P097 Triple-Band CMOS Low Noise Amplifier Design Utilizing Transformers

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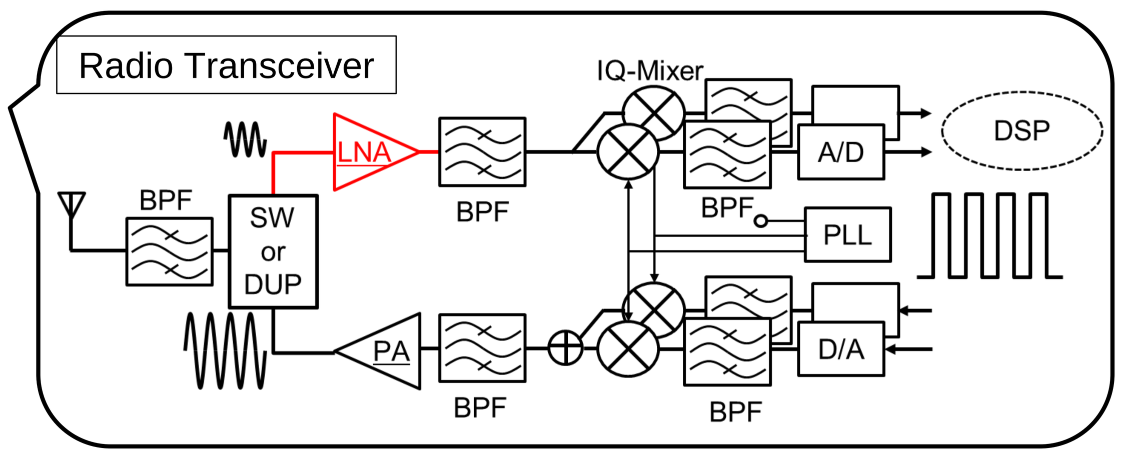
Introduction

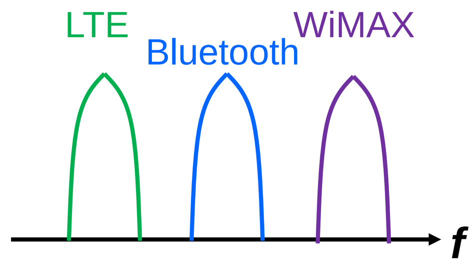
Research Background & Objective



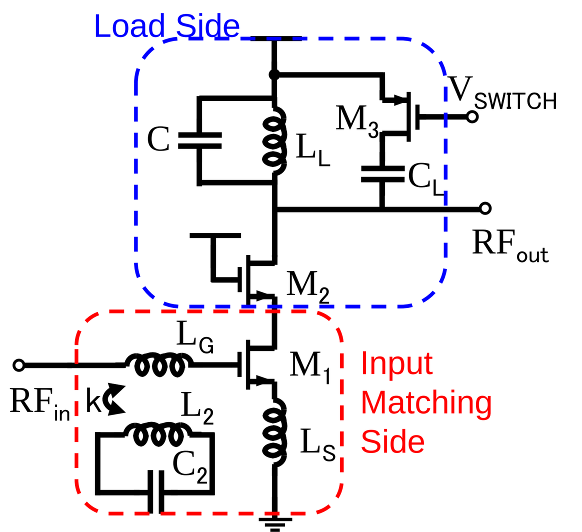
Receiver Side
Low Noise Amplifier(LNA)
・・・Amplify small signal without noise & distortion

