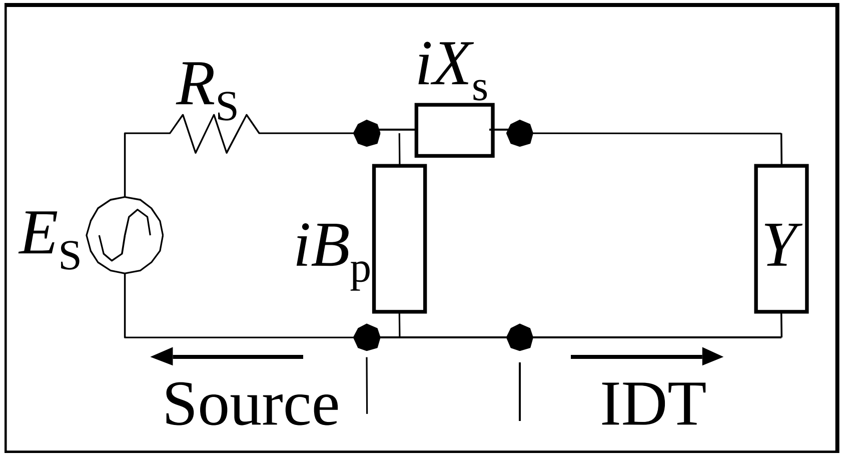



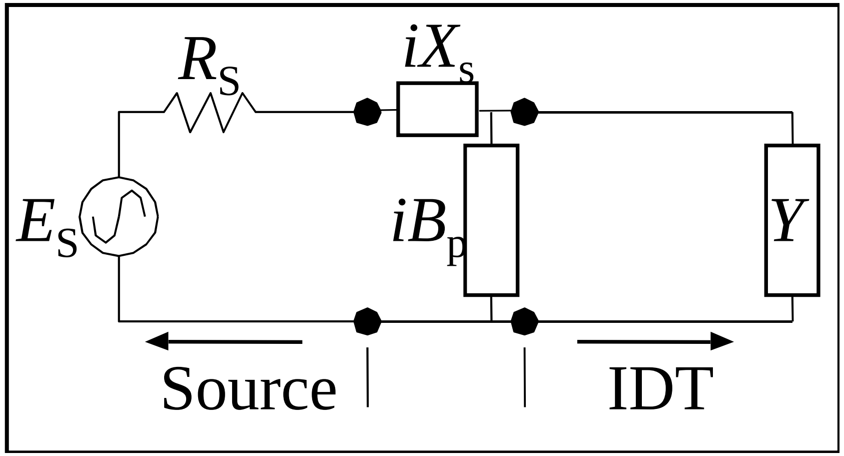
# Series+Parallel Tuning



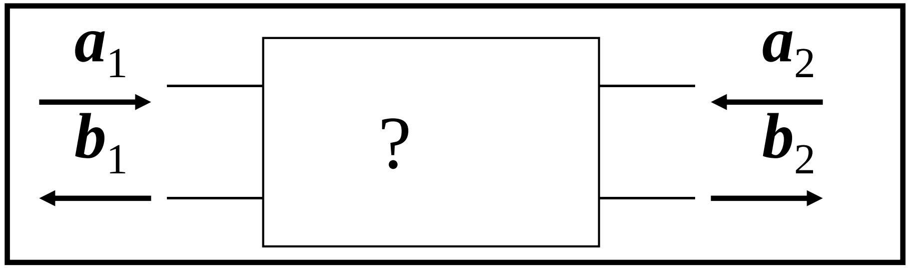

$$Y^{-1} + iX_s = (R_S^{-1} - iB_p)^{-1}$$

$$Y + iB_p = (R_S - iX_s)^{-1}$$



# Scattering Parameters (VNA Output)




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

$a_n$: Amplitude of Input Signal

$b_n$: Amplitude of Reflected Signal

$S_{nm}=S_{mn}$ for Passives (Reciprocity)

Normalized Amplitude : $|\boldsymbol{a}_n|^2$ Corresponds to Unit Power

Unit: dBm (mW)

$$a_n = \frac{V_n + R_0 I_n}{2\sqrt{R_0}}$$

$$b_n = \frac{V_n - R_0 I_n}{2\sqrt{R_0}}$$

$$\Rightarrow$$

$$\mathbf{Z} = R_0[\mathbf{I}+\mathbf{S}][\mathbf{I}-\mathbf{S}]^{-1}$$

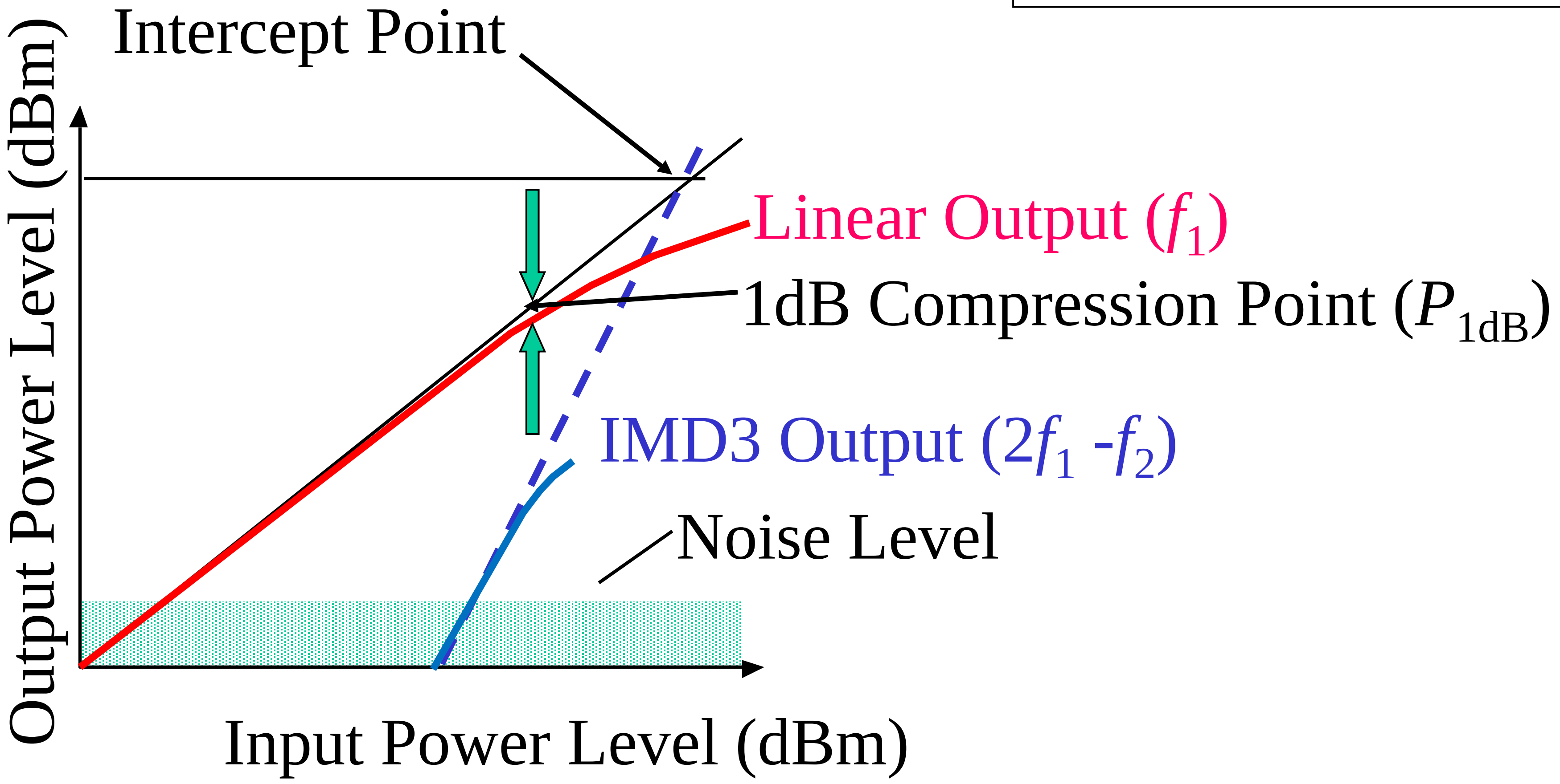
$$\mathbf{Y} = R_0^{-1}[\mathbf{I}-\mathbf{S}][\mathbf{I}+\mathbf{S}]^{-1}$$

**I**: Unit Matrix

# 3rd order Intercept Point (IP3)

Generation of Jammer signals by Intermodulation

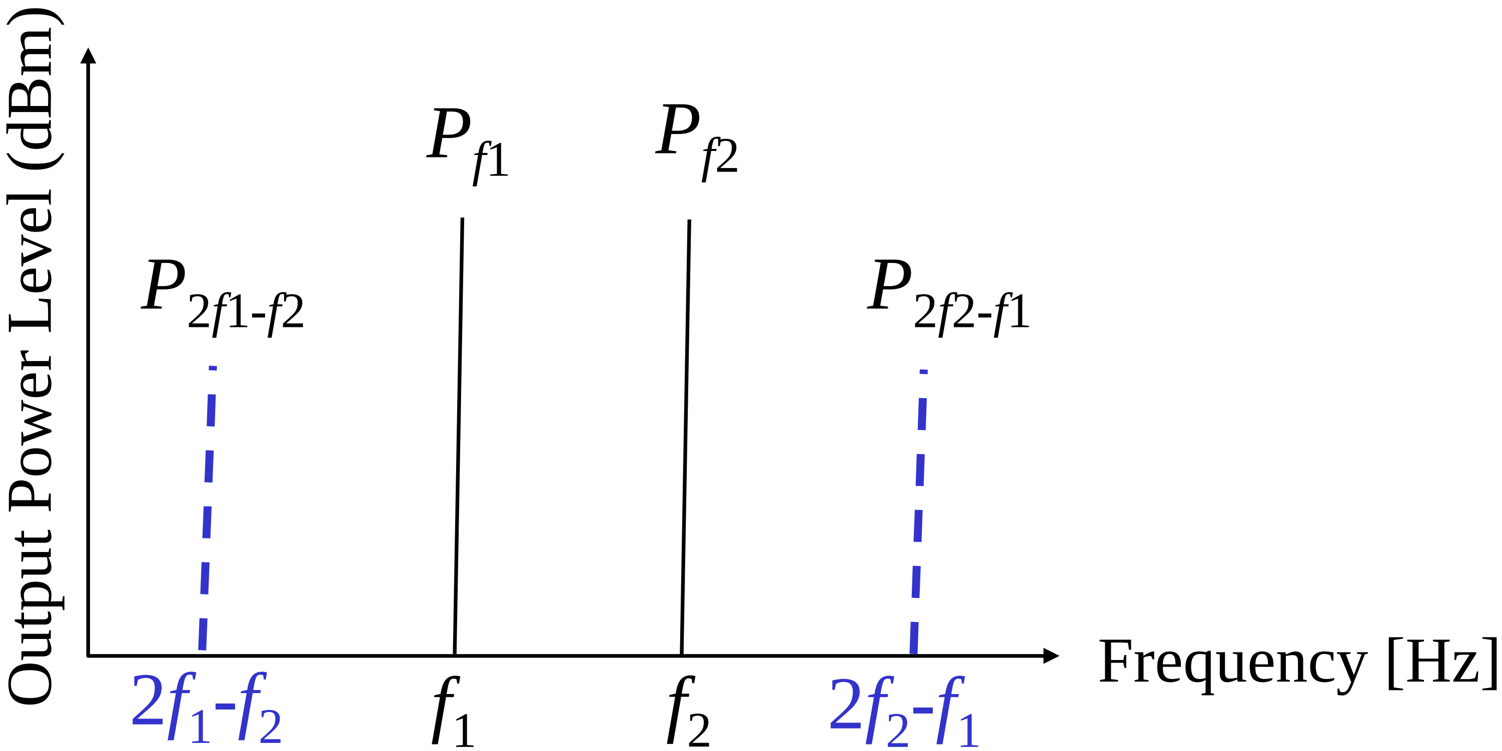
$IIP3 \approx P_{1dB} + 9.6$ [dB]



