

High Resolution Millimeter Wave SAR for Moving Target Indication



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MOTIVATION

Synthetic aperture radar (SAR) is an imaging radar technique that provides mapping of static ground scenes. Some existing and forthcoming SAR systems thereby provide very high resolution in the centimeter domain. While high azimuth resolution is achieved by signal processing techniques, range resolution for a traditional frequency modulated system is solely dependent on the signal bandwidth. For millimeter wave (mmW) SAR, operating at frequencies roughly between 30 and 100 GHz, a signal bandwidth of several hundred megahertz or even in the range of gigahertz is achievable. While mmW SAR is generally well suited for ground moving target indication (GMTI), especially at very slow radial target speeds, higher speeds may cause effects that not only displace moving targets but smear and defocus them considerably if not letting them disappear at all. This makes it difficult for GMTI algorithms to detect such targets. Additionally, smearing and defocus are more severe and disturbing at higher resolutions. We analyze the conditions where mmW SAR GMTI works fine, show simulated and real examples of moving targets at 35 GHz with FGAN MEMPHIS and compare them to L-band SAR data.



FGAN MEMPHIS
35 and 94 GHz mmW SAR



SAR Carrier: C-160 Transall

THEORY

- **Range Smear**
due to Radial Velocity

$$v_r t \geq \rho_r,$$

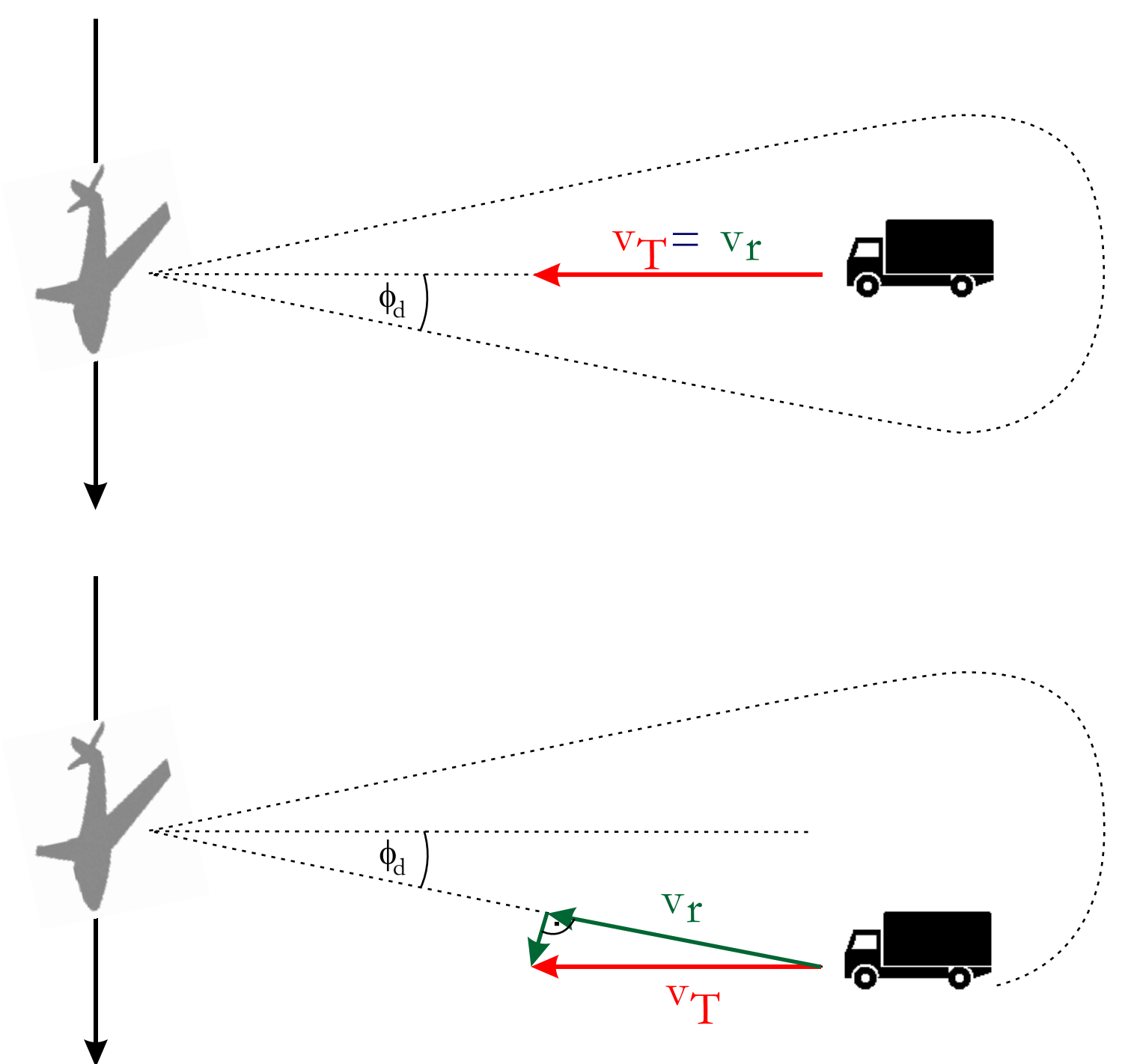
- **Azimuth Defocus**
due to Radial Target Acceleration and Tangential Target Velocity

