Analysis of through glass via (TGV) noise coupling effect to Noise Figure of 2.4GHz LNA on glass interposer

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***Abstract*—Through glass via(TGV)-TGV coupling noise could badly affect to glass interposer based 2.5D/3D ICs RF system. RF system specification is specified with RF sensitivity. And RF sensitivity is dominantly determined by LNA noise figure. Normally LNA noise figure is calculated with only device and thermal noise since it assumes no noise coupling is exist. For estimating LNA noise figure degradation by TGV-TGV coupling noise, we proposed modified LNA noise figure equation which includes coupling noise effect. For analysis, we designed 2.4GHz LNA schematic and proposed TGV-TGV coupling structure which includes TGVs and channel lines. And then we analyzed output waveform of the LNA with TGV-TGV noise coupling on time domain and frequency domain when single tone noise is injected to LNA components. Finally we estimated noise figure degradation by single tone switching noise.**

Keywords—Through glass via(TGV); noise coupling; LNA; noise figure;

I. INTRODUCTION

Recently, data bandwidth and number of I/Os are steeply increasing. For high bandwidth and high density system, interposer and through via technology is essential. Generally, silicon has been used as a material in interposer, recently glass interposer became a good candidate due to several advantages like loss insertion loss and low cost. However as glass interposer fabrication technology is developed, fine pitch and small size will become possible and it will arise coupling noise.

For designing glass interposer based 2.5D/3D ICs RF system, we should control coupling noise since RF system is very sensitive to noise effect. Normally, RF system specification is specified with RF sensitivity. RF sensitivity is the minimal input RF signal level which can be detected by device receiver. Therefore RF sensitivity is the most important specification of RF system. For RF system, Rx FEM determines RF sensitivity. Since Rx FEM is composed of LNA, switch, antenna and diplexers, receiver part is determined by Rx FEM. Since bandwidth and SNR are usually fixed in RF system, RF sensitivity is dominantly determined by RF system noise figure. [1] We could calculate RF system noise figure with (1) equation. With the noise figure equation, we could confirm that first stage LNA noise figure is the most dominant factor which determines overall RF system noise figure. Therefore controlling low noise figure of LNA is the most important for RF receiver system design.

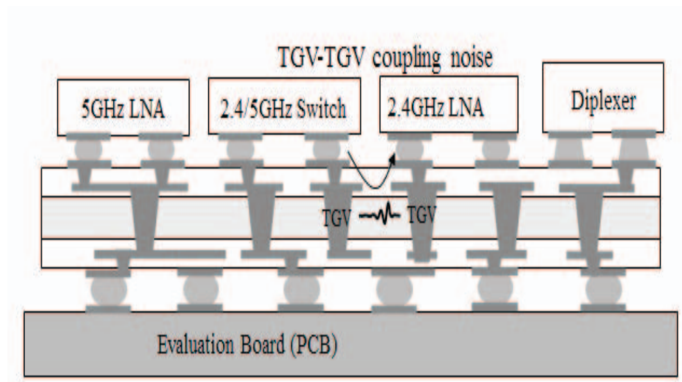


Figure 1.Conceptual figure of TGV – TGV coupling noise effects to LNA on glass interposer

$$NF_{RF\ system} = 1 + (NF_{LNA} - 1) + \frac{NF_1 - 1}{A_{LNA}} + \cdots + \frac{NF_n - 1}{A_{LNA} \cdots A_{n-1}} \quad (1)$$

For calculating LNA noise figure, equation (2) is commonly used. $A_p(f)$ is transfer function , P_{noise_floor} is thermal noise and P_{device} is device noise. We could calculate noise figure of the LNA with this equation. However this noise figure equation doesn't includes other noise coupling effects and only considers device and thermal noise.

$$NF_{LNA}(f) = 10\log\left(\frac{|A_p(f)|\ P_{noise\_floor} + P_{Device}}{|A_p(f)|\ P_{noise\_floor}}\right) \quad (2)$$

