Accuracy of Relative Distance Measurement with Ultra Wideband System

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***Abstract*—Since very short pulse waves are transmitted, UWB systems have excellent accuracy in terms of distance measurement. In order to measure the distance between the terminals, the transmitted pulses have to be synchronized by a delay-lock-loop (DLL) in the receiver. In this paper the performance of the DLL is evaluated. Its performance depends the timing jitter between the local clocks of the terminals.**

***Index Terms*—key words UWB, DLL, Distance Measurement**

I. Introduction

Recently UWB radio has been paid large attention because FCC has admitted the use of UWB system in February, 2002 [1]. Due to the regulation, the transmission power of the UWB system is limited. On the other hand, the frequency bandwidth assigned for the UWB systems is from 3.1 to 10.6 [GHz]. As the bandwidth is quite large, UWB systems are possible to measure the relative distance between the UWB terminals accurately.

Most of the UWB systems currently investigated employ very short pulse waveform in order to generate such wide band signals[2]. To detect the distance the timing of the received pulse has to be recovered. The same as the ordinary spread spectrum systems, a delay-lock-look (DLL) is required for synchronization of the pulse [3][4]. The synchronization characteristics are largely influenced by the clock jitter between the terminals as the pulse duration is very small.

In this paper the performance of the DLL for the UWB system is evaluated. The performance of the DLL depends on the waveform of the template signal and the timing jitter between the clocks in the terminals.

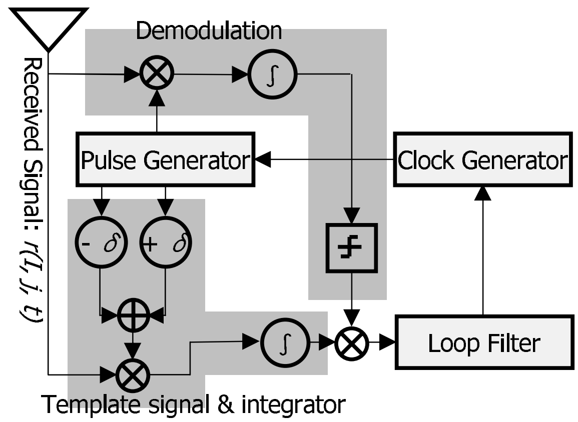

Fig. 1. Block diagram of the system.

II. System model

A. Channel model

It is assumed that the UWB systems are mainly applied for indoor wireless communications in laboratories, offices, or houses. The channel model of the UWB systems has been investigated[5]. As the duration of the pulse is very short, the transmitted pulse through the multipath channel can be received independently. Therefore, the variance of the received signal power due to fading is much smaller than the conventional narrow band signals. Thus, a AWGN channel is assumed in this paper.

B. System model

A block diagram of the UWB-DLL is shown in Fig. 1. The received signal $r(i, j, t)$ is multiplied with the template signal and integrated. It is assumed that the transmitted signal is modulated with BPSK. The data modulation is removed by multiplying the output of the detector and the output of the integrator. Then the output signal of the correlator is put into the loop filter. The output of the loop filter

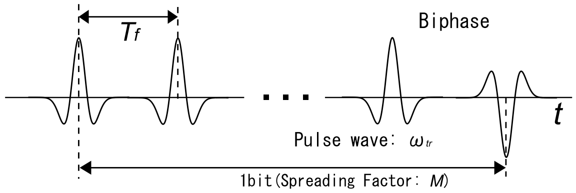

Fig. 2. Frame of the transmit signal.

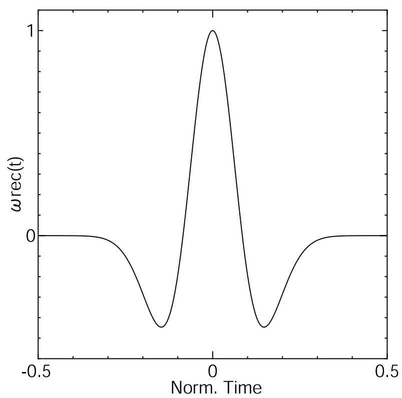

Fig. 3. Received pulse

controls the timing of the clock generator.

