Low-Cost, High Resolution X-Band Laboratory Radar System for Synthetic Aperture Radar Applications

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Abstract—**Entry into the field of radar cross section measurements or synthetic aperture radar (SAR) algorithm development is often difficult due to the cost of high-end precision pulsed IF or other precision radar test instruments. A low-cost entry-level alternative was developed in order to provide an intermediate step between high-end high precision radar systems and ad-hock spare parts systems. The system developed is a frequency modulated continuous wave radar utilizing a homodyne radar architecture. Transmit chirp covers 8 GHz to 10.5 GHz with 18 dBm of transmit power. Due to the fairly wide transmit bandwidth, this radar is capable of better than 12 inches of range resolution. The dynamic range of this system was measured to be 60 dB. Such a low-cost, high resolution X-band laboratory radar system could be utilized as a linear rail SAR, inverse SAR, or for motion compensation experiments.**

Index Terms—**FMCW Radar, Synthetic Aperture Radar, SAR, ISAR, Radar Imaging, Low Cost Radar System.**

I. Introduction

A low cost high resolution X-band laboratory radar system for Synthetic Aperture Radar (SAR) applications was developed at Michigan State University. The purpose behind this research was to develop a low cost entry level system for use by universities or small businesses looking to enter the field of radar cross section (RCS) measurements or synthetic aperture radar (SAR) algorithm development. In this paper the implementation of this radar system will be discussed in detail. An explanation of the radar design is presented in section II. Section III presents measured data results. Section IV will discuss conclusions and future work.

II. System Implementation

The low cost high resolution X-band laboratory radar system discussed in this paper is a homodyne frequency modulated, continuous wave (FMCW) system. A picture of the system is shown in Figure 1. In an FMCW radar system, the range to target information is a product of the transmitting chirp frequency times received chirp frequency. This resulting product produces an extremely low audio frequency tone known as a beat frequency. The distance from the target is directly proportional to the beat frequency. Since the beat frequencies are typically in the audio frequency range, they can easily be digitized using low cost analog-to-digital converters (ADCs). A theoretical explanation of FMCW radar can be found in [1].

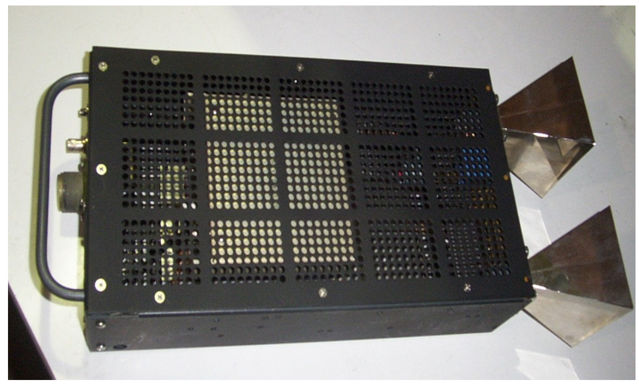

Figure 1: The low cost high resolution X-band laboratory radar system.

This particular radar system chirps linearly from 8 GHz to 10.5 GHz with a chirp rate of 250 GHz/sec. The sensitivity of this system is 25.1 µV, and the dynamic range is 60 dB. A block diagram of the system is shown in Figure 2.

OSC1 is a voltage tuned YIG oscillator that tunes from 8 GHz to 10.5 GHz. OSC1 is modulated by a linear ramp generated by DAC1 and OP3, thus producing the 8 GHz to 10.5 GHz transmit chirp. The output of OSC1 feeds into the directional coupler CLPR1. The coupled output of CLPR1 is fed through circulator Circ2 and feeds the LO port of the double balanced mixer MXR1. The through port of CLPR1 is fed through the circulator Circ1 to the transmit horn antenna Ant1. Ant1 is a standard gain X-band horn that is fed by a WR90 waveguide transition. The transmit power of the chirp signal is 18 dBm. The chirp signal from Ant1 is then radiated out toward the target scene.

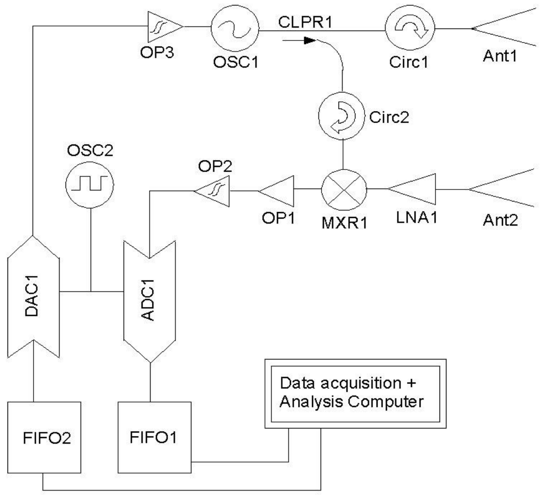

Figure 2: Block diagram of radar system.

Reflected chirp signals from the target scene are then received by the receiver antenna Ant2. Ant2 is a standard gain X-band horn that is fed by a WR90 waveguide transition. The output of Ant2 is fed into LNA1. LNA1 is a 22 dB gain, 6 GHz to 10.5 GHz LNA. The output of LNA1 feeds the RF port of MXR1. The IF output of MXR1 feeds into the video amplifier OP1. The output of OP1 is fed through a 60 KHz active low pass filter OP2. The output of OP2 is the video output of the radar system. This video output contains the beat frequencies which provide range to target information.

