Analysis of the Effect of Digital Power Ground Noise on Active Balun in UHF RFID SiP

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Abstract

In recent, as the demand for integrating radio frequency identification (RFID) system to mobile electric appliances increases, there has been strong needs for small size, light weight, and low power consumption in RFID system. To reduce size of RFID system, System-in-Package (SiP) technology has been applied to RFID system. However, there are many problems, as RFID system is integrated into a single package. One of those problems is noise coupling from noisy power/ground of digital logic circuits to noise sensitve circuits, such as RF and analog circuits. Not only package power/ground noise coupling but also on-chip substrate noise coupling could degrade the performance of RF circuit. Therefore, it is essential to analyze and solve various noise coupling problems in RFID SiP, to guarantee the performance of it. In this paper, we have analyzed the effect of digital power/ground noise coupling on the performance of active balun through modeling and simulation including chip and package level. Moreover, efficient LC filter is applied to a RF circuit to minimize package power/ground noise coupling to the RF circuit.

I. Introduction

As RFID system integrates SiP, digital chips are placed much closer to RF chips compared with previous multi-package approaches [1, 2]. In these circumstances, various noise coupling problems could reduce the performance of RFID system, since each chip is located closely in given package size. It is crucial to isolate power/ground supply of noise sensitive RF chips from other noisy digital chips in RFID SiP. Although we make an effort to avoid noise coupling from noisy power/ground of digital chips to that of RF chip using split power/ground planes between the digital chips and the RF chips, there are still noise coupling paths through coupling capacitance and mutual inductance between split power/ground planes on package level. Moreover, on-chip substrate noise coupling could severely aggravate the performance of RF circuits, when digital circuits and RF circuits are implemented on the same silicon chip.

In this paper, we have analyzed the effect of digital power/ground noise coupling on the performance of active balun of RF circuit with aspects of both on-chip substrate noise coupling and on-package power/ground noise coupling.

Figure 1 illustrates noise coupling paths from noisy power/ground of digital circuit to power/ground of active balun when the digital circuit and the active balun circuit are implemented on the same silicon chip. Major power/ground noise sources of the digital circuit is simultaneous switching noise which consists of Ldi/dt noise caused by off-chip inductance and IR drop noise of on-chip power/ground wires with much power consumption. The generated power/ground noise of the digital circuit couples to the power/ground of the balun circuit through shared on-chip substrate of lossy silicon and coupling capacitance between power/ground plane cavities.

In order to analyze these noise coupling issues, an active balun of RFID system is designed including digital inverters to investigate the effect of the digital switching noise on the active balun which is very noise sensitive. After explaining the designed active balun and noise coupling path of it in Section II, the effect of digital switching noise coupling of package layer on the performance of the active balun is introduced in Section III. Section IV describes on-chip substrate noise coupling issues. In Section V, LC filters are applied to the active balun to avoid the performance degrading of the active balun caused by the package power/ground noise coupling. Concluding remarks are provided in Section VI.

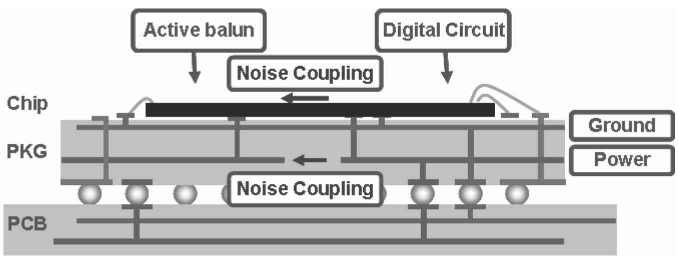
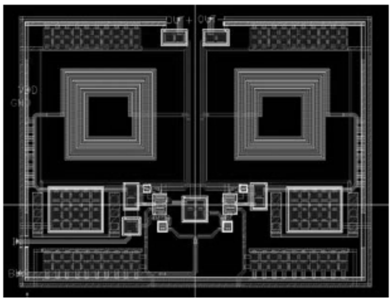


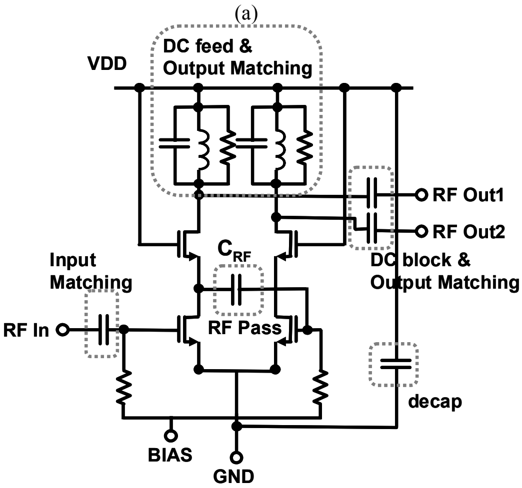
Fig. 1. Power/ground noise coupling from digital circuit to RF circuit through package power/ground planes and on-chip silicon substrate

