A Noise Coupling Effect on Reference Voltage Level of Triggering Circuit in Non-coherent UWB Communication System

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***Abstract*— This paper provides a noise coupling effect on reference voltage level of triggering circuit which determines a digital signal from an analog signal in non-coherent Ultra Wide-Band (UWB) communication system. A coupled noise to reference voltage level brings a large timing variation in a reconstructed digital signal. This coupled noise can be expressed as a combination of multiple frequencies and phases. This paper shows two worst noise waveforms with highest-positive peak and lowest-negative peak. Also, it predicts the worst timing variation in the reconstructed digital signal.**

Key words: UWB, Noise coupling, Reference voltage level, Timing variation

I. INTRODUCTION

Since 2002, Ultra Wide-Band (UWB) has become a promising wireless communication technology with a high-data transmission, low power consumption and high resolution.[1] Especially, a non-coherent UWB communication system in Fig. 1 has much more advantages in realizing small-sized system which has no additional circuits for timing such as PLL and CDR.[2][3] A triggering circuit in non-coherent recovery system plays a key role to reconstruct a digital signal from analog signal when a voltage level of an input signal goes over a reference voltage level to determine a digital high or low value. The variation of reference voltage level directly affects a timing variation in reconstructed signal whenever a digital system processes this reconstructed signal. Thus, keeping a reference voltage level stable is the most important to achieve low jitter and high BER in non-coherent UWB system.

However, a coupled noise coming from digital systems can easily inject into the triggering circuit and brings a large timing variation in reconstructed digital signal.[4][5] The coupled noise consists of random noises with their own frequencies and phases. Its effect on receiver system is always different depending on coupling paths in chip, package and board. Therefore, it is not easy to know how much coupled noise from digital system injects into the reference voltage level and estimate a timing variation depending on the coupled noise. Moreover, it is hard to determine the maximum timing variation in the reconstructed digital signal under certain coupled noise conditions.

This paper introduces a noise coupling effect on reference voltage level and the worst noise waveform depending on combination of random noises. The first section shows basic mechanisms to generate the timing variation in the reconstructed signal depending on a DC reference voltage level or reference voltage with a single noise frequency and phase. The second section gives an analysis of coupled noise with multiple frequencies and phases. The third section shows two worst noise waveforms and their conditions to bring the worst timing variation. The simulation result of the worst timing variation is also shown in the third section. The forth has a conclusion.

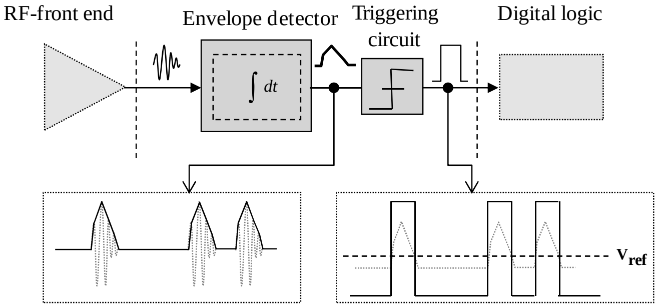


Fig. 1 Non-coherent recovery system in UWB communication.

II. COUPLED NOISE WITH SINGLE FREQUENCY

This section assumes that the coupled noise is composed of a single frequency and phase. However, a timing variation emerges differently depending on DC voltage level, noise frequency and its phase.

A. DC Variation of Reference Voltage Level

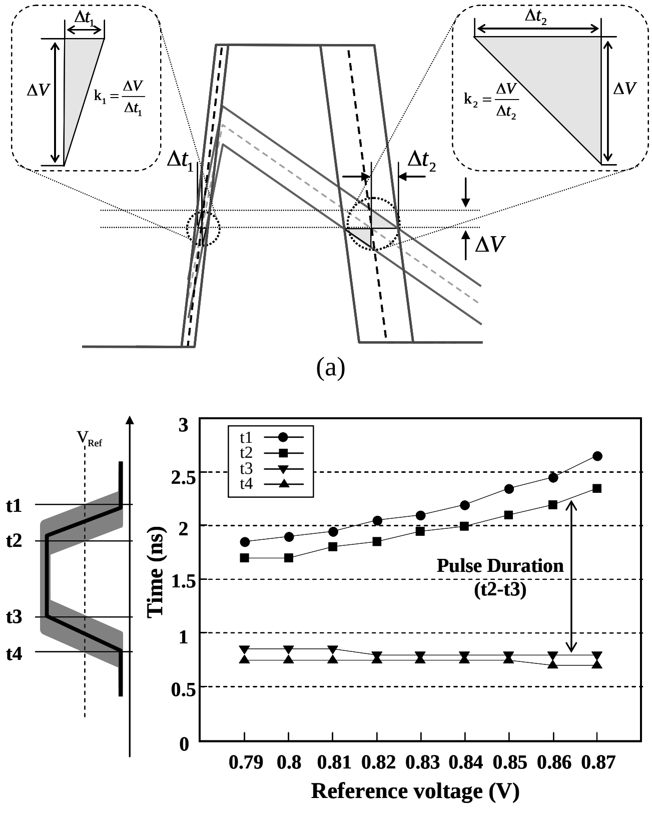
An input analog signal has two different slopes (k_1, k_2) at rising and falling transitions as shown in equation (1) and, a left slope (rising transition) has much steeper slope than right one (falling transition).

