Estimating Impacts of Mutual Interference of Automotive Radars

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NHTSA

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Radar Congestion Study Purpose

- This study characterizes the environment in which automotive radars must operate

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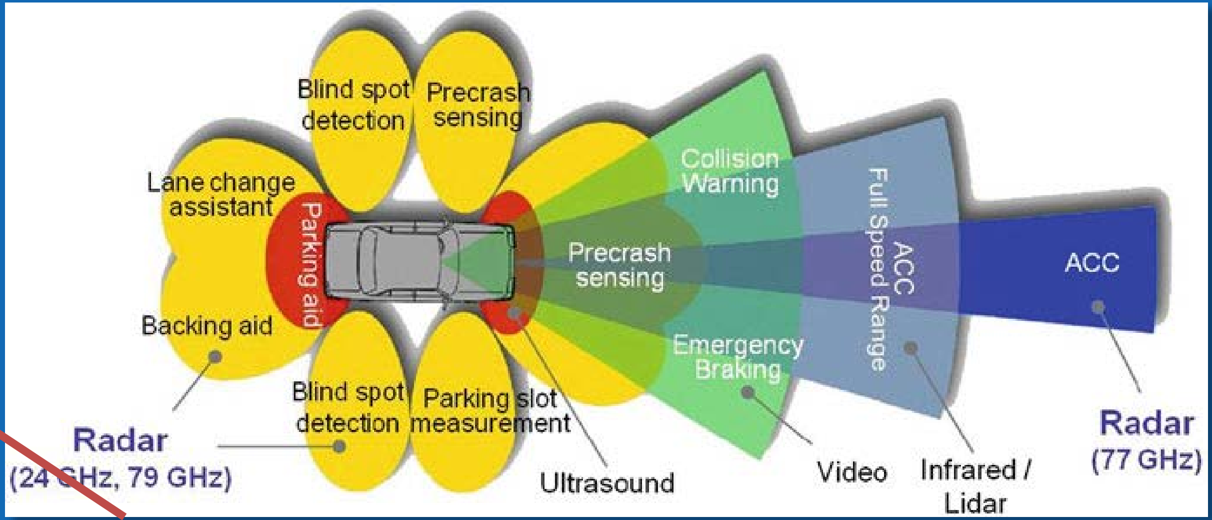
- This study characterizes the environment in which automotive radars must operate
- Especially as more systems with greater autonomy enter the market
- Systems that operate well in environments without other radars may suffer significant degradation of performance in radar congested environments

Why worry?

24 GHz spectrum being phased out



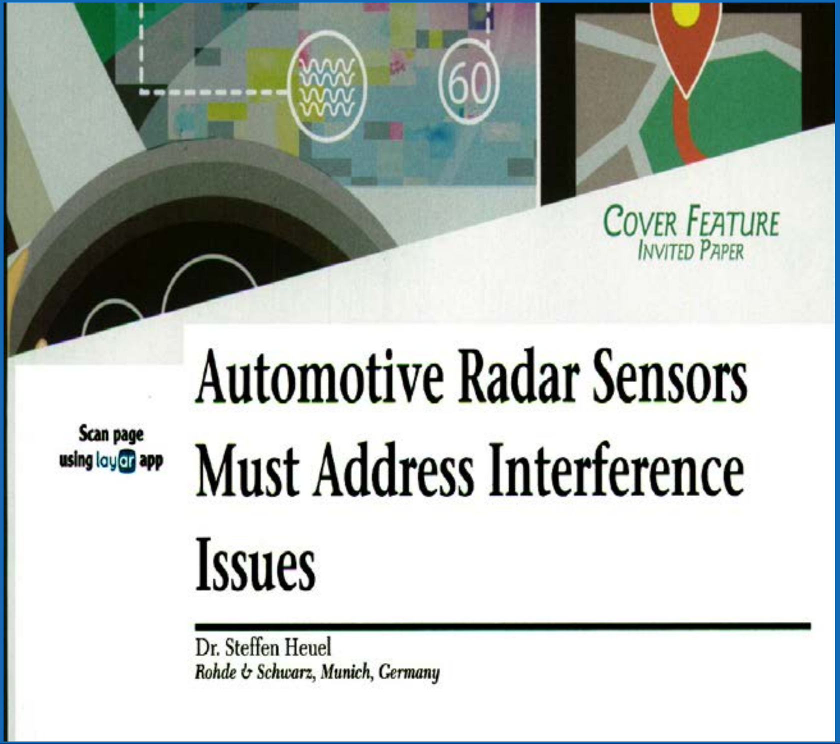
- As autonomous systems move to market, vehicles will be instrumented with multiple radars. Industry trends show increase in bandwidth and duty factor.

