Multi-Band CMOS Low Noise Amplifiers Utilizing Transformers

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Outline

- Research Background & Objective
- Dual Band LNA
  - Circuit Structure & Principle
  - Simulation
- Triple-Band LNA
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- Consideration
  - Layout of Inductor & Transformer
- Conclusion

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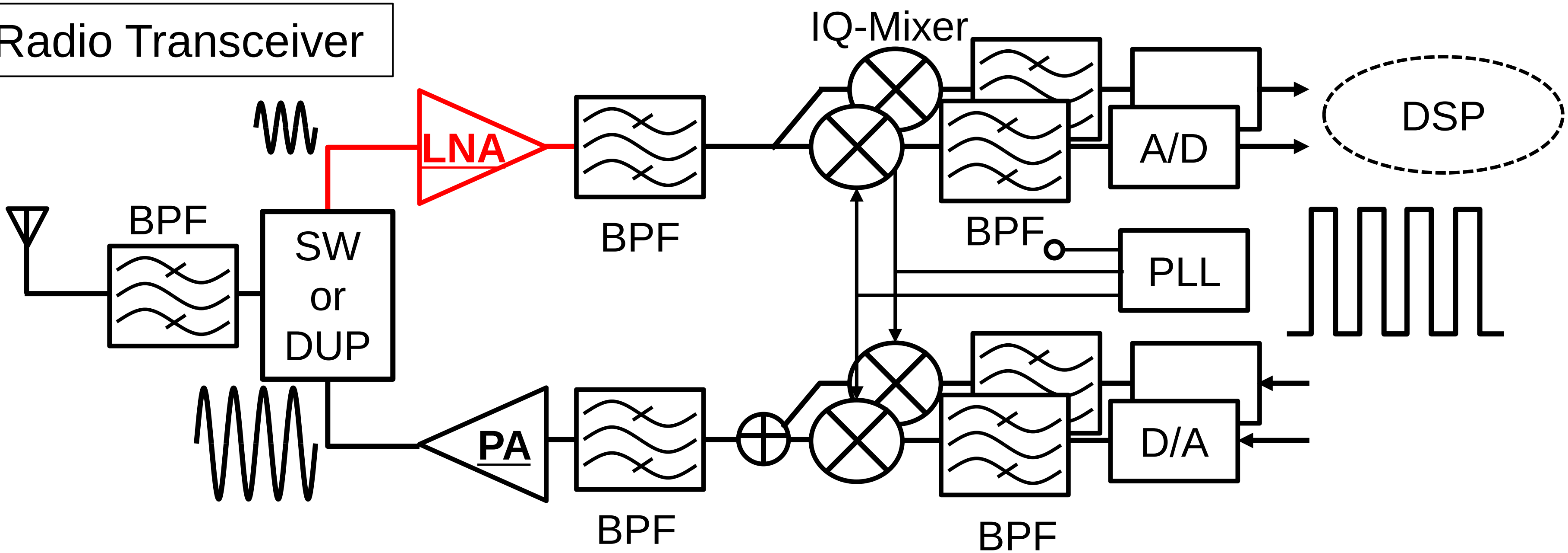
Research Background & Objective

Radio Transceiver



Receiver Side

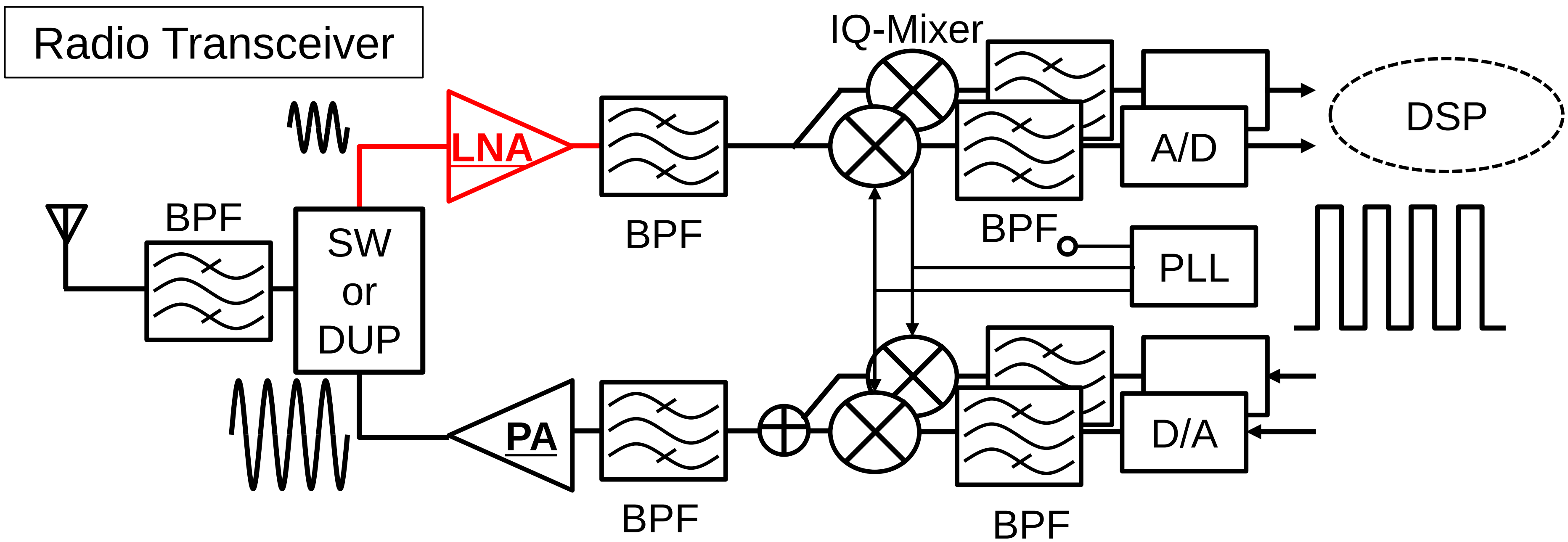
Low Noise Amplifier(LNA)

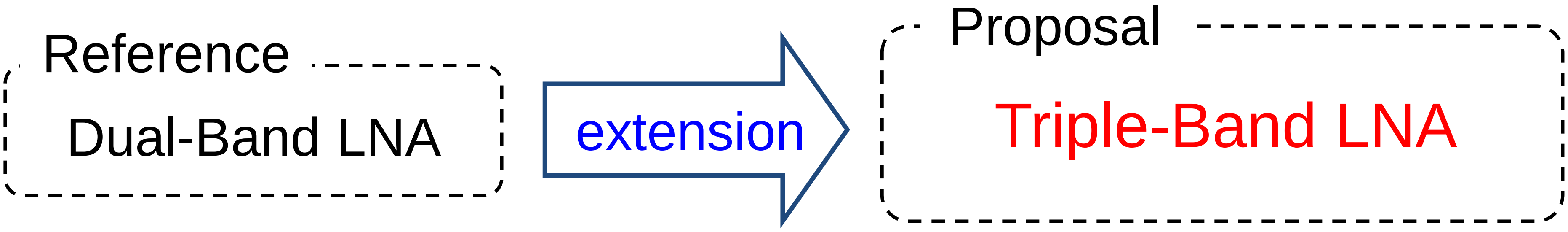
・・・Amplify small signal without noise & distortion

Challenge

Multi-Band performance for many wireless standards

Research Goal





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Research Paper

Objective Extend Multi-Band for Narrowband Amplifier

Technique of Dual-Band LNA Utilizing Transformers

- Paper Title

A Dual-Band 2.45/6 GHz CMOS LNA Utilizing a Dual-Resonant Transformer-Based Matching Network

- Author

N. M.Neihart with Iowa University

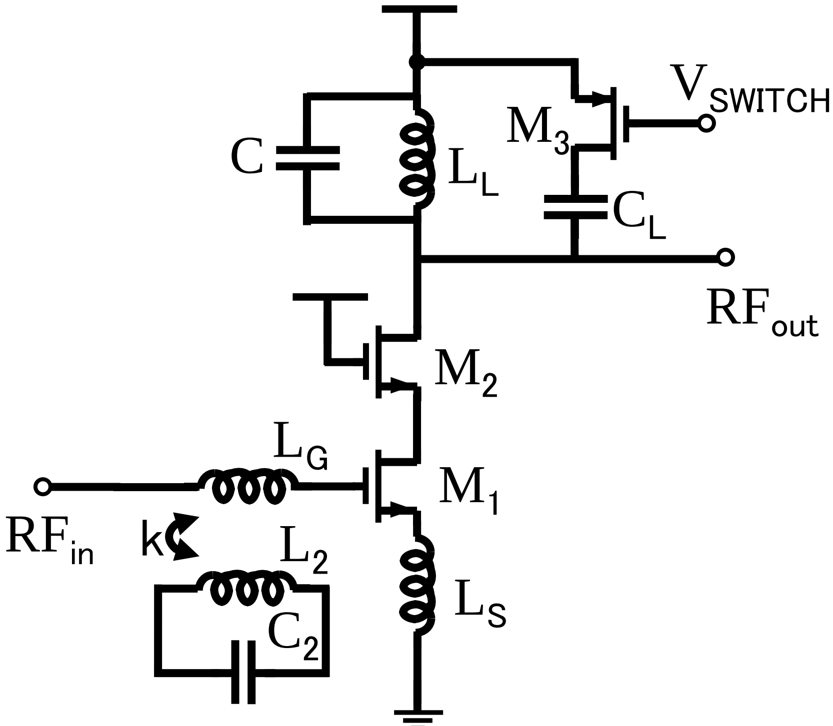
J. Brown

X. Yu

- Journal

IEEE Trans. on Circuits and Systems I, (Aug. 2012)

