

Moving Target Indication with Dual Frequency Millimeter Wave SAR



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SYSTEM AND GMTI

TABLE I

FGAN MEMPHIS DUAL-FREQUENCY SAR SYSTEM PARAMETERS.

	35 GHz	94 GHz
Transmitter		
Power	500 W	700 W
PRF	1700 Hz	1700 Hz
Pulsewidth	1200 ns	1200 ns
Waveform	200 MHz Chirp	200 MHz Chirp
Receiver		
Dynamic Range	60 dB	60 dB
Bandwidth	200 MHz	200 MHz
Antenna		
3 dB Az Beam	3°	1°
3 dB El Beam	13°	13°
Gain	27 dB	29 dB

MOTIVATION

Ground moving target indication (GMTI) for synthetic aperture radar (SAR) provides information on non-static objects in a static ground scene. An efficient approach for GMTI is the use of multi-channel SAR systems for a space- and time-variant analysis of moving targets. This allows the indication, correction of position errors, and estimation of radial velocity components for moving targets in the SAR image. All three steps are possible because of the Doppler frequency shift in the radar signal caused by the radial target movement. Our work focuses on the millimeter wave (mmW) SAR system MEMPHIS with multi-channel amplitude-comparison monopulse data recording and the ability to use carrier frequencies of 35 and 94 GHz simultaneously, making it a dual frequency multi-channel SAR. Our discussions include mmW specific SAR GMTI considerations and an adaptive algorithm to collect information on moving targets with a mmW monopulse radar, and GMTI blind speed elimination and target velocity ambiguity resolving by dual frequency SAR. For an experiment with MEMPHIS, frequency spectra, processed SAR images with position corrected moving targets, and accurate target velocities and positions are presented to verify the developed algorithm.



SAR Carrier: C-160 Transall



MEMPHIS
35 and 94 GHz SAR



Ground Moving Targets
5 Puch All-Purpose Vehicles
with D-GPS on an Airfield Runway