C. Signal model

The Signal model assumed in this paper is shown in Fig. 2. Here the received signal model is defined as

$$\begin{aligned} &r\left(i,j,t\right) \\ &= Ab_i c_j \omega_{rec}\left(t-\tau-\left(Mi+j\right)T_f\right)+n(t) \end{aligned} \tag{1}$$

where A models the attenuation over the propagation path, b_i is the given i-th binary symbol, c_j is the j-th chip on the spreading code, ω_{rec} is the received impulse wave, t is the receiver's clock time, τ is the timing gap between the synchronization timing of the DLL and the real synchorization timing, M is the number of pulses per bit, T_f is the pulse interval, $n(t)$ is noise.

Fig. 3 shows the received signal. The waveform is defined as [8]

$$\begin{aligned} &\omega_{rec}(t) \\ &= \left\{1-4\pi\left[\frac{t}{t_n}\right]^2\right\} exp\left(-2\pi\left[\frac{t}{t_n}\right]^2\right) \end{aligned} \tag{2}$$

where t_n is the scale of pulse width.

D. Template signal

The performance of the DLL depends on the waveform of the template signal. Here the template signal, ω_{cor} is defined as

$$\omega_{cor}(t) = \omega_{rec}\left(t+\delta\right) - \omega_{rec}\left(t-\delta\right) \tag{3}$$

where ω_{rec} represents the waveform of the received pulse, δ is the time delay between the pulses. The output of the integrator for the i-th bit is then expressed as

$$\begin{aligned} &x(i) \\ &= \sum_{j=0}^{M-1} \int_{-\infty}^{\infty} r(i,j,t) \\ &\quad \times c_j \omega_{cor}\left(t-\left(Mi+j\right)T_f-\tau\right)dt \end{aligned} \tag{4}$$

where $x(i)$ is the correlation value of the i-th bit.

E. Loop filter

In order to adjust the synchronization timing, it is necessary to estimate the timing gap τ as accurately as possible. To improve the accuracy N outputs of the correlator are averaged. Here, the estimated value $\hat{\tau}$ of the synchronization timing gap is defined as

$$\hat{\tau}(n) = k\frac{\sum_{i=n-N+1}^{i=n} x(i)\hat{b}_i}{N} \tag{5}$$

where k is the loop gain of the filter, $\hat{b}_i$ is the demodulated binary symbol.

F. Clock jitter model

It is assumed that the oscillators in the transmitter and the receiver have clock jitter. Since the clock jitter depends on the thermal noise [6][7], its probability density function is approximated as that of Gaussian distribution.

III. Numerical Results

The variance of the normalized tracking jitter and the normalized mean time to lose lock have been evaluated through computer simulation. The variance of the tracking jitter is the variance of the estimated timing gap $\hat{\tau}$. The

TABLE I

SIMULATION CONDITIONS.

No. of trials	100,000 (tracking jitter) 1,000 (lose lock)
Channel model	AWGN
Clock jitter	Gaussian distribution $0.0 \leq \epsilon \leq 1.0 \times 10^{-3}$
Time delay	$\delta = 0.15$
No. of averaging	$1 \leq N \leq 100$

TABLE II

RELATION BETWEEN TRACKING JITTER AND DISTANCE ESTIMATION ERROR.

jitter variance	estimation error
1.0×10^{-2}	$6.00mm$
1.0×10^{-3}	$1.90mm$
1.0×10^{-4}	$0.60mm$
1.0×10^{-5}	$0.19mm$
1.0×10^{-6}	$0.06mm$

mean time to lose lock is the average time until the DLL loses the synchronization with the received pulses. The number of the trials for the tracking jitter performance is 100,000, and for the mean time to lose lock is 1,000. It is assumed that the channel model is AWGN and clock jitter shows Gaussian distribution. The time delay between the template's pulses, δ, is set to 0.15.

The simulation conditions are shown in Table I. The Relation between the variance of the tracking jitter and the distance estimattion error is shown in Table II. The correspondence of the mean time to lose lock and real time is shown in Table III. Here, it is assumed that the pulse duration is 200 [psec].

A. Tracking Jitter Variance

The relation between the variance of the normalized tracking jitter and E_b/N_0 is shown in Fig. 4. The jitter variance is normalized with the pulse duration. It is clear that the variance of the tracking jitter shows performance floor when the clock jitter exists and the performance is sensitive to the clock jitter. As the clock jitter increases, even if E_b/N_0 improves the variance of the normalized tracking jitter does not decrease since the clock jitter is dominant in that region.

