Continuously Moving Target Simulator Design

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Abstract— The delay time of echo generated by the moving target simulator is discrete, and the moving trace of simulated target is discontinuous. In order to solve this problem, firstly, the radar digital signal processor must adjust the range gate, and the range error will be limited within one range cell. Then the rest error cannot be removed but can be adjusted by phase pre-compensation in simulator. The idea is that let the phase of simulated target be equal to the one of the real target at sampling time. After the phase pre-compensation, a real continuously moving target will be generated and the problem will be solved. Then MATLAB simulation of the method is done for linear frequency modulation radar system. The simulated results can be used to validate the effectiveness of the method.

1. INTRODUCTION

At the present time, with the development of direct digital synthesizer (DDS) and digital signal processing (DSP) technique, the moving target simulator (MTS) can simulate a moving target with high Doppler frequency resolution and high amplitude resolution [1–5]. A MTS based on digital radio frequency memory (DRFM) and the impact of discrete delay time of the MTS on radar system coherency were separately analysed in [6]. The delay time of target generated by the MTS is discrete, so the range of simulated target is discrete and it is hard to simulate real moving target. In other words, the simulated target will jump towards the radar step by step. Its track is discontinuous, especially for high range resolution (HRR) radar. It is hard for us to find a method to solve the problem in previous references. So this paper will present a method to solve the problem.

2. COMPOSITION OF THE MOVING TARGET SIMULATION SYSTEM

Figure 1 shows the composition of the moving target simulation system. The radar and MTS share a common clock source. The radar transmitter is turned off and the receiver is turned on. Then the MTS generates the needed target according to the instructions of the radar. The DSP in the radar will adjust the range gate and the DSP in MTS will compensate the phase error. More details will be shown below.

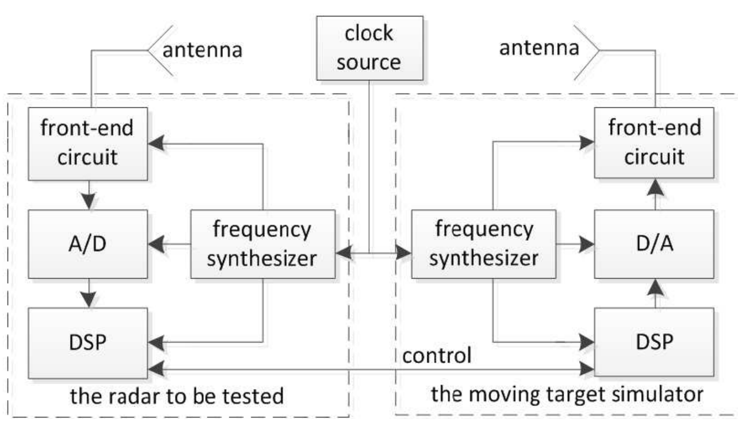

Figure 1: Composition of the moving target simulation system.

3. PROBLEM ANALYSIS

The pulses transmitted by the radar are

$$s_t = \mathrm{rect}\left(\frac{t - nT_r}{\tau}\right)\sin(\Omega_{t0}t) \tag{1}$$

where $\Omega_{t0} = 2\pi f_{t0}$, f_{t0} is carrier frequency, τ is pulse width, T_r is pulse repetition interval (PRI), n is integer. Consider a point target which is moving towards the radar at velocity v. Let R_0 refer to the range at time $t = 0$ (time reference), the pulses received by radar are

$$s_r = \mathrm{rect}\left(\frac{ut - nT_r - t_0}{\tau}\right)\sin(u\Omega_{t0}t - \phi_0) \tag{2}$$

where $u = 1 + 2v/c$, $t_0 = 2R_0/c$, $\phi_0 = \Omega_{t0}t_0$. When the reflected pulses leading edge strikes the radar, the time is

