# A Dual-Axis Interferometric Radar for Instantaneous 2D Angular Velocity Measurement

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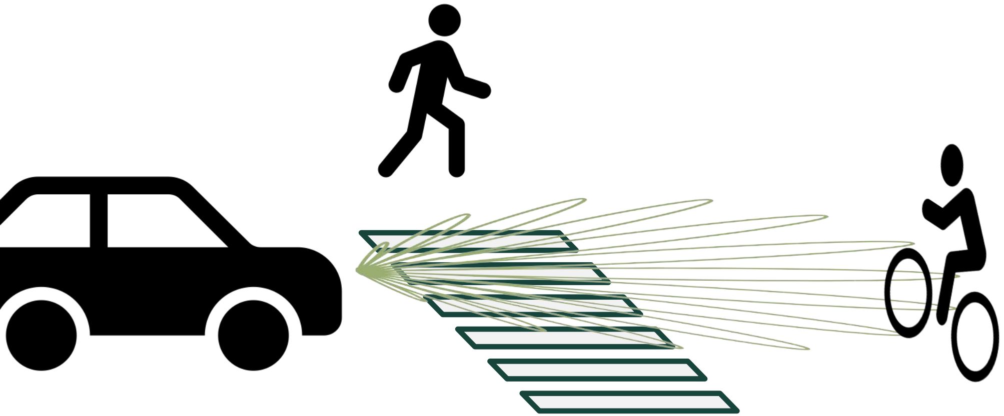
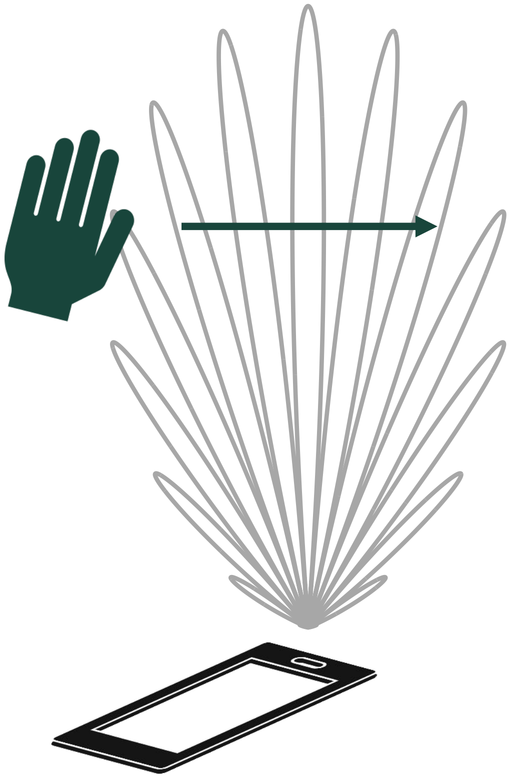
# Motivation

- Demonstrate the use of correlation interferometry to measure the **bearing and velocity** of a point target simultaneously
- Perform angular velocity measurements using **smaller lower-cost array** than conventional methods
- Perform 2D target velocity measurements tangential to the array **instantaneously, without the need for tracking**

# Motivation

- Applications
  - Human Computer Interfaces (HCI)
  - Automotive Radar
  - Airspace Monitoring





# Correlation Interferometry – 1-Dimensional

Received Signals:

