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A VEHICLE-TO-VEHICLE COMMUNICATION AND RANGING SYSTEM BASED ON SPREAD SPECTRUM TECHNIQUE

— SS Communication Radar —

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ABSTRACT

A concept of a vehicle-to-vehicle communication and ranging system, which was called Boomerang Transmission System, was first proposed by Mizui, Uchida, and Nakagawa. By exploiting the Spread Spectrum Technique, the system was capable of transmitting data and measuring the range between two vehicles simultaneously, and its theoretical validity was proved using a computer simulation. In this study, a laboratory-scale prototype system was developed to confirm the workability of the concept on real electrical circuits and the capabilities of data transmission and ranging under interference signals were evaluated.

1. INTRODUCTION

Inter-vehicle range detection has become a key technology for active safety systems for road vehicles. Headway distance warning systems have been brought to market and recently adaptive cruise control systems, which automatically maintain a safe distance to a preceding vehicle, have drawn much attention because of their collision avoidance potential. These active safety systems are expected to gain ground on the market within this decade. However, to realize a more efficient and safer road traffic, cooperative driving systems based on vehicle-to-vehicle communication technology would become necessary. And for these applications, it is essential to transmit information and to measure inter-vehicle distance at the same time.

From this viewpoint, the Boomerang Transmission System was proposed by Mizui, Uchida, and Nakagawa [1][2]. The concept is based on the SS (Spread Spectrum) technique [3] and has many advantages compared with other proposed systems. First of all, the proposed system has a capability of simultaneous data transmission and range measurement; this feature is of advantage to construct a compact and low cost device. Furthermore, the proposed concept does not assume that all the vehicles are equipped with the same system, i.e., the system works as a range radar against unequipped vehicles.

The purpose of our research is to develop a range radar which has a capability of communicating with other equipped vehicles or roadside beacons; we call this *SS communication radar*. The feasibility of such a system was proved and its characteristic features were well analyzed in reference [2]. In this study, a prototype for laboratory use hardware was developed as a preliminary step for full-scale system development. The effect of interference signals on the performances of data transmission and range measurement was evaluated and affecting parameters in designing the electric circuits were analyzed.

2. BOOMERANG TRANSMISSION SYSTEM

Figure 1 shows the operational principle of the Boomerang Transmission System. More detailed information can be found in reference [2].

First, a light wave with a PN code signal which is generated by a PN code generator in vehicle-1 is transmitted to vehicle-2. The PN code generator also generates a PN code phase timing signal which triggers a counter to start measuring propagation delay time between the two vehicles.

At vehicle-2, the received PN code signal from vehicle-1 is multiplied by coded signals which carry information of vehicle-2, and retransmitted to vehicle-1.

At vehicle-1, the returned PN code signal is processed by a PN matched filter which calculates the correlation between the generated PN signal and the received PN signal. As the result of correlation calculation, there appears

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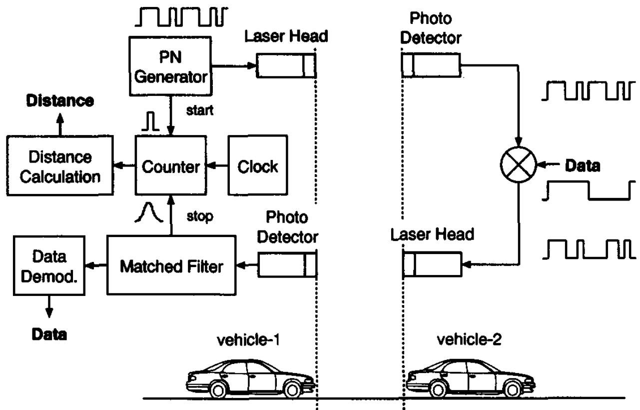

Figure 1: Operational principle of Boomerang Transmission System

a peak signal per one PN code phase in the output of the matched filter. By demodulating this output signal, the information of vehicle-2 is recovered. The peak signal of the matched filter indicates the start of received PN code phase, so the time of flight between the two vehicles can be calculated by measuring the time interval from the phase start pulse of the PN code generator to the peak of the matched filter output. Let f_c be a counted pulse frequency and N_c be a counter value measured, the distance between the two vehicles, R, is calculated as follows:

$$R = \frac{2 \cdot N_c \cdot f_c}{c}$$

where c means the velocity of light.