$$\left|Slope\ k_1\right| >> \left|Slope\ k_2\right| \tag{1}$$

$$\left|\frac{\Delta V}{\Delta t_1}\right| >> \left|\frac{\Delta V}{\Delta t_2}\right| \tag{2}$$

$$\Delta t_1 << \Delta t_2 \tag{3}$$

Therefore, if the reference voltage experiences same DC level fluctuation about (ΔV), the falling time in reconstructed digital signal has much larger timing variation (Δt_2) than one (Δt_1) at rising time as shown in equation (3) and Fig. 2 (a). As the reference voltage level decreases less than a basic reference voltage of 0.82V (ΔV < 0), a pulse duration of the reconstructed digital signal has smaller duration (t2-t3). Also, a pulse duration has wider one at an increased reference voltage level (ΔV > 0) as shown in Fig. 2 (b). However, two timing variation (t1-t2, t3-t4) has almost same changes depending on a change of the reference voltage level



(a)

(b)

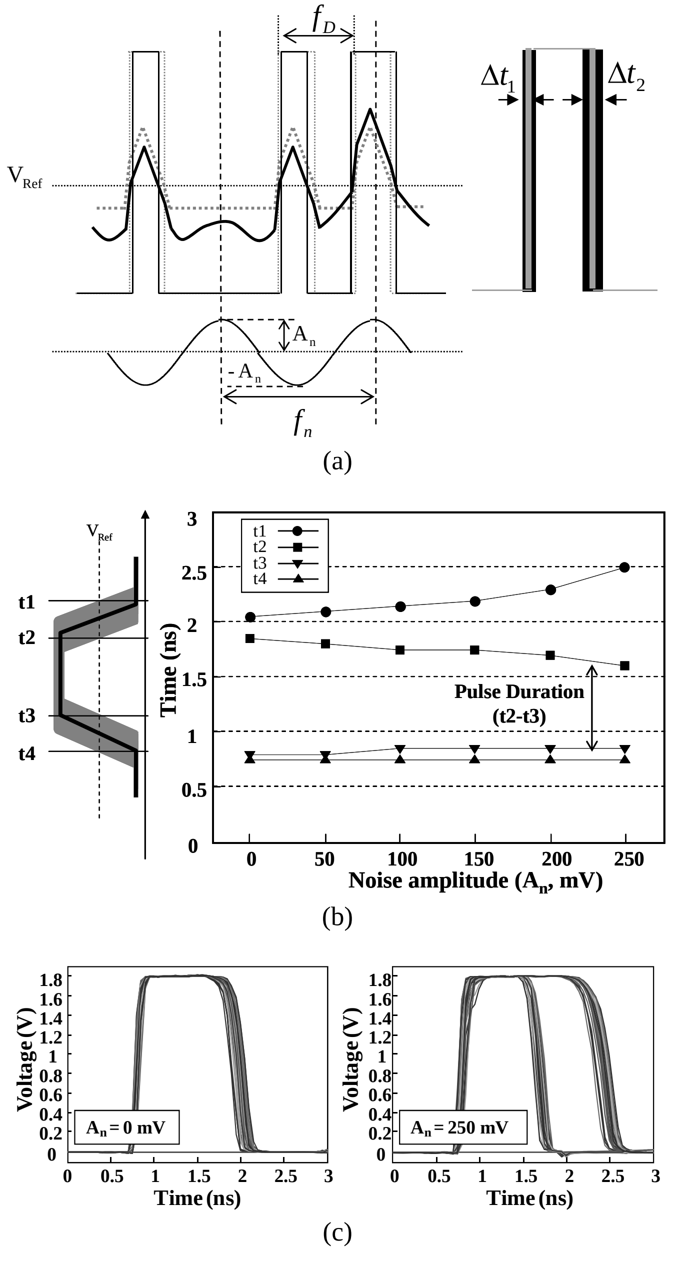
Fig. 2 DC level variation in reference voltage level affects only a pulse duration. (a) Recovery digital signal from analog signal at two different slopes (b) timing variation depending on reference DC voltage.

