CAMP LLC

Cellular V2X Device-to-Device Communication Consortium

CELLULAR V2X DEVICE-TO-DEVICE COMMUNICATION CONSORTIUM

C-V2X Performance Assessment Project

Task 8: Assessment of Wi-Fi Interference to C-V2X Communication Based on Proposed FCC 5.9 GHz NPRM

Interference Field Testing Results

9/28/2020

List of Acronyms

Abbreviation	Explanation	Abbreviation	Explanation
SEM	Spectral Emissions Mask	HP VA	High Power Variable Attenuator
OOBE	Out of Band Emissions	RMS	Root Mean Square
C-V2X	Cellular Vehicle to Everything	MCS	Modulation and Coding Scheme
U-NII-4	Unlicensed National Information Infrastructure (U-NII) radio band (5850 MHz -5895 MHz) proposed by the FCC NPRM	HARQ	Hybrid Automatic Repeat Request
ITS	Intelligent Transportation Systems	NPRM	Notice of Proposed Rule Making
3GPP	3G Partnership Project	LOS/NLOS	Line of Sight/Non-Line of Sight
VA	Variable Attenuator	V2X	Vehicle to Everything (X) where X can be Vehicle (V), Infrastructure (I) or Network (N)
TX	Transmitter	EIRP	Effective Isotropic Radiated Power
RX	Receiver	FCC	Federal Communications Commission
ACP	Average Carrier Power	PER	Packet Error Rate
CCDF	Complementary Cumulative Distribution Function	DNPW	Do Not Pass Warning
WFA	Wi-Fi Alliance	EEBL	Emergency Electronic Brake Light
AP	Access Point		

Executive Summary

- Wi-Fi Alliance proposed U-NII-4 OOBE limits for outdoor devices in their March, 2020 Comments to the 5.9 GHz NPRM
- CAMP C-V2X Consortium has field tested this proposal assuming an in-vehicle U-NII-4 interferer
  - Three (3) use cases with NLOS propagation conditions assumed
- Significant harmful interference to V2V and I2V safety communication was measured for all cases
- For this reason CAMP C-V2X Consortium strongly believes that the devices adhering to this OOBE mask should be:
  - Restricted to indoor only Wi-Fi Access Points (APs)
  - Prohibited to operate as portable Wi-Fi APs (that could be used in-vehicle)
- NOTE: Other proposals for OOBE limits of unlicensed devices are less stringent than used in this evaluation and, based on the results presented here, will cause additional harmful interference

Task 8: Technical Scope

- Evaluate the interference from Wi-Fi operations in the U-NII-4 band to C-V2X (3GPP Rel-14, mode 4) safety communications on Channel 180 and Channel 183 based on proposed rules in the January 2020 FCC 5.9GHz NPRM

- Period of Performance: February 01, 2020 – September 30, 2020

CH 180 : 5895 MHz – 5905 MHz
CH 183 : 5905 MHz – 5925 MHz
U-NII-4 (proposed) : 5850 MHz – 5895 MHz

Objective Test Description

Aimed at understanding Wi-Fi interference to C-V2X system performance in CH 180 and CH 183 under these system factors:

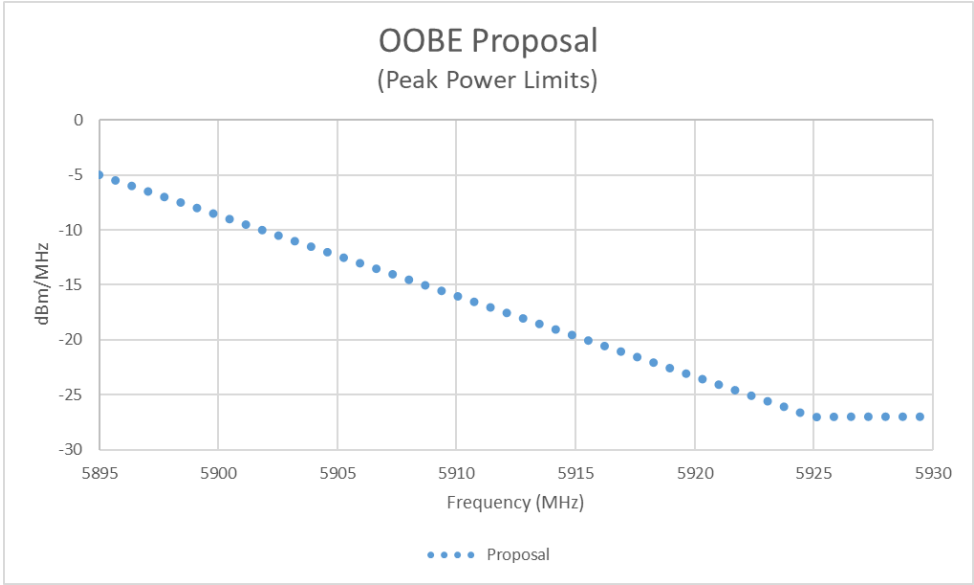
- C-V2X Device Configurations
  - Channel bandwidth – 10 MHz (CH 180) and 20 MHz (CH 183)
  - Payload size
    - 365 byte, supporting V2V messages
    - 1400 byte, supporting I2V messages

    } Implemented as per SAE J3161
- Wi-Fi Alliance OOBE March Proposal in the FCC 5.9 GHz NPRM Docket[1]
- Wi-Fi Configurations
  - In-vehicle hotspot
  - Primary focus: 80 MHz (CH 171) Bandwidth Wi-Fi 802.11ac signal

[1] https://www.fcc.gov/ecfs/filing/1030974615271

Wi-Fi Alliance U-NII-4 OOBE Proposal

- Wi-Fi Alliance OOBE mask definition [1]
  - Linearly drawn to match peak power limit of
    - -5 dBm/MHz at 5895 MHz
    - −27 dBm/MHz >= 5925 MHz
  - Expressed in terms of EIRP
  - Applies outdoors



Note: A proposals in [2] for indoor-only usage OOBE limits would include building losses, offering additional protection to CH180 & CH183 transmissions.

