

Basics of RF Amplifier Design

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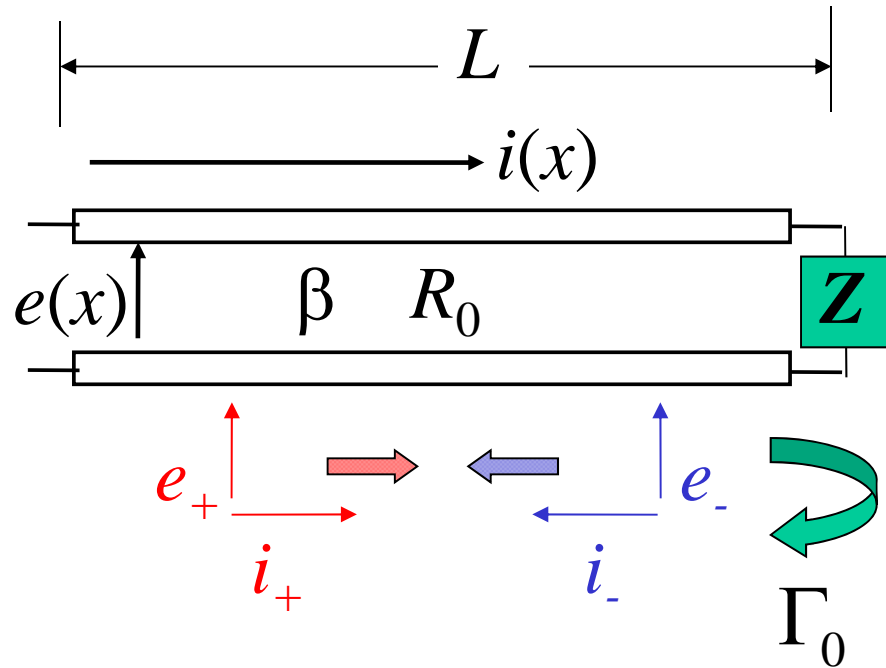
k.hashimoto@ieee.org

<http://www.te.chiba-u.jp/~ken>

Contents

- Scattering Parameters and Non-Linearities

Voltage Reflection Coefficient



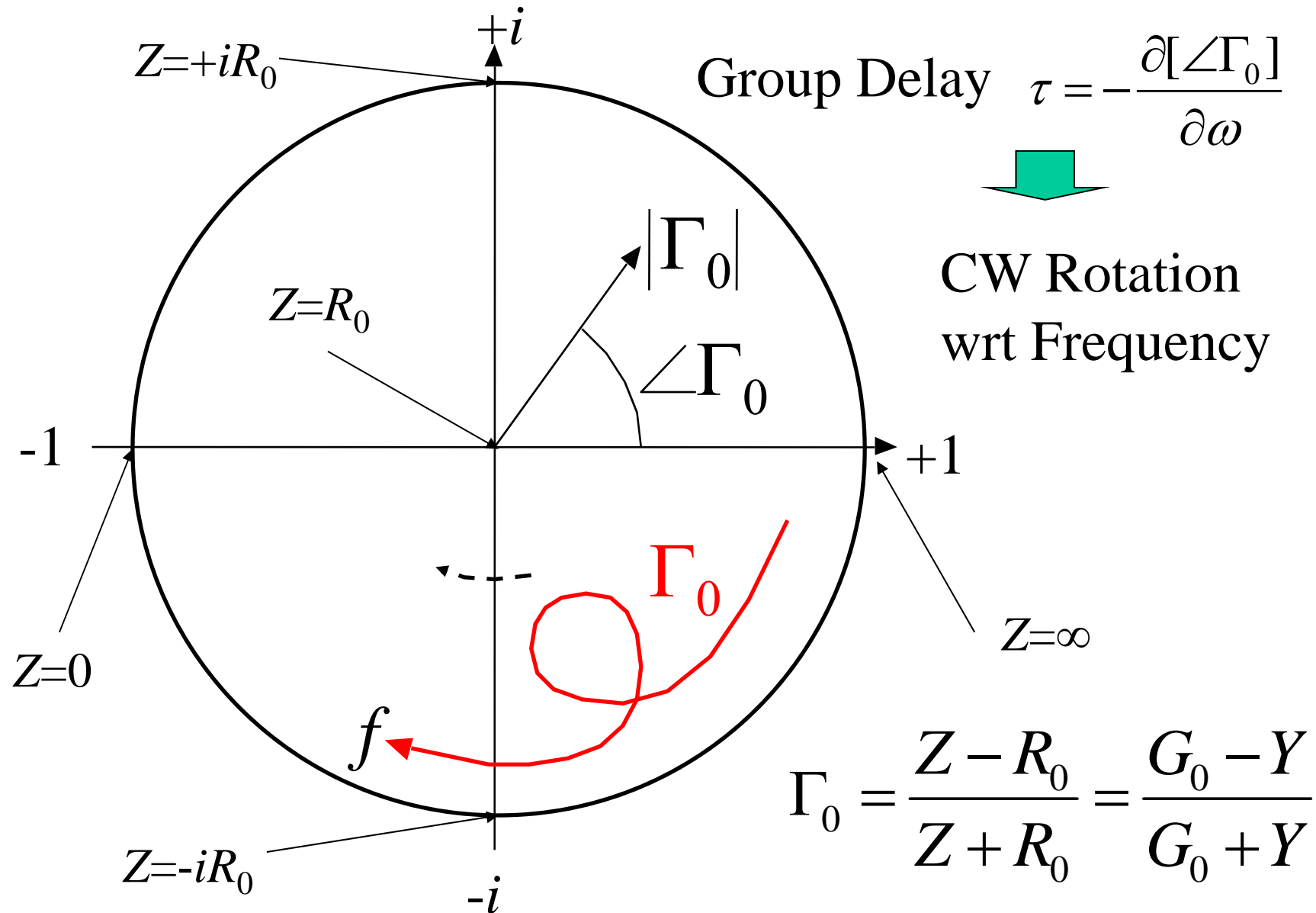
$$\Gamma_0 = \frac{e_-}{e_+} = \frac{Z - R_0}{Z + R_0} = \frac{G_0 - Y}{G_0 + Y}$$

where $Y = Z^{-1}$

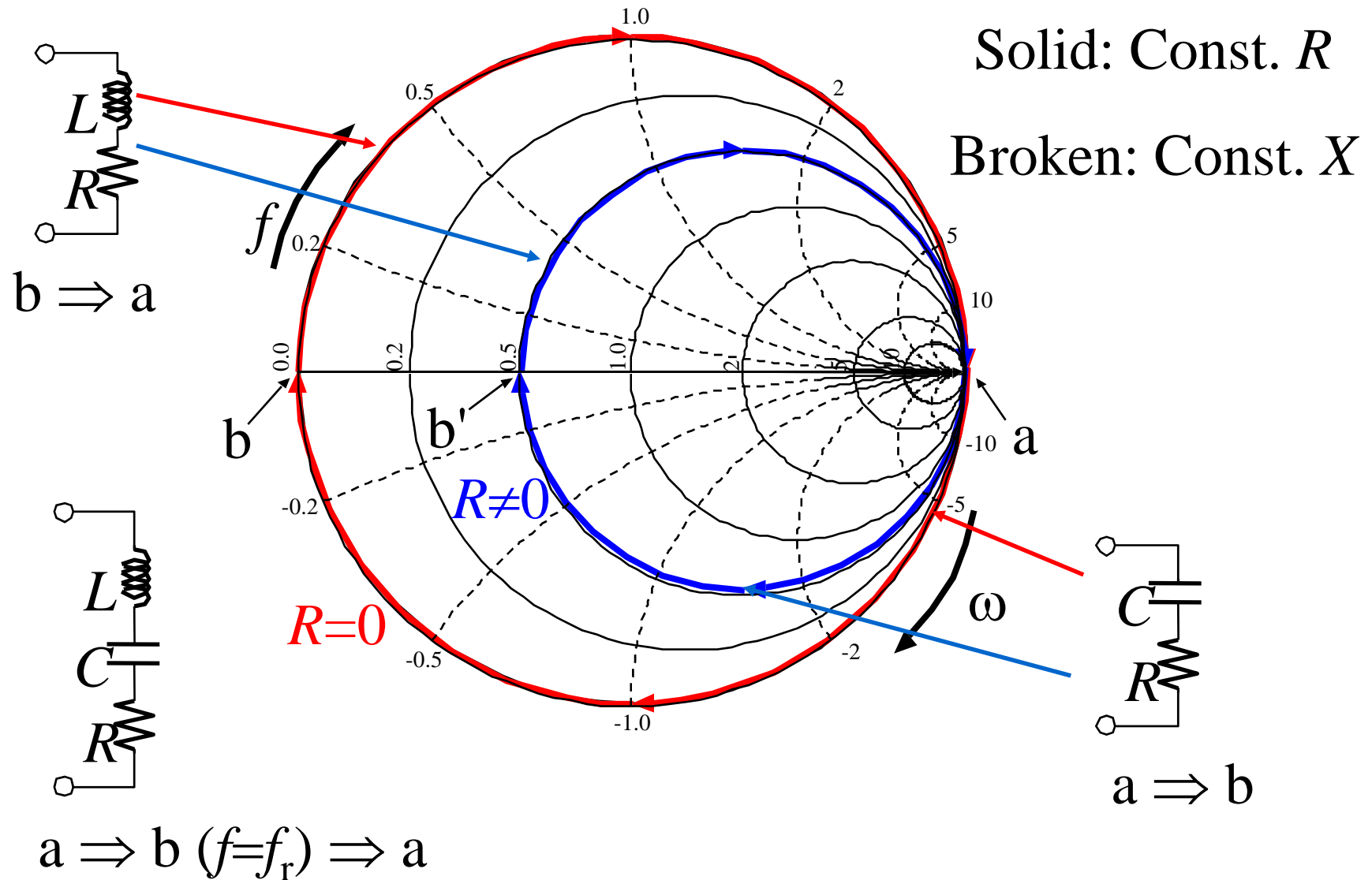
Measurable by Vector Network Analyzer
(Usually $R_0 = 50 \Omega$)

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

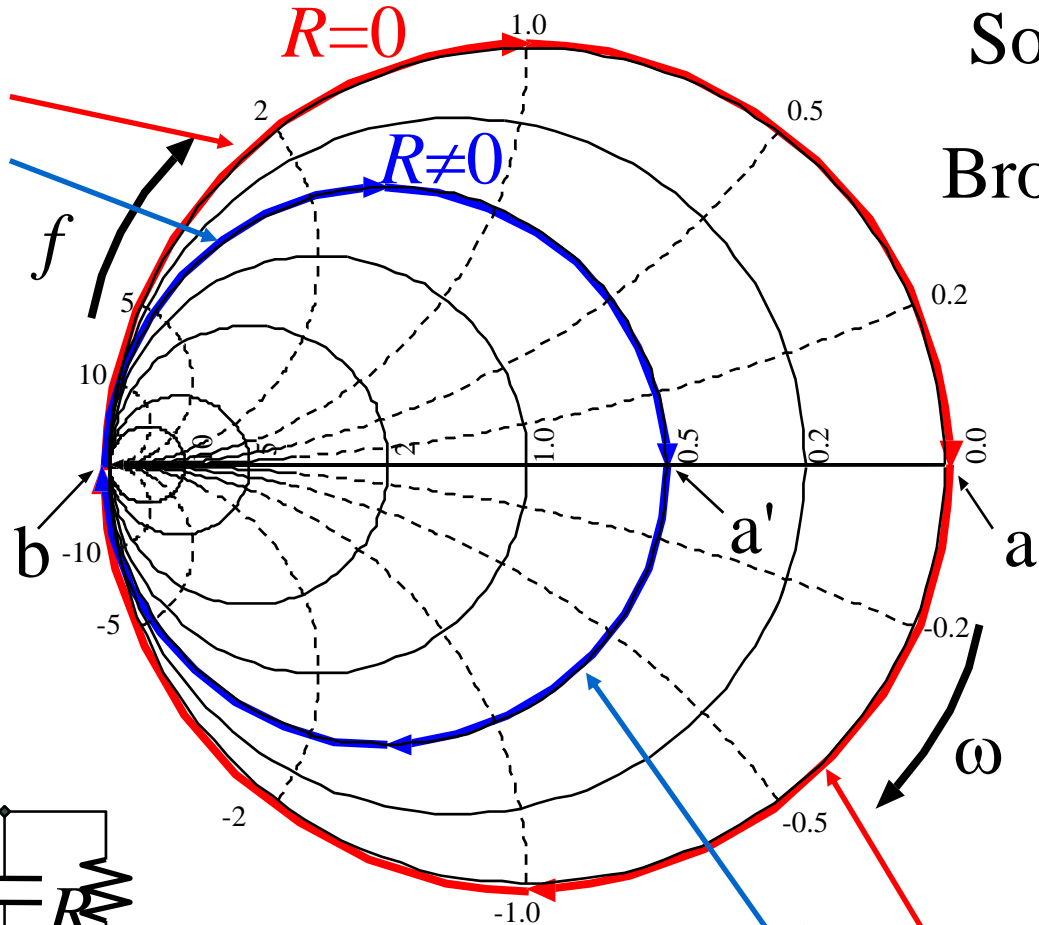
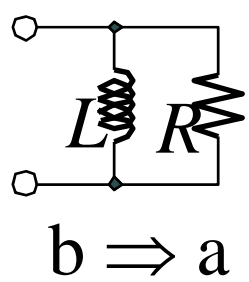
Variation of Reflection Coefficient Γ_0



Smith Chart (Impedance Plot)

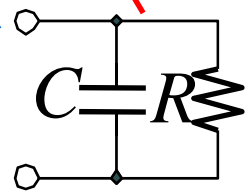
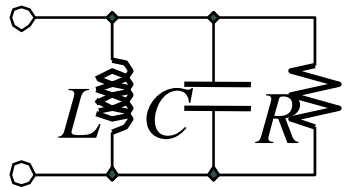


Smith Chart (Admittance Plot)