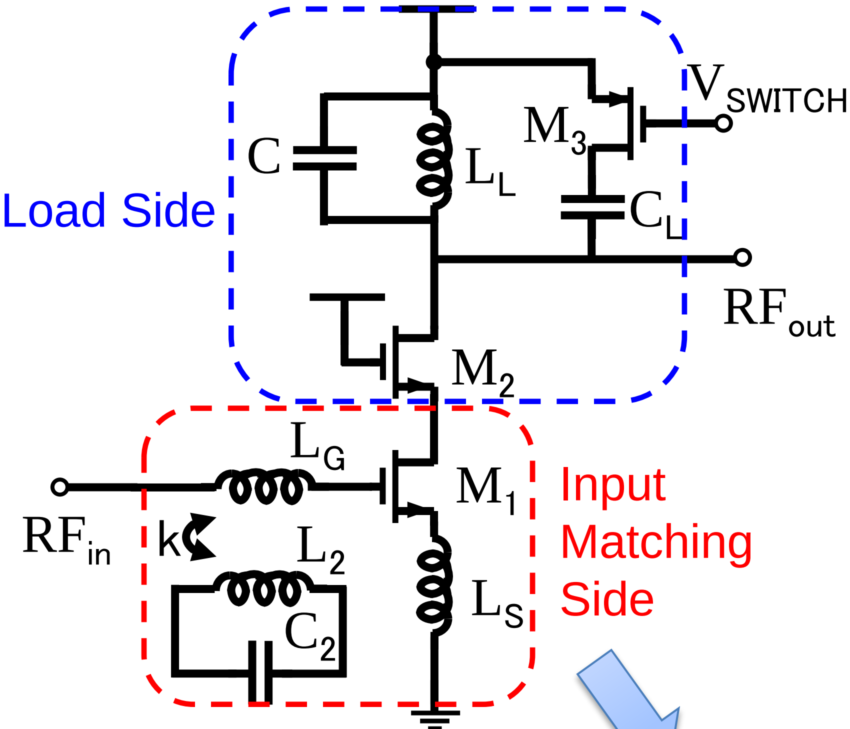
Neihart's Dual-Band LNA



Dual-Band LNA Utilizing Transformers

- L_G , L_2 : Transformer-coupled with coupling coefficient k
- Load side
  Switch 2 resonance frequencies by M_3
- Input matching side
  Realized 2 matching points by transformer-coupling

Neihart's Dual-Band LNA



Dual-Band LNA Utilizing Transformers

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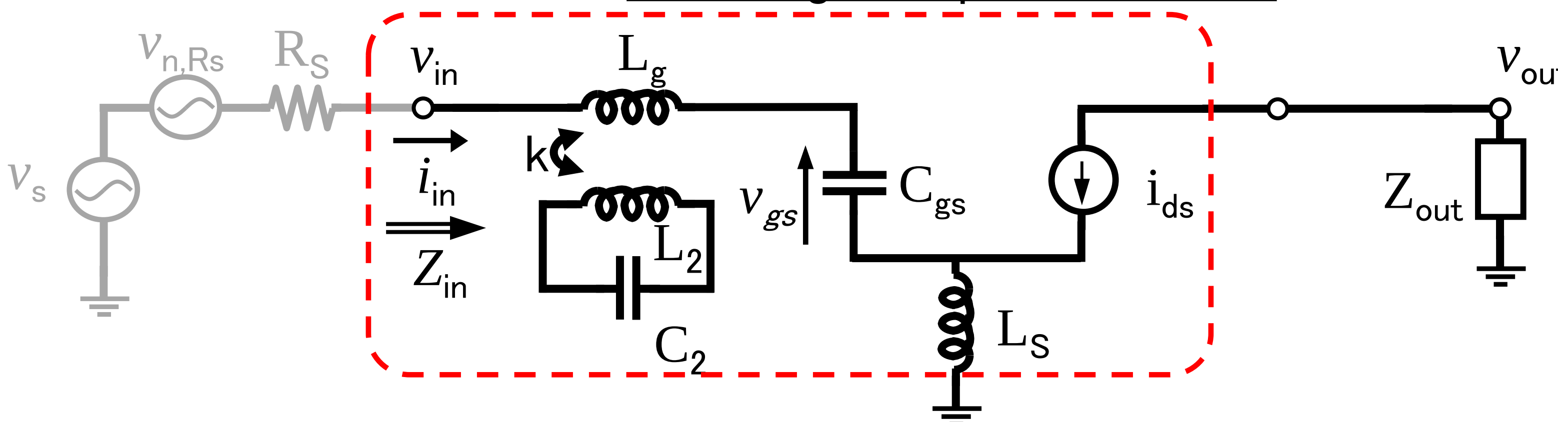
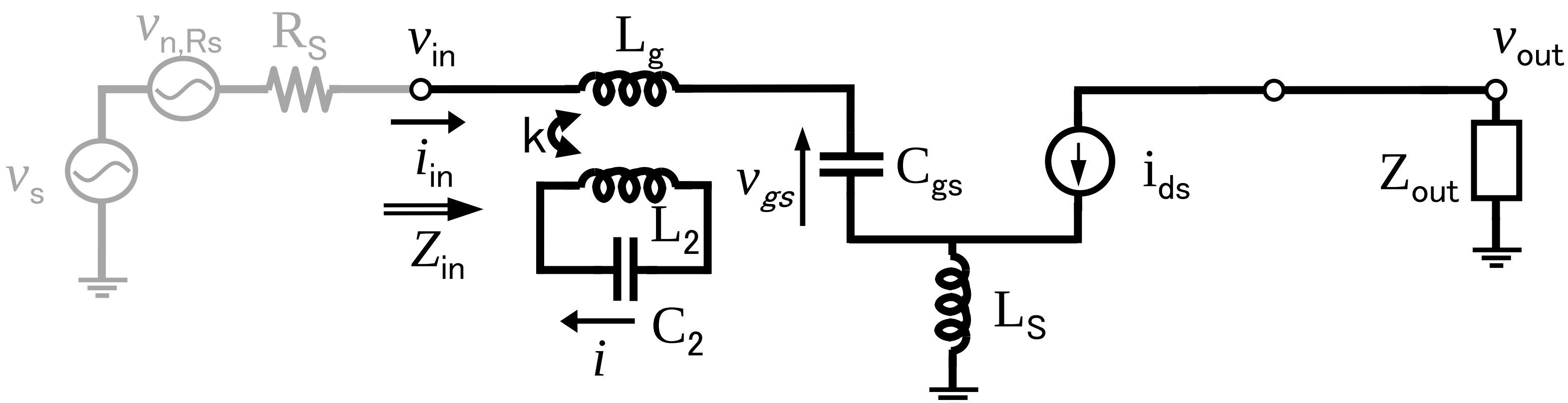
Small-Signal Equivalent Model



Neihart's Model Circuit Analysis



Input impedance Z_{in}

$$Z_{in} = \frac{g_m L_s}{C_{gs}} + j\left\{\omega\left(L_g + L_s\right) - \frac{1}{\omega C_{gs}} + \frac{\omega^3 M^2 C_2}{1-\omega^2 L_2 C_2}\right\} \qquad M = k\sqrt{L_g L_2}$$

Real Part ⇒ R_s(50Ω)

Imaginary Part ⇒ 0
ω: resonance frequency

Solving $Im(Z_{in}) = 0$

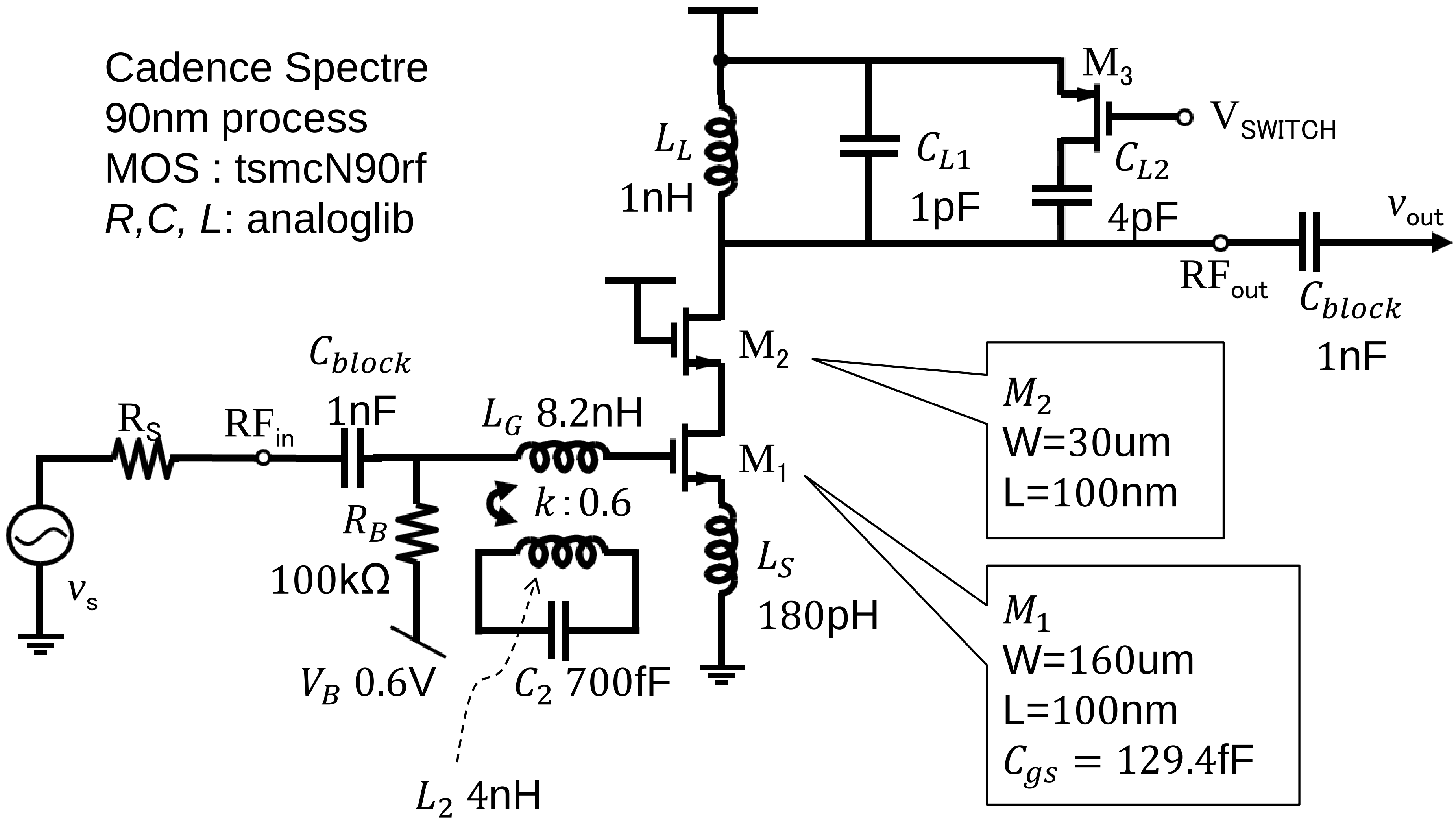
$$\omega = \pm\sqrt{\frac{a^2 + b^2 \mp \sqrt{a^4 + b^4 + a^2 b^2 (4k^2 - 2)}}{2(1-k^2)}} \qquad a = \frac{1}{\sqrt{L_1 C_{gs}}},\ b = \frac{1}{\sqrt{L_2 C_2}}$$