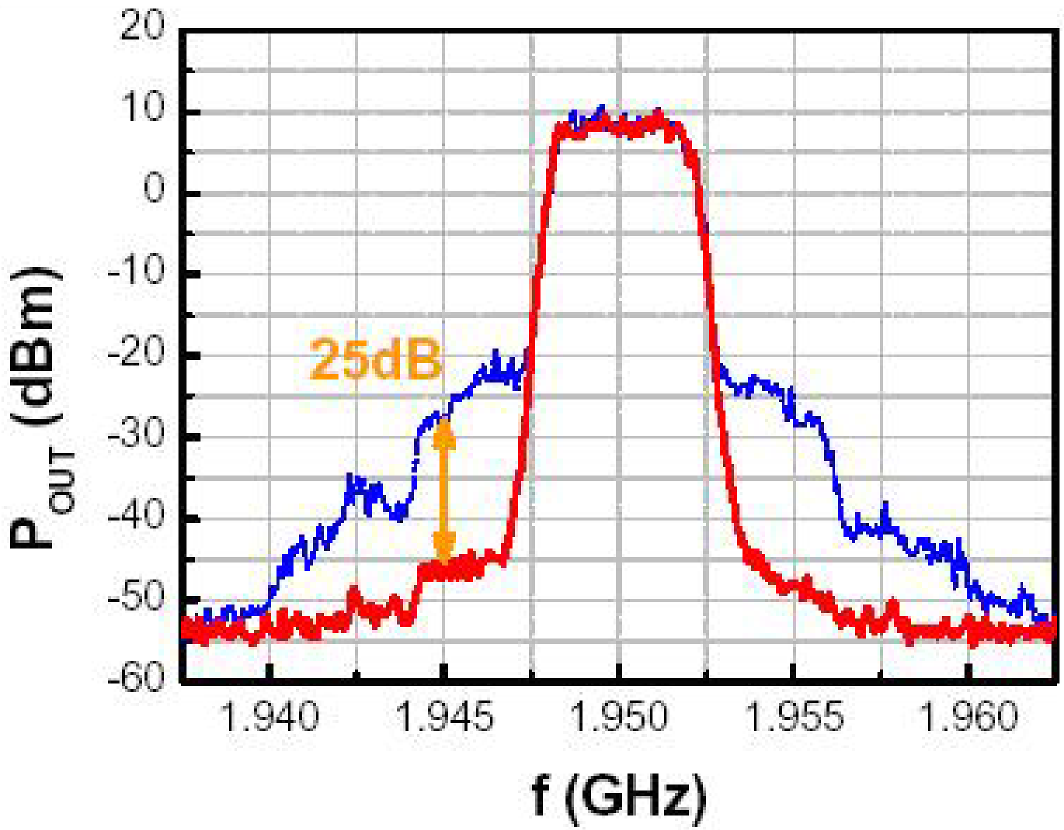
# 3rd order Intercept Point (IP3)

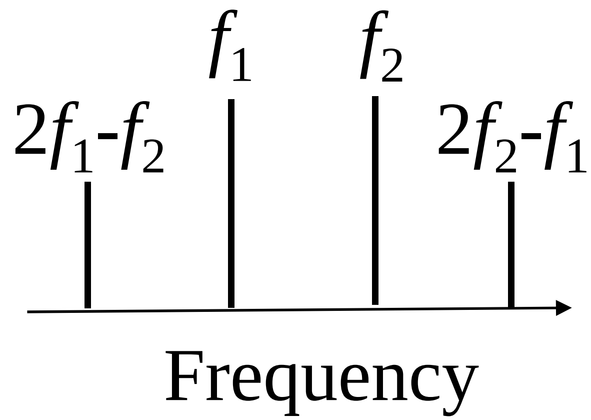
$$P_{2f1\text{-}f2}\,[\text{dBm}] = 2P_{f1}\,[\text{dBm}] + P_{f2}\,[\text{dBm}] - 2 \times \text{IP3}\,[\text{dBm}]$$

$$P_{2f2\text{-}f1}\,[\text{dBm}] = 2P_{f2}\,[\text{dBm}] + P_{f1}\,[\text{dBm}] - 2 \times \text{IP3}\,[\text{dBm}]$$



# Spectrum Regrowth in PA and DPX = Self Mixing of Tx Signals

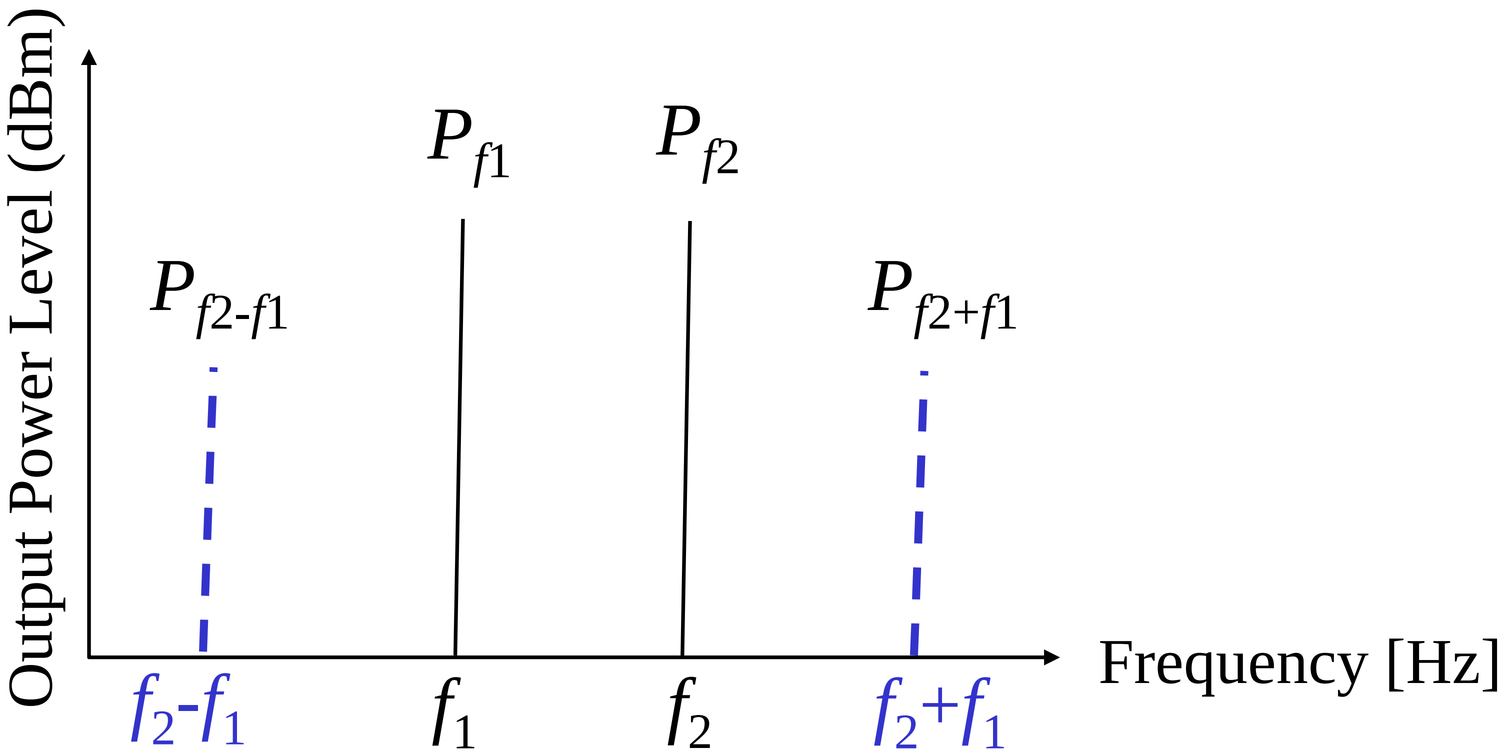


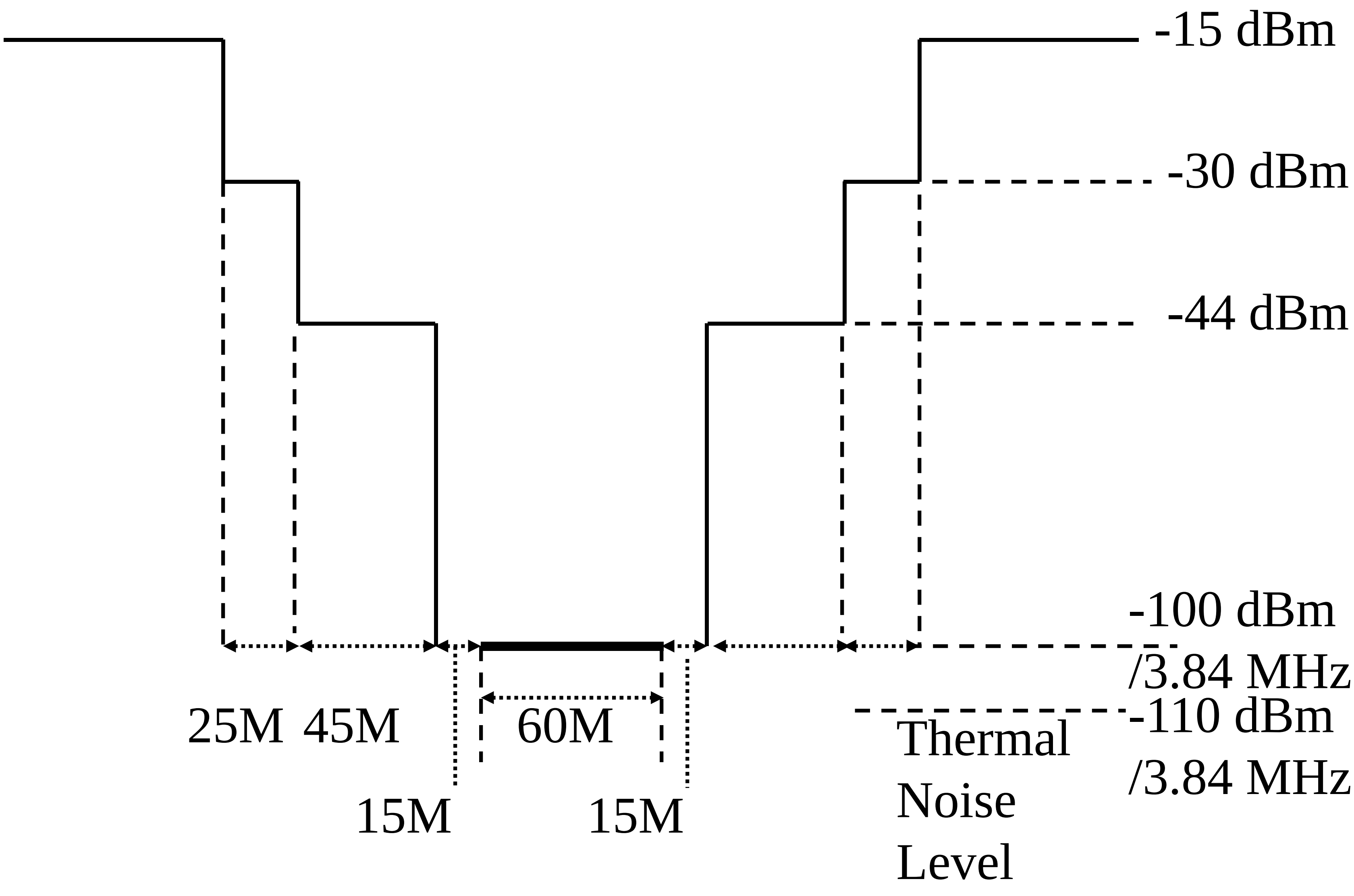

**Jammer Signal Emission to Adjacent Channels**

# 2nd order Intercept Point (IP2)

$P_{f2\pm f1}$ [dBm] = $P_{f2}$ [dBm] + $P_{f1}$ [dBm] –IP2 [dBm]



