A UWB Through-Wall Radar Using Beam Scanning Array Antenna

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***Abstract* — A UWB through-wall radar using novel beam scanning array antenna previously proposed by the authors is described. This antenna scanning system has two new technologies. First, each antenna element is equipped with an impulse generator. Second, the time control between the antenna elements is realized by using tapped delay lines and by transmitting trigger signals. Based upon above technology, experimental UWB through-wall radar having beam scanning capability is designed and constructed. The fabricated radar has compact size and light weight and is easy to use. The measurement results show excellent space resolution as a through-wall radar.**

***Index Terms* — ultra-wideband, through-wall radar, array antenna, beam scanning, impulse.**

I. INTRODUCTION

Ultra-wide band (UWB) radar system for automobile anti-collision systems has been developed because of their capability of high space resolution, [1], [2] and has been applied to through-wall radars [3]-[5] used for antiterrorism operations. A mono-pulse receiving method for direction finding has been used mainly in both radar systems; however, this method has the following intrinsic disadvantages:

1) It is difficult to distinguish received signals scattered by two targets located at different points but having the same distance from the front of the radar. Also, there is a high probability of detecting false targets in a multipath environment.
2) Measurement of longer ranges degrades the accuracy of angle resolution. Solution of this problem requires longer spacing of the two receiving antennas, and consequently antenna size becomes larger.
3) The beam width of the antenna element must be wider than the angle resolution, which yields lower antenna gain and a shorter range of detection.

The above mentioned disadvantages can be removed by introducing the beam scanning of the transmitting antenna and/or the receiving antenna, but it brings another problem that the wideband phase shifters and controllers, which are very expensive because of their complicated circuit system and large circuit size, are required to realize the scanning UWB system. To solve these problems, a novel scanning method using a newly developed UWB impulse array antenna (IAA) has been proposed by the authors[6], [7].

In this paper, a high resolution through-wall radar with compact size and light weight is designed and constructed, and its basic performance is measured.

II. IMPULSE ARRAY ANTENNA (IAA)

Fig. 1 shows the basic configuration of UWB impulse array antenna (IAA) with four antenna elements. This scanning antenna is composed of antenna elements, impulse generators and delay lines. Each delay line has a fixed delay time T_D and is driven by periodic trigger signal with an interval T. The beam scan angle of the array antenna is controlled by the trigger interval T [6]. The waveforms of the outputs of the impulse generators are exactly the same except for the delay time of the waveforms which can be controlled easily only by varying the trigger interval T.

In the case of the trigger signal (a) in Fig. 1, all impulse generators are driven simultaneously because the delay time of each delay line T_D is equal to the trigger interval T and there is no phase difference between the output pulse train of the impulse generators, which yields the beam direction $\theta = 0$. The trigger signal (b) in Fig. 1 is an example of the case in which the trigger interval T is longer than the fixed delay time T_D . In this case, the beam direction becomes $\theta > 0$. In contrast, when the delay time T_D is longer than the trigger interval T, the beam direction becomes $\theta < 0$. This seems to be one of the advantages of this method, i.e., beam scanning can be easily achieved by changing trigger interval T. The relationship among the scan angle θ, the trigger interval T and the delay time of each delay line T_D is expressed by

$$\sin\theta = \frac{T - T_D}{d/c}, \quad \frac{T_D}{2} < T < \frac{3T_D}{2} \qquad (1)$$

Where d is the spacing of array antenna and*c is the* speed of light.

The delay time between one antenna element and the next element is expressed as the time difference between the delay time T_D and the trigger interval T. This method is suitable for

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the beam steering of a wide-band antenna regardless of frequency.

Fig. 2 shows the relation between the beam direction θ and the trigger frequency calculated using equation (1). The array spacing d was chosen to be 30 mm, 37 mm, and 50 mm corresponding to 0.40λ, 0.49λ, and 0.67λ, respectively, at 4 GHz. It can be seen from that a beam scanning range -40 deg < θ < 40 deg can be obtained by changing the trigger frequency from 50 MHz -200 kHz to 50 MHz + 200 kHz, when d = 37 mm.

