TREX ENTERPRISES
CORPORATION

76-81 GHz Automotive Radar

Design for Interoperability in Densely-Trafficked Environments

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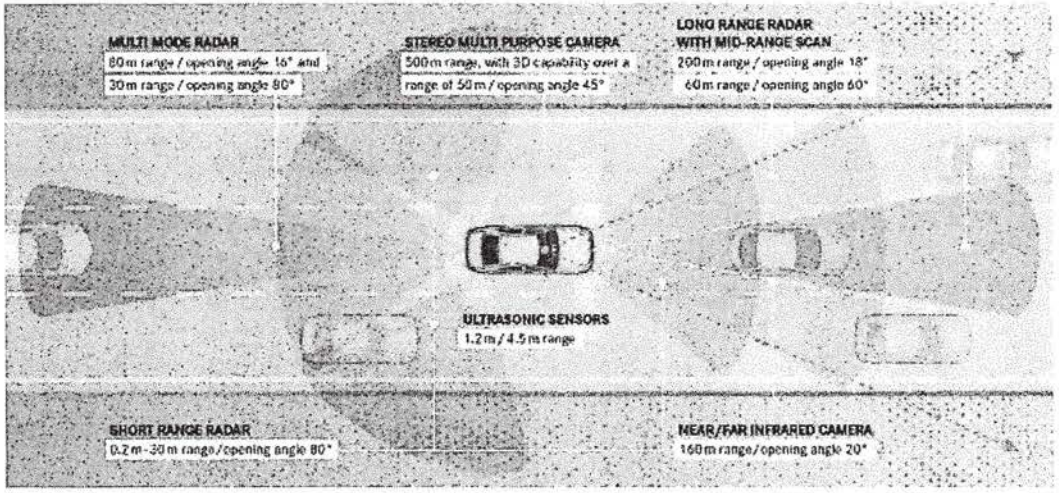
Discussion Outline

- **Automotive Radar Interoperability Issues**
  - Vision for Wrap-Around Protective Radar "Halo" on All Vehicles Creates a Very Dense Interference Environment
- **Impacts of Recent Advance in Silicon CMOS Processing**
  - Potentially Disruptive Cost with a "New" Auto Radar Architecture
- **PMCW Radar Characteristics / Contrast with FMCW**
  - Interoperability Considerations Specific to Coded Spread Spectrum Approaches
- **Future Standards for Protecting Auto Radar Interoperability**
  - Understanding the Envelope for Innovation in a Potentially Crowded Market (and Spectrum)
- **Status Review of the FCC 77-81 GHz NPRM**

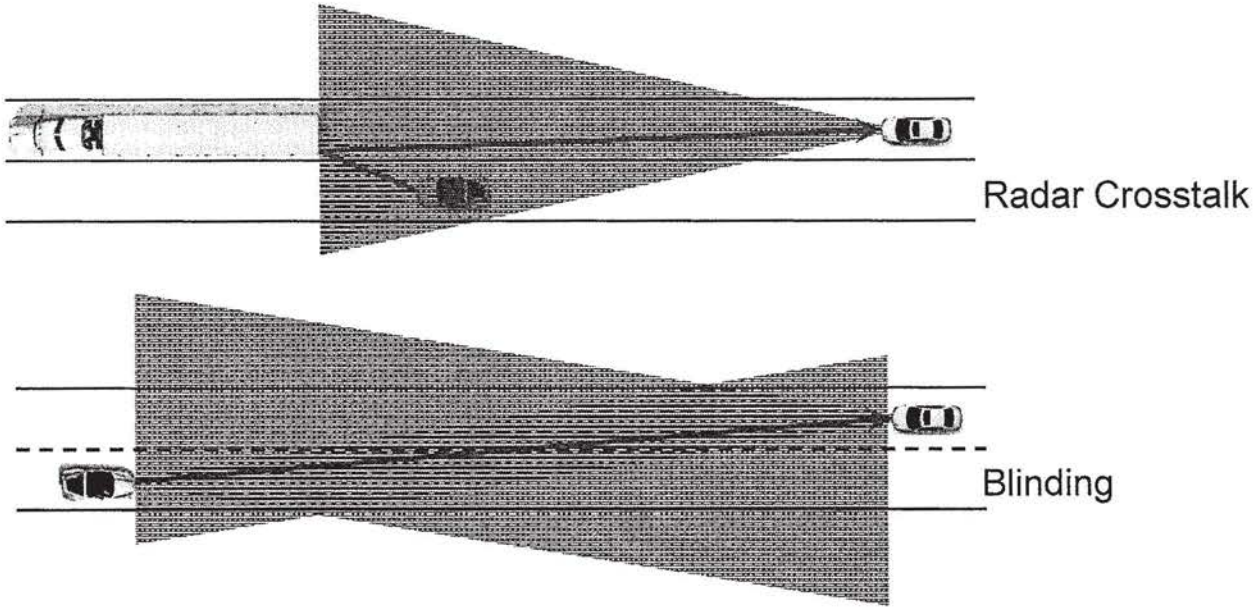
Fundamental Radar Interference Challenge