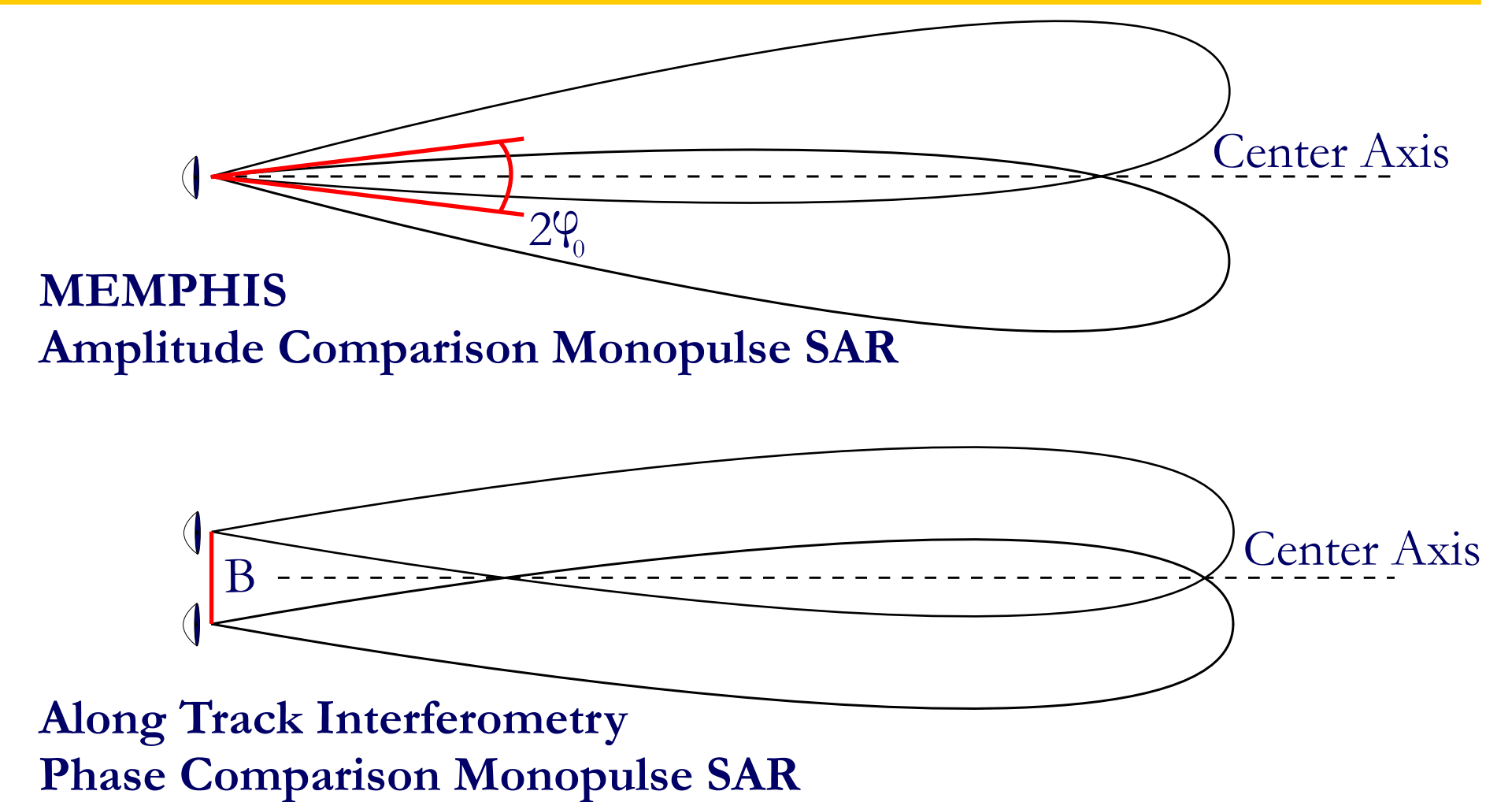