4 solutions（2 positive numbers, 2 negative numbers）

→ resonance frequencies

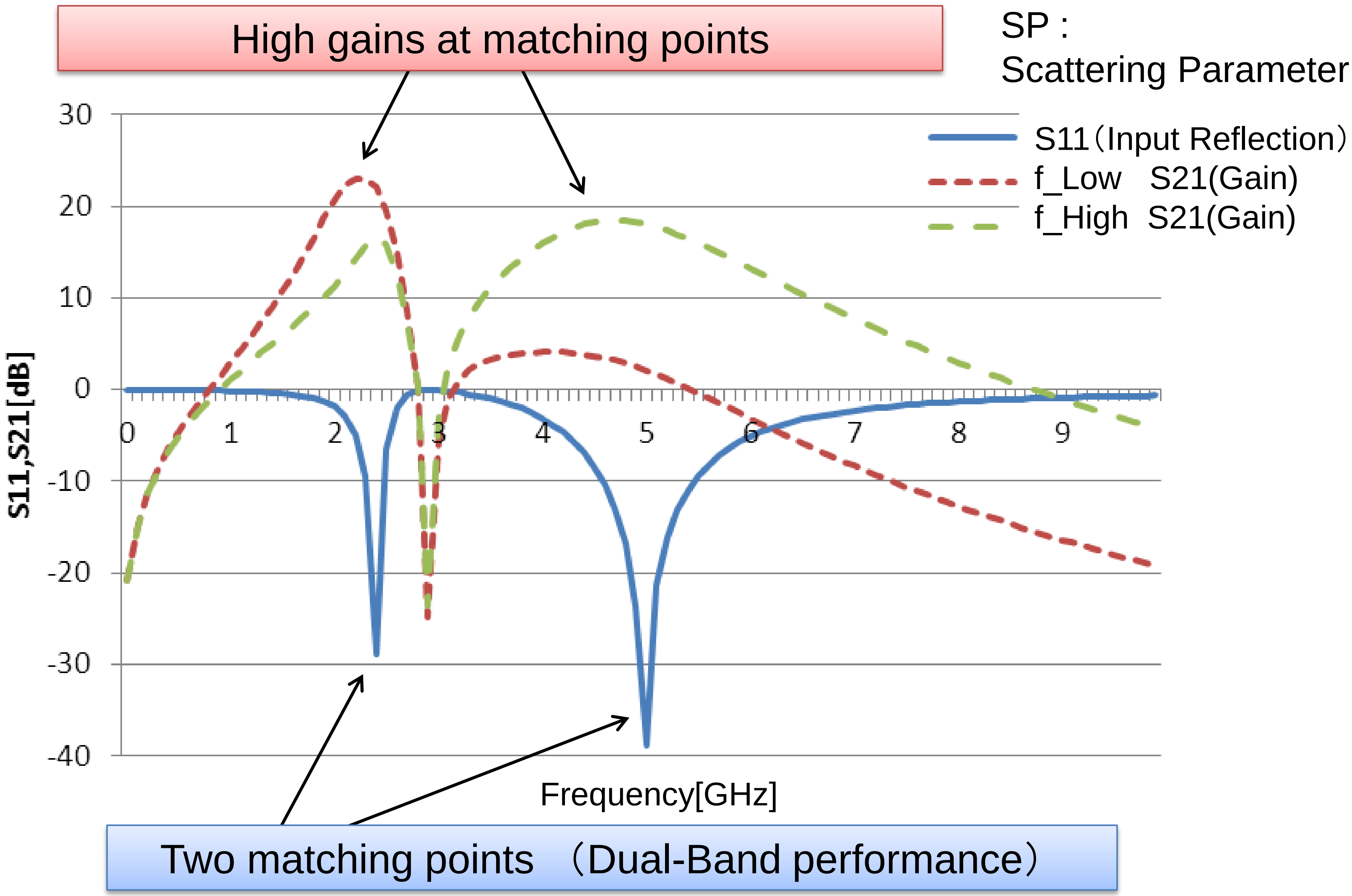
Simulation Circuit

Cadence Spectre
90nm process
MOS : tsmcN90rf
R,*C*, *L*: analoglib



Simulation Results　SP Analysis

SP :
Scattering Parameter



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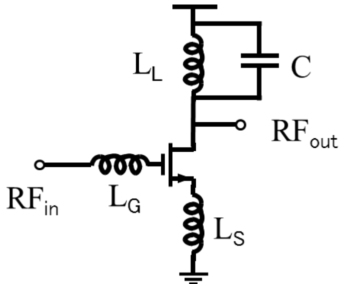
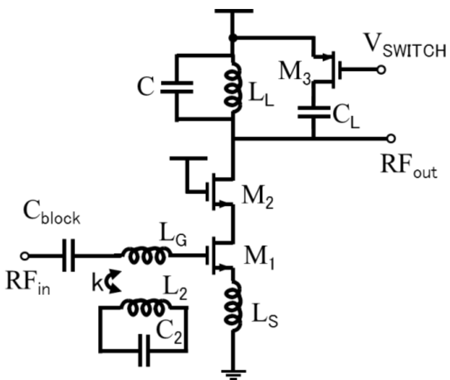
Extension to Triple-Band





Number of Transformers	Number of Resonance Frequencies
0	1 (Single-Band)
1	2 (Dual-Band)
2	Our challenge 3 (Triple-Band)

