Development of 26 GHz-band UWB Radar for Automobiles

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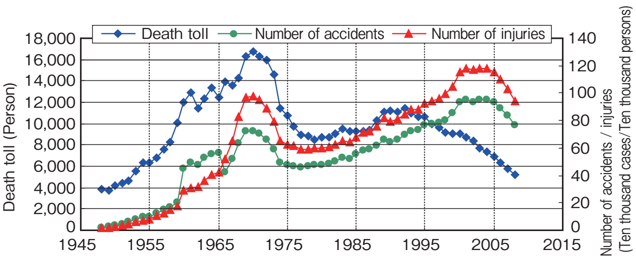
ABSTRACT Taking the opportunity of the easing of regulations by Federal Communications Commission (FCC) in the United States in Feb 14, 2002, UWB (Ultra Wide-Band) radio systems are being actively considered in the fields of communications and ITS (Intelligent Transport Systems). For an application of a UWB technology in the ITS field, SRRs (Short-Range Radar) for automobiles using quasi-millimeter-wave band (24 GHz-29 GHz) that are applied to monitoring sensors for automobile surroundings have been being considered [1]. Furukawa Electric has developed a 26 GHz band UWB Radar for automobiles which leaking signals of a radar carrier (hereinafter called carrier leakage) was considerably reduced in order to meet the world's radio wave regulations. While the size is small enough to be mounted inside automobile bumpers, a distance resolution and a detection capability less than 15 cm are also achieved applying features of the UWB technology. In addition, because a qualification for the radio experimental test station was given for the developed item by the Ministry of Internal Affairs and Communications, it became possible to mount this radar in an actual vehicle and to conduct evaluation experiments of radio propagations and detection performances while moving the vehicle. In this paper, the legislative aspects of UWB radars and details of the developed radar will be reported.

1. INTRODUCTION

Currently, governments, automobile manufacturers and parts manufacturers are going all out to promote the development of safety technologies in order to decrease the number of traffic casualty toll. In Japan, as shown in Figure 1, the number of deaths tends to decrease because of the spread of passive safety technologies (crash safety technologies: air-bag and shoulder harness). However, the number of traffic accidents and injuries are still at a high level, therefore, expectations are becoming higher for active safety technologies which prevent accidents before they happen (preventive safety technologies: pre-crash system, lane change assist, blind spot detection, anti-lock brake system (ABS)).



1. Until 1959, minor accidents (injuries fewer than 8 days, property damages less than 20,000 yen) are not included.
2. Until 1965, property damages are included in the number of accidents.
3. Until 1971, Okinawa prefecture is not included.

Figure 1 **Transition of the number of traffic accidents[2].**

In order to achieve these active safety technologies, monitoring sensors for automobile surroundings which sense dangers of crashing into human or other automobiles before anything happens are important [3]. There are various types of monitoring sensors for automobile surroundings such as a radio wave type, an optical type, a sonic wave type and a camera type. The features of various types of sensors are shown in Table 1. UWB radars can be expected to detect ranges with a high resolution up to 30 m and to be applied not only to an active safety technology, but also to a parking assistance and to a headway control in a traffic jam.

Table 1 **Monitoring sensors for automobile surroundings.**

Capability/method	UWB radar	Millimeter-wave radar	Laser radar	Ultrasonic -wave sensor	Camera	Infrared camera
Point-blank detection (-2 m)	○	△	△	○	○	○
Close/intermediate range detection (-30 m)	○	○	○	×	○	○
Long range (-150 m)	×	○	○	×	×	○
Distance resolution (less than 30 cm)	○	×	○	×	×	×
Angle detection range (more than ±30°)	○	×	×	△	○	○
Relative velocity direct detection	○	○	×	×	×	×
Weather resistance (mist / rain / snow)	○	○	×	×	×	○
Detection at night (darkness)	○	○	○	○	×	○

○: Suitable △: Avairable ×: Not avairable

1: This comparative table is an example.
2: The capabilities of the UWB radar are based on which our company developed.

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In this paper, the position of the 26 GHz band UWB radar in the administration of radio waves will be introduced. Moreover, the principle and the composition of the distance measurement, the angle measurement and the relative velocity measurement of the radar which Furukawa Electric developed will be explained. Also, the spectrum of the transmitter pulse, the distance measurement, the angle measurement, the relative velocity measurement and the in-vehicle evaluation results will be reported.