[1] https://ecfsapi.fcc.gov/file/1030974615271
[2] https://ecfsapi.fcc.gov/file/10309096401111/5GAA%20Comments%20(3-9-2020).pdf

Test Setup

Test Scenarios

Scenario	Link Test
Non-line of Sight (NLOS)	V2V, I2V
NLOS Intersection	V2V

Test Configurations

Config Item	Values
Payload	365 Byte (V2V) 1400 Byte (I2V)
Antenna Diversity	2 Rx
HARQ	ON
C-V2X Channels	180, 183
Transmit Power	17dBm (at the antenna input) Note: Device configured for 20 dB Tx power with additional ~3dB cable loss and ~0dB antenna gain at Horizon
Inter-Transmit Time	100 ms
Wi-Fi AP	In-vehicle
Wi-Fi Antenna Gain	6 dBi
Wi-Fi Channel	171
C-V2X Antenna Conf	Roof-mounted Side-view Mirror

Interference Equipment

Device	Model
Signal Generator	Rohde & Schwarz | Model: SMBV100A
Bi-Directional Amplifier	Triad TTRM4302-D04
Signal Analyzer	Keysight or Agilent | Model: N9020A

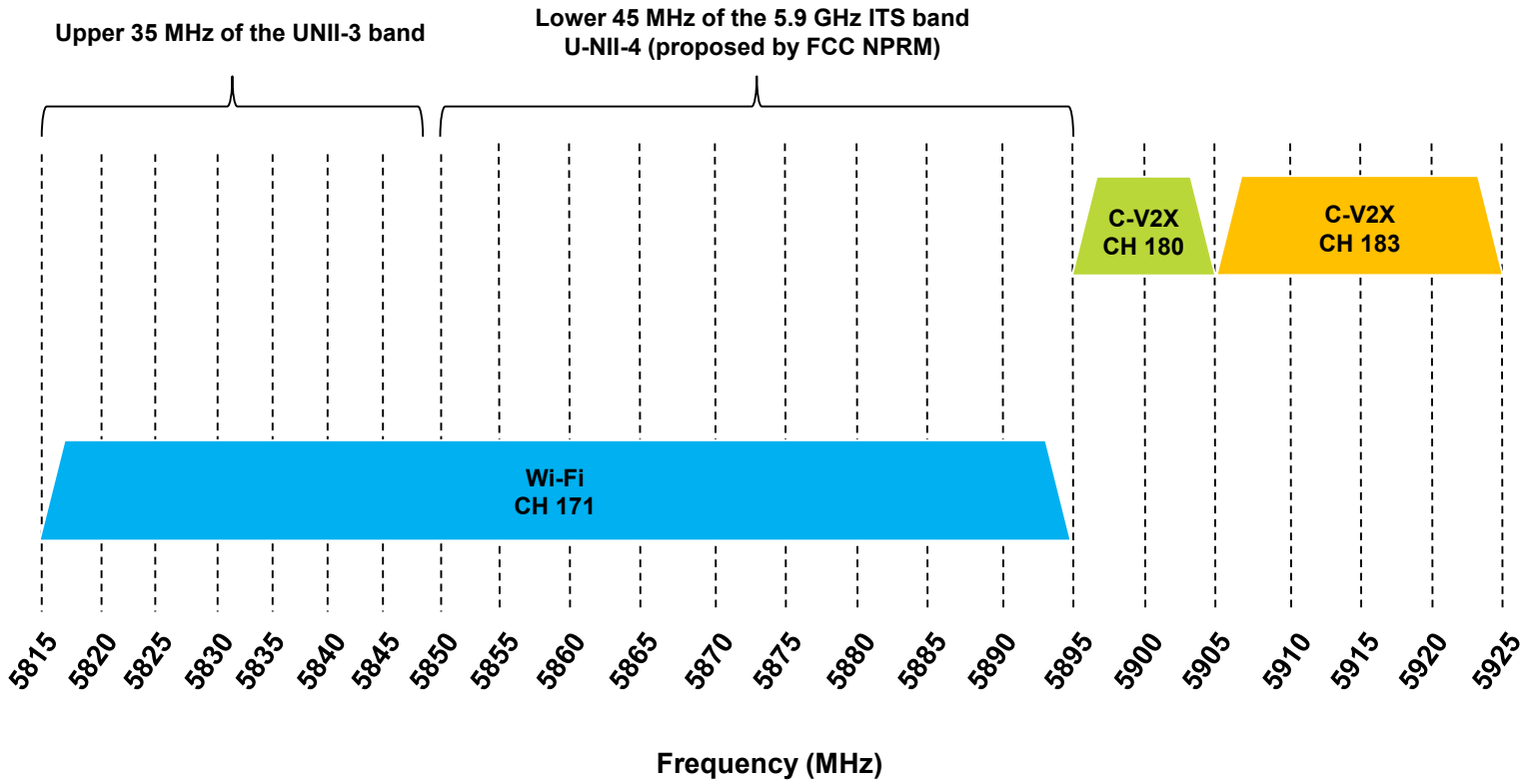
Others

Item	Value
Moving Vehicle Speed	25 MPH
Runtime / Test	6 Loops
Blocker Vehicle	26 ft truck