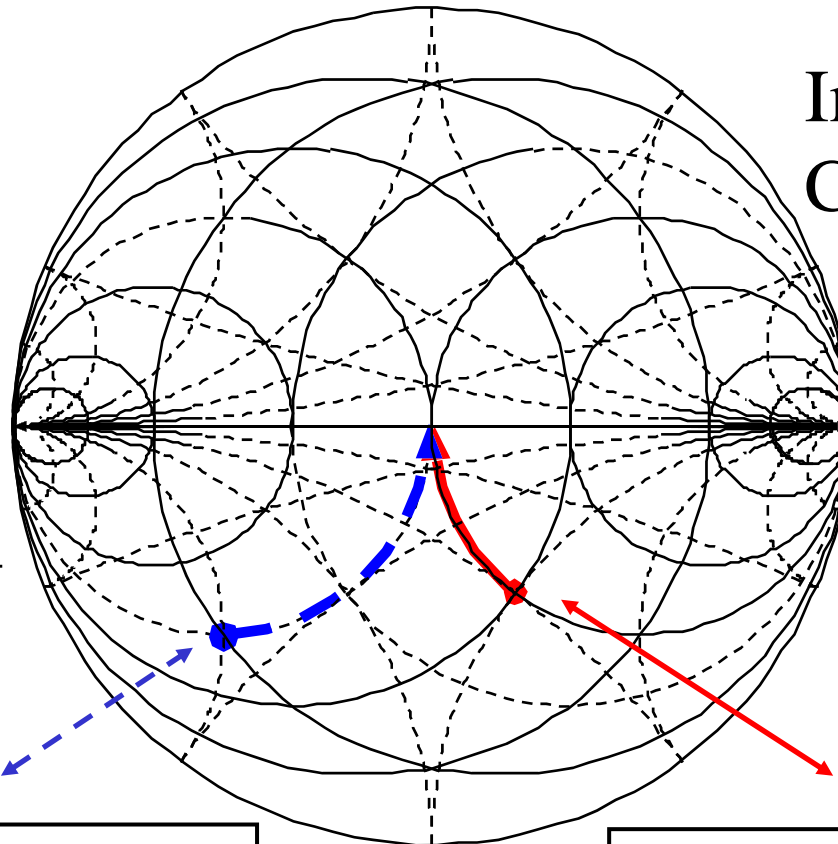
Solid: Const. G

Broken: Const. B



Impedance Matching

Immittance Chart



Parallel Tuning

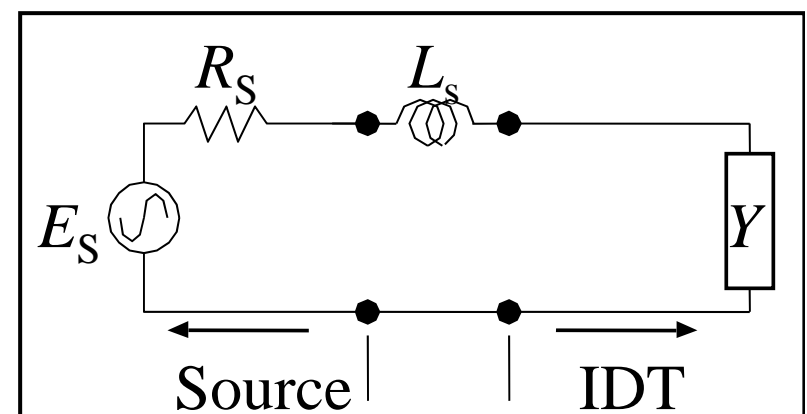
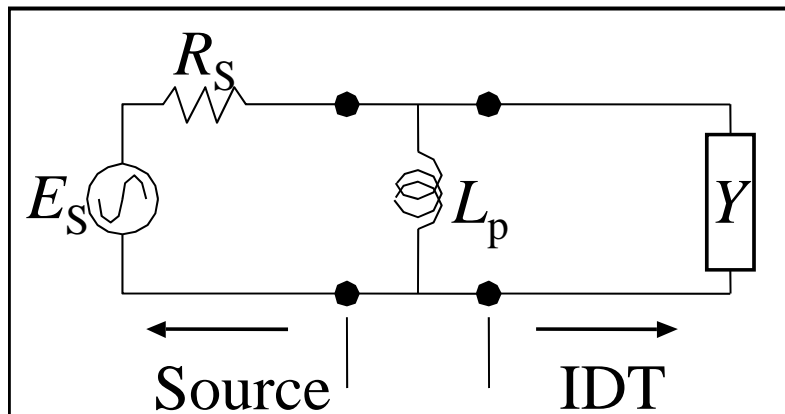
$$R_s = \text{Re}[Y]^{-1}$$

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

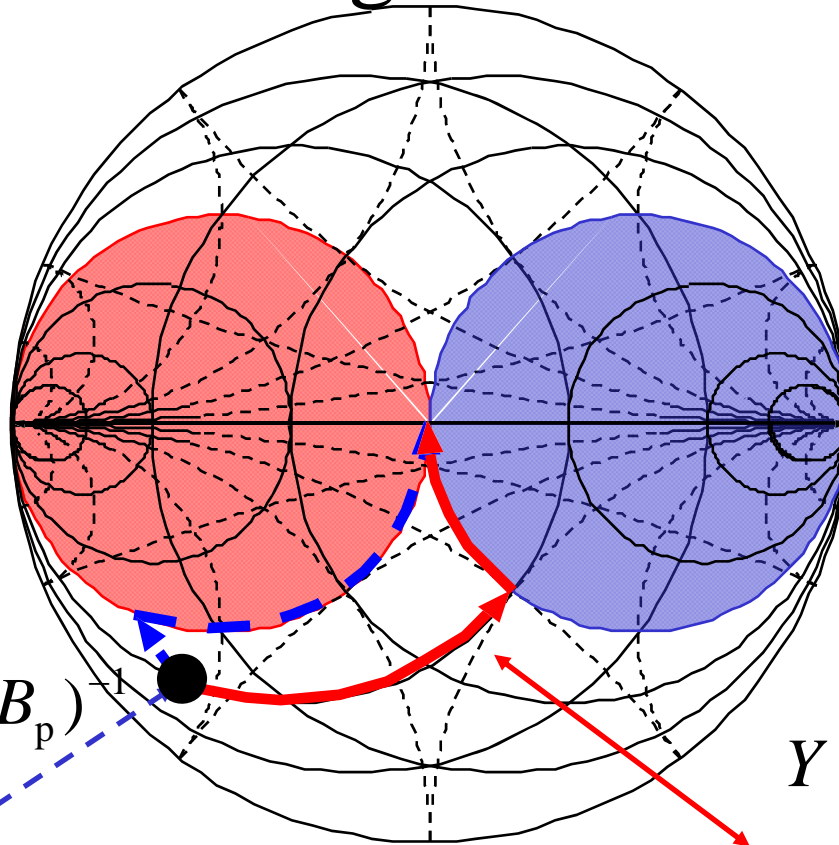
Series Tuning

$$R_s = \text{Re}[Y^{-1}]$$

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

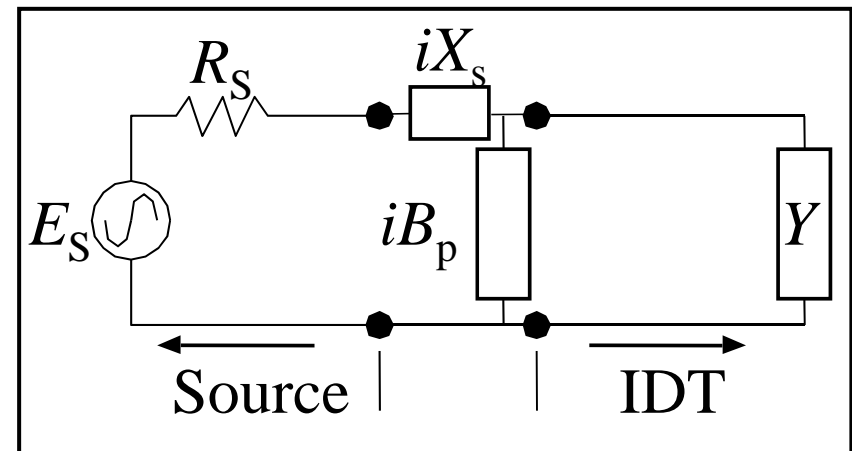
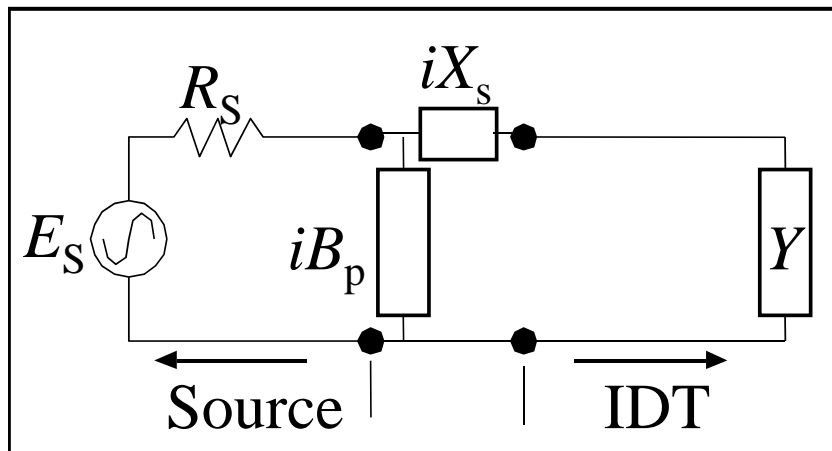


Series+Parallel Tuning



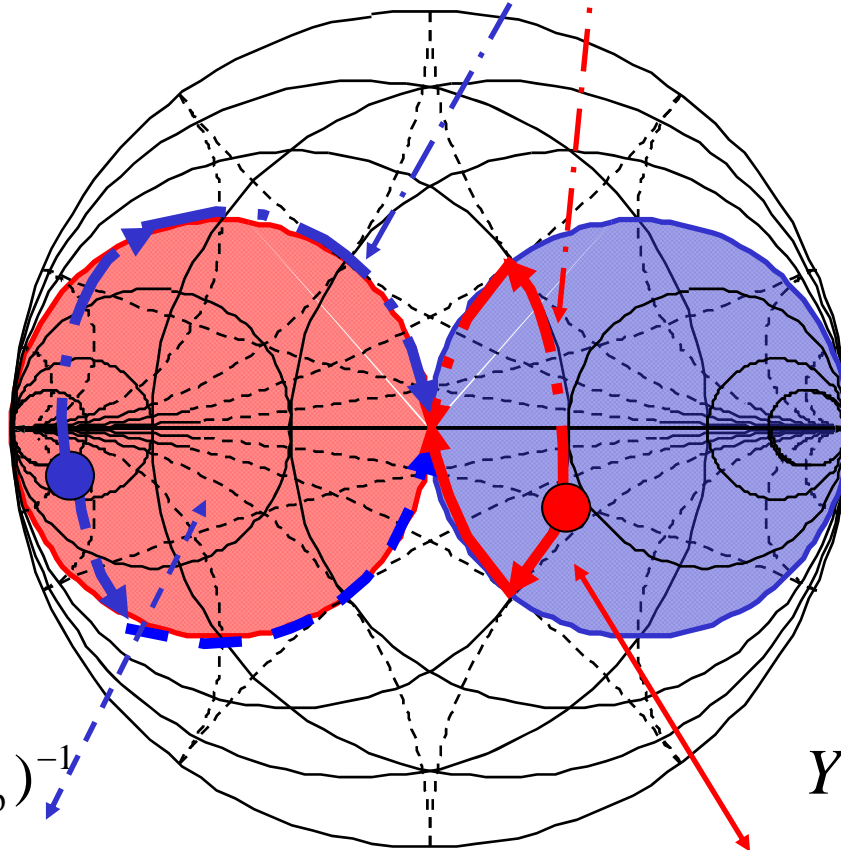
$$Y^{-1} + iX_s = (R_s^{-1} - iB_p)^{-1}$$

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



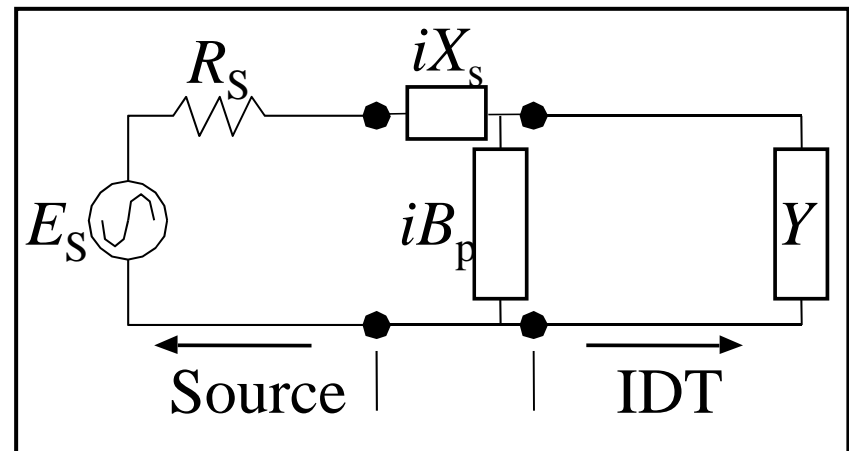
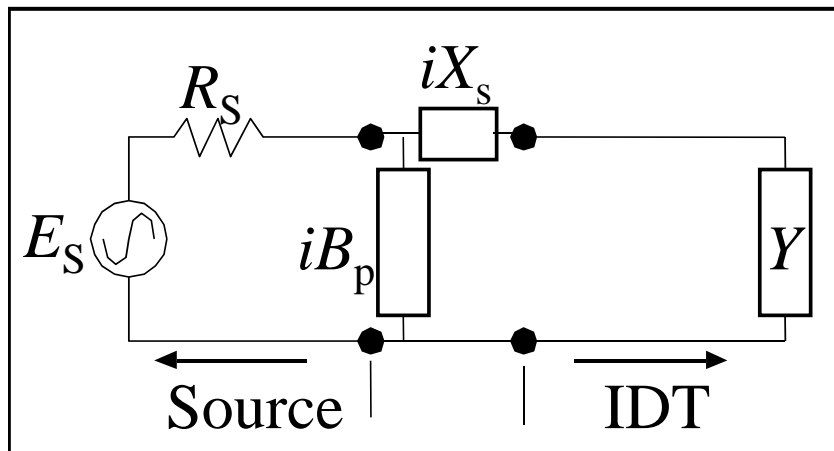
Series+Parallel Tuning

Also Possible

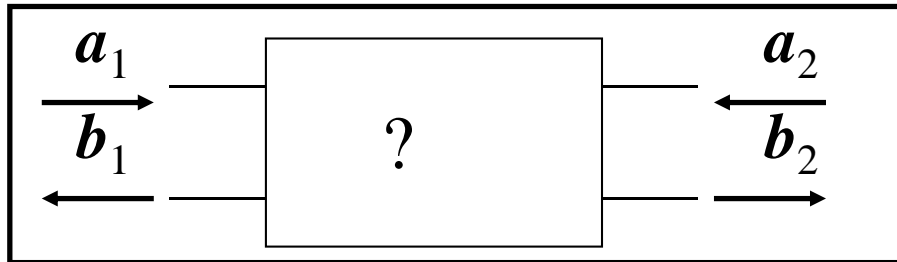


$$Y^{-1} + iX_s = (R_s^{-1} - iB_p)^{-1}$$

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



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

$S_{nm} = S_{mn}$ for Passives

b_n : Amplitude of Reflected Signal

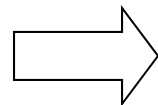
(Reciprocity)

Normalized Amplitude : $|a_n|^2$ Corresponds to Unit Power

Unit: dBm (mW)