Figure is an example deployment of multiple radar sensors used for active safety and assisted driving systems [Kissinger , 2012]

Study Approach

Heuel, Steffen
Microwave Journal; Dec 2016; 59, 12; pg. 22

- The models for automotive radars in the study are based on technical literature and interviews with OEMs and Tier 1 suppliers
- The modeling and simulation work focuses on two questions:
  - How much power does, a given radar, receive from other radar transmitters?
  - How does this impact the performance of a collision warning system?



Estimating Interference

- The first question is answered by developing a model for nominal automotive radars
  - Compute probability of intercept in spectrum, ξ_K, and time, T_K, directly from the radar parameters,
  - Use stochastic geometric model to incorporate antenna pattern and compute interference power, $\mathrm{I_K}$

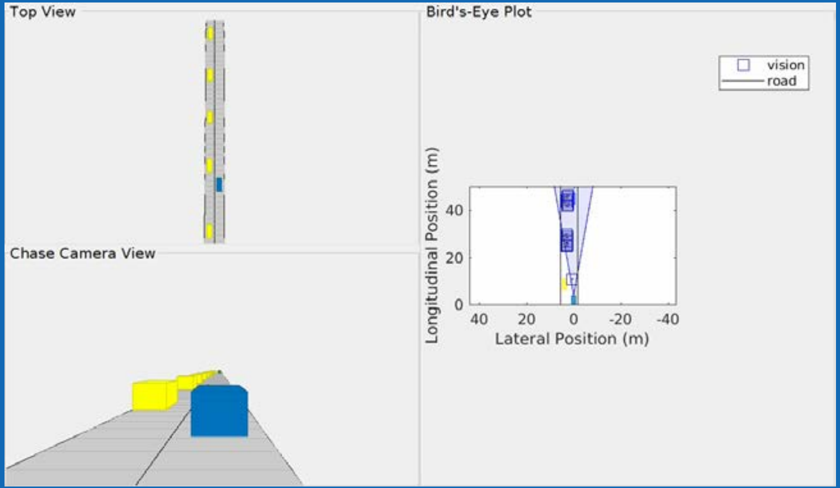
$$\xi_K = 1 - \prod_{k=1}^{K-1} (1 - CF_k)$$

$$\mathrm{T}_K = 1 - \prod_{k=1}^{K-1} (1 - DF_k)$$

$$\mathrm{I_K} = \xi_K \mathrm{T}_K \lambda \int_{\delta}^{\infty} \frac{P_0 \gamma_1}{L^2 + r^2} dr$$

Estimating Impact

- The second question is answered by introducing the interference power into a system simulation.
  - Interference is treated as noise (assumes waveform diversity)
  - Basic tracker model developed using Matlab’s ADAS Toolbox, with reasonably chosen parameters.