OBE-vehicle Mapping

OBE ID	Vehicle/ RSU
21	Nissan Pathfinder (OBE#31 used for 2 tests)
42	Nissan Rogue (OBE#32 used for 2 tests)
105	RSU w/ ECO6-5900-RN (6 dBi gain Antenna @ 18 ft)

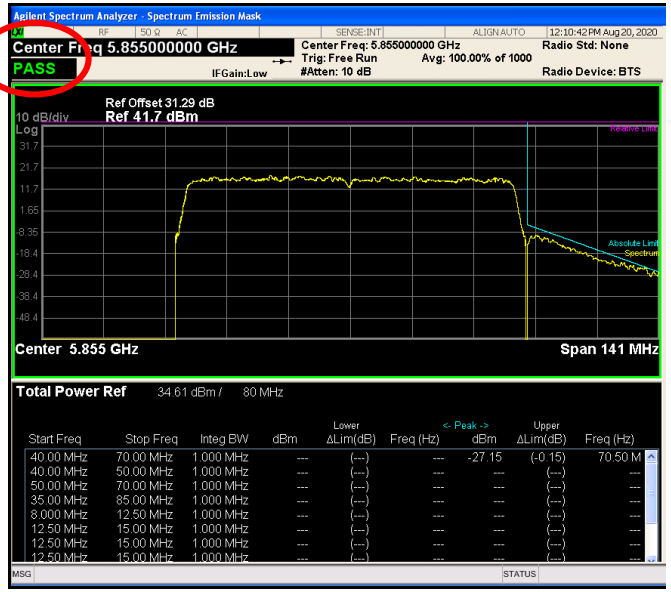
Wi-Fi and C-V2X Channels Used



Generated 802.11ac Waveform, CH 171 (80 MHz) – Wi-Fi Alliance Proposal Mask | In-vehicle Hotspot

- Spectral Emission Mask (SEM): used to confirm that the Out of Band Emissions (OOBE) of the generated waveform is met
- Average Carrier Power (ACP): used to measure the level of OOBE in the adjacent channel
- Antenna Gain (6 dBi) and cable loss (3.1 dB) of the interferer setup included as offsets in measurements and accounted for