In this scheme, vehicle-2 can transmit its data without knowing the PN code sequence of vehicle-1. This is an important characteristic of this scheme, because the equipped vehicle can receive data from many and unspecified vehicles, while in conventional SS communication systems, the receiver has to know the sender's PN code sequence.

In such a situation that vehicle-2 is not equipped with a transponder, vehicle-1 is still able to range the distance by receiving the reflected signal from the target vehicle.

In addition, the SS technique has its original advantages such as:

(1) robustness against interferences and multipath fading,

(2) little interference to existing systems.

All these characteristic features of the proposed scheme are advantageous to construct practical vehicle-to-vehicle communication systems.

3. EXPERIMENTAL SYSTEM

An experimental system was developed to conduct laboratory experiments and clarify the specifications for a full-scale system.

Figure 2 shows the block diagram of the experimental system. In the figure, shadowed blocks indicate newly developed circuits and for the remaining blocks, commercial measuring instruments were used. Table 1 shows the major specifications of the experimental system.

The maximum detection range of the optical system, which consisted of a laser head and a photo detector, was 10 m.

There were several kinds of matched filters available; we chose a SAW (Surface Acoustic Wave) matched filter because of its advantages in SS communication, such as:

(1) simplicity of despreading circuits,

(2) high speed spreading,

(3) stable operation of circuit,

(4) small size, light weight, and high reliability.

Binary phase shift keying (BPSK) was used for data modulation at the target. There are several ways to realize a PSK demodulator such as the coherent detection method or the differential detection method. From the viewpoint of bit error rate, the differential detection method has some

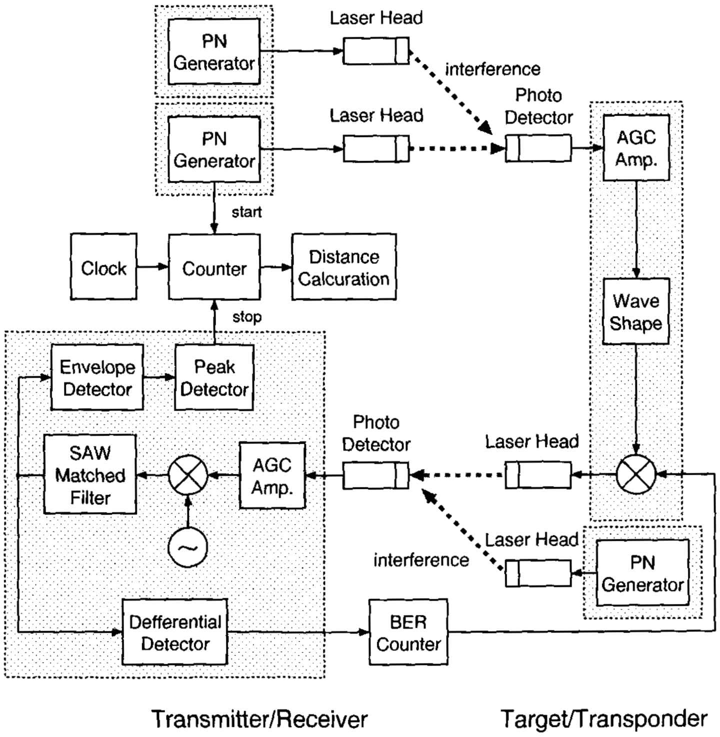

Figure 2: Block diagram of experimental system

disadvantages. But we used it because it needed no carrier recover processes.

The data transmission rate in the experimental system was limited to 12.6 kbps because of code synchronization mismatches between the data modulation phase and the PN code phase. The data transmission rate of 12.6 kbps is considered to be sufficient for transmitting speed and acceleration data of a single vehicle. However, it will not be sufficient to communicate with multiple vehicles, and the system must be improved for such applications.

A resolution of one meter in range measurement was generally required for collision warning applications. In order to achieve this resolution, a time counter with 150 MHz clock was used. The time counter was started by a trigger pulse of the PN generator which indicated the start of the PN code phase and stopped by a peak signal of the SAW matched filter.

4. EXPERIMENTAL RESULTS AND DISCUSSION

Experiments were conducted in a laboratory under normal indoor illumination.