II. Noise Path Analysis of Active Balun

Active balun is a device designed to convert between balanced and unbalanced electrical signals [3]. Figure 2 shows the designed active balun by using TSMC 0.25um CMOS process. The active balun has transformer structure, which converts single-ended signal to differential signal, and it is located between a low noise amplifier (LNA) and a mixer in a RFID SiP. Fig. 2 (a) and (b) represent the layout and the schematic circuit of the active balun, respectively. Through post-layout simulation, we have acquired that the performance of the designed active balun shows 14 dB gain, 0.3 dB gain error, and 1.5 degree phase error. Power consumption of the active balun is 8.9mW, and the target frequency is from 900 to 920 megahertz, which is suitable to an ultra high frequency (UHF) RFID reader.



(a)



(b)

Fig. 2. (a) The layout of the designed active balun (b) The schematic circuit of the designed active balun

RF pass capacitor (C_{RF}) plays important role in changing the phase of the input signal (RF In) to make the phase of 180 degree between output (RF Out1, RF Out2) as described in Fig. 2(b). To satisfy the target specification which consists of gain of -14dB and input/output return loss of -9dB, input matching and output matching is needed by tuning the value of on-chip passive components and off-chip input matching circuit. On-chip decap of 50pF is used to stabilize power/ground.

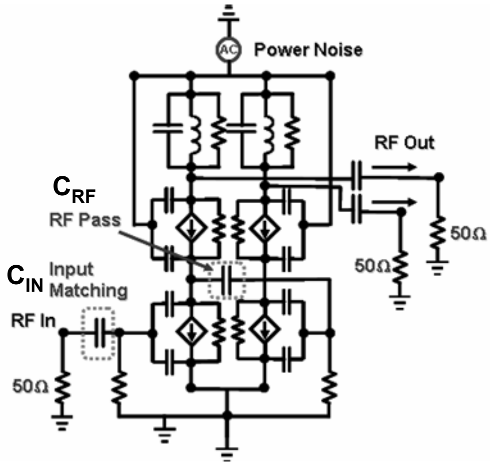


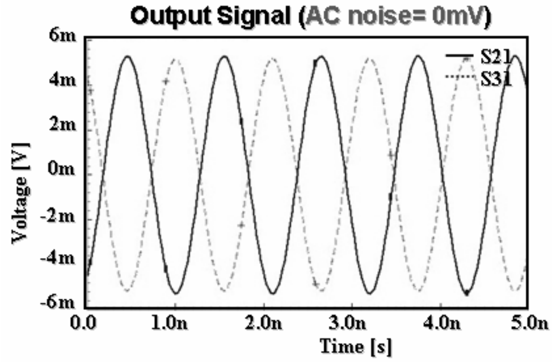
Fig. 3. Equivalent circuit to active balun induced by power noise from digital circuit]

When digital switching noise is injected to power/ground of the active balun, high frequency noise components penetrate from (VDD) to (RF Out) port in equivalent circuit model as shown in Fig. 3. Amplitude and phase error of output (RF Out) occurs due to power/ground noise. Noise level is changed as the frequency and amplitude of AC noise increase.

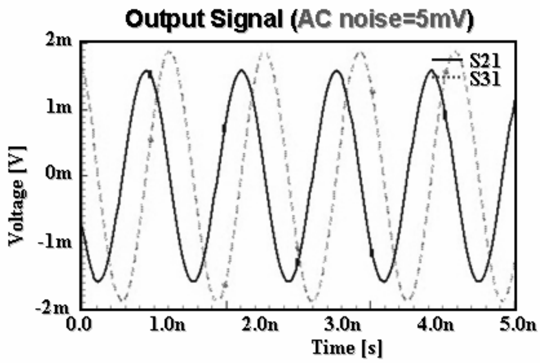
Input matching capacitor (C_{IN}) and RF-pass capacitor (C_{RF}) is important noise path which makes asymmetric characteristic. Output noise occurs since active balun has asymmetric characteristic as illustrated in Fig. 3.

III. Simulation Results of Active Balun by On-package Power/ground Cavity Coupling Noise

We assume that magnitude of digital noise has high until 1GHz. Power noise assumes 910MHz which is the frequency of the designed active balun. The performance of the active balun is degraded because of phase error and gain error as shown in Fig. 4. This simulation assumes that input amplitude of active balun is 1mV, dc level of power is 2.5V. Table 1 shows that as power noise increase, phase error and gain error increase until 7mV. After AC noise of 8mV, phase error and gain error decease as AC power noise increase roughly.