# Blocking Test Example（W-CDMA Band II）

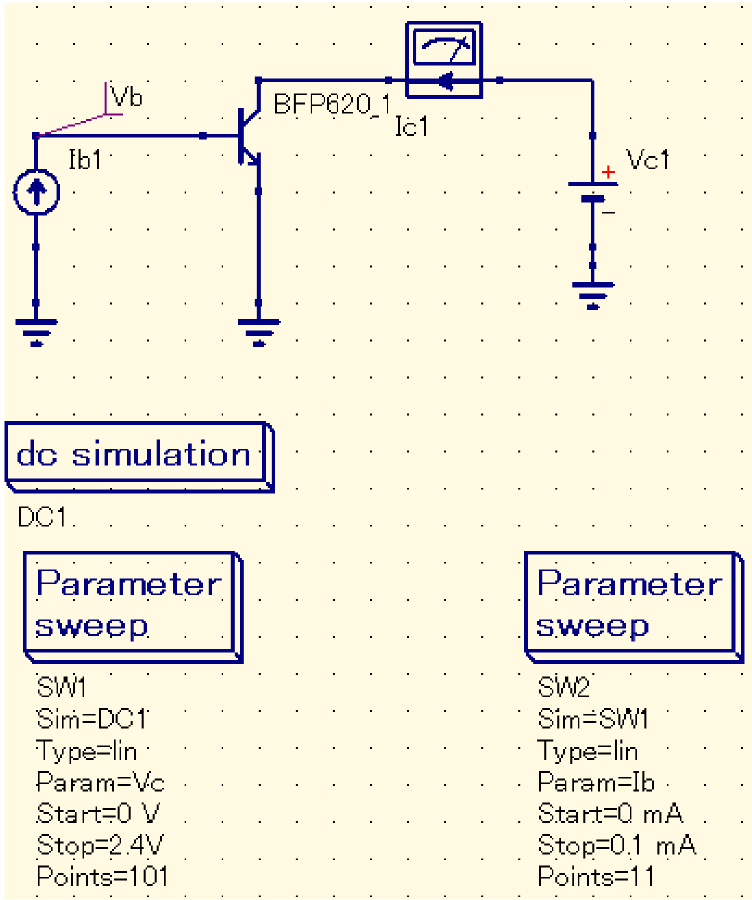


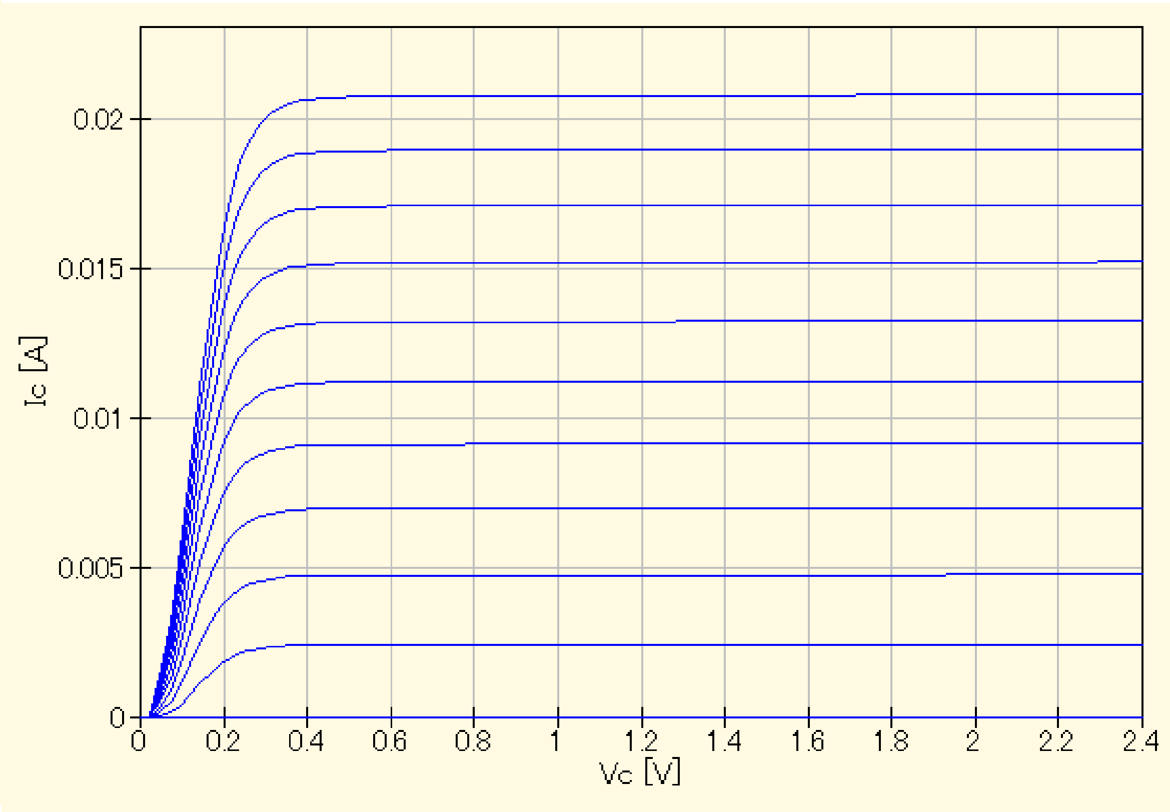
# Contents

- Low Noise Amplifier Design Example

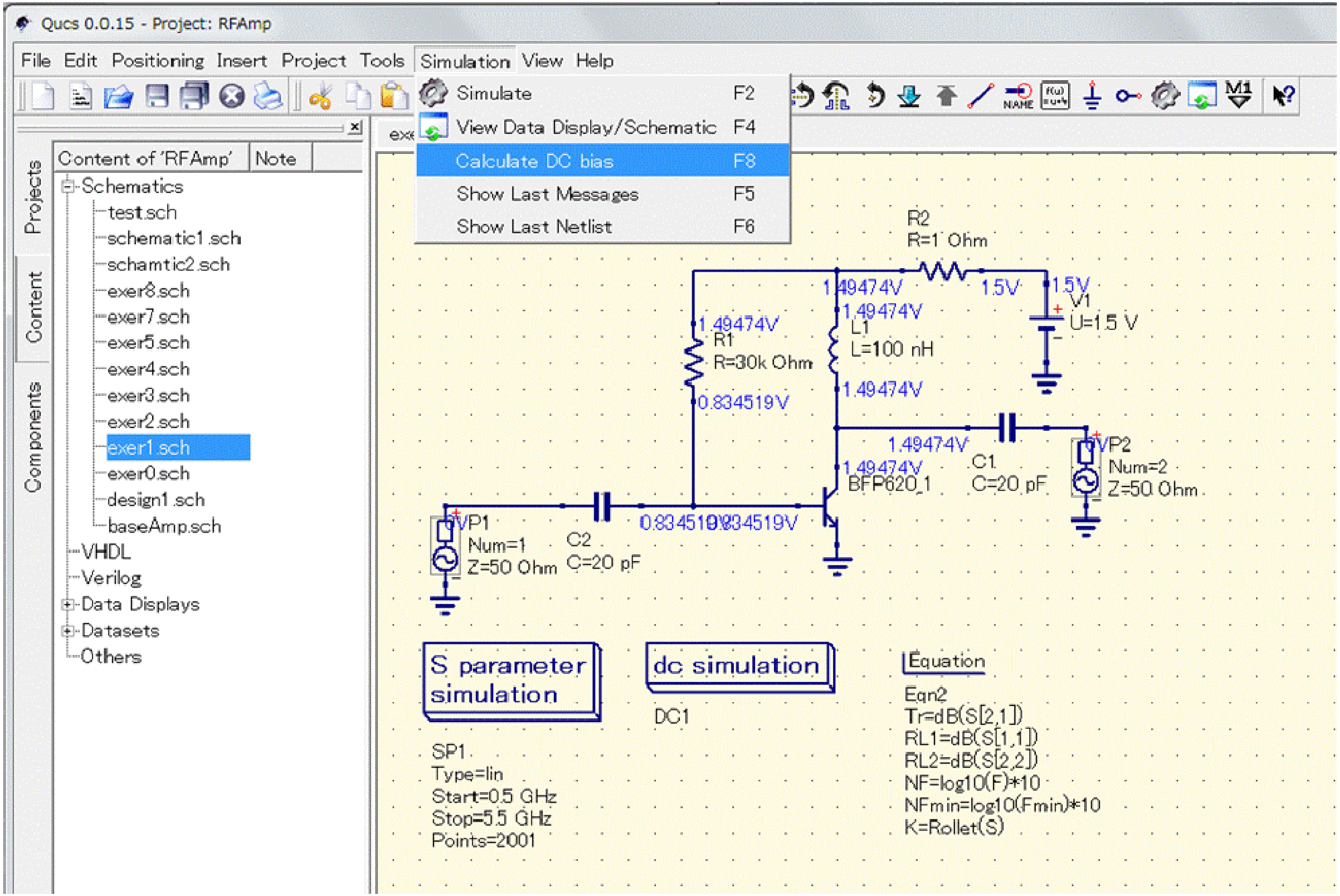
# Use of High Speed Transistor BFP620

Design Low Noise Amplifier at 2.488 GHz. $V_{cc}$=1.5 V and $I_c$=5 mA. Low NF and Return Suppression Mandatory. How High Gain Achievable?

