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IMPLEMENTATION OF DIGITAL RADAR TECHNOLOGY FOR IMAGING AND REMOTE SENSING IN INTELLIGENT TRANSPORT SYSTEM

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Abstract—With the growth of broadband wireless technology like code division multiple access (CDMA) and ultra-wideband (UWB), lots of development and efforts towards wireless communication system and imaging radar system are well justified. Efforts are also being imparted towards a convergence technology involving both communication and radar technology which will result in intelligent transport system (ITS) and other applications. The authors have tried to converge the communication technologies towards radar and to achieve the interference free and clutter free quality remote images of

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targets using DS-UWB wireless technology. In this paper, we propose a direct sequence spread spectrum (DSSS) radar for remote sensing in ITS system. We have successfully detected single target using 1D radar imaging, and also separated multiple targets and implemented DSSS radar using software defined radio (SDR) to get continuous connectivity of the system. We have sought to overcome the limitations of DSSS radar which can be solved by using adaptive equalizer and rake processing.

1. INTRODUCTION

Road accidents have been a major cause of deaths and economic losses for decades. Regardless of the security systems or passive safety devices such as airbags and safety belts incorporated by terrestrial transport system, traffic accidents cost around 45 billion euro each year in Europe itself (as per the EU commission road accidents). This comprises 15 billion of medical care, police involvement and vehicle repair and 30 billion in lost economic production due to fatalities or injuries. Not much can be done with passive safety devices [1, 2].

The ITS will improve safety in highway and reduce travel delay by integrating vehicles and infrastructure into a comprehensive system, through a range of technologies, to estimate highway capacity and vehicle level [3–8] for collision prevention. It effectively adapts information technology, electronic contact technology, data communication technology and computerized processing technology to the whole transportation management and establishes a precise integrated transportation and management system which can widely be used. The obstacle detecting method using millimetre wave radar has attracted much attention [5].

In this paper, we are focusing on the detection and imaging of nearby vehicle. There are several remote sensing techniques, including radar for target detection in ITS. Among the various sensors available for ITS applications RADAR has the advantage of high detection range, high range resolution, and low algorithmic complexity with moderate hardware cost. Also, it actively works in darkness, rainy and foggy conditions with high accuracy [9]. The authors would like to highlight the use of DSSS based digital radar in ITS, due to its distinct advantages of most powerful air interface for the reverse link of next generation broadband mobile communication system, such as 4G wireless networks, remote sensing, robustness, flexibility, spectral efficiency, interference rejection capability (ISI reduction) and efficient bandwidth utilization and network throughput [10–20]. The basic

DSSS radar for target detection and imaging is developed at 2.4 GHz carrier. Outcome of the hardware experiment is quite interesting. It is capable of detecting multiple targets but unable to separate them. To overcome this limitation, MATLAB/SIMULINK based simulation is performed. Instead of single frequency carrier of 2.4 GHz, the step frequency mode will be the objective for target separation and imaging [21].

We have successfully developed this end to end radar system simulation. In the 1st phase, attempt is made on simulation of single carrier frequency (2.4 GHz) using this target model to detect a single target. After successful detection of single target, the simulation is extended to find the effect of multiple targets. Hardware simulation of additive and subtractive effect for resultant attenuation is also observed. From the above discussion we find that single frequency radar is unable to separate different targets.

In the 2nd phase, frequency stepping (Figure 6 and Figure 7) is used to separate the targets and their images (Figure 8). Thus, a block for frequency stepping is added to the RF block of transmitter and receiver of the main simulation model. Frequency stepping method is simulated for proper detection and separation of different targets at very preliminary level. More elaborate works yet to be done for proper imaging of targets using simulation. The 3rd phase of radar signal processing simulation is also performed using rake processing at the receiver. All the radar signal processing discussed above cannot be implemented using additional hardware or software in hardware simulation model.

A need for SDR is thus justified. There is also tremendous technological growth in embedded system realization. Multiprocessor technology utilizing DSP, and FPGA helps a lot in this regards. The sub system in the form of SDR is commercially available. The programmability of the SDR is also simplified utilizing very high level languages like MATLAB and SIMULINK. With additional daughter board the SDR sub system can be best and efficiently utilized for the development of the system. In essence, the development of the digital radar is almost ready for its deployment at the vehicle for collision avoidance and remote sensing in ITS system [5].