2. The position and the legislative trend of the 26 GHz UWB radar

The 26 GHz band, which Furukawa Electric is developing, is becoming a common band for the UWB radar which, in the long term, will be operated in the world (Japan, the United States and Europe). However, regulations are slightly different depending on the regions. For instance, while Europe and the United States are based on a radiometric measurement, Japan is premised on a regulation by output power not including antenna gain (antenna terminal regulation). While contributing to build up the technical standards by taking part in a domestic legislation, Furukawa Electric advanced technology developments. As a result, along with the enhancement of the understandings of the various regulations, we developed a radar which is available in every region. In this chapter, regulations on the 26 GHz band, the contents and the trends of the regulations in the world will be introduced.

2.1 Europe and the United Stated

In the United States, FCC started out the legislation of UWB in 1998 and two standards are instituted at present. The limitation in the elevation direction radiation level of the 24 GHz band will be tightened in stages by 2013. The 26 GHz band is positioned as a band which is available perpetually and without any restriction. These regulations are shown in Table 2.

In Europe, legislation was started according to e-Safety vision SEC (2003) 963 proposed in the European Parliament on September 15, 2003. Two regulations (the 79 GHz band and the 24 GHz band) are instituted at present. The 24 GHz band is due to expire in June 2013. The 26 GHz band is under discussion, and almost the same regulation as FCC04-285 in the United States is due to be instituted in March 2010 if all goes smoothly. The abstract of the European regulations are shown in Table 3. Because the regulation values of the 26 GHz are under discussion, possible conditions are described.

2.2 Japan

Legislative actions in Japan started at the end of December 2006 in the UWB radar task group set up in the UWB Radio Systems Committee of the Information and Communications Technology Sub-Council of the Information and Communication Council of the Ministry of Internal Affairs and Communications and deliberations on quasi-millimeter-wave bands have started. Meetings were set up per passive interference systems (Ad-hoc interference examinations) which had been stated at a public hearing conducted by the Ministry of Internal Affairs and Communications in April 2007. Discussions have been held based on the interference examination model and the calculated results being proposed by the businesses which promote the legislation of the UWB radars (hereinafter called promoter). Interference examinations were completed in September 2009 and revision procedures of the ministerial ordinance will be completed by March 2010. If all goes smoothly, the operation of the radars will be available in April. Both the 24 GHz band and the 26 GHz band regulations are instituted, and the 24 GHz band regulation is due to expire in December 2016. The abstract is shown in Table 4.

The EIRP regulation value is based on a case when the antenna gain is 0 dBi, and actually, it is premised on the antenna terminal regulation, not on the radiometric measurement.

Those listed below also have to be considered.

- An immediate interference examination and an appropriate countermeasure have to be taken when the operational condition of the passive interference system is changed or a new passive interference system appears in the future.
- Mainly businesses seek a solution when an unexpected interference which was not expected in the examination occurs.

In Japan, the millimeter-wave UWB radar is called “high resolution radar” to which the exclusive wave band is assigned. And the different regulation from quasi-millimeter-wave band is in discussion.

Table 2 Radio regulation in USA.

Frequency band	24 GHz band 22 GHz - 29 GHz (1st Report and Order)	26 GHz band 23.12 GHz - 29 GHz (2nd Report and Order)
Time of introduction	February 2002	December 2004
Average power (EIRP)	Less than −41.3 dBm/MHz	←
Peak power (EIRP)	Less than 0 dBm/50 MHz	←
Purpose	Radar for automobiles	←
Expiration date	None	None
Special conditions	· There is a limitation in the elevation direction radiation level of the radiation forbidden band (23.6 - 24.0 GHz). · It is ruled in Subpart F which governs the UWB wireless stations. · Center frequency and maximum output frequency are more than 24.075 GHz.	· it is ruled in Section 15.252 which governs general qualification unnecessary stations. · Radio wave emissions in the 23.6-24 GHz bands are less than −61.3 dBm/MHz. There is no rule about radiation level in elevation directions.

Table 3 Radio regulation in Europe.

