V2V-Aided Adaptive FMCW Radar Interference Mitigation

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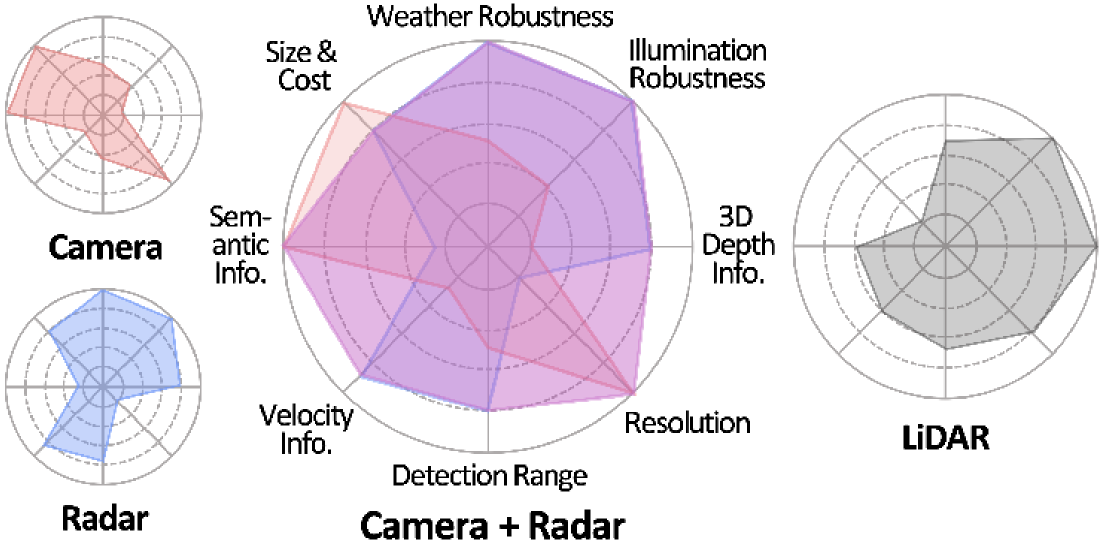
Outline

- Motivation: Radar in ADAS and ADS
- Radar fundamentals
- Radar interference: How does it take place?
- Proposed method for radar-radar interference mitigation
- Experimental results
- Conclusions

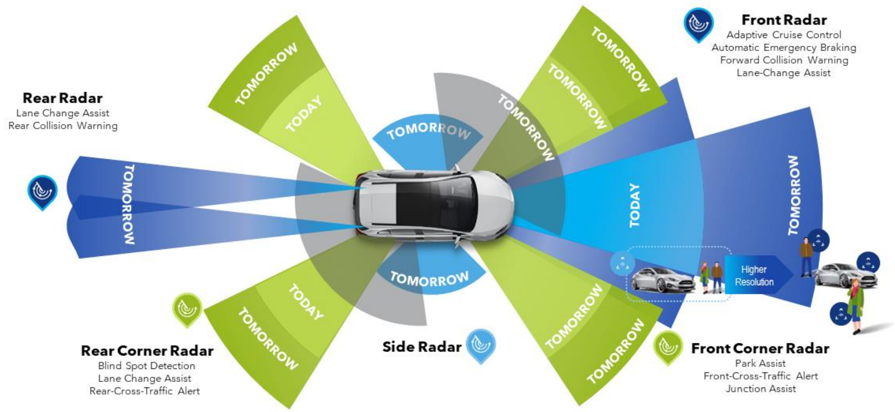
Radar in ADAS and ADS

The characteristics of radars complements ideally with other frequently used sensors.



Vision-RADAR fusion for Robotics BEV Detections: A Survey. Apoorv Singh

Radars are versatile sensors that can be configured to different precepting tasks for a wide range of fields of view and use cases.



NXP semiconductors

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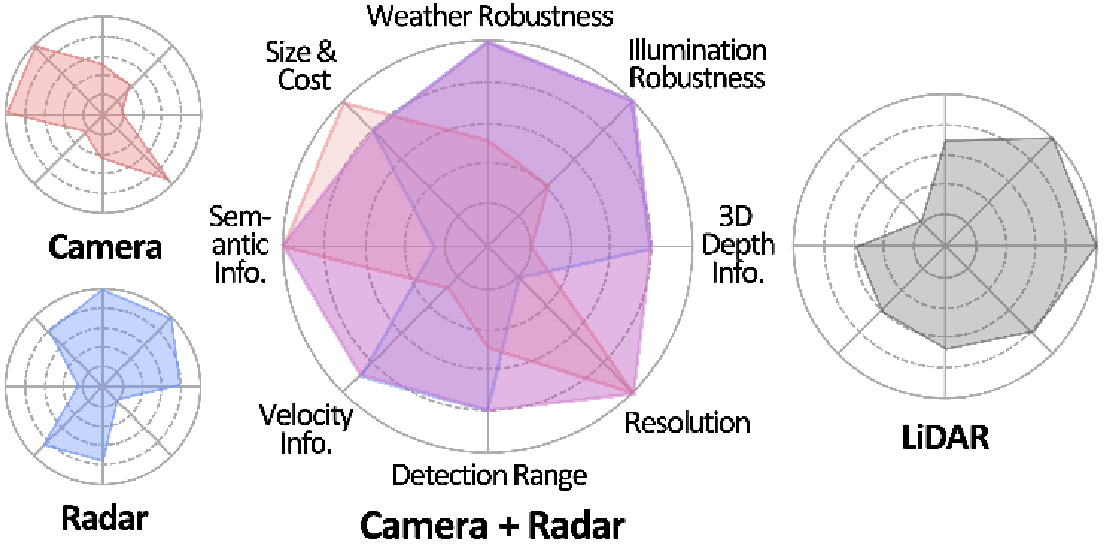