(a)



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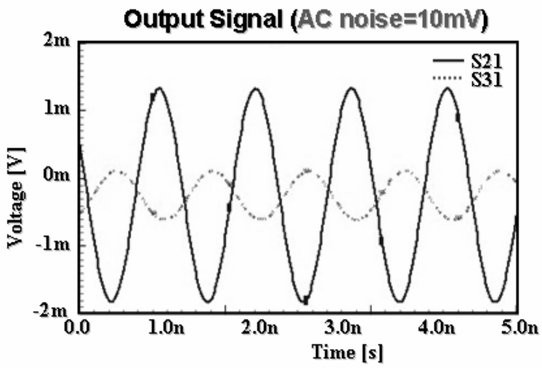


(c)

Fig. 4. Output results of active balun affected by 910MHz noise component. (a) Without noise (b) With 910MHz noise of magnitude of 5mV (c) With 910MHz noise of magnitude of 10mV

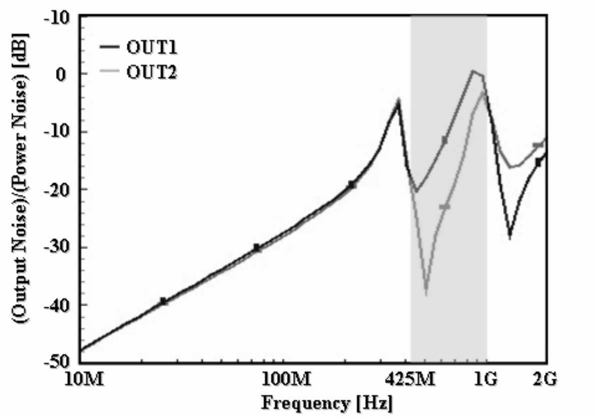
Noise simulation is executed as the frequency of noise source increases as shown in Fig. 5. Pre-condition is that input and output port is terminated 50ohm without input source. And power noise is supplied from wire-bonding. Fig. 5(a) shows that when the frequency of AC power noise increase, noise at output port increases until 320MHz.

Table 1. Output results of active balun affected by 910MHz noise depending on AC noise magnitude

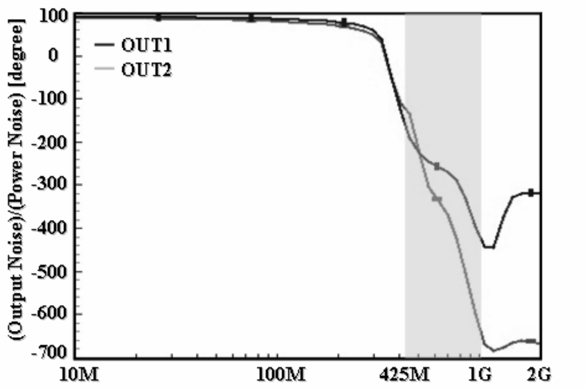
AC noise [mV]	Phase error [degree]	Gain error [dB]	Gain Min. [dB]
0	0.1	0.1	14.4
1	1.8	0.58	12.5
3	29	3.04	7.04
5	91.9	0.84	4.69
7	118.74	14.84	-4.87
8	22.4	25.6	-13.2
9	15.23	16.32	-1.95
10	16.2	12.7	3.23

Noise simulation is executed as the frequency of noise source increases as shown in Fig. 5. Pre-condition is that input and output port is terminated 50ohm without input source. And power noise is supplied from wire-bonding. Fig. 5(a) shows that when the frequency of AC power noise increase, noise at output port increases until 320MHz. The amplitude and phase difference of noise between output ports until 425MHz are same almost as shown in Fig. 5(a) and 5(b). Noise which has the frequency less than 425MHz can be eliminated because output ports are differential ports. But the amplitude and phase difference of AC noise which has the range from 425MHz to 1GHz has larger that noise under 425MHz. Thus it is important to consider digital noise which has the frequency from 425MHz to 1GHz.

Maximum amplitude difference of noise at output has 19.2dB at the frequency of 504MHz as shown in Fig. 5(a). The range of phase difference of noise at output is from -30 degree to 214 degree at the frequency of 504MHz as shown in Fig. 5(b).