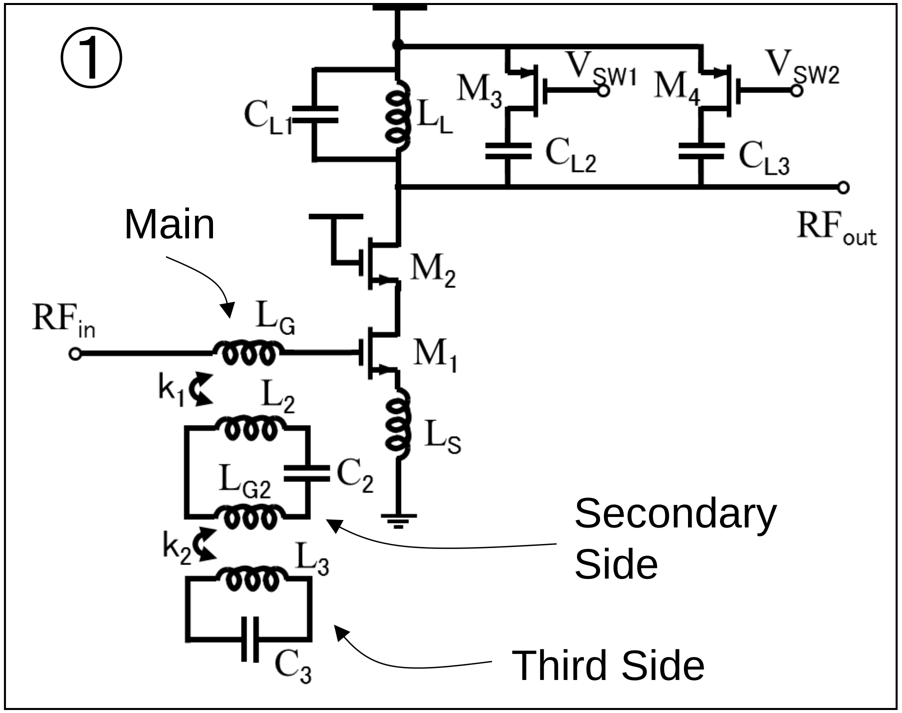
Our Design

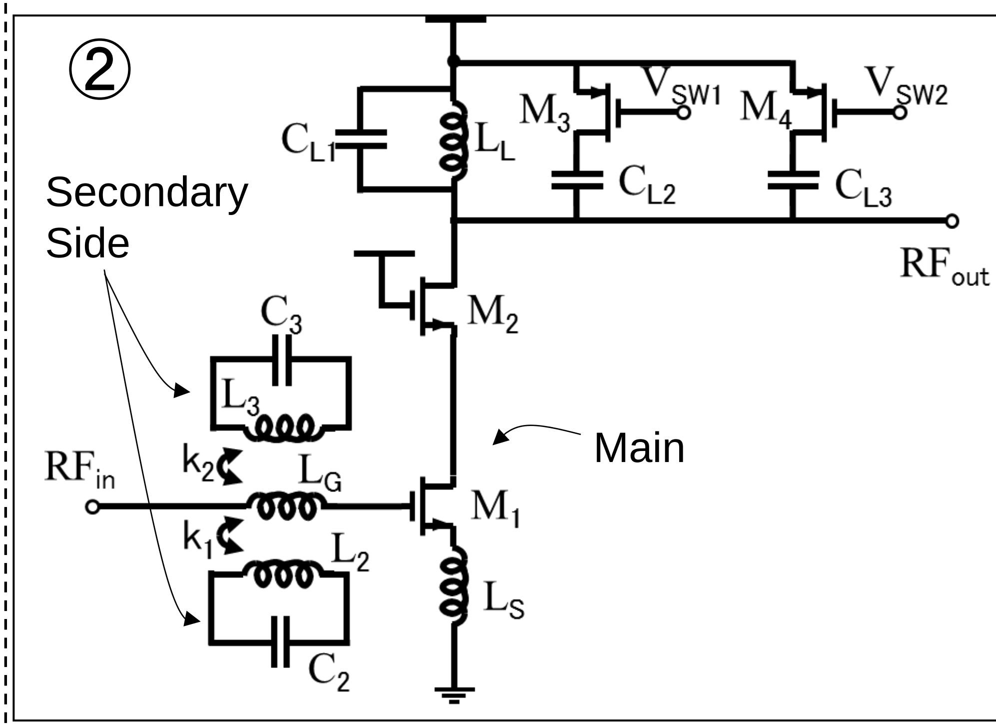
Expectation

Two transformers can realize Triple-Band

Proposed Triple-Band LNA

Two types of Triple-Band LNA circuits ① ②





- Transformer-coupled

  L_G - L_2 L_{G2} - L_3
- Structure

Main - Secondary Side - Third Side

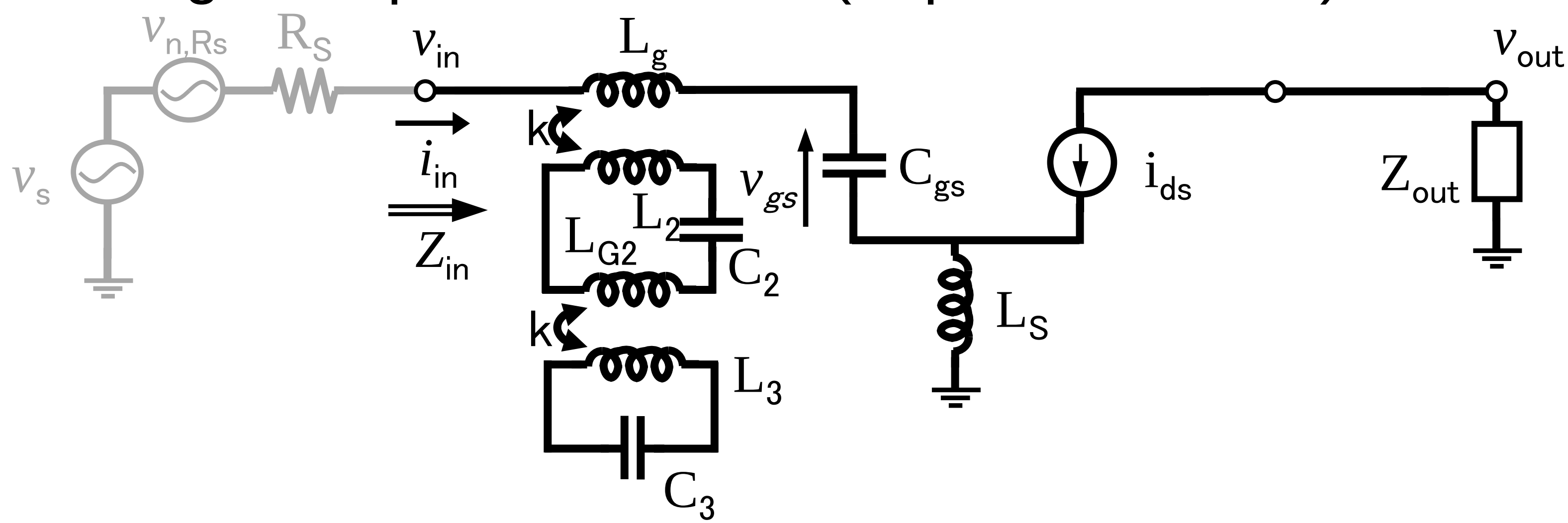
- Transformer-coupled

  L_G - L_2 L_G - L_3
- Structure

Main - Two Secondary Side

Analysis of Triple-Band LNA①

Small-Signal Equivalent Model (Triple-Band LNA)



Input impedance Z_{in}

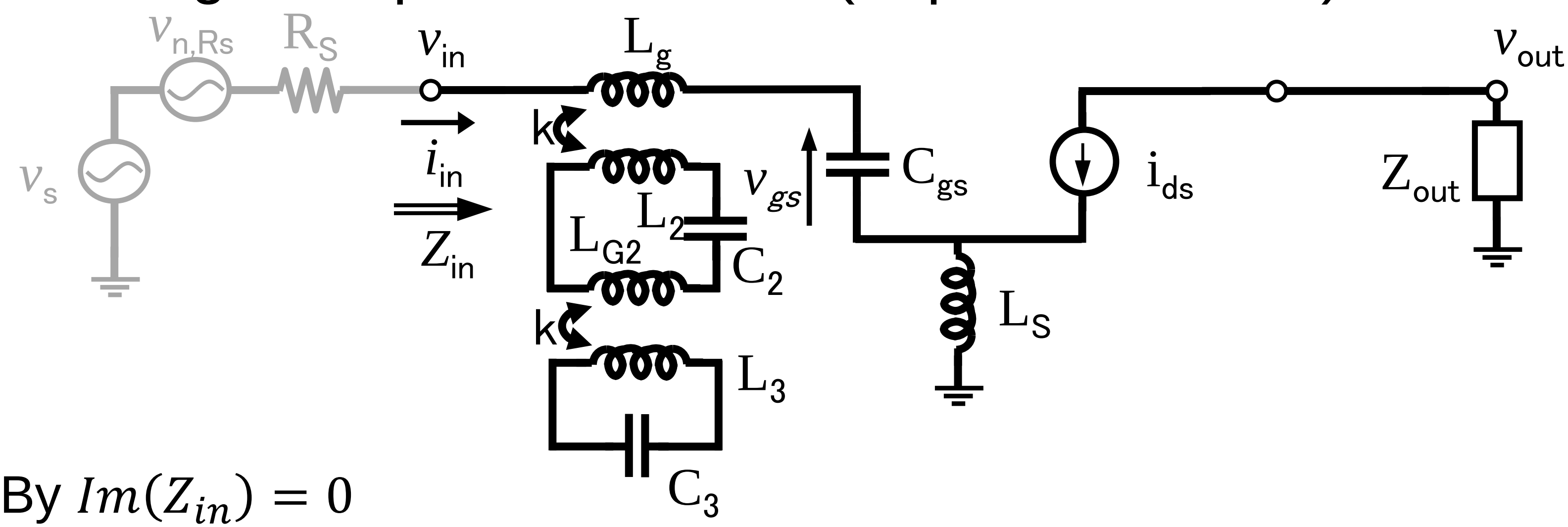
$$Z_{in} = \frac{g_m L_s}{C_{gs}} + j\left\{\underline{\omega\left(L_g + L_s\right) - \frac{1}{\omega C_{gs}}}\right.$$
$$\left.\underline{+ \frac{j\omega^5 {M_1}^2 C_2 C_3 L_3 - j\omega^3 C_2 {M_1}^2}{\omega^4\{C_2 C_3 {M_2}^2 - C_3 L_3 C_2 (L_2 + L_{g2})\} + \omega^2\{C_3 L_3 + C_2(L_2 + L_{g2})\} - 1}}\right\}$$

=0

Imaginary Part ⇒ 0

Analysis of Triple-Band LNA①

Small-Signal Equivalent Model (Triple-Band LNA)



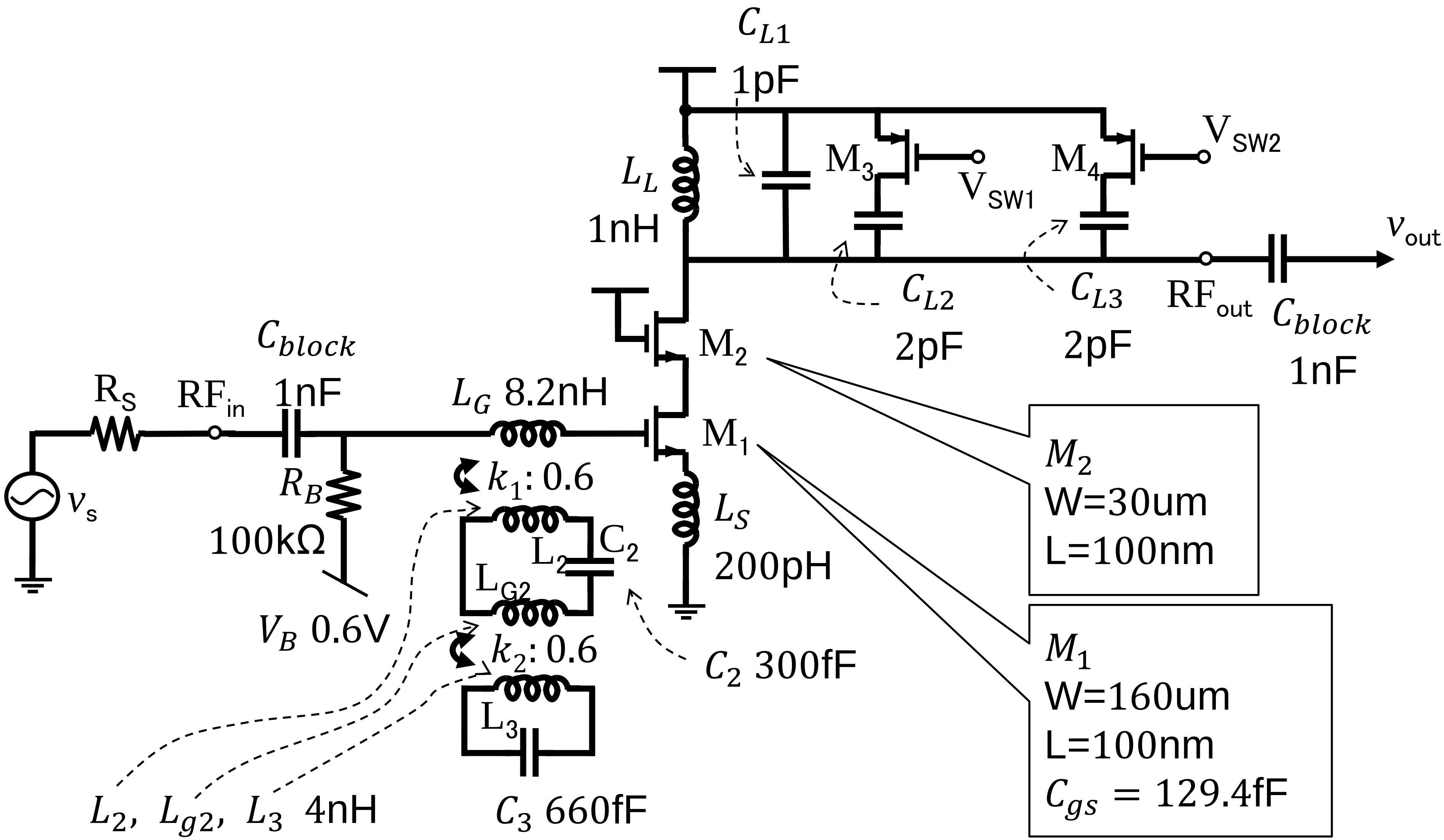
By $Im(Z_{in}) = 0$

Calculate formula for determining resonance frequencies

$$\boldsymbol{\omega^6} C_{gs}C_2C_3\{(L_g+L_s)(L_2+L_{g2})L_3-(L_g+L_s){k_2}^2L_{g2}L_3-{k_1}^2L_gL_2L_3\}$$
$$+\boldsymbol{\omega^4}\{-(L_g+L_s)C_{gs}(L_2+L_{g2})C_2-(L_g+L_s)C_{gs}L_3C_3-(L_2+L_{g2})C_2L_3C_3$$
$$+{k_2}^2L_{g2}C_2L_3C_3+{k_1}^2L_gC_{gs}L_2C_2\}$$
$$+\boldsymbol{\omega^2}\{(L_g+L_s)C_{gs}+(L_2+L_{g2})C_2+L_3C_3\}-\boldsymbol{1}=0$$