B. Single Frequency with Half Data-Rate

If a coupled noise signal (n(t)) in equation (4) with single frequency (f_n) and phase (Φ_n) injects into the reference voltage level, different timing variations at two edges in reconstructed digital signal occurred as shown in Fig. 3.

$$n(t) = A_n \cos(2\pi \cdot f_n \cdot t + \phi_n) \tag{4}$$

When a noise frequency (f_n) is as same as half data-rate ($f_D/2$), the timing variation has the largest change. The reconstructed digital signal has the widest pulse duration at positive noise amplitude (+A_n) and the narrowest pulse duration at negative noise amplitude (–A_n). As the noise amplitude increases from 0mV to 250mV, the eye-opening decreases and timing variation (Δt_1, Δt_2) is proportional to the noise amplitude as shown in Fig. 3 (b). Especially, at 250mV of noise amplitude, two falling edges emerge as shown in Fig. 3 (c), the one (t2) comes from low reference voltage level due to a negative amplitude and the other (t1) comes from high reference voltage level caused by a positive amplitude.



(a)

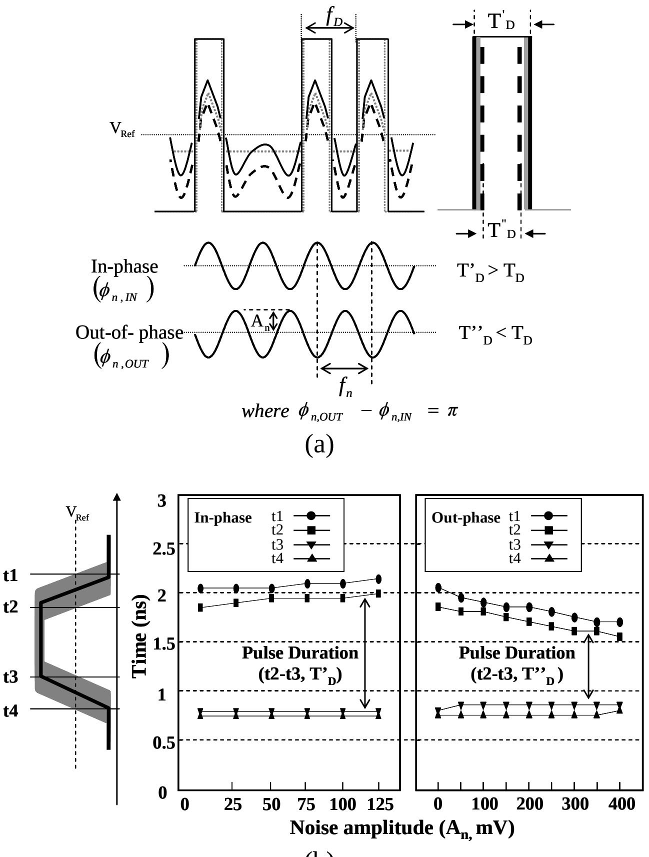
(b)

(c)

Fig. 3 Noise signal with its frequency as same as half data-rate. (a)Two different timing variations depending on a polarity of noise amplitude (b) Timing variation at two edges depending on noise amplitude, (c) eye-diagram at 0V and 250mV of noise amplitude.

C. Single Frequency with Data-Rate

If the noise signal has its frequency (f_n) as same as a data-rate (f_D) of reconstructed digital signal, there are two worst cases that influence the timing variation. The positive amplitude meeting analog signal is an in-phase case and negative amplitude affecting analog signal is an out-of-phase case as shown in Fig. 4 (a). These two cases are dependent on a phase (Φ_n) term in noise signal. In-phase noise signal rises the reference voltage level overall when an analog signal is reconstructed. Thus, a pulse duration (T'_D) has a wider duration than basic pulse duration (T_D). On the other hand, since out-of-phase noise signal decrease the reference voltage level, the reconstructed digital signal has narrower pulse duration (T''_D). Fig. 4 (b) shows timing variation of two different cases depending on noise amplitude. As the amplitude of in-phase noise signal increases, pulse duration in left graph increased a little bit. The duration of reconstructed digital signal from out-of-phase noise is getting narrower as noise amplitude increases. However, a timing variation for two cases is almost same change when a noise signal has 0V of amplitude.