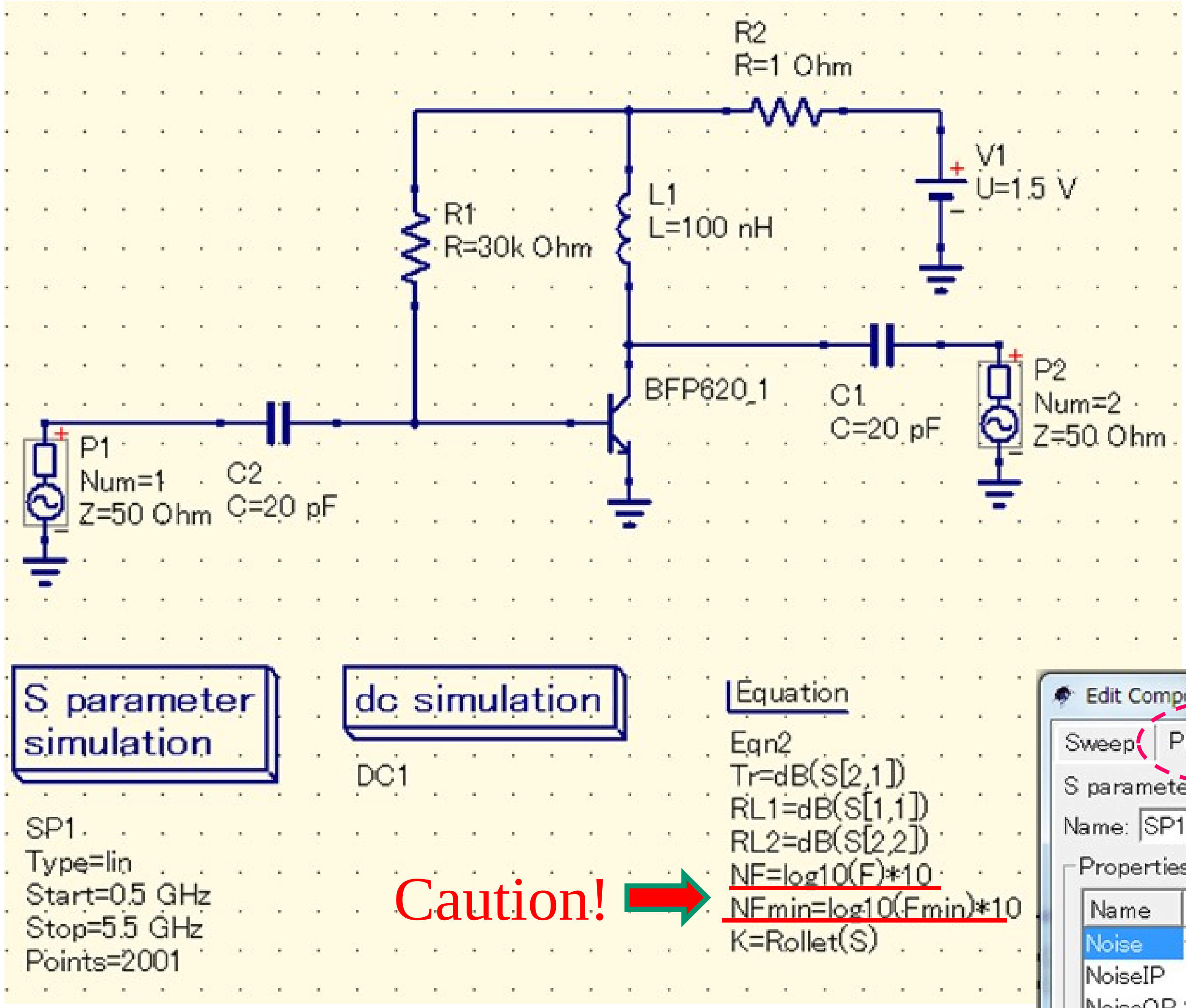


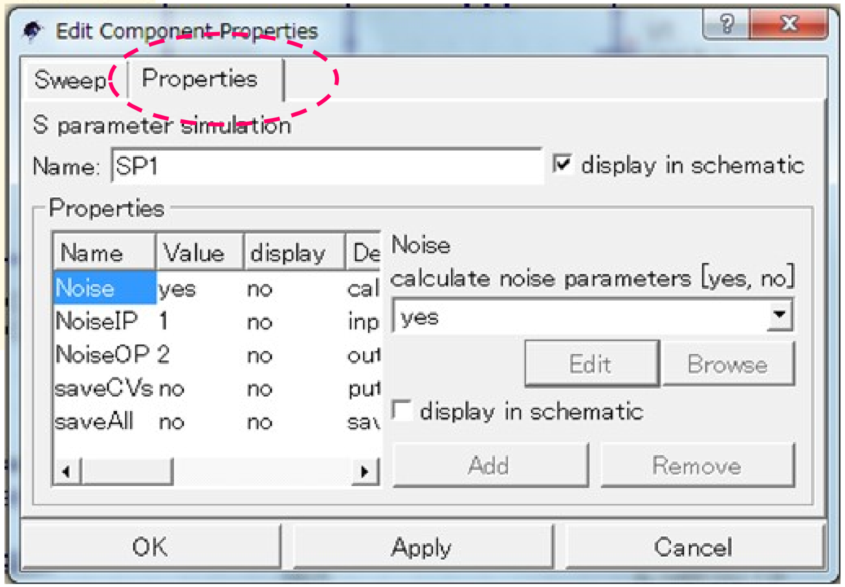



# Step 1 Bias Circuit Design

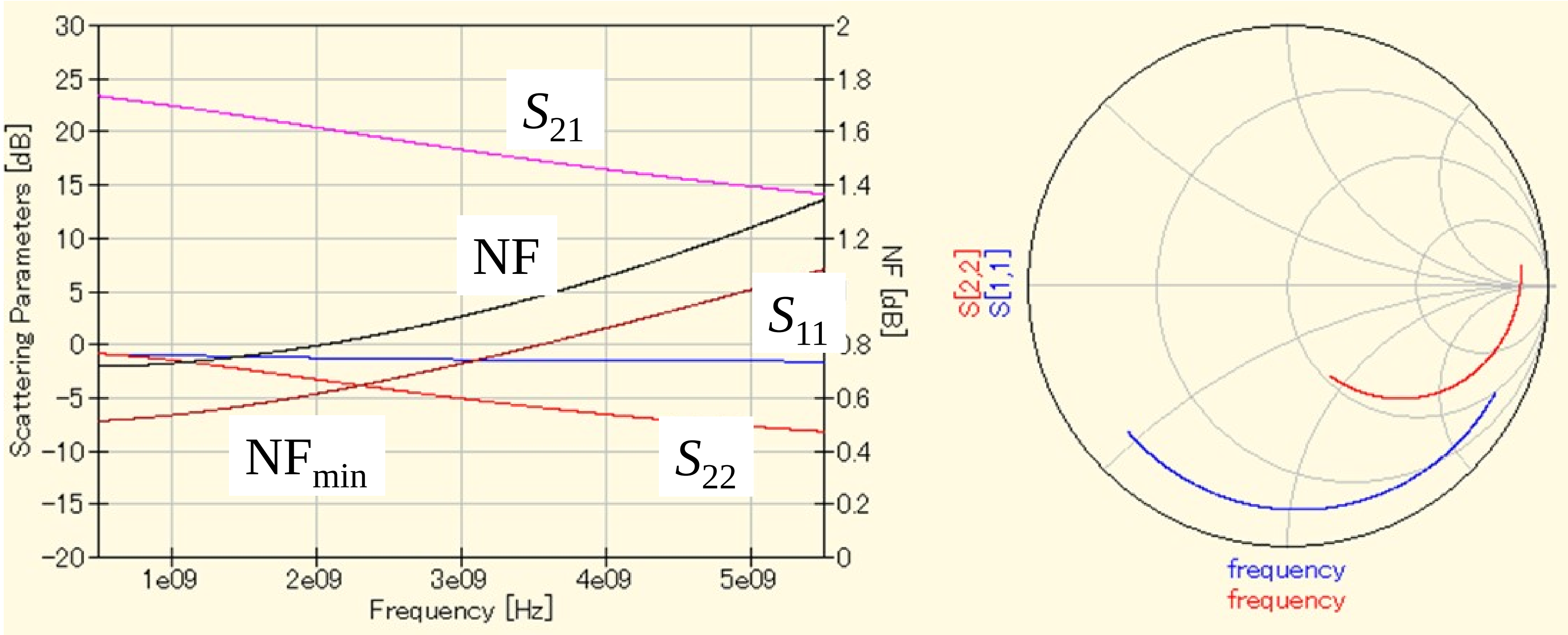


# Step 2 *S* Parameter Simulation



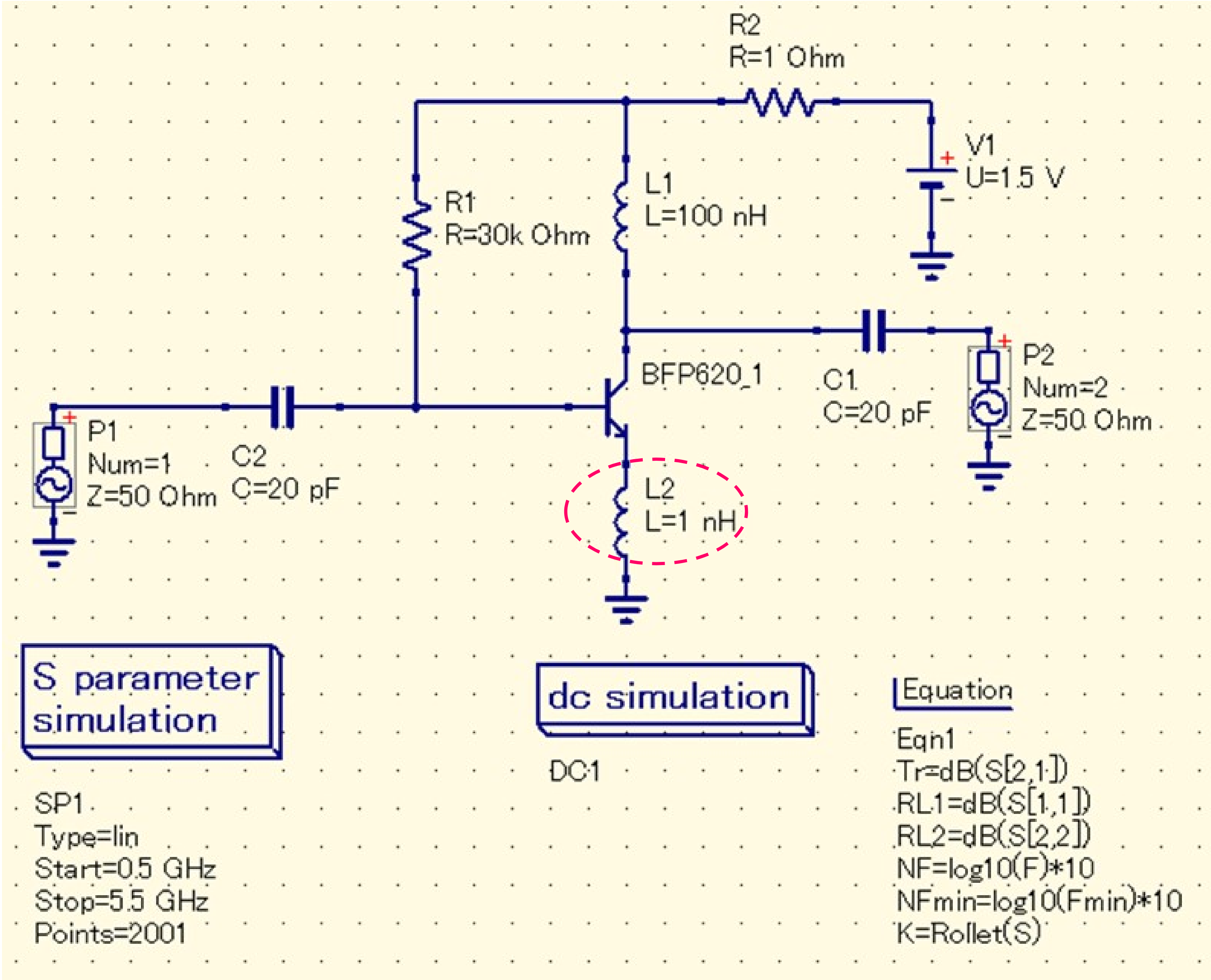



# S Simulation Result

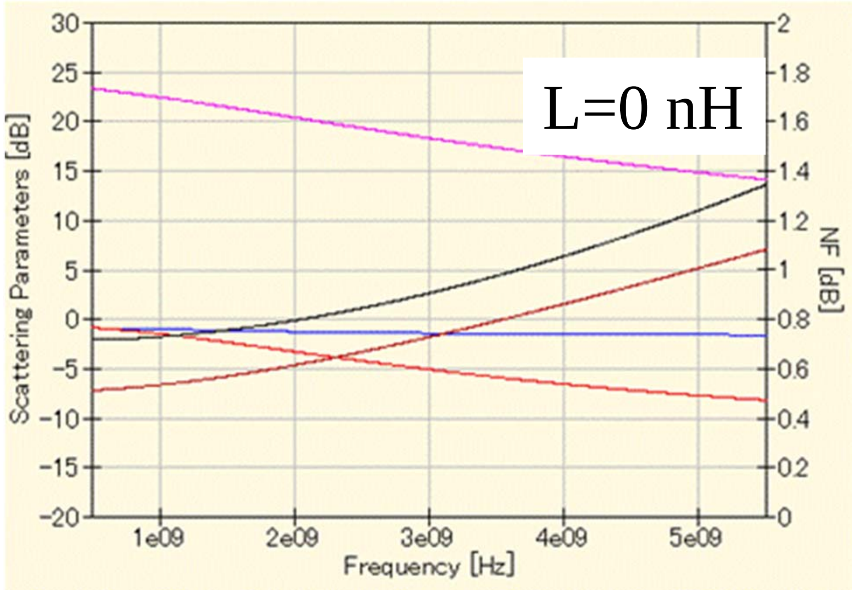


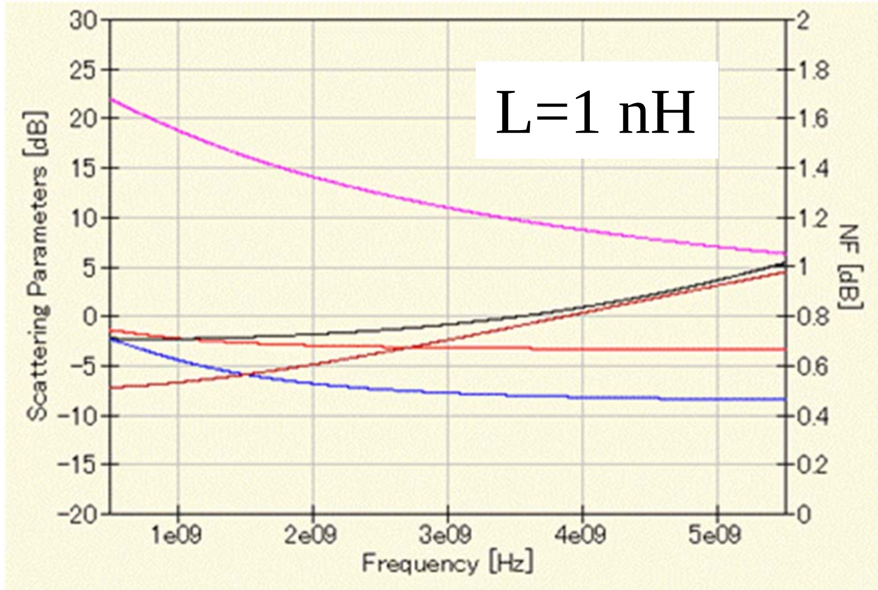

$NF_{min}$: Achievable minimum NF at the given frequency

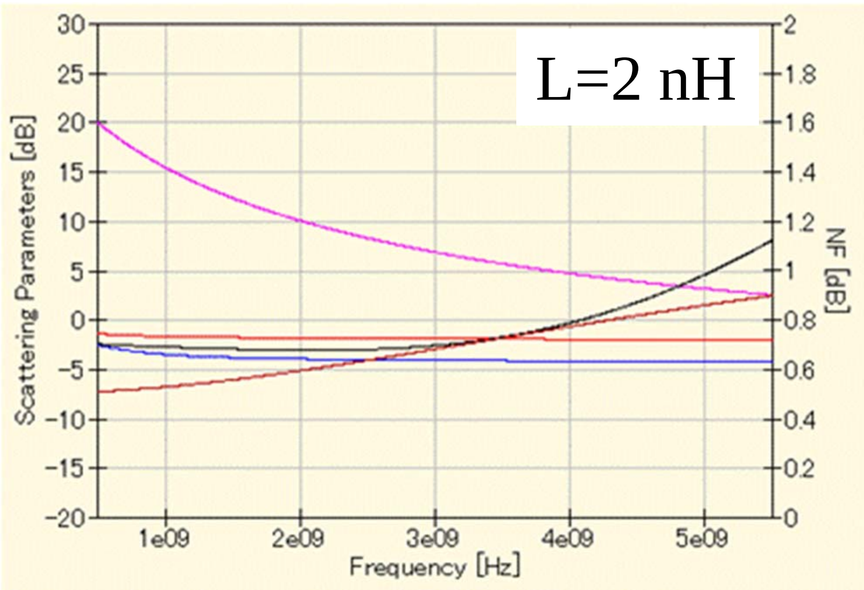
# Impact of Emitter Degeneration Inductor