6-th order equation　(3 resonance frequencies)

Simulation Circuit



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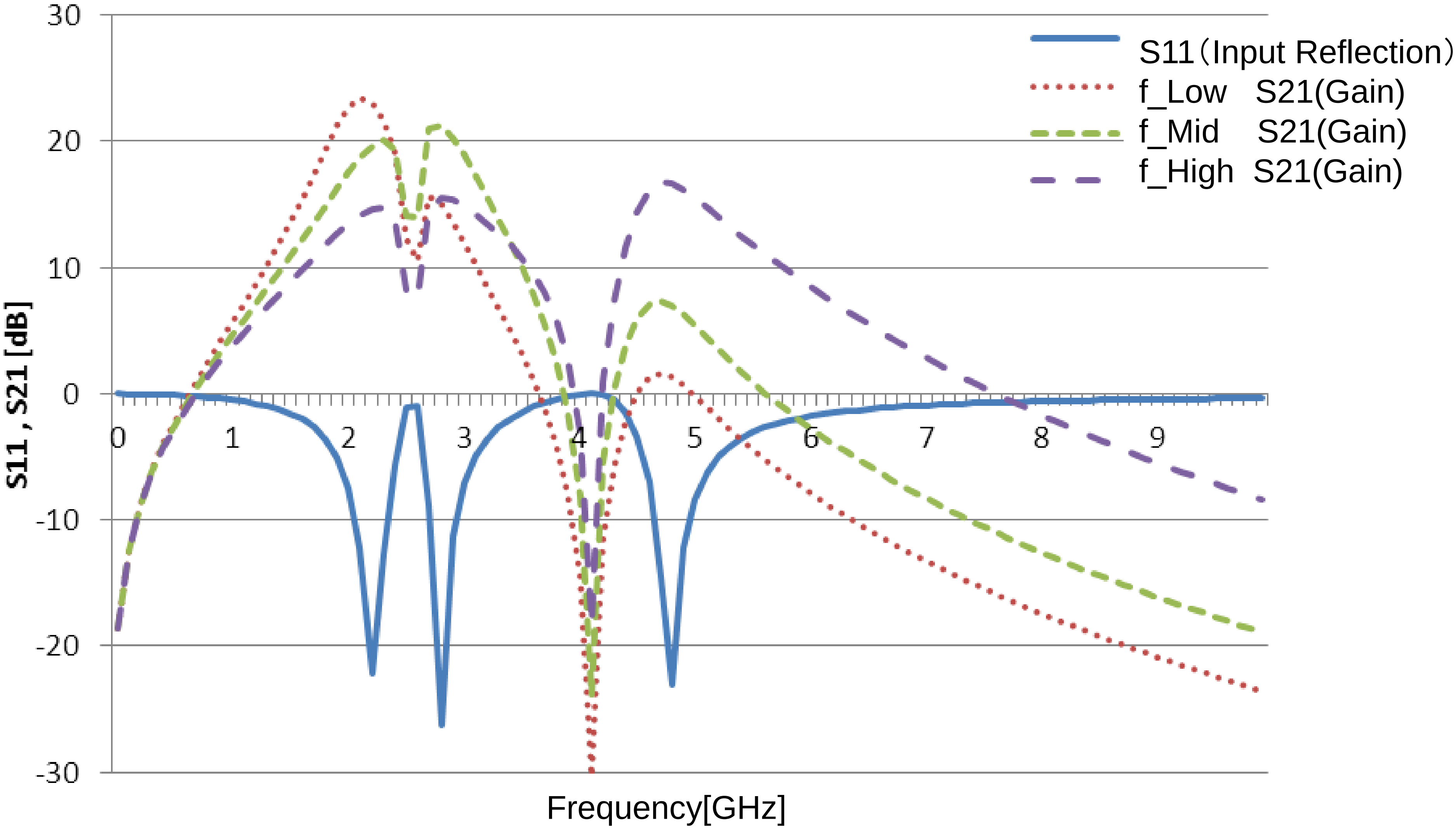
SP : Scattering Parameter



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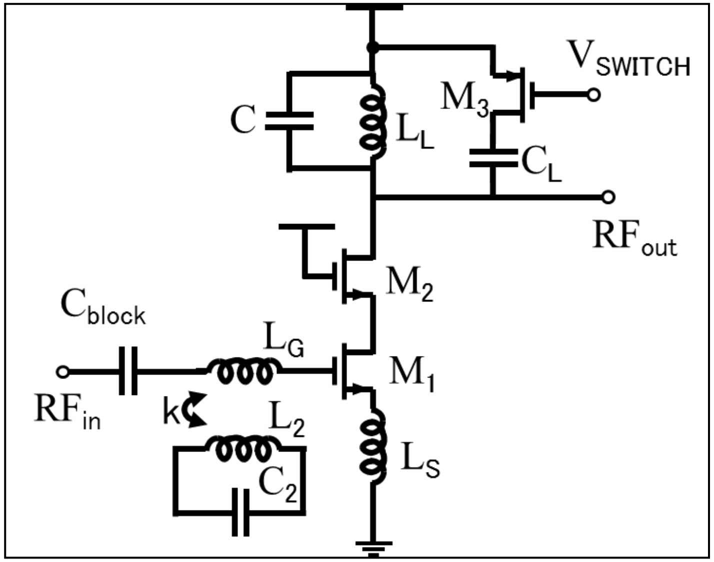
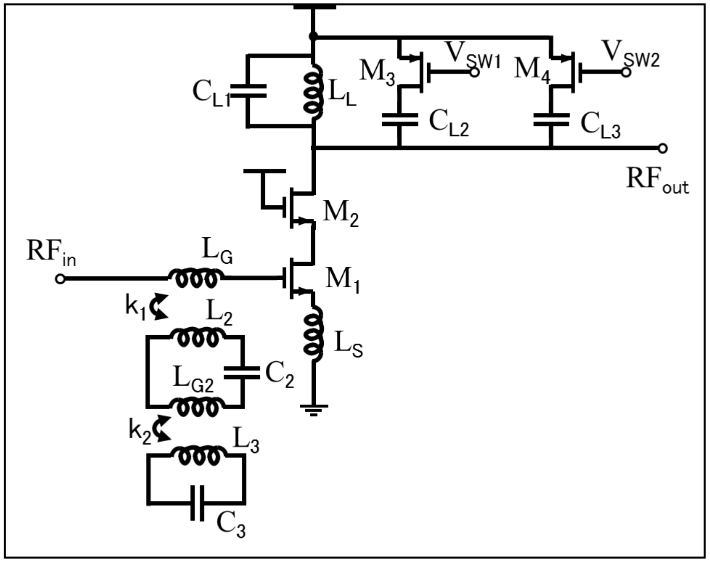
Problems when extending to Triple-Band



Dual-Band LNA



Triple-Band LNA

Dual-Band LNA

Adding Inductor

Triple-Band LNA

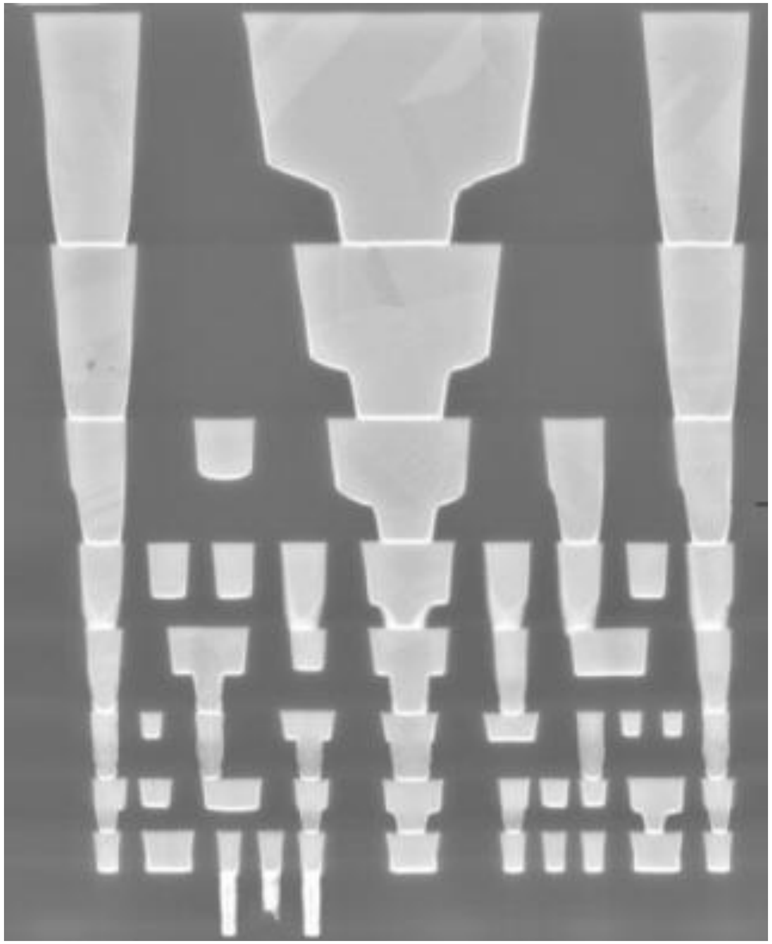
Problems

・Area increase

・Noise increases
(by associated circuits with inductor)

Consider inductor layout
for solving these problems !!