Source: Bleckmanan, Novedades, Technologia 5/6/13

- **Lots of Radars on the Road…**
  - Forward Facing Long-Range Radar (76.5 GHz) and Mid-Range Radar (76.5 or 79 GHz) on Every Car
  - Rear-Facing Multi-Mode Radar (79 GHz), on High-end Cars
  - Corner Short-Range Radars (79 GHz), on High-end Cars
- **In Bumper-to-bumper Traffic, Forward- and Backward-Facing Radars will Transmit into One Another from Point-blank Range**

Other Common Interference Challenges



- **Automotive Radars Will Interact in Different Ways**
  - e.g. FMCW-on-FMCW, FMCW-on-PMCW, Scanned-beam-on-MIMO
- **Radar Manufacturers Can Prevent Self- or Like-type Interference through Judicious Systems Engineering**
  - Managing radar beamwidth, direction and/or power dynamically
  - Coordinating antenna polarizations and/or employing MRR/SRR band segmentation
  - Offsetting FMCW chirps or orthogonalizing PMCW codes
- **In Absence of Standards, New Market Entrants Can Negate Such Efforts**

Dynamic Range Requirements

- **Automotive Radar Receiver Sees ~180 dB of Dynamic Range**
  - To limit distortion, tasks must be divided into smaller ranges of target distance
  - Assume LRR is in separate band (existing 77 GHz Allocation)
  - Forward SRR/MRR and Rear-Facing MRR Radar will share the 77-81 GHz Radar Band

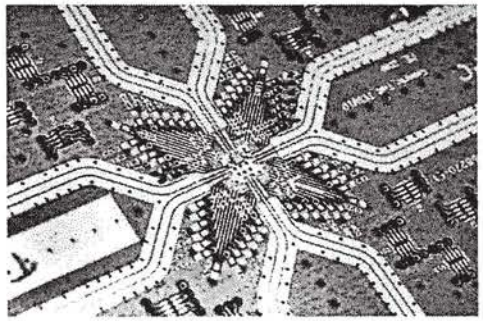
Function	Range (m) Min	Range (m) Max	σ (dBm^2) Min	σ (dBm^2) Max	Dynamic Range (dB)	Radar Frequency (GHz)
LRR	30	320	0	40	81	76.5
MRR	5	30	-10	40	81	79*
SRR	1	6	-10	40	81	79*
Parking	0.2	1.2	-10	40	81	79*

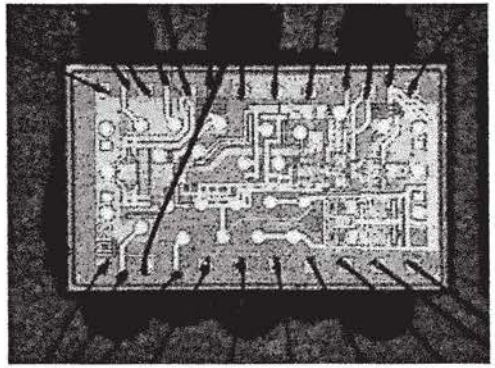
$$\text{Dynamic Range} = 40 \log_{10}\left(\frac{R_{max}}{R_{min}}\right) + (\sigma_{max} - \sigma_{min})$$

*Could Be Subdivided, by Rule or by Convention

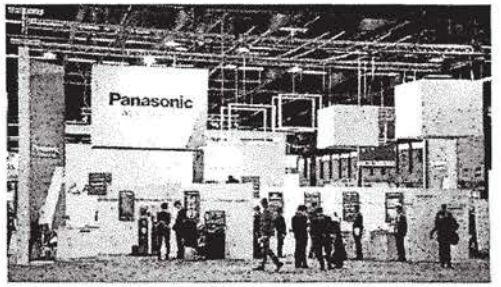
New Development in Silicon CMOS

- **Single-Chip 79 GHz PMCW Radar Transceiver Produced with 28 nm Lithography on Bulk-Silicon CMOS**
  - Record Efficiency (~10%) and Low-Cost (~$0.25), not attainable using emergent SiGe technology
  - First Published in IEEE Journal of Solid State Circuits, Vol. 49, No. 12, December 2014
- **Chip Comprises the Entire Transceiver Front End:**
  - Receiver LNA with 7 dB NF
  - Transmitter PA with +11 dBm output power
  - 5x Multiplier for 15.8 GHz external LO (79 GHz radar carrier)
  - 2 Gbps BPSK signal modulator/demodulator at 79 GHz

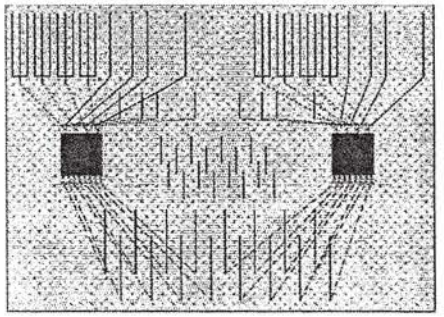




"New" Radar Architecture



- **Phase-Modulated Continuous Wave Radar**
  - Currently under development at Panasonic, under investigation at Magna
  - Coded BPSK waveform, similar to CDMA, GPS (spread spectrum)
  - Occupied Bandwidth Depends upon Modulation Rate, e.g.:
    - LRR: 76.25-76.75 GHz
    - MRR: 78.5-79.5 GHz
    - SRR: 77.5-80.5 GHz
  - Interference Susceptibility Dependent upon Code Type



