An Obstacle Sensing Radar System for a Railway Crossing Application: A 60GHz Millimeter Wave Spread Spectrum Radar

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***Abstract* • • We have developed a 60GHz millimetre wave spread spectrum radar system. The radar was designed as a sensor for an obstacle sensing radar system for a railway crossing application, in which the sensing range per radar installation covers up to 90 degrees. With a pair of these radar systems (radar 1 and radar 2), the whole area of the railway crossing can be monitored. This paper describes the structure of the radar and it's working principles, and also our experimental test results.**

• : INTRODUCTION

The aim of an obstacle sensing radar system for a railway crossing application is to detect any obstacles at a railway crossing in order to prevent a train from touching, hitting or colliding with them and to keep the trains operating normally. Therefore, considerable impetus is expected to develop a reliable obstacle sensing radar system as soon as possible. In fact, a higher level of transportation efficiency has increased the number of accidents recently where automobiles or persons in wheelchairs have become stranded inside railway crossings where the volume of traffic is very heavy. There are some recent reports of an optical detecting system that can detect obstacles with a line sensing radar system, but it is not suitable for use to cover a plane or for surface sensing. There are unsolved issues with this system in that it is easily affected by the weather conditions, it is difficult to achieve axial alignment and there are high installation costs. The development of a new radar system capable of sensing obstacles using millimetre waves is expected to solve these problems.

In Japan, the Radio Law was revised in August 2000 and a license is now open for radio stations operating in the frequency range from 59GHz to 66GHz if they can meet specified technical requirements (for electrical power, bandwidth, spurious radiation and devices to prevent illegal remodelling). In this situation, new radio systems using the millimetre waveband are now under development. The 60GHz millimetre wave regime has advantages in its physical characteristics in that it can not travel long distances and it minimises wave interference due to a large absorption and attenuation by oxygen. Therefore, these advantages result in this system being particularly suitable for sensing obstacles, even in a small area or for broadband-communication applications. In addition, the use of millimetre waves allows for the possibility of downsizing the system, which is a strong point in its favour.

• : STRUCTURE

A. Radar Sensing System for a Railway Crossing

Fig. 2.1-1 shows an obstacle sensing radar system. The radar is designed such that the detection angle of each radar unit covers up to 90 degrees of arc. A pair of radar units allows us to monitor the whole area covered by the railway crossing.

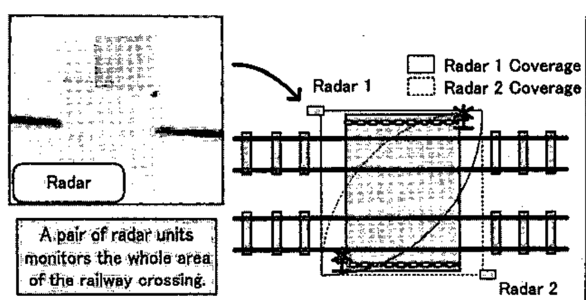

Fig.2.1-1 Radar System Image for a Railway Crossing

B. 60GHz Millimeter Wave Spread Spectrum Radar

Fig.2.2-1 shows the structure of the 60.5GHz millimetre-wave spread spectrum radar for the railway crossing radar system. It consists of both transmitting and receiving antennas (TX/RX antennas), RF modules, an IF module, an SS (spread spectrum) modulator/ demodulator, a radar signal processor and a display and controller for the debugger.

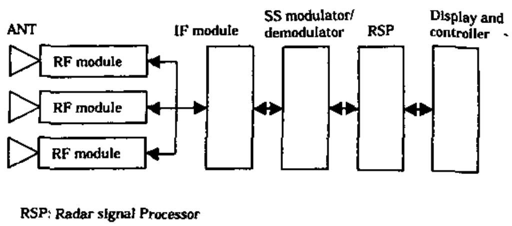

Fig. 2.2-1 Block diagram of Radar

Table 2-1 shows the main specifications of the radar. The radar can calculate its distance from up to twenty different targets within a cycle of 100 milliseconds.