Realization of Inductor on chip



Thick Wiring at Top Layer

Section View of LSI

Inductor is realized in high Q value at top layer on chip

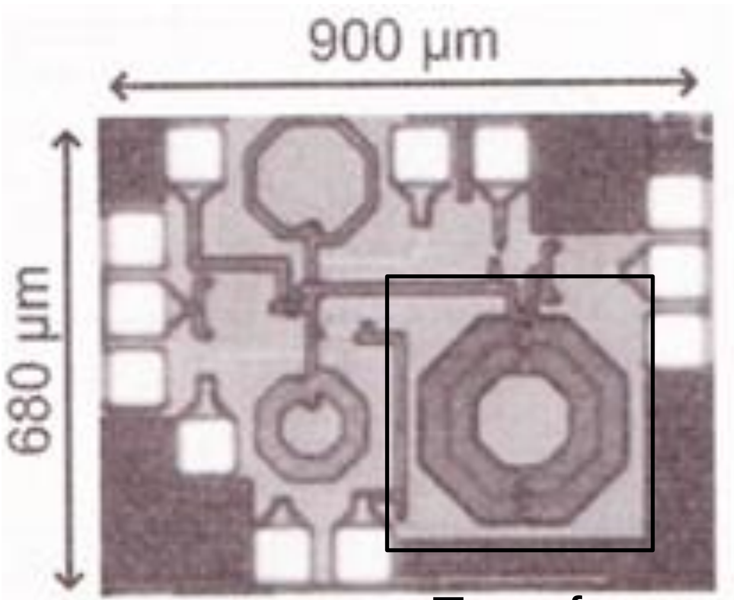
（Q value is high, inductor's parasitic resistance is small）

http://techon.nikkeibp.co.jp/members/NEWS/20040827/105151/?SS=imgview&FD=-195807635

Consideration of Layout

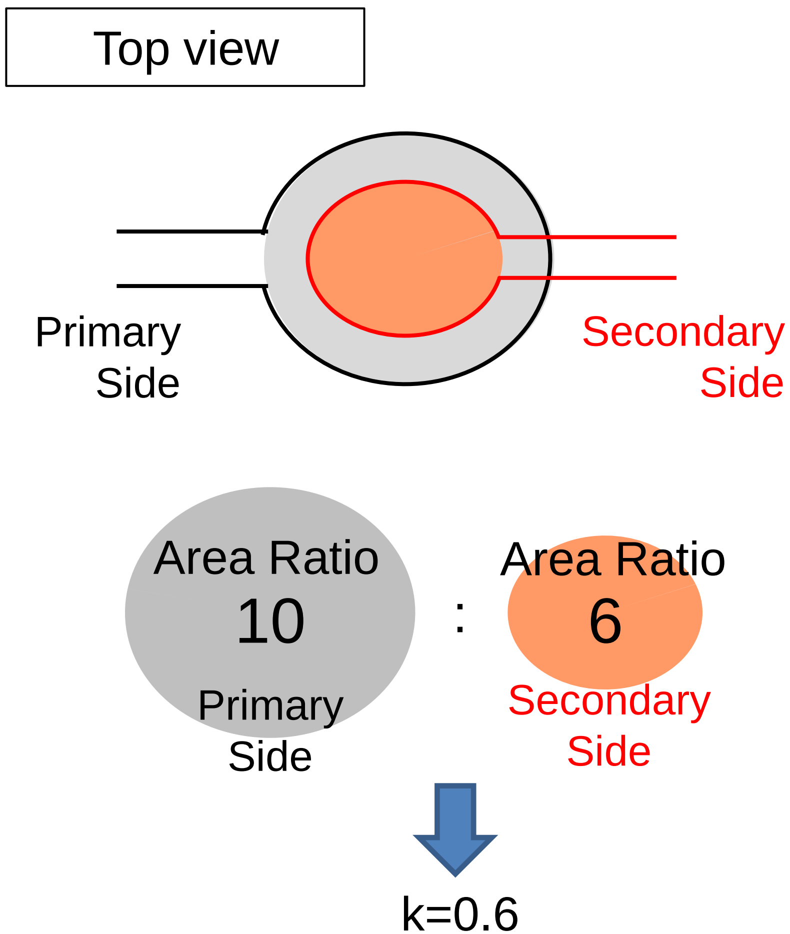
Schematic diagram of a transformer or inductors

(Coupling coefficient is determined by shared area of 2 inductors)