Objective

Multi-Band performance
for many wireless standards in one LNA



Neihart's Dual-Band LNA



Dual-Band LNA Utilizing Transformers

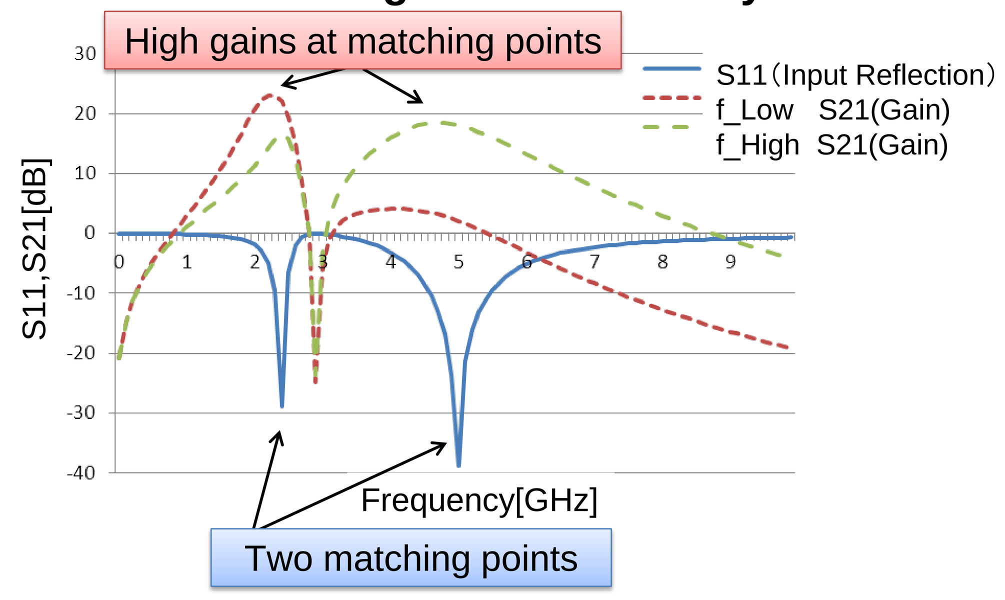
- L_G , L_2 : Transformer-coupled with coupling coefficient k
- Load side
  Switch 2 resonance frequencies by M_3
- Input matching side
  Realized 2 matching points by transformer-coupling

resonance frequency is

$$\omega = \pm\sqrt{\frac{a^2+b^2 \mp \sqrt{a^4+b^4+a^2b^2(4k^2-2)}}{2(1-k^2)}} \quad a=\frac{1}{\sqrt{L_1C_{gs}}} \quad b=\frac{1}{\sqrt{L_2C_2}}$$