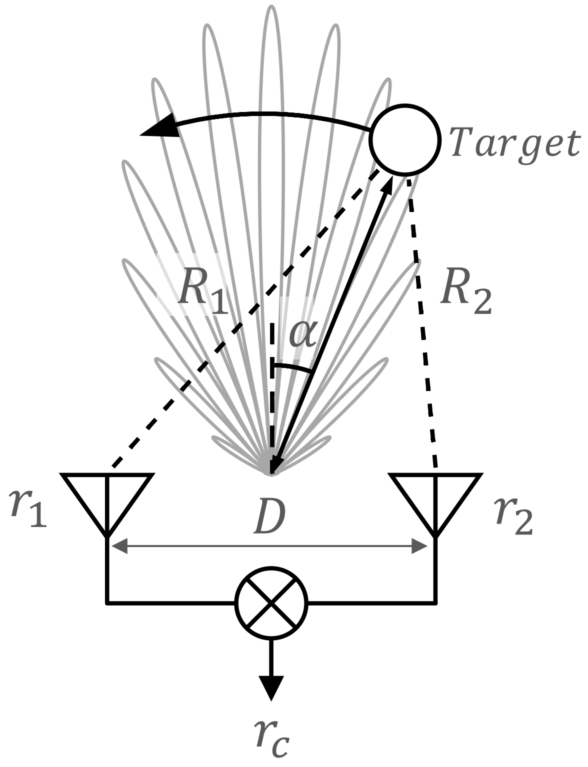
$$r_1(t) = \mathrm{A}(\alpha)\exp(j2\pi f_0 t)$$
$$r_2(t) = \mathrm{A}(\alpha)\exp\left[j2\pi f_0\left(t - \tau_g\right)\right] \qquad (1)$$

Geometric Time Delay:

$$\tau_g = \frac{D}{c}\sin\alpha \qquad (2)$$

Correlator Output:

$$\begin{aligned} r_c(\alpha) &= r_1(t)\cdot r_2^*(t) \\ &= \mathrm{A}^2(\alpha)\exp\left(j2\pi f_0 \tau_g\right) \\ &= \mathrm{A}^2(\alpha)\exp\left(\frac{j2\pi D}{\lambda}\sin\alpha\right) \end{aligned} \qquad (3)$$




1-Dimensional correlation interferometer

# Correlation Interferometry – 1-Dimensional

Correlator Output:

$$r_c(\alpha) = \mathrm{A}^2(\alpha)\exp(j2\pi D_\lambda \sin\alpha) \qquad (4)$$

where $D_\lambda$ = baseline in wavelengths

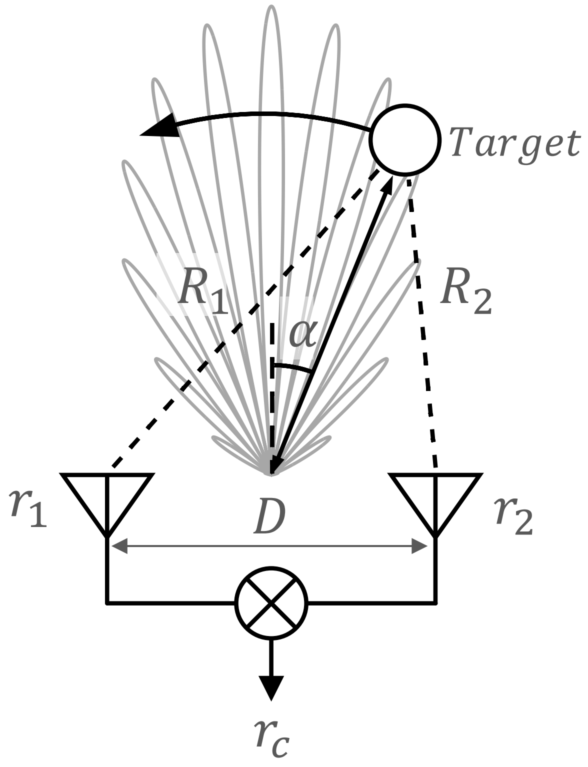
Angular Rate Measurement:

