Short-term stay in UC Davis
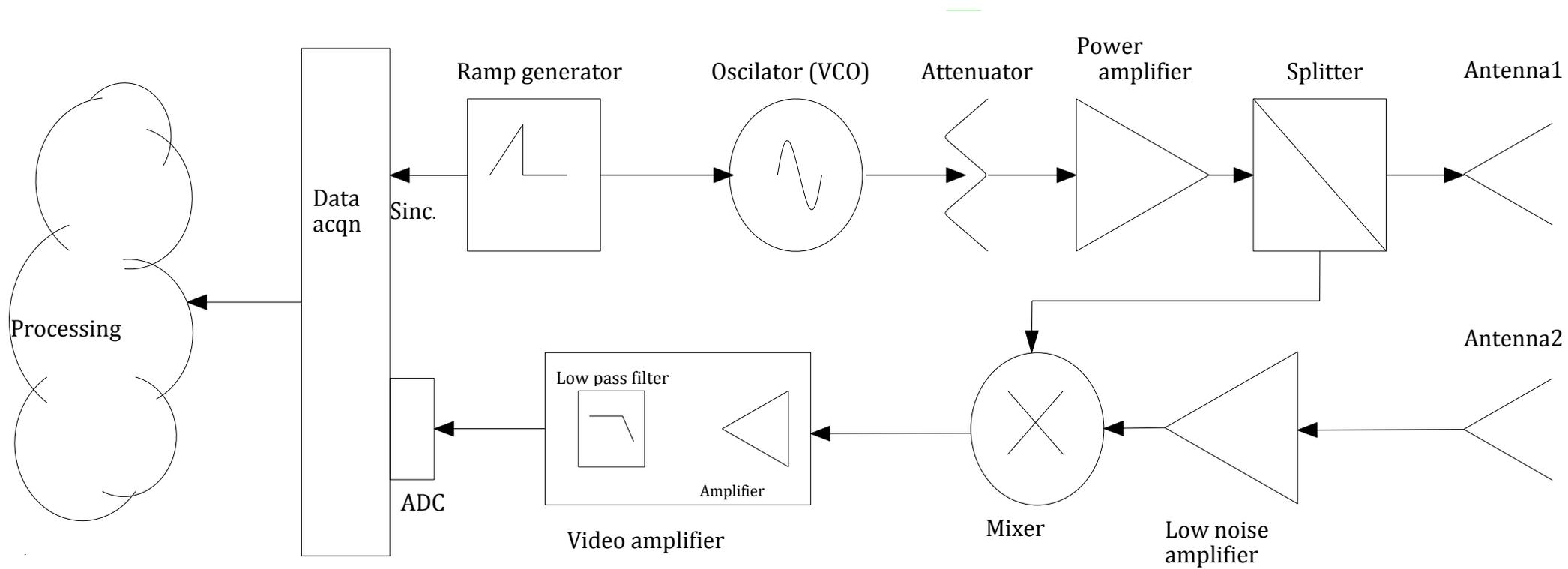# Technical report

Introduction

The purpose of this document is reporting the activities conducted during the short-term stay in UC Davis by José Enrique Almanza Medina during the period from January 19th to April 24th 2015 supported by the UC MEXUS-CICESE program.

The purpose of this stay was to build a Frequency Modulated Continuous Wave (FMCW) radar in the ISM frequency band of 2.4GHz capable of performing ranging and speed measurement and generating images using it as a Synthetic Aperture Radar (SAR).

In order to complete this project, the lab materials used in ECC 193 class were used as a guide but making some changes in the radar proposed in it such as using different the components in the generation and acquisition of analog signals.

The construction and testing were done in the laboratory 3182 in Kemper Hall in UC Davis and outside of the building.

The blocks diagram of the radar is shown in Figure 1 and each individual part is described in the following sections.

Processing

Data acqn

Sinc.

Ramp generator

Oscilator (VCO)

Attenuator

Power amplifier

Splitter

Antenna1

ADC

Low pass filter

Amplifier

Video amplifier

Mixer

Low noise amplifier

Antenna2

Figure 1

Triangle and square signals

The first part of the radar construction was generating a triangle and a square wave using the DAQ card NI 6211 of National Instruments. This was done writing a Matlab script to control the DAQ. Figure 2 shows the result of generation of the signals.
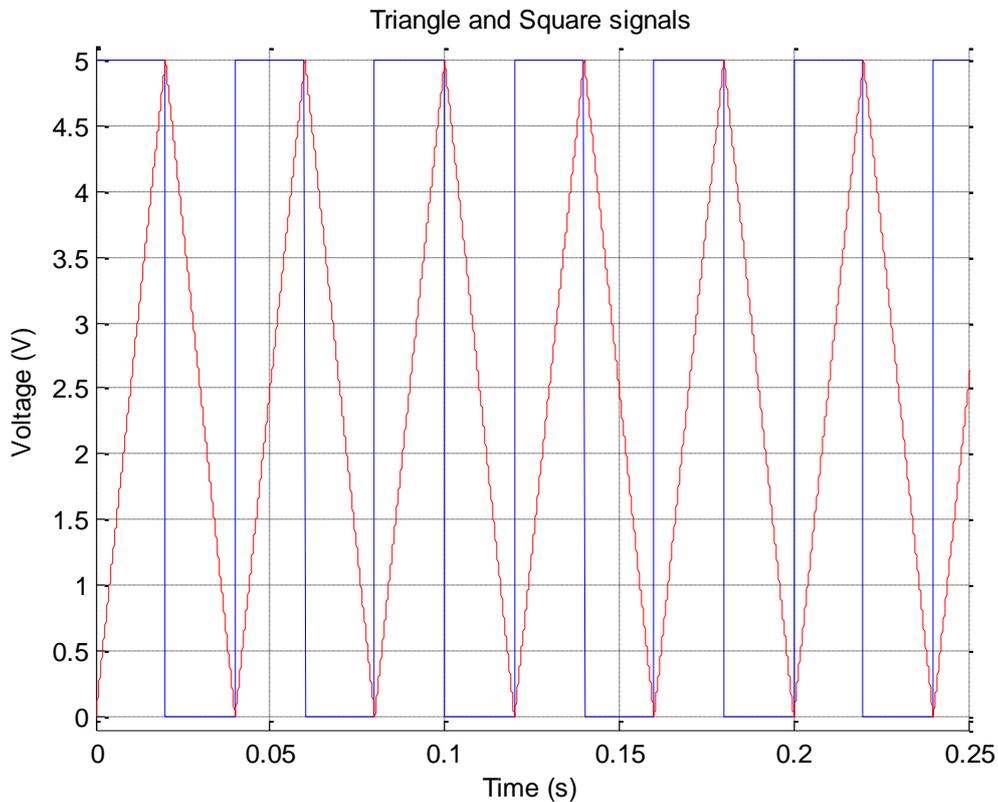
Figure 2

RF components

In this part the RF components were connected based on the diagram in Figure 1.

