Lab 6 : Assembly of the Radar System

Xikai Chen
School of Microelectronics
Southern University of Science and Technology
Shenzhen, China
12440044@mail.sustech.edu.cn

Wenting Song
School of Microelectronics
Southern University of Science and Technology
Shenzhen, China
12432979@mail.sustech.edu.cn

Minghu Zhao
School of Microelectronics
Southern University of Science and Technology
Shenzhen, China
12432967@mail.sustech.edu.cn

Yuncheng Tu
School of Microelectronics
Southern University of Science and Technology
Shenzhen, China
12111008@mail.sustech.edu.cn

I. RADAR MEASUREMENTS

In the initial stages, we assembled our radar system and tested both the analog baseband and RF circuits to ensure their proper functionality.

To evaluate the basic radar operation, the antennas were connected, and the audio signal output was observed using an oscilloscope. A reflective object, such as a metallic plate, was placed in front of the radar and moved back and forth to analyze the system's response. The oscilloscope displayed a sinusoidal-like waveform, as shown in Figure 1, which illustrates the time-domain representation of the received signal and the generated triangle wave shape. This initial test provided basic confirmation of the radar's operational capability.

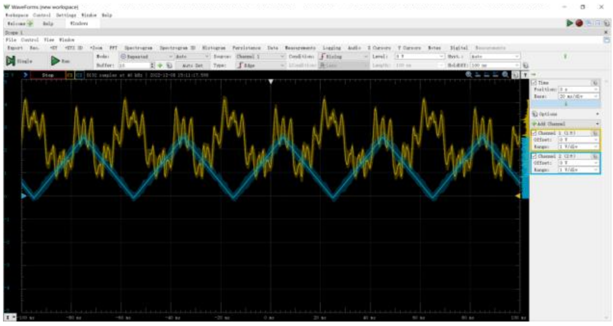

Fig. 1. The generated triangle wave and the received signal.

The signal characteristics varied with the distance of the reflector. When the reflector was closer to the antenna, the signal exhibited a lower frequency and greater amplitude. This occurs because the intermediate frequency (IF) signal is proportional to the distance of the target; closer reflectors result in lower mixing frequencies. Additionally, received power diminishes inversely with the square of the distance, meaning closer targets experience less power loss and produce larger signal amplitudes. Conversely, when the reflector was farther away, the signal showed a weaker amplitude and higher frequency due to increased transmission loss and greater mixing frequencies.

It is important to note that the lab environment posed challenges for radar characterization due to the presence of multiple strong reflectors and moving targets. For more reliable results, testing the system in an open outdoor space is recommended.

A. *Range measurement*

1. To perform range measurement, the VTUNE pin of the VCO was connected to the output of the function generator (Lab 1). The function generator was configured to produce a triangular wave signal with an amplitude ranging from 0 V to 3.5 V, corresponding to a frequency range of 2.3 GHz to 2.5 GHz. The period of the triangular waveform was set to 40 ms, consisting of 20 ms for ramping up and 20 ms for ramping down.

Figure 2 illustrates the generated triangular wave, displaying a signal amplitude between 0 V and 3.52 V and a period of 40.91 ms. This waveform served as the tuning voltage for the VCO, ensuring the system swept across the desired frequency range for radar operation.

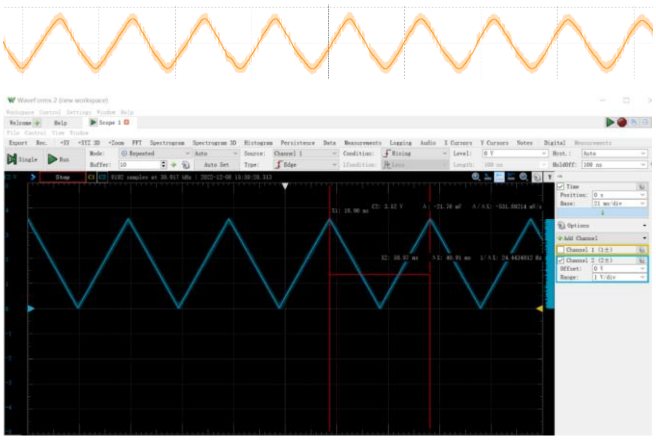

Fig. 2. The generated triangular wave.