4 solutions (2 positive numbers, 2 negative numbers) → resonance frequencies

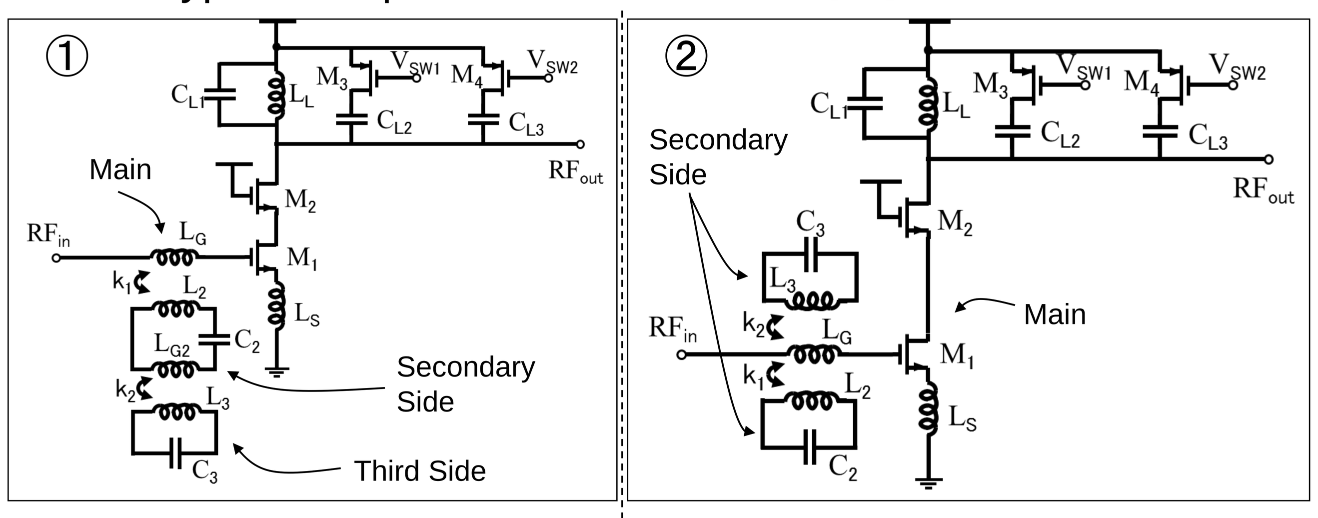
Scattering Parameter Analysis



Proposed Circuit

Proposed Triple-Band LNA

Two types of Triple-Band LNA circuits ① ②

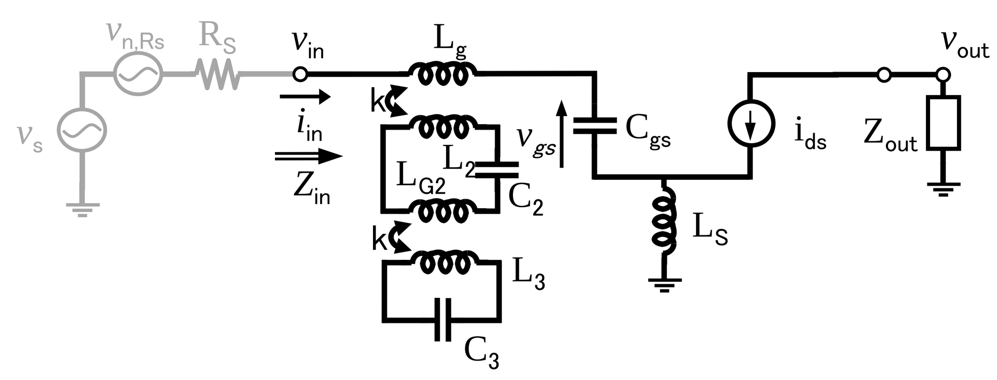


①
- Transformer-coupled
  L_G - L_2 L_{G2} - L_3
- Structure
  Main - Secondary Side - Third Side

②
- 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 LNA①)

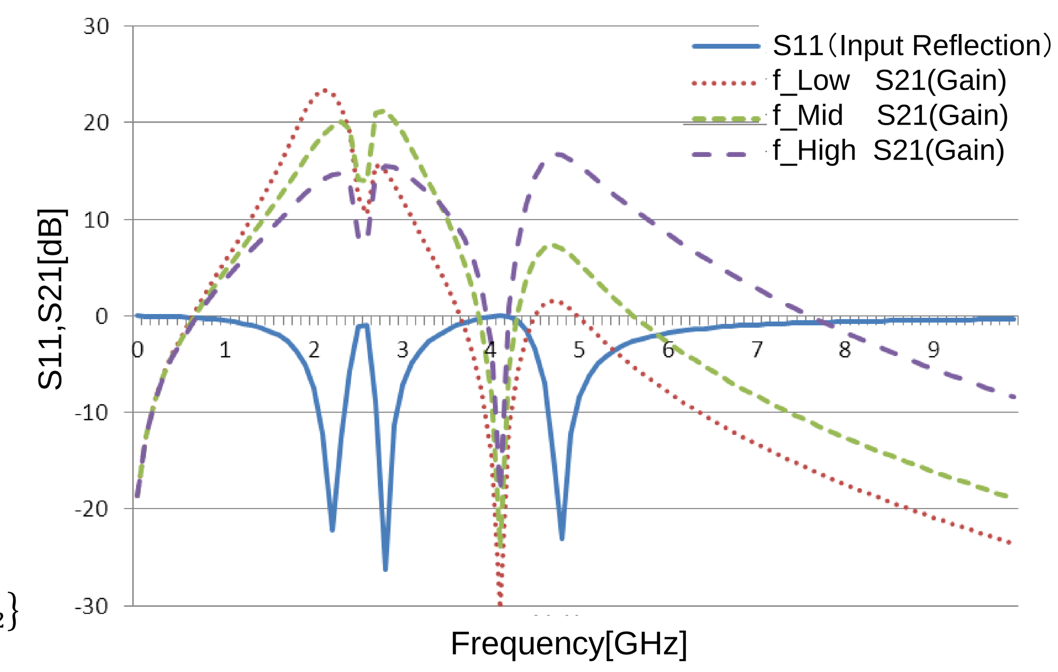


Calculate formula for determining resonance frequencies

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

6-th order equation (3 resonance frequencies)