2. PAST EXPERIENCE AND PROBLEM DEFINITION

The authors' past experience in developing an imaging radar instrumentation system at W-band in a closed chamber reminds them the following points:

i). Narrow band operation of network analyzer (bandwidth 10 KHz) used for radar instrumentation restricts the image resolution.

ii). Step frequency waveform over a bandwidth of 2 GHz centre around 94 GHz and using 201 acquisition points improves the range resolution considerably. But the system becomes sluggish (typically a time of 20 minutes is required to complete a single measurement).

iii). Clutter effects outside the quiet zone of the closed chamber is severe which results in some clutter energy distribution over the quiet zone of the chamber.

iv). This ultimately introduces extra phase noise in the system resulting in weak target spot measurement and sometimes unstable, particularly for small targets. For example, the radar return signal of a small sphere (used for the calibration of radar) −30 dBsm RCS value was found to be oscillatory from sweep to sweep and very difficult to predict the actual RCS value.

2.1. Caution

The imaging radar instrumentation system in the open field, particularly the same clutter problem, may become more serious and should not be allowed to repeat. Additionally, the active interference from operational radio system (mostly lies in the 300–3000 MHz radio band) and manmade noise are severe. So a suitable modern radar technology is justified which will be able to tackle all above problems.

2.2. Necessity of Broadband Operation

The vast majority of modern radio systems have a narrow frequency range and carrier waveform using harmonic (sinusoidal) or quasi harmonic signals to transmit information.

The reason is very simple. Sinusoidal oscillations are generated by the RLC oscillation contour itself. The narrow frequency range of the signal restricts the information capacity of the radio system. So it is necessary to expand the frequency range in order to increase the information capacity. Future development of radar lies in employment of signals with frequency up to 1 GHz (the duration of the radiated pulses around 1 ns). The informational content in the UWB location increases owing to the range reduction of the pulse volume of radar. Thus, when the length of a pulse changes from 1 μs to 1 ns the depth of the pulse volume reduces from 300 m to 30 cm. It could be said that the instrument, which investigates the space, becomes finer and more sensitive. It allows to obtain the radio image of the targets [9].

2.3. Salient Features of Spread Spectrum Based CDMA Approach

Spread spectrum based digital technology is utilized for better radar operation, provision for both DSSS and frequency hopping spread spectrum (FHSS) mode of operation, QPSK modulation is utilized for better spectral efficiency, enhances spreading codes security, solves lots of radio wave propagation problems and can be changed at any time. Pulse mode provides range resolution and also hardware gating of the RF carrier and supports VV, HH, VH, HV polarizations and full automation through PC programming in instrument settings, control, data acquisition and display.

3. HARDWARE EXPERIMENT OF DIGITAL RADAR

The basic DSSS radar for target detection, imaging and RCS measurement is developed and now operational at the laboratory. Several experiments are successfully conducted by using the DSSS radar for the detection and characterization of targets. In order to measure the target parameters we make roof top floor into two dimensional coordinates. Each of the square plates at the roof top has area of $1\,\mathrm{ft}^2$, which helps us in radio mapping. The foiled globe is taken as a target because of its spherical nature. The received signal strength (SNR) is noted with the target placed at different coordinates. The background signal strength without any target is noted to be $-78\,\mathrm{dBm}$. The signal strength varies with the number of scatterers. The variation of signal strength with different number of scatterers is shown in Table 1. It is interesting to note that the received signal strength is additive or subtractive depending on the positions of the scatterers. The additive or subtractive nature of signal strength is due to multipath signals. Multipath signals are added at different phases which, in effect, is reducing the main signal. Figure 1 shows the multipath effect using two targets. Effectively, instead of multiple target resolution, they may be treated as multipath targets, and the presence of one target will influence the other in additive and subtractive way. The radar is not able to resolve the effect of multiple targets. This is, therefore, the limitation of DSSS radar hardware simulation. Hence the radar needs to be modified for better signal processing capabilities using adaptive equalizer and rake processing.