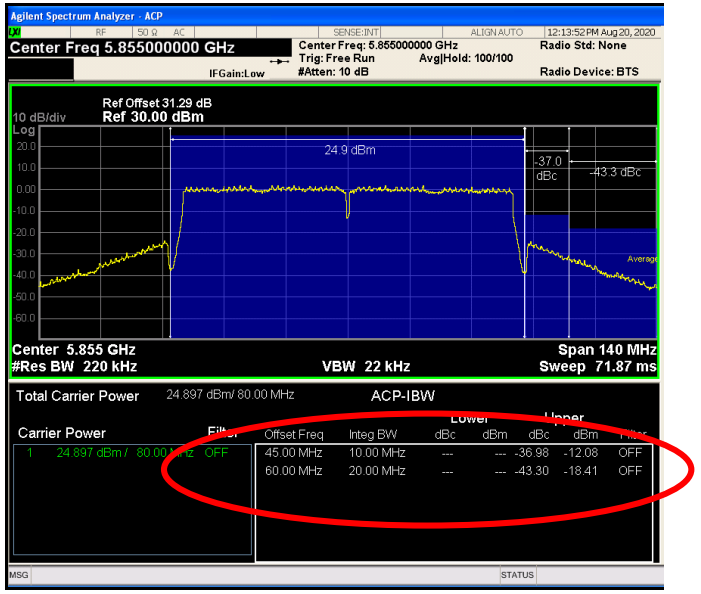
SEM



Total Power Ref 34.61 dBm / 80 MHz

Key Settings: Res BW: 1 MHz, Max Hold, Peak Detector

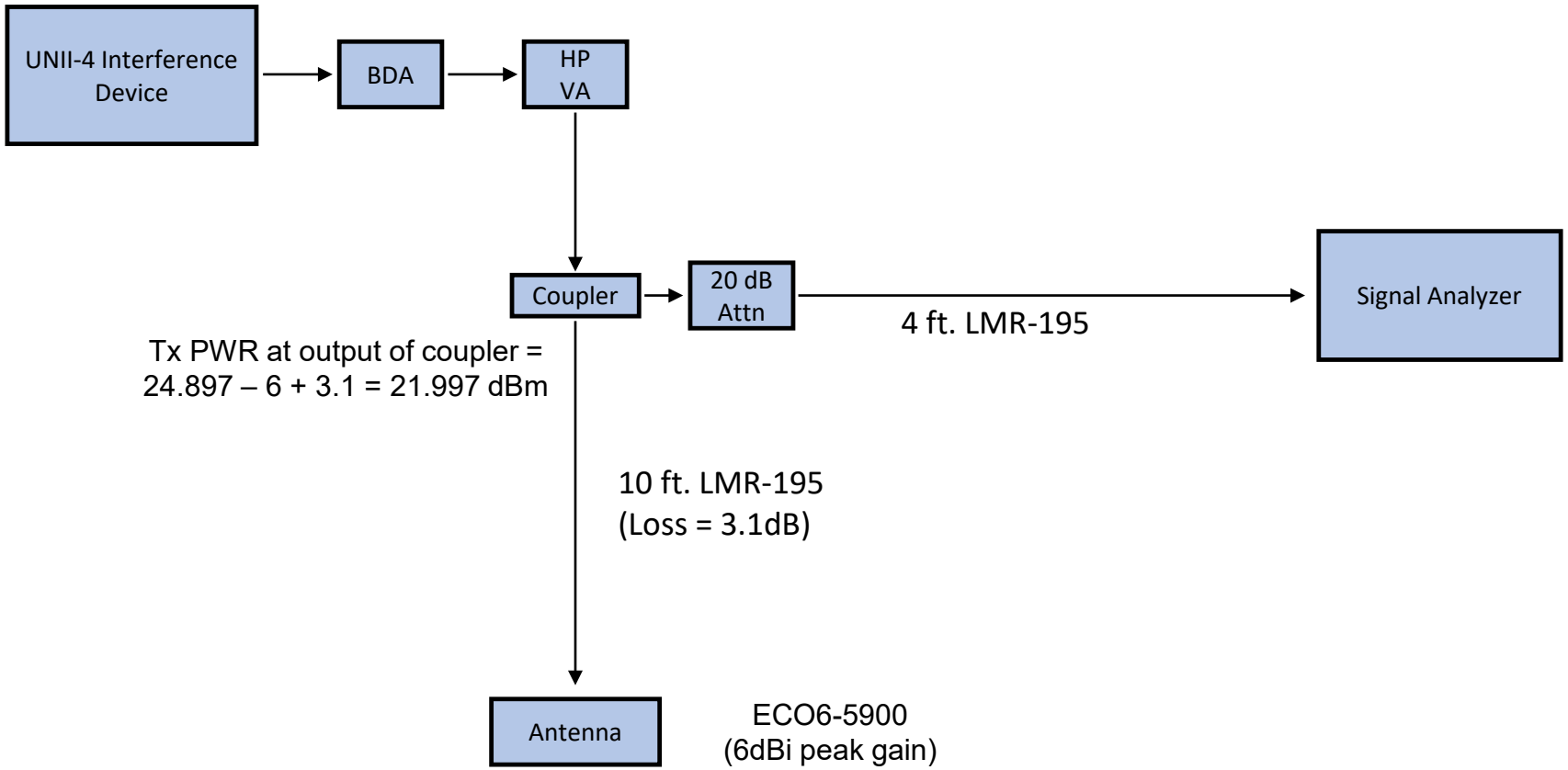
ACP



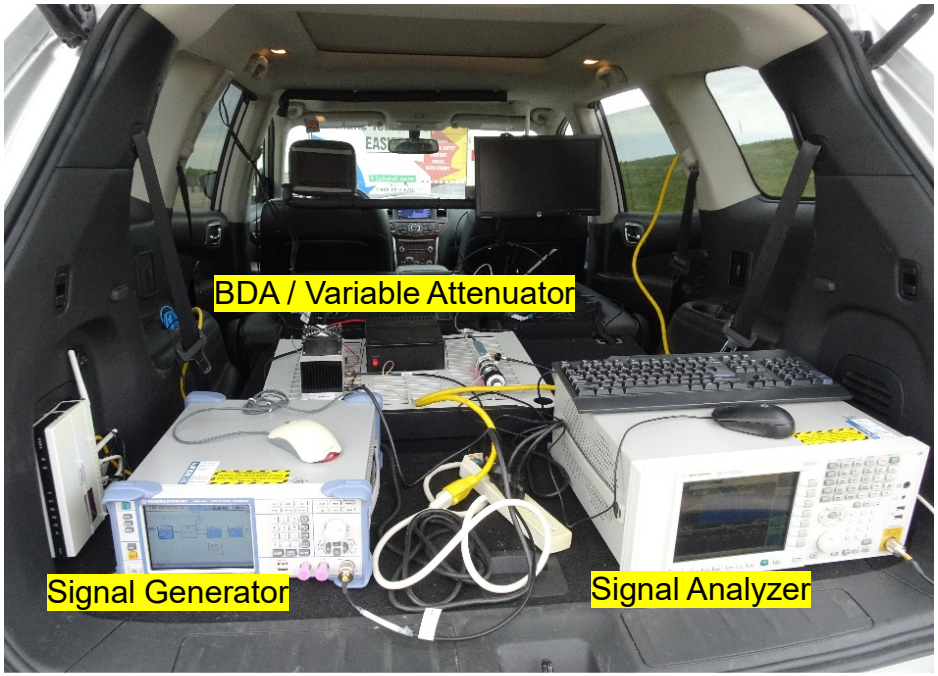
Total Carrier Power 24.897 dBm / 80 MHz

Key Settings: Avg Detector, RMS Avg

Interferer Setup



In-vehicle Hotspot Setup

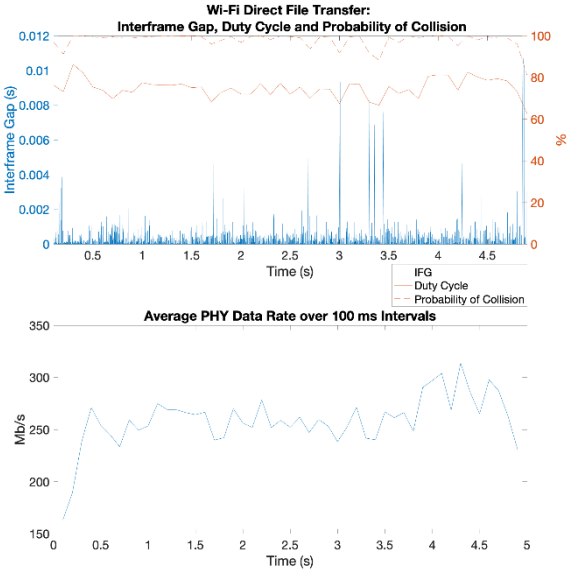


- Wi-Fi Interference Source - Signal Generator with Generated 802.11ac waveform
- Duty cycle was set at 60%
- 80 MHz (CH 171) waveform complied with the Wi-Fi Alliance proposal mask
- The Wi-Fi antenna was placed on the front passenger seat