The part number of each component can be seen in Table 1.

| Part no.	Description	Brand
ZX95-2536C+	VCO, +6 dBm Out. 2315-2536 MHz	Mini-Circuits
VAT-3+	3dB SMA M-F attenuator	Mini-Circuits
ZX60-272LN-S+	Power Amplifier (PA) & Low Noise Amplifier (LNA) - Gain 14 dB, NF=1.2 dB, IP1= 18.5 dBm	Mini-Circuits
ZX10-2-42+	Splitter - 1900-4200 MHz, 0.1 dB insertion loss	Mini-Circuits
ZX05-43MH-S+	Mixer - 13 dBm LO, RF to LO loss 6.1 dB, IP1 9dBm	Mini-Circuits
SM-SM50+	SMA-SMA M-M barrel	Mini-Circuits

Table 1

Antennas

The construction of the antennas was done following the theory from the book "Antennas, For All Applications", Chapter 2 & 3, John D. Kraus, 3rd Ed., McGraw Hill, 2001 and "Waveguide Handbook", N. Marcuvitz, Nework: MIT Radiation Laboratory Series, 1951.

Based on these books, 2 coffee can antennas were built and tested using a network analyzer, obtaining the response in their S_{11} parameters shown in the Figure 3 and Figure 4.
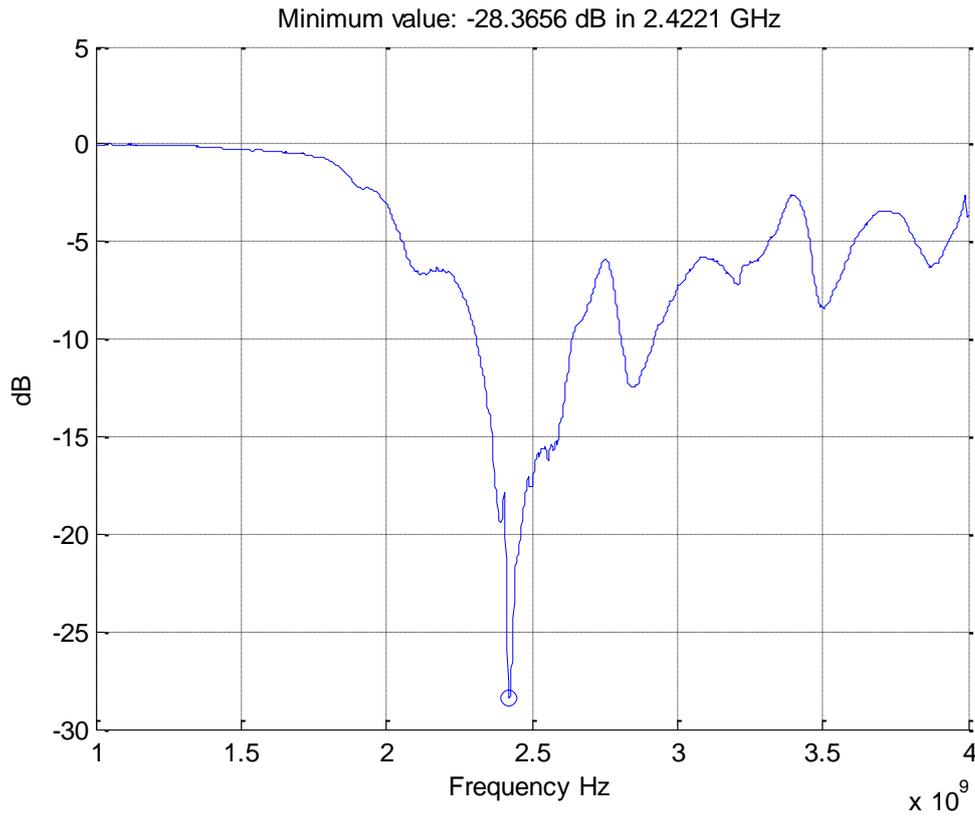
Figure 3
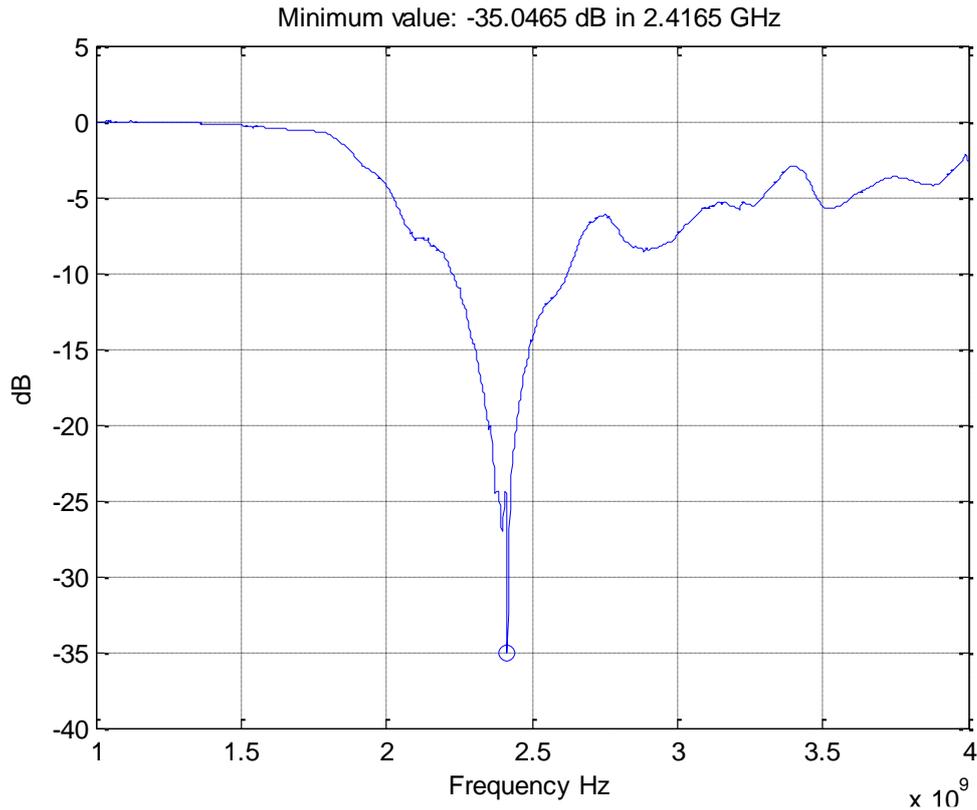
Figure 4

It can be seen that both antennas can work correctly in the frequency band of 2.4GHz as required.