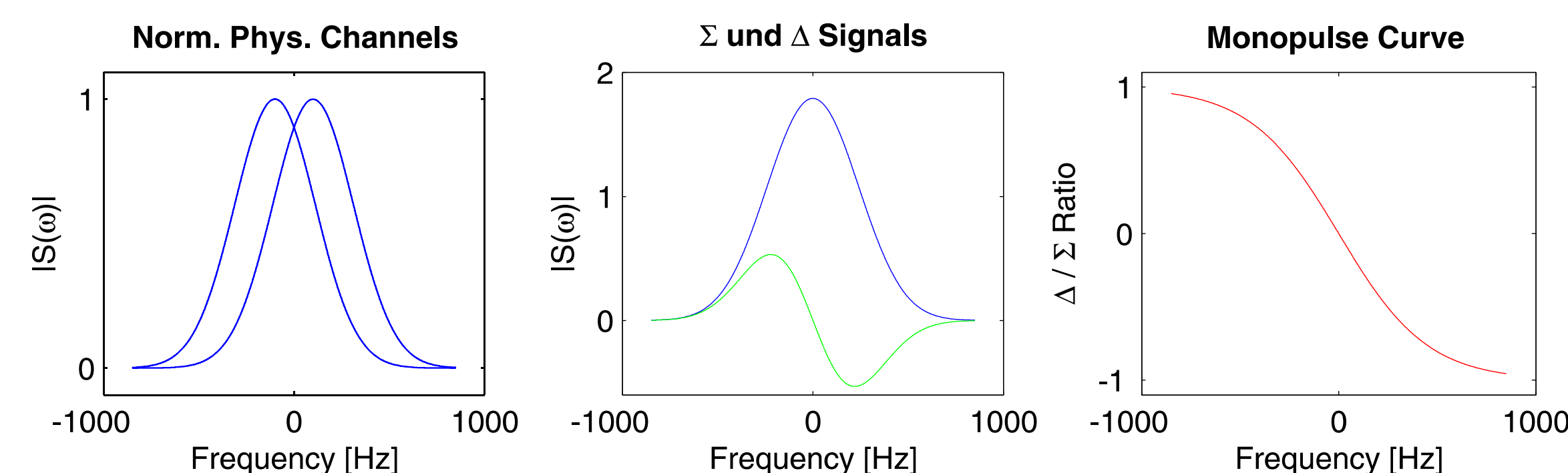
Experiment:
GMTI with MEMPHIS