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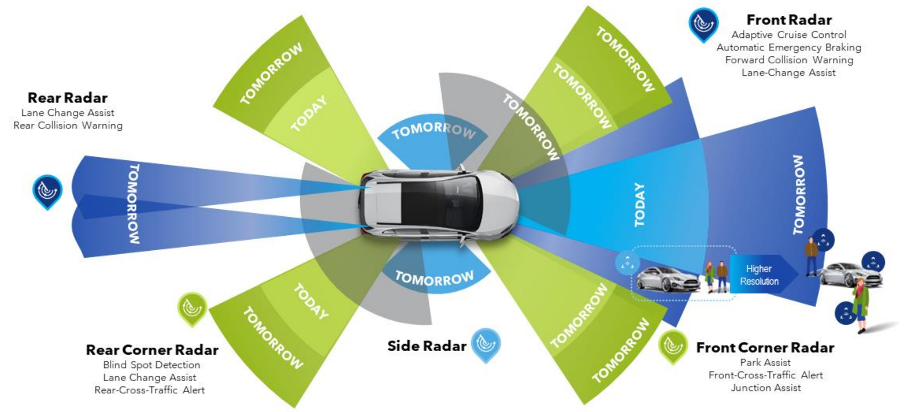

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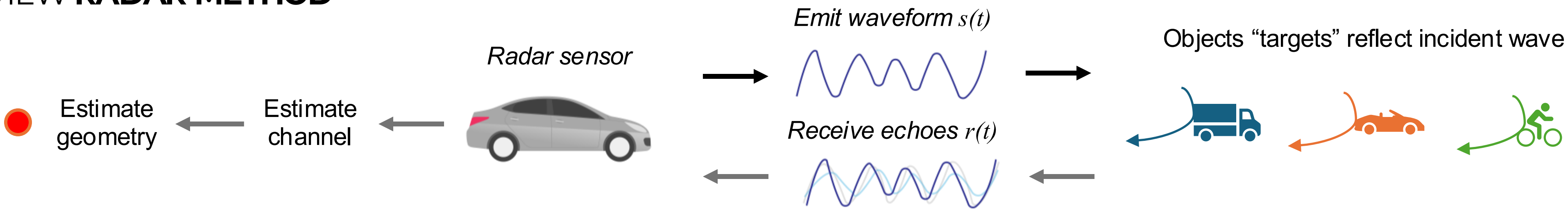
Challenge: Increased demand leads to higher density of radar sensors in limited electromagnetic spectrum 76-81 GHz.

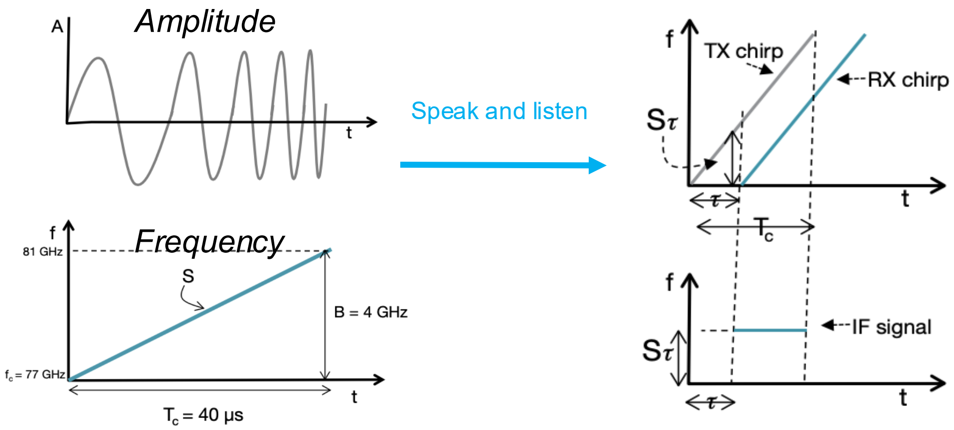
RADAR BASICS

1. **Emit an EM radar-wave,** detect its reflection and compare both waves: gives range
2. **Repeat** many times and obtain information of its speed
3. **Repeat from several points** of view and obtain information of DoA (azimuthal and elevation): 4D matrix: (radial distance, radial speed, az, el)

OVERVIEW **RADAR METHOD**



UNIT MEASUREMENT: **WAVE CHIRP**



The emitted and received waveform are compared:

The output is a plane wave related to each target

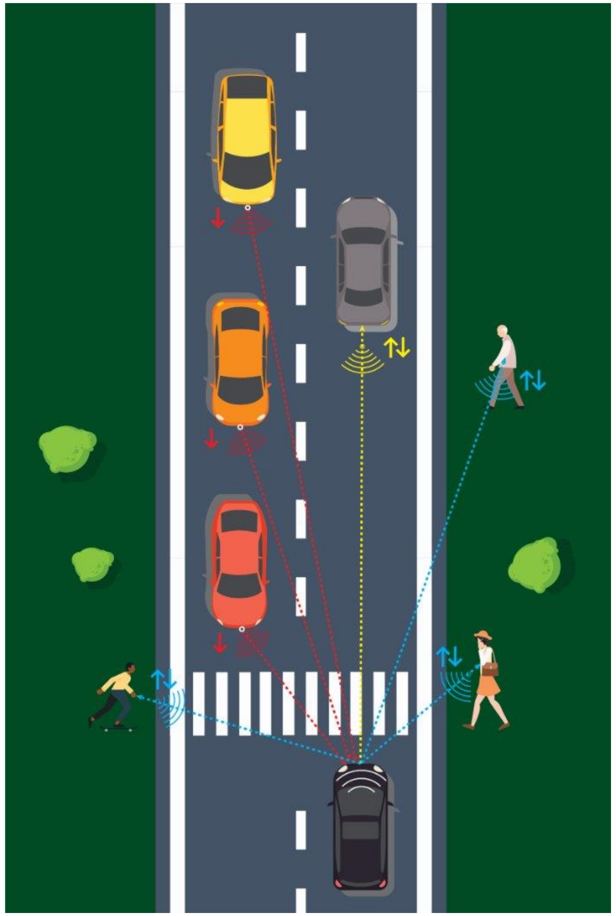
$$\Phi = A.\sin(\,\omega(r).t + \phi(\theta,\square e,\square v\_obj)\,)$$

THE **OUTCOME**

4-dimensional radar "cube" with the intensity values in the 3D field of view: range, azimuthal, elevation; and the radial speed of the targets.

Radar-Radar interference

Typical R-R interference scenario



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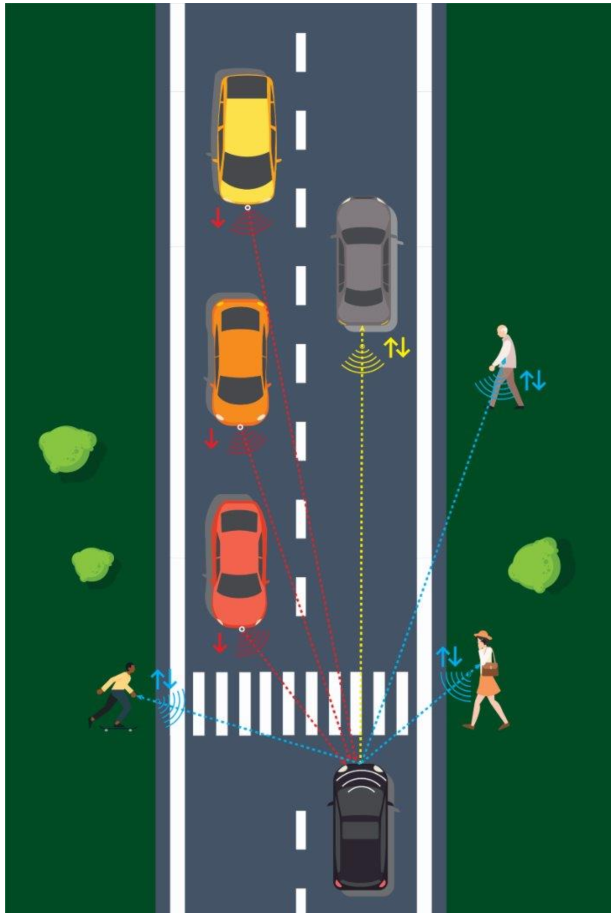
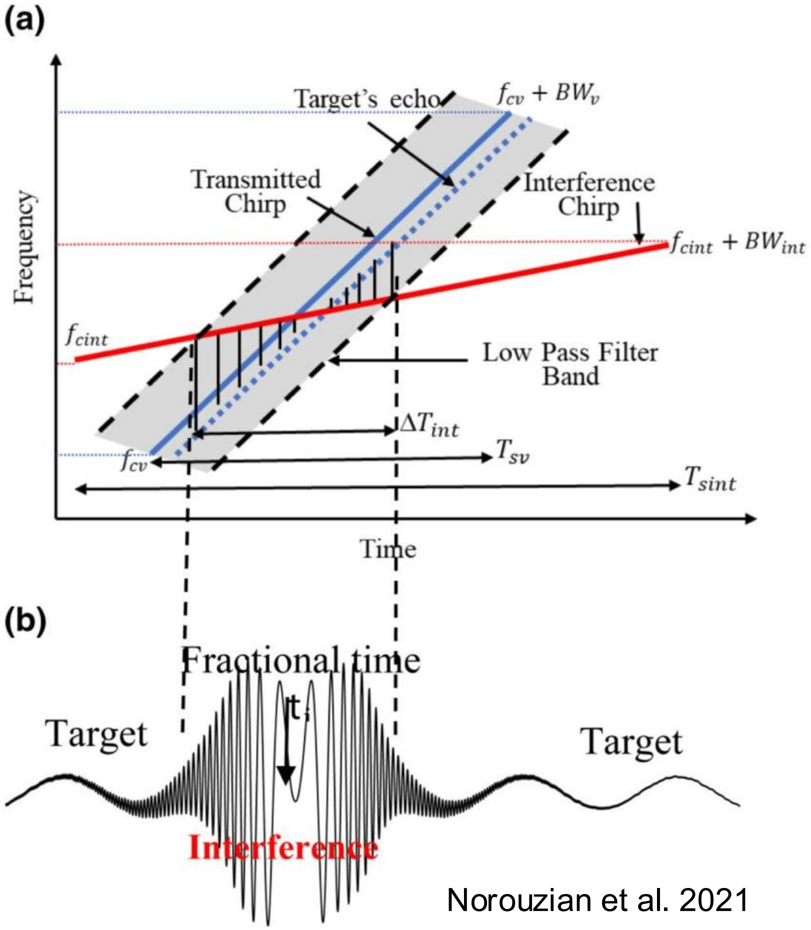