Video section

This part was accomplished assembling the schematic diagram shown in Figure 5.

The purpose of this section is to reduce the noise of the resulting signal from the mixer using a low pass filter of 20 KHz approximately, letting pass only the baseband frequencies. This avoids that the data acquisition card receive unnecessary noise signals. This section also amplifies the signal one more time to make it easier to be sensed by the card.
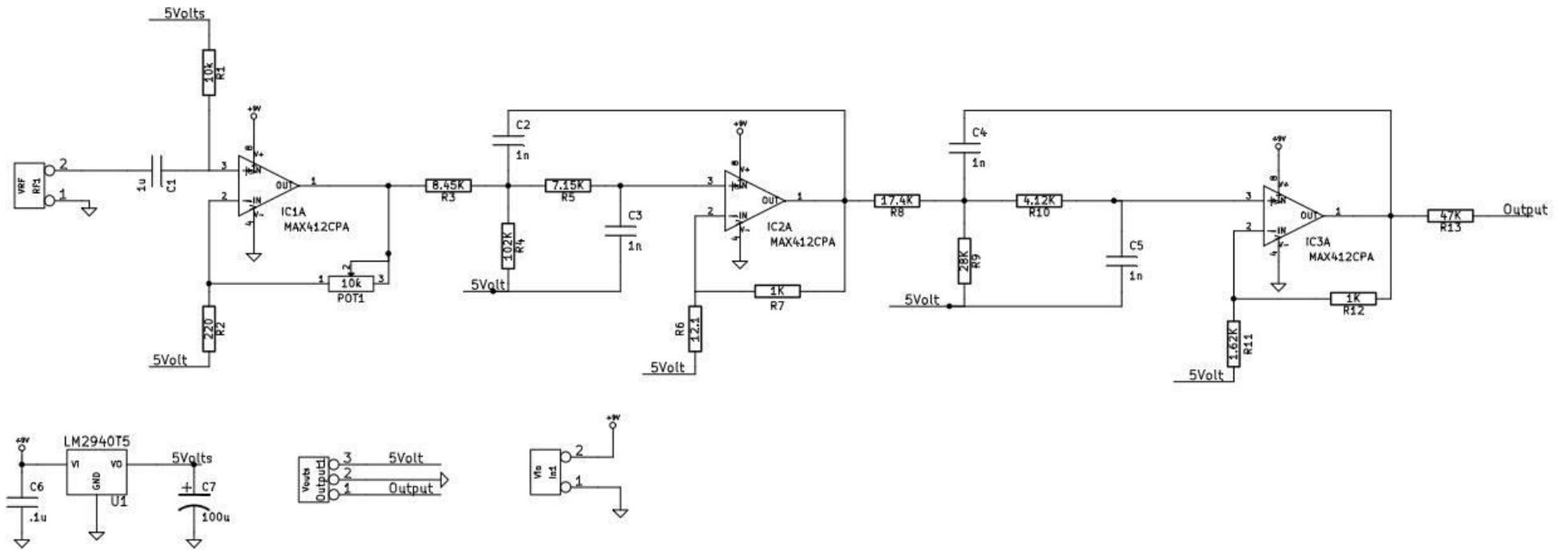
Figure 5

The circuit was tested using a function generator and an oscilloscope. It was calibrated putting a sine wave of 100 KHz with 50mVpp as input of the video amplifier and adjusted the potentiometer (POT1) to obtain a sine wave of 3Vpp in the output.

Data processing for ranging

This section as mentioned before was done using a Matlab script which was provided by Prof. Leo Liu and originally written by Gregory L. Charvat. It works using the output of the mixer after video amplification/filtering. This signal is the frequency difference of the frequency transmitted (output of the VCO and it is a FM modulation done by triangle signal generated by the DAQ) and the frequency received by the receiving antenna. This can be represented as

$$f_{IF} = f_T - f_R = m\tau = \frac{\Delta F}{T}\frac{2R}{c}$$

Rearranging gives the range
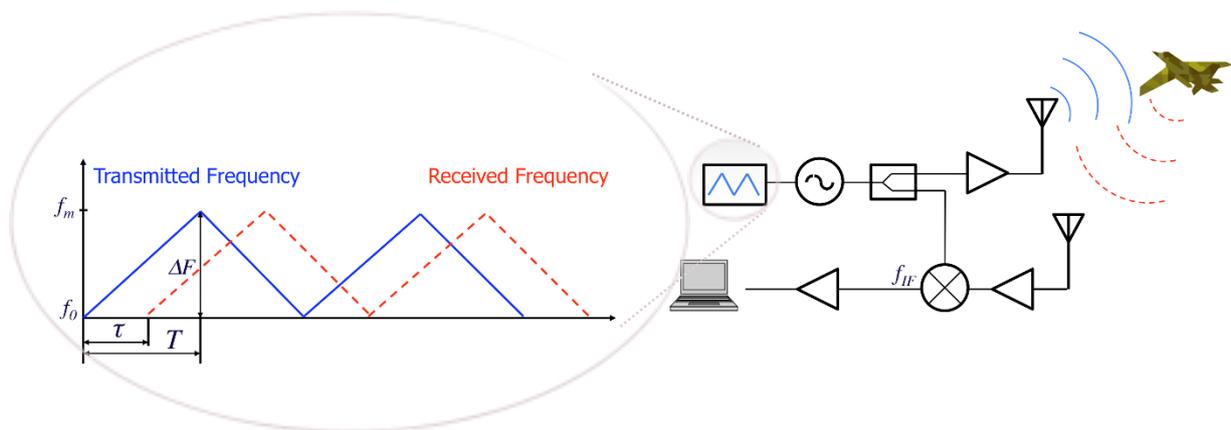
$$R = \frac{cT}{2\Delta F}f_{IF}$$