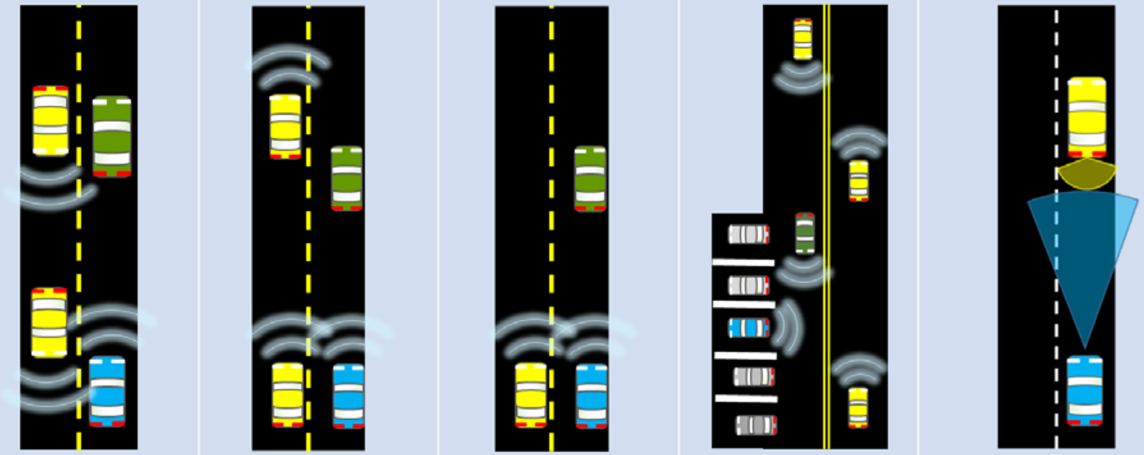
Generic Automotive Radar Parameters

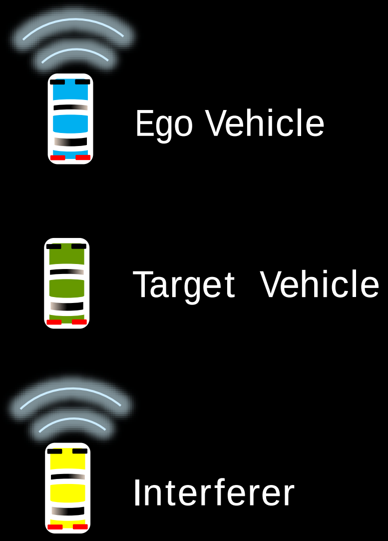
- For the purposes of modeling and simulation, we used a generic class of radar sensor parameters
  - Based on values selected from radar specifications and automotive radar experts.
- The resulting parameters are shown in table at right.

	Long Range Radar	Medium Range Radar	Short Range Radar	Units
Mean Transmitter Power $\bar{P}_S$	1	0.3	0.1	Watts
Reference Target (Range, RCS)	100, 0 (175, 10)	50, 0 (88, 10)	20, 0 (35, 10)	(meters, dBm^2)
Transmitter Bandwidth B_{TX}	200	400	500	MHz
Range resolution $\left(\frac{c}{2\,B_{TX}}\right)$	0.75	0.375	0.3	meters
Range bins	200	200	60	#
Compression Gain	23	23	18	dB
Carrier Frequency	76-77 76-81	76-77 76-81	76-77 76-81	GHz GHz
Noise Factor, f_N	10	10	10	Ratio
Duty Factor DF	0.5	0.9	1	Ratio
FOV θ Azimuth	20	90	150	Degrees
FOV θ Elevation	5	10	10	Degrees
Antenna Gain	27	20	17	dB
Azimuth Resolution	5	15	50	Degrees
Range rate limits	[-100 100]	[-100 100]	[-100 100]	m/s

Scenarios in Study

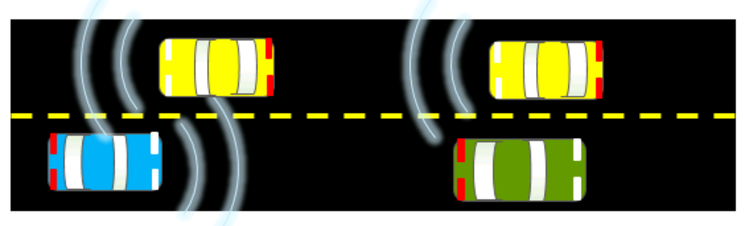
SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5
Opposing Traffic	Multiple Lane Congestion	Side-by-Side Forward Illumination	Backing Out of Parking Space	Rear and forward facing in traffic
Case1: Ego LRR, Inter. LRR Case2: Ego MRR, Inter. MRR	Case1: Ego LRR, Inter. LRR Case2: Ego MRR, Inter. MRR	Case1: Ego LRR, Inter. LRR Case2: Ego MRR, Inter. MRR	Case1: Ego SRR, Inter. LRR Case2: Ego SRR, Inter. MRR	Case1: Ego LRR, Inter. SRR Case2: Ego SRR, Inter. LRR





