Development of Ultra Wideband Radio System for Short-Range Radar Applications

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ABSTRACT Recently ultra wideband (UWB) radio systems have been extensively considered in the field of intelligent transport systems (ITS) and communications since Feb. 2002, when the United States Federal Communication Commission (FCC) mitigated its restrictions on noise emission levels to permit UWB radio. Taking notice of automotive short range radar (SRR) in the sub-millimeter wave radio band (22∼29 GHz), the authors have been researching and developing this technology and, have taken part in a joint study consortium led by the National Institute of Information and Communication Technology (NICT). As a result of these activities, the authors have successfully developed a UWB multi-function system that features pulse position modulation (PPM) for data communication as well as radar function.

The system consists of an antenna, transmitter, receiver, and baseband part. The authors developed the baseband part, which plays a key roll for ranging and communication functions as well as a radio frequency (RF) part. The baseband part was adopted by the NICT, and the system was demonstrated at IWUWB 2005, the international UWB conference held in Dec. 2005. In the demonstration system, the authors also supported the design of an RF receiver, while the other parts, including the antenna and RF transmitter devices, were provided by the NICT. The system simultaneously realized both ranging detection at a resolution of less than 10 cm and a communication function up to 1 Mbps. The authors report the structure and performance of the developed system as well as an outline and trends in UWB radio systems.

1. INTRODUCTION

UWB radio has attracted attention in high-speed data communication with a very weak signal, of the same levels as emission noise from electrical equipment because of its ultra wideband frequency from several hundred MHz to several GHz. While UWB realizes high-speed communication by varying pulse position (PPM) or by modulating data by phase (PM), amplitude (AM) or frequency (FM), it also realizes very high-resolution radar with a ranging resolution of less than 10 cm owing to the feature of very short pulse (impulse). Recently UWB radio has been actively researched by many institutes and industries, with focus on a number of applications: high-speed wireless personal area network (WPAN), sensor networks with low power consumption in the microwave radio band, and automotive SRR in the sub-millimeter band (22∼29 GHz) and millimeter band (77∼81 GHz).

UWB SRR is considered a key device to survey around automobiles for the prevention of traffic accidents and casualties, and specifically is expected to detect targets with high resolution for other automobiles and pedestrians within 20 m in a wide angle. At the end of 2005, automotive UWB SRR was brought to market in Europe for the first time in the world.

The 22∼29 GHz UWB SRR system consists of multiple radar units with antenna (for example, 8 units), and estimates the exact position of a target by triangulation.

Figure 1 shows possible applications for UWB SRR. Major applications of UWB SRRs are adaptive cruise control (ACC) with Stop & Go, parking assistance, and warning in blind spots. In the figure, ACC indicates different applications in the millimeter radio band (77 GHz) to detect range up to 200 m which will be equipped with UWB SRR.

In this paper, the authors report on standardization trends in UWB, and developments including impulse gen-

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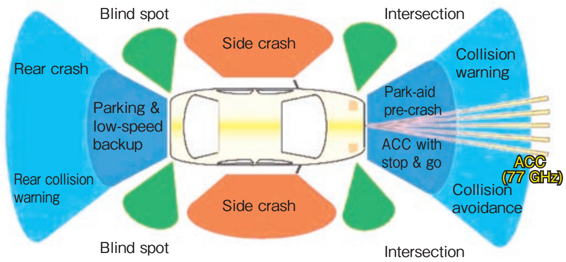

Figure 1 Possible applications for 24-GHz UWB radar.

eration/detection for high-resolution ranging, data modulation/demodulation for simultaneous ranging and data communication, and system evaluation.