Figure 6

R is the range, the distance from the radar to any object detected.
f_{IF} is the difference of the frequency transmitted and the frequency received.
f_T is the frequency transmitted.
f_R is the frequency received.
c is the value of the speed of light ($\approx 3.00\times10^8$ m/s)
the delay τ is directly related to the distance R between the radar and the target ($\tau=2R/c$)
m is how fast the frequency changes relative to time ($\Delta F/T = (f_m-f_o)/T$)

This way the distance to an object is calculated for each instant of time and displayed in a Matlab graph.
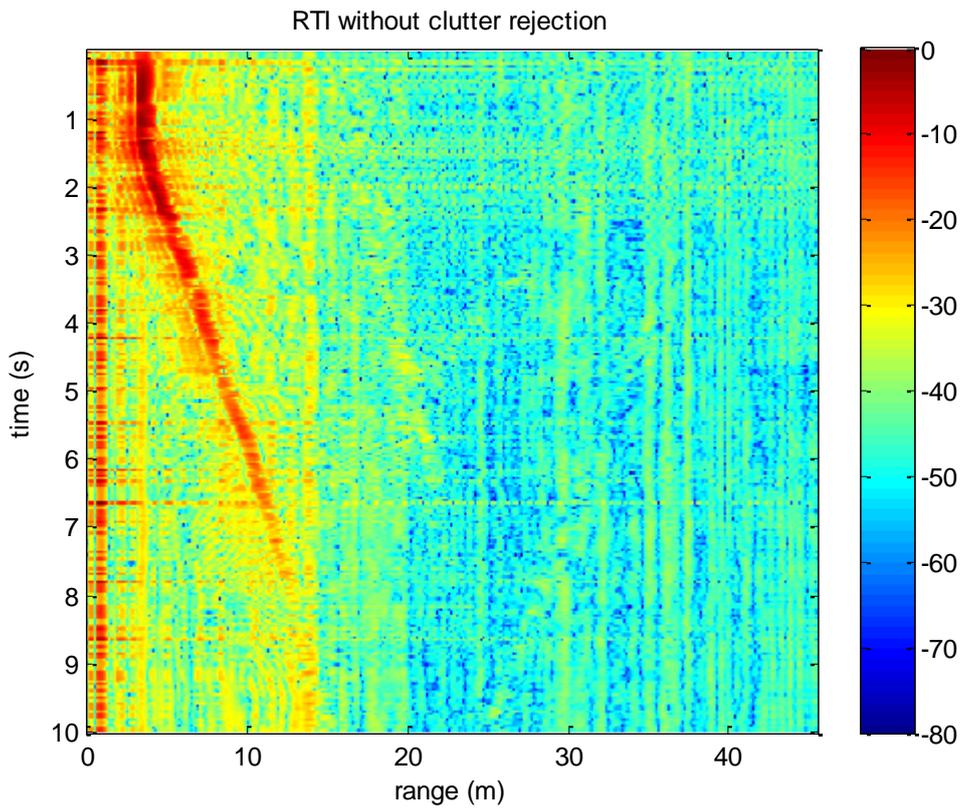
Radar assembling

After assembling all the components described in the previous sections, the result is the radar built and it is shown in Figure 7.
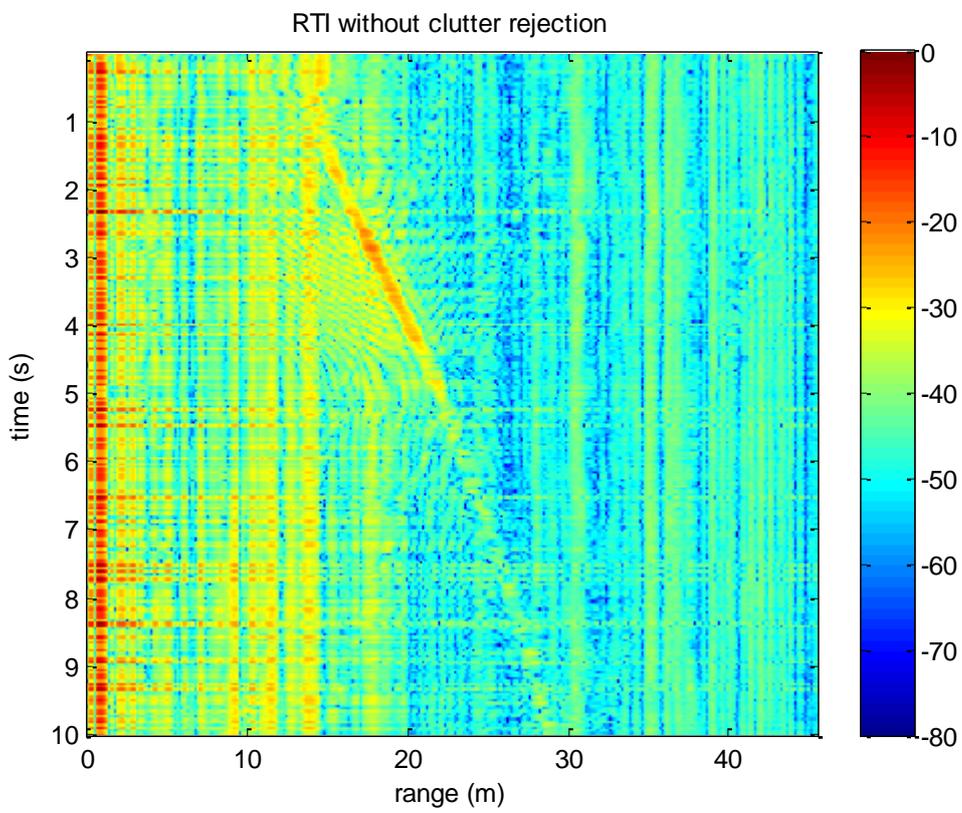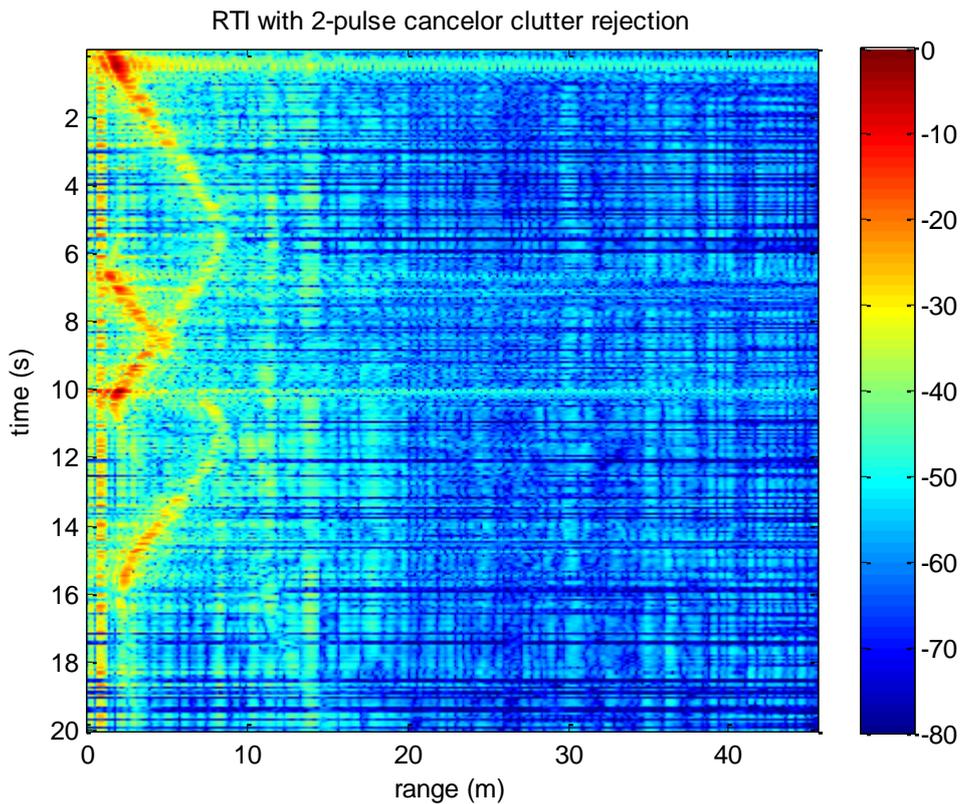