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

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



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

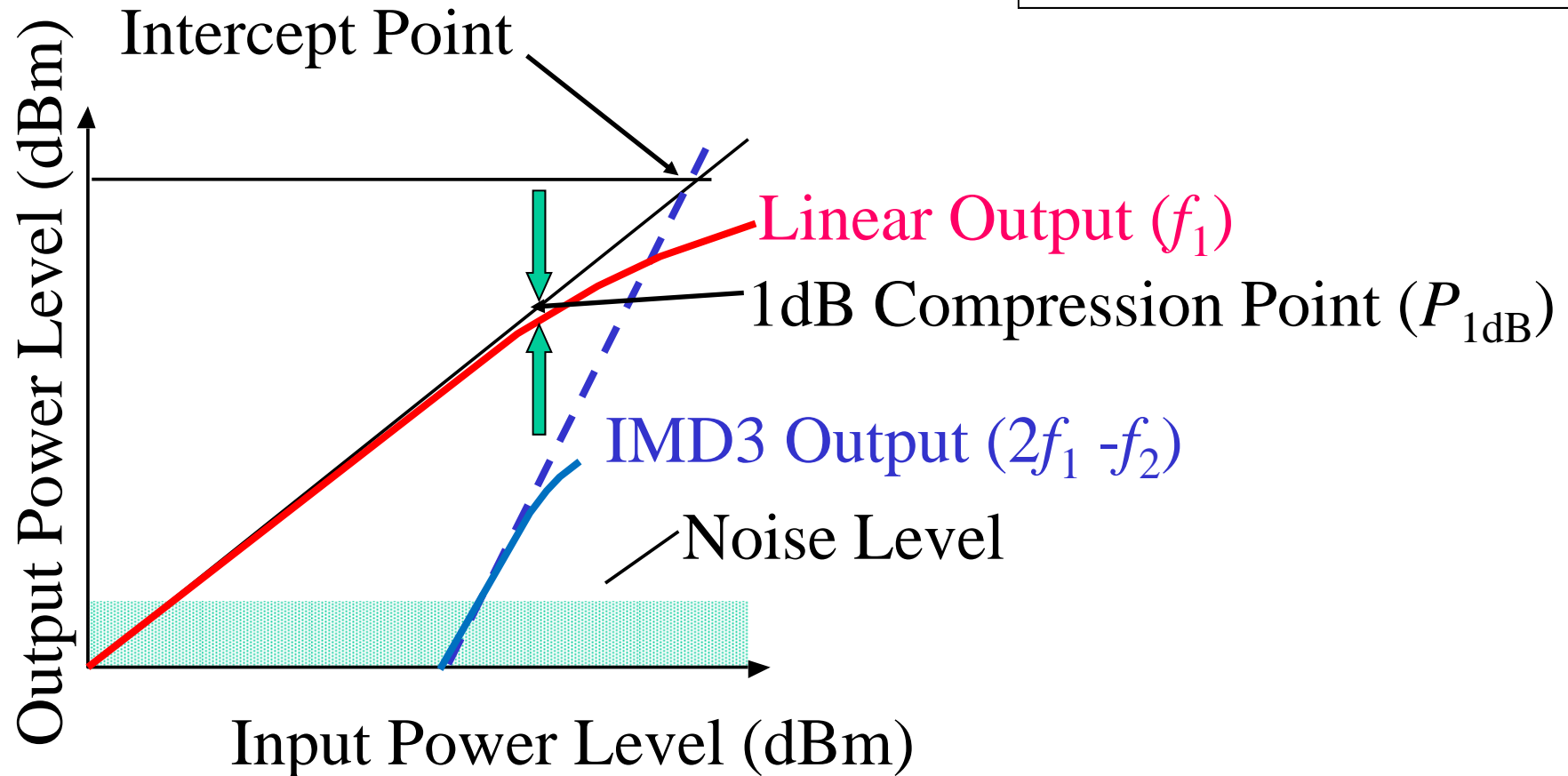
$$b_n = \frac{V_n - R_0 I_n}{2\sqrt{R_0}}$$

I: Unit Matrix

3rd order Intercept Point (IP3)

Generation of Jammer signals by Intermodulation

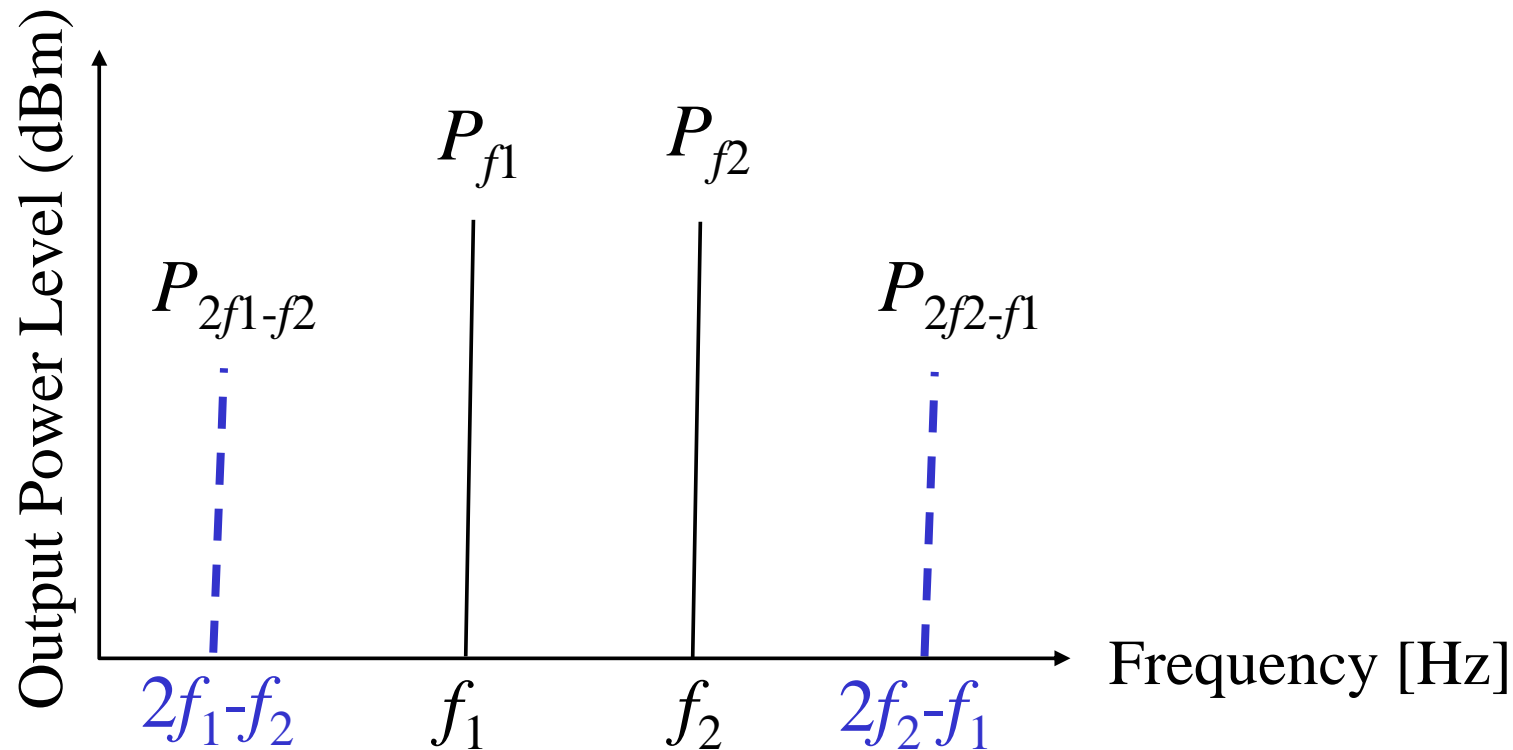
$$IIP3 \approx P_{1dB} + 9.6 \text{ [dB]}$$



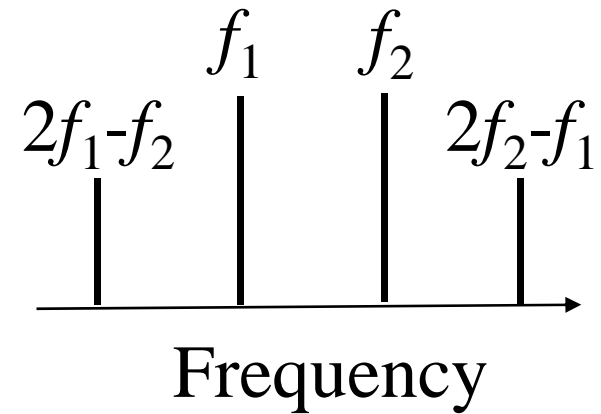
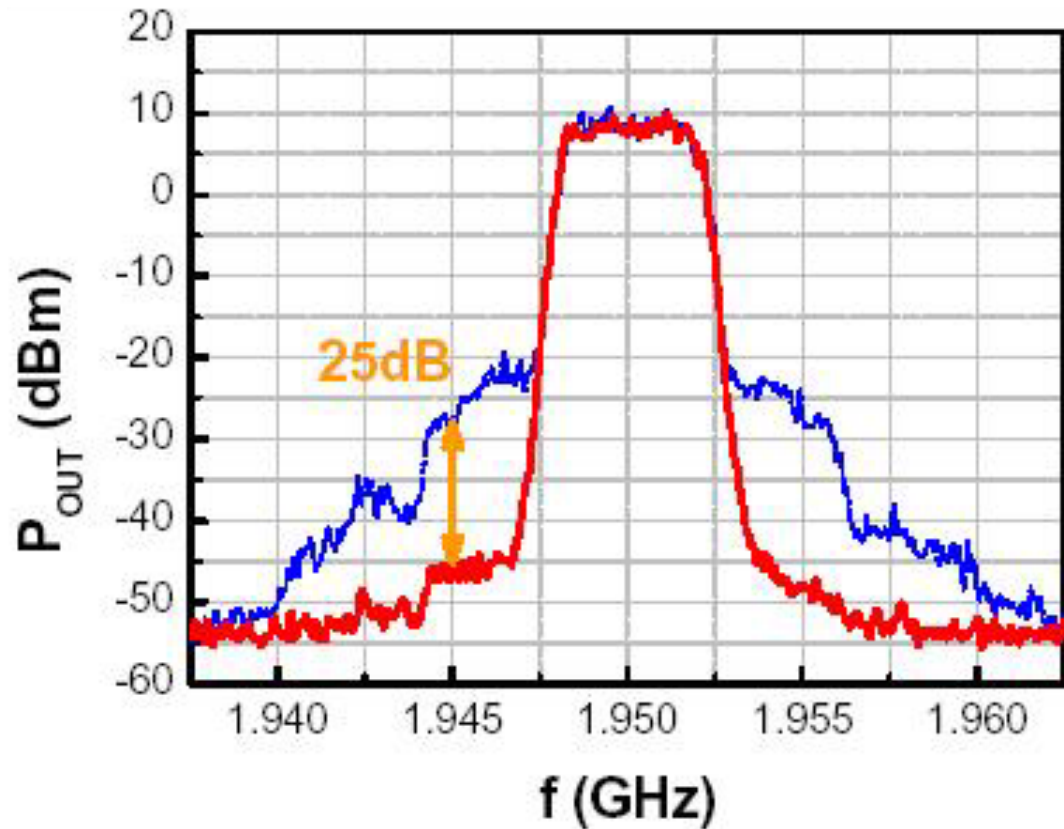
3rd order Intercept Point (IP3)

$$P_{2f_1-f_2} [\text{dBm}] = 2P_{f_1} [\text{dBm}] + P_{f_2} [\text{dBm}] - 2 \times \text{IP3} [\text{dBm}]$$

$$P_{2f_2-f_1} [\text{dBm}] = 2P_{f_2} [\text{dBm}] + P_{f_1} [\text{dBm}] - 2 \times \text{IP3} [\text{dBm}]$$



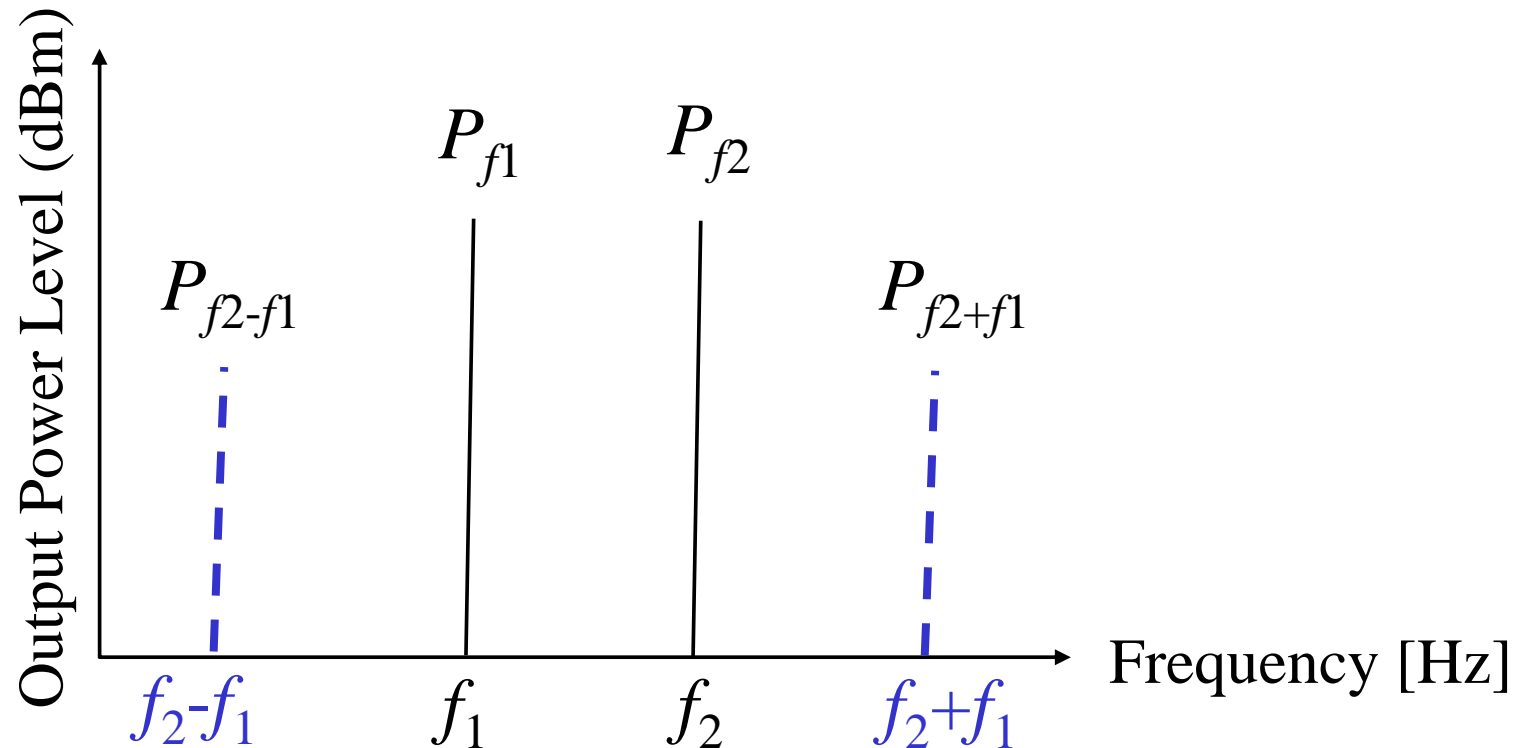
Spectrum Regrowth in PA and DPX = Self Mixing of Tx Signals