$$\frac{2\pi}{\lambda R(t)} \left| \left(1 - \frac{v_c}{v_s}\right)^2 - \frac{a_r R_0}{v_s} - 1 \right| (v_s t)^2 \geq \pi$$

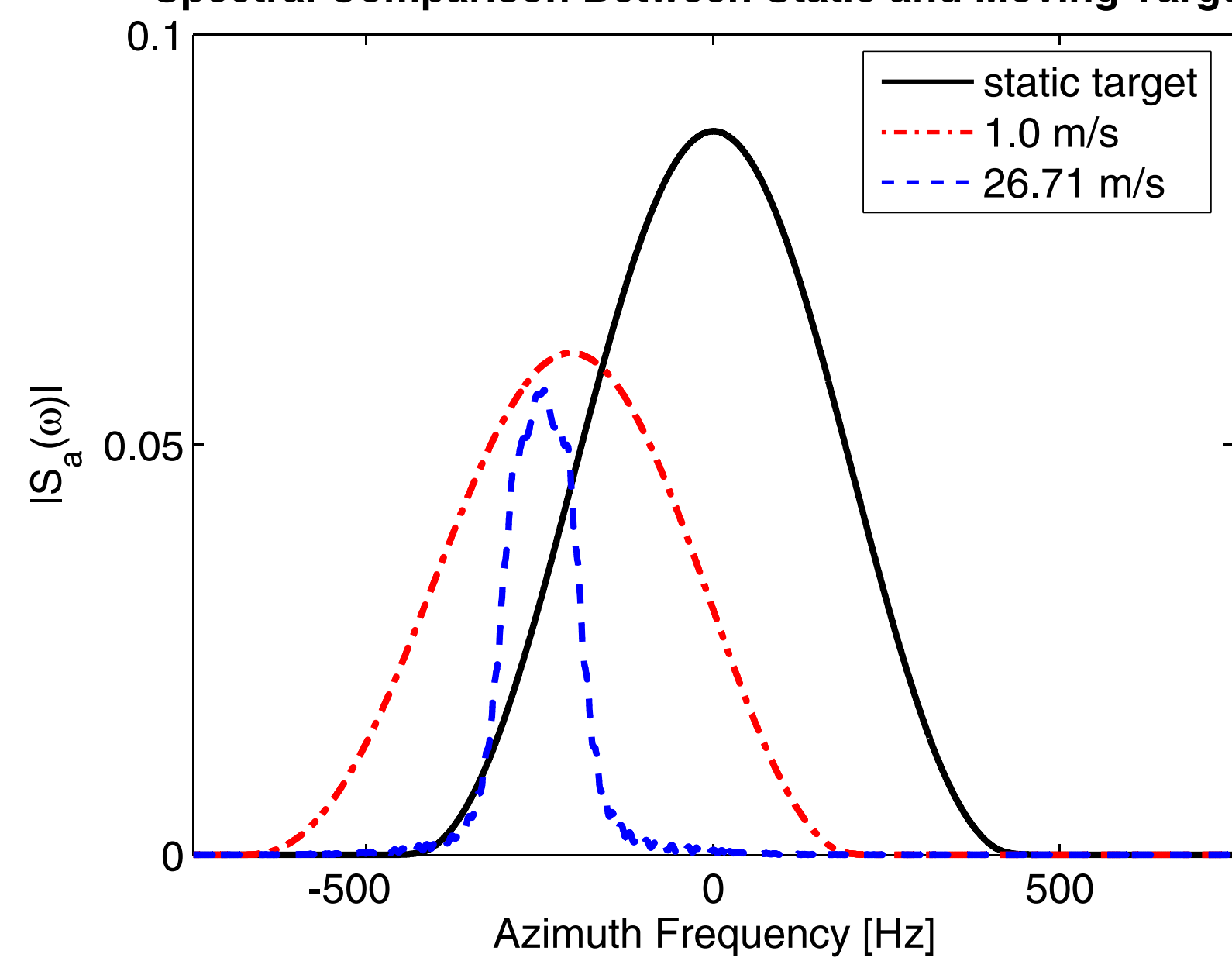
- **Displacement in Azimuth**
due to Radial Target Velocity