How does the radar interference affect the signal processing?

- The amplitude of the reflected wave (dashed blue) is reduced in the reflection.
- The aggressor chirp (red) is detected by the victim radar during the listening window.
- After multiplication of the signals the aggressor appears as a frequency variational wave.



Norouzian et al. 2021

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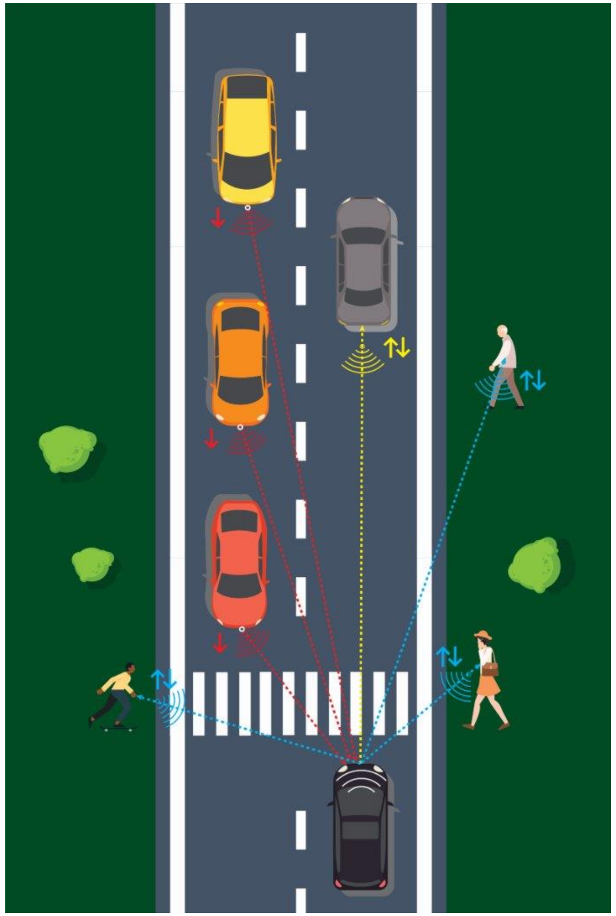

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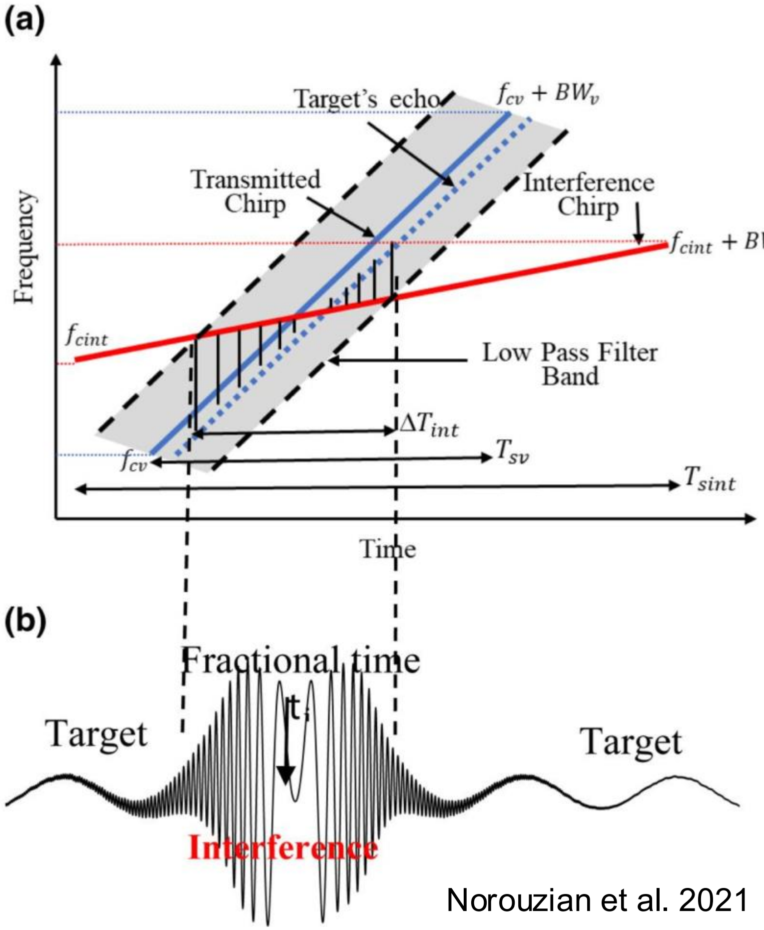