Scattering Parameter Analysis



Consideration

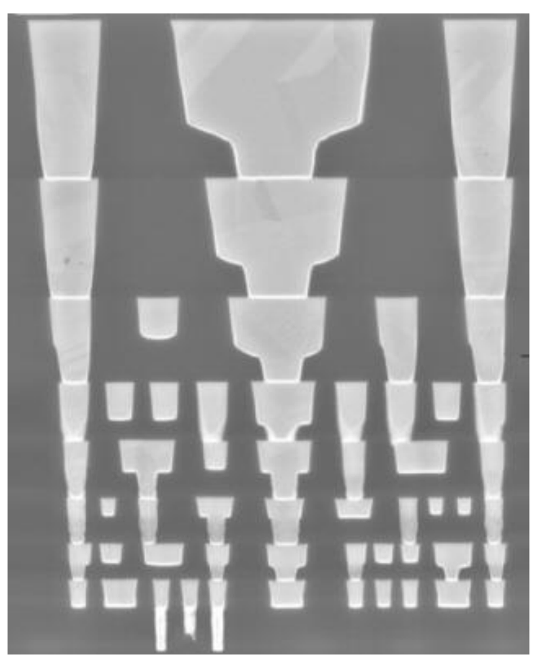
Investigation of Problems

Dual-Band LNA
Adding Inductor
Triple-Band LNA

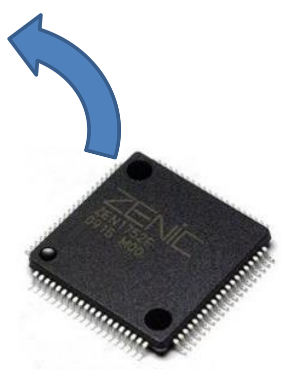
Problems
・Chip area increase
・Noise increases (by associated circuits with inductor)

Consider inductor layout for solving these problems !!

Realization of Inductor on chip



Thick Wiring at Top Layer



LSI

Section View of LSI

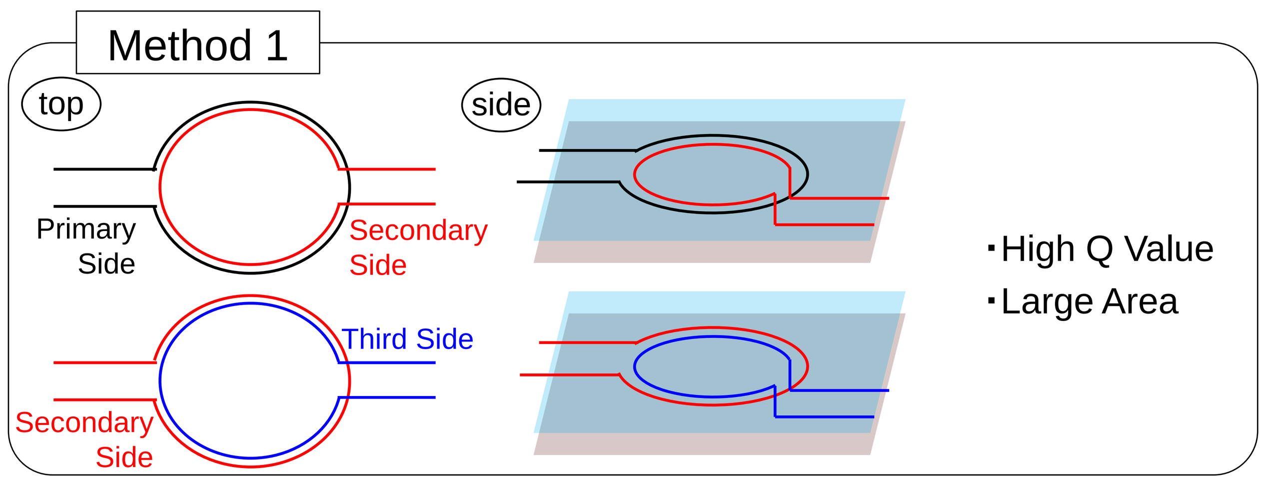
Inductor is realized in high Q value at top layer on chip