First, the performance of the communication and ranging was evaluated without any interference signals.

To evaluate the accuracy of ranging, the rate of correct ranging (RCR) which represents the probability of calculating exact values with a ranging error of less than 0.5 m was measured, and the results are shown in Figure 3.

In the figure, the solid line shows the averaged value of 1000 measured range data, the dotted line shows the averaged value of 100 data, and the broken line shows raw range data without averaging. The rate of correct ranging (RCR) was nearly constant throughout ranging distances, and increased significantly with the number of averaging data. In the case of averaging of 1000 data, the rate of correct ranging (RCR) values were very close to 1 throughout

Table 1: Experimental specifications

Laser Head	
Output Power	0.3 mW
Lens Efficiency	56 %
Peak Wavelength	670 nm
Beam Width	15 mrad (both H/V)
Photo Detector	
Device	PIN Photo Diode
Minimum Sensitivity	0.6 μW
Cut Off Frequency	100 MHz
Transponder	
Data Modulation	BPSK
Transmitter/Receiver	
Despreading Device	SAW Matched Filter
PN Code	127 bit, M Sequence [7, 1]
PN Chip Rate	16 Mchip/s
Data Demodulation	Differential Detection
Data Bit Rate	12.6 kbps
Clock Speed	150 MHz

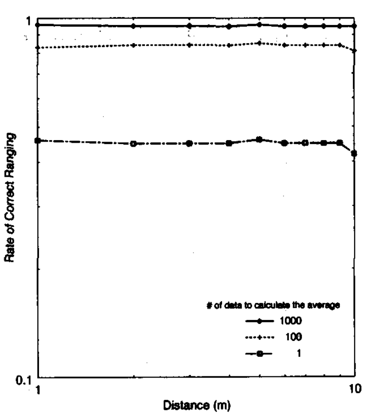

Figure 3: Ranging performance (no interference)

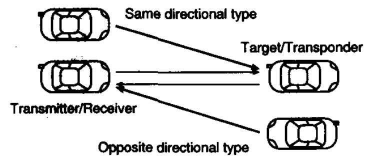

Figure 4: Interference model

the detection range of 1 m to 10 m, and therefore, the ranging error was expected to be within ± 1 m.

The major source of the ranging error was considered to be circuit delays especially in the transponder at the target and the SS demodulation circuit. In the transponder, opto-electronic conversion, level shift, binary quantization were included and all these circuitry had time delays with different distributions. Signal wave distortion through level shift and binary quantization processes also seemed to be one of the causes of performance deterioration. Additionally, the frequency characteristics of the AGC amplifier in the demodulation circuit also might affect the performance.

The performance of data transmission was evaluated in the same experiment, and it was confirmed that the measured Bit Error Rate (BER) values were stable and sufficiently low throughout the test distance for all the three cases of averaging.

Next, the performance of communication and ranging under the existence of interference was evaluated. There are two types of possible interference in the proposed vehicle-to-vehicle communication system. Figure 4 shows two models of interference. One is the interference from vehicles moving to the same direction in neighboring lanes (same directional type interference). The other is from vehicles closing to the Transmitter/Receiver vehicle (opposite directional type interference).

First, the effects of the opposite directional type interference were investigated. A situation in which all the vehicles were equipped with the same system was assumed. A PN code signal of the same code length, the same chip frequency, and different tap positions, which was emitted by a separate laser head, was used for the interference source. The interference light wave was emitted to the photo detector of the receiver mixed with the return signal from the target.

Figure 5 shows BER performance with varying distances and power of interference light waves. Figure 6 shows

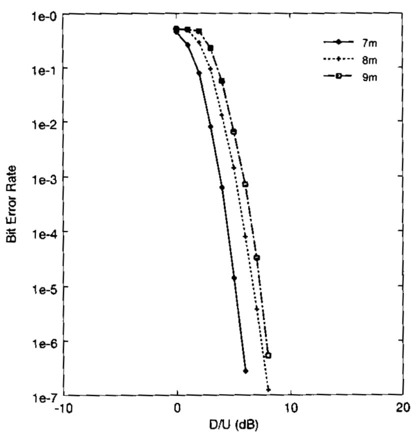

Figure 5: BER performance
(opposite directional type interference)