TABLE III

CORRESPONDENCE OF MEAN TIME AND THE REAL TIME.

mean time	real time
1.0×10^1	$1\mu s$
1.0×10^2	$10\mu s$
1.0×10^3	$100\mu s$
1.0×10^4	$1ms$
1.0×10^5	$10ms$

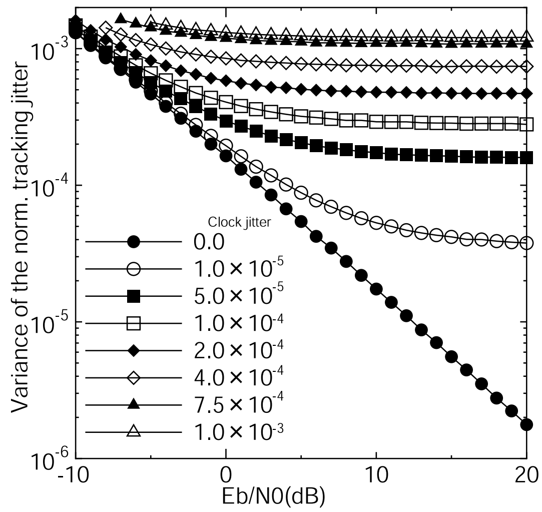

Fig. 4. Variance of the normalized tracking jitter vs. E_b/N_0.

The relation between the variance of the normalized tracking jitter and the clock jitter is shown in Fig. 5. The variance of the normalized tracking jitter is more sensitive to the increase of the clock jitter in the low clock jitter region.

B. Mean Time To Lose Lock

The relation between the mean time to lose lock and E_b/N_0 is shown in Fig. 6. The performance is normalized by the pulse interval. The performance is deteriorated if the clock jitter becomes large.

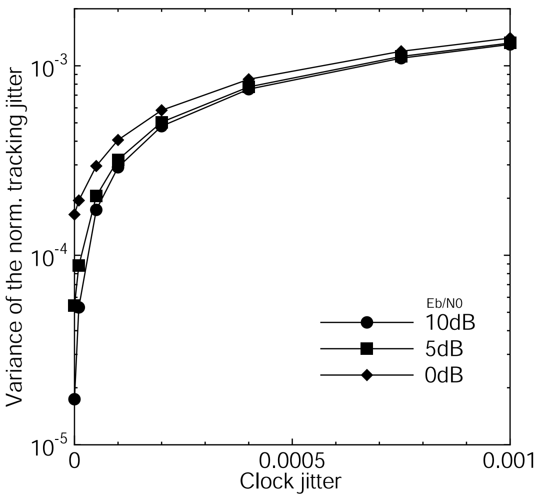

Fig. 5. Variance of the normalized tracking jitter vs. clock jitter.

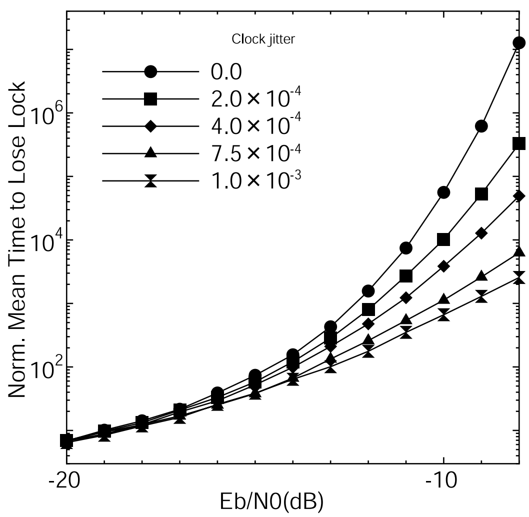

Fig. 6. Normalized mean time to lose lock vs. E_b/N_0.

The relation between the mean time to lose lock and the clock jitter is shown in Fig. 7. The same as Fig. 5, the mean time to lose lock in the low clock jitter region is more sensitive to the increase of the clock jitter in the low clock jitter region. The influence of AWGN becomes dominate if E_b/N_0 is low, so the performace is hardly influenced by the clock jitter.