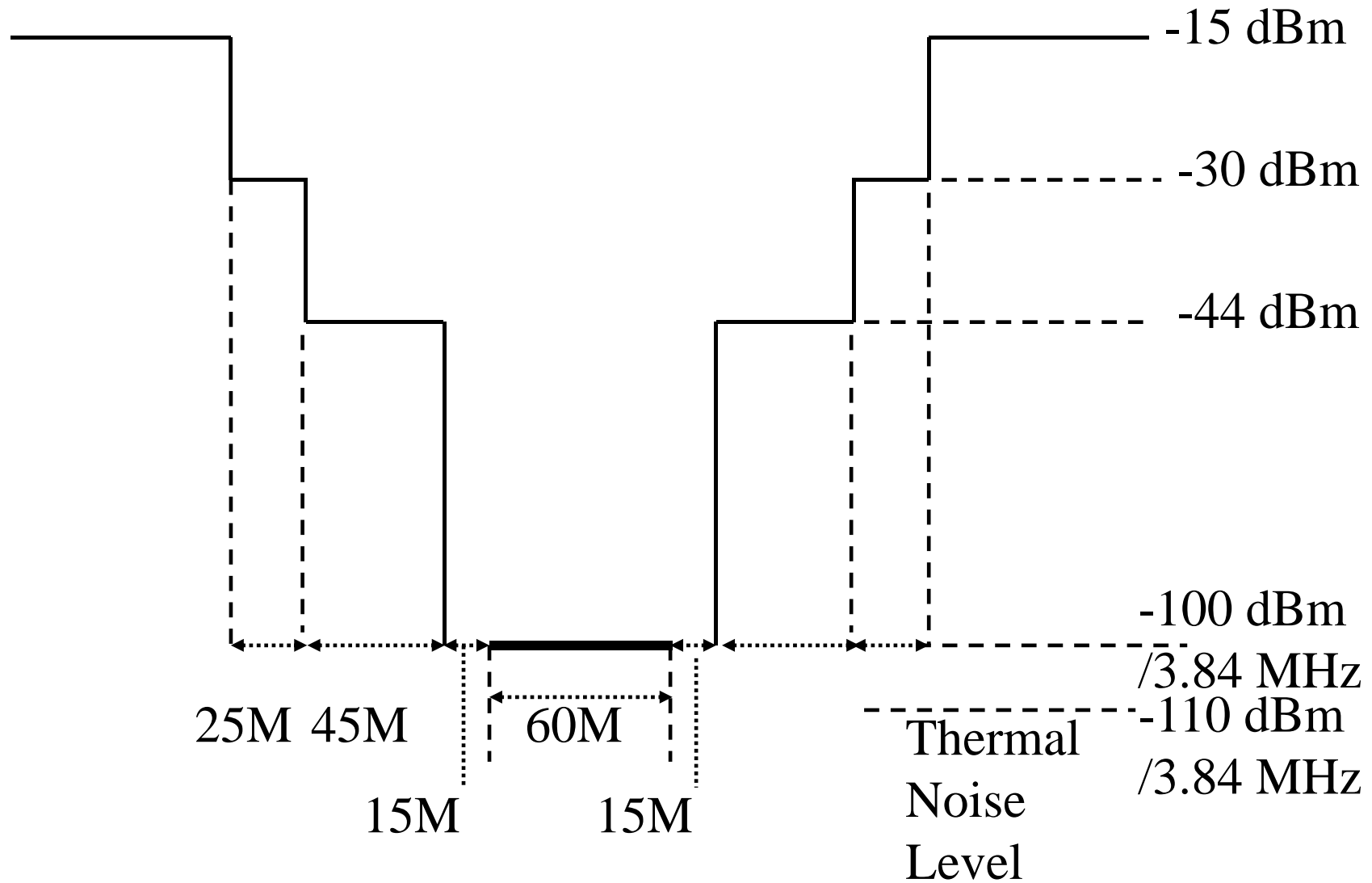
Jammer Signal Emission to Adjacent Channels

2nd order Intercept Point (IP2)

$$P_{f_2 \pm f_1} \text{ [dBm]} = P_{f_2} \text{ [dBm]} + P_{f_1} \text{ [dBm]} - \text{IP2 [dBm]}$$



Blocking Test Example (W-CDMA Band II)

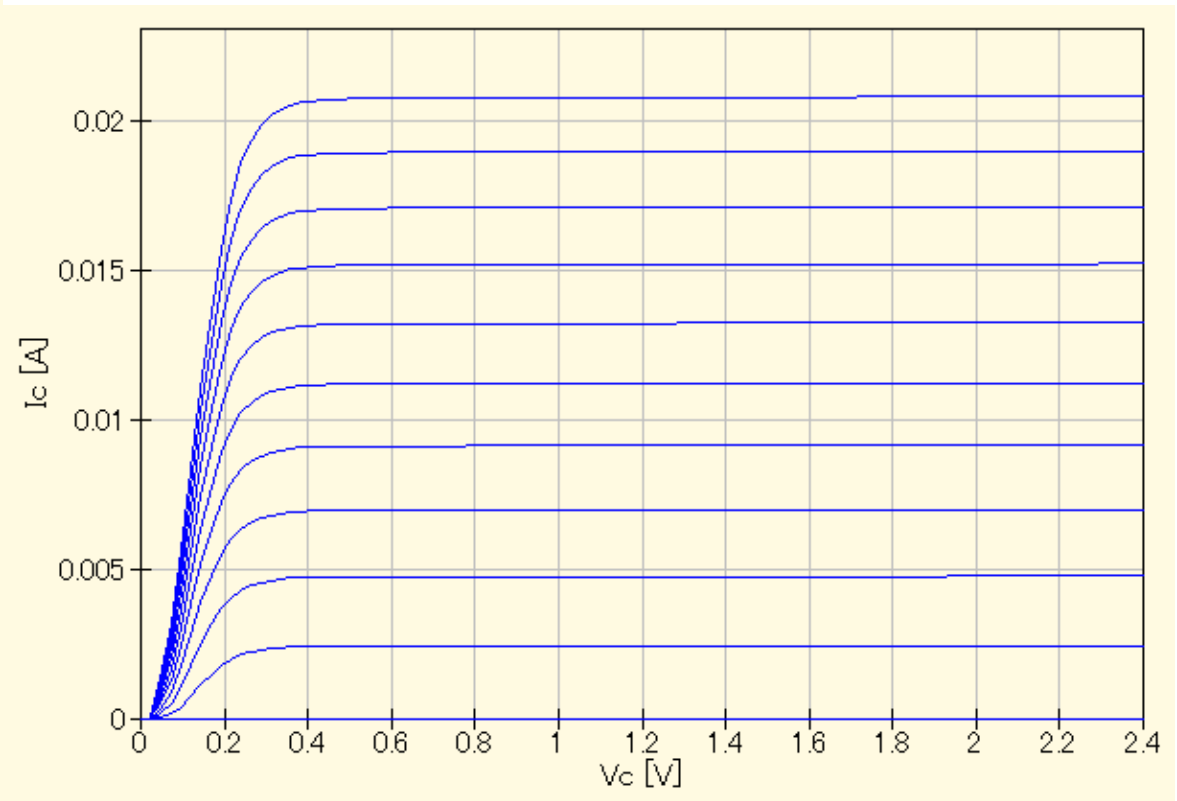
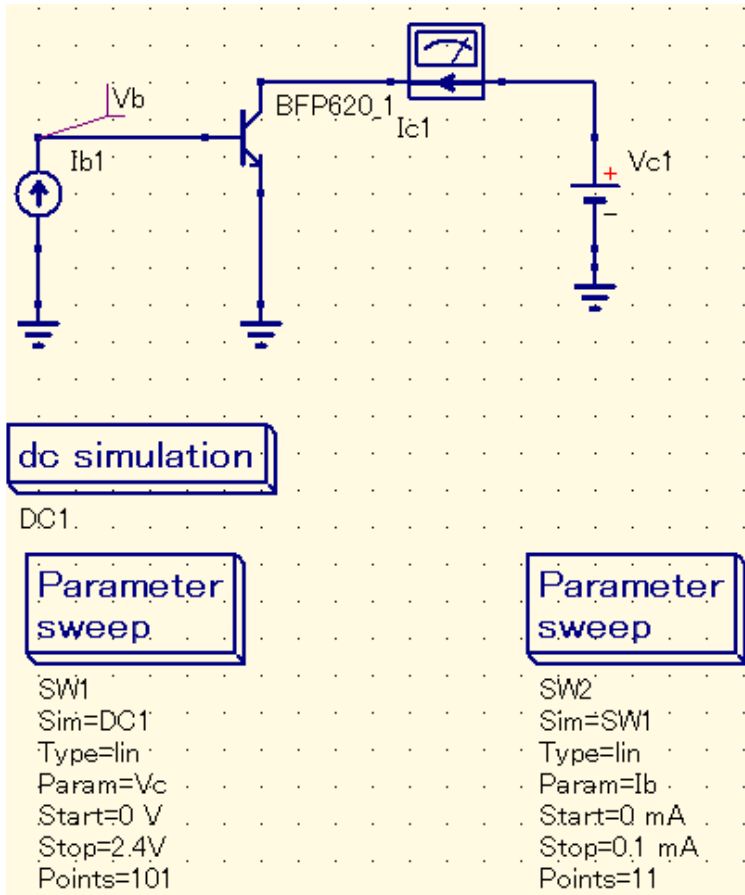


Contents

- 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

Qucs 0.0.15 - Project: RFamp

File Edit Positioning Insert Project Tools Simulation View Help

Simulate F2
View Data Display/Schematic F4
Calculate DC bias F8
Show Last Messages F5
Show Last Netlist F6

Content of 'RFamp'

- Schematics
 - test.sch
 - schematic1.sch
 - schematic2.sch
 - exer8.sch
 - exer7.sch
 - exer5.sch
 - exer4.sch
 - exer3.sch
 - exer2.sch
 - exer1.sch**
 - exer0.sch
 - design1.sch
 - baseAmp.sch
- VHDL
- Verilog
- Data Displays
- Datasets
- Others

S parameter simulation

SP1
Type=lin
Start=0.5 GHz
Stop=5.5 GHz
Points=2001

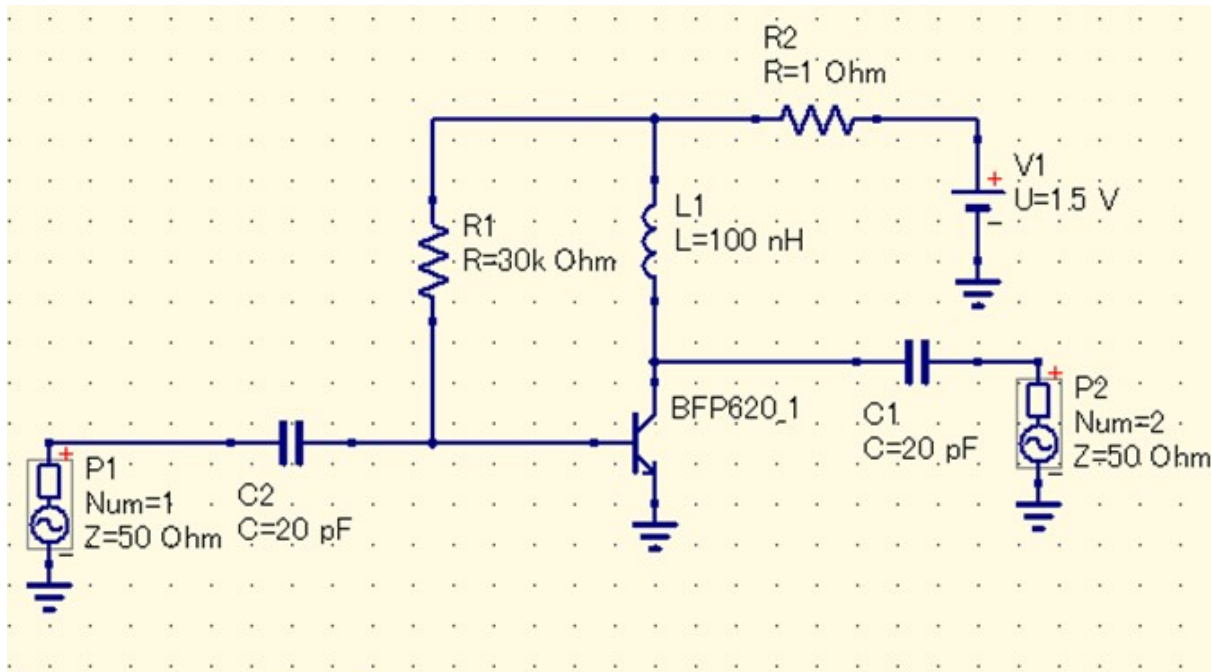
dc simulation

DC1

Equation

Eqn2
Tr=dB(S[2,1])
RL1=dB(S[1,1])
RL2=dB(S[2,2])
NF=log10(F)*10
NFmin=log10(Fmin)*10
K=Rollet(S)