2. The output of the active low-pass filter was connected to the "1+" terminal (analog input channel 1) of the Analog Discovery. Simultaneously, the SYNC output from the Teensy was connected to the "2+" terminal (analog input channel 2). The ground of the radar system was tied to the analog ground of the Analog Discovery to ensure proper grounding. Finally, the Analog Discovery was connected to a computer using a USB cable for data acquisition and analysis. Figure 3 depicts the radar system setup constructed during the experiment.

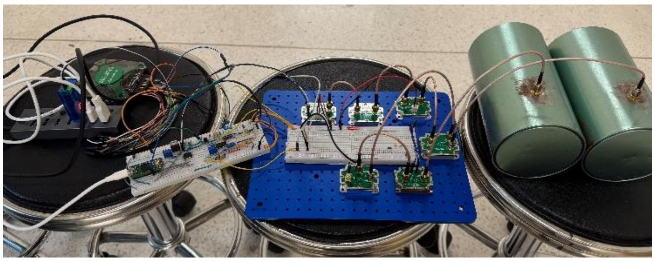

Fig. 3. FMCW radar system.

3. Slowly walk away or towards the radar. Run the Python script “ad record.py” to record data from the radar. Here, the Python script calls the Analog Discovery SDK to configure it as an analog to digital converter

4. Use the Python script “range dat.py” to process the recorded .dat file. To analyze your data, a few changes need to be made in the script.

- T_p=20E-3
- f_{start}=2260E6
- f_{stop}=2590E6
- Fs=50000

5. Plot of the Range of a Moving Object.

Figure 4 illustrates the range plot of a person walking in a nearly uniform linear motion from 30 meters away to the radar's transmitting and receiving point (the origin). The plot clearly demonstrates the continuous change in range as the person approaches the radar.

Figure 5 depicts the range measurement of a person walking back and forth, starting from 20 meters, reaching the origin, and then walking away. The range plot captures the bidirectional motion, providing a clear visualization of the person's movement pattern.

Figure 6 presents precise distance measurements for a person starting from the radar's antenna (the origin) and walking in a straight line to specific distances of 5 meters, 12 meters, and 24 meters. The plot shows distinct and precise breaks in the curve at each stopping point, demonstrating the radar's accuracy in detecting and measuring distances.

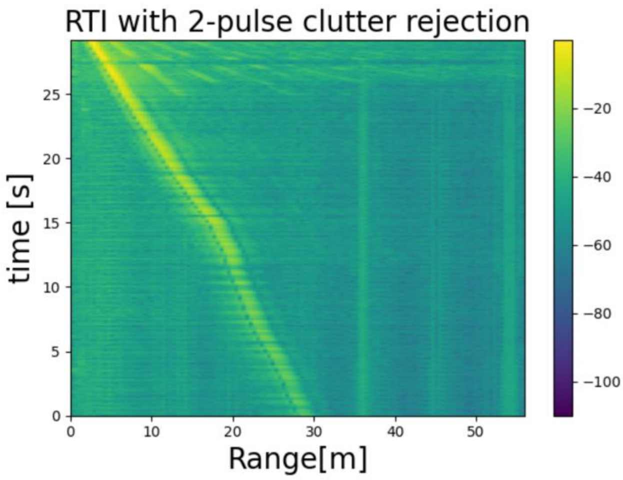

Fig. 4. Range plot of a person walking uniformly towards the radar.

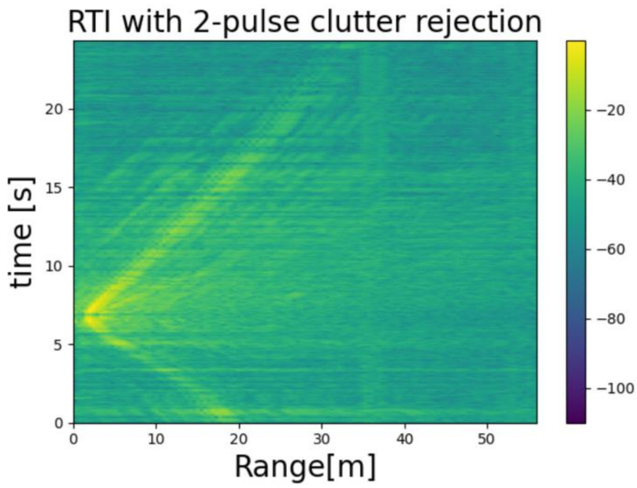

Fig. 5. Range plot of a person walking back and forth.