2. TRENDS OF STANDARDIZATION AND REGULATION FOR UWB RADIO SYSTEM

2.1 ITU-R TG1/8

In ITU-R, TG1/8 was established from 2003 to Oct. 2005 for the international standardization of UWB. Especially for the microwave radio band, the usage of bands between 3.1 and 10.6 GHz was mainly discussed. The permitted radiation level was recommended to be 20 dB lower than the level permitted by the FCC. However, it was also approved that the authorities of each country or region can establish their own domestic UWB regulations. The spectrum masks proposed by Europe, the USA and Japan are attached for reference. For the millimeter wave radio band, the treatment for the protection band (23.6~24 GHz) is particularly being discussed at TG1/8 for the decrease in UWB radiation to protect other existing radio systems, while Europe and the USA has already permit UWB radiation under their own restrictions. Other counties, including Japan, China and Korea, are to study their own spectrum masks.

2.2 Trends in the USA

The frequency allocation for UWB in the USA is shown in Table 1. The other related regulations are as follows:

(1) −10 dB bandwidth shall be within 22 to 29 GHz

(2) The radiation level in the protection band (23.6~24 GHz) shall be decreased gradually by 2005, 2010 and 2015.

(3) Frequency hopping modulation and stepped frequency modulation are also to be made available in the band between 23.12 and 29 GHz except for the protection band, on the following conditions: that the methods have a −10 dB bandwidth of more than 10 MHz; that the maximum average radiation power and peak radiation level is higher than 24.075 GHz; and that the devices operate only when the automobile engine is running.

Table 1 FCC frequency allocation.

Frequency in MHz	EIRP* in dBm
960~1,610	−75.3
1,610~23,120	−61.3
23,120~23,600	−41.3
23,600~24,000	−61.3
24,000~29,000	−41.3

*effective isotropic radiated power (EIRP)

2.3 Trends in Europe

Figure 2 shows the spectrum mask in Europe. The short range device (SRD) band is assigned for Doppler-shift measurement of automotive radar, apart from wideband spread spectrum frequencies. In Jan. 2005, the EC committee issued an order that allows automotive radar in the 24-GHz band until 2013 and bans the introduction of applications other than automotive radar for the 24-GHz band. The 77~81-GHz band is also considered for use after 2013.

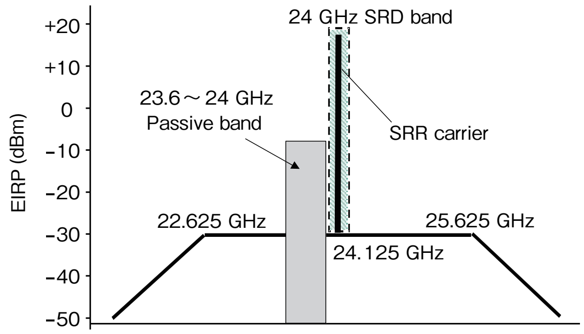

Figure 2 European Telecommunications Standards Institute (ETSI) spectrum mask.

2.4 Status in Japan

In Japan, the frequency band around 26.5 GHz is being proposed in order to avoid the protection band. Enactment of regulations for sub-millimeter band UWB is still a task for the authorities. The Ministry of Internal Affairs and Communications (MIC) held a public hearing on this issue in Mar. 2006.

3. DEVELOPMENT OF TECHNICAL ELEMENTS FOR UWB

In this section, the development of technical elements are introduced including impulse generation, reception and detection in UWB radar.

3.1 UWB pulse generation

Capacitors and switches are widely used to generate impulses. Though a switch is useful for on/off switching of oscillators for UWB communication, a costly control circuit is needed for high-speed switching. Recently, low voltage differential signaling (LVDS) is becoming popular to generate high-speed signals for serial interfaces, because LVDS features low voltage, which reduces the load for high-speed data generation, and handles differential signals which reduce the influence of common-mode noise. As the authors focused on the feature of LVDS for high-speed data transmission and its controllability, it was decided to apply LVDS to generate stable UWB pulse.

Figure 3 shows a method of impulse generation with LVDS. The differential signals consist of N (negative) and P (positive) signals for offset voltage V_o. The desired impulse can be generated by picking up only P, and by then cutting off the DC component of P with a DC blocker such as a capacitor. If P−N>0 then “1” is transmitted, and if P−N<0 then “0” is transmitted. By changing data series of “0” and “1”, impulses can be generated for timing at will. For example, an impulse of 320 ps width can be generated from 1 bit by a differential pulse of 400~800 mV in amplitude (or 800~1600 mVpp) when the LVDS data rate is 3.125 Gbps.