III. THROUGH-WALL RADAR DESIGN

Based upon the fundamental discussion of IAA scanning system and the experimental verification [7], a trial through-wall radar was designed and constructed. Fig. 3 shows the block diagram of the through-wall radar using UWB IAA. The target design specifications are as follows,

System:
1) Frequency bandwidth: 3.4 GHz -4.8 GHz
2) Detection range: 20 m
3) Space resolution
   Distance: 25 cm
   Angle: 15 deg
4) Scanning speed: 0.5 sec
5) Display: 4.3 inch LCD
6) Size: 24.7 cm L x 36.5 cm W x 6.5 cm D
7) Weight: 4 kg
8) Supply Voltage: 5 V
9) Signal Interface: LAN

Hardware:
1) Transmitting antenna:
   ・Antenna elements: Patch antenna
   ・ Number of antenna elements: 2 x 8
   ・ 3 dB beam width
      E-plane: 15 deg at 4 GHz
      H-plane: 40 deg at 4 GHz
   ・ Array spacing: 37 mm (0.49λ at 4 GHz)
2) Receiving antenna:
   ・Antenna elements: Patch antenna
   ・Number of antenna elements: Fixed 2 x 1
   ・ 3 dB beam width
      E-plane: 72 deg at 4 GHz
      H-plane: 40 deg at 4 GHz
3) Delay time: T_D = 20 ns (approximately)
4) Trigger frequency: Fc = 50 MHz (center)
5) Signal detection: Correlation detector

Each Tx circuit of element in the figure is composed of a delay line, an impulse generator, a band-pass filter, and an antenna element integrated on the same substrate. The impulse generator is composed of a high-speed switching device and a driver amplifier, and the delay lines are commercially available IC's having a delay of approximately 20 ns.

Fig. 4(a) and Fig. 4(b) show the top and the bottom view of the antenna and RF circuit pattern, respectively. As shown in the figure, the transmitting antenna is composed of 2x8 patch elements and the receiving antenna is composed of 2 x1 same patch element. In the receiving circuit, a correlation detector is adopted to detect received signals. Tx and Rx section including antenna elements and delay lines are integrated in a multi-layered printed circuit boards.

The photograph of the trial UWB through-wall radar is shown in Fig. 5. Small size of 24.7 cm L x 36.5 cm W x 6.5 cm D and light weight of 4 kg are realized for the portability and easy handling.

IV. EXPERIMENTS

Prior to the measurement of radar property, experiment of Tx scanning antenna was carried out. Trigger frequency is set to be 50.0 MHz so that the beam direction becomes $\theta = 0$. The frequency of the beam direction $\theta = 0$ become 46.98 MHz because of a small deviation in the delay time of the delay lines. The measured data of the antenna pattern in azimuth angle obtained by changing trigger frequency in the range of $Fc \pm 230$ kHz (Fc: center frequency) in 23 kHz increments are shown in Fig. 6, and the pattern in. It can be seen that the change in beam direction is proportional to the change in trigger frequency as indicated in Fig. 2. The measured data also show that the beam width is ±18 deg and the side lobe level is -21 dB when $\theta = 0$.

The experiment as the radar system was carried out through 6 cm thick concrete wall by detecting signals from two targets of human bodies located about 3 m to 4 m from the radar, and the transmitting antenna beam was scanned in 4 deg. step.

Fig. 8(a) and Fig. 8(b) show the measured data of the target imaging. The scattered signals from targets are displayed in the 4.3 inch LCD monitor as the radar scope image. In these figures only moving targets among various scattered signals are indicated by image signal processing. It is clearly indicated from such basic experiments that a distance resolution of 25 cm and an angle resolution of 15 deg are obtained, respectively. Furthermore, Fig. 8(a) shows that it is possible to distinguish two targets located at the same distance from the radar. When the conventional mono-pulse radar is used under these measurement conditions, it is impossible to separate two signals and this is one of the notable advantage of the proposed system.

V. CONCLUSION

A UWB through-wall radar utilizing a newly developed electrical scanning system with impulse array antenna has been constructed and its usefulness has been experimentally verified. The transmitting array antenna is composed of impulse generators installed in antenna elements and tapped delay lines used to generate transmitting trigger signals. This is a considerably simplified circuit configuration. It is clearly indicated that the beam direction can be controlled from −40 deg to +38 deg by changing the trigger frequency in the range of 46.98 MHz ± 230 kHz. An evaluation of this system for a use as a through-wall radar was carried out. The obtained data proved that this radar system has excellent distance and angle resolution of 25 cm and 15 deg, respectively. The UWB radar system proposed here is applicable to high resolution through-wall radar with low cost, light weight and small size.