Table 2.2-1

MAIN SPECIFICATIONS OF THE RADAR

No	Item	Description
• •	Radar signal processing	Spread Spectrum (SS)
• •	Detection Range	60m(detect a person)
• •	Refresh rate	100ms
• •	Detection area	over • 45• •
5	Beam numbers	9 beams (switched Electrically)
6	Multi-target	20 targets
7	Output Data	Distance, Velocity, Azimuth Angle

C. RF module

A millimetre-wave RF module is a key component in this radar system, which incorporates monolithic microwave integrated circuits (MMICs). Fig.2.3-1 shows the structure of the RF module in which the antennas are included. The RF module first converts (up-converts) the IF signals at 2.45GHz for transmission as RF signals at 60.50GHz. The RF signals are then sent to a transmitting antenna set with a beam direction selected by the switch section, and they are then emitted into space. A receiving antenna set to the same beam direction as that of the transmitting antenna receives the signals that are reflected from the target. The received signals are then converted (down-converted) again to IF signals at 2.45GHz. A filter (FIL) on the transmitting side removes any local 58.05GHz oscillator (LO) signals and the 55.6GHz image signals (IS) that may leak from the mixer. A filter (FIL) on the receiving side removes any local controller (LO) signals and image signals that may leak between the transmitting antenna and the receiving antenna. A high-pass filter (HPF) is inserted after the transmitting mixer to remove possible local oscillator (LO) leakage signals and image signals at 55.6GHz. Another high-pass filter is inserted before the receiving mixer to prevent the receiving mixer from transmitting local oscillator (LO) leakage signals through the receiving (Rx) antenna. The beam direction for transmission is synchronised with that for receiving, and three different beam directions can be used. Because the direction can be set to any of the three beam directions by manipulating the electronically controlled switch section, the task of beam direction setting and management, (which requires careful, minute detailing), can be carried out much more easily than with the mechanical scanning method. This three-direction beam control allows one RF module to detect over an azimuth range of ±15°. Therefore, a total of three modules can detect over an azimuth range of ±45°. In addition, an electronic beam scanning mechanism is used to control the transmitting beam angle synchronously to the receiving beam angle.

Table 2.3-1 shows the main specifications of the RF module.

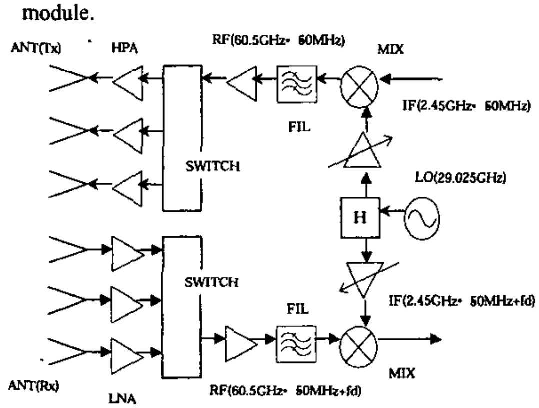

Fig 2.3-1 Block Diagram of RF module

Table 2.3-1

ELECTRICAL PERFORMANCE OF RF MODULE

No	Item	Description
1	Centre frequency	60.5GHz
2	Chip rate (Band width)	50MHz (• 60MHz)
3	Transmitter power	+10dBm
4	Module Gain• Tx, Rx• •	+17dB
5	Antenna Gain• Tx, Rx• •	+23dB
6	Isolation• Tx to Rx• •	over 50dB
7	Isolation (beam to beam)	over 50dB
8	Isolation (RF on/off)	over 70dB
9	NF	6dB (designed)
10	Spurious level	below −10dBm

The spread spectrum waveform is shown in Fig. 2.3-2.

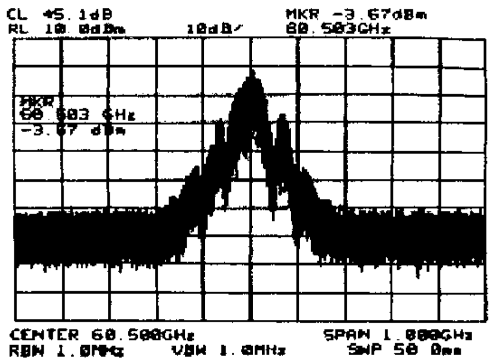

Fig. 2.3-2 SS Waveform on 60.5GHz

• :MEASURING PRINCIPLES

A. Distance Measuring Processing

The distance from the vehicle to the target is calculated from the travelling time of the reflected wave. This distance R is calculated by:

• • • ••• $R=C\cdot Td/2$ •• (1)

where C is the speed of light and Td is the travelling time to the target and back. Therefore, in order to calculate the distance, it is necessary to measure Td. In the radar system, a spread spectrum technique is adopted for radar signal processing. Therefore the travelling time Td is evaluated by the correlation between the received PN code and the reference PN code, which is shifted by the transmitted PN code, as shown in Fig.3.1-1.