C. Performance with Feedback Loop

The variance of the normalized tracking jitter versus E_b/N_0 with the averaging period

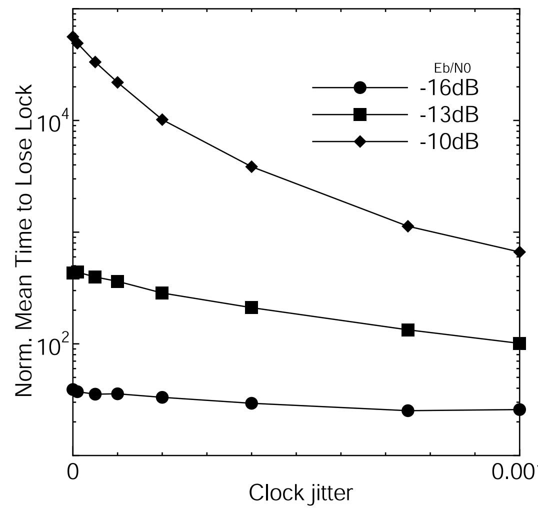

Fig. 7. Normalized mean time to lose lock vs. clock jitter.

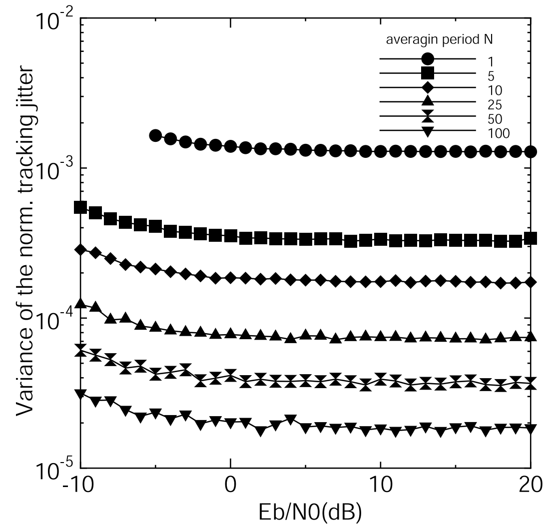

Fig. 8. Variance of the normalized tracking jitter of the feedback loop vs. E_b/N_0(clock jitter$= 1.0 \times 10^{-3}$)

N of the feedback loop is shown in Fig. 8. The variance of the normalized tracking jitter decreases about 10 times when $N = 10$, and about 100 times when $N = 100$. Even if E_b/N_0 is high, the tracking jitter does not improve because of the clock jitter in Fig. 4. However, with the loop filter, it is possible to reduce the influence of the clock jitter as well as AWGN.

The relation between the variance of the normalized tracking jitter and the clock jitter

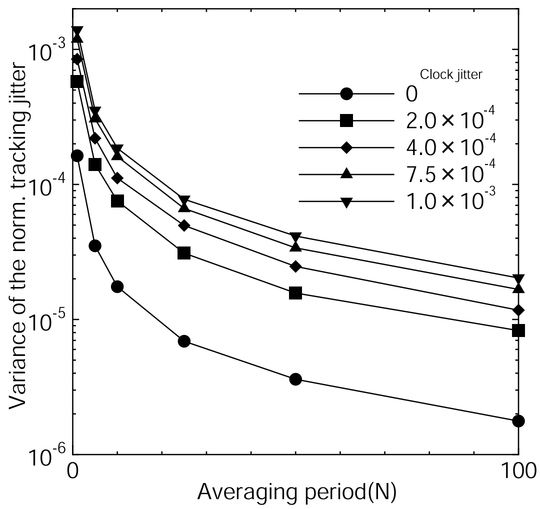

Fig. 9. Performance gain of feedback loop samples($E_b/N_0 = 0dB$)

is shown in Fig. 9. The variance reduces as the averaging period N of the loop filter increases, especially when N is small. Thus, these results indicates the performance improvement by the feedback loop.

IV. Conclusions

In this paper, the UWB system for location estimation has been modeled. In order to estimate the relative distance, the transmitted pulses have to be synchronized by the DLL.

It has been shown that the clock jitter causes performance floor in the variance of the normalized tracking jitter. The performance improvement can be expected by increasing the averaging period of the loop filter.

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