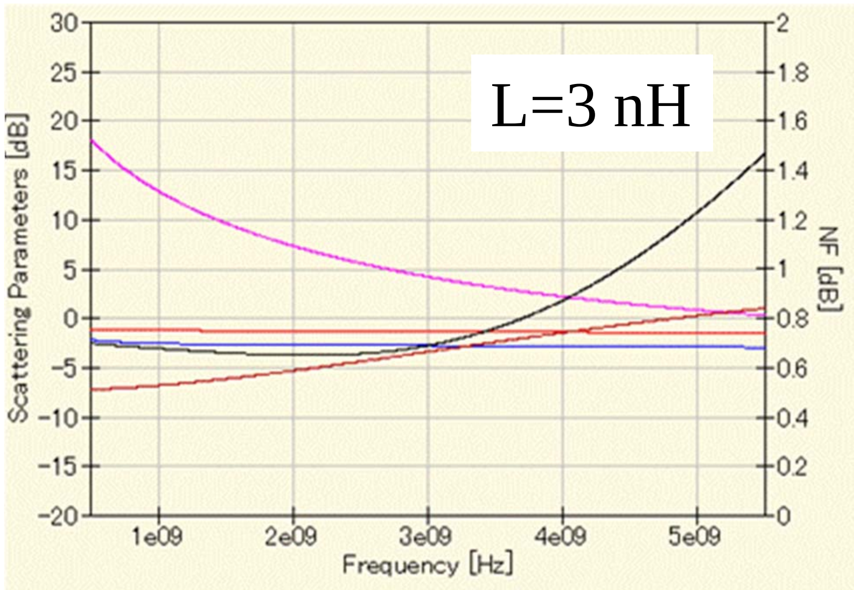


# Simulation Results



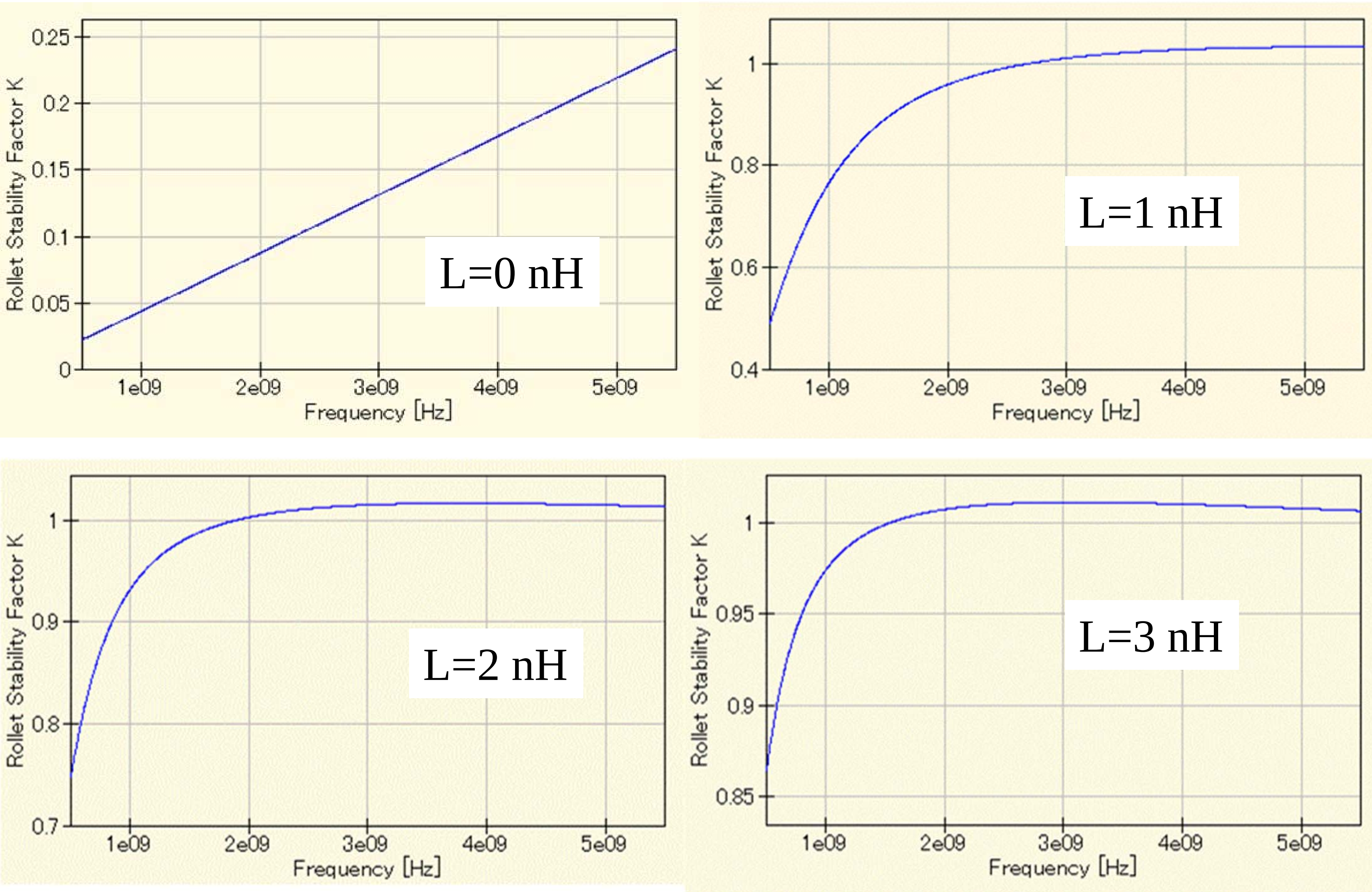



# Rollet Stability (*K*) Factor

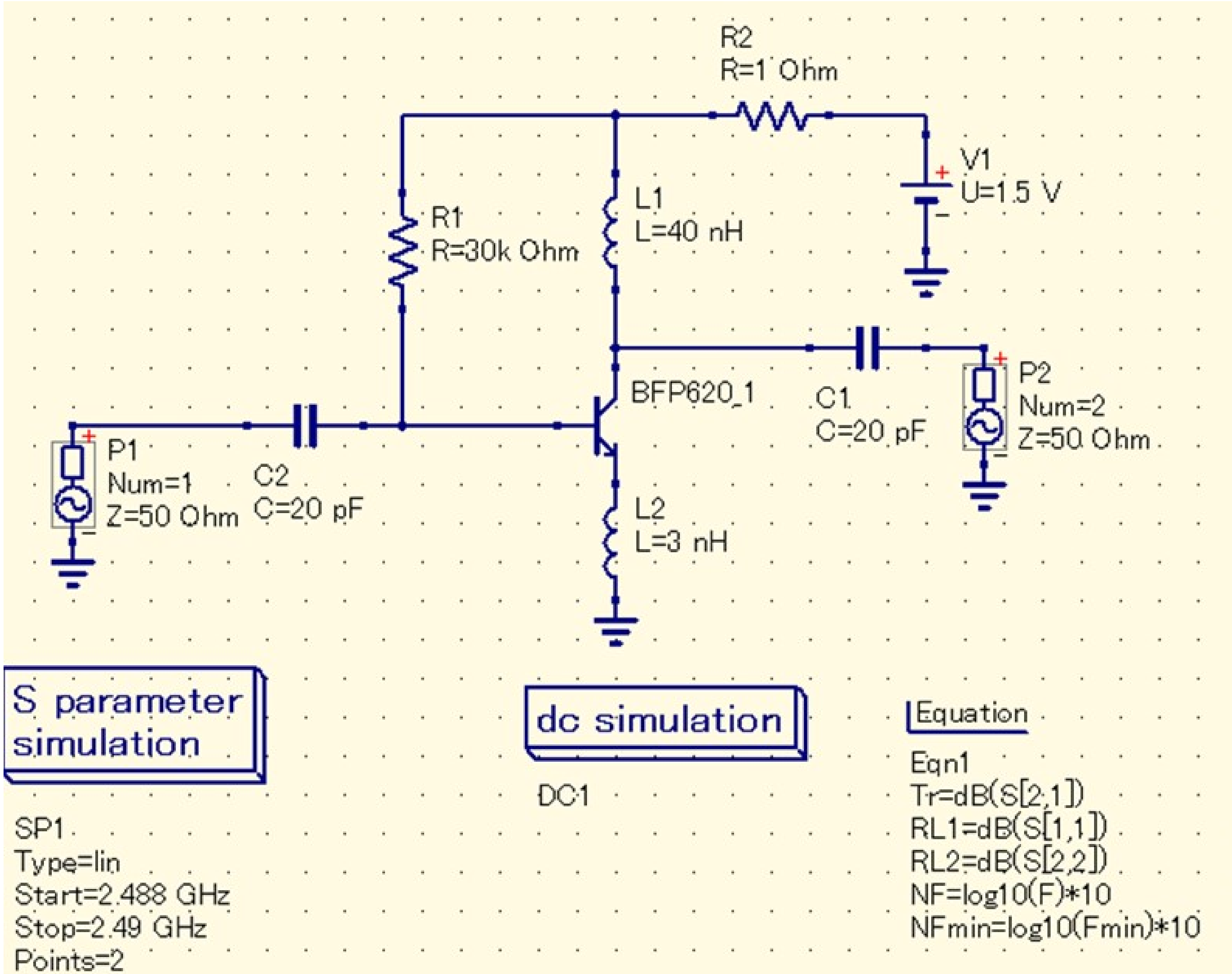
Unconditionally Stable When *K*>1

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

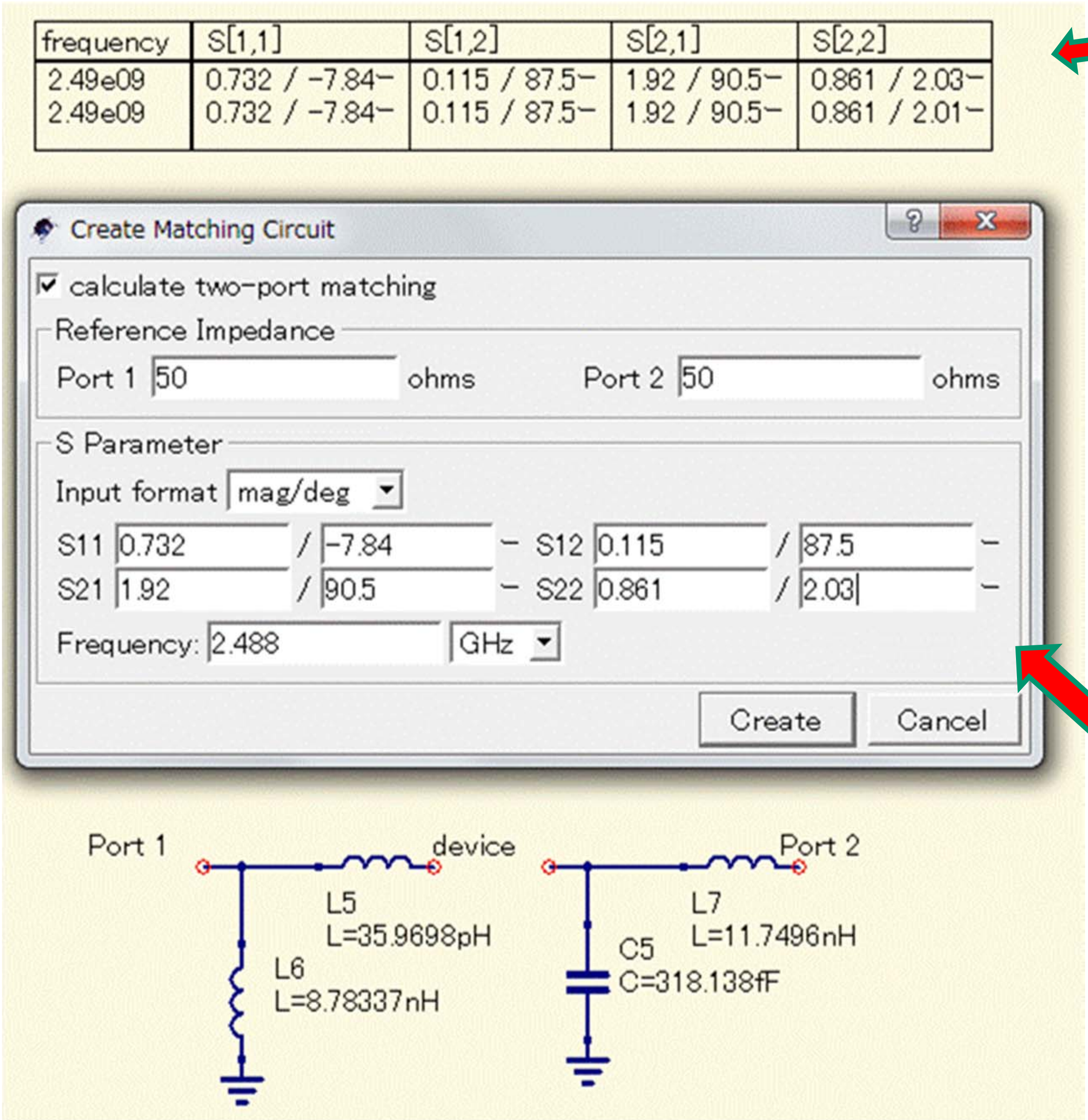
# Simulation Results



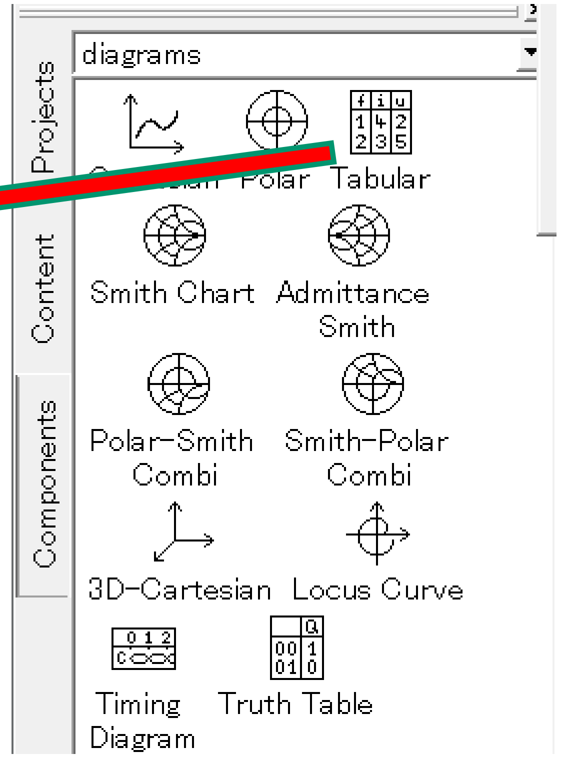
# Step 3 Design Matching Circuits



# Procedure



frequency S[1,1] S[1,2] S[2,1] S[2,2]
2.49e09 0.732 / -7.84- 0.115 / 87.5- 1.92 / 90.5- 0.861 / 2.03-
2.49e09 0.732 / -7.84- 0.115 / 87.5- 1.92 / 90.5- 0.861 / 2.01-
Create Matching Circuit
calculate two-port matching
Reference Impedance
Port 1 50 ohms
Port 2 50 ohms
S Parameter
Input format mag/deg