Norouzian et al. 2021

Outcome issues

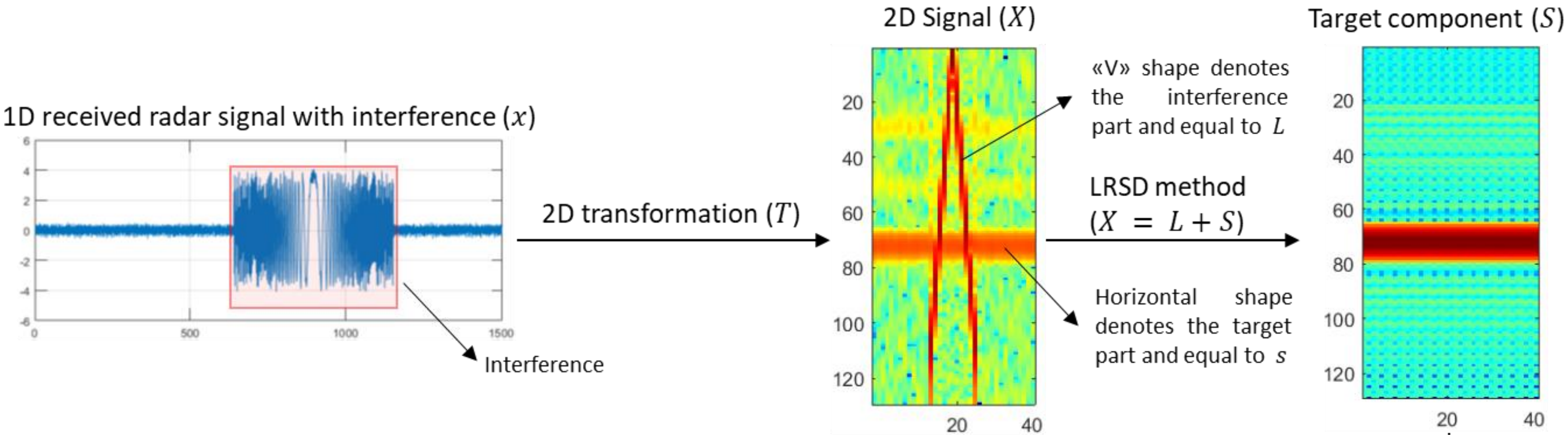
- Misinterpretation: Interference can result in reporting ghost targets.
- Signal Masking: Can completely obscure weak, real target reflections.

Proposed Adaptive Interference Mitigation Strategy

- **Overall Goal**: Enhance radar performance by dynamically adapting interference mitigation.
- **Core Contribution**: A novel approach to dynamically adapt the Robust Principal Component Analysis (RPCA) λ parameter (Low Rank Sparse Decomposition type LRSD).
- **Key enabler**: Leveraging Vehicle-to-Vehicle (V2V) communication to share aggressor radar parameters.
- **Process Flow**:

1. Convert 1D raw radar signals to 2D using Short-Time Fourier Transform (STFT).
2. Apply RPCA to separate target and interference components.
3. Reconstruct the interference-free target signal using Inverse STFT (ISTFT).
4. Adapt λ based on V2V-shared interference characteristics.

LRSD and RPCA for Signal Separation



The **2D STFT** matrix X is decomposed into two components : **X = L + S**

- **L** $\in R^{M \times N}$: Low-rank component representing the desired target signal.
- **S** $\in R^{M \times N}$: Sparse component representing the interference.

RPCA solves this problem via convex optimization:

$$\min_{L,S}(\|L\|_* + \boldsymbol{\lambda}\|S\|_1) \quad \text{s.t.} \quad X=L+S$$

$\|\cdot\|*$: Nuclear norm (promotes low rank of L).
$\|\cdot\|1$: L1-norm (promotes sparsity of S).
λ: Penalization parameter, balancing the trade-off.

Adaptive λ via V2V Communication

- **Motivation for Adaptive λ:** The optimal value of **λ** is highly dependent on the characteristics of the interference.
- **V2V Communication Role:** Aggressor radar parameters are shared between vehicles.