METHOD

A monopulse radar has a sum signal Σ and multiple difference signals Δ . They are the result of two, four, or more separate channels sending the same radio signal at the same time (hence the term monopulse), but receiving ground return echoes independently. While Σ is the sum signal of echoes from all channels, Δ is formed from the differences thereof. These differences in amplitude as well as phase come from different viewing angles or, in the case of moving targets in SAR, from different Doppler frequencies.

Dual Frequency GMTI:

Ambiguous velocity measurements and, closely related, blind target speeds, are two important issues that almost always arise when looking at GMTI for mmW SAR because of high carrier frequencies and a limited PRF. The basic idea of exploiting dual-frequency radar to resolve Doppler ambiguities is to resolve Doppler shifts that are multiples of the PRF for one carrier frequency by using a second frequency where the Doppler shifts are a different multiple of the PRF. Hence, the problem reduces to a matter of least common multiples.

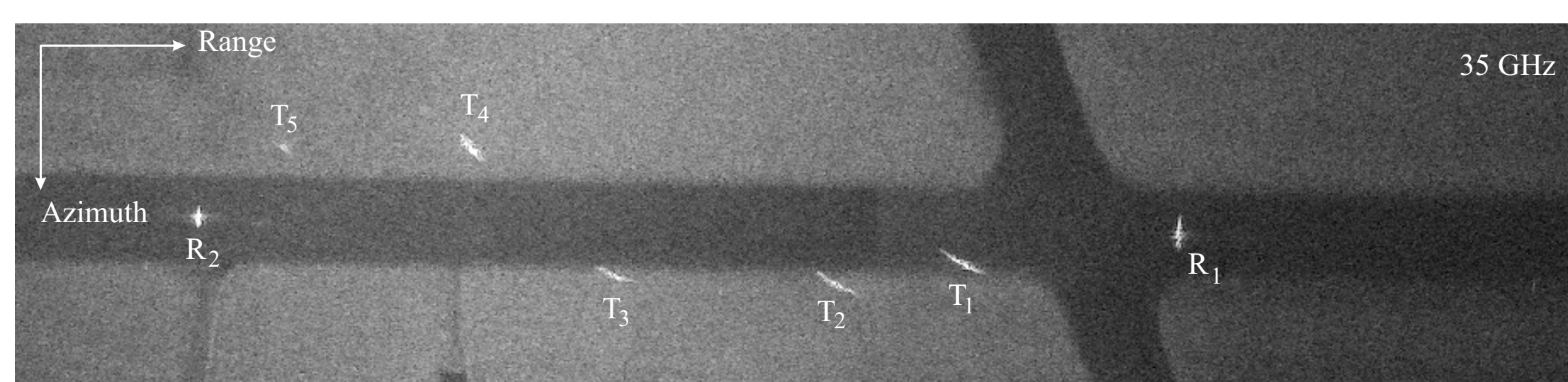


The monopulse curve of all Doppler frequencies from the static ground scene in a SAR may be described mathematically by a hyperbolic tangent as