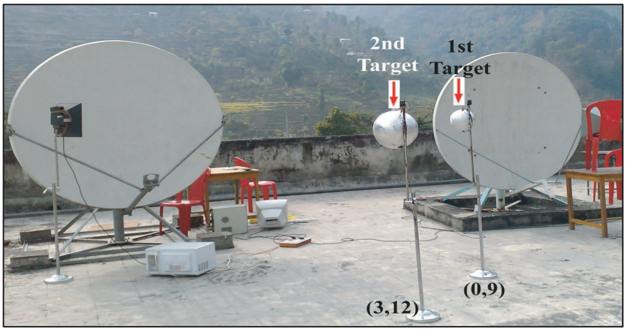

Figure 1. Multipath effects using 2 targets.

Table 1. Different signal strength for multi-target effect.

Coordinates of desired Target (ft)	Signal Strength of single object (dBm)	Coordinates of second object (ft)	Combined Signal Strength (dBm)	Remarks
0,9	−63	3,12	−58	Additive
−3, 6	−59	3,12	−57	Additive
−3, 6	−59	0,9	−64	Subtractive
0,9	−63	−3, 6	−54	Additive

4. DETECTION OF SINGLE TARGET THROUGH SOFTWARE SIMULATION AND PERFORMANCE ANALYSIS ON DIGITAL RADAR SYSTEM

The simple way to implement a target model is to represent it as a collection of point scatterers. Each scatterer, therefore, will be characterized by a distance from radar and the strength of reflection (and thus, a path loss and a delay associated with that distance). In the DSSS radar (Figure 2), the target is modeled as a cascade of path loss and phase change as shown in Figure 3. In this target model a provision for doppler frequency shift is also included which is mainly due to the motion of the target. Since in the open range measurement, the target will be static, the doppler frequency is kept as 0.1 Hz for all target detections. Simulation is conducted at 2.4 GHz carrier frequency using this target model to detect a single target on the basis of signal attenuation and phase change made by the target. Table 2 shows some data obtained during the simulation. For performing simulation it is assumed that a large target will attenuate the signal less and make less phase change compared to a smaller target as less amount of power (RCS) is being reflected by the smaller targets. Extraction of phase change and signal attenuation made by the target is achieved with very good accuracy. It can also be observed that the accuracy of measurement is better for bigger targets compared to smaller ones.

Table 2. Results obtained for single target detection, transmission frequency = 2.4 GHz, doppler frequency offset 0.1 Hz.

SL. No.	*Single Target*			
	Phase Change introduced by the Target (degree)	*Measured Phase Change at the receiver*	*Signal Attenuation introduced by the target* (dB)	*Attenuation measured from Received Signal* (dB)
1.	1	1.167	2	2.09
2.	10	10.1	4	4.026
3.	15	15.06	6	5.986
4.	18	18.05	7	6.972
5.	20	20.04	8	7.961
6.	25	25.03	9	8.953
7.	30	30.02	10	9.946
8.	40	40.02	11	10.94
9.	45	45.01	12	11.94
10.	50	50.01	13	12.93
11.	60	60	14	13.93
12.	70	70	15	14.93
13.	75	75	18	17.92
14.	80	80	20	19.92
15.	90	90	22	21.92
16.	95	95	25	24.92
17.	100	100	30	29.92
18.	105	105	35	34.92
19.	110	110	40	39.92

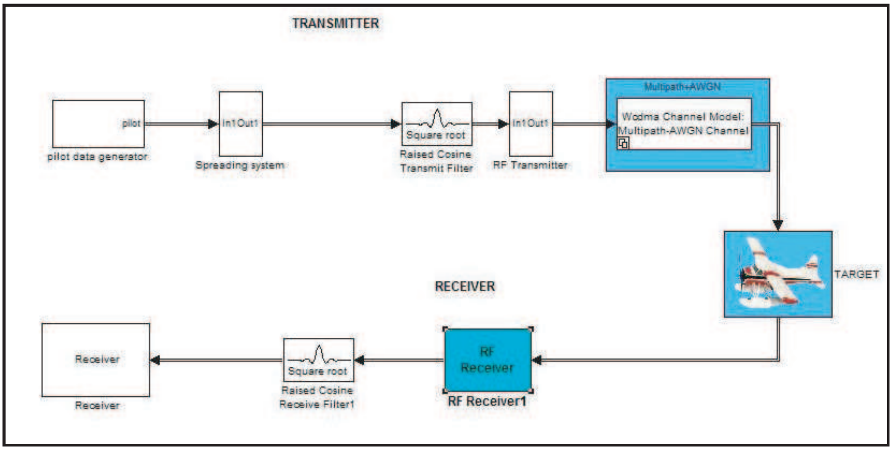

Figure 2. Simulation Model of DSSS radar used for target detection.

