Research Report

Radar Cross Section for Pedestrian in 76GHz Band

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76GHz帯における歩行者の電波反射特性

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Abstract

This paper describes the results of our evaluation of a pedestrian's radio wave reflection characteristics. Recently, the demands made for safety systems, such as the Forward Collision Avoidance Assistance System (FCAAS), have been increasing. The radar sensors of such safety systems have to be capable of detecting not only vehicles but also pedestrians, bicycles, and roadside objects. Furthermore, such a safety system should be able to make a decision without any mistake as to whether a collision occurs. Therefore, the radar sensor must be capable of detecting objects with 100% certainty up to a point immediately before a collision would otherwise occur.

The reflection characteristics of radio waves from a pedestrian were measured as part of the effort to improve the pedestrian detection performance of the radar sensor. A pedestrian's radio wave reflection intensity is low, at about 15-20 dB less than that of the rear of a vehicle, and can vary by as much as 20 dB. Evaluating these characteristics in detail is a prerequisite to the development of a radar sensor that is capable of detecting pedestrians reliably.

Keywords Pedestrian, Radar, Radar cross section, Clothes, 76GHz

要　旨

本報告では，歩行者の電波反射特性を評価した結果について述べる。近年，車両周辺監視などの安全システムに対するニーズが高まってきている。安全システム用の電波センサでは，車両だけでなく，歩行者，自転車，路側物などまで検出しなければならない。さらに，安全システムは衝突するかどうかの判断を誤りなく行わなければならない。そのため，電波センサは，衝突直前の距離に至るまで，物体を確実に検出する必要がある。

電波センサによる歩行者検出性能を向上させるために，歩行者からの電波反射特性を測定した。歩行者の電波反射強度は車両の後部と比較して15～20dB程度低いこと，変動幅は20dB程度あることを確認した。これらの特性を詳しく評価することが，歩行者検出性能の高い電波センサの開発に繋がっていく。

キーワード　歩行者，レーダ，レーダ反射断面積，衣服，76GHz

1. Introduction

Recently, the demands made for safety systems, such as the Forward Collision Avoidance Assistance System (FCAAS), have been increasing. The radar sensor of such a safety system has to be capable of detecting not only other vehicles but also pedestrians, bicycles, and roadside objects.[1, 2) Furthermore, such a safety system should be able to make a decision without any mistake as to whether a collision occurs. Therefore, the radar sensor must be capable of detecting objects with 100% certainty up to a point immediately before a collision would otherwise occur. The development of a radar sensor for such safety systems requires that we know the radio wave reflection characteristics, such as the average value of the radio wave reflection intensity, of an object relatively close to the sensor, as well as the range of fluctuation. That is, if the radio wave reflection characteristics of objects are known, the performance of a safety system using a radar sensor can be refined.

In this report, we consider the case of pedestrians, collisions with which must be avoided at all costs. We then describe a technique of measuring a pedestrian's radio wave reflection characteristics in the 76 GHz band.[3)] Finally, we discuss our findings related to the orientation of the pedestrian and the influence of clothes, etc.

2. Pedestrians' radio wave reflection characteristics

There have been very few detailed studies of a pedestrian's radio wave reflection characteristics. From past experiments, however, it is known that a pedestrian's radio wave reflection intensity is lower than that of the rear of another vehicle, and the range of fluctuation is also greater than in the case of vehicles. Although these basic facts are known, no good quantitative evaluations have been performed. Some factors can be considered regarding the time variance of the radio wave reflection intensity of a pedestrian. While the pedestrian is walking, his or her posture, relative orientation, irradiated aspect, and distance from the sensor, are constantly changing. The reflection intensity is affected by all of these factors. Moreover, the size of a pedestrian can vary, from a child to an adult. Furthermore, pedestrians' clothes are made of various materials and take different forms. Then, we subdivided those factors that may affect the radio wave reflection characteristics, and investigated the time variance characteristic for each factor in detail. The variance factors for the radio wave reflection intensity for a pedestrian are shown in **Table 1**.