Step 2 S Parameter Simulation



S parameter simulation

SP1
Type=lin
Start=0.5 GHz
Stop=5.5 GHz
Points=2001

dc simulation

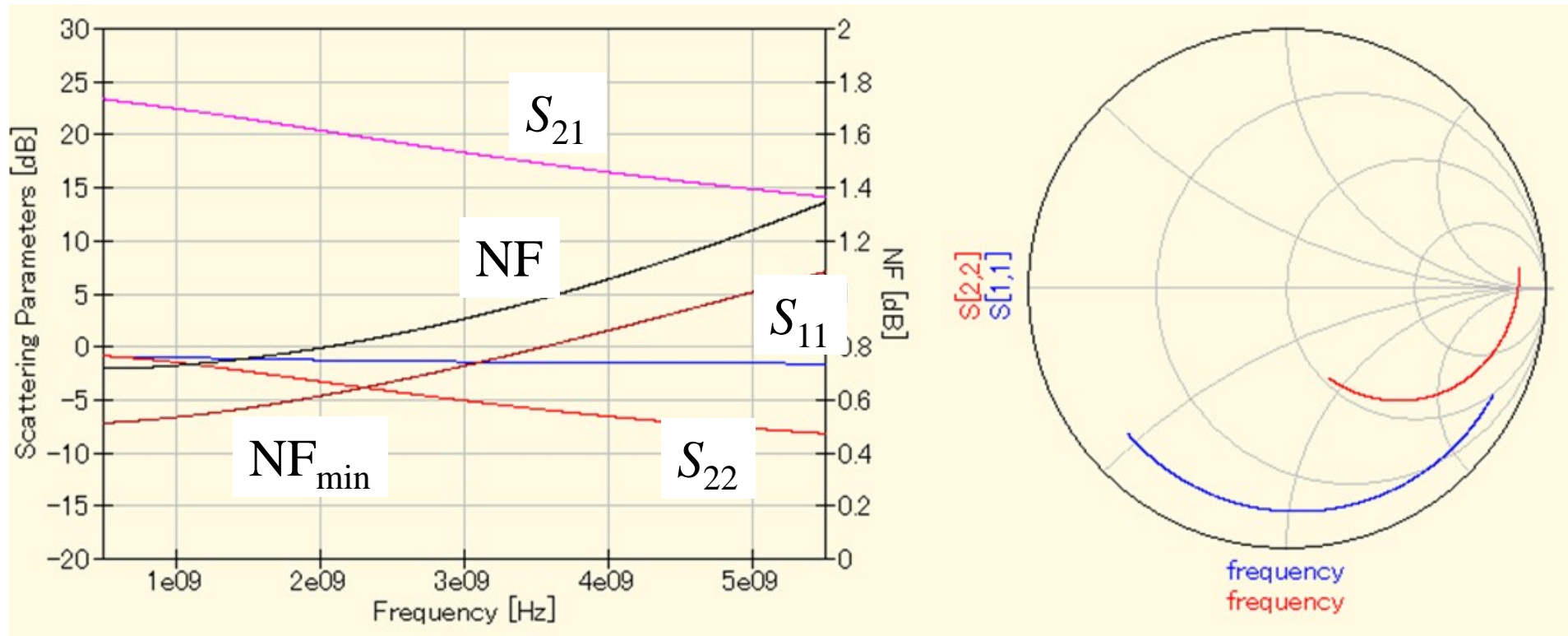
DC1

Equation
Eqn2
Tr=dB(S[2,1])
RL1=dB(S[1,1])
RL2=dB(S[2,2])
NF=log10(F)*10
NFmin=log10(Fmin)*10
K=Rollet(S)

Caution! →

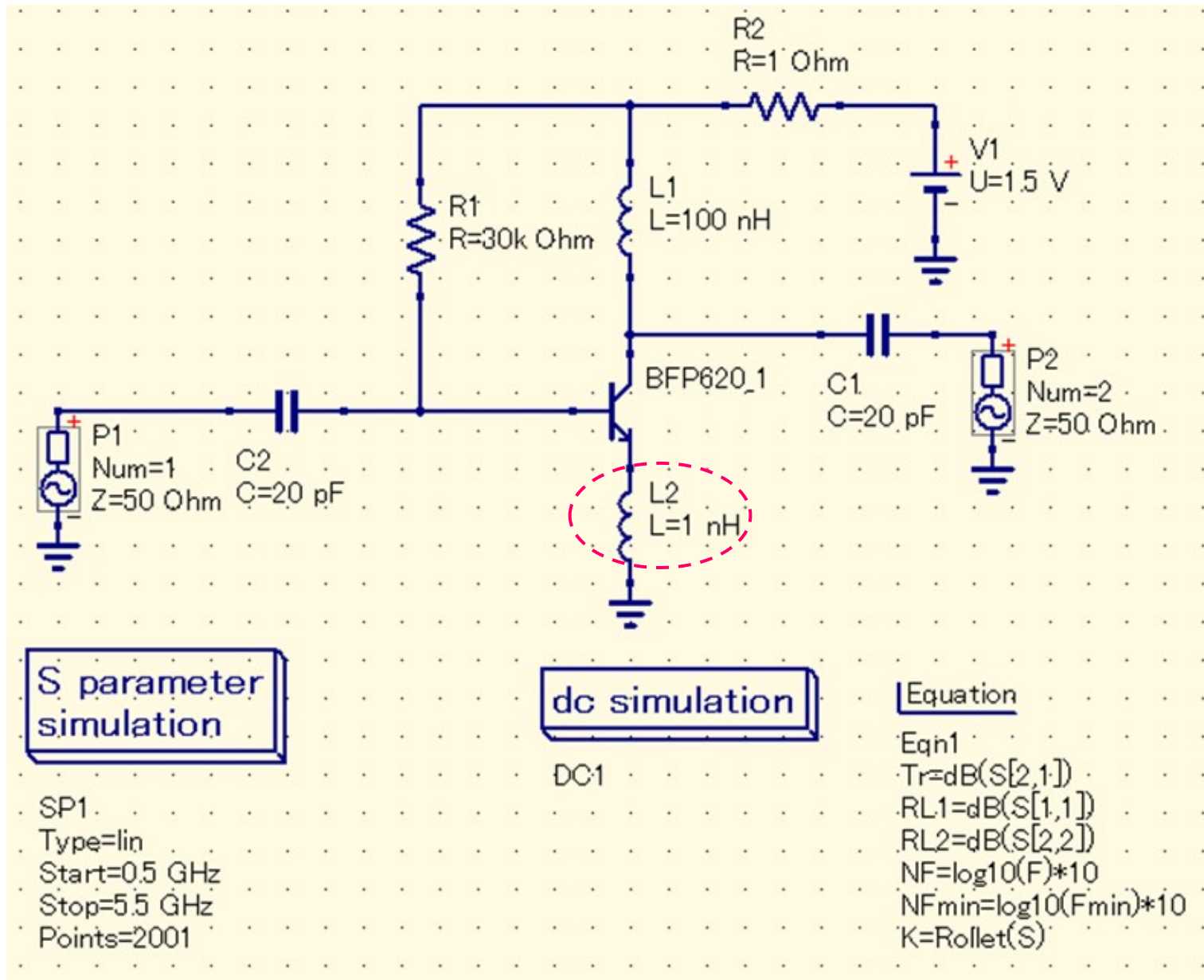
Name	Value	display	De	Noise
Noise	yes	no	cal	calculate noise parameters [yes, no]
NoiseIP	1	no	inp	yes
NoiseOP	2	no	out	
saveCVs	no	no	put	
saveAll	no	no	sav	<input type="checkbox"/> display in schematic

S Simulation Result



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

Impact of Emitter Degeneration Inductor



S parameter simulation

SP1
 Type=lin
 Start=0.5 GHz
 Stop=5.5 GHz
 Points=2001

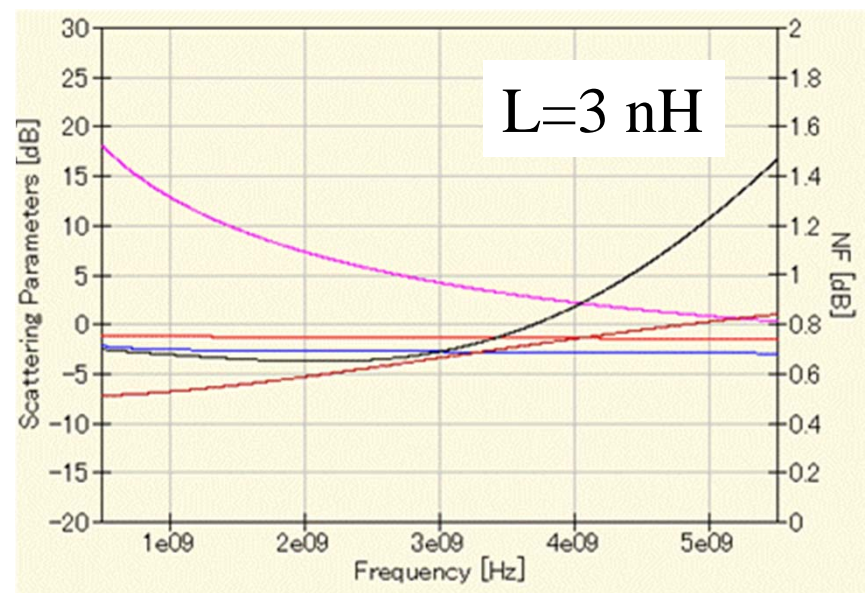
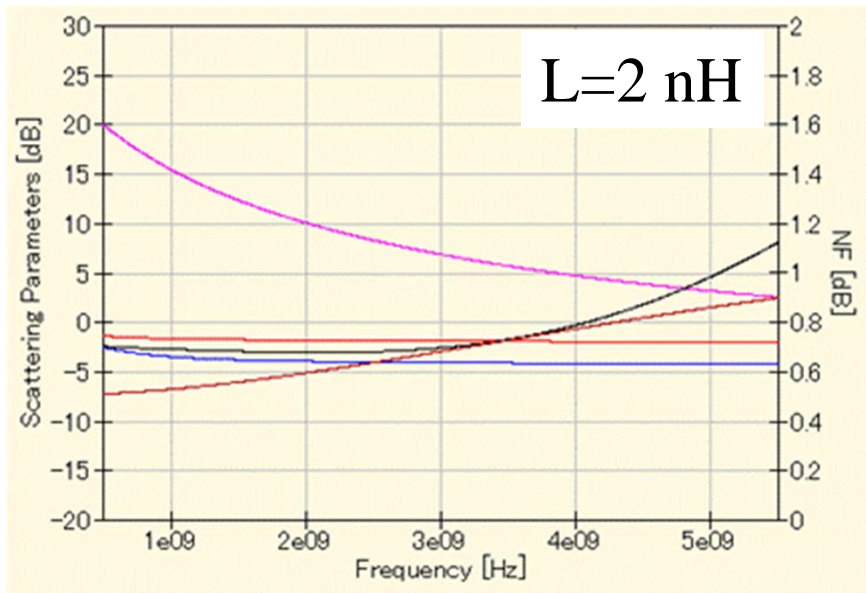
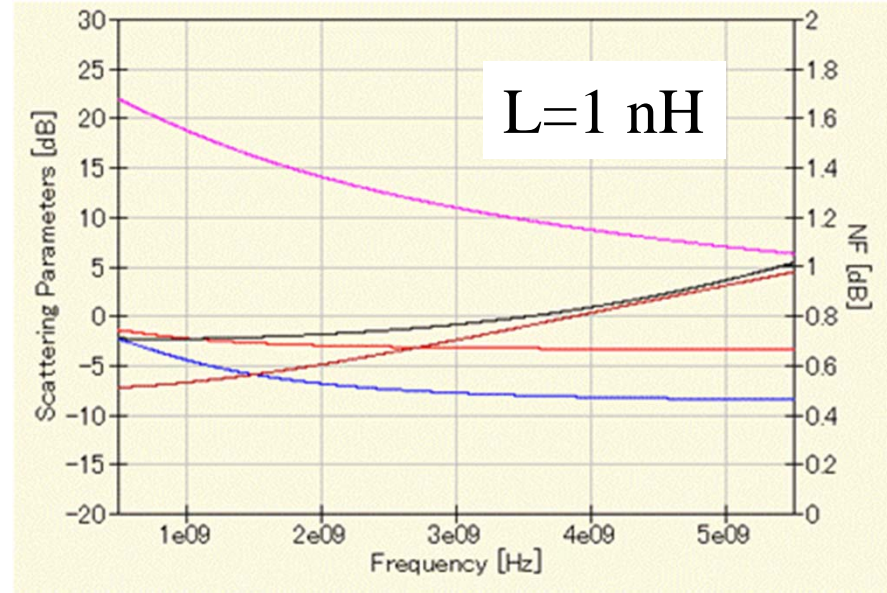
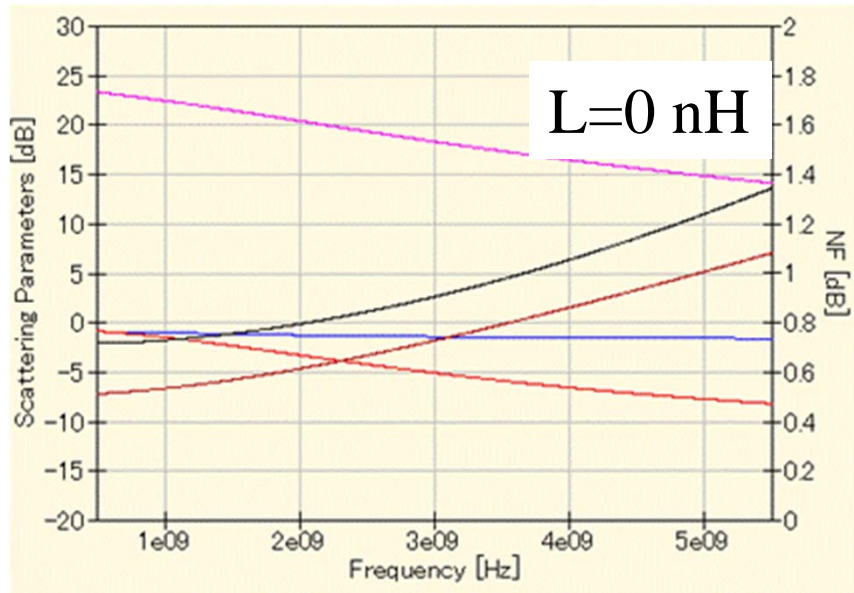
dc simulation

DC1

Equation

Eqn1
 $Tr = dB(S[2,1])$
 $RL1 = dB(S[1,1])$
 $RL2 = dB(S[2,2])$
 $NF = \log_{10}(F) * 10$
 $NFmin = \log_{10}(Fmin) * 10$
 $K = Rollet(S)$

