Lawrence Berkeley National Laboratory

Waves of Vision: mmWave Radar for Near-Surface observations of environmental processes

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1. Earth and Environmental Sciences Area

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Measuring impacts of climate change

- The negative impacts of climate change on natural resource management and carbon cycles.
- Near-surface observations on snowpack facilitate scientists observation of vertical snow face from the snow to the ground.
- Vertical snow face is used to characterize different layers of snow and gain insight into compaction from weather changes.
- Near-surface processes require spatiotemporal data, time and space.

Image credit: Top left: Mike McMillan/USFS. Bottom: Tomas Castelazo / Wikimedia Commons / CC BY-SA 4.0, Top Middle and right:NASA

Radar Platforms

- mmWave radar from the automotive industry can detect range and doppler velocity of static and moving objects
- Frequency Modulated Continuous Wave(FMCW) radars transmit a signal whose frequency changes with time known as a chirp
- A received chirp is a delayed transmitted chirp
- The data analysis requires Fourier analysis.

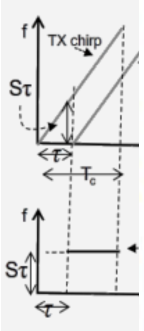
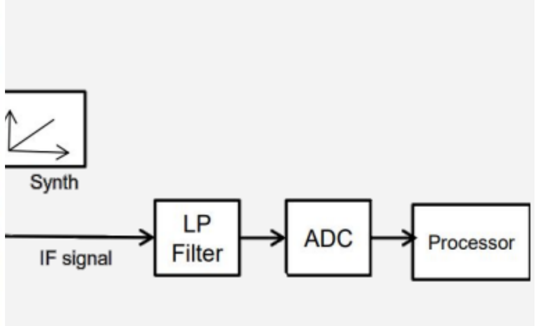


Figure 2:



…duction to mmWave sensing

Figure 3

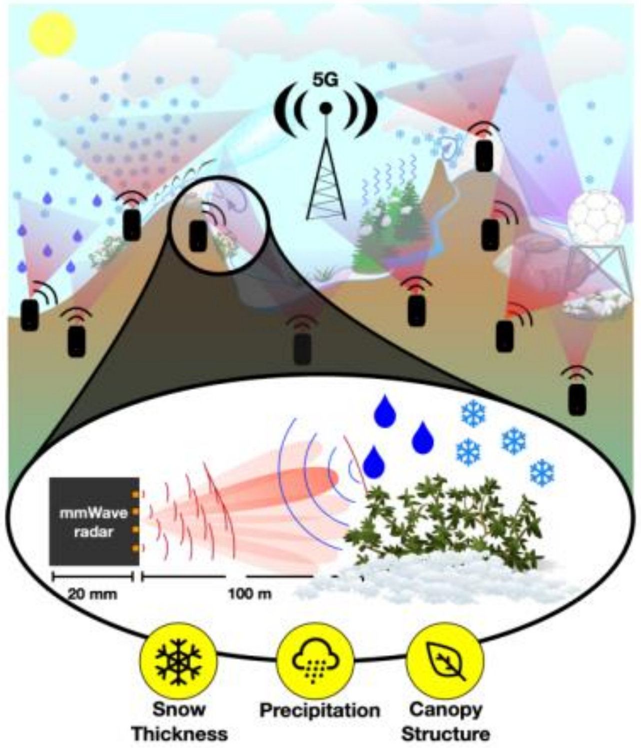


Figure 1: Concept for mmWave radar for near-surface observations. Credit: Stijn Wielandt