Several papers have studied the noise coupling effect to LNA. [3][4] Especially previous work by Kyoungchoul Koo has studied the LNA degradation by coupling effect on noise figure to differential LNA and proposed modified noise figure equation. [5]

However, it only focuses on power supply imbalance on differential LNA. In glass interposer, TGV–TGV noise coupling could be arisen and it could badly affect to system performances. Noise figure equation should be modified to estimate TGV-TGV coupling noise effect in the glass interposer system. We proposed modified noise figure equation which includes TGV-TGV coupling effect. This equation could be applied to glass interposer based RF system. With the proposed noise figure equation, we could estimate TGV-TGV noise coupling effects to LNA and RF system sensitivity

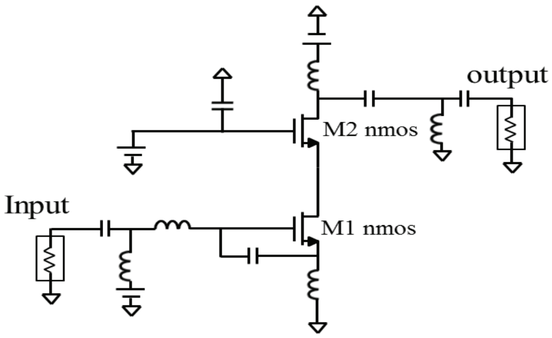


Figure 2. A Schematic of 2.4GHz cascade single-ended LNA

II. ROPOSAL OF MODIFIED NOISE FIGURE EQUATION INCLUDING TGV-TGV COUPLING NOISE EFFECT

For noise figure calculation, equation (2) is commonly used. But it only includes device noise and thermal noise. And equation (2) ideally assumes no coupling noise is injected to LNA circuit. However TGV-TGV coupling noise could be injected to the various LNA components like Vdd power, input source and M1, M2 NMOS and consequently the output waveform become distorted. The distorted waveform badly affects to noise figure and LNA performance become degraded. Since original LNA noise figure couldn't estimate those TGV-TGV noise coupling effect, we proposed new noise figure equation.

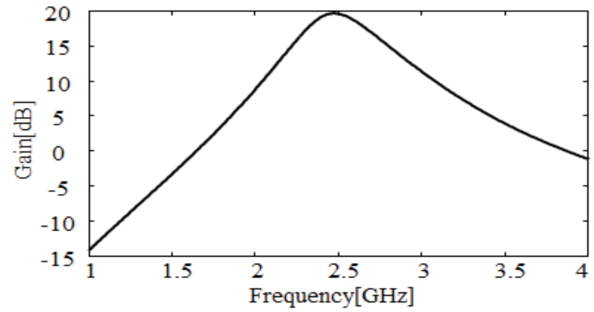
$$NF_{modified}(f)=10log(\frac{|A_p(f)|\ \ P_{noise\_floor}+P_{Device}+P_{noise\_coupling}}{|A_p(f)|\ \ P_{noise\_floor}}) \quad (3)$$

Equation (3) is the modified noise figure equation which includes the effect of TGV-TGV noise coupling.

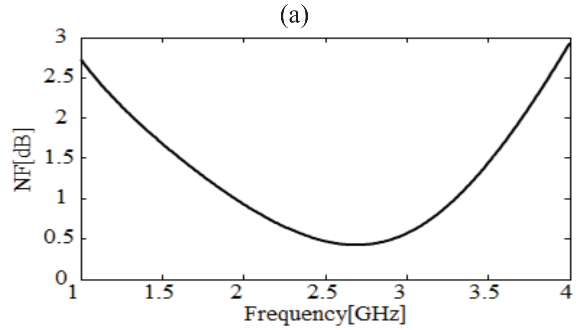
III. 2.4GHZ LNA CIRCUIT SCHEMATIC DESIGN AND STRUCTURE OF TGV-TGV NOISE COUPLING

