November 20, 2015

Chief, FCC Office of Engineering Technology

Dr. Julius Knapp
Presented to:

Trex Enterprises Corporation

Dr. John Lohberg
Presented by:

Design for Interoperability in Densely Trafficked Environments

76-81 GHz Automotive Radar
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

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
  - Offseting 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

<table>
<thead>
<tr>
<th>Function</th>
<th>Range (m)</th>
<th>$\sigma$ (dBm$^2$)</th>
<th>Dynamic Range (dB)</th>
<th>Radar Frequency (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>LRR</td>
<td>30</td>
<td>320</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>MRR</td>
<td>5</td>
<td>30</td>
<td>-10</td>
<td>40</td>
</tr>
<tr>
<td>SRR</td>
<td>1</td>
<td>6</td>
<td>-10</td>
<td>40</td>
</tr>
<tr>
<td>Parking</td>
<td>0.2</td>
<td>1.2</td>
<td>-10</td>
<td>40</td>
</tr>
</tbody>
</table>

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

*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 cm² 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
  - 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