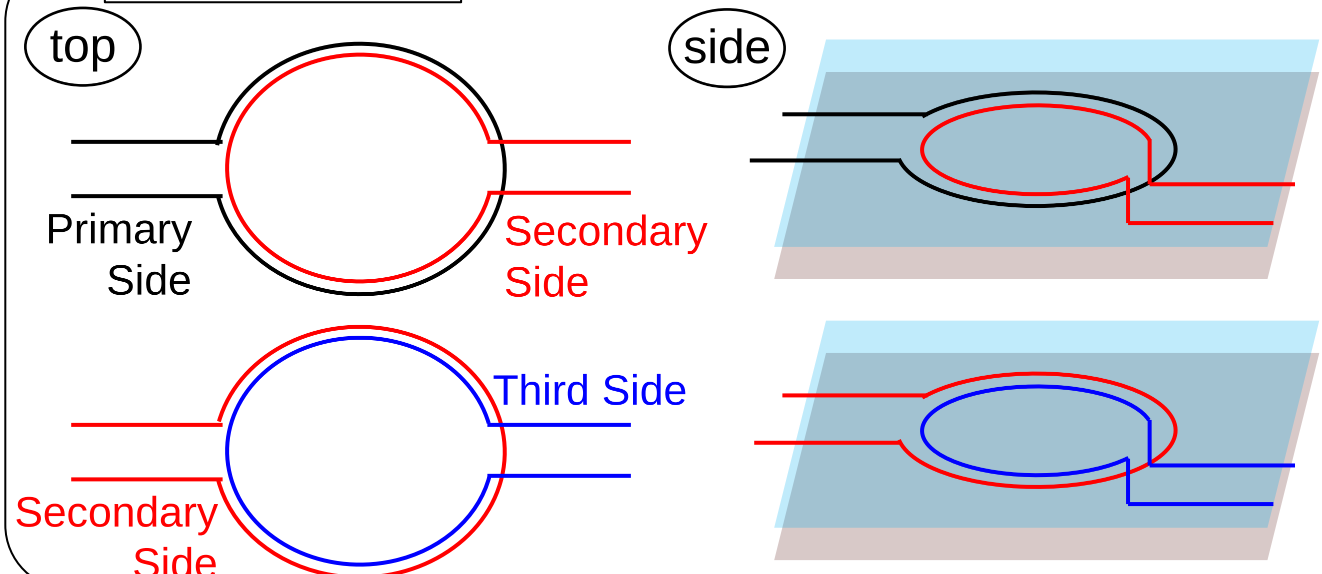
Transformer

Implementation of Dual-Band LNA



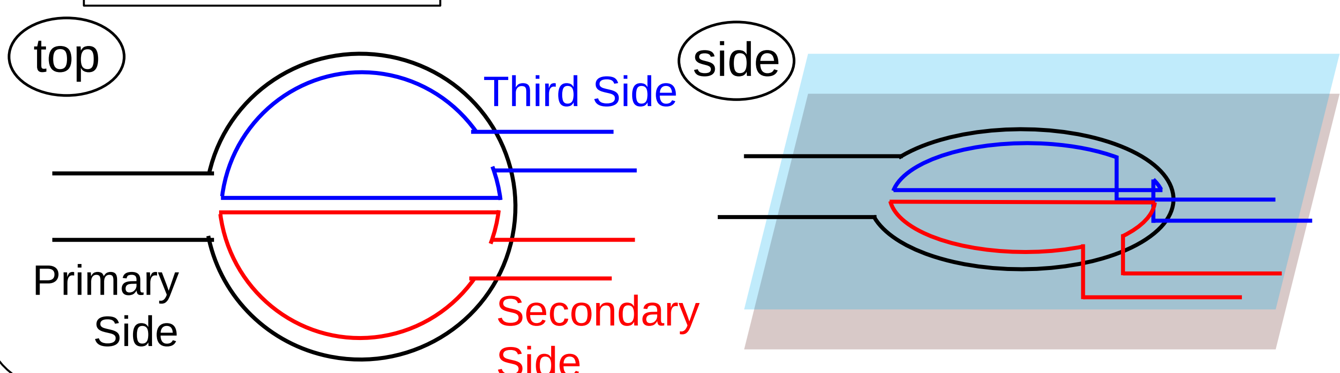
Consideration of Layout

Method 1



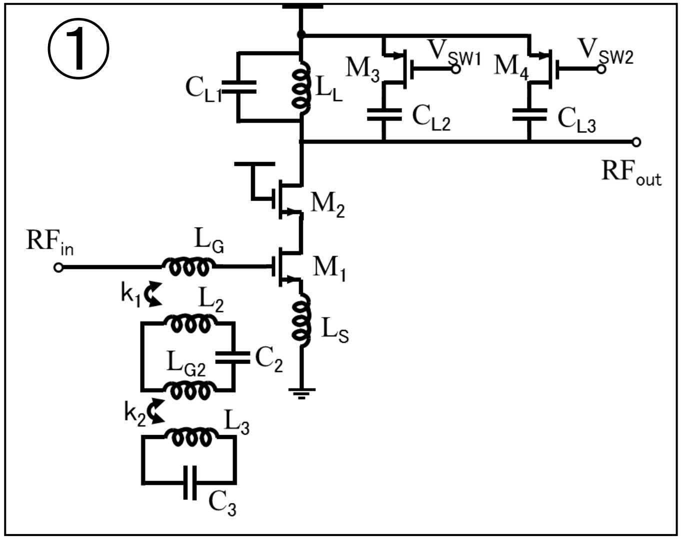
- High Q Value
- Large Area

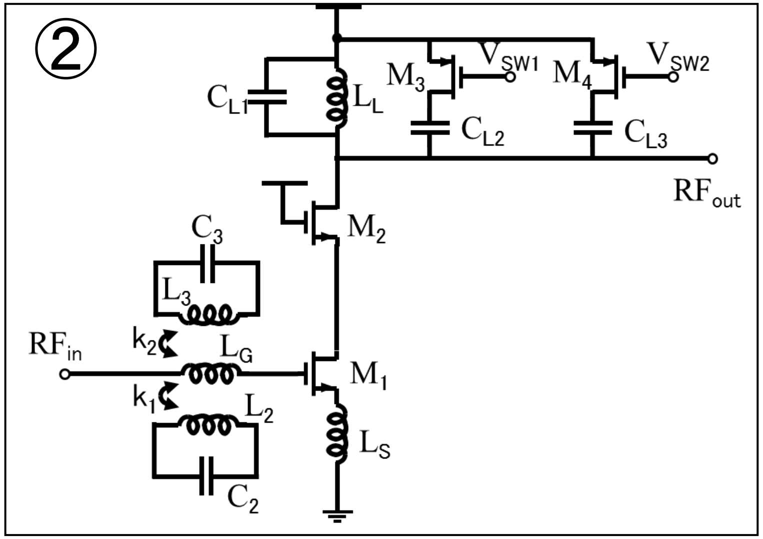
Method 2



- High Q Value
- Small Area
- Feasible
  if coupling
  coefficient is small

Triple-Band LNA





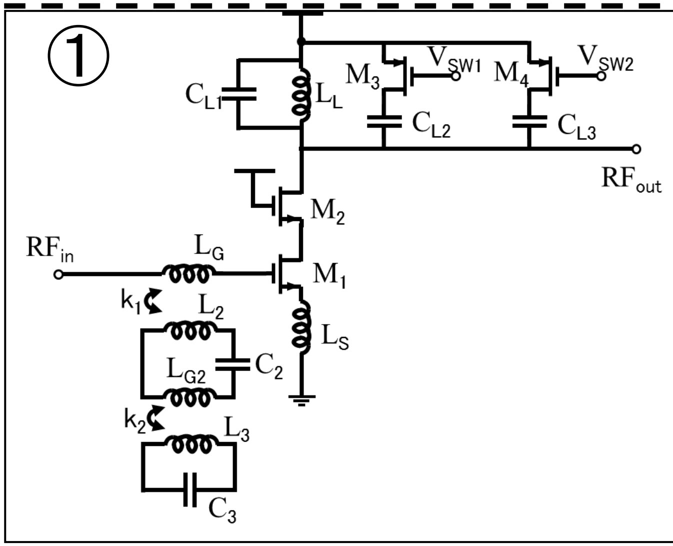
Proposed Circuit ①

Proposed Circuit ②

Design circuits as follows:

- High resonant frequency up to 5 ~ 6GHz
- Area reduction

Comparison of ① and ②



$L_G = 8.2\text{nH}$

$L_2 = 4\text{nH}$

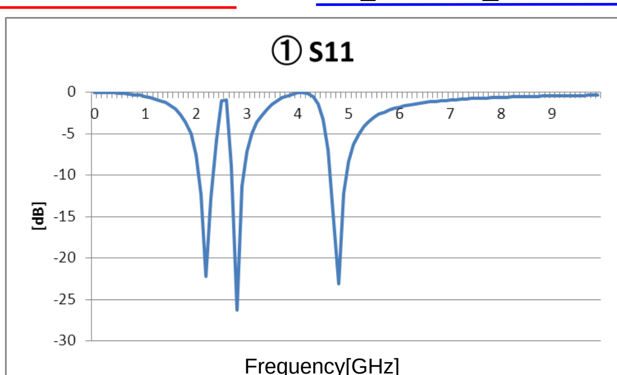
$L_{g2} = 4\text{nH}$

$L_3 = 4\text{nH}$

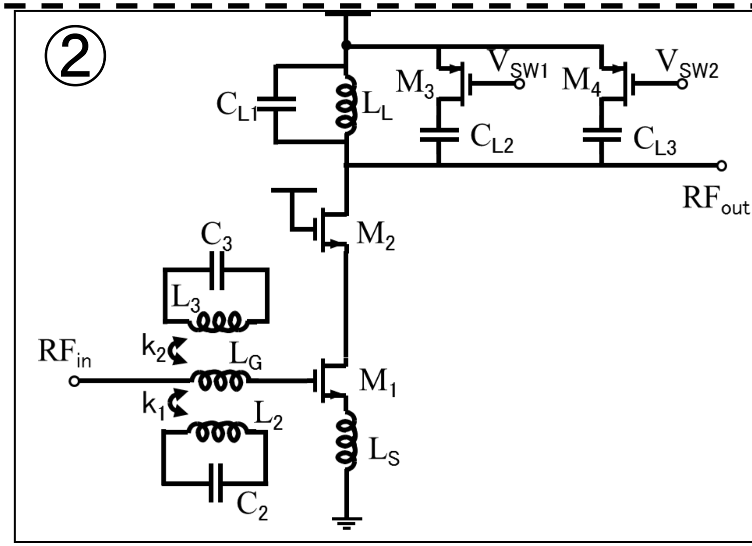
$C_2 = 300\text{fF}$

$C_3 = 660\text{fF}$

$k_1 = k_2 = 0.6$



reduce



$L_G = 4\text{nH}$

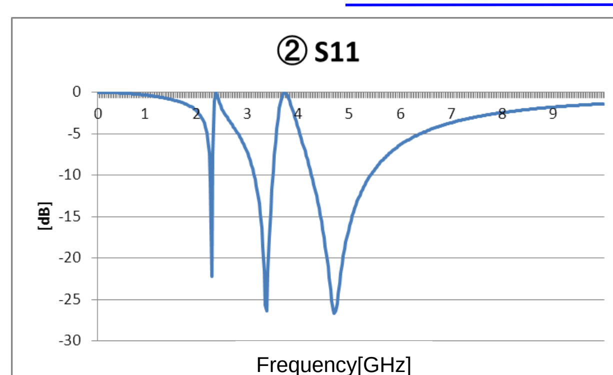
$L_2 = 3\text{nH}$

$L_3 = 5\text{nH}$

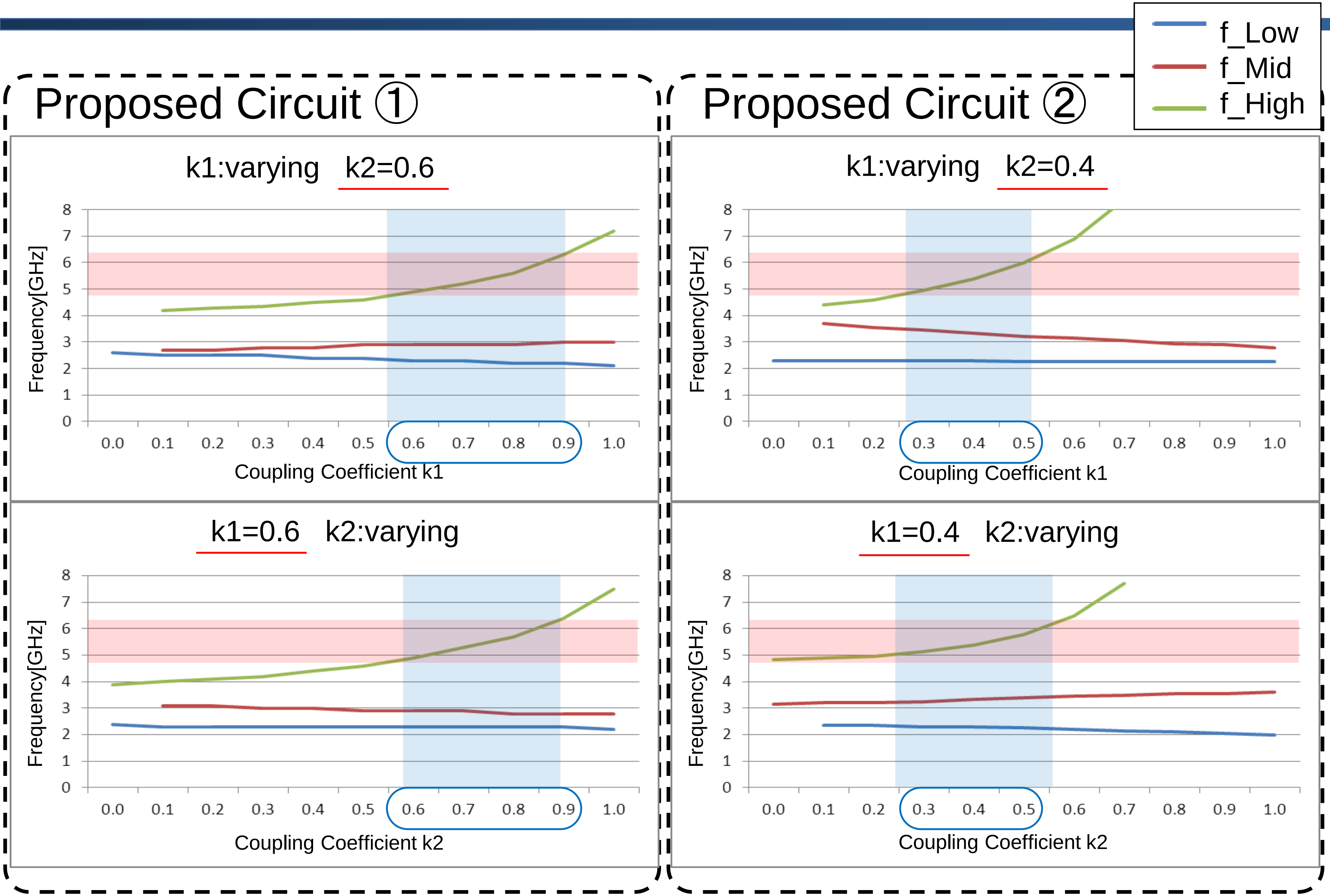
$C_2 = 600\text{fF}$

$C_3 = 880\text{fF}$

$k_1 = k_2 = 0.4$

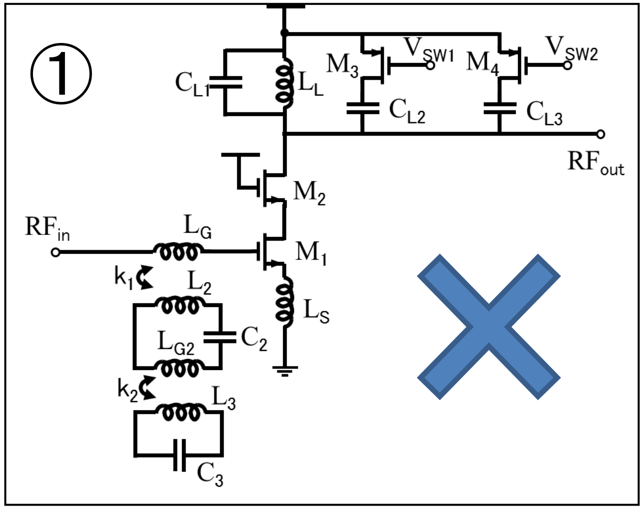


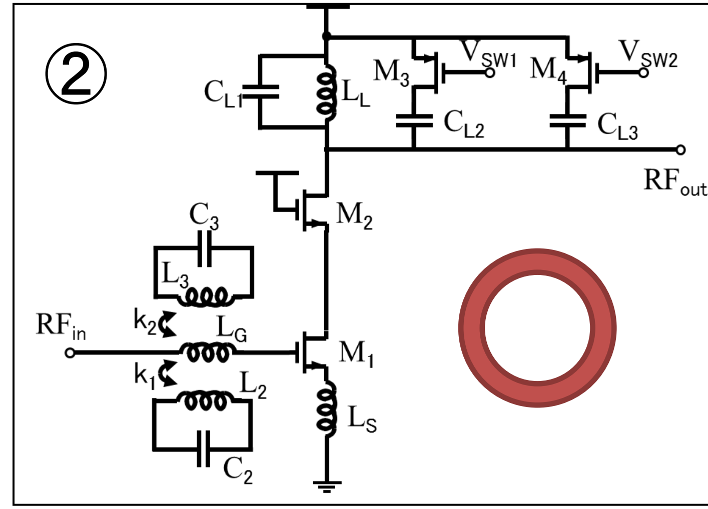
Comparison of ① and ② Coupling Coefficients