Figure 7

It is capable of range measuring. Figure 8 shows a person walking away from the radar from 2 to 12 meters approximately in 10 seconds. Figure 9 shows again a person walking away from the radar but from 15 to almost 30 meters approximately in 10 seconds. Figure 10 shows 2 people walking away from the radar and returning, this demonstrates the capability of measuring 2 different objects at the same time.

RTI without clutter rejection

Figure 8

RTI without clutter rejection

Figure 9

RTI with 2-pulse cancelor clutter rejection

Figure 10

Resolution tests were done as well, for this, 2 metal plates were placed separated at different distances from the radar (moving one of the targets and letting fixed the other) as can be seen in Figure 11. This was done to visually obtain a range resolution value of the radar. The different distances and their resulting graphs can be seen in Figure 12 to Figure 15.

Figure 11

In Figure 12, the objects can be observed at approximately 6 and 11.5 meters from the radar, represented with a yellow strip in the graph. Clearly they are not overlapped.
In Figure 13, the objects can be observed at approximately 6 and 9 meters from the radar, represented with a cyan strip in the graph. They are not overlapped either.

In Figure 14, the objects can be observed at approximately 6 and 7.5 meters from the radar, represented with a yellow strip in the graph. It can be seen that the object at 7.5 meters introduces noise to the detection of other object.