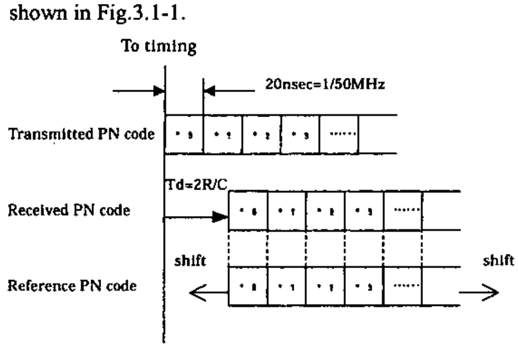

Fig. 3.1-1 Correlating PN codes

In Fig.3.1-1, the sequence $a_0, a_1, \cdots$ is the pattern of the PN code. The auto-correlation function for the PN code is shown by:

$$R_{aa}(\tau)=\frac{1}{T}\int_{-T/2}^{T/2} a(t)a(t-\tau)dt$$

$$=\begin{cases} 1 & for \quad \tau=0 \\ 1-((n+1)/n)|\tau|/\Delta & for \quad -\Delta \le t \le \Delta \\ -1/n & for \quad otherwise \end{cases} \qquad (2)$$

where $a(t)$ is the PN code, n is the length of the PN code and Δ is the reciprocal of the chip rate. As mentioned in the previous section, the phase of the reference PN code can be shifted discretely for the transmitted PN code at every 1/3 chip, i.e. every 6.7ns. Target detection is made by the correlation characteristic of the PN code, as shown in Fig.3.1-2.

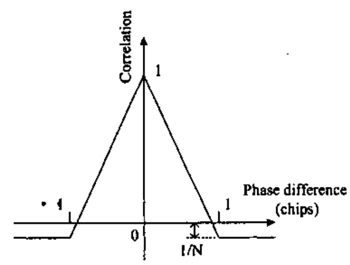

Fig. 3.1-2 Correlation characteristic of the PN code

In Fig.3.1-2, N is the length of the PN code, and in the case of this radar system, N is 1023. When the phase difference is zero, the correlation is 1, and when the phase difference is more than 1 chip, the correlation is $-1/N$. When the phase difference is between −1 and 1, the correlation has a triangular characteristic. In other words, if a target exists and if the radar receives the reflected wave at the phase of the PN code corresponding to the distance to the target, the correlation will be 0dB (normalised), and at other phases the correlation is −60dB (= $-20\log_{10}1023$).

B. Velocity Measuring Processing

After the target is detected by the correlation hardware, in order to sample the necessary length of the beat signals (I, Q), the phase of the reference PN code is controlled such that it is fixed at the point that has maximum magnitude. In the radar system, FFT is used to measure the velocity, and therefore the length of the period necessary to sample the beat signals depends on the specified resolution of the velocity and the radio frequency of the radar. As the specified resolution is 1km/h (= 0.28m/s) and the radio frequency is 60.5GHz, the minimum Doppler frequency f_{dmin} is 112Hz. Therefore, the period necessary to achieve this is $1/f_{dmin}$ = 8.9(ms). On the other hand, the sampling velocity depends on the specified maximum velocity, which is 120km/h (= 33.3m/s) in this radar system. As f_{dmax} is 13.5kHz, the sampling velocity must be at least twice f_{dmax}, i.e. 27kHz. After the I and Q beat signals are determined, the velocity of the target is calculated using the complex FFT. The sign of the Doppler frequency is also determined by the complex FFT, and therefore the longitudinal direction of motion can be identified.

C. Azimuth Angle Measuring Processing

The azimuth angle of the target is measured by a sequential lobing algorithm. The azimuth angle of the target is calculated using a sequential lobing algorithm based on the difference of the magnitude determined by one beam to the magnitude determined by another.