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

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

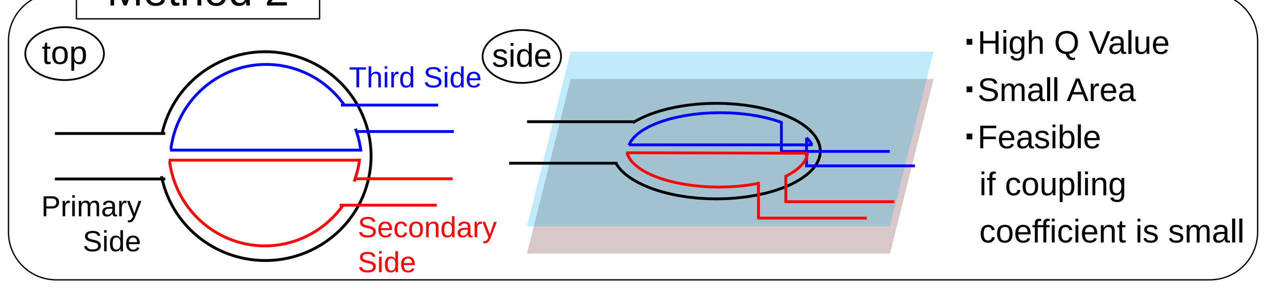
Consideration of Layout

Method 1



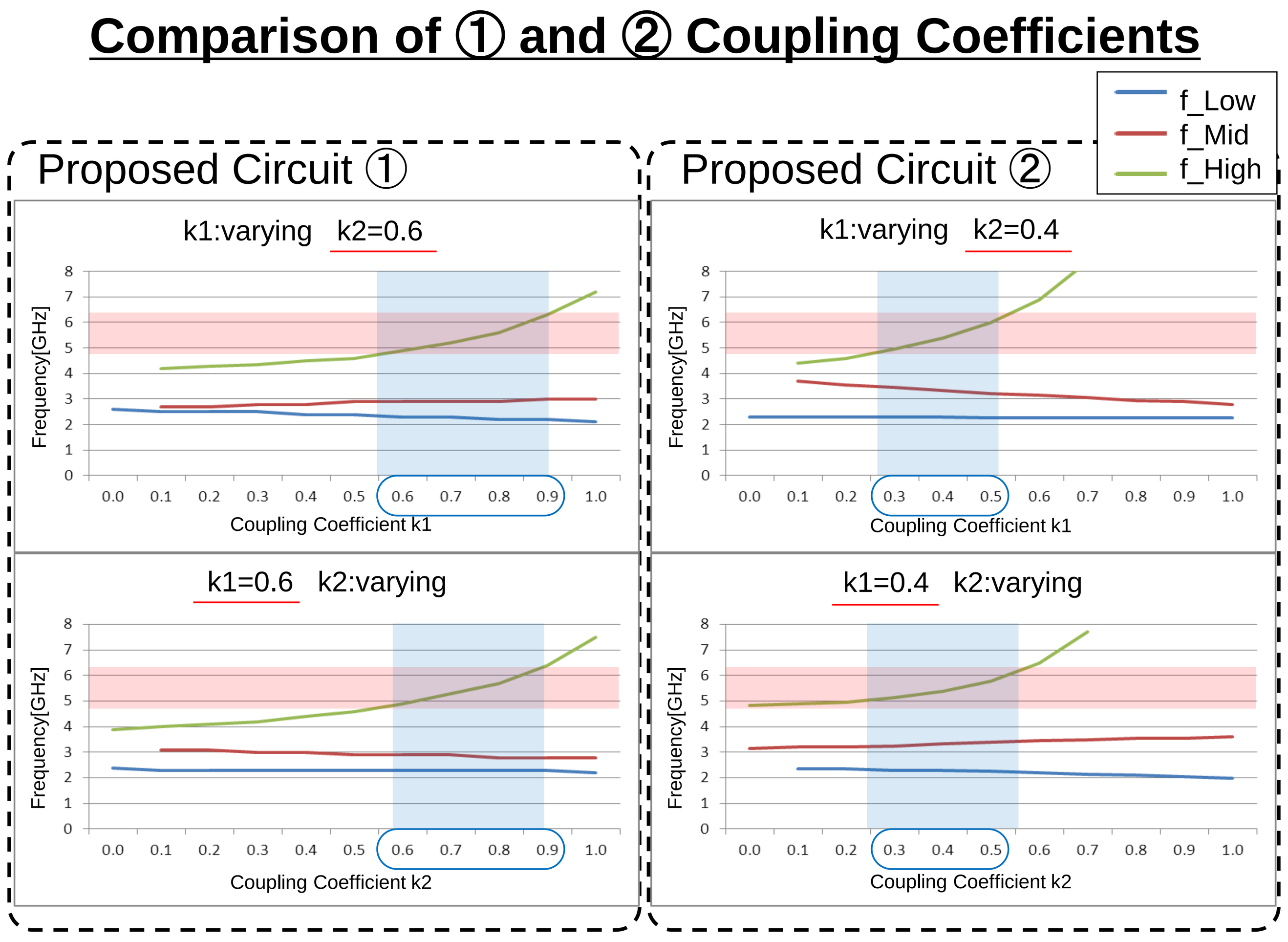
・High Q Value
・Large Area

Method 2



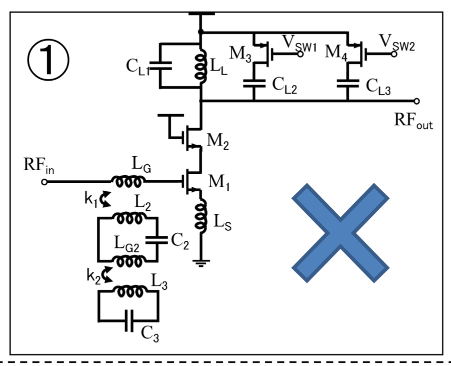
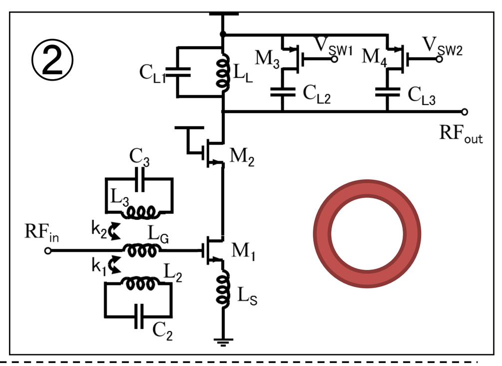
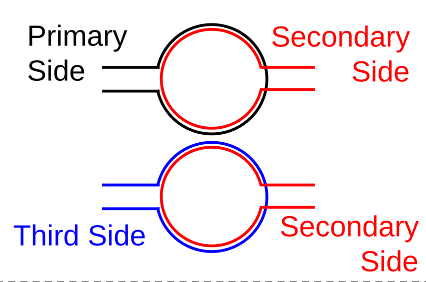
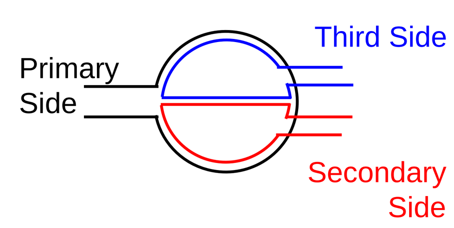
・High Q Value
・Small Area
・Feasible if coupling coefficient is small

Comparison of ① and ② Coupling Coefficients



Conclusion

Triple-Band LNA

	①	②
Circuit	 ✕	 ○
Coupling Coefficient	High k k_1 k_2=0.6	Low k k_1 k_2=0.4
Transformer Layout (Conceptual Diagram)		
Area	Large Area ☹	Small Area ☺

Summary

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.

References

[1] Nathan M. Neihart, Jeremy Brown, Xiaohua Yu : "A Dual-Band 2.45/6 GHz CMOS LNA Utilizing a Dual-Resonant Transformer-Based Matching Network," IEEE, Circuits And Systems I, vol.59, no.8, pp1743-1751 (August 2012).
[2] Hideo Yamamura : *Toroidal Core Utilization Encyclopedia*, CQ Publisher, p118-126 (2007).
[3] Kunihiro Asada, Akira Matuzawa : *Analog RF CMOS Integrated-Circuit Design Beyond the Basics* , Baifukan, p166-174 (Feb. 2011)