- This placement approximates a passenger holding a mobile device

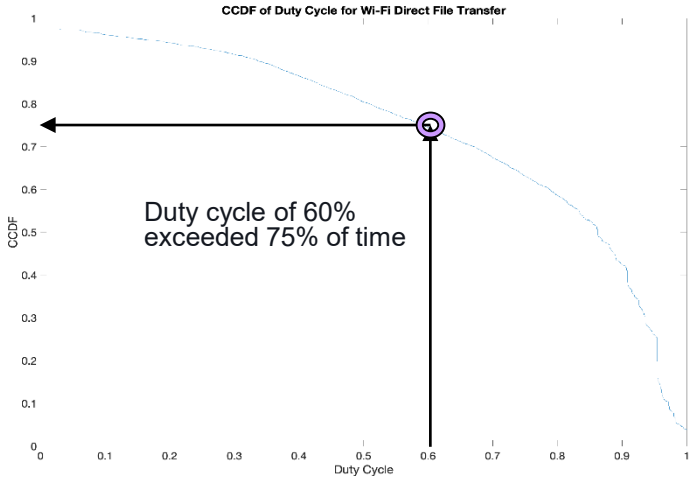
Interference Duty Cycle Comparison to Sniffed Wi-Fi Activity

- The duty cycle of the Wi-Fi signal in the field tests was set at 60% which is not the worst case
- In the peer-to-peer direct file transfer test reported in [3] the average duty cycle was above 75% measured over 100 ms periods
- Duty cycle measurement over periods that last minutes, as reported in other studies, does not provide accurate information to assess harmful interference in collision scenarios