  Number of interferers

  Frequency slopes

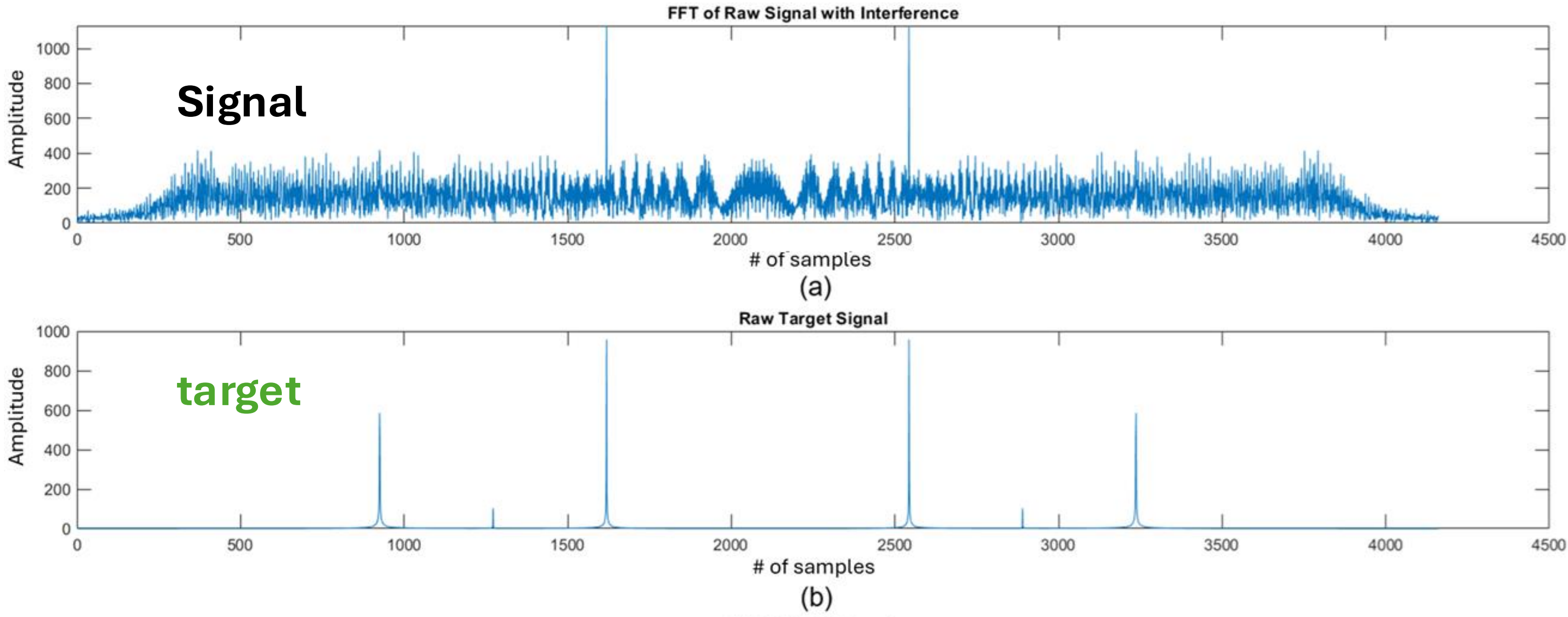
  Signal amplitudes
- **Mechanism:** This real-time shared information allows for dynamic, informed selection of the **λ** parameter.
- **Benefit:** Improves the robustness and adaptability of RPCA in dynamic interference environments.

Simulated scenarios

Scenarios conditions

- Variation of the target scenario.
- Variation of the aggressor conditions: #of aggressors, chirp slopes, amplitude of the aggressor, etc.

Figure: FFT of the wave signals related with: **Signal**, **target** and **target'.**
The spikes' position indicate the distance of the targets



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Signal = target + interference
Signal' = RPCA (Signal)
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The result obtained after applying RPCA method are compared with the ground truth state of the scenario: the **targets** signal

MSE (**target'**, **target**)

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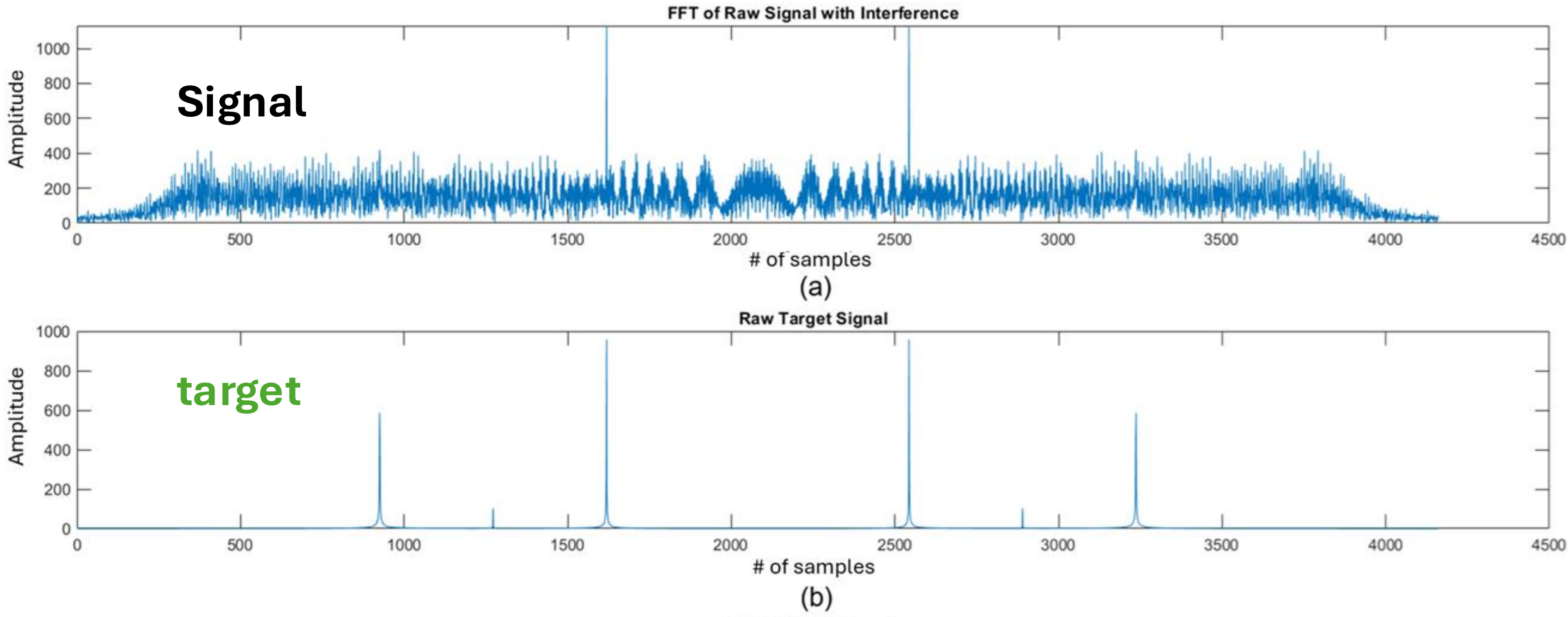