…igure 4: Infineon demo board

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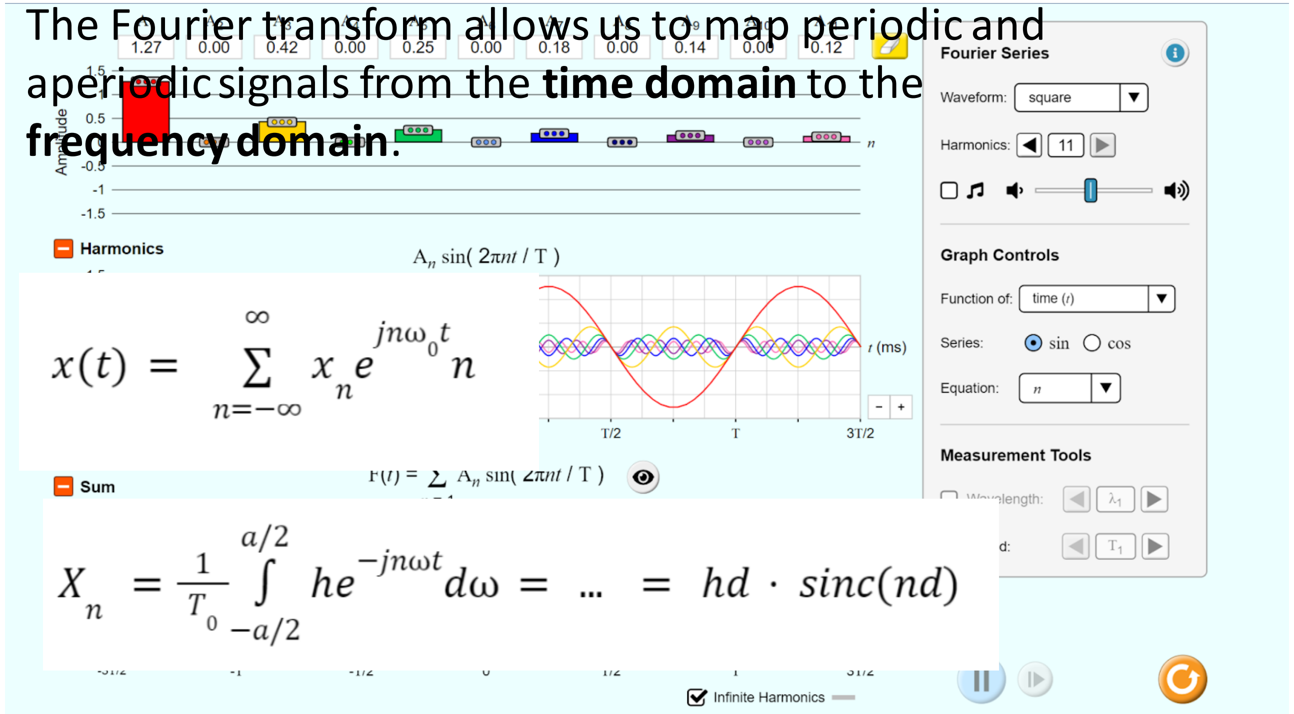
Fourier Series and Transform

Any square-integrable function, *f(x)*, which is periodic on the interval $0 < x \leq L$ can be written as

$$f(x) = a_0 + \sum_{n=1}^{\infty} a_n \cos\left(\frac{2\pi n}{L}x\right) + \sum_{n=1}^{\infty} b_n \sin\left(\frac{2\pi n}{L}x\right)$$

The Fourier Series can be applied to periodic signals to decompose them into a sum of sine and cosine functions.

The Fourier transform allows us to map periodic and aperiodic signals from the **time domain** to the **frequency domain**.



$$x(t) = \sum_{n=-\infty}^{\infty} x_n e^{jn\omega_0 t}$$

$$X_n = \frac{1}{T_0}\int_{-a/2}^{a/2} h e^{-jn\omega t} d\omega = \ldots = hd \cdot sinc(nd)$$

$$X_n = \frac{1}{T_0} F(\omega)$$

Fig ation - Fourier: Making Waves. The figure above shows the sum of the Har ct a rectangular pulse train.