Using $\omega = \frac{d\alpha}{dt} \implies \alpha = \omega t + \alpha_0$

$$f_s = \omega D_\lambda \cos(\omega t) \qquad (5)$$

Finally, using $\omega = \frac{v}{R}$

$$\boxed{v_\alpha = \frac{f_s R}{D_\lambda}} \qquad (6)$$

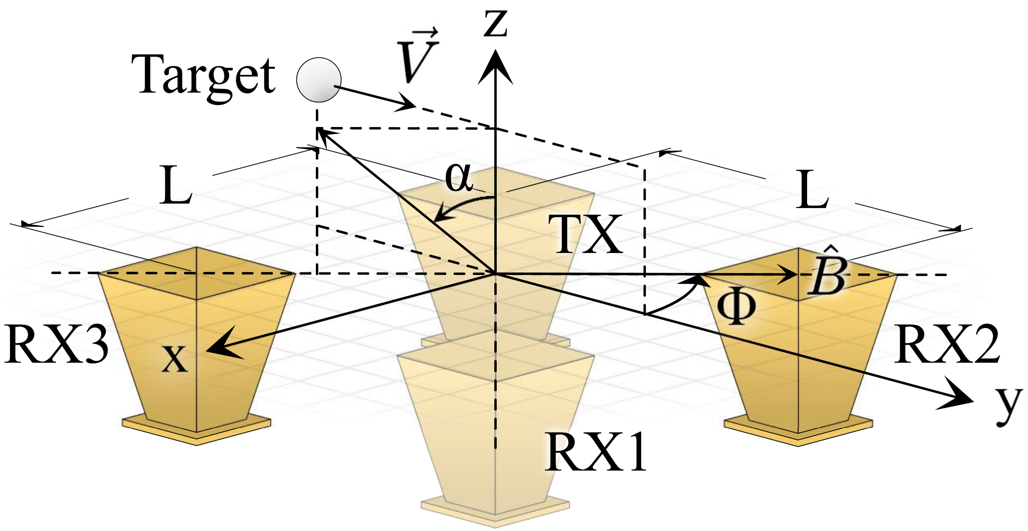



1-Dimensional correlation interferometer

# Correlation Interferometry – 2-Dimensional

- Three baseline pairs with baseline distance $D$
  - $D_{12} = L,\ D_{13} = L,\ D_{23} = \sqrt{2}L$
- Angular velocity along $\hat{B}$:

$$v_\alpha = \frac{f_s R}{D\lambda}\cos(\Phi) \qquad (7)$$



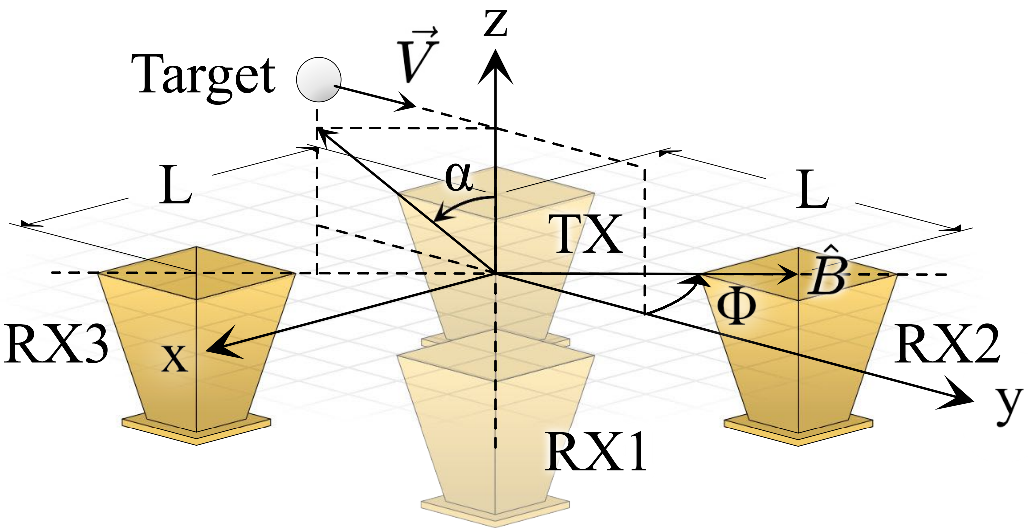

2-Dimensional correlation interferometer

# Correlation Interferometry – 2-Dimensional

- 2D Tangential Velocity:

$$\phi = \operatorname{atan2}(v_{\alpha y}, v_{\alpha x}) \qquad (8)$$

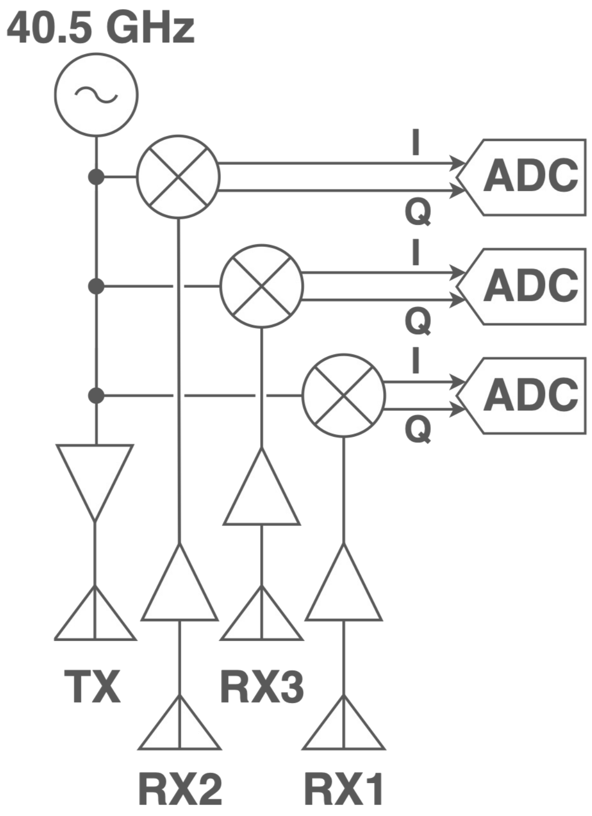
$$V = \sqrt{v_{\alpha y}^2 + v_{\alpha x}^2} \qquad (9)$$