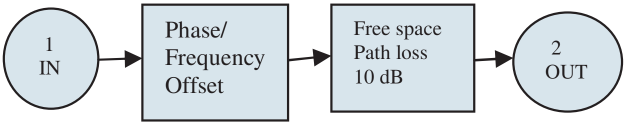

Figure 3. Target model in DSSS radar simulation.

5. MULTIPLE TARGET DETECTION

After successful detection of single target, the simulation is extended to find the effect of multiple targets (Figure 4). Here two targets are placed in front of the radar. One target is kept static, and position of the other is varied at different relative distances (d_1, d_2, d_3, etc.) and hence phase shift will vary. The resultant signal attenuation is measured at 2.4 GHz having $\lambda = 12.5$ cms. Since λ corresponds to 360° phase shift, it can be said that a relative distance of 12.5 cms corresponds to 360° phase shift. This logic is used to find the resultant signal attenuation at different relative distances between two targets. In this simulation both targets can make 10 dB attenuation to the transmitted signal individually. Two scattered signals are interfering with each other at different phases, and thus the resultant signal attenuation will be different at different relative distances. Here, relative distance is varied from 0 to 3 meters, and resultant signal attenuations are noted, where relative distance brings both the targets in phase where resultant attenuation noted is minimum (4.006 dB). On the other hand, for 180° out of phase maximum signal attenuation (161.3 dB) is observed. Since our desired target attenuation is 10 dB, it can be said that the effect of multiple targets is additive for resultant attenuation less than 10 dB and subtractive for resultant attenuation more than 10 dB [similar observations are noted in hardware experiment as in Table 1]. For example, let us assume the transmitted signal strength is +5 dB. For a single target which produces 10 dB attenuation, received signal strength will be −5 dB. Now for two targets of the same kind if resultant attenuation is 4 dB then received signal strength will be +1 dB. This is an example of additive multiple target effect. Similarly, if resultant attenuation is 15 dB then received signal strength will be −10 dB which is a subtractive effect.

In Figure 5, points below the red line represent the additive zone and those above the red line are subtractive zone for our simulation with the target of 10 dB attenuation. Some simulated data are shown in Table 3.

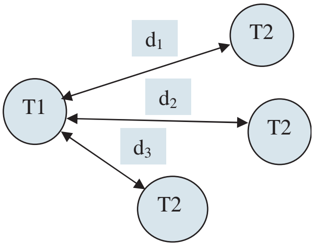

Figure 4. Target 1 is fixed and Target 2 is varied.

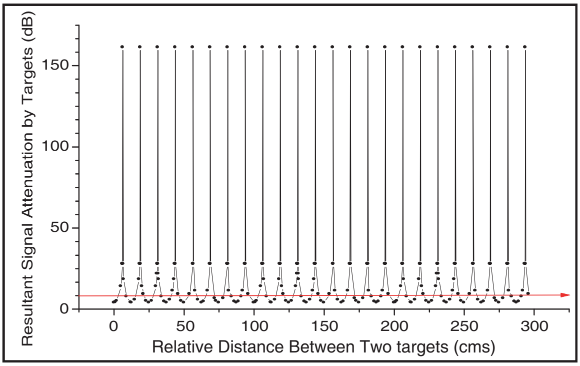

Figure 5. Variation of resultant signal attenuation with relative distance.

Table 3. Results obtained from software simulation of DSSS radar for multiple target (two targets) detection. Transmission frequency = 2.4 GHz, signal attenuation by the Target I = 10 dB, signal attenuation by the Target II = 10 dB, phase change made by the Target I = 0 degree (Static), doppler frequency offset = 0.1 Hz.