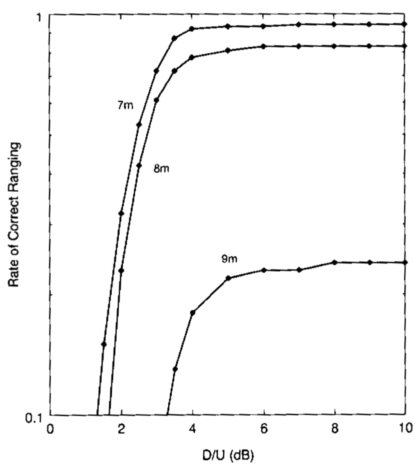

Figure 6: Ranging performance
(opposite directional type interference)

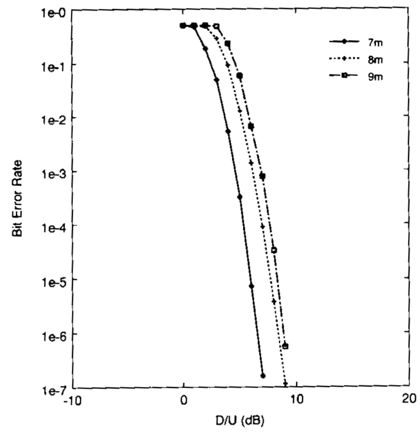

Figure 7: BER performance
(same directional type interference)

the relationship between the power of interference signal and the rate of correct ranging (RCR). In this experiment, the averaging calculation was done for 1000 successive data. In each figure, x-axis shows the power ratio of desired (from target) and undesired (from interference source) light waves (D/U) in dB.

As shown in figure 5, BER was measured for three ranging distances. BER values decreased rapidly with the increase of D/U value and the decrease of ranging distance. It was found that BER is less than 10^{-5} at a D/U level of 5 dB up to 7 m range.

As shown in Figure 6, the rate of correct ranging (RCR) values decreased with decreasing D/U values and with increasing ranging distances. It was also found that the rate of correct ranging (RCR) values were sufficiently high and stable at a D/U level of 5 dB up to 7 m range.

Next, the effects of the same directional type interference was investigated. Figure 7 and Figure 8 show similar results as those of Figure 5 and Figure 6.

As shown in Figure 7, BER values were less than 10^{-5} up to 7 m range at a D/U level of 5 dB. BER showed the same characteristic less than 7 m range and rapidly deteriorated beyond that. These characteristics were similar to those in the case of the opposite directional type, but the effects of interference were slightly larger in the same directional type.

As shown in Figure 8, the performance of the rate of

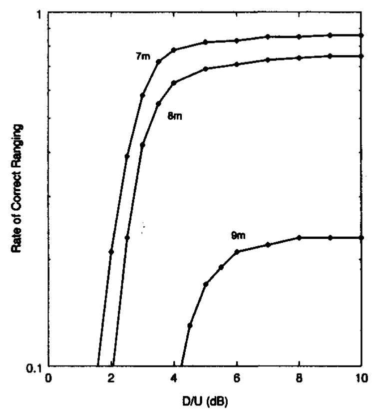

Figure 8: Ranging performance
(same directional type interference)

correct ranging (RCR) deteriorated rapidly with the ranging distance. However it was found that the rate of correct ranging (RCR) was sufficiently high at a D/U level of 5 dB up to 7 m range.

5. SUMMARY

A prototype of the SS communication radar was developed and its performances were evaluated at a laboratory. The results are summarized as follows:

(1) The workability of the proposed concept was confirmed on a real electrical circuitry.

(2) A range resolution of 1 m at a D/U level of 4 dB was obtained taking average of 1000 successive data.

(3) A data transmission rate of 12.6 kbps with a BER less than 10^{-5} was achieved at a D/U level of 5 dB.

These performances are considered to be sufficient for cooperative driving of two vehicles such as adaptive cruise control systems, however, further studies are necessary in the following subjects.

- Optimization of circuit parameters to improve the performances of data transmission and ranging.
- Evaluation of alternative designs of modulation, demodulation and despreading subcircuits.

The next step of our research will be the construction of a full-scale system, and various problems such as multipath fading, background noise should be investigated on actual roads.

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