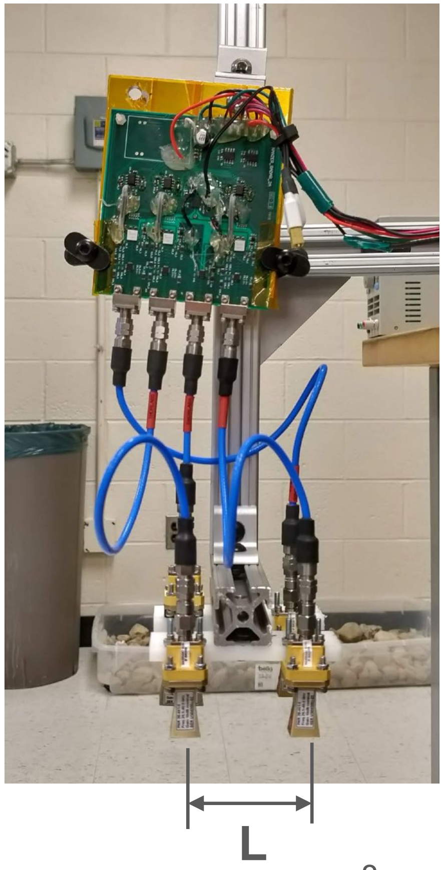



2-Dimensional correlation interferometer

# Measurement System – Radar Hardware

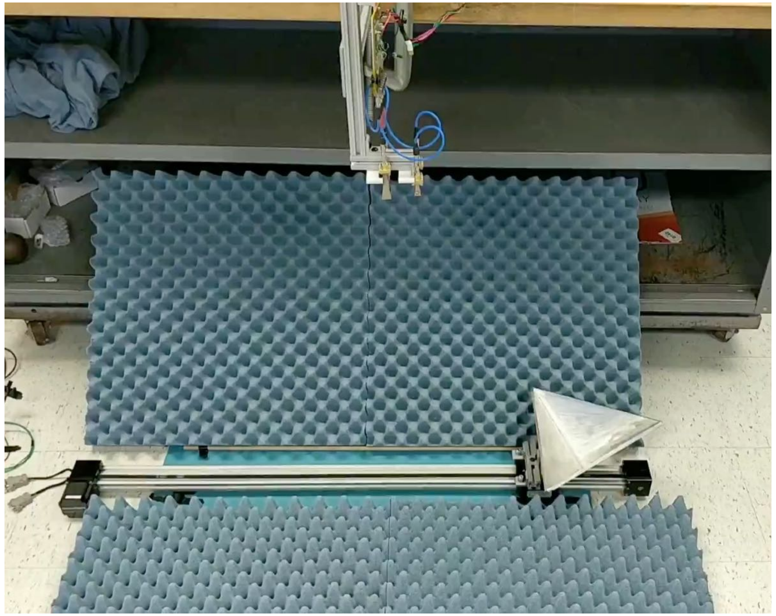
- Transmitter:
  - 40.5 GHz Continuous Wave
- Antennas:
  - TX: 15 dBi
  - RX: 10 dBi
  - L=7λ
- ADC:
  - National Instruments USB-6002 DAQ
  - Sample Rate: 4.166 kHz



