A Golay Complementary Coded Through-the-Wall Radar for Moving Target Indication

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***Abstract*—A Golay complementary coded ultra-wideband (UWB) through-the-wall radar (TWR) system for moving target indication (MTI) is developed in this paper. The sine-modulated Golay complementary code signal is used as the transmitting signal, and the equivalent-time sampling technique is adopted for the digital double-channel receiver. In order to evaluate the performance of the system, two experiments have been conducted. The results show that the TWR can detect up to 33 meters in courtyard through the brick wall and 70 meters in corridor through the gypsum board wall.**

Keywords—Golay complementary code, through-the-wall radar (TWR), moving target indication (MTI)

I. INTRODUCTION

UWB radar, owning to its strong penetrating ability and high-range resolution, has been widely applied in through-the-wall imaging (TWI) [1], ground penetrating inspection [2], earthquake rescue and moving target detection [3]. In order to obtain both large detectable distance and high range resolution, pseudo-random noise (PRN) [4], stepped-frequency continuous wave (SFCW) and frequency-modulated continuous wave (FMCW) signal are used as transmitting signal of UWB radar associated with the large time bandwidth product [5]. However, most of them suffer the defect of high side lobes and their maximum detection range is limited. For example, the maximum detection distances of the proposed Doppler radar [6] and the pseudo random coded radar [7] are 10 meters and 17 meters in the through-wall scene, respectively. Although the FMCW radar system proposed in [5] can detect 50 meters in the free space, it can only detect about 10 meters through the wall.

In this paper, the Golay complementary coded signal associated with low side lobes is proposed as the transmitting signal, and a low-cost high-resolution equivalent-time sampling technique is adopted to the double-channel digital receiver. In order to obtain small size and light weight of the system, resistively loaded bowtie antennas are used as the transmitting and receiving antennas. In addition, a global clock synchronization module is designed to synchronize each subunit. Finally, two experiments are conducted respectively in courtyard through the brick wall and in corridor through the gypsum boards wall to evaluate the detection performance of the presented Golay complementary coded TWR system.

II. DESIGN OF GOLAY COMPLEMENTARY CODED TWR SYSTEM

As shown in Fig. 1, the proposed Golay complementary coded TWR system consists of a personal computer (PC), one transmitting antenna, two receiving antennas and a radar host containing a digital transmitter, a double-channel receiver, a clock synchronization, a power-supply module and a Ethernet communication module. In this work, the signal generator for the digital Golay complementary coded signal and the main controller are implemented with a single Xilinx Artix-7 FPGA, and a communication module control the Ethernet module to exchange the raw radar data and commands with the PC. In order to obtain strong penetrating ability and sufficient resolution, 500 MHz is selected as the central frequency of the transmitting signal [8].

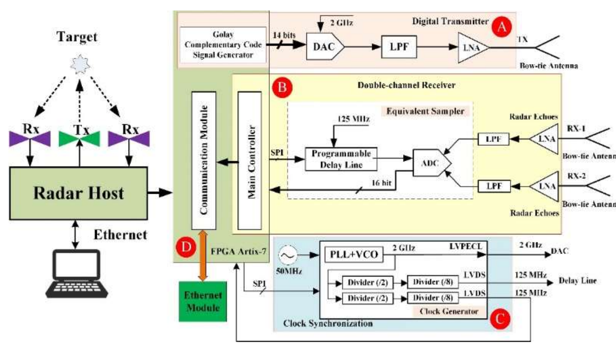


Fig.1 The blocks of the proposed Golay complementary coded TWR

For a sequence $\mathbf{a} = [a_0, a_1, \cdots a_{N-1},]^T$ with N elements, its aperiodic autocorrelation is defined as:

$$A_{a,a}(k) = \sum_{j=0}^{N-1-k} a(j)a(j+k)\,, 0 \le k \le N-1. \quad (1)$$

Consider two sequences with length of N: $\mathbf{a} = [a_0, a_1, \cdots a_{N-1},]^T$ and $\mathbf{b} = [b_0, b_1, \cdots b_{N-1},]^T$, where $a_i, b_i \in \{+1, -1\}$, If $\mathbf{a}$ and $\mathbf{b}$ satisfy

$$A_{a,a}(k) + B_{a,a}(k) = \begin{cases} 2N, k = 0 \\ 0\ , k \ne 0 \end{cases} \quad (2)$$

they are called a Golay complementary pair. Any sequence which is included in a Golay complementary pair is called a Golay complementary sequence [9]. As shown in Eq. (2), it has good autocorrelation characteristic with no side lobes.