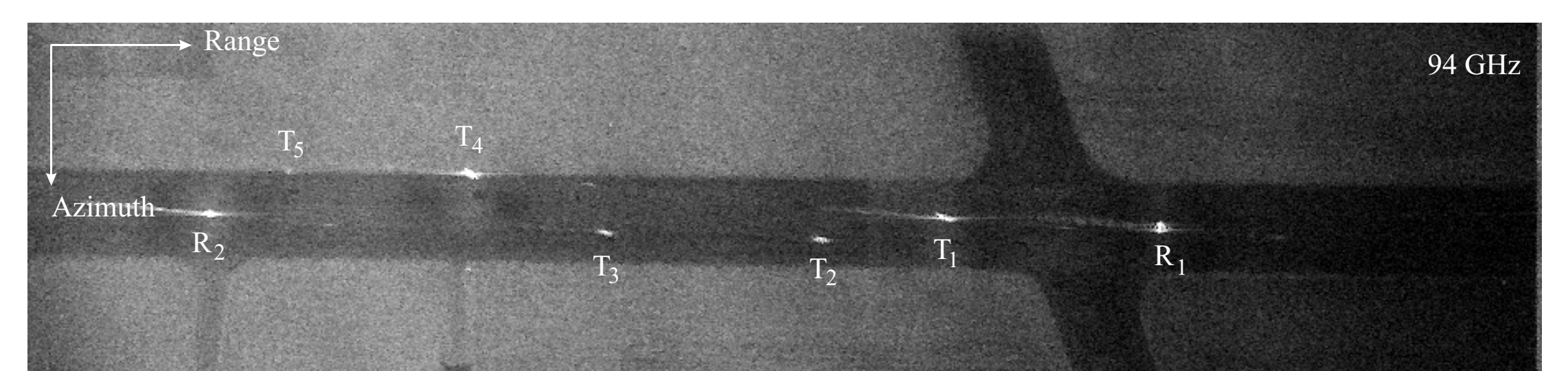
$$M(\omega) = \frac{\Delta(\omega)}{\Sigma(\omega)} = \tanh(2\nu^2\omega\omega_0)$$

ω : Doppler frequency
 ω_0 : Doppler Shift due to Antenna Squint φ_0
 ν : normalization constant

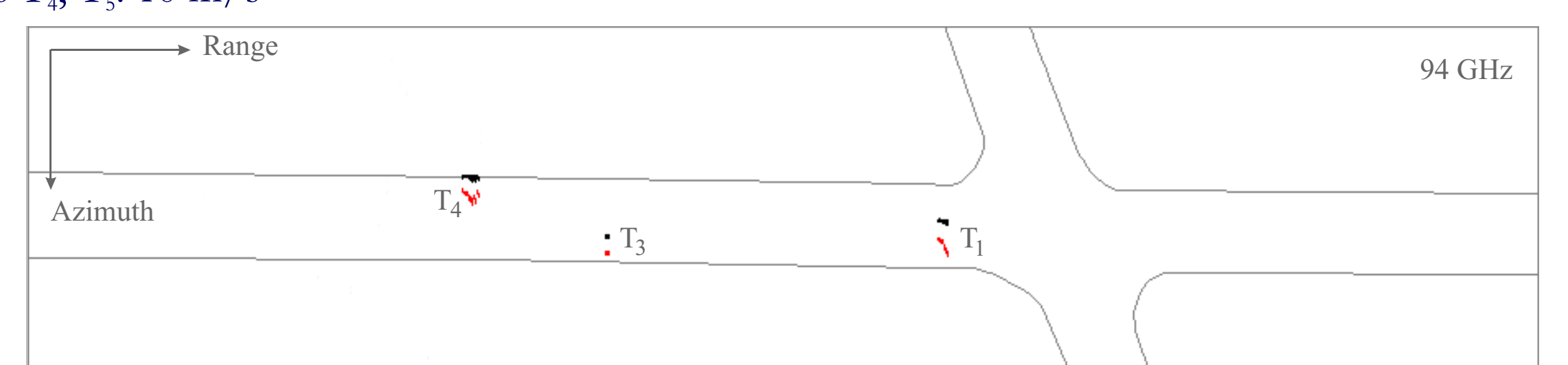
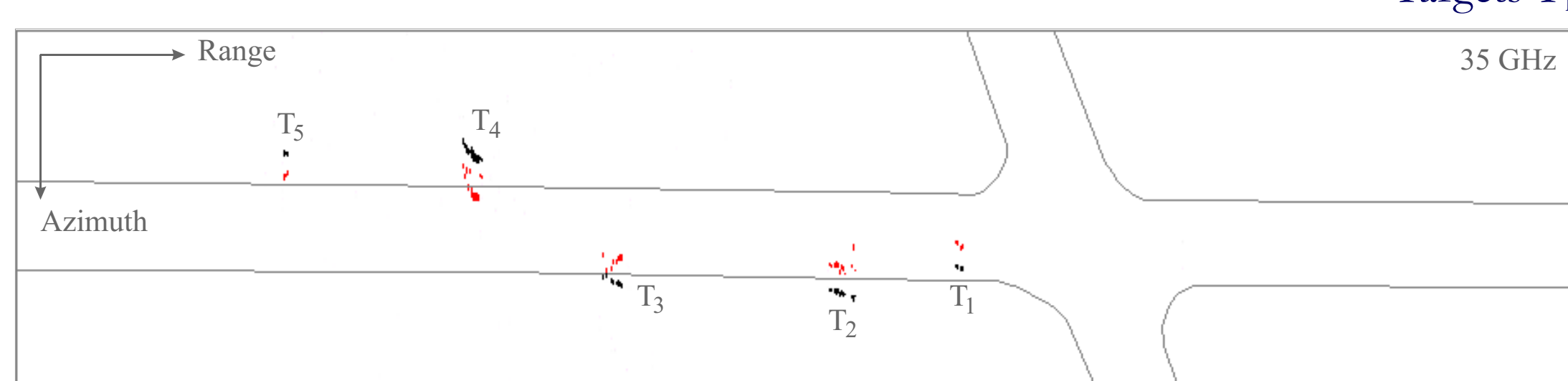
TIME