Finally in Figure 15, the objects were placed at approximately 6 and 6.5 meters from the radar, represented with a red/yellow strip in the graph. It can be seen how the objects cannot be recognized separately and they are totally overlapped.
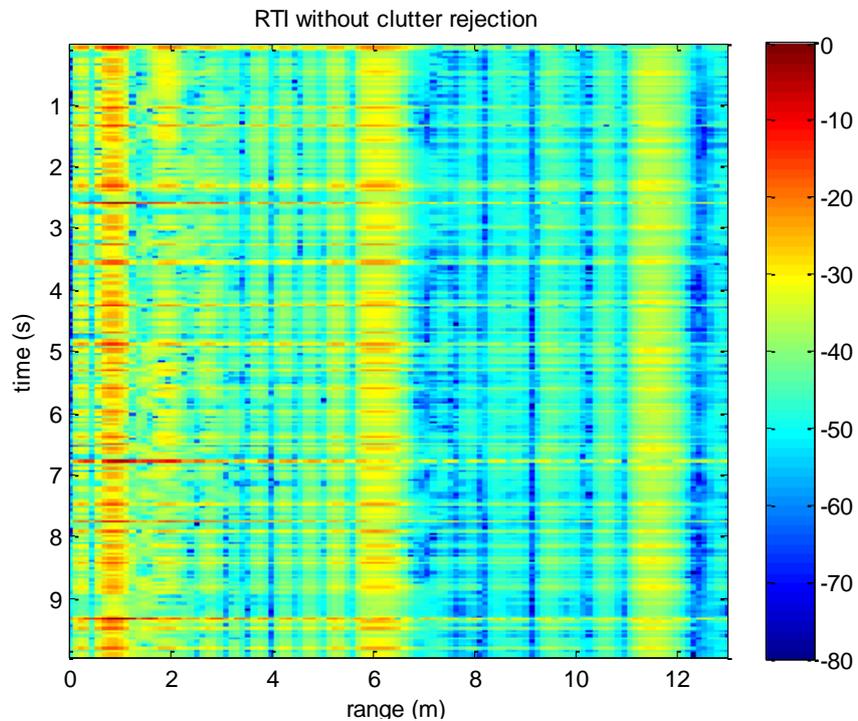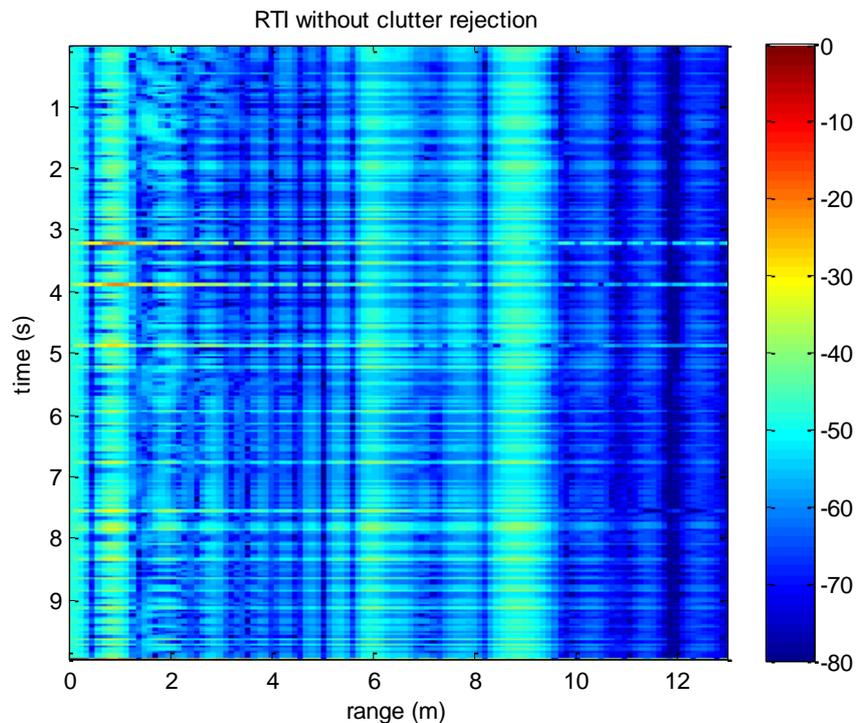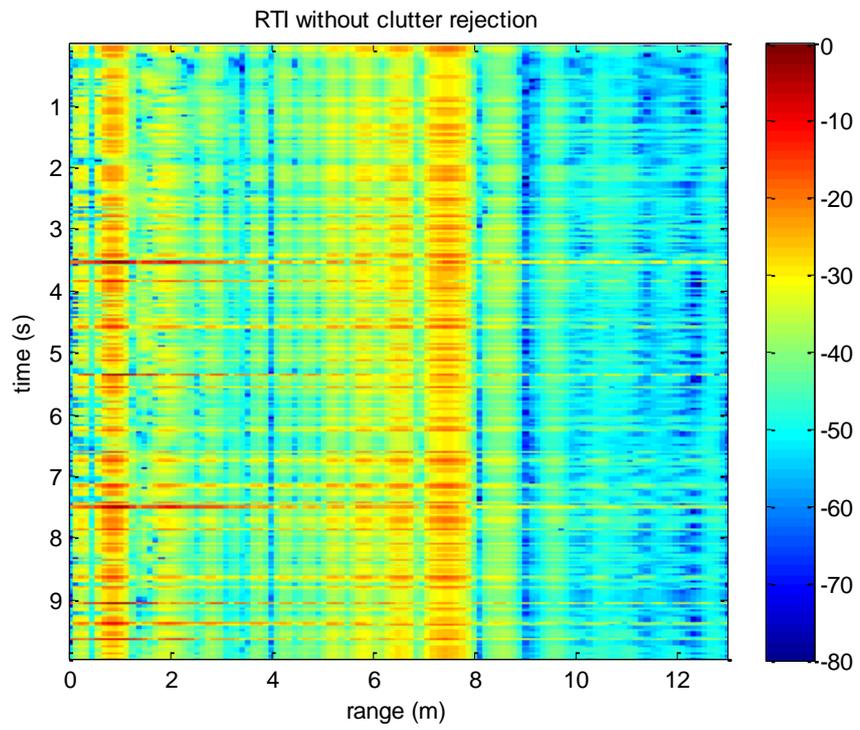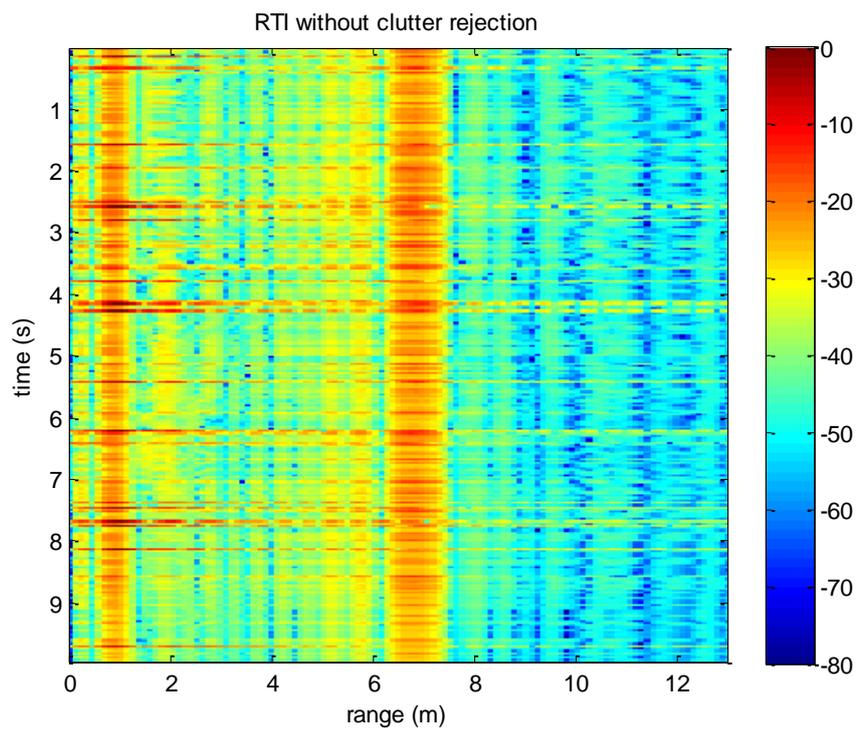

Figure 12

Figure 13

RTI without clutter rejection

Figure 14

RTI without clutter rejection

Figure 15

Rail construction

In this section it is described how the rail which carries the SAR was designed and constructed.

For this, the components listed in Table 2 were used:

Component picture	Component description	Part no.	Brand	Quantity
	T-slot Alluminium extrusion (97 inch)	1010	80/20	1
	Double flange linear bearing	6725	80/20	1
	Double mesh retainer - Black (10 S)	2523	80/20	1
	BOLT ASSY 1/4-20 X 1/2" FBHSCS+NUT	3321	80/20	2
	SCREW FBHSCS 1/4-20 X 3/8"	3390	80/20	4
	Tripod	724282	Sokkia	1