Measuring Range and Doppler Velocity

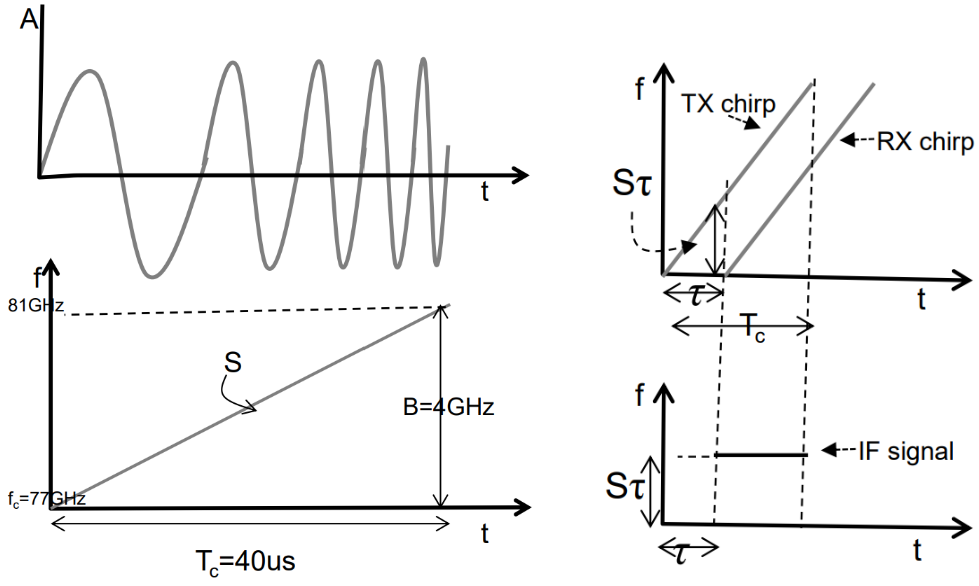


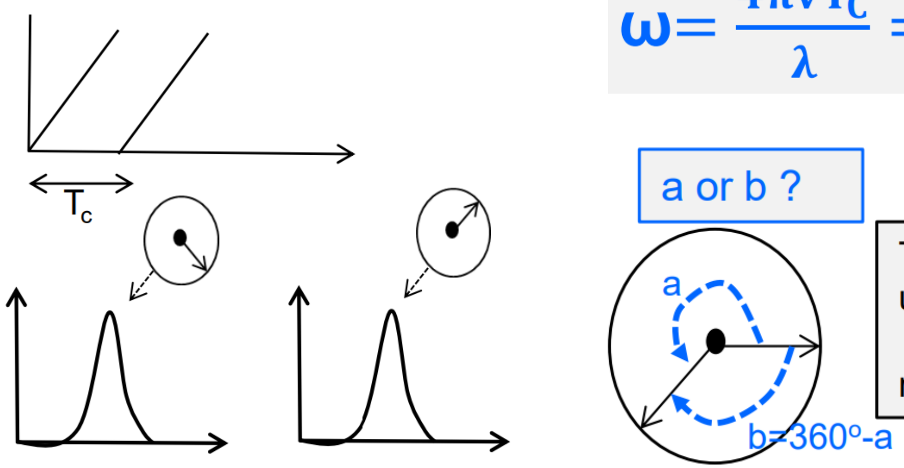
Figure B: Credit Texas Instruments. Top Left- Amplitude and time plot shows a signal whose frequency is changing. Bottom Left- Frequency and time plot. Top Right – A transmitted and received chirp. Bottom Right – The result of mixing the Tx and Rx chirp.

$$f_{IF} = \frac{S2d}{c}$$

$$d_{max} = \frac{F_{IF} \cdot c}{2 \cdot S},$$

$$S = \frac{BW}{t_c},$$

$$\omega = \frac{4\pi v T_C}{\lambda} \Rightarrow v = \frac{\lambda\omega}{4\pi T_c}$$



The measurement is unambiguous only if | ω | < 180º (i.e. π radians)

Figure C: "The measured phase difference (ω) corresponds to a motion in the object v*Tc". - Credit Texas Instruments. We can measure unambiguous using the equations below.

$$v_{max} = \frac{\lambda}{4 \cdot t_{c*}}$$

$$\lambda = \frac{c}{f_{start}}$$

Results

- Collect data using mmWave Studio
- Perform Analysis on Raw Data using Python
- Perform experiments in low-reflectivity environments, figure 5
- **Platform 1 – Texas Instruments IWR6843**
  - **Experiment 1:** Radar facing concrete wall 2.1m away
  - **Experiment 2:** Person walking to radar
  - **Experiment 3:** Moving radar to and aw from reflector.