Simulation Results

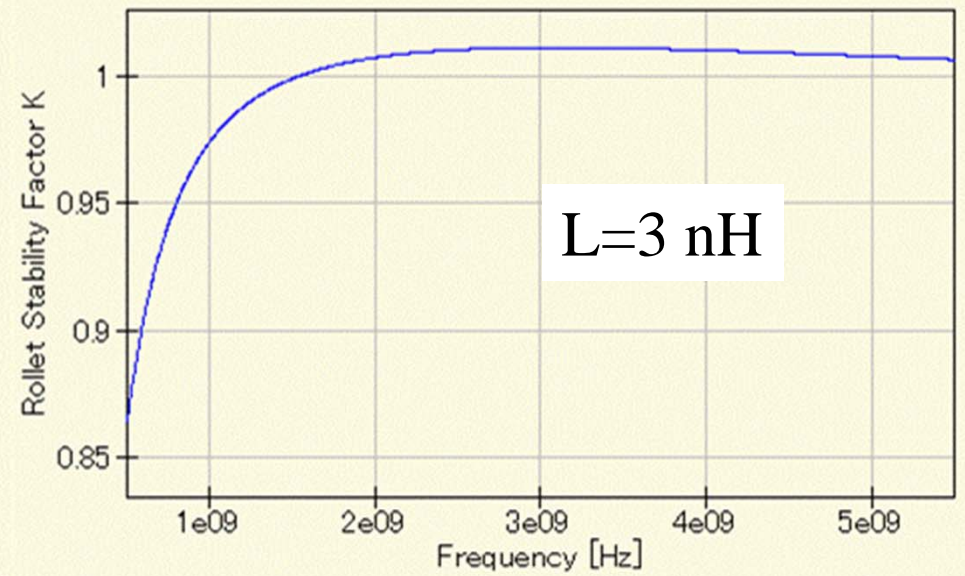
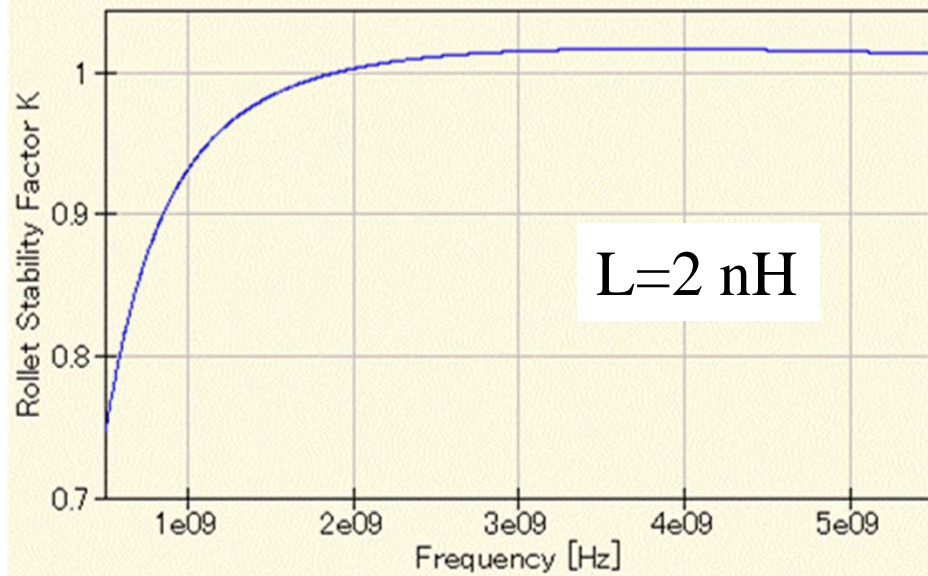
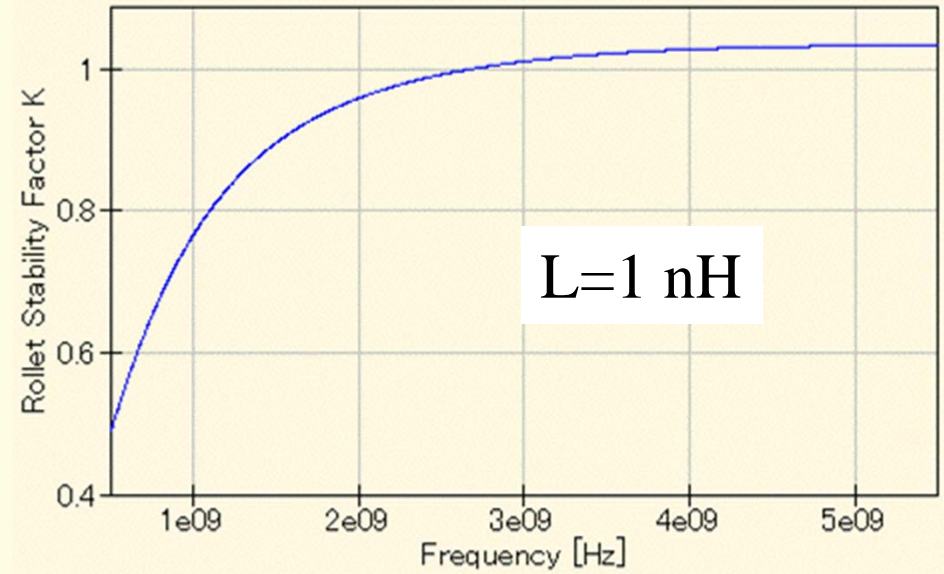
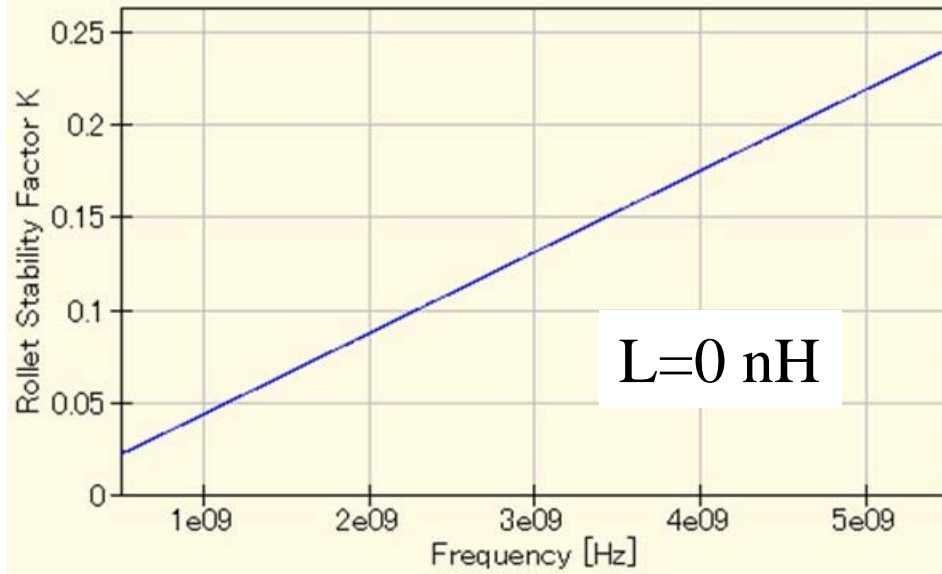


Rollet Stability (K) Factor

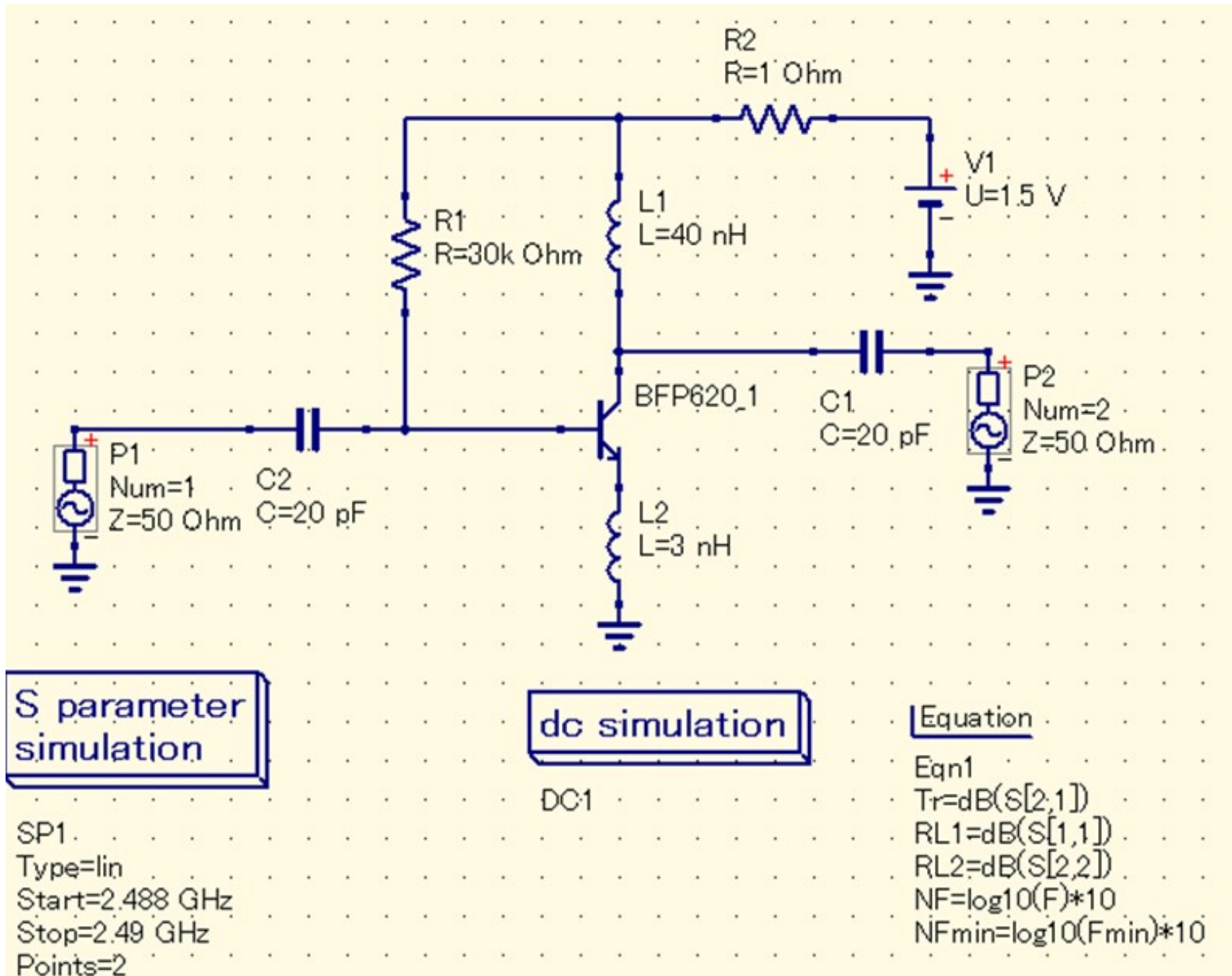
Unconditionally Stable When $K > 1$

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

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

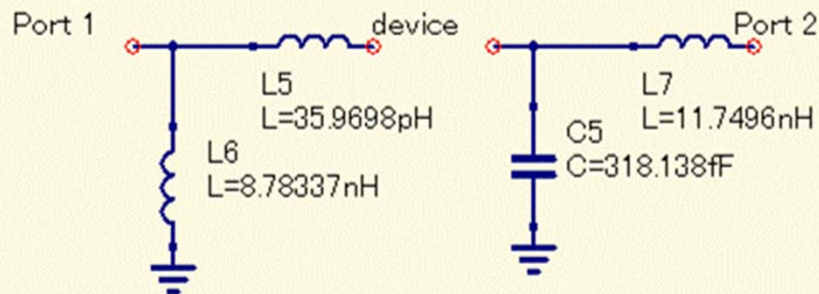
calculate two-port matching

Reference Impedance
 Port 1 ohms Port 2 ohms

S Parameter
 Input format

S11 / - S12 / -
 S21 / - S22 / -

Frequency: GHz



diagrams

Projects

Content

Components

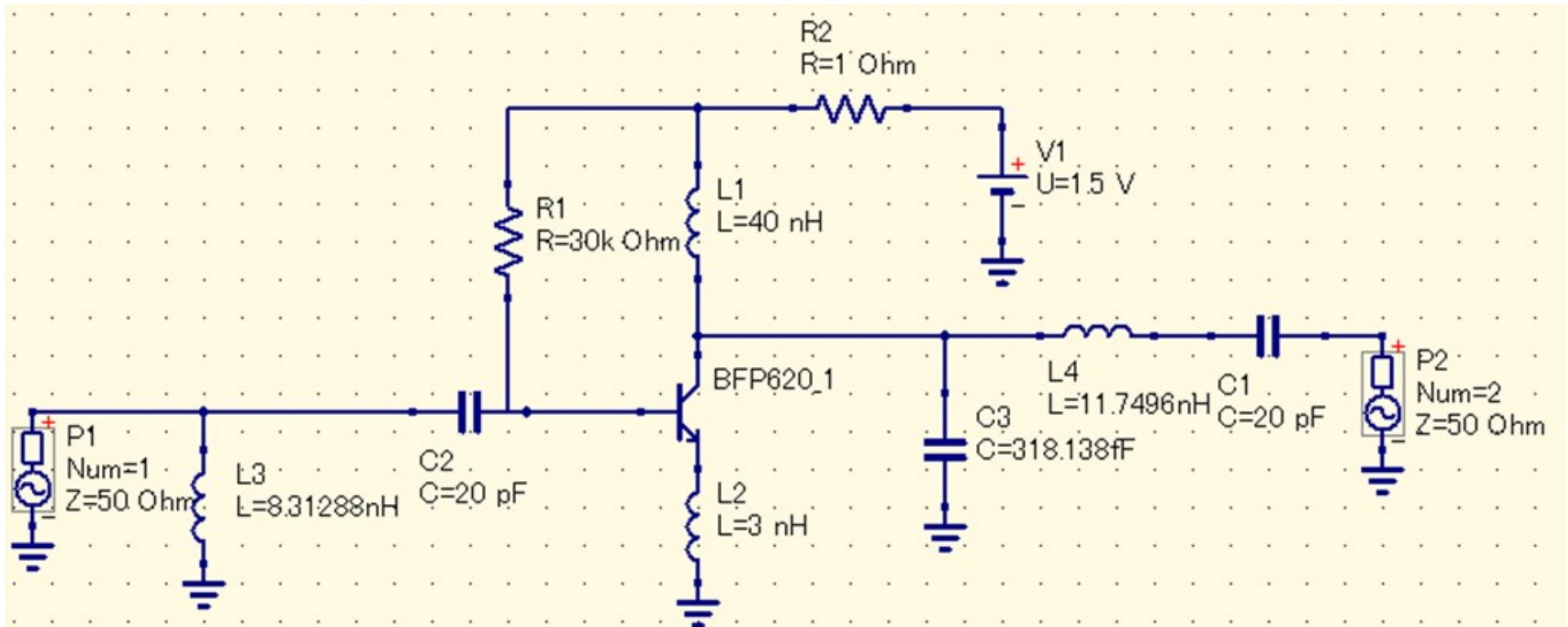
- Smith Chart
- Admittance Smith
- Polar-Smith Combi
- Smith-Polar Combi
- 3D-Cartesian
- Locus Curve
- Timing Diagram
- Truth Table

RF Circuit Basics_SJTU - Po

Tools Simulation View Help

- Text Editor Ctrl+1
- Filter synthesis Ctrl+2
- Line calculation Ctrl+3
- Component Library Ctrl+4
- Matching Circuit Ctrl+5
- Attenuator synthesis Ctrl+6