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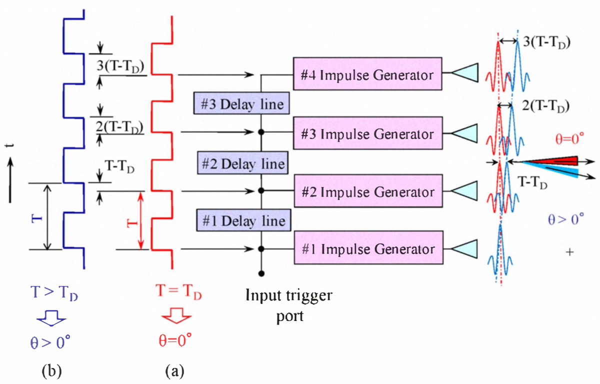


Fig.1 Principle of impulse array beam scanning system.

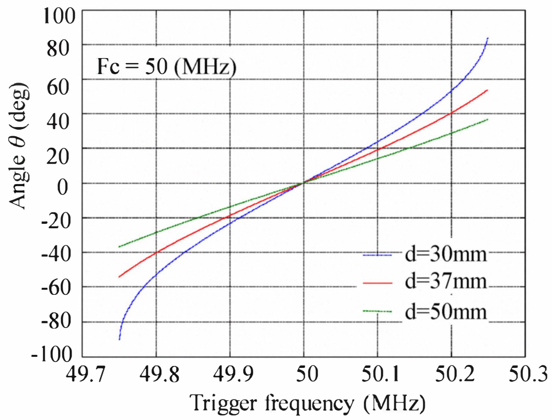


Fig.2 Relationship between beam angle and trigger frequency

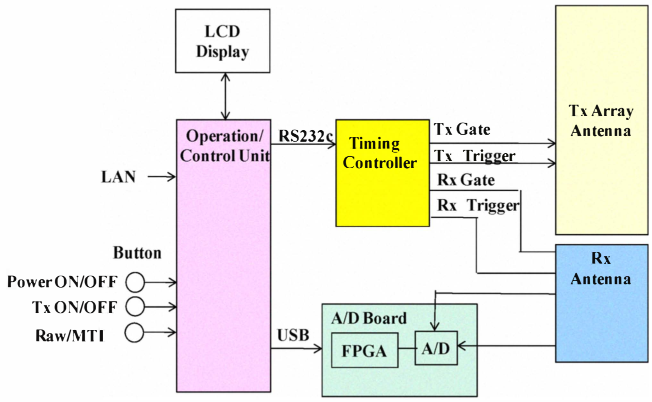
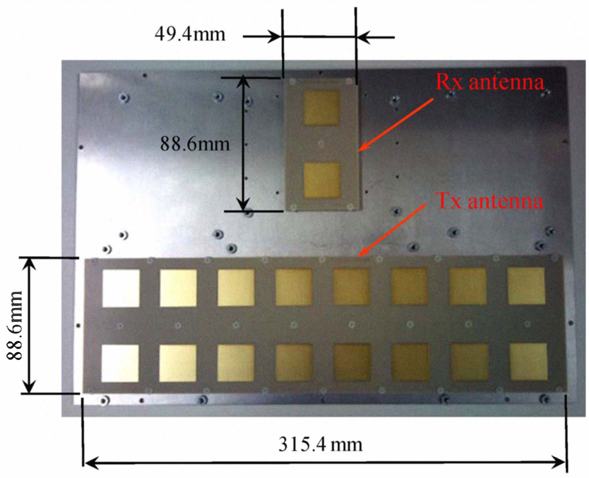
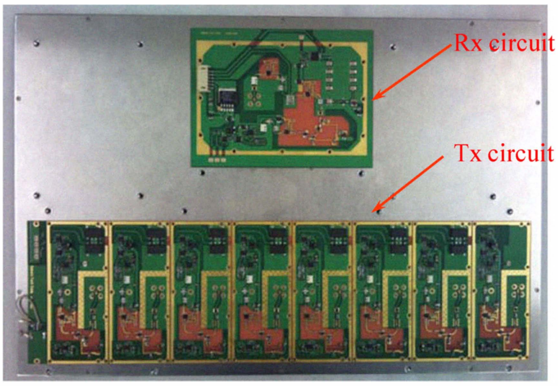


Fig. 3 Block diagram of through-wall radar.