An example of an impulse generated by this method is shown in Figure 4 for time domain and Figure 5 for frequency domain.

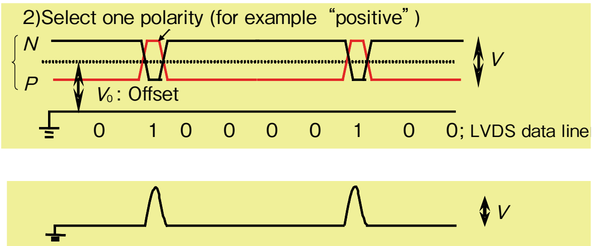

Figure 3 Impulse generated with LVDS.

3.2 RF Circuit

Though a double-balance mixer can be applied for converting UWB pulse signals, it causes a carrier-leakage of the local oscillator (LO) signal for lack of isolation performance. To avoid this problem, the authors adopted an RF switch to reinforce isolation of the double-balance mixer. Waveguides are widely used to build the circuit for the sub-millimeter and millimeter radio wave bands because of good transmission performance (low attenuation), but size increases. Thus the authors adopted coaxial RF devices to build the circuit.

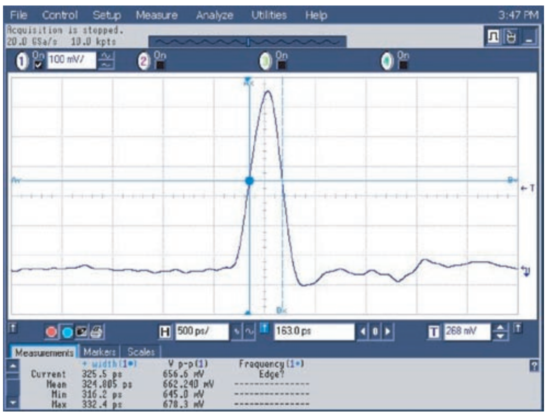

Figure 4 Typical time domain signal.

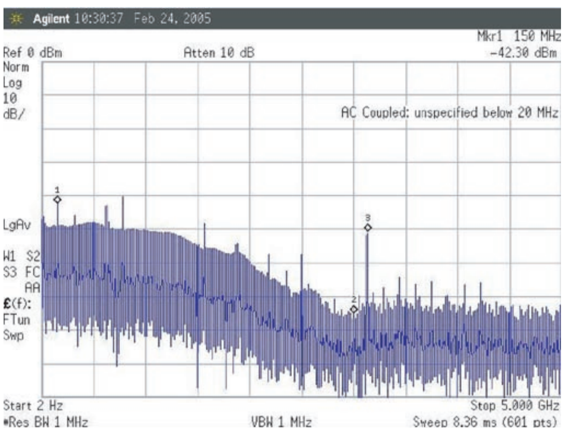

Figure 5 Typical frequency domain signal.

3.2.1 RF Transmitter

Figure 6 (a) shows a block diagram of the RF transmitter. An RF pulse of the desired frequency (26.5 GHz) can be obtained by mixing baseband impulse and phase lock oscillator (PLO) output at 26.5 GHz via a switch at the double-balance mixer. Then, through a band pass filter (BPF) and power amplifier, the desired pulse power of at 26.5 GHz can be caused to radiate from the Tx antenna. In the actual configuration, a coaxial cable is connected between transmitter output and receiver input to replace RF wave radiation in the air because of licensing issues.

3.2.2 RF Receiver

Figure 6 (b) shows a block diagram of the RF receiver. The RF signal received by the Rx antenna is amplified by a low noise amplifier (LNA), and is converted to a baseband signal with a device such as an in-phase quadrature (IQ) demodulator, mixer or diode. The authors adopted a diode-type detector for cost reduction. With the detector, the RF signal is demodulated to a baseband video signal after limiting the bandwidth by a BPF. Detection performance varies by the type of diode, and the authors chose a tunnel diode for good sensitivity and response. Figure 7 shows an example of the video signal detected.