After Adding Designed Matching Circuit



S parameter simulation

SP1
 Type=lin
 Start=0.5 GHz
 Stop=5.5 GHz
 Points=2001

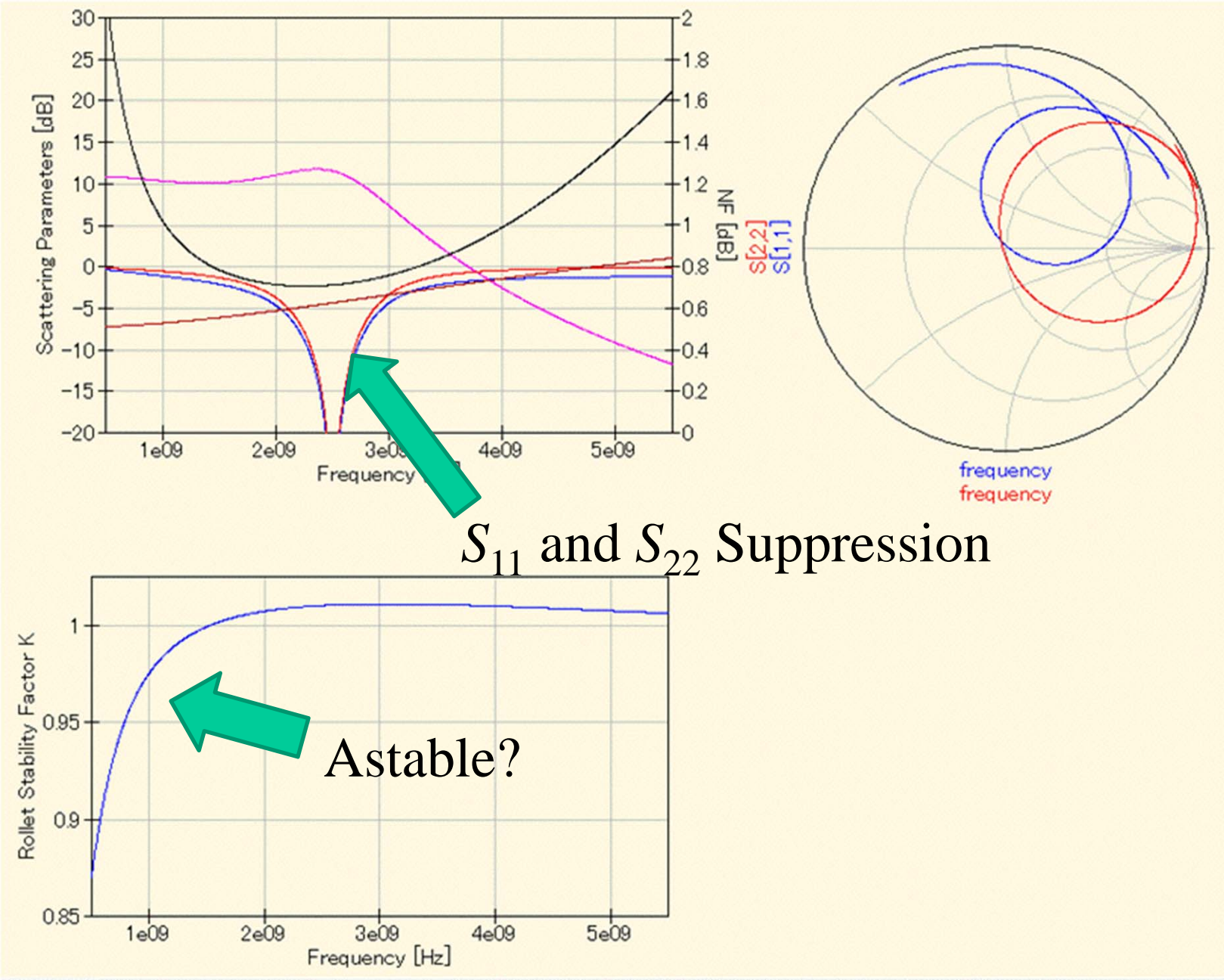
dc simulation

DC:1

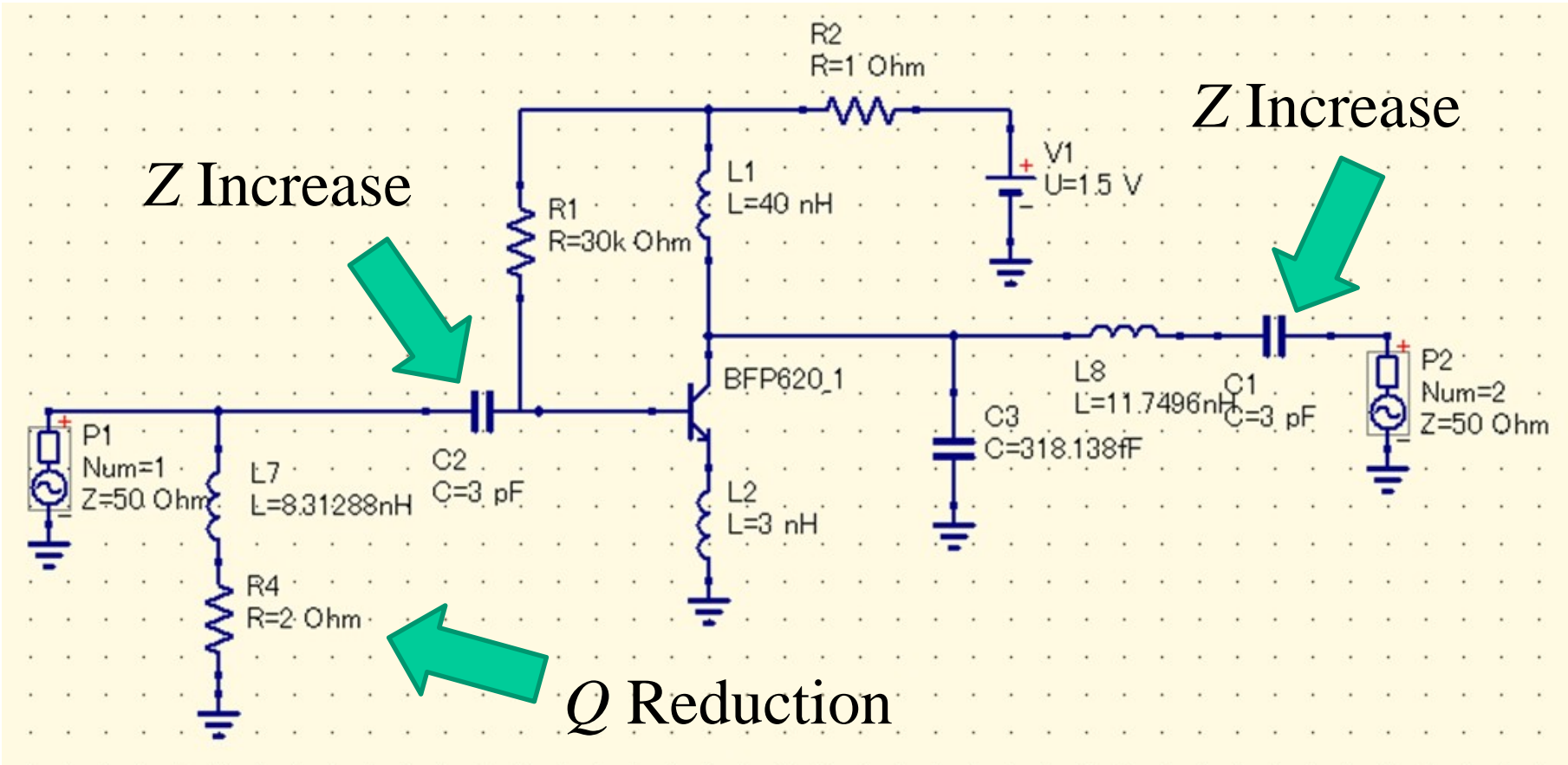
Equation

Eqn1
 Tr=dB(S[2,1])
 RL1=dB(S[1,1])
 RL2=dB(S[2,2])
 NF=log10(F)*10
 NFmin=log10(Fmin)*10
 K=Rollet(S)

Simulated Results



Step 4 Stabilization



S parameter simulation

SP1
 Type=lin
 Start=0.5 GHz
 Stop=5.5 GHz
 Points=2001

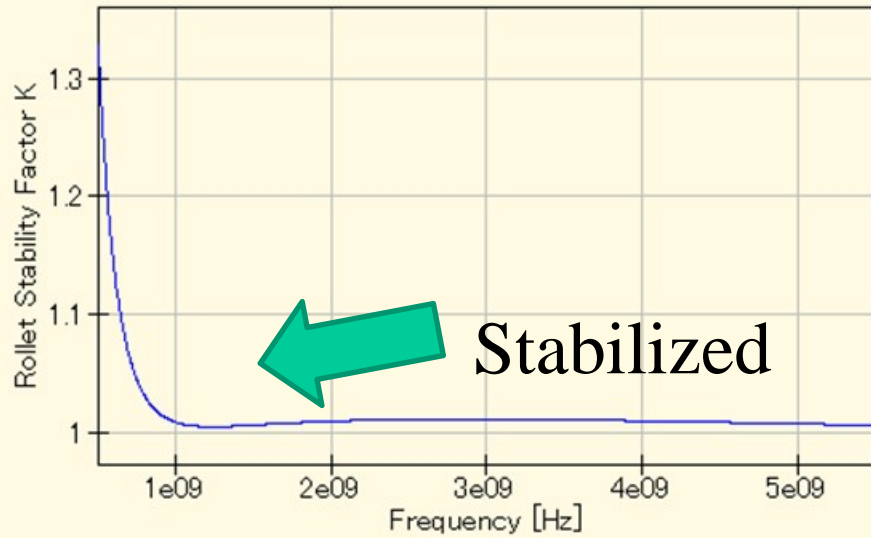
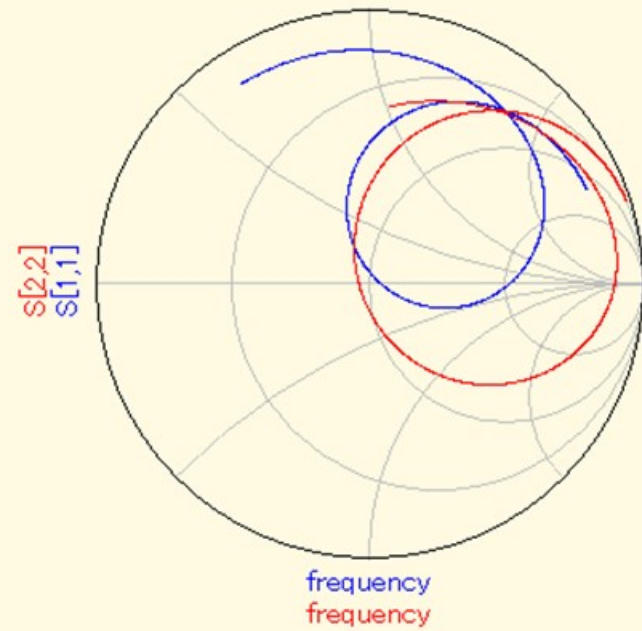
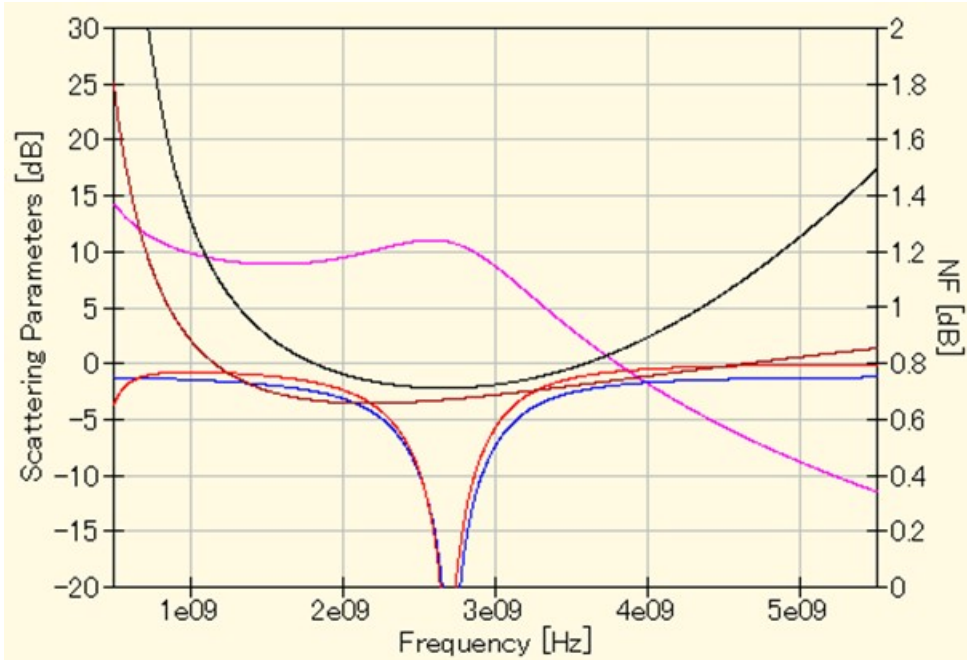
dc simulation

DC1

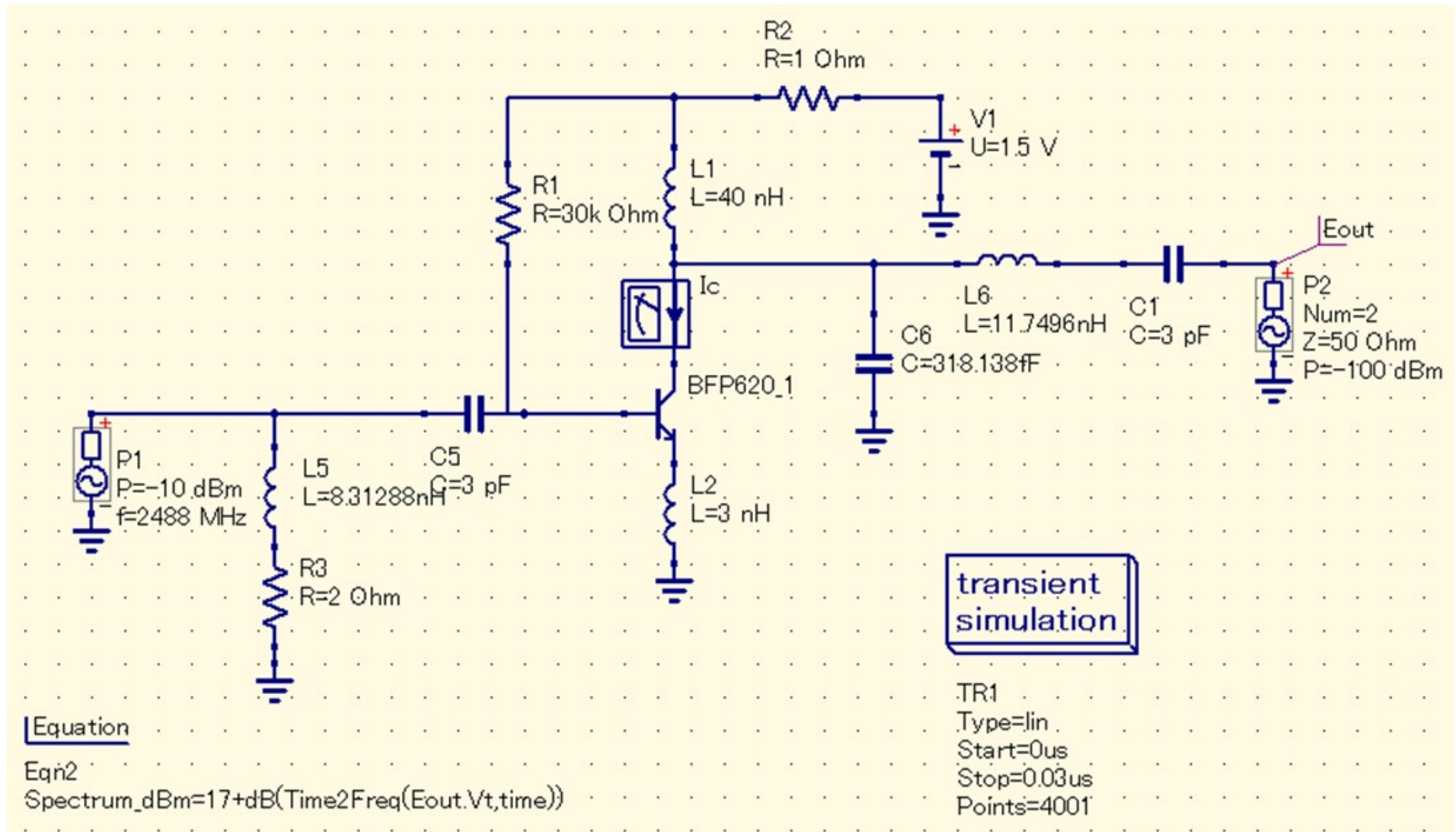
Equation

Eqn1
 Tr=dB(S[2,1])
 RL1=dB(S[1,1])
 RL2=dB(S[2,2])
 NF=log10(F)*10
 NFmin=log10(Fmin)*10
 K=Rollet(S)