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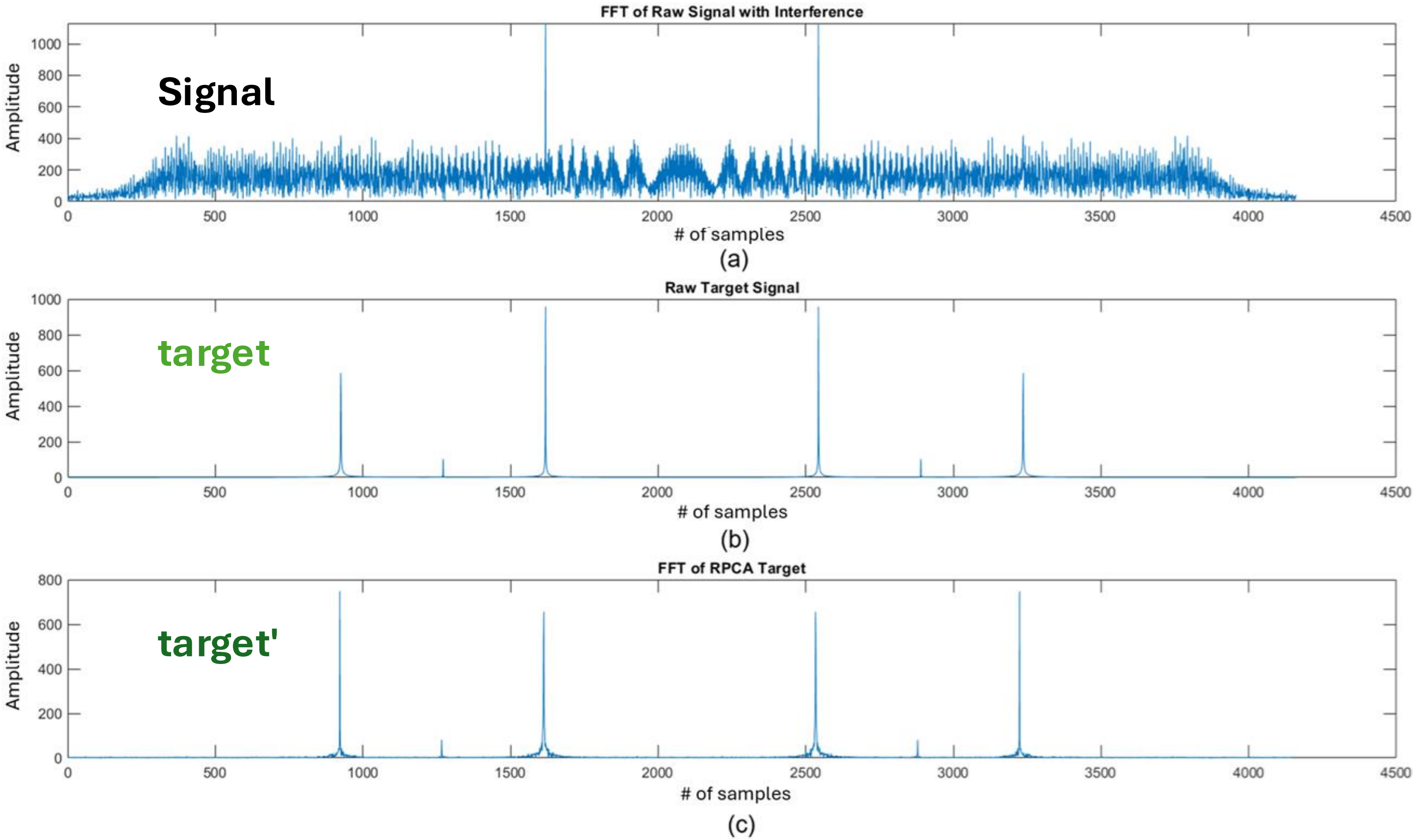
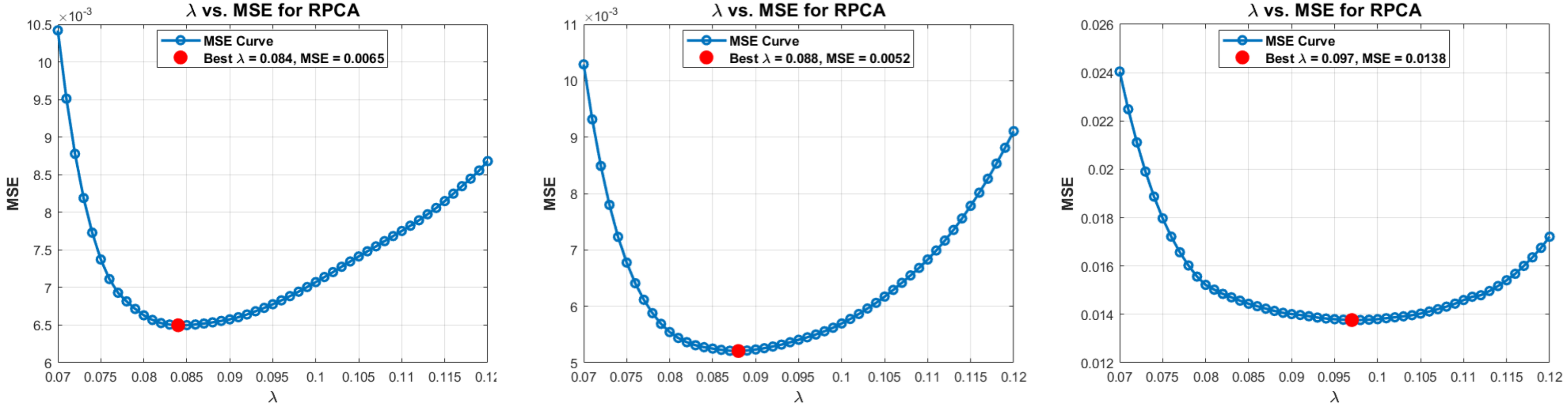