(a)

(b)

Fig. 4 Noise signal with its frequency as same as data-rate. (a) Two different timing variations depending on two different phases of noise signal. (b) Timing variation at two edges in case of in-phase noise (left) and out-of-phase noise (right).

III. COUPLED NOISE WITH MULTIPLE FREQUENCIES

The coupled noise can be generally expressed as a linear summation of noise waveforms with their own frequencies and phases in equation (5). It is possible to extract their frequencies and phases using Fast Fourier Transform (FFT). According to a simple mathematical calculation, the amplitude of linear summation relates to individual amplitude and phase of noise waveform. Amplitude and phase of coupled noise depends on various coupling paths in chip, package and board.

$$\begin{aligned} n(t) &= \sum_{k=1}^{N} A_k \cos(\omega_k \cdot t + \phi_k) \\ &= \sum_{\substack{k=-N \\ k\neq 0}}^{N} c_k e^{j\omega_k t} \qquad where \begin{cases} c_k = \dfrac{A_k}{2}\left[\cos\phi_k + j\sin\phi_k\right] \\ c_{-k} = \dfrac{A_k}{2}\left[\cos\phi_k - j\sin\phi_k\right] \end{cases} \end{aligned} \tag{5}$$

We can estimate susceptibility of non-coherent UWB recovery system using the worst noise combination of several single frequency noise waveforms.

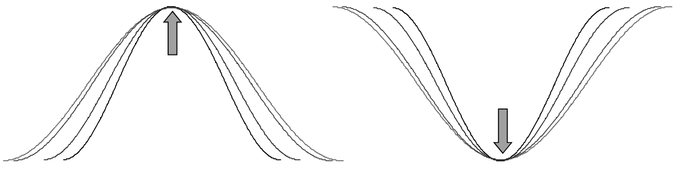
A. *Worst Noise Waveforms*

As explained in the previous section, when the analog signal meets noise amplitude, the reconstructed digital signal has a large timing variation at its two edges. When the reference voltage level has a fluctuation, the reconstructed digital signal from the analog signal has a large timing variation. The coupled noise can be generated with high-positive peak as shown in Fig. 5 (a) under certain condition of equation (6) and brings the largest pulse duration. After FFT of coupled noise, the high-positive peak defined as worst noise waveform is obtained.

$$\frac{\phi_1}{\omega_1} = \frac{\phi_2}{\omega_2} = \bullet\bullet\bullet = \frac{\phi_n}{\omega_n} \tag{6}$$

In contrast to the condition for high-positive peak, the low-negative peak of coupled noise comes from a summation of negative amplitudes of single noise waveforms. The relation between frequencies and phases of noise signal shows a certain condition in equation (7) for generating the low-negative peak defined as another worst noise waveform in Fig. 5 (b). The analog signal will be reconstructed with the narrowest pulse duration when it meets the lowest peak.

$$\frac{\phi_1 + \pi}{\omega_1} = \frac{\phi_2 + \pi}{\omega_2} = \ldots\ldots = \frac{\phi_n + \pi}{\omega_n} \tag{7}$$