Simulation Results

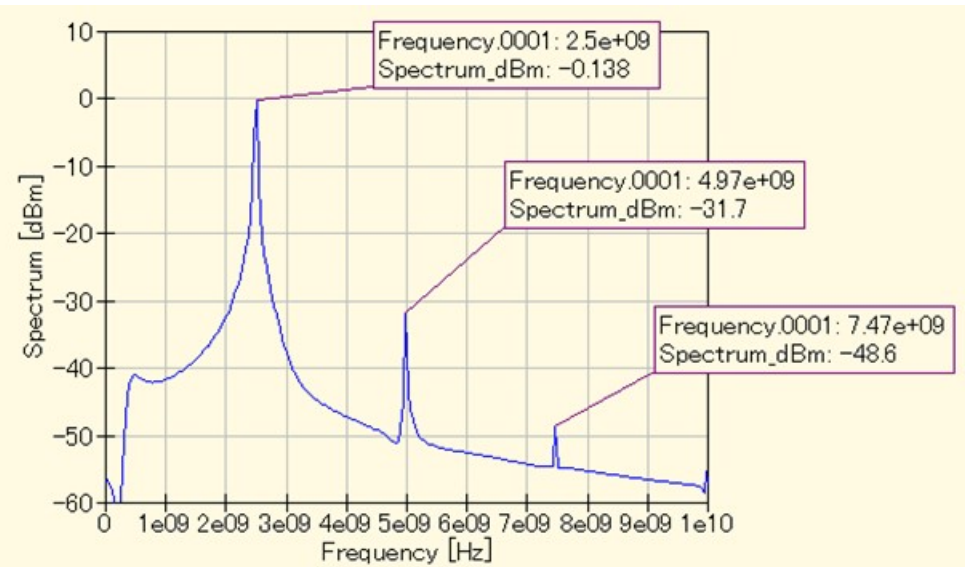
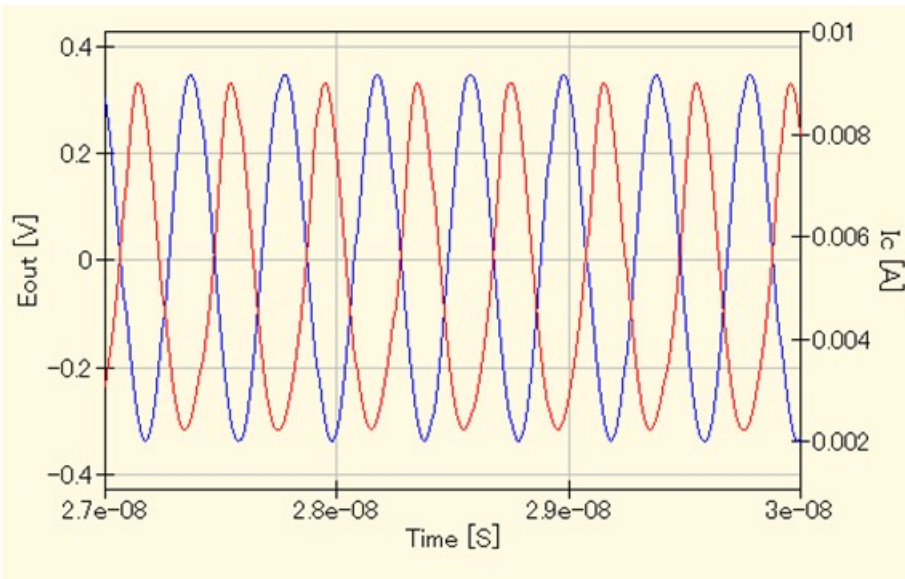


Step 5 Transient Analysis

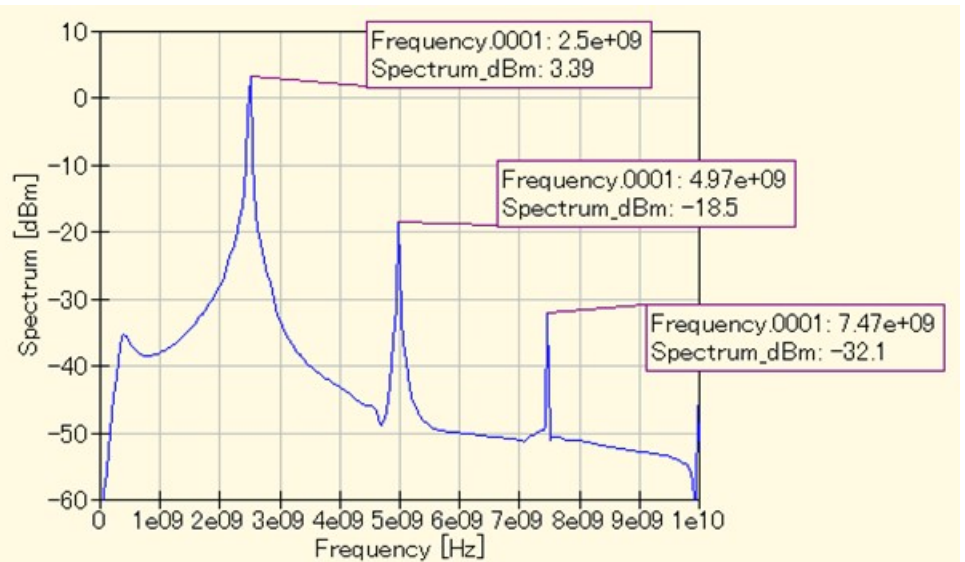
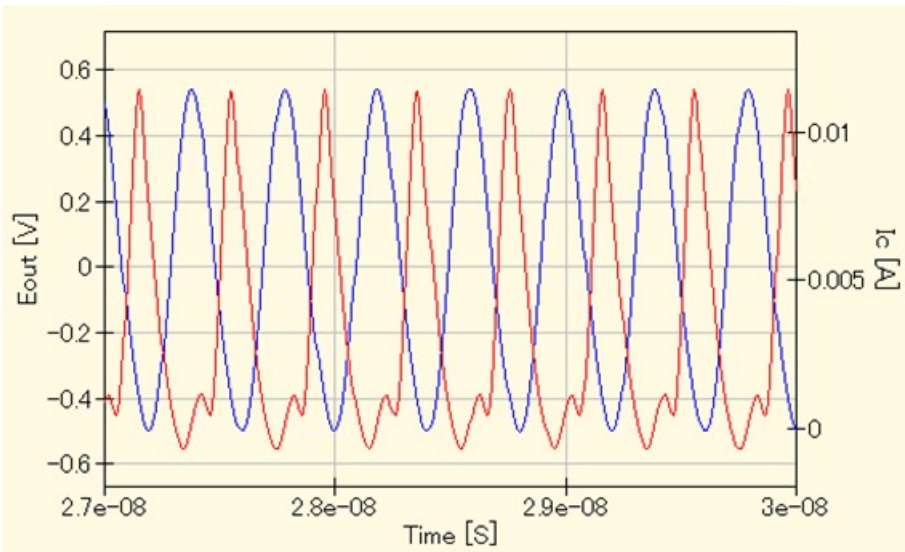


Simulation Results

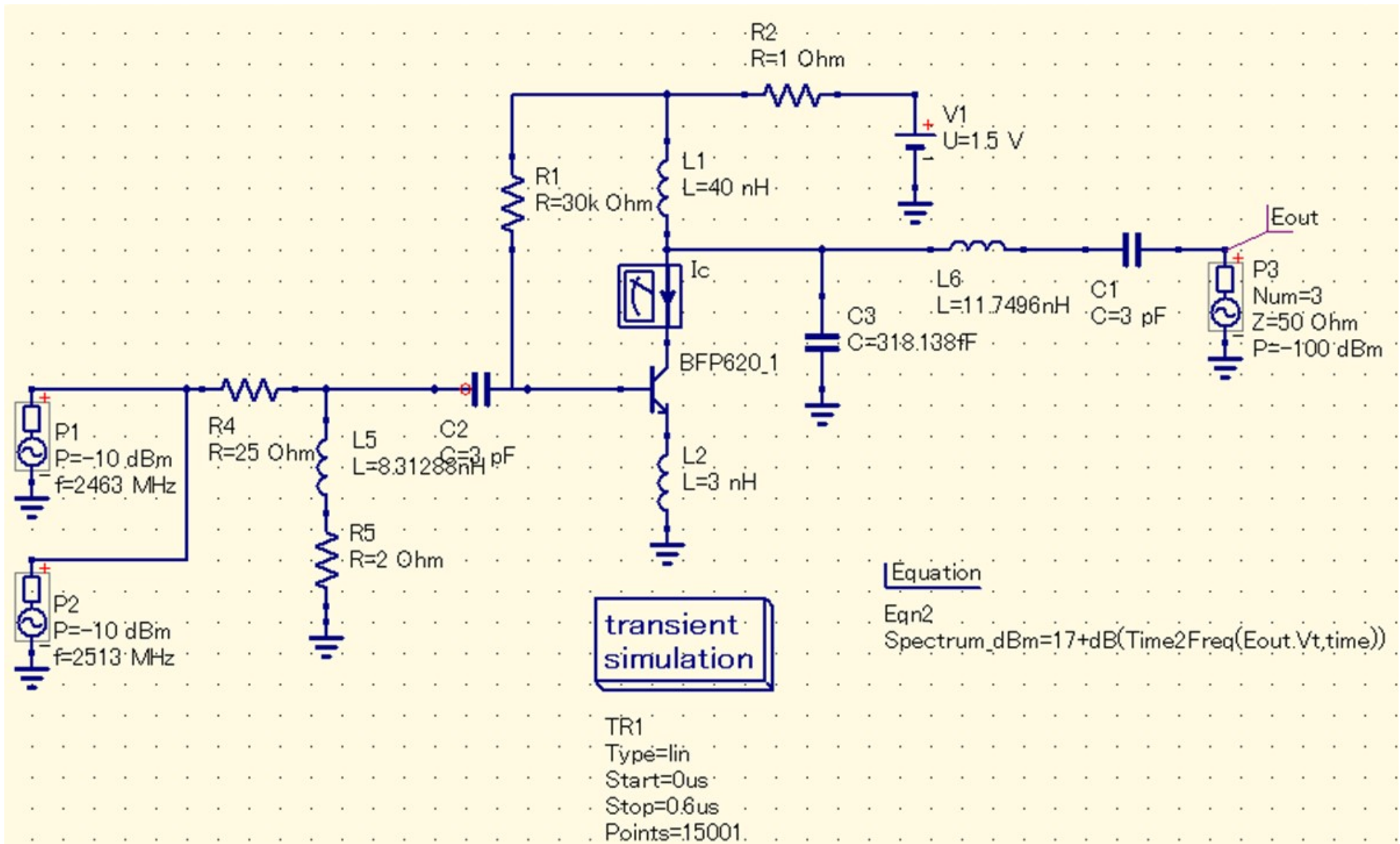
Pin=-10 dBm



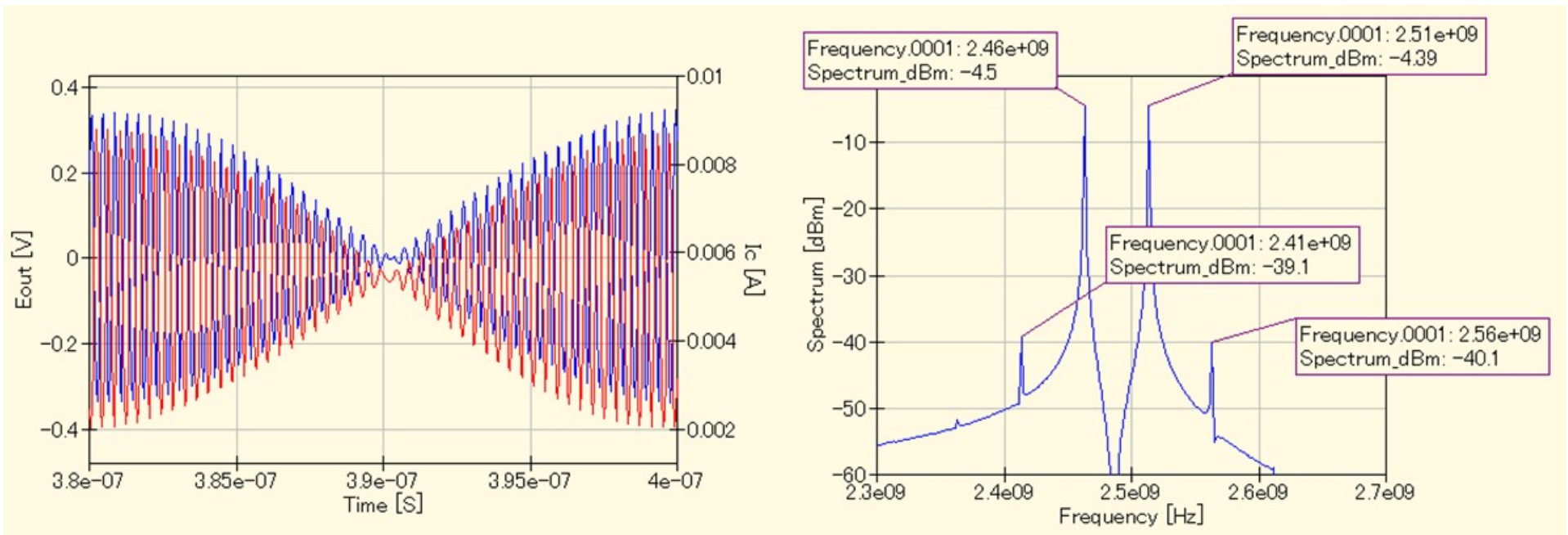
Pin=-5 dBm



Step 6 Two Tone Analysis



Two Tone Test Result



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

➡ $-40.1 = 2 \times (-4.39) + (-4.5) - 2 \times \text{OIP3}$

➡ $\text{OIP3} = 13.4 [\text{dBm}]$

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?