The Golay complementary sequence can be searched by computer according to the definition. In order to obtain a longer complementary code sequence, it can be generated by the following formula.

$$\begin{Bmatrix}\boldsymbol{A}\\ \boldsymbol{B}\end{Bmatrix} \rightarrow \begin{Bmatrix}\boldsymbol{A}|\boldsymbol{B}\\ \boldsymbol{A}|\overline{\boldsymbol{B}}\end{Bmatrix} \tag{3}$$

The sequence **A** of new Golay complementary pair can be obtained by cascading the old sequence **A** and the old sequence **B**, while the sequence **B** can be achieved by cascading the old sequence **A** and the inversion of the old sequence **B**.

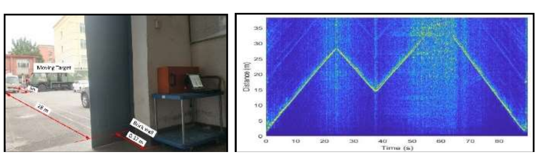
III. FIELD TESTS AND RESULTS

The radar host, power supply and the antennas are packaged in a polyvinyl chloride (PVC) box. Table. I shows the key parameters of the proposed radar system. The band pass filter and the automatic gain control are applied to the raw data, then the range profile is achieved after background removal. In order to verify the performance of the new UWB radar system, two experiments of moving target detection were implemented.

TABLE I. KEY PARAMETERS OF THE PROPOSED GOLAY COMPLEMENTARY CODED TWR

Parameters name	***Parameters***
Center Frequency of Radar System	500MHz
Pulse Repeat Period (PRP)	8us
Number of averaged values (N_A)	64
Equivalent Sampling Frequency (F_S)	16GSPS
Real-time Sampling Frequency	125MSPS
Resolution of the ADC	16 bits
Average Power	7.8mW
Antenna Type	Bow-tie Antenna

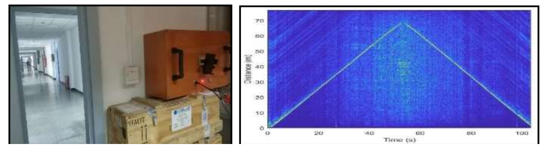
The setup of moving target detection through the wall is shown in Fig. 2(a). The radar is placed behind the 37cm brick wall, and a human object is walking along the scheduled route in the courtyard as the moving target. In addition, there are several cars, truck and bus distributed in the courtyard. Fig. 2(b) shows the result of range profile after the background removal. It indicates that the object walks away from the radar to the bus at 28 meters during 0-25s, then returns and walks to the position at 15 meters during 25-38s. After that, the object walks to the red building at 37 meters through the gap between the bus and the truck, and finally returns straight to the radar during 38-90s. Meanwhile, we could find that the echo signal of moving target is submerged in the noise when he walk through the gap between the bus and truck.



(a) (b)

Fig. 2. The through-the-wall experiment. (a) The setup of the moving target detection through the wall. (b) The range profile with the slow time.

Another experiment was taken in a corridor, and the scenarios are described in Fig. 3(a). This wall is made up of two 100mm gypsum boards 12 cm apart, and the length of the corridor is about 70 meters. From the range profile shown in Fig. 3(b), we could see that the echo signal of the moving target is very clear as the object walks from the radar to the end of the corridor and returned to the radar.



(a) (b)

Fig. 3. The moving target in corridor experiment. (a) The setup of the moving target detection in corridor. (b) The range profile with the slow time.

IV. CONCLUSION

In this paper, we have presented a Golay complementary coded TWR system for MTI. The Golay complementary codes modulated by sinusoidal signal is generated by the transmitter, and its side lobe is under -60dB. In addition, the equivalent-time sampling technique is used to the digital receiver. The resistively loaded bowtie antennas are used as the transmitting and receiving antennas. Two experiences were conducted to evaluate the performance of the system. It shows that the proposed TWR system can detect reach up 33 meters through the 37cm brick wall and 70 meters in the corridor through the gypsum board wall. The performance of our proposed TWR system is much better than the proposed ones in the previous literatures. Additionally the improvement will be studied on.

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