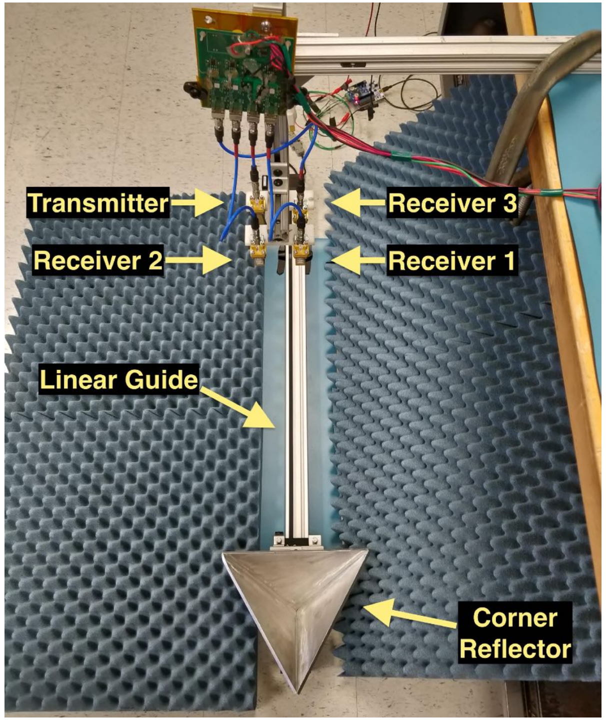
# Experimental Configuration

## Target Trajectory



Target velocity: 501.31 mm•s$^{-1}$

## Measurement Configuration

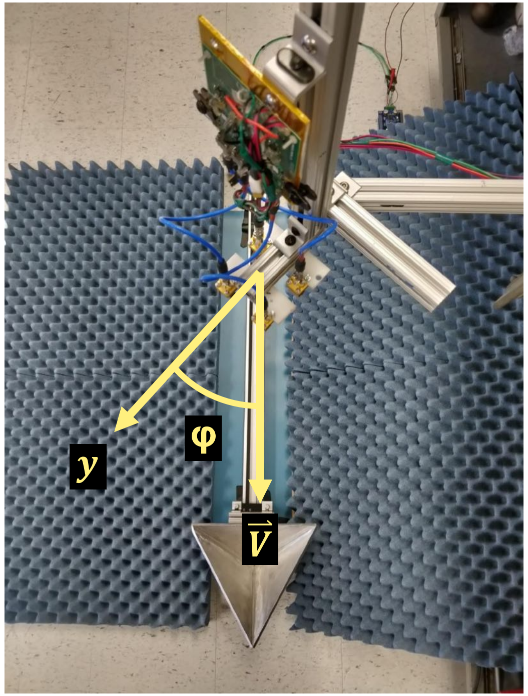


# Experimental Configuration

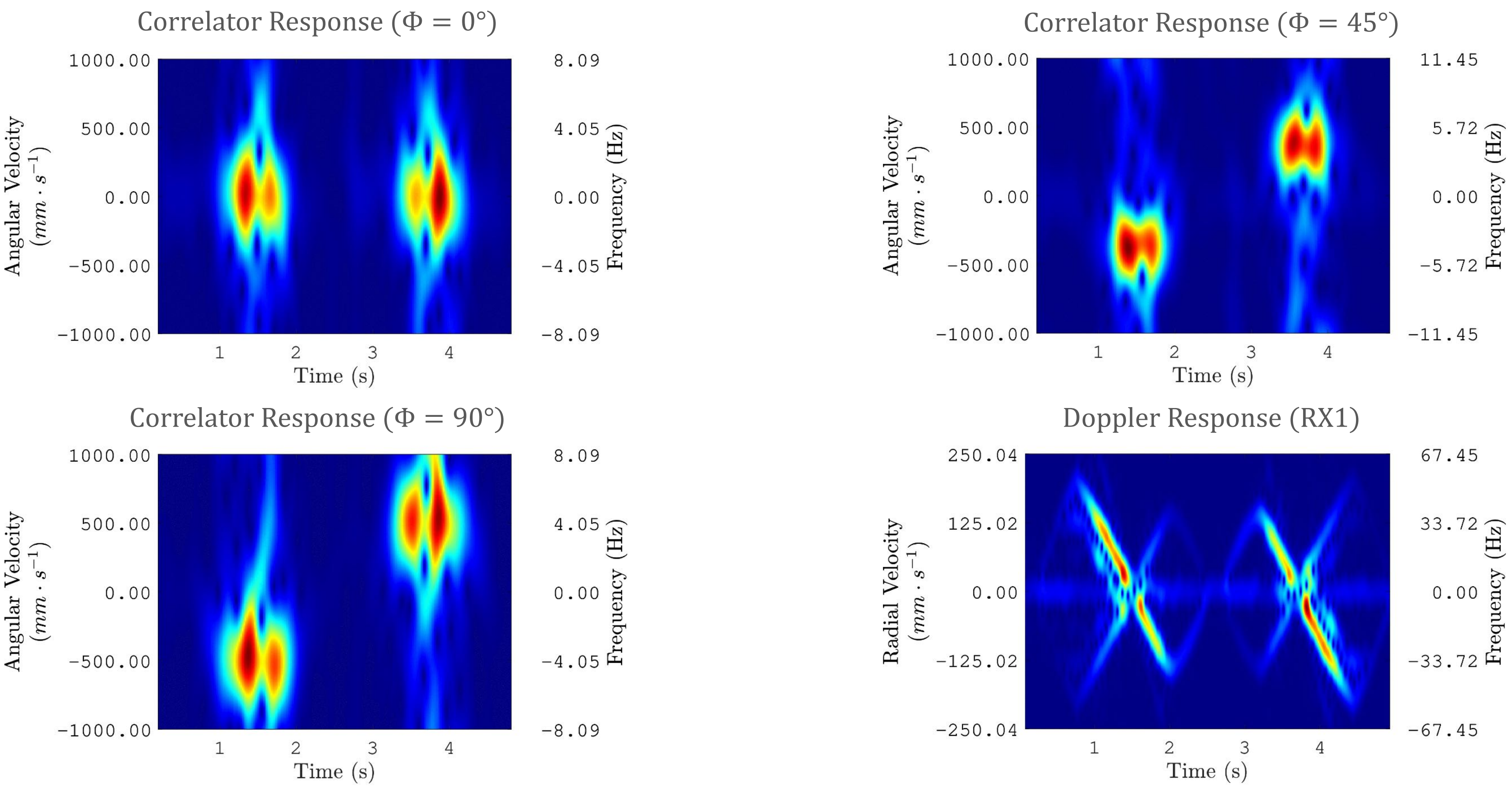
- Radar rotated to demonstrate reconstruction of target bearing angle