Next, we describe the principle applied to the detection of the existence of an object by the radar sensor. The radio waves emitted by the transmitting antenna irradiate an object. The waves that are reflected back by an object are received by the receiving antenna. By applying signal processing to the reflected wave, the distance to an object, its relative velocity, direction, etc. can all be calculated. There is a close correlation between the rate of reflection of the radio waves by an object and the distance up to which an object can be detected by the radar sensor. The received power of the reflected wave under the conditions shown in **Fig. 1** is derived from Eq. (1).

$$P_r = \frac{P_t G_t}{4\pi R^2} \cdot \sigma \cdot \frac{1}{4\pi R^2} \cdot \frac{G_r \lambda^2}{4\pi} \quad \cdots\cdots\cdots\cdots\cdots (1)$$

P_r : Received signal power
P_t : Transmitted signal electric power
G_t : Transmitting antenna gain
G_r : Receiving antenna gain

Table 1 Variance factor of radio wave reflective intensity in pedestrian.

・frequency	
・distance	
・body	size
	direction・posture
・movement	centroid movement
	heart beat・breathing
	walking motion
・irradiated area	antenna beam pattern
	mono-static・bi-static
・clothes	material
	smoothness of surface
	sheathing rate
・outward things	road bed
	road side object

σ : Radar cross section (RCS)
λ : Wavelength
R : Distance between sensor and object

If the distance to the object, or the area being irradiated by the radio waves changes, G_t, G_r, and R will also change. It is thought, however, that many other change factors originate from a change in the pedestrian's RCS. If, therefore, a pedestrian's RCS can be evaluated correctly, it will be possible to derive the distance up to which a pedestrian can be detected by the radar sensor.

Originally, an RCS value can be used only when an object is irradiated by a plane wave. That is, the RCS value can be used when the object is far enough away from the source. For example, to make a plane wave irradiate a pedestrian with a height of 1.7 m, a distance of at least 1500 m is needed. For the measurements described in this report, however, the irradiation distance was less than 10 m, such that the objects were not irradiated by a plane wave. The RCS value shown here is obtained by converting from the value for a standard reflector (trihedral reflector of +2.5 dBsm). Since it differs from the RCS value when a plane wave is irradiated, it is referred to as the Fresnel zone RCS.

3. Measurement system

A pedestrian's radio wave reflection intensity is quite low compared to the rear of a vehicle. Furthermore, previous experiments have shown that the reflection intensity changes considerably, even if the pedestrian is standing still. Since there was no existing system for correctly measuring such low-level reflected waves, we designed and built our own system. To measure a pedestrian's radio wave reflection intensity with a high degree of accuracy, some prerequisites must be satisfied by the measuring system. These requirements are listed in **Table 2**.

Figure 2 shows an outline of the system. By utilizing the FM-CW method, waves that pass directly from the transmitting antenna to the receiving antenna are rejected, while those waves that are reflected from the surfaces of the anechoic chamber are separated out. Furthermore, waves that are reflected from other objects are eliminated as much as possible by performing the measurements in an anechoic chamber. The signal captured by the receiving antenna is sampled every 100 msec. in the signal processing section, and then quantized by the A/D converter. A dynamic range of 36 dB is realized, and the reflected wave intensity for a range of -30 ~ +5 dBsm can be observed.

4. Direction dependability

To correctly measure a pedestrian's average radio wave reflection intensity, we measured the radio wave reflection intensity for a pedestrian's entire

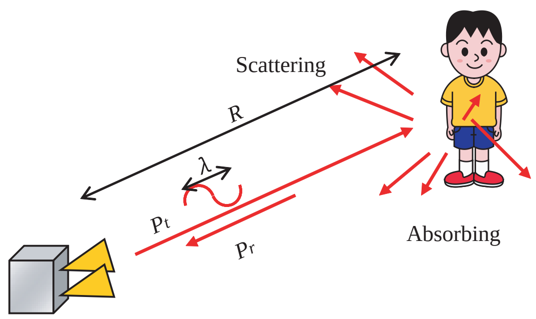

Fig. 1 Radio wave reflective model in pedestrian.

Table 2 Requirements for measurement system.

a) A direct pass from a transmitting antenna to a receiving antenna can be eliminated.
b) The influence of the reflective wave from without the object in the measurement environment can be suppressed.
c) The intensity of a reflective wave can detect to about -30 ~ +5dBsm.
d) In order to grasp the time variance of reflective wave intensity, the sampling rate of beat signal is less than 100 msec.