Scenario 1: Opposing Traffic

Blue = Ego Radar
Green = Target Vehicle
Yellow = Interferers



For the case of opposing traffic the power from the target vehicle is computed at the reference range (10 dBsm at 100 m)

$$P_T(R) = \frac{P_{tx} G_{tx} G_{rx} \lambda^2 \sigma_T}{(4\pi)^3 R^4}$$

The results in the table consider opposing traffic, distributed as a Poisson process with average density of 1 car per 15 meters.

dB Watts	Ego Radar	Other Radar	P_T	P_C	P_I
76-77 GHz	LRR	LRR	-107	-128	-69
	MRR	MRR	-115	-138	-80
76-81 GHz	LRR	LRR	-107	-129	-76
	MRR	MRR	-115	-138	-87

Interference power exceeds power of target returns by more than 30 dB

Scenario 5: Rear-view Short Range Radar Illuminated by Long Range Radar

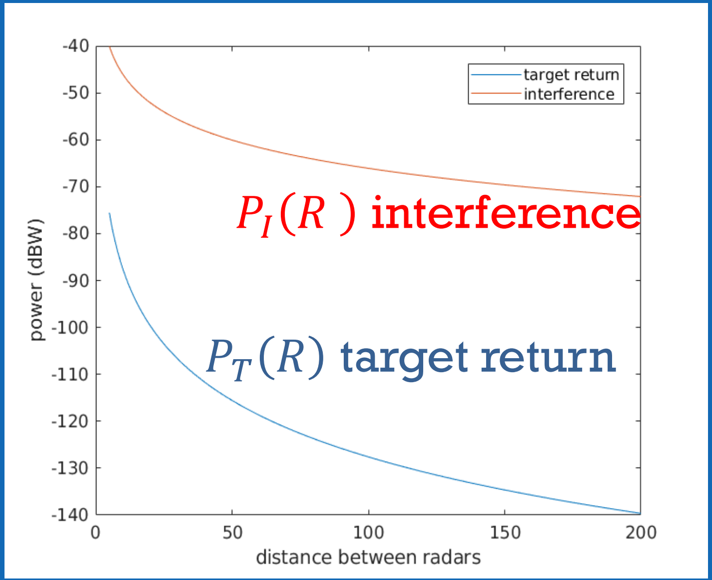
Interference power exceeds power of target returns by more than 50 dB

- The LRR has more power and greater antenna gain
- The graph shows the blue radar power reflected from the yellow car

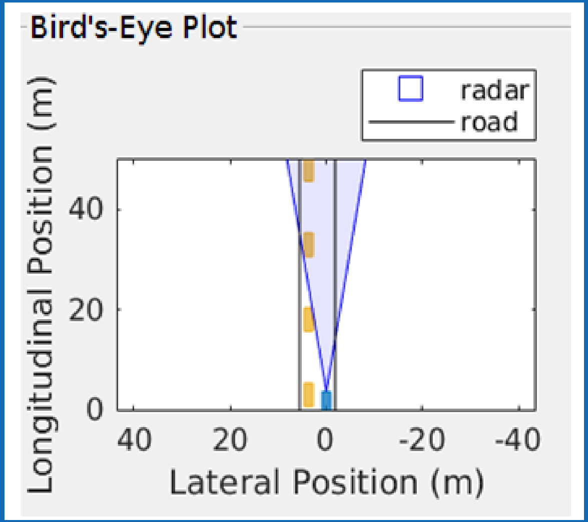
$$P_T(R) = \frac{P_{tx} G_{tx} G_{rx} \lambda^2 \sigma_T}{(4\pi)^3 R^4}$$