Interframe gap, duty cycle, probability of collision, data rate



Duty Cycle CCDF

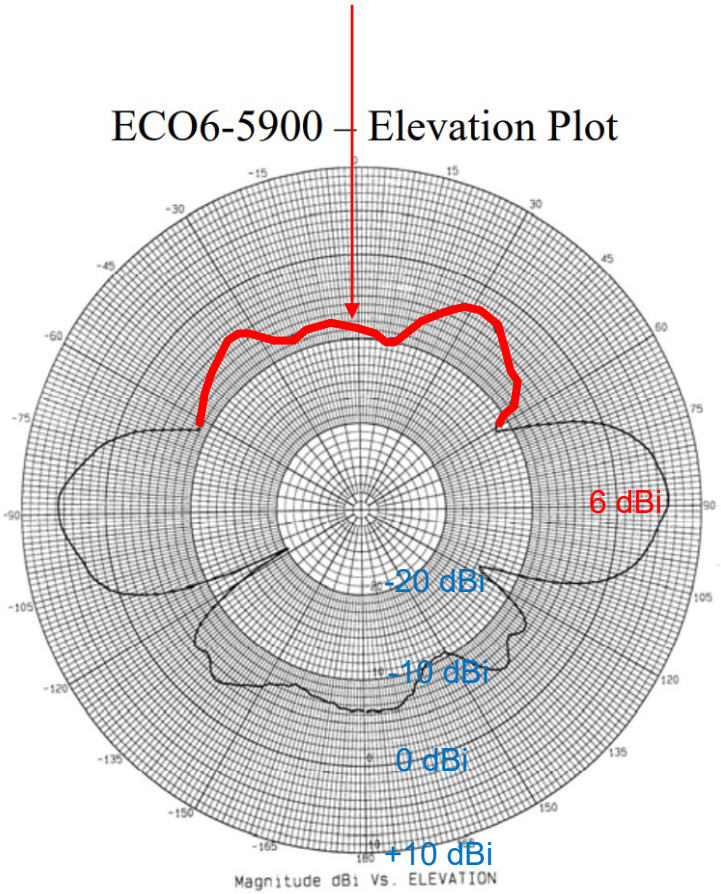


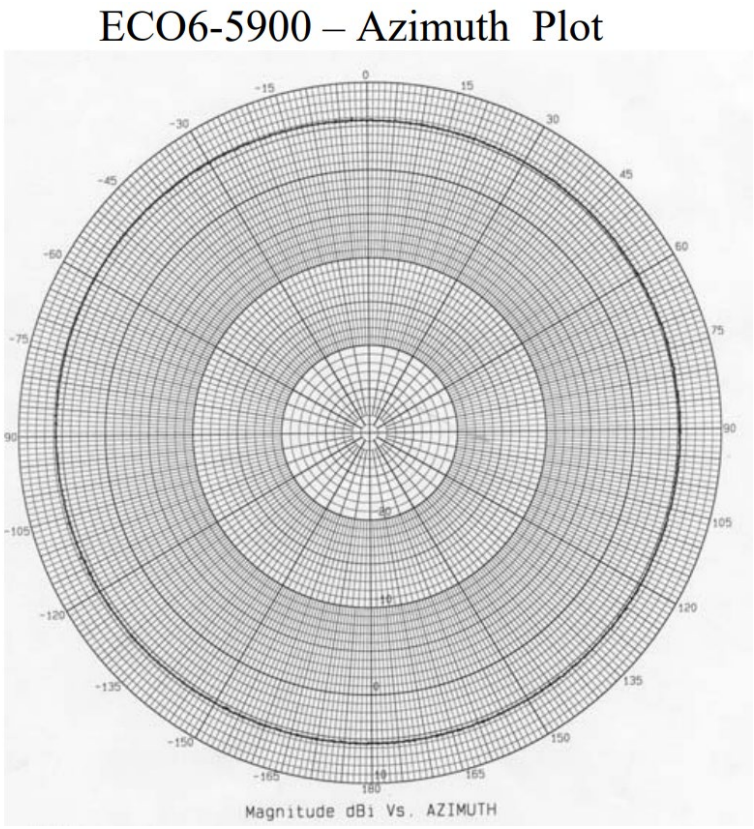
[3] https://ecfsapi.fcc.gov/file/1042725827205/Ford%20Motor%20Company%205.9%20GHz%20FCC%20Reply%20Comments%20as%20Filed%204-27-20.pdf

Wi-Fi Antenna Pattern (ECO6-5900)

Given the position of the antenna the average gain in the elevation toward the roof of the car is approximately -7 dBi

Given this antenna emission pattern, this set-up is estimated to provide ~13 dB of isolation between the Wi-Fi and C-V2X antennas – this implies that resulting interference could be worse than observed when smaller gain, more omni-directional antennas are used.

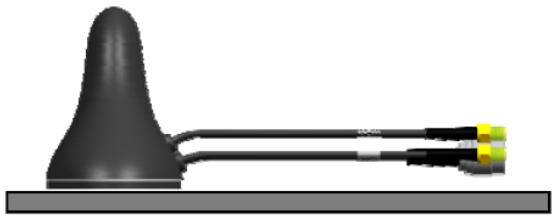




[4] https://www.mobilemark.com/wp-admin/admin-ajax.php?juwpfisadmin=false&action=wpfd&task=file.download&wpfd_category_id=2014&wpfd_file_id=6589&token=13fbaaa1df6f6e0b3daa4b4fcf9d31e7&preview=1

Vehicle Radiated RF Power

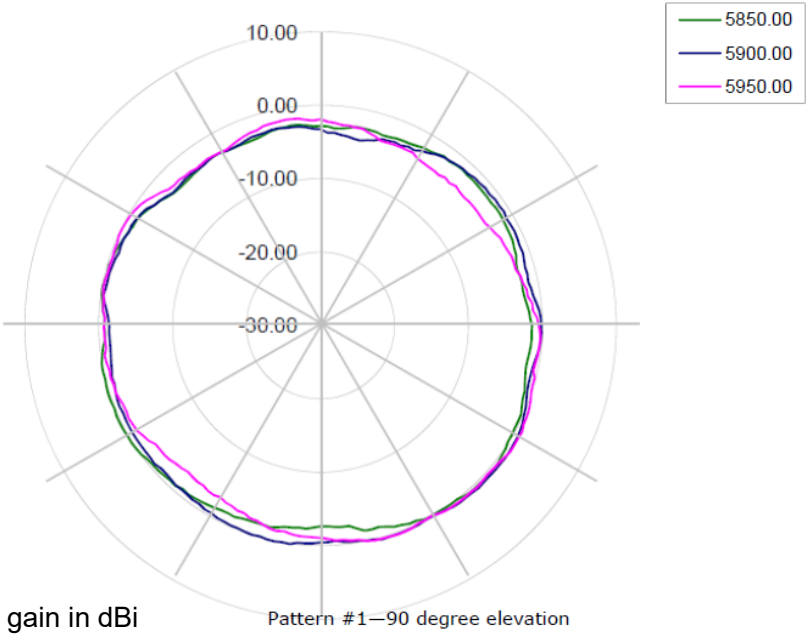
Radiated Power = Antenna Gain + Tx Power (unit) – Cable Loss
Tx Power (unit) = 20 dBm
Cable Loss (LMR 200, 3 meters) = ~ 3 dB
Antenna gain (horizon) = ~ 0 dBi
Radiated Power = ~ 17 dBm