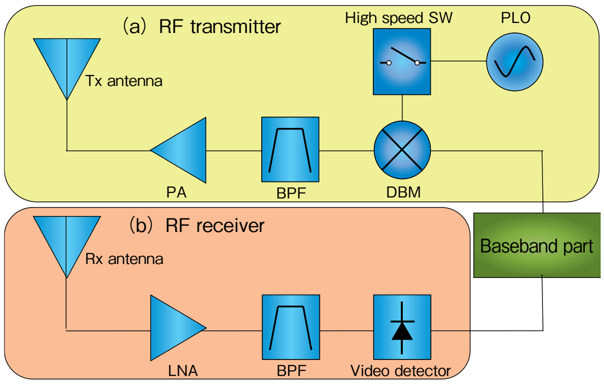

Figure 6 Schematic diagram of RF parts of radar.

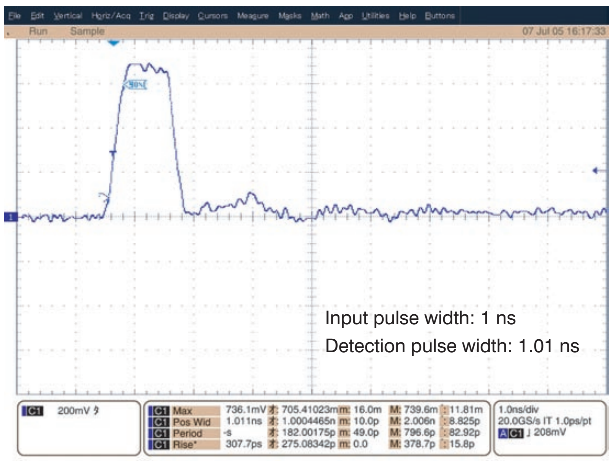

Figure 7 Typical video signal detected.

4. UWB MULTI-FUNCTION SYSTEM FOR RANGING AND COMMUNICATION

The UWB multi-function system developed in this work is introduced in this section. While the system has radar function with impulse, it also realizes a communication function by adding PPM at the same time. The RF part described in this section was developed on our own, however, and is not identical to the RF part adopted in the demonstration system.

4.1 Summary of UWB Multi-function

The outline of the system is shown in Figure 8 and Figure 9, and Table 2 shows the main specifications of the radar developed here. In the transmitter (Tx), each baseband impulse is generated in a pulse repetition cycle, either with or without delay of a time-slot depending on the desired data ("0" or "1") to modulate. The generated baseband impulse is converted to an RF pulse of the desired frequency (26.5 GHz) mixing with the carrier signal. The RF pulse is amplified by the LNA and radiated from the Tx antenna. The RF signal reflected from the target is received by the Rx antenna, amplified by the LNA and then detected by a wave detector (for example, a tunnel diode). The output signal is branched to the ranging circuit for the distance measurement transaction and to the communication circuit for the data demodulation transaction.

4.2 Development of Baseband Part

To realize a UWB multi-function system, a baseband part with a signal transaction function should be developed as well as the elements introduced in the previous sections. In the development of the baseband part, the authors decided to use a high-performance all-purpose field programmable gate array (FPGA) for efficiency and more rapid development. As well, an embedded CPU was adopted for low-speed signal transaction and as an interface with an external PC. The transmitter, ranging circuit and communication circuit of the baseband part are introduced in this section.

4.2.1 Transmitter Part

The modulation method of the transmitter part is introduced here. Depending on data, the impulse is generated either without delay (when the data code is "0") or with a delay of $\mathrm{d}T$ (when the data code is "1"), where $\mathrm{d}T$ is much smaller than the pulse repetition cycle, T.