Frequency band	79 GHz band 77 GHz - 81 GHz	24 GHz band 22 GHz - 26.65 GHz	26 GHz band (assumption) 24.25 GHz - 29 GHz
Time of introduction	July 2004	January 2005	March 2010 (approximately)
Average power (EIRP)	Less than −3 dBm/MHz	Less than −41.3 dBm/MHz	Less than −41.3 dBm/MHz
Peak power (EIRP)	Less than 55 dBm	Less than 0 dBm/50 MHz	←
Purpose	Radar for automobiles	←	←
Expiration date	None	June 2013	None
Special conditions	None	· There is a limitation in the elevation direction radiation level of the radiation forbidden band (23.6-24.0 GHz). · A radar auto-off function has to be mounted in the neighborhood of radio observatories. · The allowable diffusion rate is 7%.	None

Table 4 Radio regulation in Japan.

Frequency band	24 GHz band 22 GHz - 24.25 GHz	26 GHz band 24.25 GHz - 29 GHz
Time of operation	April 2010 (approximately)	April 2010 (approximately)
Average power (EIRP)	Less than −41.3 dBm/MHz	Less than −41.3 dBm/MHz
Peak power (EIRP)	Less than 0 dBm/50 MHz	←
Purpose	Radar for automobiles	←
Expiration date	December 2016	None

2.3 Other countries

Currently, UWB radars are approved in about 60 countries in the world. The 24 GHz band is approved in Canada, Singapore, countries which are affiliated with CEPT (Switzerland, Russia, etc), South Africa, Australia and Mexico. Moreover, an approval for the 79 GHz was added in Singapore. The 26 GHz is likely to be deliberated and approved in the future in each country as a permanently usable band, in accordance with the regulation in Japan, Europe and the United States in the same way as the 24 GHz band.

3. OVERVIEW OF THE UWB RADAR

3.1 Distance measuring method

The time of flight (TOF) method is adopted as a distance measuring method of the radar. In the TOF method, shown in Figure 2, a distance measurement is done by the amount time required to go through the following; first, a transmitter pulse is discharged from the radar, the transmitter pulse reflects on the target and then it is received by the radar.

The distance R (m) is defined by the following formula using the transmitter pulse propagation time T (s) and the speed of light c (m/s) (=2.998×10^8).

$$R=\frac{cT}{2}\ \text{(m)} \tag{1}$$

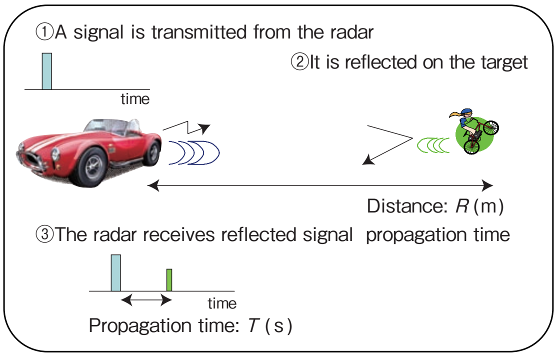


Figure 2 Principle of TOF.

The distance resolution ΔL is defined by the following formula if the radiation time of the radio wave is τ because the UWB radars emit ultra-short pulse.

$$\Delta L=\frac{c\tau}{2}\ \text{(m)} \tag{2}$$

A distance resolution around 15 cm is required for short-range radars and to enhance the distance resolution, a signal with a narrower pulse width has to be transmitted. The necessary frequency bandwidth W (Hz) to transmit this signal is defined by the following formula.

$$W=\frac{2}{\tau}\ \text{(Hz)} \tag{3}$$

If ΔL=0.15 m, τ =1 ns and W=2 GHz.
It means an ultra wideband frequency band from several hundred MHz to several GHz is required. That is, a UWB has to be used as a necessary component of a highly accurate radar [5].

3.2 Angle measuring method

For an angle measuring method which detects Doppler directly, the signal switch method using Σ (sum pattern) and Δ (delta pattern), which is based on the phase comparison mono-pulse method, is adopted.

The phase comparison mono-pulse method is a method where the phase difference of the signals received by each antenna is detected and converted into angles by using two different types of antenna patterns. Although the signal processing has to be done in parallel in the mono-pulse method, the control which shifts patterns by the time-sharing was done in consideration of the circuit sizes and the data spread.