S11 0.732 / -7.84
S12 0.115 / 87.5
S21 1.92 / 90.5
S22 0.861 / 2.03
Frequency: 2.488 GHz
Create
Cancel
Port 1
device
Port 2
L5
L=35.9698pH
L6
L=8.78337nH
C5
C=318.138fF
L7
L=11.7496nH

Projects
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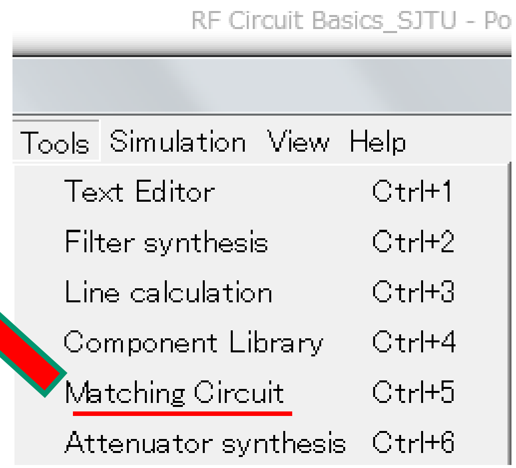
Tabular
Smith Chart
Admittance Smith
Polar-Smith Combi
Smith-Polar Combi
3D-Cartesian
Locus Curve
Timing Diagram
Truth Table

RF Circuit Basics_SJTU - Po
Tools Simulation View Help
Text Editor Ctrl+1
Filter synthesis Ctrl+2
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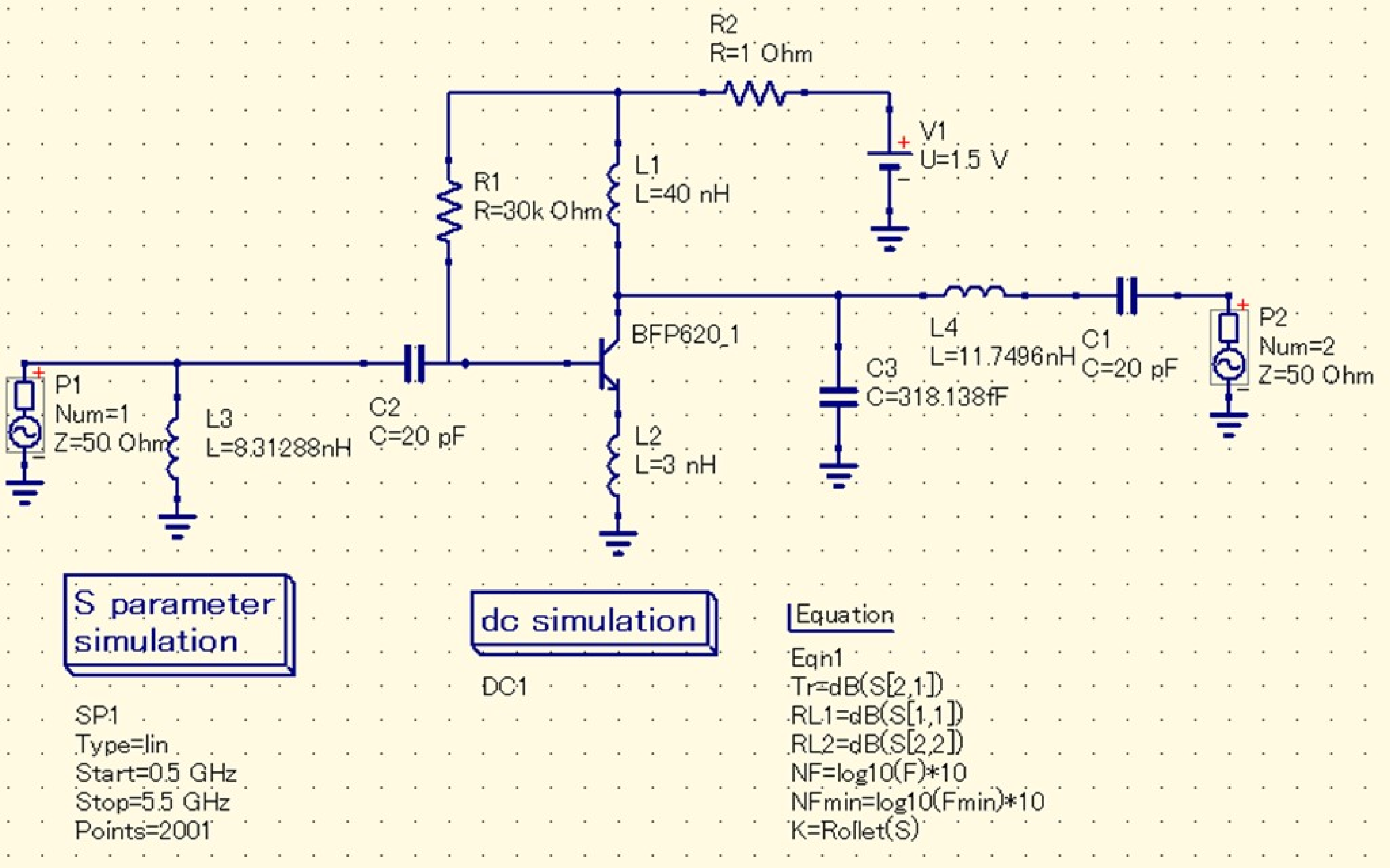
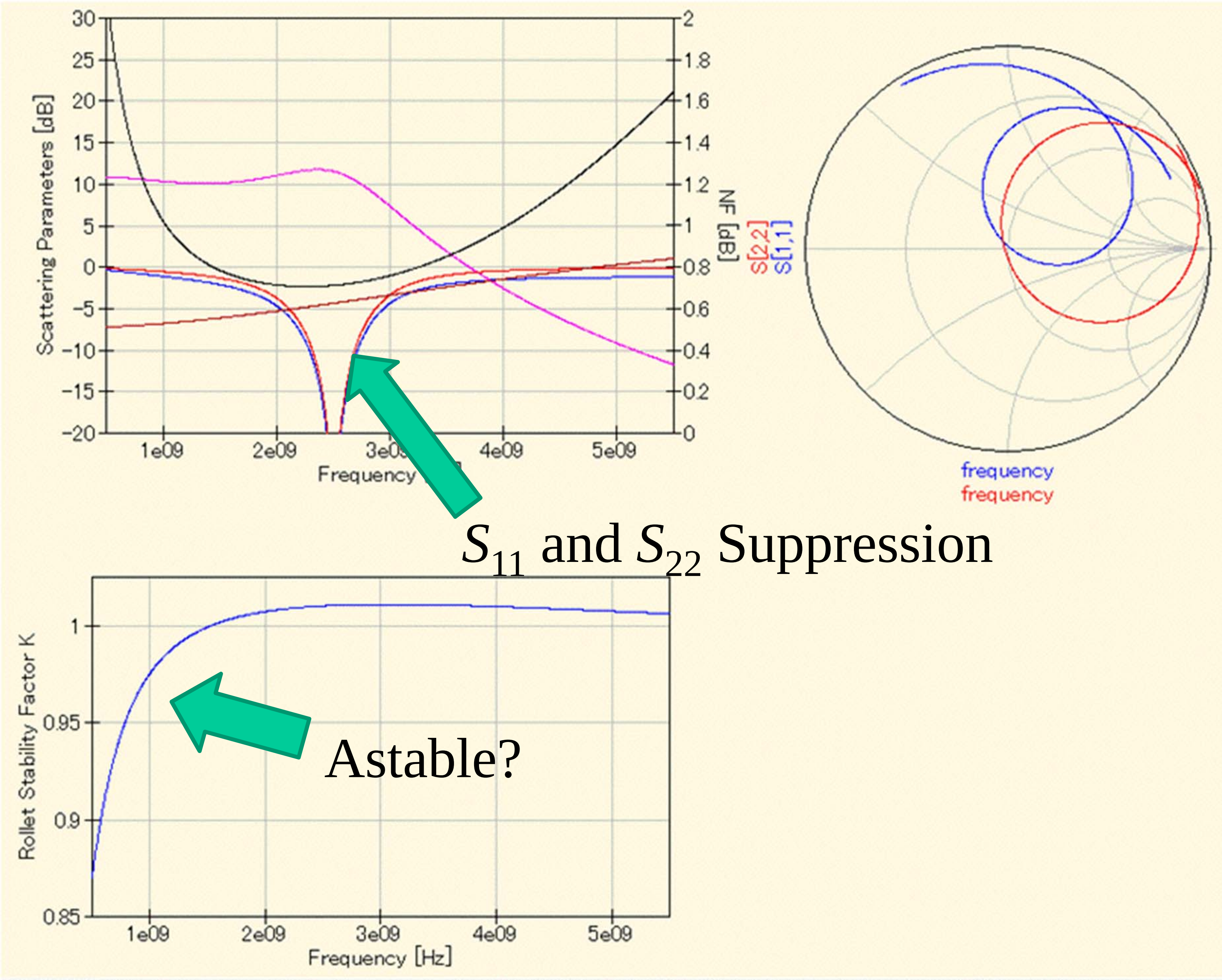
Component Library Ctrl+4
Matching Circuit Ctrl+5
Attenuator synthesis Ctrl+6