- **MIMO Antenna Array**
  - Low EIRP (~5 dBW), Digital Beamforming
  - Channel Orthogonality Dependent upon Code Type
  - ~70 cm^2 Combined Antenna Aperture Multi-Function (Long-, Mid- and Short-Range) Radar
  - Larger Distributed Apertures also Possible in Future
- **Pertinent to Front, Corner, and Rear-Facing Radars**
  - High-End and Mass Market Radars using Single-Chip Transceiver Arrays

PMCW Characteristics Compared to FMCW

- **FMCW is Essentially "Incumbent" in this Space**
  - Pulse compression is performed in frequency space
    - Narrowband instantaneous transmission, "spread spectrum" only when averaged over slower chirp period
    - Potential interference involves probability of chirp collisions (duty cycle)
  - Log amp reduces IF dynamic range requirements
  - Linearity of sweep module ("chirp"), LO phase noise and bit depth of (post-compression) digitizer drive cost
- **PMCW is Not Technically a New Approach, but Will Be Newer to the Automotive Radar Space**
  - Pulse compression is performed temporally, using a matched filter
    - BPSK modulation at 1-2 Gcps; "spread spectrum" in the true sense of the phrase
    - Potential interference involves probability of code collisions (design criterion)
  - High IF dynamic range requirements
    - Coding gain from long matched filter drops digitizer bit depth requirement relative to FMCW, but increases digitizer speed requirement
  - No significant cost drivers

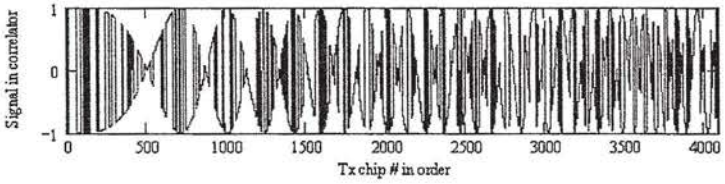
PMCW MIMO Radar Interference: Intrusiveness and Susceptibility

♦ Interference from MIMO PMCW Radar

- True spread spectrum (low instantaneous PSD) is maximally benign to all similar and non-similar radar approaches
- Non-scanning MIMO antenna, with digital beamforming (low instantaneous irradiance / EIRP) is maximally benign to all antenna types

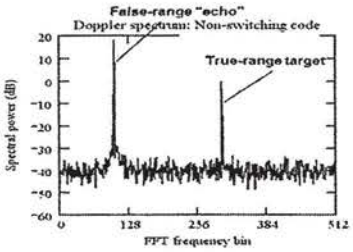
♦ Interference to MIMO PMCW Radar

- Very slow scanning FMCW radar (tone-like emitter) could create false targets
  - Not likely given update rate requirements for automotive radar
  - Modeling suggests that existing FMCW radar causes no performance degradation to PMCW



PMCW Chirp Averages to Zero in Correlator

- Auto- and Cross-Correlation sidelobes from host and other PMCW radars could create false targets
  - Interference susceptibility can be mitigated by proper code selection and cycling
  - A poor "first to market" PMCW design could limit performance and restrict future market entry



How Will Auto Radar Interoperability Be Enforced?

- **ECC/ITU has Identified SRR in 77-81 GHz as Operating on a "Non-interference and Non-protected Basis"**
  - "No harmful interference may be caused to other users of the band and no claim may be made for protection from harmful interference received from other systems" [2004/545/EC]
  - Seems there is nothing to enforce here – how can this be the basis for a safety-of-life feature that will soon be mandated for all vehicles?
  - A better approach might be something similar to PCI-SIG "Plug-Fest," where new products must first prove harmonious interoperability with radars already on the road
- **ECC/ITU Emissions Limits:**
  - 25 dBW EIRP peak
  - -9 dBm/MHz mean PSD radiated outside of vehicle
- **Typical PMCW Radar:**
  - 5 dBW EIRP peak
  - -14 dBm/MHz mean PSD radiated outside of vehicle
  - Modeling suggests that PMCW is fully harmonious with FMCW
    - However, e.g., narrowband tone emissions could be harmful to both

FCC NPRM and Rulemaking Timeline

- **Trex has seen and read the NPRM and subsequent comments**
- **Trex resonates with Bosch reply comments regarding restricting LRR operations to 76-77 GHz band**
  - Although definition of LRR operations needs further detail
- **Trex is engaging in R&D work associated with future automotive radar technology**
  - … and therefore seeks clarification on the current status and timeline for the FCC Rulemaking process related to 77-81 GHz
  - … as well as an "on-ramp" for participating in future FCC/Industry discussions related to this Rulemaking

Thank You!