$$d = \frac{v_r}{v_s} \cdot R(t)$$

a_r : Radial Target Acceleration
 d : displacement
 $R(t)$: Range to the Target
 R_0 : Target Range of Closest Approach
 t : Observation Time
 v_c : Cross-Range Target Velocity
 v_r : Radial Target Velocity
 v_s : Sensor Velocity in Cross-Range
 λ : Carrier Wavelength
 ρ_r : Range Resolution



Spectral Comparison Between Static and Moving Targets



- The static target shows a typical azimuth frequency spectrum with highest signal intensities at antenna broadside (0 Hz).

- The fast target moving in range with 26 m/s has large tangential velocity and radial acceleration components, jolting its signal spectrum.

- The slow target moving in range with 1 m/s shows mostly a frequency shift and decreased intensities.

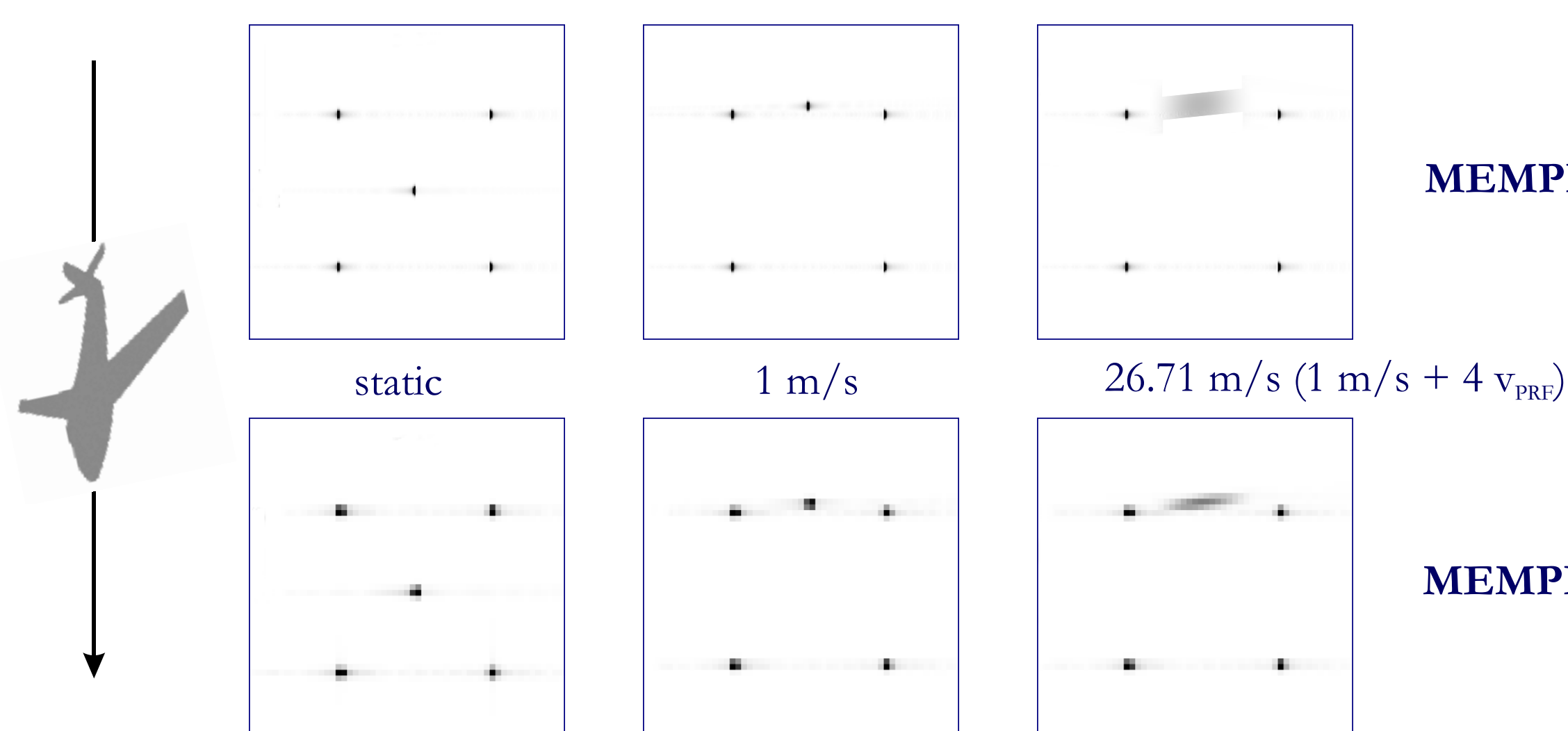
- In MEMPHIS, the fast and the slow target are displaced by the same distance because of a fourfold PRF ambiguity.