4.2.2 Ranging Circuit

An ordinary impulse radar detects an echo from the target by converting the received RF signal to a low frequency and sampling the signal with an analog digital converter (ADC). Because the developed system uses PPM for data communication, the pulses are not always transmitted in a constant interval. In the ranging circuit, the influence of delay by PPM is removed by compensating for the time of delay ($\mathrm{d}T$). The circuit also has an averaging function for amplitude of each range information, and the averaging number is variable. The circuit judges the presence of the target by comparing the averaged signal in the range information to a threshold value. The distance of the counterpart transmitter/receiver can also be estimated from the above range information.

4.2.3 Communication Circuit (Data Demodulation Circuit)

In the communication circuit, the detected signal is judged either "H" or "L" directly by a comparator. The threshold value for the comparator is variable and easily changed. Figure 10 shows the flow of data demodulation. The received signal is judged either "H" or "L" by a comparator, using the following process: wait for the first "H" reception; count the time (T_{count}) until the next "H" reception; compare T_{count} with pulse repetition cycle (T). If $T_{\mathrm{count}} < T$, the data is reset to 0, but if $T_{\mathrm{count}} > T$ the data is set to 1. If $T_{\mathrm{count}} = T$ the data keeps its previous state. In a case where $T_{\mathrm{count}} > 2T$, the counter pauses as there is no data transmission and waits for another "H" to come. After data is demodulated, the counter is reset and restarts counting.

5. EVALUATION OF DEVELOPED SYSTEM

The evaluations of the proprietary system and the demonstration system for the NICT consortium are introduced in

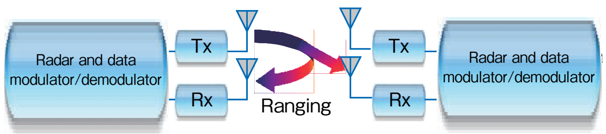

Figure 8 Block diagram of the communications and ranging device.

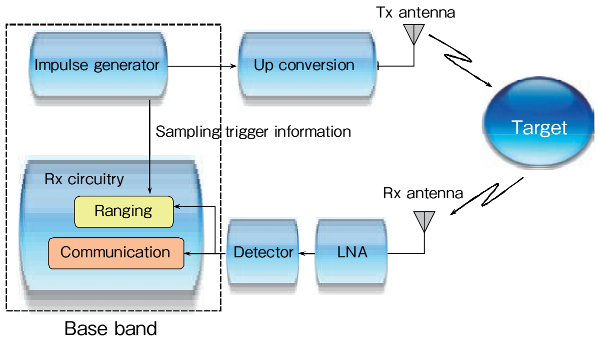

Figure 9 Schematic diagram of multi-function radar.

Table 2 Performance specification of the developed radar.

Parameter	Specification
Pulse shape	Uni-polar rectangular pulse
Pulse repetition frequency	1 MHz
Pulse width	1 ns
Rx frequency	26.5 GHz
Distance coverage	24 m
Distance resolution	15 cm, 7.5 cm
Modulation	Binary-PPM

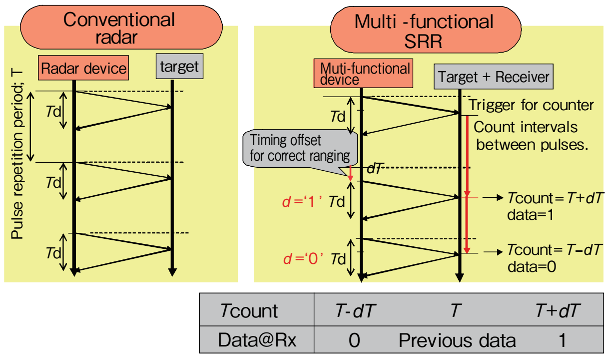

Figure 10 Flow of communication and ranging procedure.

the first and second parts, respectively.

5.1 Experimental Result of Ranging Function

The ranging performance is evaluated by LVDS impulse. Three coaxial cables of different length were prepared and connected directly from the RF transmitter to the RF receiver to simulate echo from the target, instead of RF radiation from the antenna. The result of these measurements is shown in Table 3, where the velocity factor of coaxial cable is 0.7 and the ranging resolution mode is 15 cm, and demonstrates that the function works accurately within the resolution.

Table 3 Target ranging results (resolution = 15 cm).