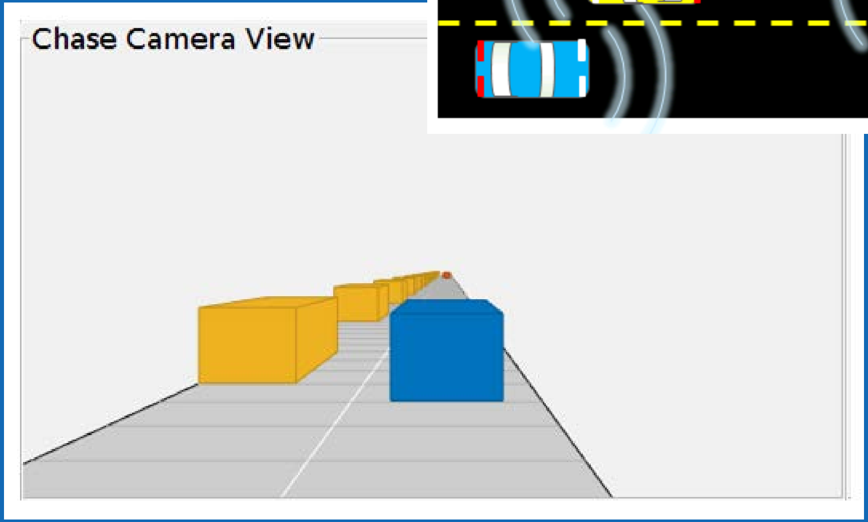
- The interference from the yellow radar is calculated by Friis equation

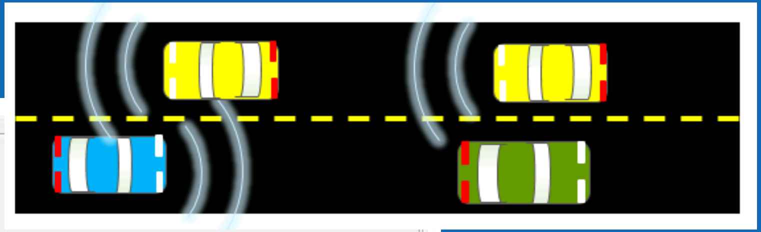
$$P_I(R\ ) = \frac{P_{TX,Int} G_{Ego} G_{Int} \lambda^2}{(4\pi)^2 R^2}$$