The video output of OP2 feeds into the analog to digital converter ADC1. Data acquisition and ramp modulation are performed coherently and synchronized by clock generator OSC2. ADC1 is a 16 bit ADC sampling at 200 KSPS. ADC1 samples the video output of OP2 coherently with the digital to analog converter DAC1. The output of ADC1 is fed into a first in, first out (fifo) register denoted as FIFO1. The data output of FIFO1 is then transferred to the data acquisition and analysis computer. The data acquisition and analysis computer controls the entire system and its parameters. This computer also processes the range profile data.

The data acquisition and analysis computer fills the second fifo, FIFO2, with values for linear ramp modulation of OSC1. The data from FIFO2 is sampled into DAC1. DAC1 outputs samples coherently with ADC1. The ramp output of DAC1 is a stair cased digital version of a pure ramp. OP3 is a 5 KHz active low pass filter that filters the stair case effect thus smoothing the linear ramp waveform which is modulating OSC1.

III. Measured Data

A number of range profiles were acquired using the low cost high resolution X-band laboratory radar system. These range profiles were acquired to get a rough idea as to the SAR imaging possibilities of this system. Targets were placed in front of the radar system at various ranges. Figure 3 is a picture of the experimental setup, with seven 0 dBsm cylinders placed in the snow (range profile data was acquired outdoors during the winter). Coherent background subtraction was used in all range profile experiments.

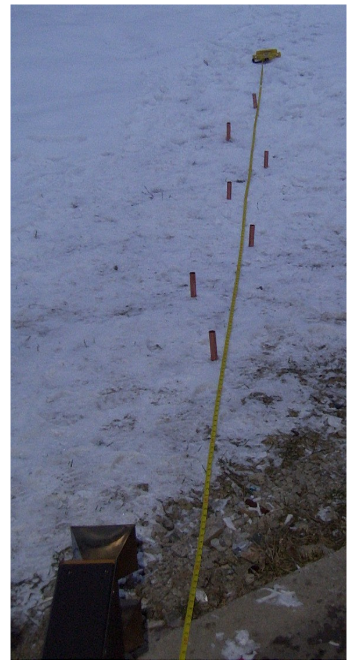

Figure 3: Range profile experimental setup showing seven 0 dBsm cylinders spaced every 2 ft placed in the snow.

Figure 4 shows a range profile of seven 0 dBsm cylinders placed in a staggered line spaced every 2 ft, starting at a range of 7 ft and ending at a range of 19 ft. From this range profile plot, the position of each of the seven cylinders is clearly indicated. The first two cylinders are slightly lower in amplitude than the last five. There is a slight range error probably due to slant angle of the radar to the ground. In these experiments, the radar is approximately 2 ft above the line of cylinders. Also, the cylinders are staggered slightly (as shown in Figure 3) so that the maximum amplitude return occurs.

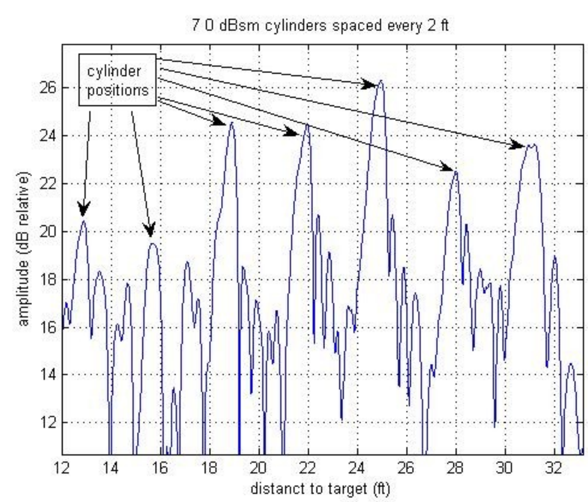

Figure 4: Seven 0 dBsm cylinders spaced every 2 ft.

Figure 5 shows a range profile of seven 0 dB/sm cylinders placed in a staggered line spaced every 1 ft, starting at a range of 7 ft and ending at a range of 13 ft. From this range profile plot, the position of each of the seven cylinders is clearly indicated. There is a slight range error probably due to slant angle of radar and the staggering of cylinders.

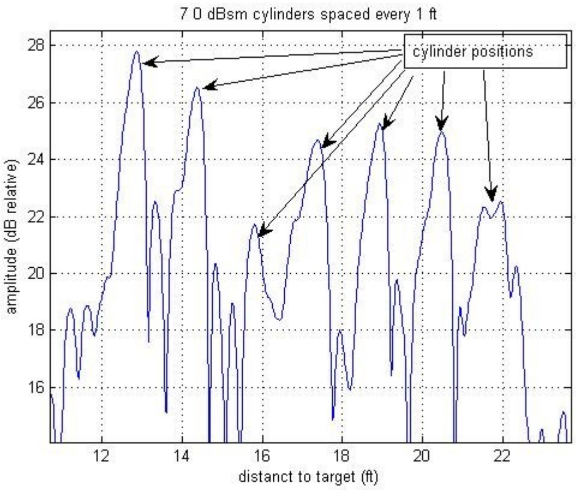

Figure 5: Seven 0 dBsm cylinders spaced every 1 ft.

In both figures 4 and 5 it is clear that the first cylinder at 7ft shows up at approximately 13ft on the radar display. This is due to a constant delay internal to the radar system due physical parts layout and cable lengths. This delay can easily be calibrated out later when SAR imagery is made using this system.

IV. Conclusions and Future Work

From the results presented in this paper it is clear that the low cost high resolution X-band laboratory radar system is capable of significant range resolution and dynamic range. Future work will include tests in a less cluttered environment (not in the snow). Future work will also include linear rail SAR measurements using this system in order to test its ability to image in a laboratory environment.

References

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