Cable length (cm)	Result (cm)
100	101.43
200	187.14
300	301.43

5.2 Experiment with Multi-function System

The demonstration system consists of an antenna, RF transmitter, RF receiver and baseband part. The baseband part in the developed system was adapted to the demonstration by the NICT UWB consortium. The RF receiver was developed by the NICT in cooperation with the authors. The other parts were provided by the NICT. The system was demonstrated at IWUWBT2005 the international UWB conference held in Dec. 2005, and showed that the impulse for ranging can be also utilized for data communication. The demonstration attracted attention there. The baseband part has two operational modes, the proprietary mode and the demonstration mode. Here, the performance of the demonstration system is introduced as a result of experiments. For data communication, visual information for the automobile including direction indicators (blinkers), brake-lamps, and hazard lamps are assumed to be transmitted to the other automobiles to remind drivers to acknowledge the behavior or intention of other automobiles. Data slots with 8 bits are prepared and assigned to the above information. For example, information on the brakes is assigned to the first bit, and the data becomes "1" when the driver applies the brake. For synchronization of the receiver, an additional 8 bits are prepared for the preamble. Thus, 16 bits of data (preamble and information) make a frame. The graphical user interface (GUI) is shown in Figure 11. The parameters can be set up from the console (shown in the center). The signal reflected from the target in raw waveform is indicated at the upper left. The table at the upper right indicates numerical peaks (maximum 20) with distance and intensity of reflected signal from the target. The lower side (with pictures of automobiles) indicates the status of communication: reception from other vehicle in left side, and transmission from own vehicle in right side. The demonstration showed that communication was performed without disturbing the ranging function.

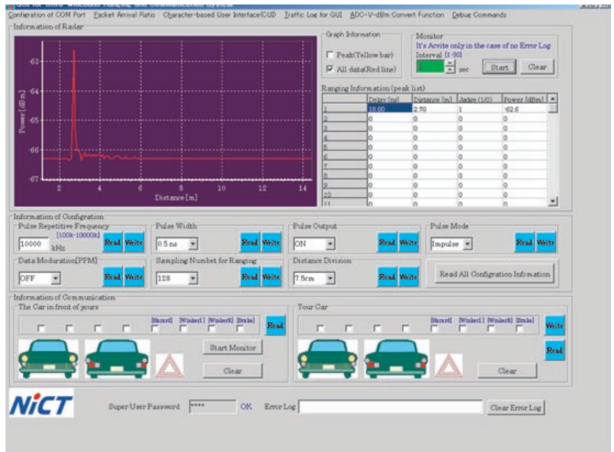

Figure 11 Screen of measurement result.

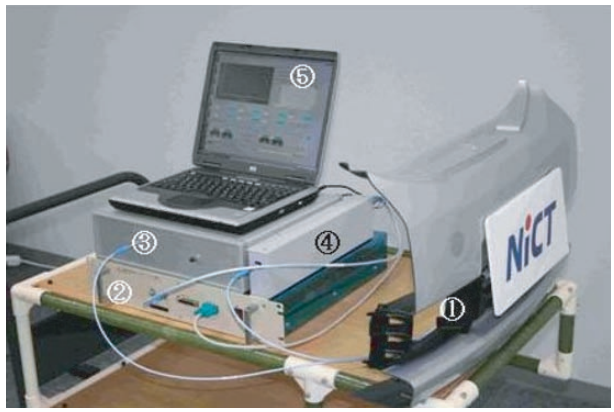

Figure 12 UWB communication and ranging demonstration device.

6. CONCLUSION

The authors have successfully developed a UWB-based short range radar system in the 22~29 GHz band. It is the first system in Japan that realizes multi-function for high-resolution ranging and low-speed data communication. The system is expected to contribute to road safety.

The baseband part of the developed system was adopted in a demonstration by the NICT UWB consortium and played a core role in a demonstration at the international UWB conference in Dec. 2005. The demonstration attracted the attention. Following the development, the authors plan to conduct research toward a small-size low-cost product for UWB SRR.

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