Table 2

Assembling all the components the result is shown in Figure 16.
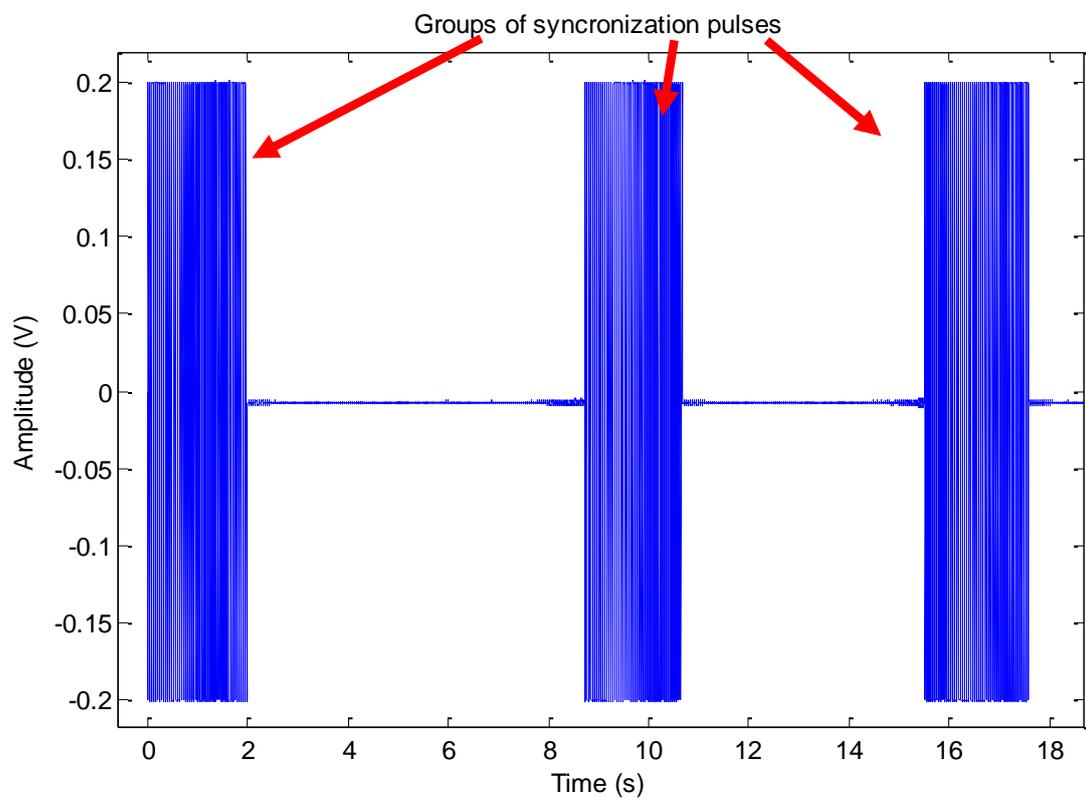
Figure 16

SAR processing

The radar was mounted on the rail and set up to use the script in MATLAB to generate the continuous signals (square and ramp) as show in the Figure 17.
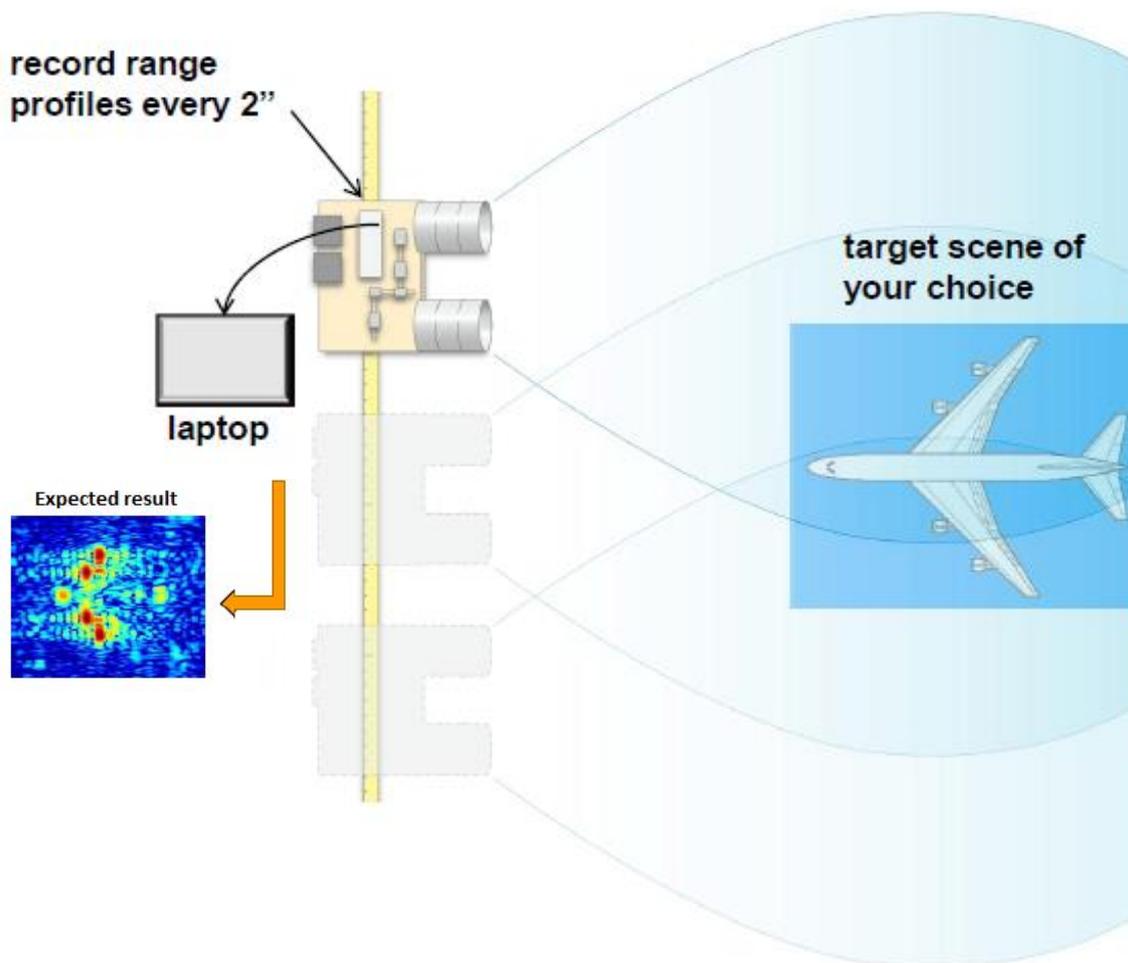

Figure 17

The SAR operating mode consists in moving the radar over the rail every 2 inches and every step (48 steps for the 96 inches rail) the radar records 250 ms of returns in ranges measured like in range measuring mode explained before. Each record is called Range profile, so it generates a total of 48 Range profiles.