(a)



(b)

Fig. 5. Output results of Active Balun when the frequency of the power noise changes (input, output are terminated at 50 ohm) (a) Amplitude result (b) Phase result

IV. Simulation Result of Active Balun by On-chip Substrate Coupling Noise

Substrate noise from digital circuit has a negative effect on active balun at RFID system since digital circuit and active balun share the substrate ground. Output of active balun has not sine waveform since digital inverter makes simultaneous switching noise (SSN) due to Ldi/dt noise as shown in Fig. 6.

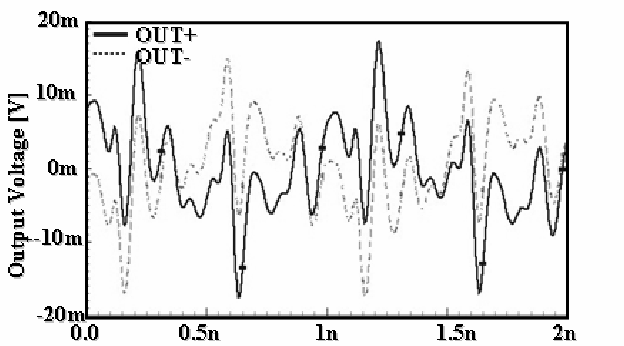
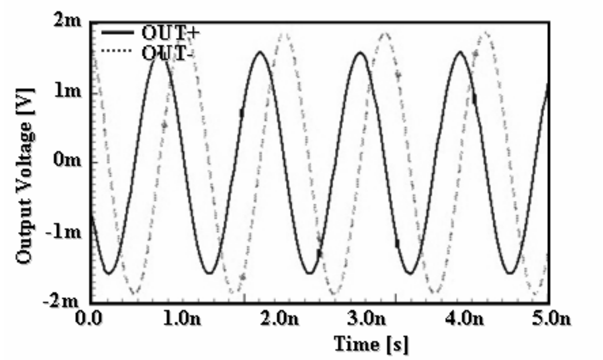


Fig. 6. Output results of active balun affected by substrate noise from digital inverter

Voltage drop of Ldi/dt noise due to wire-bonding penetrates through silicon substrate which is modeled as resistance.

V. Verification of LC Noise Filtering Method

LC filter is very useful to decouple the balun power/ground voltage from the digital switching noise. When LC filter is used, output results become better gain and smaller phase error than without LC filter shown in Fig. 7.



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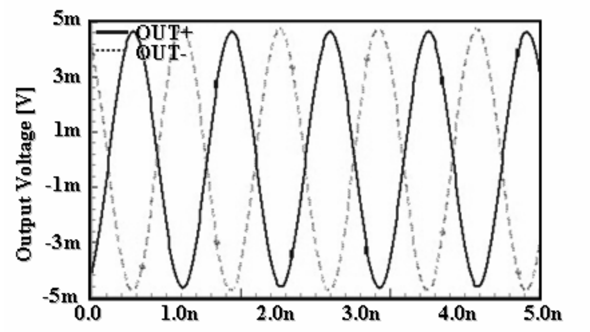
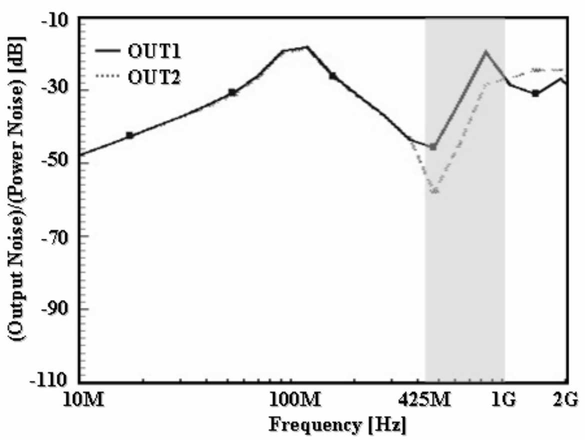


(b)

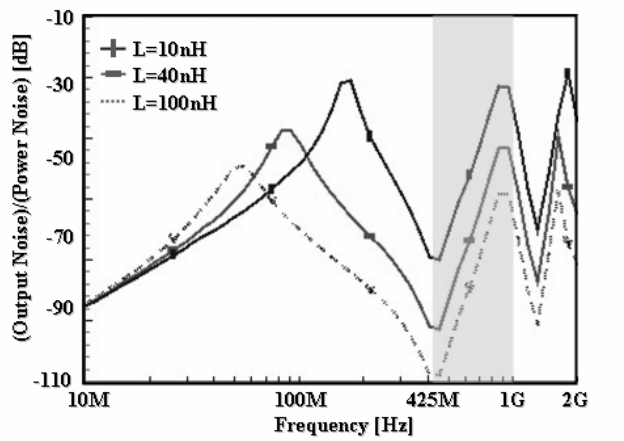
Fig. 7. Output results of active balun affected by 910MHz noise (a) without LC filter, (b) with LC filter

When LC filter is used at power/ground line between PKG and on-chip line, the difference of noise amplitude at output ports is same as without LC filter. But absolute level of maximum noise amplitude decreases by -19dB when LC filter is used as shown in Fig. 8(a).