$$t_{rn0} = \frac{-\tau/2 + nT_r + t_0}{u} \tag{3}$$

Now, the MTS should transmit signal s_r at time t_{rn0}. But the delay time of MTS is discrete, and t_{rn0} is continuous function of v. As a result, the delay time error is generated by MTS, and the simulated target will jump towards the radar. Consider a MTS with the delay time resolution T_{dl}. The delay time of MTS referring to t_{rn0} is

$$t_m = \mathrm{fix}\left(\frac{t_{rn0}}{T_{dl}}\right)T_{dl} = mT_{dl}, \quad m = \mathrm{fix}\left(\frac{t_{rn0}}{T_{dl}}\right) \tag{4}$$

where fix(x) is MATLAB function. The delay time error is

$$\Delta t_{rn} = t_{rn0} - t_m \geq 0 \tag{5}$$

Now let us analyse the impact of delay time error on the radar. Suppose that the sampling interval of the radar is $T_s < T_{dl}$. The simulated target and the real target locate at different range gates and their phases are different at the sampling time, as illustrated in Fig. 2.

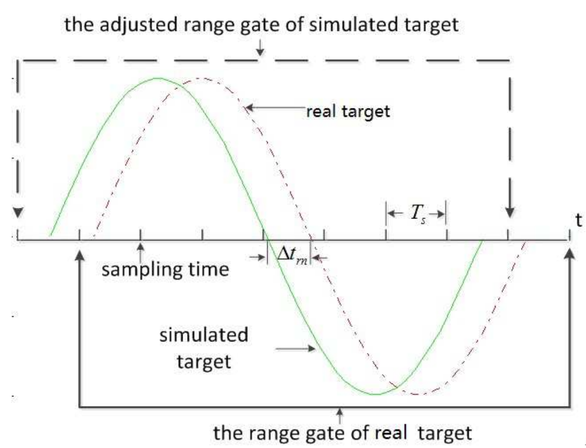

Figure 2: Illustrates the impact of delay time error on the radar.

4. METHOD TO SOLVE THE PROBLEM

We should firstly adjust the range gate. The number of range cell to be adjusted is

$$\Delta r_n = \mathrm{fix}\left(\frac{t_{rn0}}{T_s}\right) - \mathrm{fix}\left(\frac{t_m}{T_s}\right) \tag{6}$$

The adjusting process is shown in Fig. 2, and $\Delta r_n = 1$. After that, the simulated target and the real target will equivalently locate at the same range gate, as shown in Fig. 3. Then, the equivalent delay time error is given by

$$\Delta t_n = \left[t_{rn0} - \mathrm{fix}\left(\frac{t_{rn0}}{T_s}\right)T_s\right] - \left[t_m - \mathrm{fix}\left(\frac{t_m}{T_s}\right)T_s\right] = \Delta t_{rn} - \Delta r_n T_s \tag{7}$$

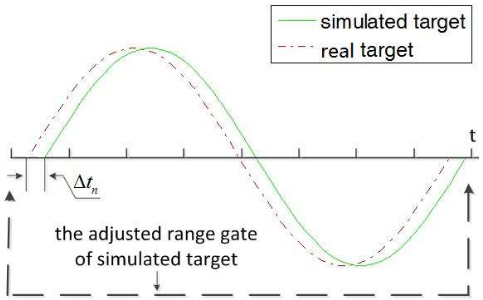

Figure 3: Equivalent result of range gate adjusting.

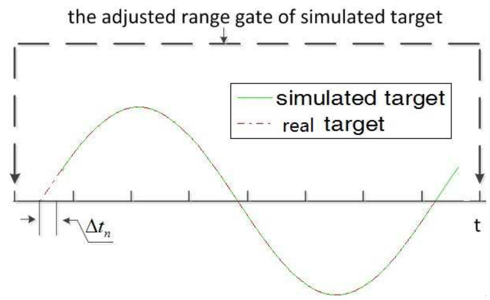

Figure 4: Simulated target after phase pre-compensation.