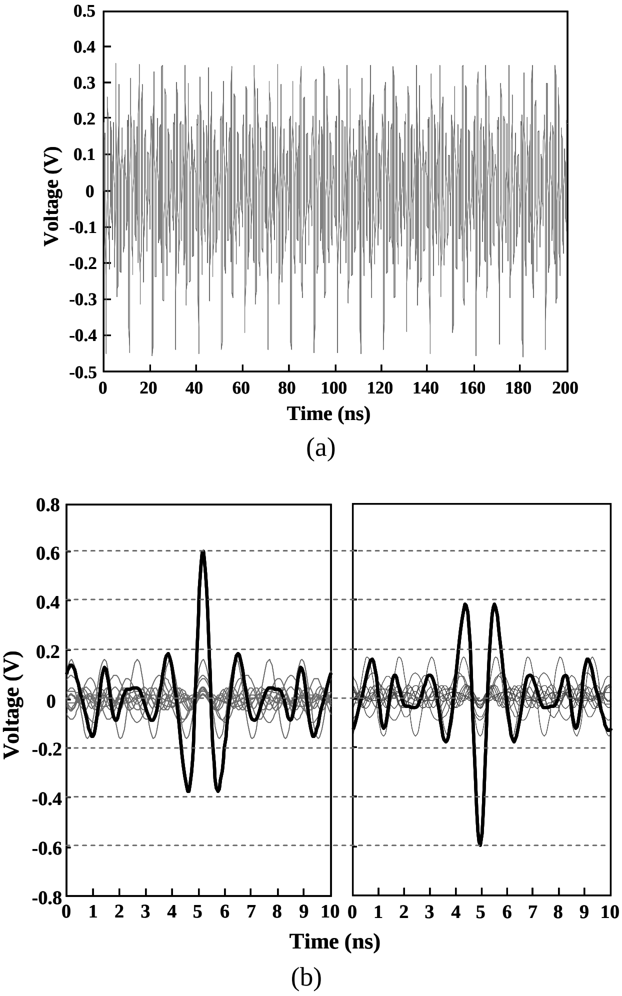


(a) (b)

Fig. 5 Two worst conditions of coupled noise to bring the largest timing variation. Two noise waveforms with high-positive peak (a) and with low-negative peak (b)

B. *Multiple-Frequency Noise*

The coupled noise with multiple frequencies and phases as shown in Fig. 6 (a) can be analyzed using two worst noise waveforms with high-positive peak and low-negative peak. Each frequency and phase is obtained through FFT. Then, high-positive and low-negative noise waveform in Fig. 6 (b) is reconstructed using equation (6), (7). The high-positive noise waveform has a summation of positive amplitudes from individual noise waveforms. On the other hand, the low-negative peak in right waveform of Fig. 6 (b) consists of negative amplitudes from individual noise waveforms.



(a)

(b)

Fig. 6 (a) coupled noise with multiple frequencies and phases (b) high-positive peak (left) and low-negative peak (right) of the worst noise combination of several single frequency noises.

C. Worst Timing Variation

The worst timing variation from two worst noise waveforms can be obtained. Fig. 7 shows the widest pulse duration from high-positive peak and the narrowest one from low-negative peak. When high-positive peak meets the analog signal at the input of triggering circuit, doted-line in Fig. 7 occurs. Dashed-line in Fig. 7 is obtained when analog signal suffers from a low-negative peak of worst noise waveform. A time difference between left two edges (Δt_1) or right two edges (Δt_2) is the worst variation in the reconstructed digital signal if a coupled noise with multiple frequencies and phase in Fig. 6 (b) injects into the reference voltage level of triggering circuit. Other combinations of multiple frequencies and phases from Fig. 6 (a) make a reconstructed digital signal to put inside the worst timing variation.

If a certain digital circuit generates a noise, it transfers into non-coherent receiver circuit located in different position from the digital system. Although the original magnitude and phase in noise source will change, its worst combination is still obtained from a high-positive peak and a low-negative peak of noise waveforms.

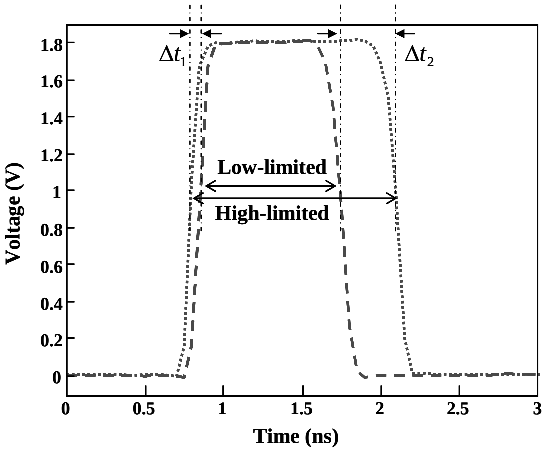


Fig. 7 Two worst timing variation from two worst noise waveforms with high-positive peak (dot-line) and low-negative peak (dash-line)

IV. CONCLUSION

This paper introduces an effect of noise coupling to reference voltage level of triggering circuit using two worst noise waveforms with high-positive peak and low-negative peak in non-coherent UWB communication system. The timing variation comes from DC voltage fluctuation in reference voltage level. Also, the timing variation shows dependence on a phase and amplitude of coupled noise. The worst timing variation due to coupled noise is predicted with high-positive peak and low-negative peak of coupled noise waveform.

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