A. 2.4GHz LNA circuit schematic design

For analysis of TGV-TGV coupling noise effect to LNA, we designed 2.4GHz cascode single-ended LNA as shown in figure 2. Our 2.4GHz LNA operating frequency range is 2.4GHz ~ 2.5GHz. Cascode LNA is commonly used in LNA design, and it shows high power gain, good noise performance and low power consumption. Also, single-ended LNA consumes small power and decreases chip size. Since minimizing glass interposer size is important, we assumed single-ended cascade LNA chip is put on the glass interposer. Figure 3 (a), (b) is LNA performance simulation result. Figure 3 (a) shows transfer function and gain range on the operating

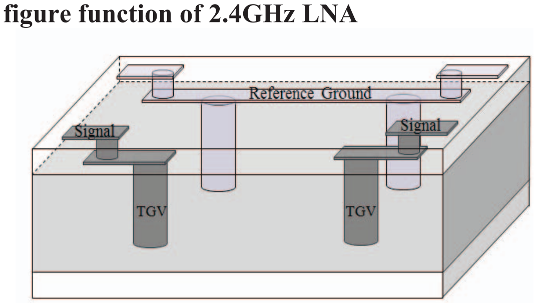


(a)

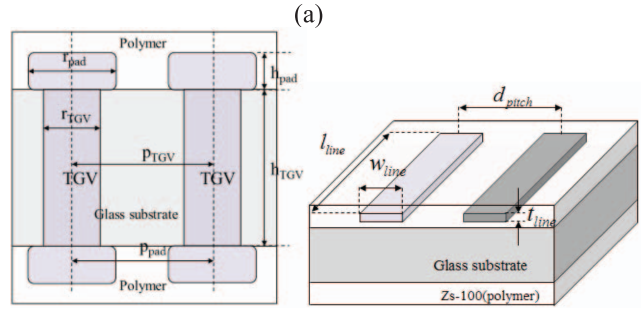


(b)

Figure 3. (a) Transfer function of 2.4GHz LNA and (b) noise figure function of 2.4GHz LNA



(a)



(b)

Figure 4. (a)TGV-TGV coupling structure and (b)TGV and channel structure used in our TGV-TGV coupling structure

frequency is 19~19.5. Figure 3 (b) shows noise figure function and noise figure range on the operating frequency is 0.6~0.7.

B. Structure of TGV-TGV coupling

Our TGV-TGV coupling structure is figure 4 (a) which includes TGVs, buried vias and 3, 4th layer channel lines and there are no interconnection on 1, 2th metal layer in our coupling structure. When designing glass interposer, we

Table 1
Description and dimensions of parameters in the TGV-TGV coupling structure

parameter	description	dimensions
r_{TGV}	Radius of TGV	50um
p_{TGV}	Signal to ground pitch between TGVs	300um
h_{TGV}	Height of TGV	135um
r_{pad}	Radius of pad	80um
p_{pad}	Pitch between pads	300um
h_{pad}	Height of pad	10um
$\varepsilon_{r,glass}$	Relative permittivity of glass	5.3
$\varepsilon_{r,polymer}$	Relative permittivity of polymer	3
$\tan\delta_{glass}$	Loss tangent of glass	0.004
$\tan\delta_{polymer}$	Loss tangent of polymer	0.005
w_{line}	Channel line width	85um
t_{line}	Channel line thickness	10um
l_{line}	Channel line length	200um
d_{pitch}	Channel line pitch	300um

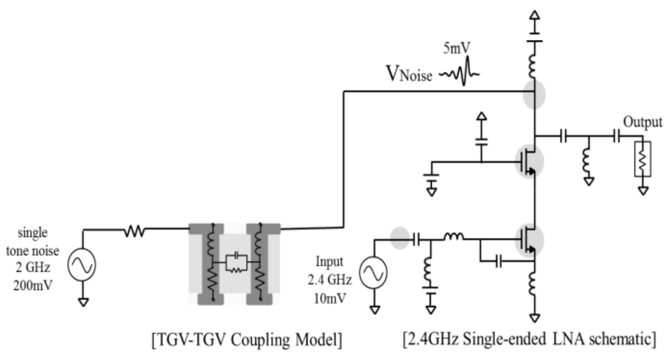


Figure 5. Simulation setup for noise coupling effects to LNA performance

followed the glass interposer design rule of Packaging Research Center, Georgia Institute of Technology. For parameter dimensions, we followed table 1 parameter values. For designing proposed TGV-TGV coupling structure, we used 3D EM simulator(HFSS).