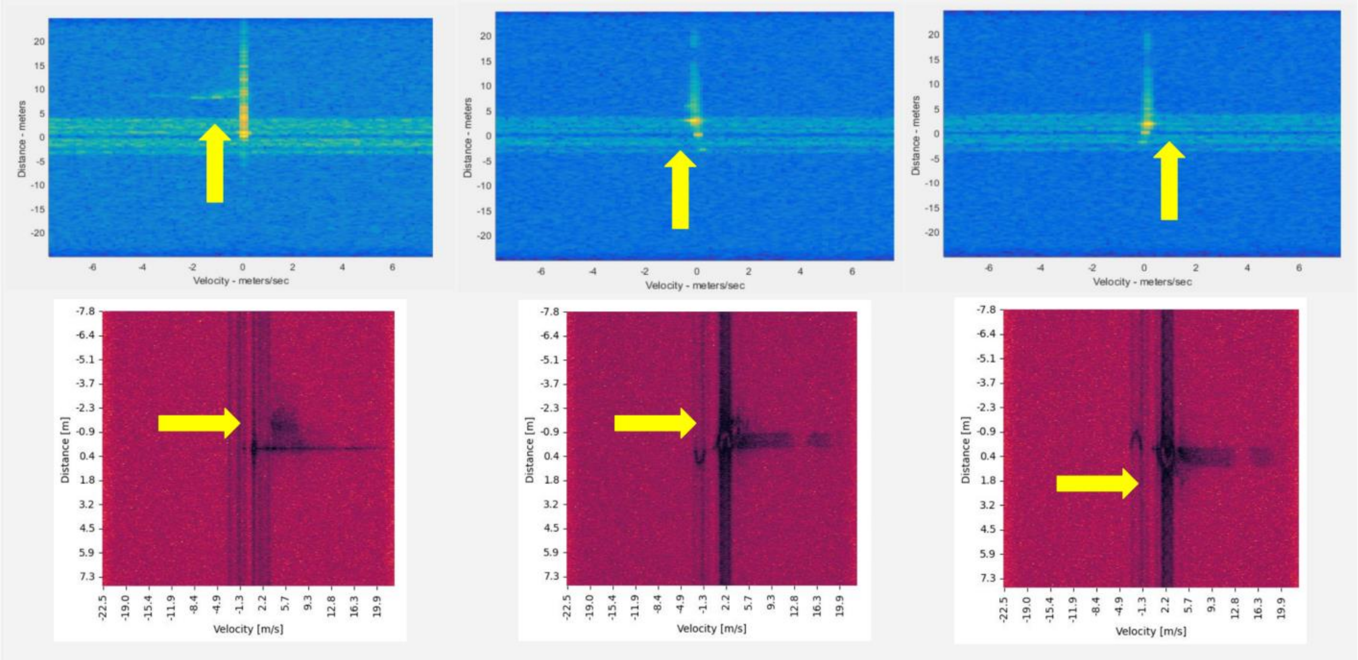


Figure 7: Top row- mmWave results. Bottom row- Python results. Left-Person walking towards, middle- radar towards reflector, right- moving away from reflector.

Results

- **Platform 2 – Infineon BGT60TR13C**
  - Nome: collected using Radar Fusion GUI
  - Colorado: collected using process in Figure 8.
- Outcomes
  - Developed two mmWave platforms with different purposes.
  - Developed Signal Processing scripts for Range and Doppler Velocity
  - Tested and verified both platforms