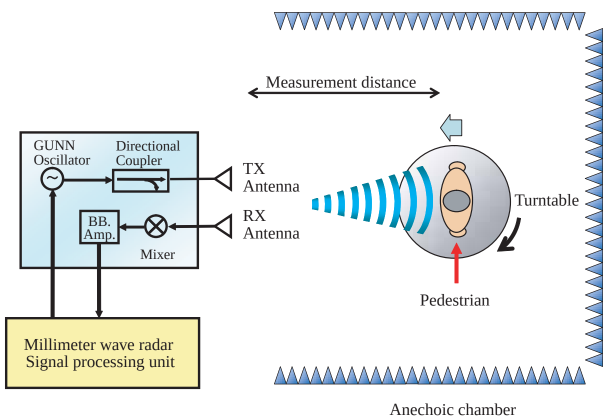

Fig. 2 Structure of the measurement system.

circumference. To evaluate the radio wave reflection intensity for a pedestrian's entire circumference, we used the measuring system (Fig. 2) described in **Sec. 3**, combined with a turntable, on which the pedestrian stood, placed 5 m ahead of the antennas. The rotation speed of the turntable was 2.6 deg./sec. By rotating the pedestrian on the turntable, we could measure the radio wave reflection intensity from all directions.

Figure 3 shows the appearance of the pedestrian that we measured. The results that we obtained for the pedestrian's radio wave reflection intensity are shown in **Fig. 4**. This figure shows a plot of the reflection intensity that was measured at 3.7 points per angle. Moreover, **Fig. 5** shows the results that we obtained for the moving average of the data in Fig. 4 about an angle of 2.6 degrees. **Figure 6** shows a histogram of the measured radio wave reflection intensity.

The average value for the radio wave reflection intensity was found to be -8.1 dBsm, and these results further show that the distribution of the variance has a spread of more than 20 dB. Moreover, the results for which we took a moving average show that the reflection intensity of the pedestrian's front and back is high, at about 5 dB, relative to that of the pedestrian's side. It is thought that the radio wave reflection intensity has a high correlation with the pedestrian's aspect.

Fig. 3 The appearance of the pedestrian for measurement.

5. Clothes dependability

In this chapter, we describe our findings on the effect of clothes on the radio wave reflection intensity. Our goal was to clarify the relationship between the pedestrian's radio wave reflection intensity and the clothes that he or she is wearing.

First, to determine the influence of the differences in the material, the five kinds of clothing shown in **Fig. 7** were measured. Since our goal was to measure the reflection intensity of the clothes themselves, the clothes were hung on a styrene foam board. The measured radio wave reflection intensity for each of the types of clothing is shown in **Fig. 8**.

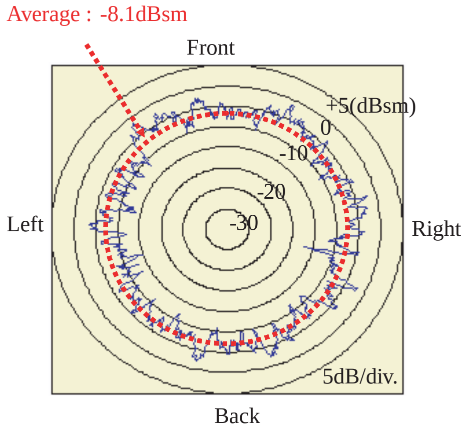

Fig. 5 The moving average of the data of Fig. 4.

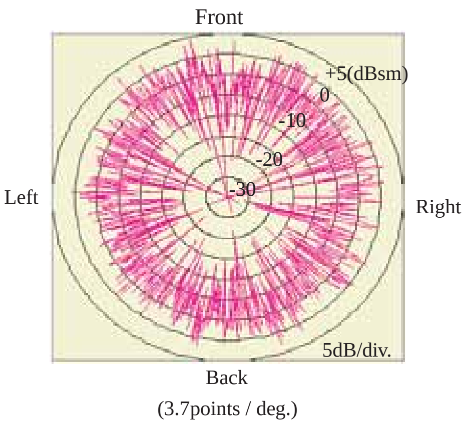

Fig. 4 Measuring result of pedestrian's radio wave reflective intensity.

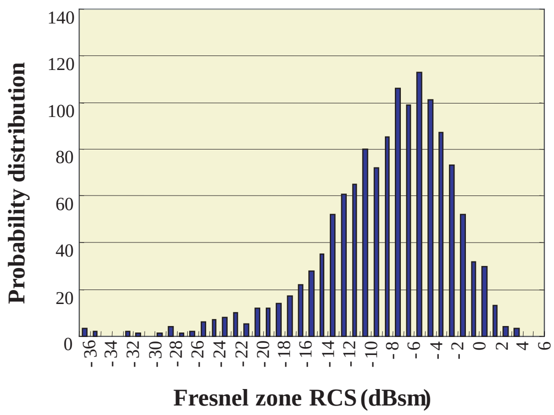

Fig. 6 The histogram of the measured radio wave reflective intensity.