Optimal λ vs. Interference Characteristics



(a) (b) (c)

Scenarios with increasing complexity →

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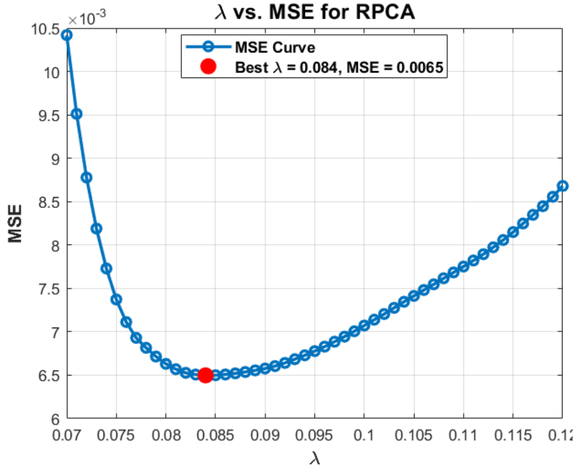

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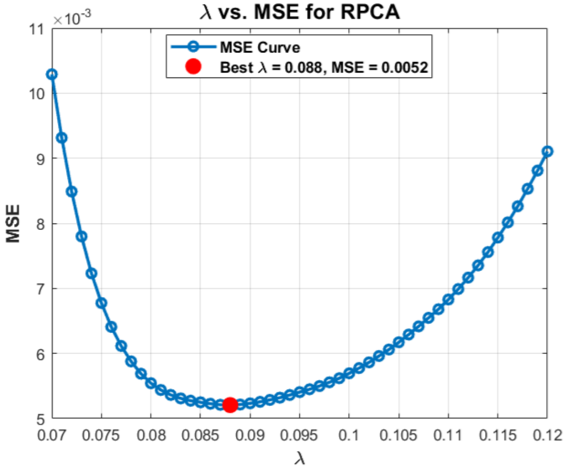

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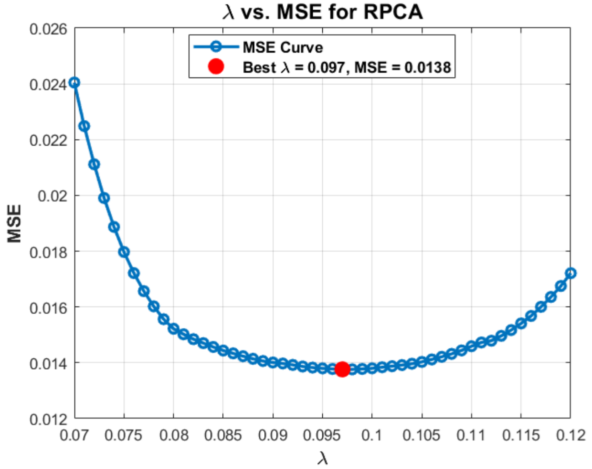

(c)

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Scenarios with increasing complexity

Key Finding: The optimal λ value is directly influenced by interference complexity.

Observation:

1. Lower λ values are suitable for simpler interference (fewer interferers, lower amplitudes).
2. Higher λ values are required for more challenging interference scenarios.

Conclusion: This dependency underscores the importance of V2V communication for adaptive λ tuning.

Conclusion

- Demonstrated that optimal penalization parameter (λ) in RPCA is strongly influenced by interfering radar characteristics.
- Showed that V2V communication can significantly enhance the robustness of interference mitigation strategies.
- The proposed approach effectively improves weak target signal reconstruction even under challenging interference conditions.
- Highlights the potential for advancing radar system performance in dense, dynamic environments, supporting advanced autonomous vehicle systems.