IV. Analysis of TGV noise coupling effects to 2.4GHz LNA performanceb degradation

Switching noise could be arisen from the switching activity of a chip. And switching noise could be delivered to LNA chip through TGV-TGV noise coupling. Then TGV-TGV coupling noise could be injected to each coupling node of LNA and various LNA components like Vdd power, input source and NMOSs could be victims. With TGV-TGV coupling model and a LNA circuit schematic like figure 5, LNA performance degradation could be analyzed in the simulation environment. In this paper, we injected 200mV 2GHz single tone noise into the TGV-TGV noise coupling structure and 5mV noise coupling voltage arisen as shown in figure 6. We injected 5mV arisen TGV-TGV coupling noise into the Vdd power and observed LNA output waveform change. Figure 7 (a) (b) shows

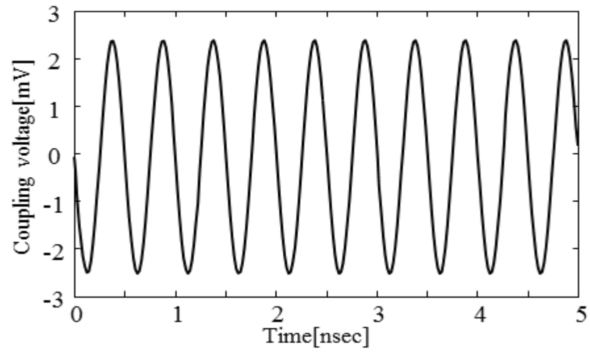
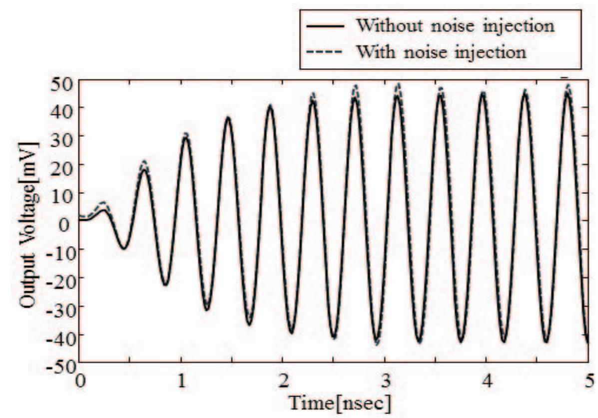
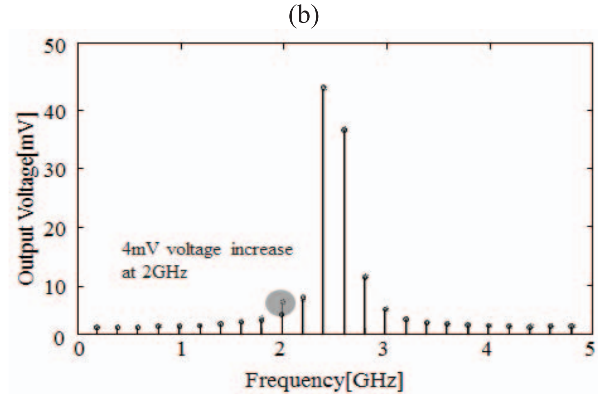


Figure 6. Time domain waveform of arisen TGV-TGV coupling voltage when 200mV 2GHz single tone noise is injected



(b)



(c)

Figure 7. (a) time domain and (b) frequency domain simulation of LNA output waveform w/o TGV-TGV coupling noise injection to the LNA Vdd power

simulation result of LNA output waveform w/o TGV-TGV coupling noise injection to the LNA Vdd power on time domain and frequency domain. As shown in figure 7 (a), output voltage waveform is changed a little bit however it is difficult to analyze detailed coupling effect. Thus we did FFT simulation for output waveform and figure 7 (b) is the simulation result. It shows output waveform at 2GHz is changed about 4mV. Therefore we could confirm TGV-TGV noise coupling effect at target frequency.