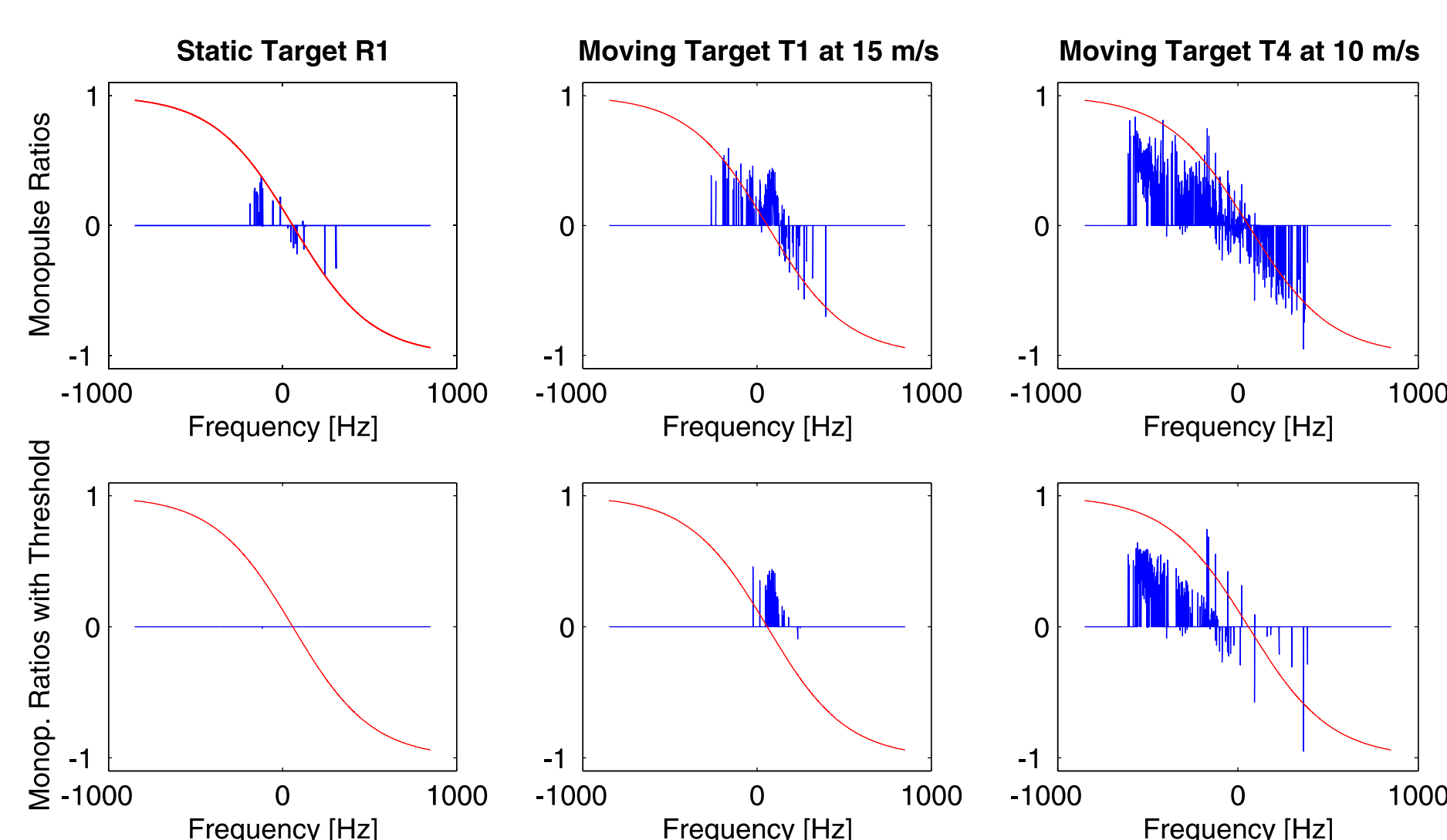
SAR Sum Channel
Intensity Image



Automatic GMTI
and Position
Correction



FREQUENCY



Monopulse GMTI processing gives us the spectral results shown at the left for 35 GHz and at the right for 94 GHz. Given are the spectra for the static reflector R_1 and targets T_1 moving at 15 m/s and T_4 at 10 m/s. The calculated monopulse ratios at the range bin of the reflector at the top left of the figure correspond very well to the estimated monopulse curve. At the bottom left, we see that no frequency remains in the spectrum after including a monopulse threshold. However, the target T_1 (middle) as well as the target T_4 (right) are clearly identified via monopulse processing. Their relative frequency shifts are easily discernible.