- Target bearing φ was varied from 0° to 45° in 15° increments

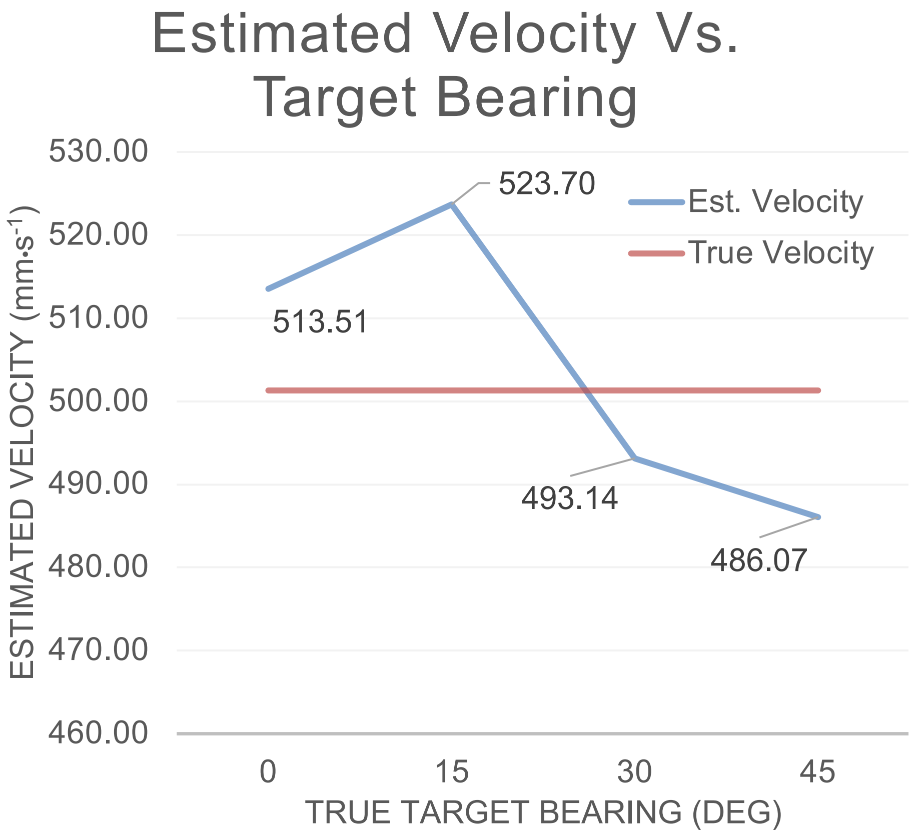
## Varying Target Bearing (φ)