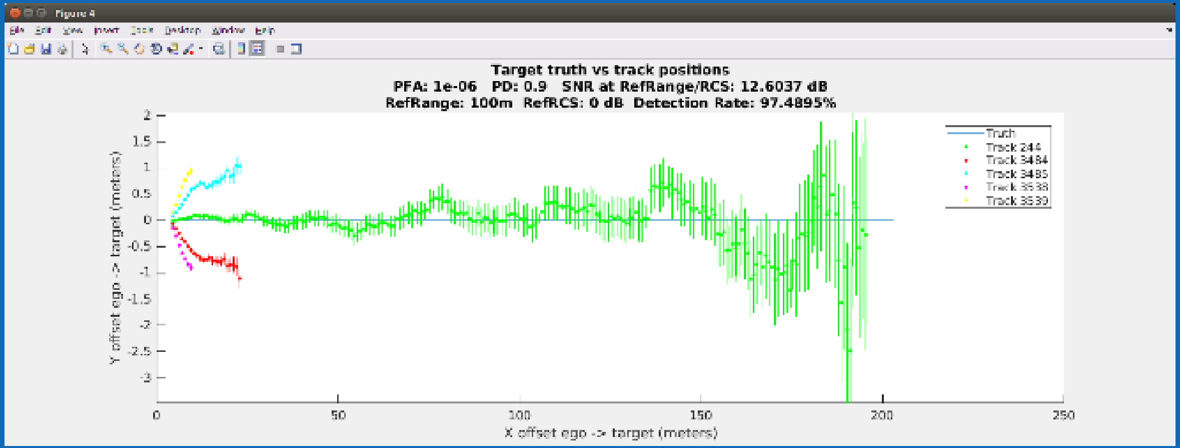
Simulation in Matlab ADAS Toolbox



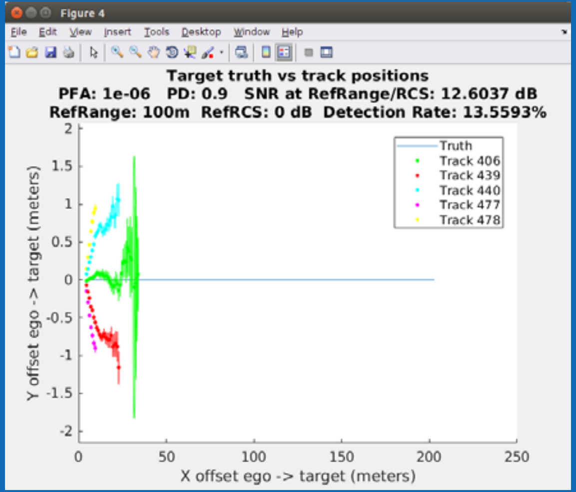




Impact on performance



Plot of persistent target tracks from Scenario 1, long-range radar with no interference



Plot of persistent target tracks with interference (76-81 GHz)

- The plots show the range at which a track is formed that persists to collision
- Without interference this occurs near 190 meters
- With interference this occurs near 30 meters

SINR and impact on Track Range for the Scenarios using the 76-81 GHz band

- Using generic automotive radar parameters, and tracking algorithm, terminal track ranges were reduced to as little as 16% of the range without interference

Scenario	Band	Victim Radar	Interfering Radar	SINR	Track Range
1	76-81	LRR	LRR	-31	16%
1	76-81	MRR	MRR	-28	44%
2	76-81	LRR	LRR	10	100%
2	76-81	MRR	MRR	23	94%
3	76-81	LRR	LRR	-4	100%
3	76-81	MRR	MRR	2	70%
4	76-81	SRR	LRR	-22	41%
4	76-81	SRR	MRR	-18	34%
5	76-81	LRR	SRR	-17	Not simulated
5	76-81	SRR	LRR	-44	

Mitigation Strategies

ID	Counter Measures	Interference Reduction	Comment
MOSARIM T6.2	Detect interference and repair Rx results (time domain)	3-20 dB , depending on environment	The influence of fast or slow crossing FM chirps still needs further investigation on mitigation margin impact
RCS Study	Stretch processing	10 dB	The main cost of the stretch processing technique is the loss of signal to noise ratio. So long as the interference is at least 10 dB greater than the noise, the technique is advisable.
MOSARIM T5.4	Digital Beam Forming	5-10 dB	Mitigation effect depends on beamwidth (space domain), based on number of elements in receiver array
MOSARIM T1.2	Specific polarization following the Radar location *	10-15 dB for co pol - systems using the same convention	This is already partially used for ACC radars that have 45 degree slant linear polarization (reduced interference from oncoming radars by 15 dB). **Requires harmonization**.
RCS Study	Spectrum division following Radar location *	60 to 80 dB for forward and rearward facing radars in traffic	As all automotive radars move to W-band, 76-81 GHz, splitting the spectrum could reduce interference between forward and rearward looking radars by 60 to 80 dB. **Requires harmonization.**

* front, side, or rear of vehicle

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Conclusion

- Automotive radar must perform in a challenging environment, which will become more challenging as a greater density of advanced driver assist, and autonomous systems, populate roadways
- The Radar Congestion Study estimates these level will have significant impact on existing systems, and has tabulated the most promising mitigation strategies in practice
- Existing strategies promise to mitigate the impacts of interference and allow for good performance, but some require industry harmonization
- There is a need for methods to evaluate these strategies in automotive safety tests

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ESTIMATING IMPACTS OF MUTUAL INTERFERENCE OF AUTOMOTIVE RADARS

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