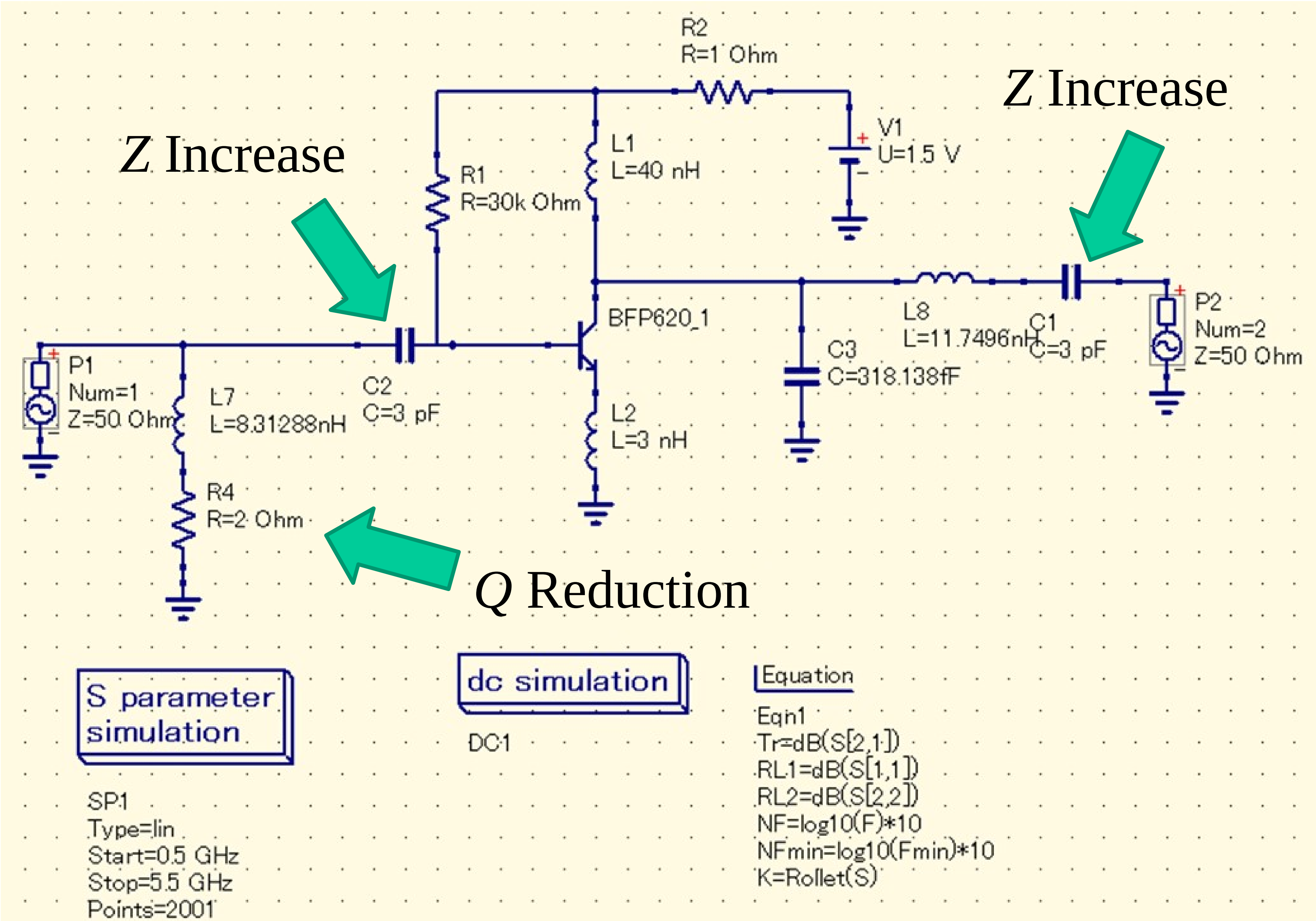
# After Adding Designed Matching Circuit