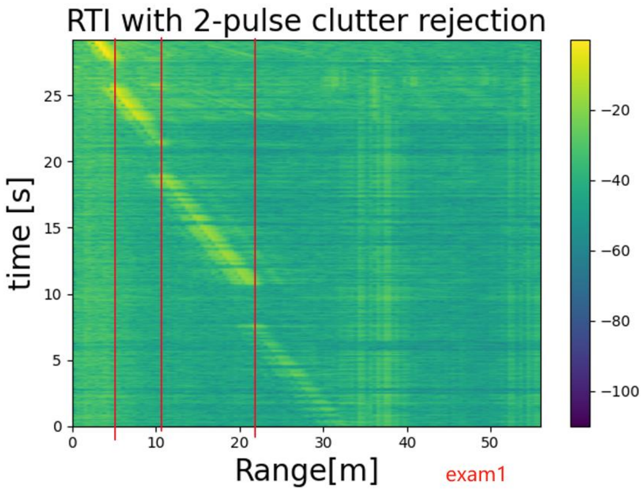

Fig. 6. Precise range measurement of a person walking to specific distances.

	Location1	Location2	Location3
Range	5	12	24

6. Try to refine your measurement results and answer the following questions

a) What is your measurement setup? What is the object that you measured? How is the environment like in terms of background reflection? You may include pictures for illustration

The measurement setup consists of an FMCW radar system. The VCO's VTUNE pin is connected to a function generator outputting a triangular wave, with the received signal processed by an active low-pass filter. The processed signal and SYNC signal are fed into the Analog Discovery for data acquisition. The object under test is a moving human subject. Measurements were conducted indoors, where reflections from walls and objects introduced noise. This setup could benefit from an outdoor environment with fewer reflective surfaces to reduce interference.

b) Include your own plot of the range of a moving object. What is the typical range for the object under test?

Figure 6 illustrates the Range-Time-Intensity (RTI) plot generated using 2-pulse clutter rejection. The range measurements demonstrate a maximum range of approximately 40 meters for a typical human subject under the current setup, as determined by the bandwidth and pulse duration parameters.

c) Calculate the free-space range of our radar for a typical human with σ=1m2. Compare with your test results.

The radar's maximum theoretical range, *R*max, is given by the radar equation:

$$R = \sqrt[4]{\frac{P_t G_t G_r \lambda^2 \sigma}{P_r \left(4\pi\right)^3}}.$$

Using this, we can calculate the theoretical maximum range and compare it with the observed range of approximately 40 meters, considering system losses.

d) Explain how the code works.

The ad_record.py script captures raw data using Analog Discovery. It samples two channels (signal and SYNC) at a rate of 50 kHz, saving data to recording.dat for post-processing. The script uses the Analog Discovery SDK to configure acquisition and handle data loss or corruption during sampling.

The range_dat.py script processes the recorded data. It segments data into pulses based on the SYNC signal, averages pulse sequences to eliminate system drifts, and applies a Hamming window to reduce FFT sidelobes. Finally, it computes the inverse FFT (IFFT) to produce the RTI plot, normalized to 0 dB.

e) What determines the cut-off frequency (15 kHz in our system) of the low-pass filter? (Hint: What system parameters are impacted by changing the ramp time, say from 20 ms to 1 ms?)

The cut-off frequency of the low-pass filter depends on the system's sweep time and bandwidth. Specifically:

$$f_{cut-off} = \frac{BW}{T_p}$$

Where:

- BW = bandwidth of the radar signal
- T_p = pulse duration (ramp time)

Decreasing the ramp time (e.g., from 20 ms to 1 ms) increases the slope of the frequency modulation, resulting in higher IF frequencies. Thus, the filter's cut-off must adapt to preserve the signal while rejecting noise.

f) Any particular tricks or tips that you found helpful in improving the quality of the measurement?

Conduct measurements in an open environment to minimize background reflections.

Increase the sampling rate if data resolution or signal-to-noise ratio is inadequate.

Apply averaging or filtering techniques to reduce noise and enhance signal clarity.

Use precise synchronization with the SYNC signal to avoid timing errors in pulse segmentation.

Perform clutter rejection (e.g., 2-pulse cancellation) to mitigate static reflectors' impact.