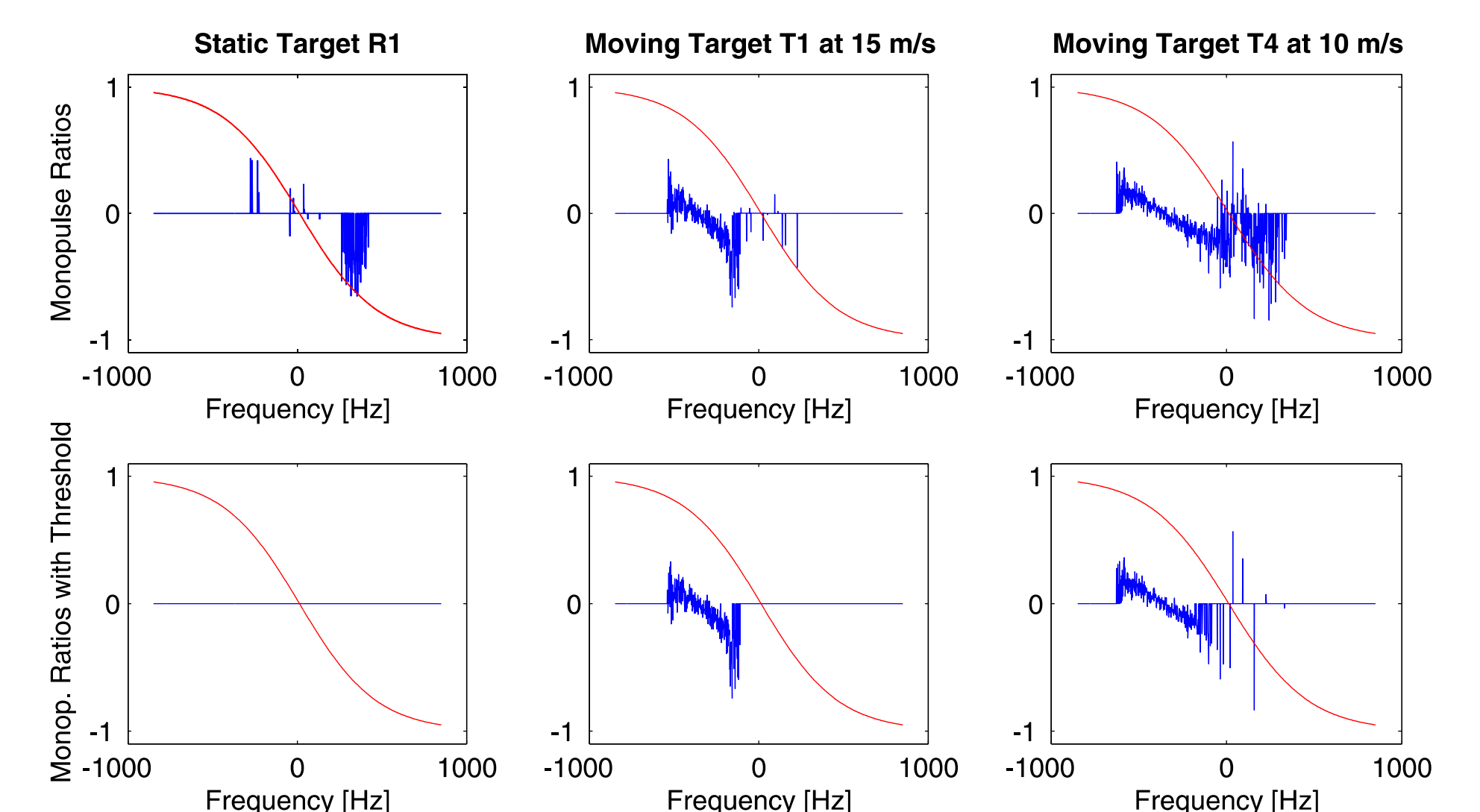


TABLE II

NOMINAL VALUES AND MEASURED RADIAL VELOCITIES OF MOVING TARGETS T_1 TO T_5 BY DIFFERENTIAL GPS AND BY THE MEMPHIS DUAL-FREQUENCY MONOPULSE SAR SENSOR. NEGATIVE VALUES INDICATE A MOVEMENT AWAY FROM THE SAR. THE NUMBERS OF DOPPLER AMBIGUITIES m AND n ARE RESOLVED VIA LEAST COMMON MULTIPLES TO GET THE DUAL-FREQUENCY VELOCITY ESTIMATE.

Target	Nom. Velocity (ground) [m/s]	35 GHz SAR Vel (radial) [m/s]	94 GHz SAR Vel (radial) [m/s]	m	n	Mean Dual-Freq Vel (radial) [m/s]	GPS Vel (radial) [m/s]	Δ SAR-GPS [m/s]
T_1	15	$0.57 + m \cdot 7.28$	$-0.64 + n \cdot 2.71$	-2	-5	-14.1	-14.4	0.3
T_2	15	$0.66 + m \cdot 7.28$	blind	-2	—	-13.9	-14.0	0.1
T_3	15	$0.73 + m \cdot 7.28$	$-0.46 + n \cdot 2.71$	-2	-5	-13.9	-14.2	0.3
T_4	10	$-1.05 + m \cdot 7.28$	$-0.58 + n \cdot 2.71$	-1	-3	-8.5	-8.8	0.3
T_5	10	$-0.64 + m \cdot 7.28$	too weak	-1	—	-7.9	-8.7	0.8

RESULTS

CONCLUSIONS

For mmW SAR systems, amplitude-comparison monopulse data recording is a very effective GMTI technique that solves the dilemma of extremely short interferometric mmW baselines. It is a sound method with multiple channels sharing a single phase center.

Processing of monopulse data for SAR GMTI includes nonlinear data modeling to fit received and compressed signals to a monopulse curve in the range Doppler domain. Resulting deviations of moving targets from this function and thus from the static scene are well detectable and compensable, allowing for exact radial target velocity calculations and position shift corrections.

When calculating radial target velocities, a general problem for mmW SAR MTI are high Doppler frequency shifts from the detected targets even at low velocities. Using dual-frequency information, high PRF requirements may be eliminated via the theory of least common multiples.