The principle will be explained below using Figure 3. Now, the angular difference θ between the antenna's central angle and the target becomes the ideal angle.
In this method, the phase difference is detected as the ratio of the amplitude of both antenna patterns: Σ/Δ (indicated as A in the Figure). The Angle is calculated by obtaining the angle conversion table beforehand which corresponds a one-to-one to this amplitude ratio.[6]

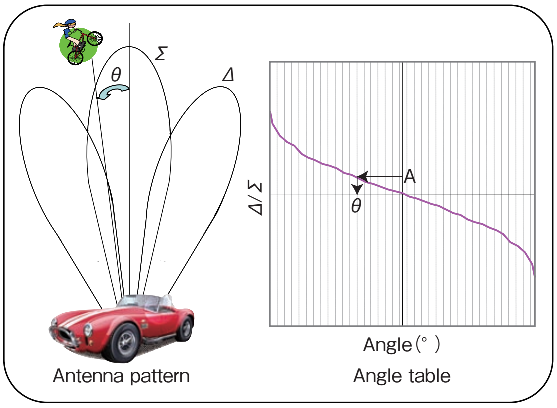


Figure 3 Principle of phase comparison mono-pulse system.

3.3 Relative velocity detection method

The pulse Doppler method which detects Doppler directly, is adopted as a relative velocity detection method. As shown in Figure 4, when a target with the relative velocity is detected, signals whose pulse are amplitude-modulated by their Doppler frequency (sinusoidal waves indicated by blue lines in the Figure) are detected (in fact, only amplitude values of the received signals indicated by red circles in the Figure). Pulse signals are emitted continuously and the Doppler frequency is measured by the envelope curve of the received signals' amplitude values. If the measured Doppler frequency is Δf (Hz), the frequency of the transmitting pulse signal is f_0 (Hz) and the speed of light is c (m/s), the relative velocity v (m/s) between the radar and the target is defined by the following formula.

$$v = \frac{\Delta f}{2 f_0} \times c \ (m/s) \tag{4}$$

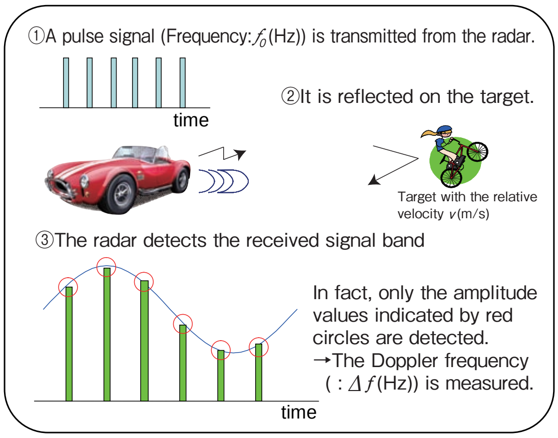


Figure 4 Relative velocity detection method.

3.4 Radar composition and specifications

The radar composition is shown in Figure 5, the appearance is shown is Figure 6, and the specifications are shown in Table 5. The antenna and the RF circuit were integrated, thereby a small size (110 mm×75 mm×25 mm) which is mounted in automobile bumpers including the control circuit was achieved.

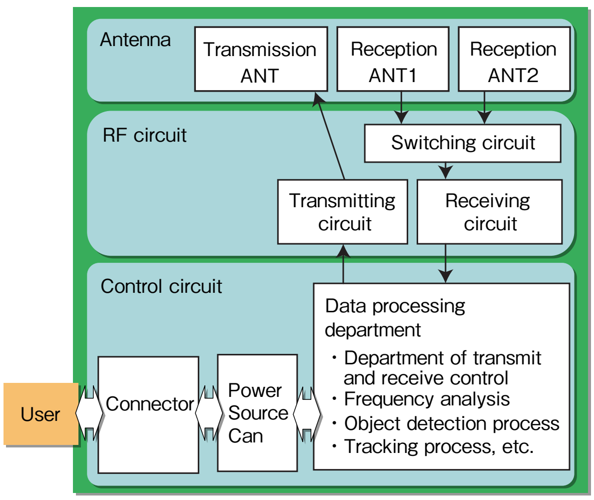


Figure 5 Block diagram of the developed radar.