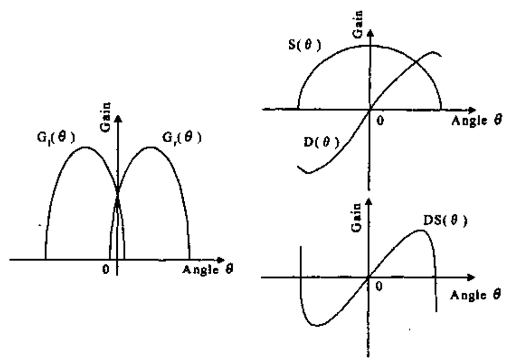

Fig.3.3-1 Beam patterns

Now, there are two beams and their beam patterns are shown in Fig.3.3-1, where the pattern on the right-hand side is G_r (θ), and the one on left-hand side is G_l (θ). The difference between these patterns $D(\theta) = G_r(\theta) - G_l(\theta)$ also shown in Fig.3.3-1. Between the centre of each beam, the relationship of D (θ) to the angle θ is unique. In addition, the magnitude of the received signal changes not only with the gain of the beam but also with the distance, the Radar Cross Section (RCS) of the target and so on. Therefore, in order to calculate the azimuth angle of the target, D (θ) must be normalised by the sum of the two patterns, $S(\theta) = G_r(\theta) + G_l(\theta)$, and then $DS(\theta) = D(\theta) / S(\theta)$ is defined, as is also shown in Fig.3.3-1. In the same way as D (θ), the relationship of DS (θ) to angle θ is unique between the centre of each beam. Furthermore, in the range between the centre of each beam, the DS (θ) characteristic can be approximated to a linear relationship. Then, $1/k$ is defined as the approximated slope of DS (θ), and θ_c is defined as the centre angle of the two beams. The azimuth angle θ of the target is calculated by:

$$\theta = k \cdot DS + \theta_c \qquad (3)$$

where $DS = (M_r - M_l) / (M_r + M_l)$, and where M_r is the magnitude of the signal received by the right-hand side beam and M_l is the one received by the left-hand side beam. In the radar system, 9 beams are spread out to measure a maximum field of ±45°. Therefore, k and θ_c must be calculated in advance for about 8 neighbouring pairs with 9 beams.

• : EXPERIMENTAL RESULTS

Fig. 4-1 shows the experimental results. The levels of the signals received are shown for 5 metre intervals when pedestrians or persons on bicycles or in wheelchairs are sensed on the railway crossing. This gives a successful result in terms of sensing performance, with almost a 100% success rate for the data, even for a long-term test. No interference is propagated between radar 1 and radar 2, and a pair of radar units allows us to monitor the whole area of the railway crossing.

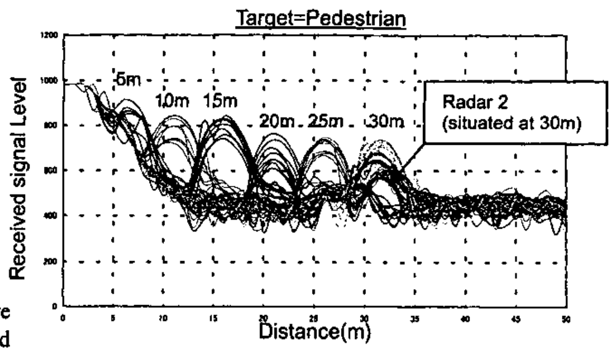

Fig. 4-1 Data for radar sensing

• :CONCLUSION

By using a 60GHz spread spectrum radar assembly, a practical sensing system that could detect pedestrians or persons on bicycles and wheelchairs on a railway crossing was developed that has almost a 100% success rate. A pair of these radar units allowed us to monitor the whole area of the railway crossing, and no interference developed between radar 1 and radar 2. This radar is certified by the Ministry of Posts and Telecommunications in conformance to specified technical standards. Various other data relating to different obstacles have been collected at several railway crossings in Japan. In conclusion, some other applications for the 60GHz waveband are planned in the near future, such as Inter-Vehicle Communication, Collision avoidance radar for Train and Rail-road.

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