TYPICAL SAR SYSTEM PARAMETERS

	MEMPHIS High Res	MEMPHIS Low Res	E-SAR L-Band
Carrier Frequency	35 GHz	35 GHz	1.3 GHz
PRF	1500 Hz	1500 Hz	670 Hz
Pulsewidth	4.8 μs	1.2 μs	5 μs
Waveform	800 MHz Chirp	200 MHz Chirp	100 MHz Chirp

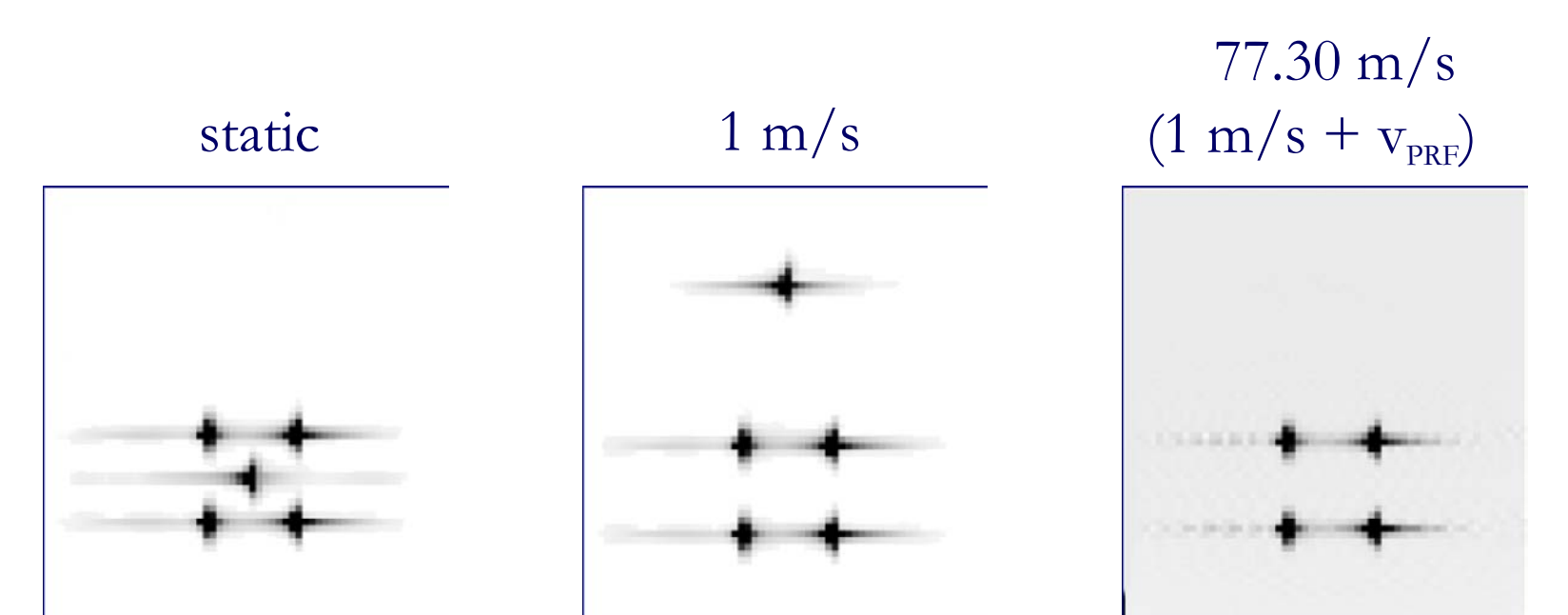
SIMULATIONS

TIME



The four static corner targets form a square of 20 m edge length

E-SAR 100 MHz



EXPERIMENTAL DATA



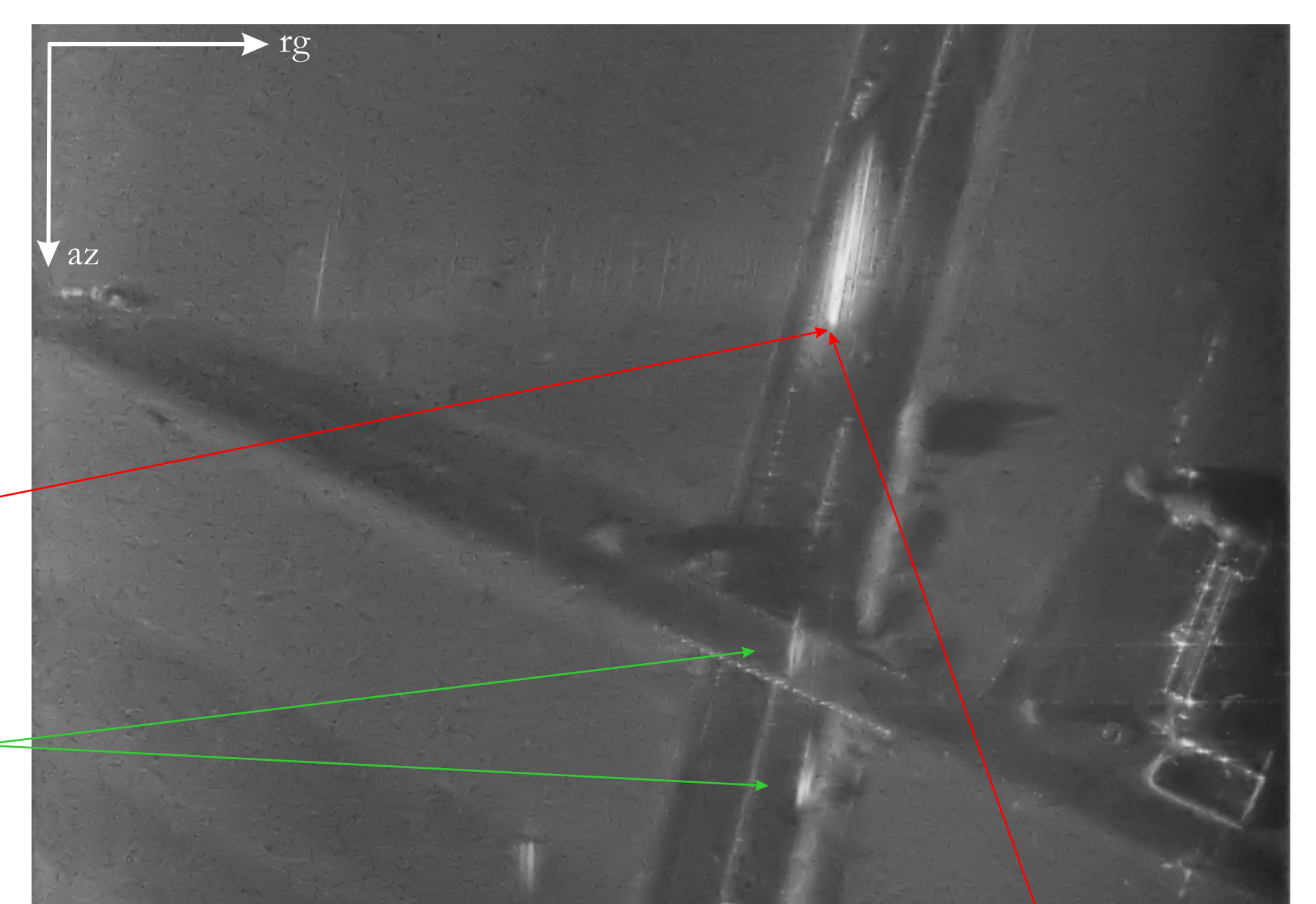
MEMPHIS Image Resolution: 19 cm

2 Puch all-purpose vehicle, moving on a runway in range at 15 m/s.

Truck on a highway moving with 10 m/s in range and 28.5 m/s in cross-range

True Vehicle Dimensions: 4.6 m x 1.7 m