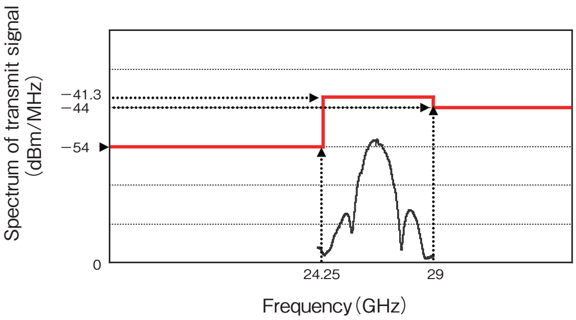
Figure 6 Appearance of the developed radar.

Table 5 Specifications of the radar.

Item	Specifications
Radar method	Coherent pulse Doppler radar
Frequency	26 GHz band
Distance resolution	0.15 m
Detection angle	±60°
Relative velocity resolution	1.38 m/s
Power specification	+8 - +16 VDC
Communication standard	CAN and UART (switching)
Size	110 mm×75 mm×25 mm ※not including projection

3.5 The UWB radar radiometer measurement

The measurement result of the developed UWB radar's antenna terminal power is shown in Figure 7. It shows that the radar doesn't exceed the regulation value (a red line in Figure 7) which is planned to be legislated in Japan. Moreover, it is confirmed that there is no carrier leakage in this radar.



Note) The expected maximum gain of the used transmission antenna is 9 dB.

Figure 7 Spectrum of transmit pulse.

The detection results of the distance measurement, the angle measurement, the relative velocity measurement, and the detection conditions are shown below.

Table 6 Conditions of target detection.

Item	Distance measurement	Angle measurement	Relative velocity measurement
Target	Corner reflector		Metal pole
	+10 dBsm	+5 dBsm	
Distance	7 cm - 700 cm	300 cm	20 cm
Detection angle	0°	−60° - 60°	—

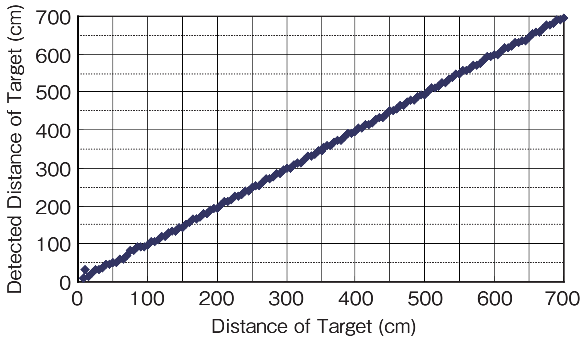


Figure 8 Test result of distance measurement.

Figure 8 shows the result that the target placed in the front direction of the radar moving by 7.5 cm was detected by the radar. It shows that the target detection and the distance measurement were conducted accurately in the range of extremely close (7 cm) -700 cm from the radar.

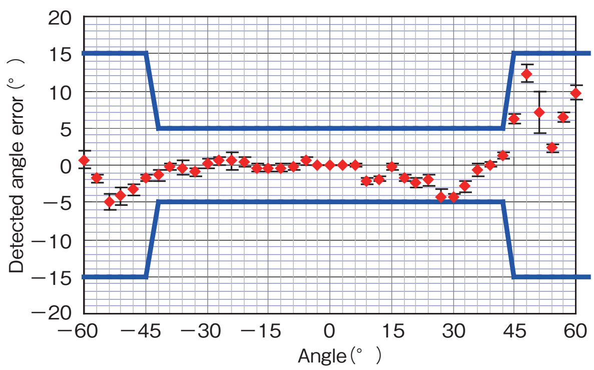


Figure 9 Test result of angle measurement.

Figure 9 shows the result of the angle measurement error in the direction of the radar. The blue lines in the Figure indicate the specifications of this radar's angle measurement error. If an angle is detected in the range of ±60° from the center of the radar, the target is detected with an angle error ±5° in the range of ±45° and with an angle error ±15° in the range of more than ±45°.