Triple-Band LNA

Circuit

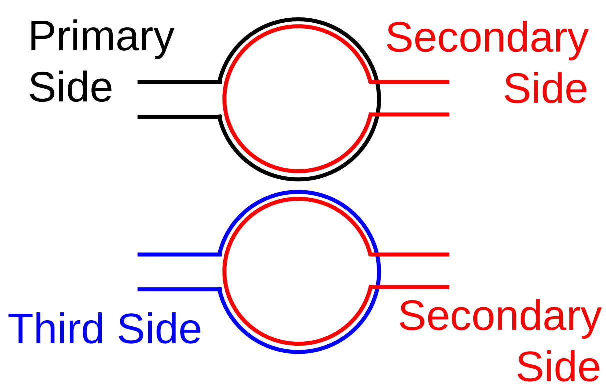


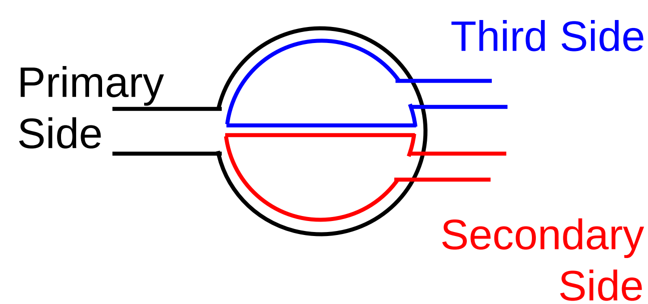


Coupling Coefficient

	①	②
Coupling Coefficient	High k $k_1, k_2 = 0.6$	Low k $k_1, k_2 = 0.4$

Transformer Layout (Conceptual Diagram)





Area

	①	②
Area	Large Area ☹	Small Area ☺

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Conclusion

Conclusion

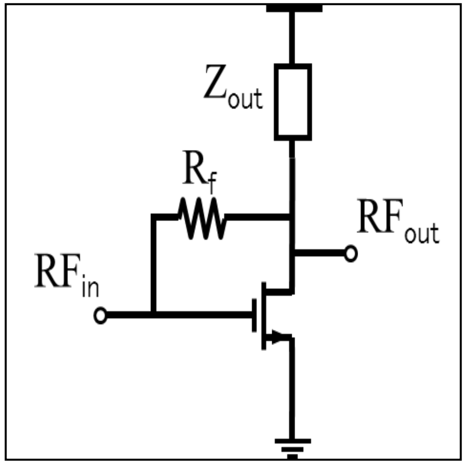
- Proposed & analyzed Triple-Band LNA
- Showed that proposed Triple-Band LNA circuit ② can meet higher frequency with small area

Challenge for the future

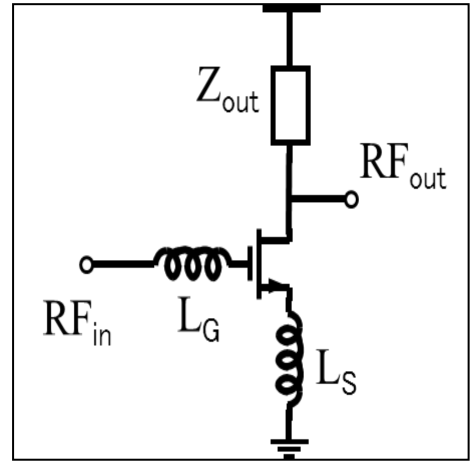
- Detailed Triple-Band LNA design by electromagnetic field analysis of transformer
- Additional features of higher order multi-band.

Appendix

About LNA



Resistance Feedback LNA



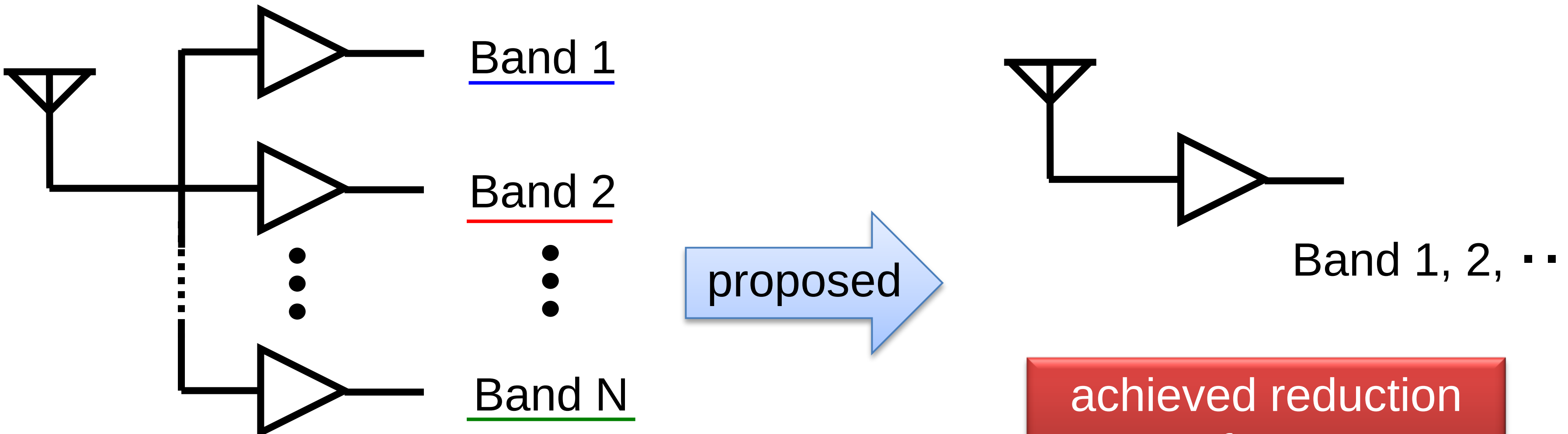
Inductive source degeneration LNA

Focused Method

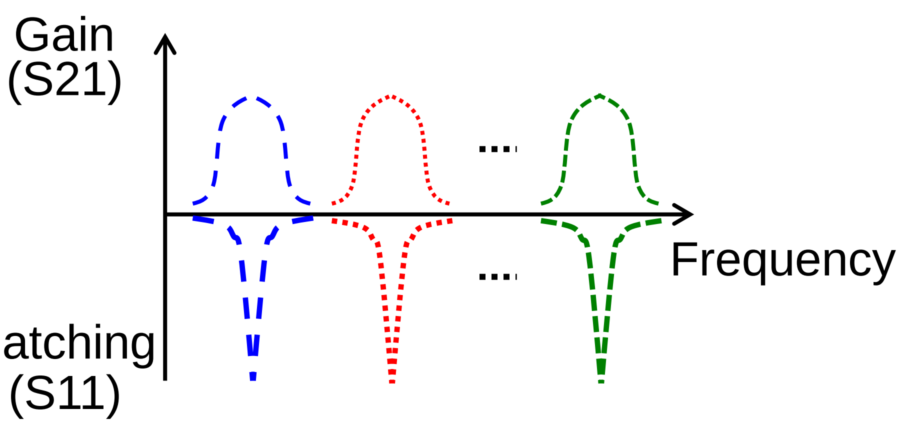
	Resistance Feedback LNA	Inductive source degeneration LNA
Frequency Bandwidth	Wideband	Narrowband
Gain	Low	High
Noise	Bad	Good

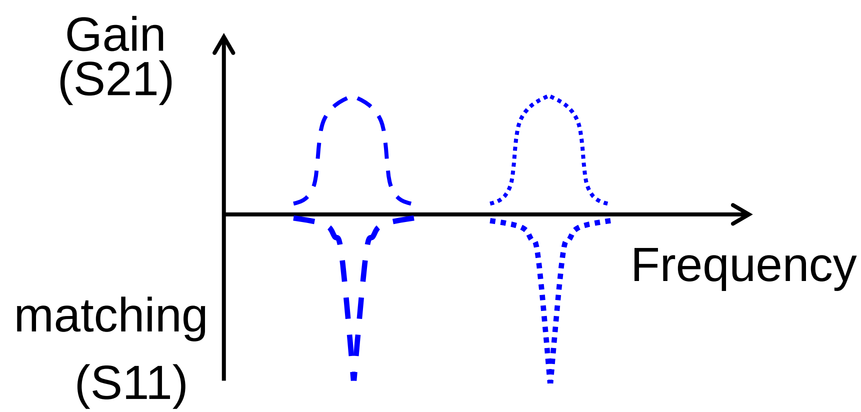
LNA with multiple bands

To include many narrowband in one



achieved reduction of area





Questions!

Q.発表資料には、高周波回路の解析に重要なパラメータであるNFについて
載っていないのですが、どうですか？
A.論文には載っているのですが、資料には載っていません。
高周波のマッチング点で約4dBです。

Q.どのようなアプリケーションを見越していますか？
A.携帯用端末の送受信

Q.インダクタの提案をしていますが、EMIシミュレーションはどうですか？
A.EMIシミュレーションはまだしていません。