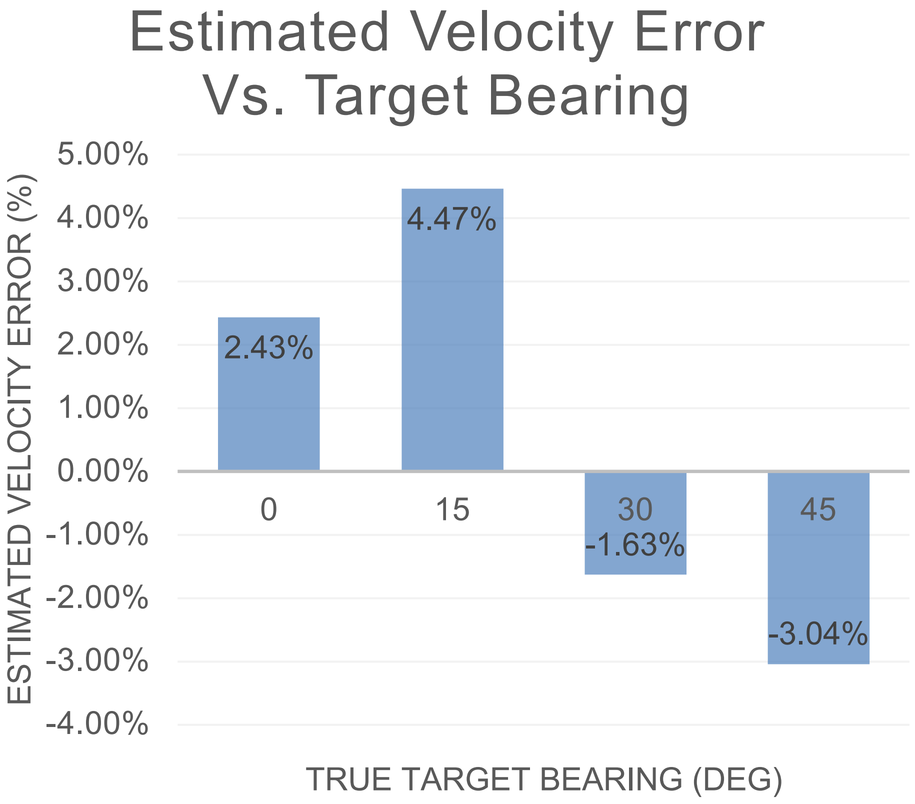
# Varying φ: β=0°; φ=0°

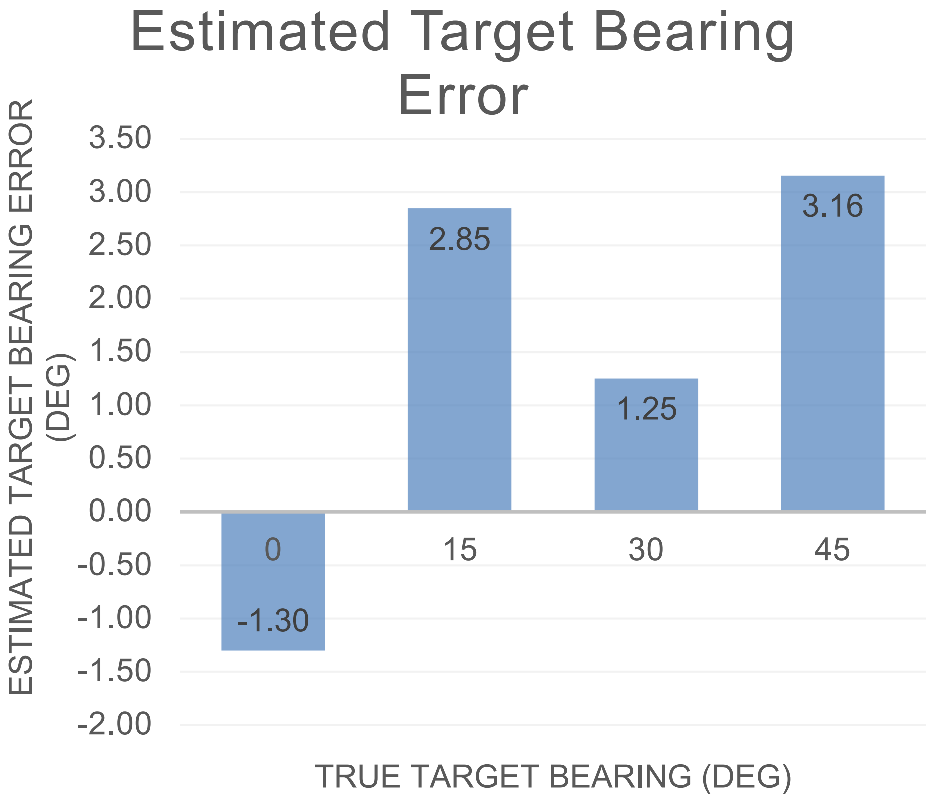


# Varying Bearing Measurements




# Varying Bearing Measurement Error



# Conclusions

- A dual-axis interferometric radar is capable of measuring 2D motion tangential to the array
- At mmWave frequencies, the total array size can be made very compact as was demonstrated using 7λ baseline
- Target bearing and velocity estimation can be performed with high accuracy:
  - Bearing estimates often under 3° absolute error
  - Velocity estimates often under 5%