The amplitude of noise at output port 1 decreases as the inductance increases at the frequency from 425MHz to 1GHz, as shown in Fig. 8(b). This figure assumes that the capacitance is 3pF.



(a)



(b)

Fig. 8. Output results of active balun when the frequency of the power noise changes (input, output are terminated at 50 ohm) (a) Amplitude result with LC filter (b) Amplitude result of OUT1 with LC filter depending on L parameter

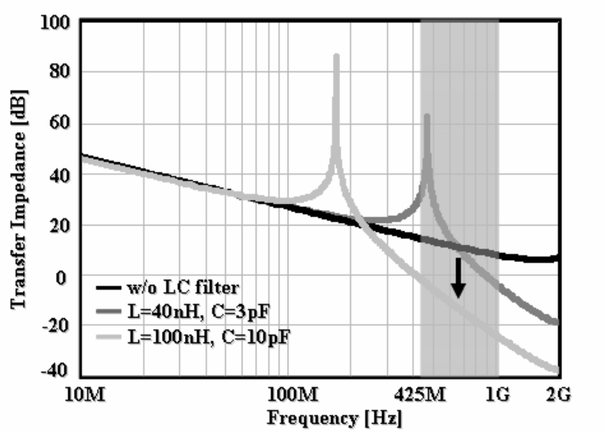


Fig. 9. Transfer impedance of power distribution network (PDN) of package considering LC filter

Fig. 9 is transfer impedance from package to on-chip power line without active circuit. This plot is obtained from the modeling of package which has the size of 50mm by 26mm. The modeling of package consists of resistance of 16mohm/cell, inductance of 1nH/cell, and capacitance of 195fF/cell. By using a LC filter which consists of series inductance and parallel capacitance between power/ground lines, we can achieve lower transfer impedance at the frequency from 425MHz to 1GHz as shown in Fig. 9. Inductance of LC filter blocks high frequency noise, and capacitance of LC filter functions as decoupling capacitor. Although self impedance increases, active balun with LC filter can be immune to power/ground coupled noise since active balun needs low current of 3mA.

As described in Fig. 10, $V_{p\text{-}p}$ of SSN saturates at 380uV as inductance of LC filter increases. The pre-condition of Fig. 10 is that power/ground coupled noise from digital circuit does not exist. The SSN noise which has 380uV at the inductance of 120nH is lower than power/ground coupling noise of 7mV which makes severe noise as shown in Table 1.

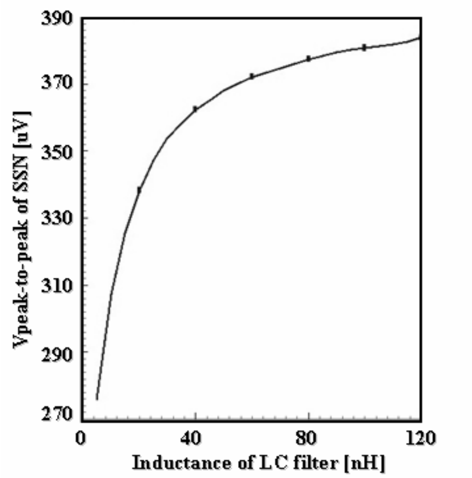


Fig. 10. $V_{p\text{-}p}$ of SSN depending on inductance

VI. Conclusions

In this paper, we have analyzed noise path in the active balun in UHF RFID SiP as power/ground noise occurs. Phase error and gain error as noise error factor of active balun are generated by asymmetric characteristic. We have investigated the effect of the digital switching noise on the active balun. We have analyzed phase error and gain error as magnitude and frequency of power/ground coupling noise in the package. We have found the range of the frequency which degrades the performance of active balun more than other frequency range. We have investigated the effect of substrate noise from digital inverter to active balun.

Moreover, we have verified that the package LC filter reduce the coupling of the digital switching noise. We have analyzed the effect of the digital switching noise and the LC filter on the active balun in terms of frequency domain. We have incorporated model of package into simulation of transfer impedance. We have analyzed the effect of LC filter considering package model as inductance of LC filter changes. Power consumption of active balun need to be considered carefully as LC filter is used since large current flow makes SSN in terms of self impedance.

Acknowledgments

Place acknowledgments here, if needed.

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