Sketch #2—Mount on surface

Magnet Mount Antenna

Radiation Pattern @ 5.85 GHz, 5.90 GHz, 5.95 GHz



Pattern #1—90 degree elevation

The scale on the patterns is gain in dBi

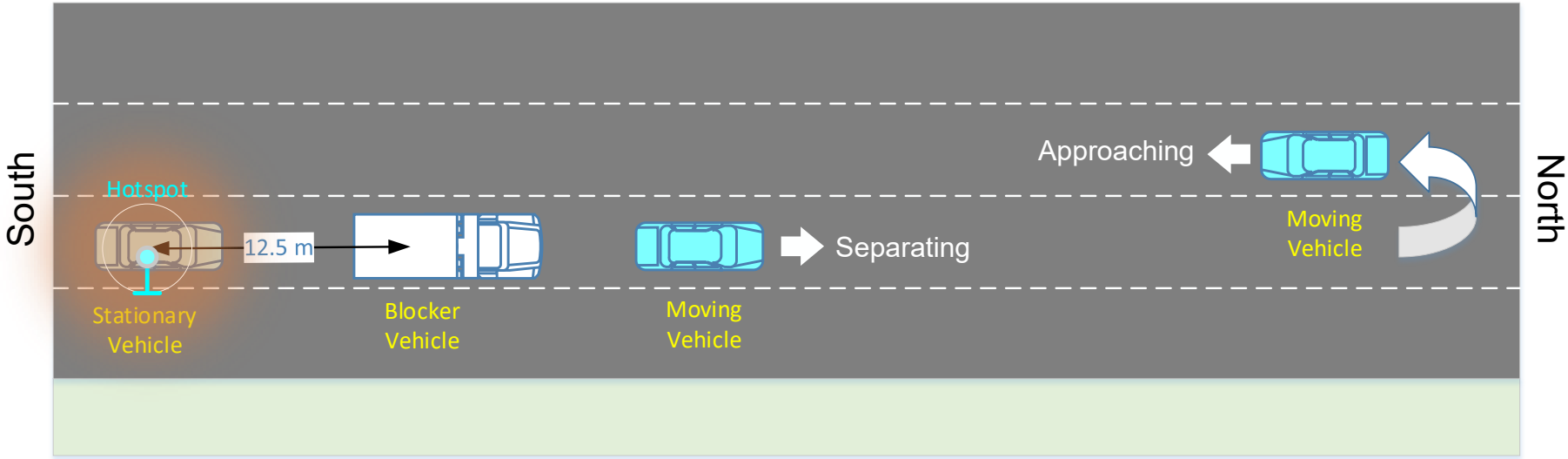
These patterns were measured on a 1m diameter circular ground plane with the antenna in the center

V2V Non-line of Sight (NLOS)

Test Setup: V2V NLOS

Primary Rx (Stationary) → 21 [Nissan Pathfinder]
Primary Tx (Moving) → 42 [Nissan Rogue]

In-vehicle Hotspot



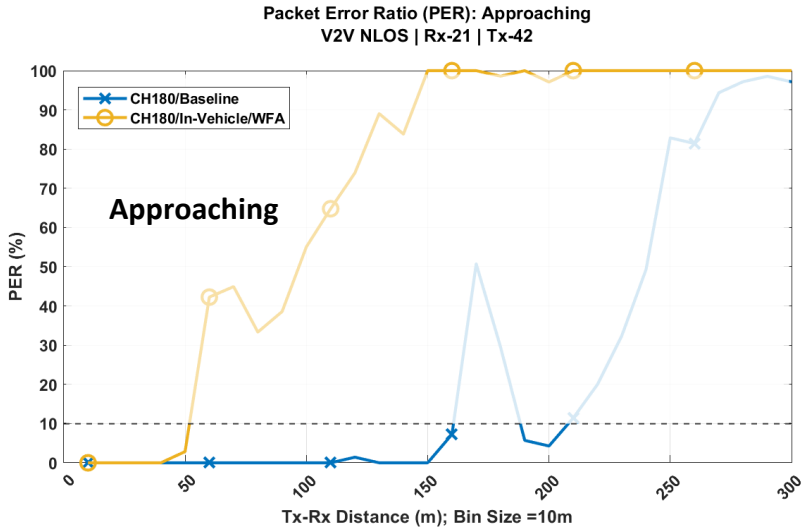
Roof-mounted C-V2X Antenna Setup

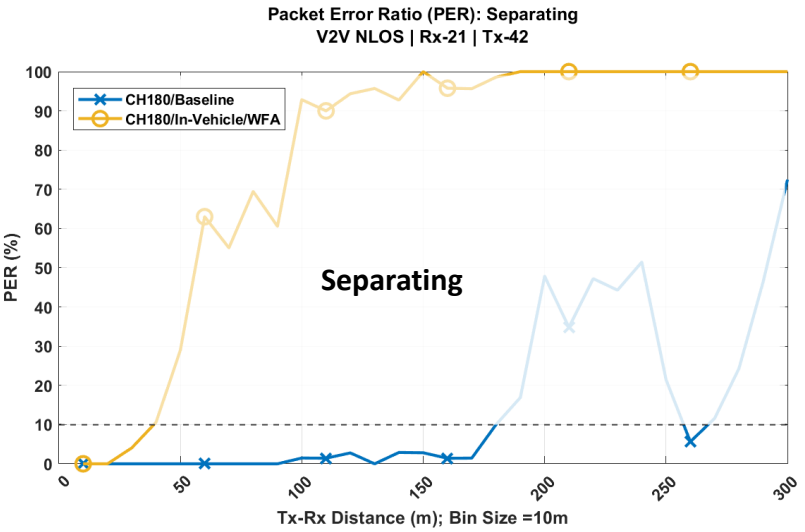
- The isolation between the in-vehicle hotspot and the primary and secondary V2X antennas was measured at 56 dB and 64 dB, respectively

V2V NLOS (Roof-mounted C-V2X Antenna)