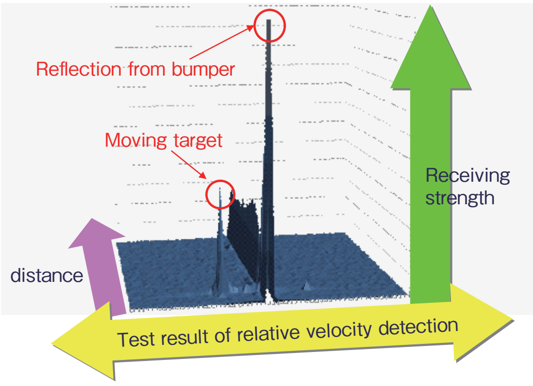


Figure 10 Test result of detected relative velocity.

Figure 10 shows the evaluation result when an automobile with the radar (inside the rear bumper) approached the extremely close range (20 cm) of a metal pole. The metal pole, as an object with the relative velocity in the distance of 20 cm, was detected without an influence of the reflection from the bumper (distance: 0 cm, relative velocity: 0 m/s).

Also, the result of capability evaluation of the UWB radar mounted to an automobile is shown in Figure 11. With respect to the object detected by the radar, the image figure (hereinafter called radar chart figure) viewed from the sky is shown in the upper side of the screen and the actual landscape figure is shown in the lower side of the screen. In the radar chart figure, 1 scale indicates 1 m and the point marked by a yellow circle indicates the mounting location of the radar. The parts marked by red boxes in the radar chart figure and in the landscape figure are associated. It means that obstacles in the field of view of the radar can be detected accurately.

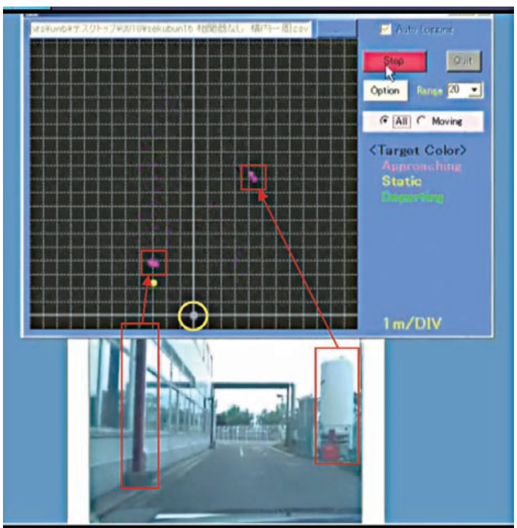


Figure 11 Test result of the UWB radar mounted to an automobile.

4. IN CONCLUSION

In this paper, the development result of the 26 GHz band UWB radar and each country's position on the radio wave control over quasi-millimeter-wave band including 26 GHz were introduced. We were successful in adapting to the radio wave controls around the world by reducing the carrier leakage by a large margin with our unique circuit technology. In addition, a qualification for the radio experimental test station of the developed item was given by the Ministry of Internal Affairs and Communications and the emission measuring result was reported. Not only evaluating at a resting state but also conducting evaluation experiments of a radio wave propagation and a sensing capability in a running vehicle on which the radar is mounted became possible.

In the future, taking advantage of the know-how and the detection data obtained through experiments, we would like to improve driving assistance and comfort by developing more reliable products, thereby contributing to the reduction of the number of traffic accidents and injuries.

REFERENCES

1) “Development of Ultra Wideband Radio System for Short-Range Applications,” Furukawa Review No.30, (2006).
2) “Fatalities from traffic accidents in 2008,” Data of the National Police Agency Traffic Bureau, (2009, in Japanese).
3) “Regulatory Status of Quasi-Millimeter wave Short-Range Radar for Automobile in Japan,” IEICE technical report 108 (339) pp.49-52 20081204, (2008).
4) “Abstract of the UWB Radio Systems Committee of the Information and Communications Technology Sub-Council of the Telecommunications Council Report (Draft)” “Technical Conditions of UWB Radar Systems,” the Telecommunications Council, (2009, in Japanese).
5) “Measurement Techniques on 26 GHz Ultra-wideband Short Range Radar,” IEICE technical report vol. 105, no. 365, WBS2005-46, pp. 43-48, (2005)
6) “Development of SSR Mode S and Experiments on Surveillance,” SANE, Space, Aeronautical and Navigational Electronics, 96 (205) pp.1-8 19960726, (1999).