 Smear and Defocused: 17 m x 7 m
 Displacement: ~5 - 15 m

True Ground Speed: 110 km/h
 Large Smearing and Defocusing
 Displacement: ~3 - 10 m

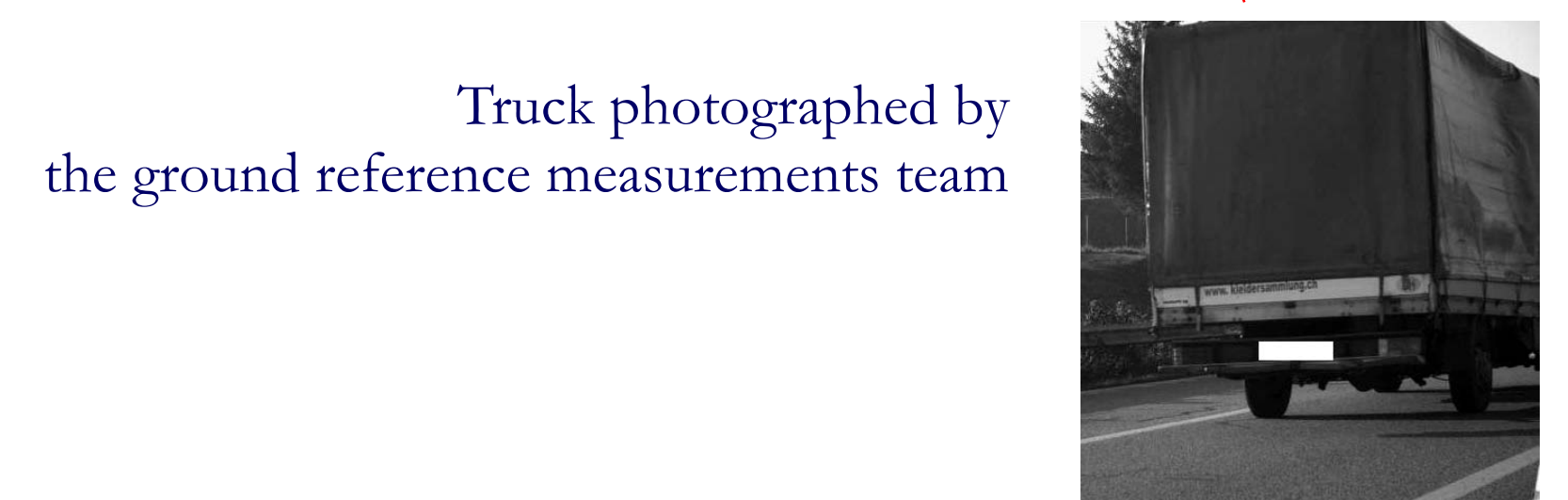


Additionally visible: 2 cars

CONCLUSIONS

SAR systems working in the mmW domain have some clear advantages as well as disadvantages over other, more conventional systems when GMTI algorithms are applied. The small antenna aperture reduces smearing and defocusing effects of moving targets while at the same time, the small wavelength is very sensitive to minor movements. Unfortunately, the same small wavelength causes high Doppler frequency shifts requiring either a very large system PRF or additional target information to solve velocity measurement ambiguities.

We showed for simulated as well as real data how much targets are smeared and defocused at small and large target velocities in high resolution mmW SAR, and we compared simulated results to low resolution images and also to those of an L-band SAR. Overall, mmW high resolution SAR seems well suited for low speed GMTI and less so for fast moving targets. Still, because of the small antenna aperture, it is a SAR solution for GMTI that offers good detection probabilities.



Truck photographed by the ground reference measurements team



Highway as seen by a camcorder from the SAR carrier