Here, we compare the reflection intensity with that of a metal plate having the same surface area. As shown in Fig. 8, the reflection intensity is about 1/10 - 1/100 of that of the metal plate as a result of the difference in the material or the surface. Moreover, it worth pointing out that the reflection intensity of a wool sweater is low compared to that of clothes made of other materials. The results obtained by measuring the reflection intensity of a naked human body shows that the reflection intensity enters the range shown in (a) of Fig. 8. We found that the reflection intensity of a naked body is almost the same as that of those clothes having a comparatively high radio wave reflection intensity, such as a cotton shirt.

Next, for a single given material, we investigated how the radio wave reflection intensity would change if the form of the clothes was changed. The cotton shirt was wrinkled, and the radio wave reflection intensity obtained for a swing of 36 mm to the right and left was measured. **Figure 9** shows the results that we obtained. In the case of the unwrinkled shirt, there is little change in the reflection intensity, even when the shirt is swung to the right and left. For the wrinkled shirt, however, the reflection intensity changes considerably with the swing. Two or more scatter points (where the radio waves are reflected strongly) were created by wrinkling the clothes. We believe that this change in the reflection intensity is generated because the waves reflected from these scatter points causes phase interference.

6. Conclusion

Safety systems such as FCAAS must be able to identify a pedestrian with absolute certainty. A pedestrian's radio wave reflection intensity was measured with the goal of determining the improvement in the detection of a pedestrian using the radar sensor.

First, a system that can reliably measure a weak reflected wave was proposed. The pedestrian's radio wave reflection intensity was measured using this system. We found that the pedestrian's average radio wave reflection intensity is about -8 dBsm. This is about 15 - 20 dB less than the reflection intensity of the rear of a vehicle. Moreover, the range of fluctuation is about 20 dB.

Future studies will aim to verify the dependability of these measurements, such as the frequency dependability, as well as clarify the effect of the pedestrian's physique, posture, and aspect area.

(1) Under ware (cotton : 100%) (2) T shirt (polyester : 50%, cotton : 50%) (3) Sweater (wool : 100%) (4) Windbreaker (nylon : 100%) (5) Work wear (polyester : 45%, cotton : 55%)

Fig. 7 Five difference kinds of clothes for the measurement of the reflective intensity of the clothes.

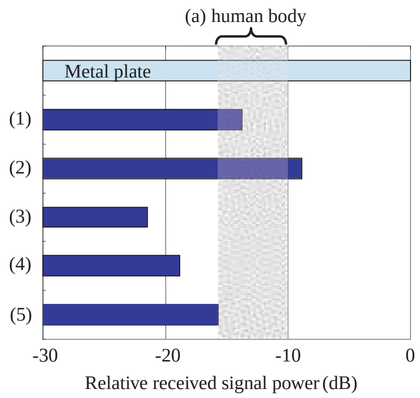

Fig. 8 The measurement result of the reflective intensity of the clothes.

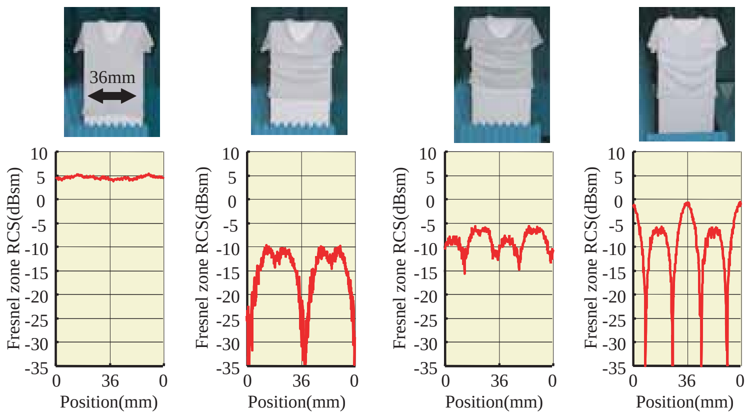

Fig. 9 The measurement result of the reflective intensity of the clothes with wrinkle.

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(Report received on Nov. 1, 2004)

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Research fields : Radar system
Academic society : Inst. Electron. Inf. Commun. Eng. of Jpn.