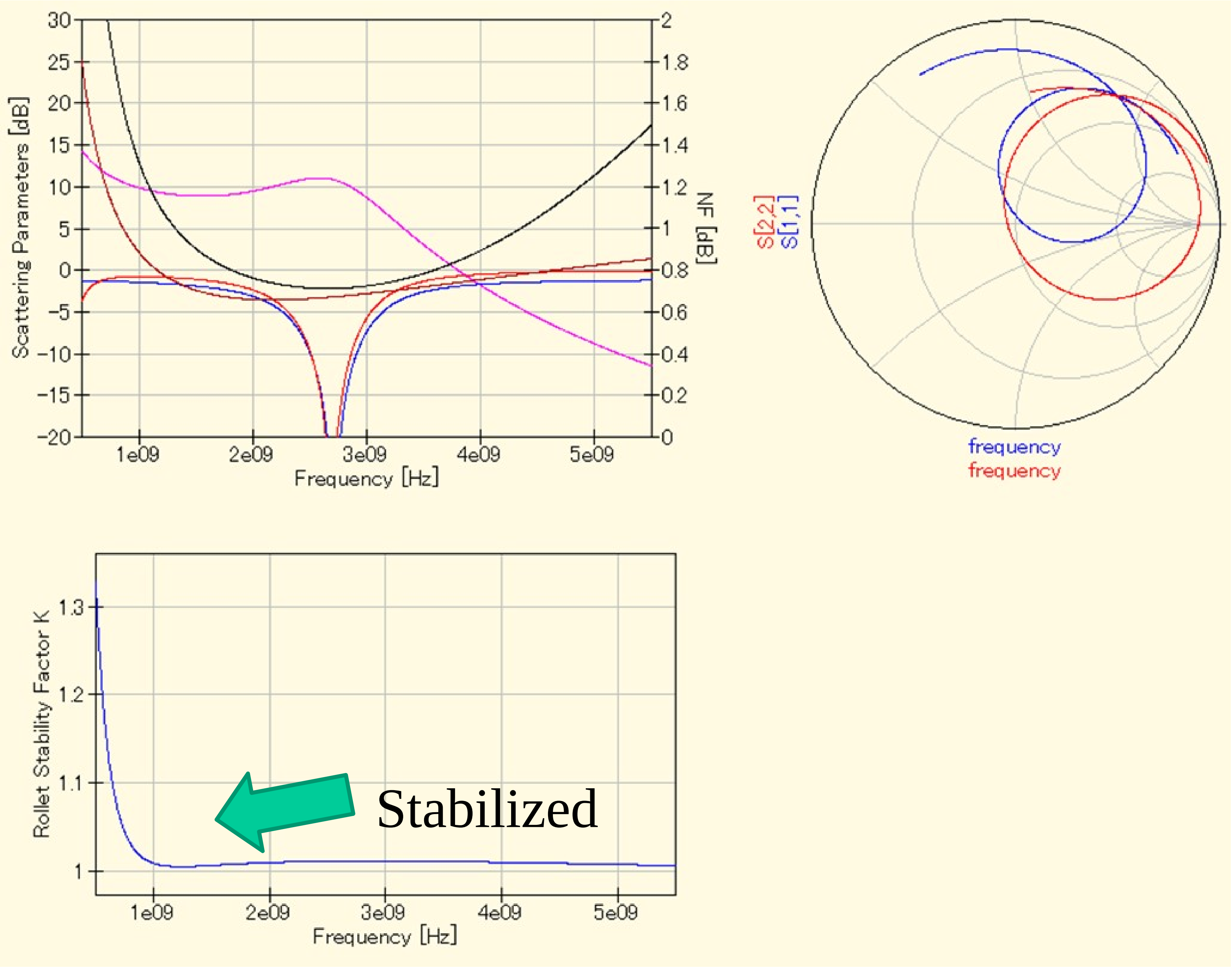
# Simulated Results



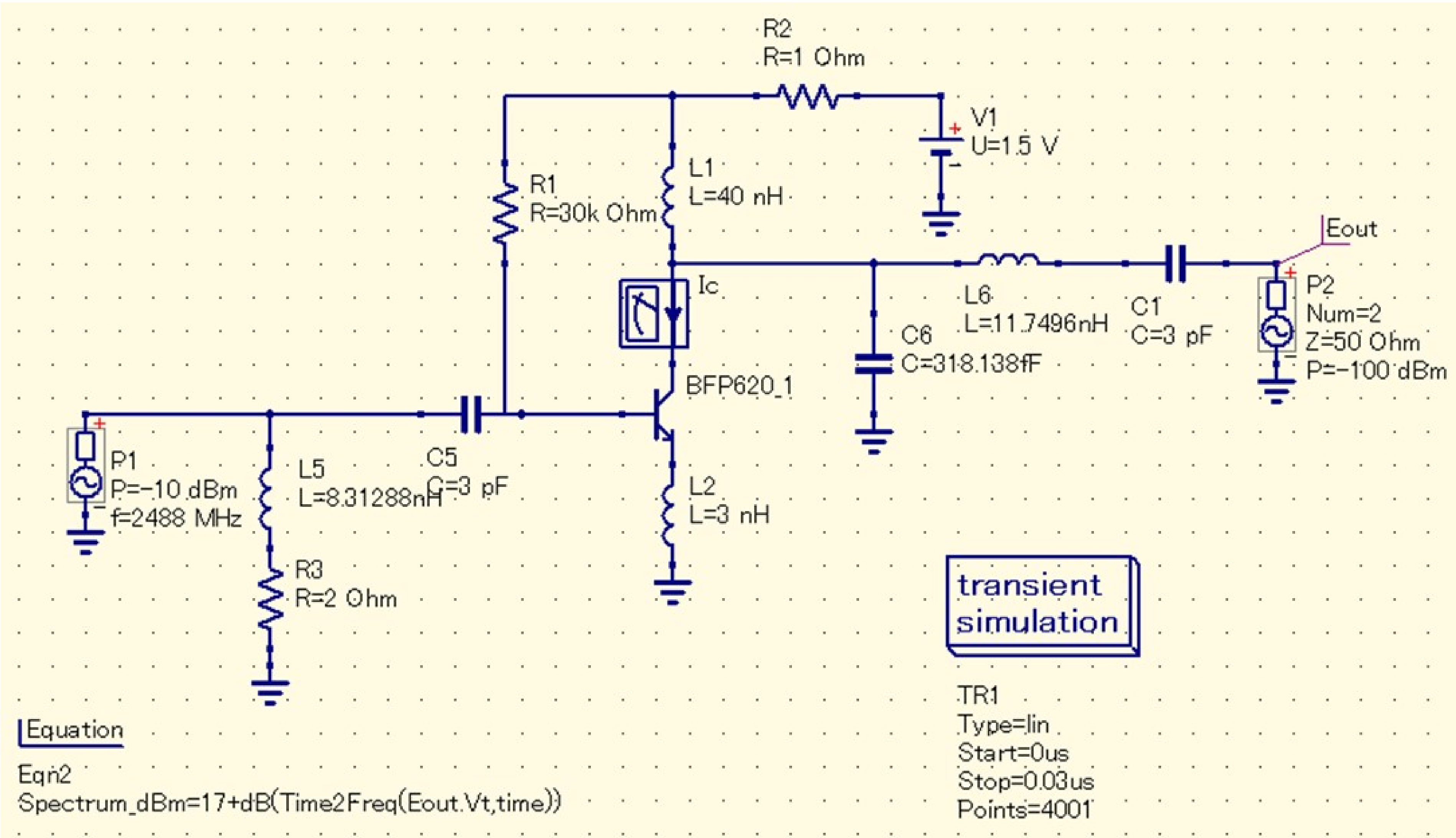
# Step 4 Stabilization



# Simulation Results

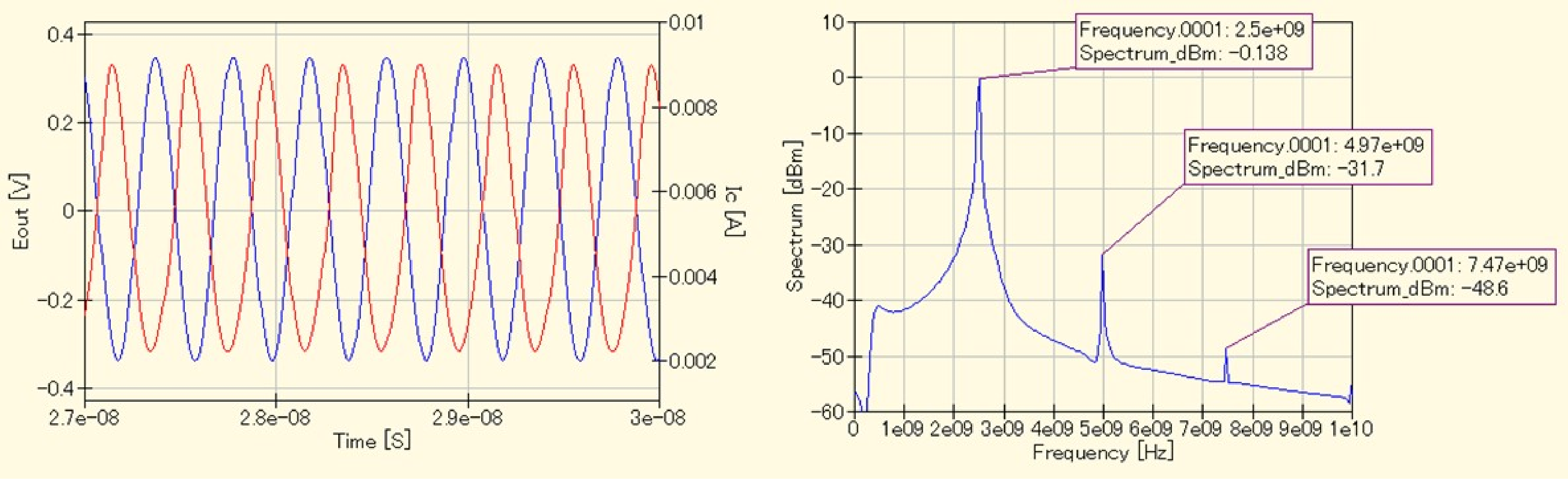


# Step 5 Transient Analysis

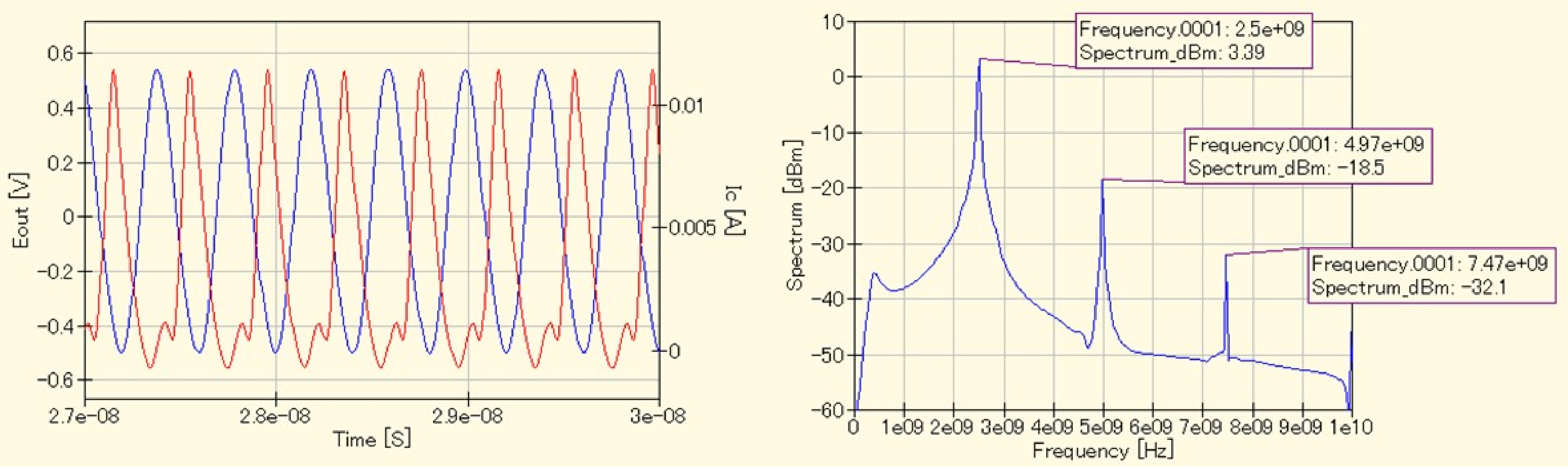


# Simulation Results

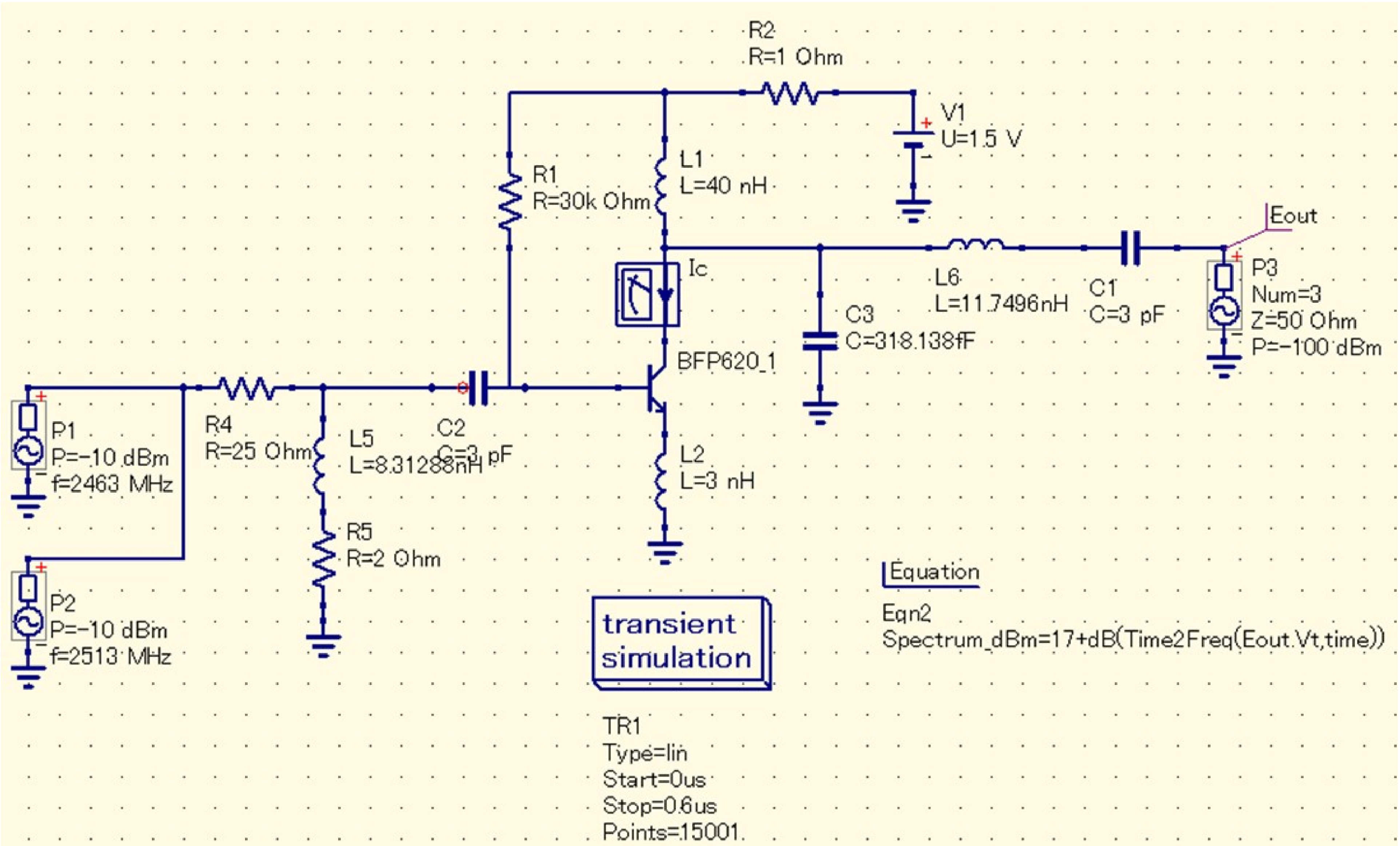
Pin=-10 dBm



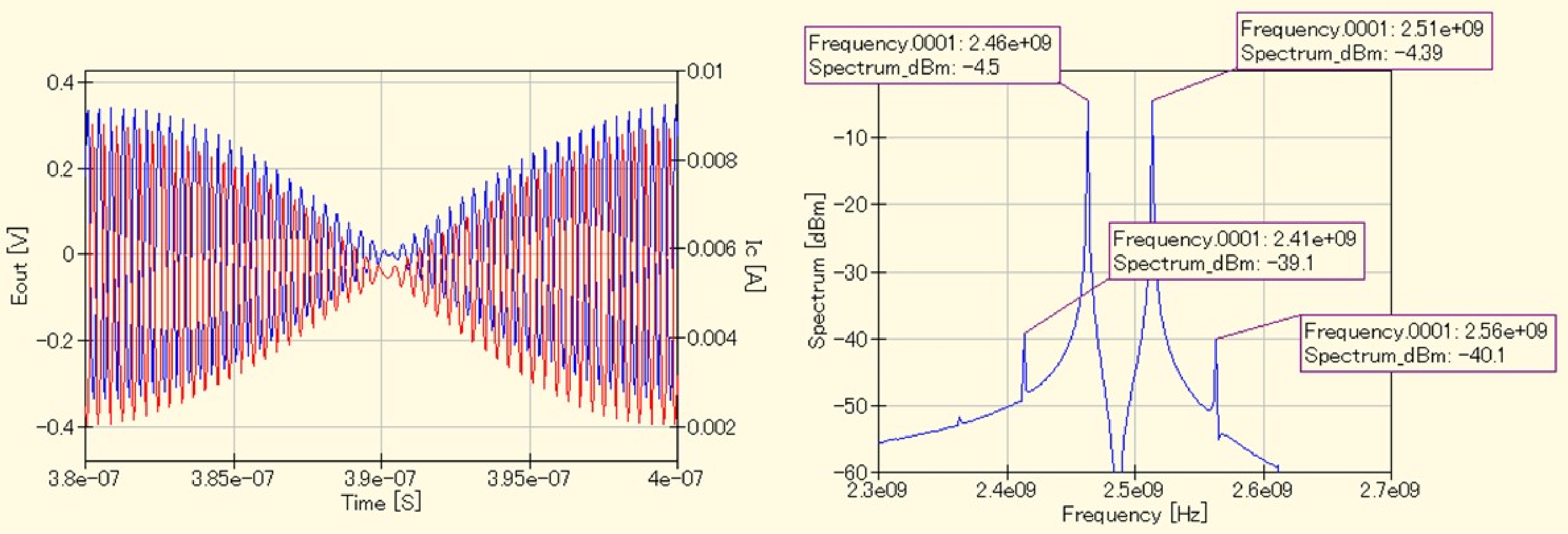

Pin=-5 dBm



# Step 6 Two Tone Analysis



# Two Tone Test Result




$P_{2a\pm b}$ [dBm]=2×$P_a$ [dBm] + $P_b$ [dBm] - 2×OIP3 [dBm]

➡ -40.1=2×(-4.39) + (-4.5) - 2×OIP3

➡ OIP3 =13.4 [dBm]

# Exercise: Design LNA using BFP620

Design Low Noise Amplifier at 2.488 GHz. $V_{cc}$=2 V and $I_c$=10 mA. Low NF and Return Suppression Mandatory. How High Gain Achievable?