In order to make the recording more simple, synchronization pulses (square signal) are interrupted by toggle switch whenever the radar is moved between 2 inch increments, thereby showing the MATLAB script the position of the radar along the linear rail as can be seen in Figure 18.

Figure 18

Figure 19

After recording all the Range profiles, the MATLAB script parses through the channel with the square signal first, searching for groups of synchronization pulses and saving both the group of synchronization pulses and the corresponding channel video data to an array. It then parses through each of these arrays, coherently integrating all video data lined up with their synchronization pulses within the pulse group. These video data for each two inch position are then fed to an RMA SAR imaging algorithm which produces the SAR image as expected in Figure 19.

The RMA SAR imaging code was provided by Prof. Leo in the ECC 193 course and it was originally written by Gregory L. Charvat. To learn more about the algorithm, it can be reviewed in book:

W.G. Carrara, R.S. Goodman, and R.M. Majewski, Spotlight Synthetic Aperture Radar Signal Processing Algorithms, Artech House, Boston, MA, 1995.

Results and further work

The complete system was tested in the lab and in some green areas of UC Davis.

Unfortunately during the short-term stay in UC Davis, it wasn't possible to generate an image with the SAR system that proves the correct performance of it. The images obtained show unidentified forms. An example of this is the following, Figure 20 shows a scene that was tried to be imaged and Figure 21 and Figure 22 show the result of capturing data twice along the rail and introducing the data to the RMA script in MATLAB.

Figure 20
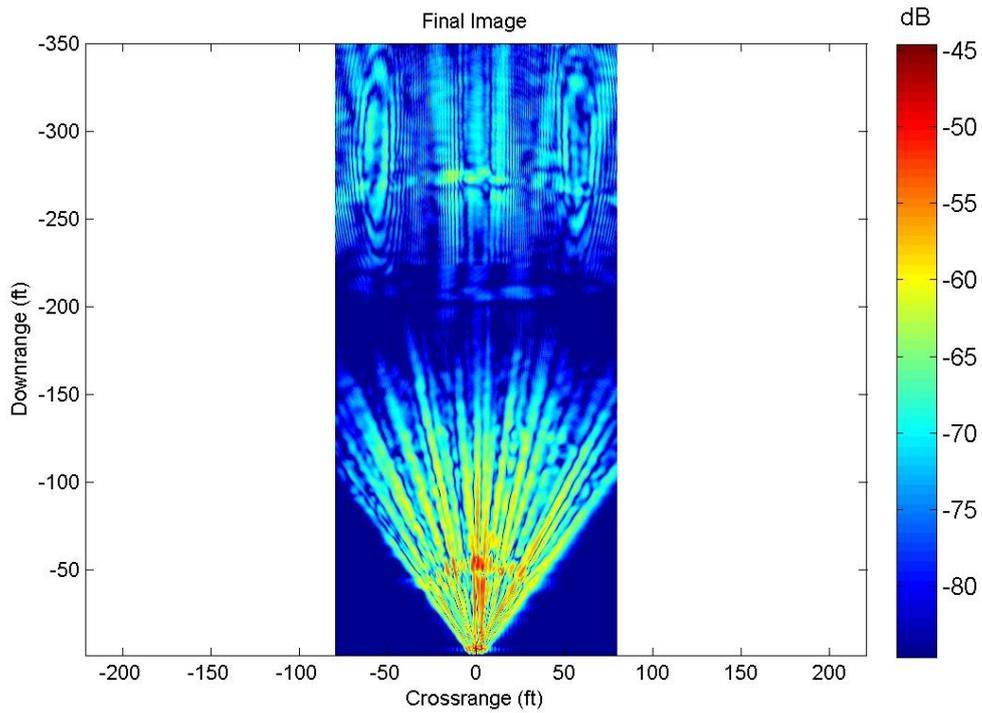
Figure 21
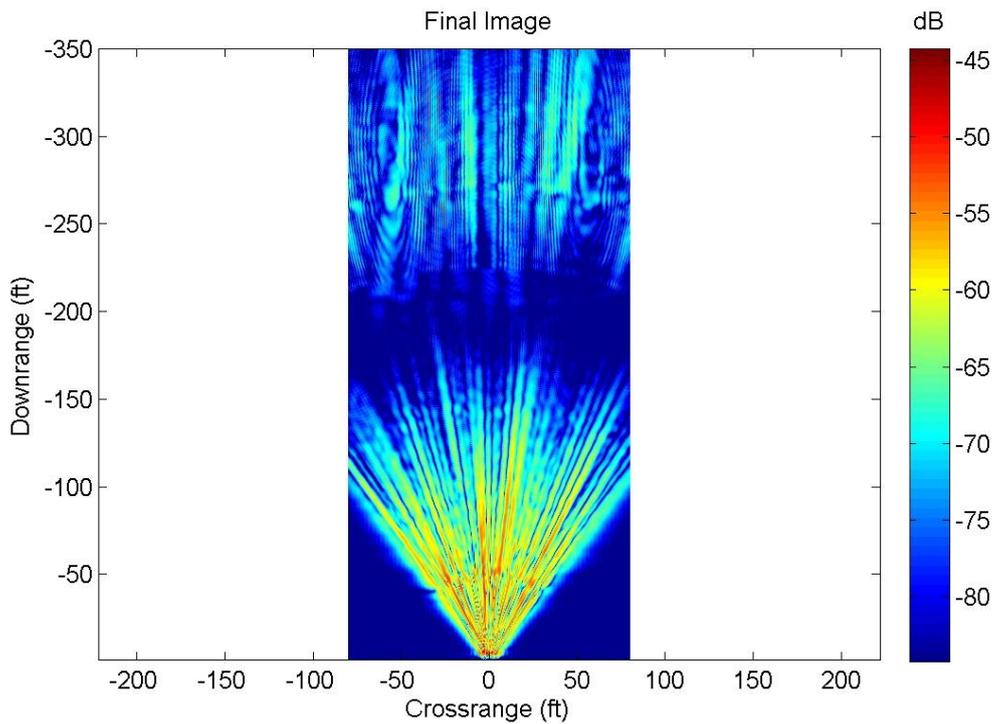
Figure 22

This could not be completed due to some unexpected delays occurred in the delivery of the components to build the rail.

The research and correct implementation is still being worked in the CICESE as part of the thesis research and continuing with the work done in Davis.

The results will be shared with Prof. Leo Liu in the future.