(a) Top view



(b) Bottom view

Fig. 4 Photograph of Tx and Rx circuit.

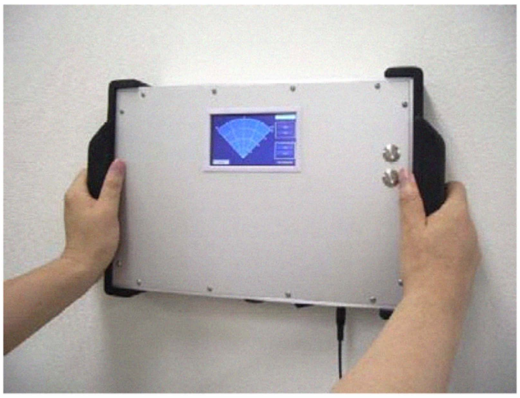


Fig. 5 The photograph of trial UWB through-wall radar.

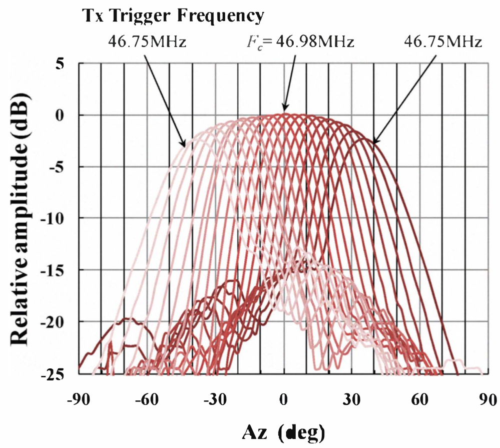


Fig. 6 Tx antenna scanning pattern in horizontal plane.

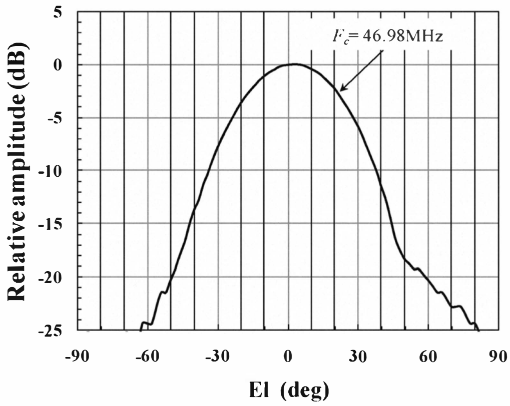
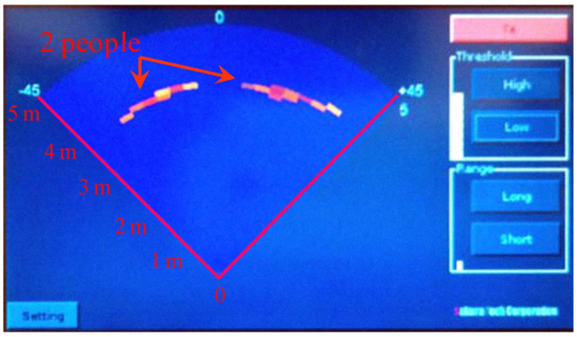
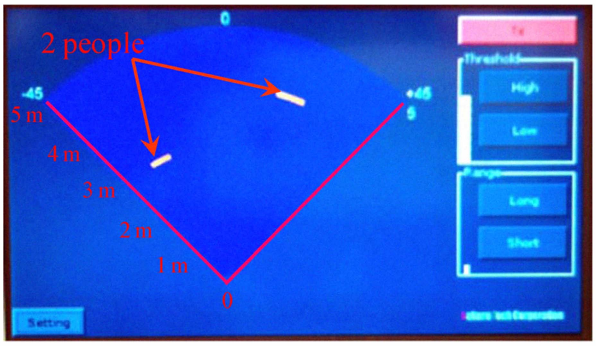


Fig. 7 Tx antenna pattern in vertical plane.



(a) Data 1



(b) Data 2

Fig. 8 Target image.

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