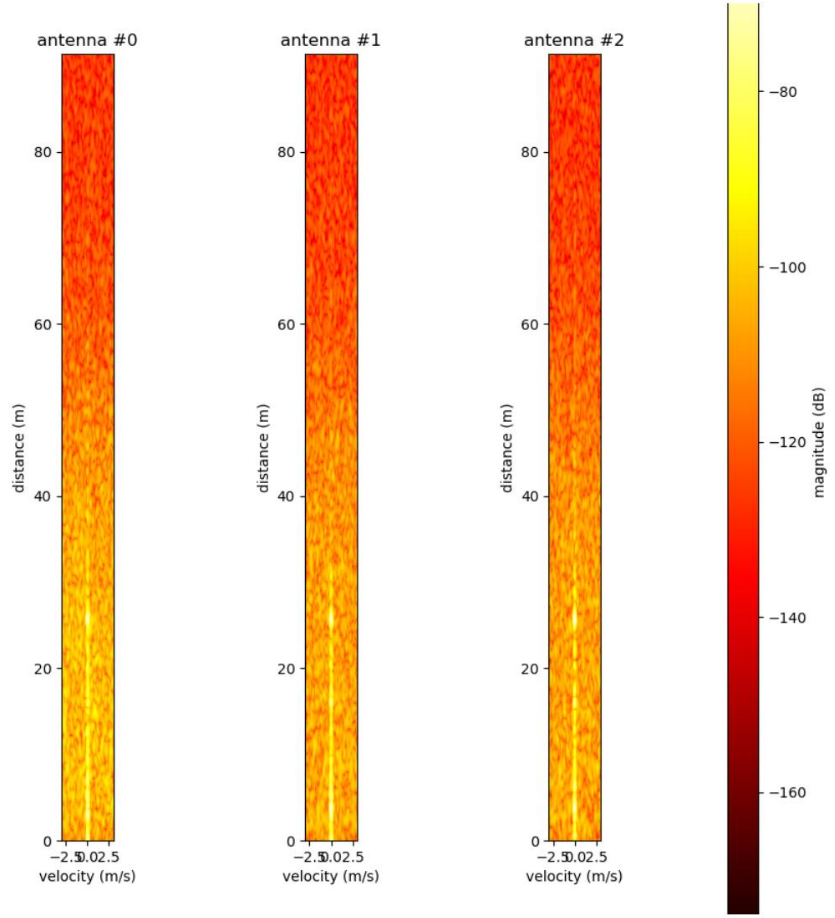
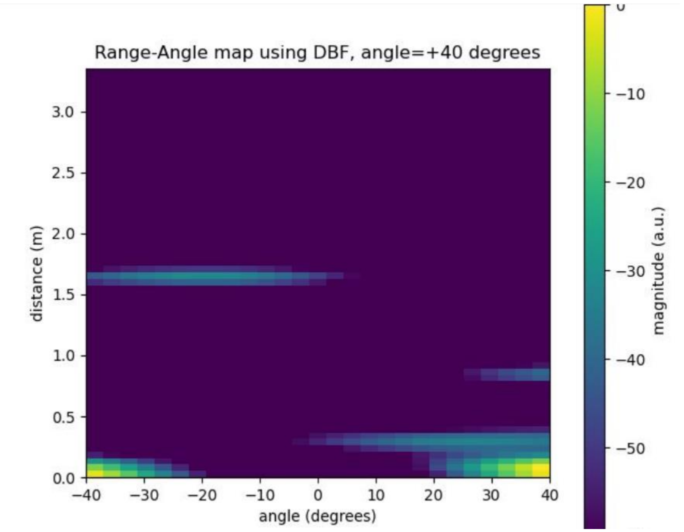
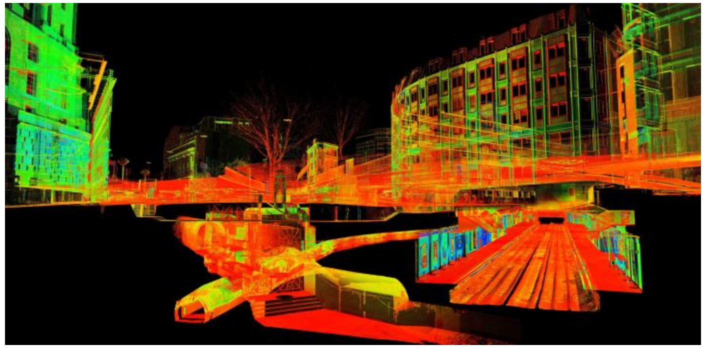


Figure 10: Modified python sdk doppler velocity for Rx1, Rx2, and Rx3

Future Work

- Process 100% of Colorado Data
- CA-CFAR for SNR parameter
- Beamforming to focus field of view
- Further Experiments
- Different environmental processes
- TI-AWR 2243 Cascade EVM
- Point Cloud data