The error Δt_n cannot be removed due to the discrete delay time of MTS and their phases are different at sampling time. However, we can compensate the phase differences. The idea is that the MTS pre-adjusts the signal (2) and let the phase of the simulated target be equal to that of the real target at sampling time. In other words, their waveforms are the same at sampling time. That is why we do range gate adjusting firstly. In Fig. 4, the delay time error is Δt_n. But at any sampling time, their phases are equal and their waveforms are the same. So the radar digital signal processor will not treat them as distinct targets and they are the same for the radar. Then the simulated target would not jump towards the radar but continuously move towards the radar as real target. The adjusted signal transmitted by MTS is

$$s_{rm}(t) = \text{rect}\left[\frac{t - t_m - \tau/2}{\tau}\right] \sin[u\Omega_{t0}(t + \Delta t_n) - \phi_0] \tag{8}$$

5. APPLICATION TO LINEAR FREQUENCY MODULATION (LFM) RADAR

Consider a radar system using LFM waveforms. The pulse width is $\tau = 10\,\mu\text{s}$, bandwidth is $B = 200\,\text{MHz}$, PRI is $T_r = 0.1\,\text{ms}$, the carrier frequency is $f_{t0} = 1.4\,\text{GHz}$ and the sampling frequency is $F_s = 800\,\text{MHz}$. Then a point target is moving towards the radar at velocity $v = 800\,\text{m/s}$ and its

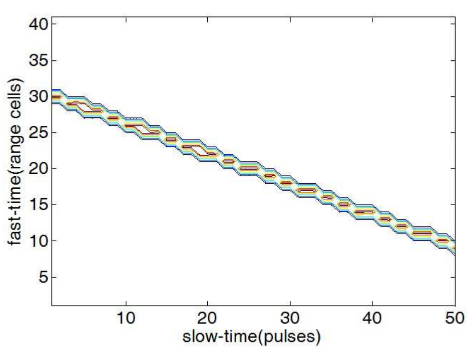

Figure 5: Trace of true moving target.

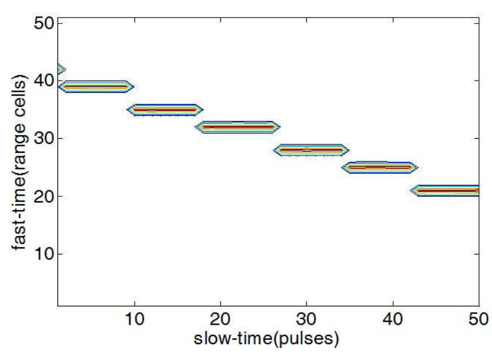

Figure 6: Trace of simulated moving target before adjusting.

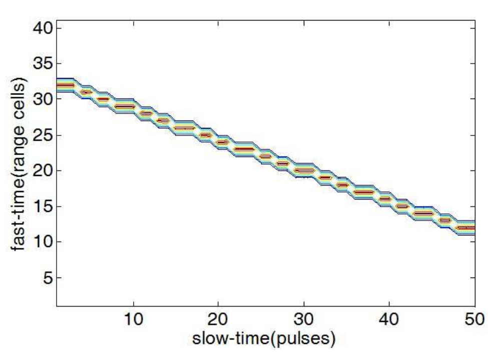

Figure 7: Trace of simulated moving target after adjusting.

initial range is $R_0 = 40\,\mathrm{km}$. After pulse compression, the trace of real target is shown in Fig. 5. Now consider a simulator with delay time resolution $T_{dl} = 1/225\,\mu\mathrm{s}$. The trace of simulated target before adjusting is shown in Fig. 6. We can see that the trace is discontinuous, which implies that the simulated target is jumping towards the radar. After adjusting the range gate and adjusting the phase differences at sampling time, the trace of simulated target is nearly the same as the trace of real target, as shown in Fig. 7.

6. CONCLUSION

This paper treats the radar and MTS as a cooperation system to solve the problem. Firstly, the radar must adjust the range cell error, and then the MTS should pre-compensate the phase differences at sampling time. The equivalent effect on radar is that the simulated target will continuously move towards the radar. The MATLAB simulation results can validate the method. After solving the problem we can simulate real moving target by using MTS.

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