Sl. No.	*Relative Distance between Target I and Target II* (cms)	*Attenuation measured from Received Signal* (dB)	*Remarks*
1	0	4.006	Additive
2	20	14.11	Subtractive
3	40	5.809	Additive
4	134	7.853	Additive
5	172	6.701	Additive
6	244	27.94	Subtractive

6. RELATION BETWEEN SOFTWARE SIMULATION AND HARDWARE EXPERIMENTION OF DIGITAL RADAR

Table 1 shows the results obtained from the hardware experiment of DSSS radar. It is clear from the observation that multiple targets produce some additive effect at some distances and subtractive effects at some other distances. Our simulation result supports the hardware experiment. In Table 1, one target at $(-3, 6)$ coordinate and other at $(3, 12)$ produce an additive effect. Each coordinate corresponds to 1 ft distance. Thus, the relative distance between Target I and Target II for Sl.No. 2 of Table 1 can be calculated as,

$$\begin{aligned} R &= \left[(x_1 - x_2)^2 + (y_1 - y_2)^2\right]^{1/2} = \left[(-3-3)^2 + (6-12)^2\right]^{1/2} \\ &= [36+36]^{1/2} = 8.4852\,\text{ft} = 258.6288\,\text{cms}. \end{aligned}$$

From the plot shown in Figure 6, we can observe that multitarget effect is additive at 258.6288 cms relative distance. Similarly, the relative distance between Target I and Target II for Sl.No. 3 can be calculated as,

$$R = \left[(x_1 - x_2)^2 + (y_1 - y_2)^2\right]^{1/2} = \left[(-3-0)^2 + (6-9)^2\right]^{1/2}$$
$$= [9+9]^{1/2} = 4.2426\,\text{ft} = 129.3144\,\text{cms}.$$

From the plot shown in Figure 5, we can observe that multitarget effect is subtractive at 129.3144 cms relative distance. Hence, it is clear that the MATLAB simulation and hardware experiment of DSSS radar produce similar results.

6.1. Separation of Targets

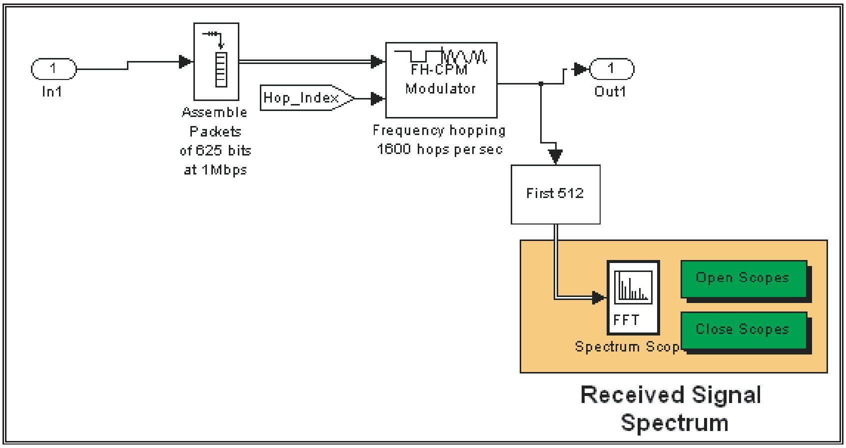

Figure 6. Block diagram of frequency stepping.

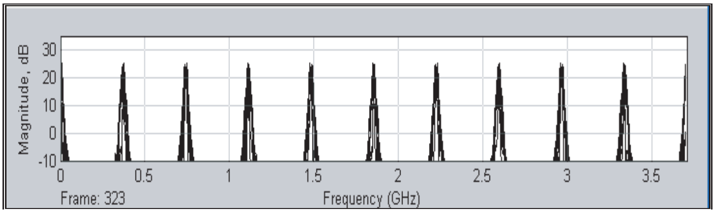

Figure 7. Details of frequency stepping spectrum.

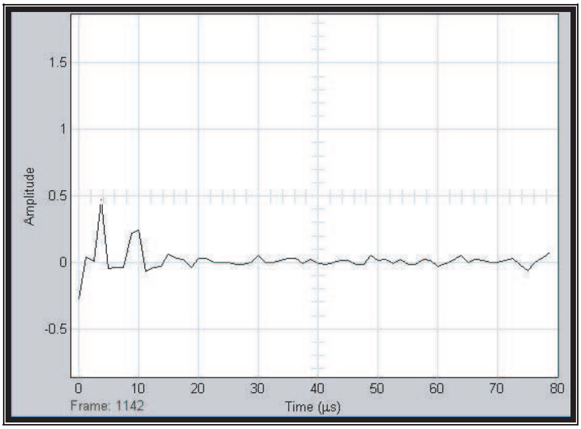

Figure 8. 1D imaging through software.