Next, with the proposed modified noise figure equation, we observed noise figure changes. Figure 8 (a) shows noise

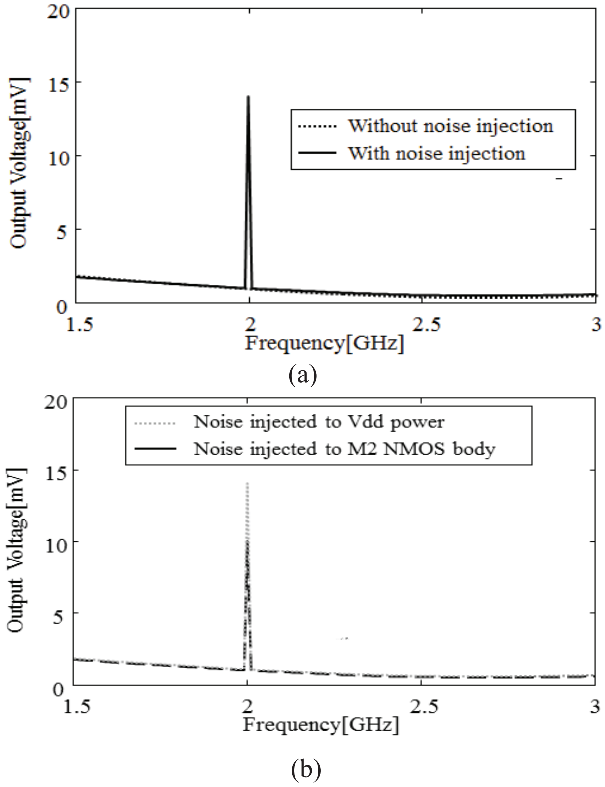


Figure 8. (a) Noise figure w/o TGV-TGV coupling noise injection and (b) comparison of noise figure between noise injection to Vdd or M2 NMOS body

figure change w/o TGV-TGV coupling noise injection to the Vdd power. Originally noise figure at 2GHz is 0.8, but when the TGV-TGV coupling noise is injected with upper simulation setup, noise figure become 14. Since common LNA performance specification of noise figure is 3~5, LNA specification could be violated with TGV-TGV noise coupling effect. Figure 8 (b) shows comparison of noise figure between TGV-TGV coupling noise injection to Vdd power and M2 NMOS body. For observing TGV-TGV coupling noise effect to other LNA components, we injected TGV-TGV coupling noise in to the M2 NMOS body.

In this case, noise figure of M2 NMOS body is 10. Therefore we could confirm that other components of LNA could be vulnerable to the TGV-TGV coupling noise. And for glass interposer based 2.5D/3D ICs RF system design, we should carefully consider TGV-TGV coupling noise effect.

V. Conclusions

This paper discusses the TGV-TGV noise coupling effect to 2.4GHz LNA performance degradation. We proposed modified noise figure equation which includes TGV-TGV noise coupling effect in the glass interposer based RF system. For analysis of LNA, we designed a schematic of 2.4GHz LNA and showed performances. Next we injected TGV-TGV coupling noise into the LNA components like Vdd power, NMOS body. With the time domain and frequency domain simulation, we could confirm output waveform distortion by coupling noise. Finally with the modified noise figure equation, we confirmed the noise figure degradation by TGV-TGV coupling noise. With 10mV TGV-TGV coupling noise injection to the Vdd power, noise figure is degraded by 13dB at 2GHz

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