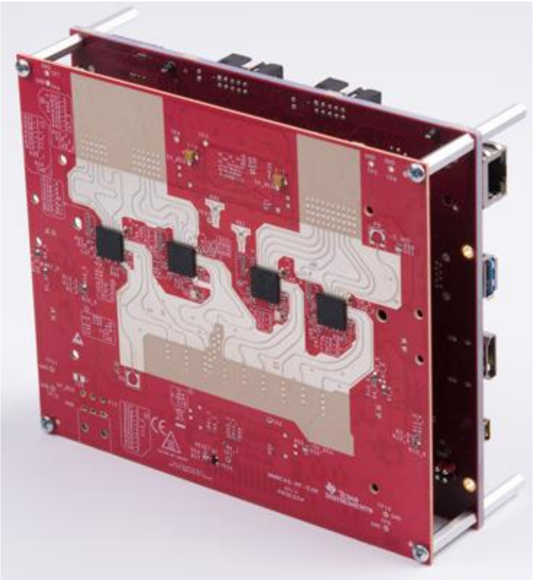


Figure 11: Clockwise: Credit – Texas Instruments AWR 2243 Cascade EVM, Credit – ABA Surveying Point cloud data, Beamforming with Infineon sensor performed in lab.

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References and Acknowledgments

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Thank You.

Questions?

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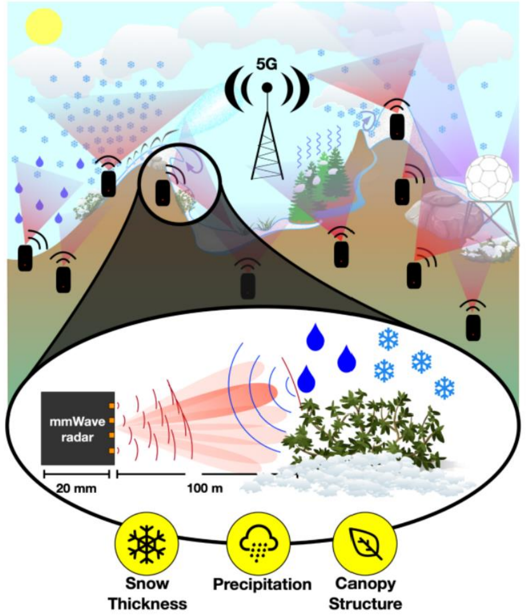

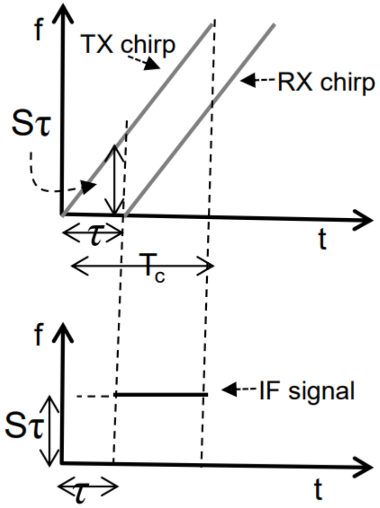

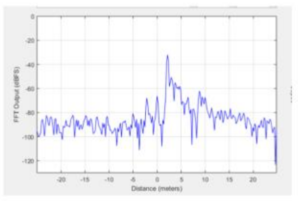

Figure 6.a: mmWave Radar Studio Rx1 output for concrete wall 2.1 meters from radar sensor. Frame 1, chirp1, Hann window has been applied. We can visually observe the peak is at ~2 meters and above -40 dBFS.

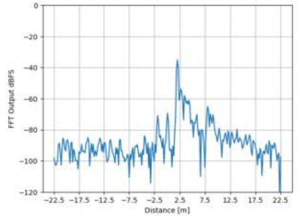

Figure 6.b: Python Rx1 output for concrete wall 2.1 meters from radar sensor. Frame 1, chirp 1, Hann window has been applied. We can visually observe the peak is at ~2 meters and above -40 dBFS.

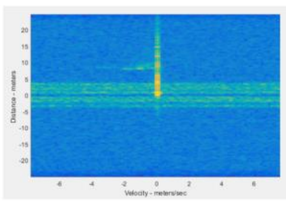

Figure 7.a: mmWave Radar Studio common doppler velocity output for person walking towards radar.

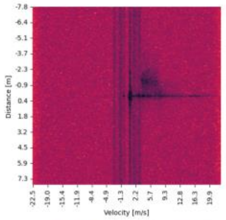

Figure 7.b: Python Rx1 doppler velocity output for person walking towards radar.