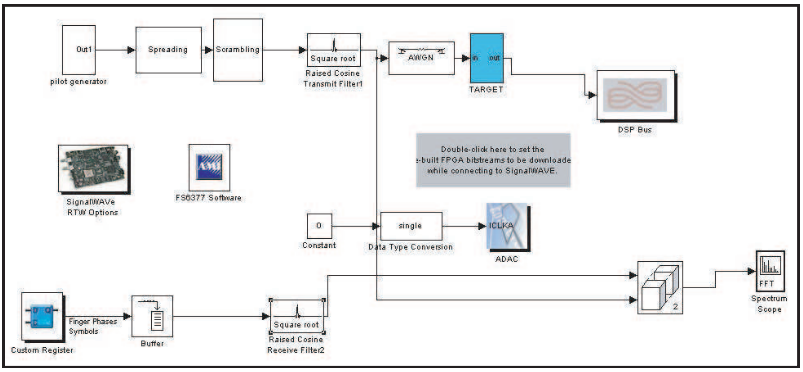

Figure 9. DSP Section for the DSSS radar system.

7. SDR IMPLEMENTATION

DSSS radar is implemented by using SDR kit. This SDR board consists of a DSP section and an FPGA section. DSP and FPGA are programmed separately. SIMULINK is used for model based design to programm the SDR. Simulation model of Figure 3 has been modified a bit for implementation spread spectrum based CDMA approach through SDR, shown in Figure 9. Loop back test is done, and transmitted and received power spectrum is observed for different kinds of signal attenuation introduced by the target (Figure 11).

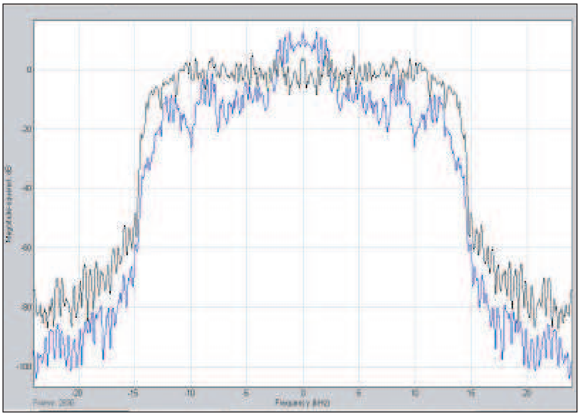

Figure 10. Spectrums of Tx and Rx signal power through SDR (0 dB path loss).

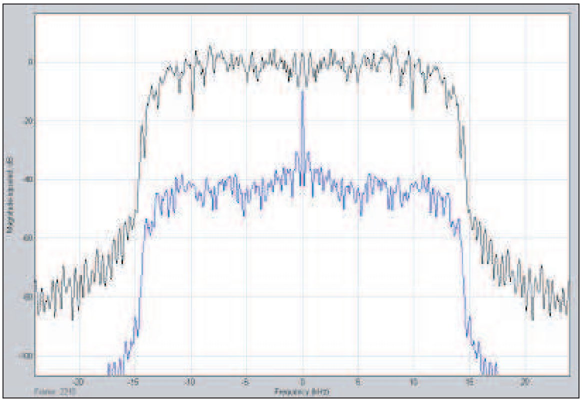

Figure 11. Spectrums of Tx and Rx signal power through SDR (30 dB path loss).

8. CONCLUSION

In this paper, we introduce a general multiple antenna system and it is successful in detecting single target using simulation as well as hardware. 1D imaging is successfully done using frequency stepping method, and the separation of multiple targets is possible by using radar imaging. Digital radar implementation is done for single target detection using SDR. But, here we could only extract the signal attenuation. Phase and frequency offset extraction are yet to be implemented. Limitation of DSSS radar can be solved by using adaptive equalizer and rake processing. DSSS radar using SDR will be useful for implementation in a car, which will be able to provide information (distance and type or size of the vehicle) about the nearby vehicle for automatic cruise control (ACC). It is observed that multi-target effect can be additive or subtractive depending on the relative distance between the targets. The simulation and hardware experiment results support each other. But the limitation of this single frequency radar is that it is unable to separate different targets. Thus, we need radar RF frequency to be stepped. Finally, in Section 6, a frequency stepping method is simulated for proper detection and separation of different targets at very preliminary level. This work can be best exploited in ITS application for collision avoidance in car to car and car to roadside communication.

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