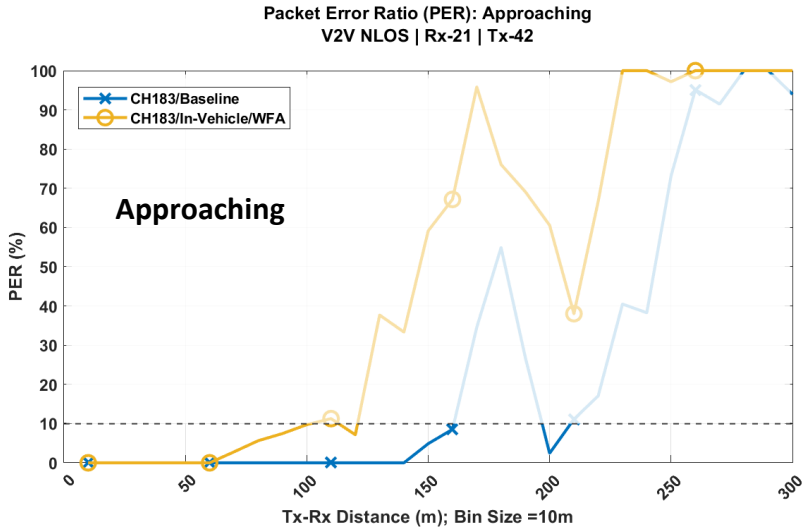
Stationary Vehicle Receiving

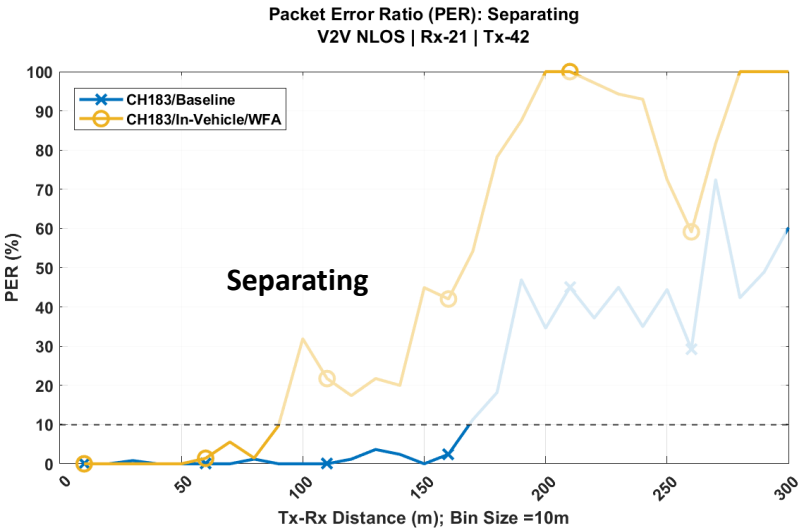
CH 180





CH 183





Impact on Safety Applications in CH 183

Test	Safety App	Warning Distance (10% PER) (m) w/o and w/ Wi-Fi	No Wi-Fi Maximum Safe Relative Speed (mph)	Wi-Fi Active Maximum Safe Relative Speed (mph)
V2V NLOS (approaching)	DNPW	160/110	45	31
V2V NLOS (separating)	EEBL	160/80	68	45

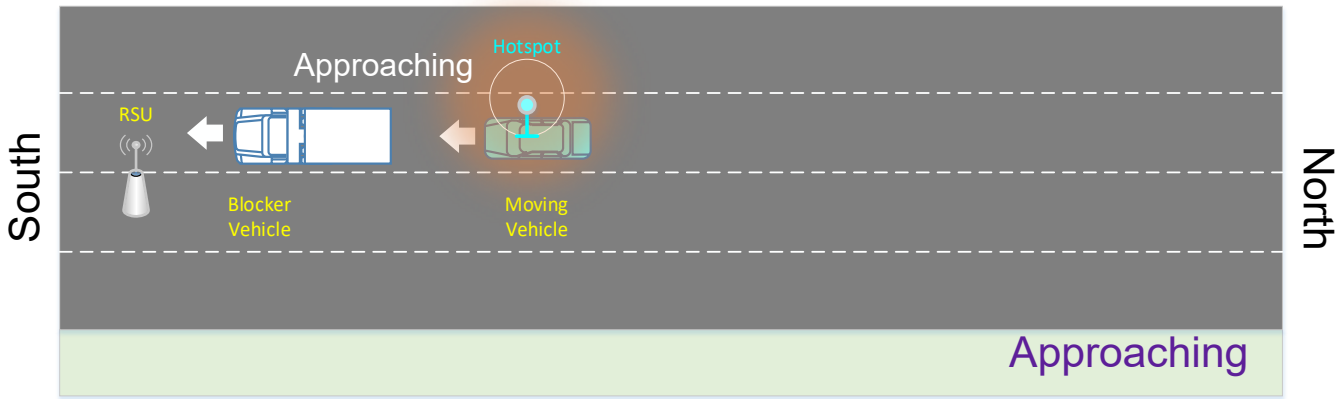
- Vehicles emulate Do Not Pass Warning (DNPW) Scenario while approaching and emulating the Electronic Emergency Brake Light (EEBL) Scenario while separating
- DNPW: Assuming 8 second margin between safe cross-over between north-bound and south-bound vehicles
- EEBL: Truck suddenly changes lane late and with 1.5s driver reaction, rear vehicle decelerates at 4 ms^{-2} just before vehicle in the front that is assumed stopped
- In both cases, the presence of Wi-Fi interference causes reduction in safe relative speed

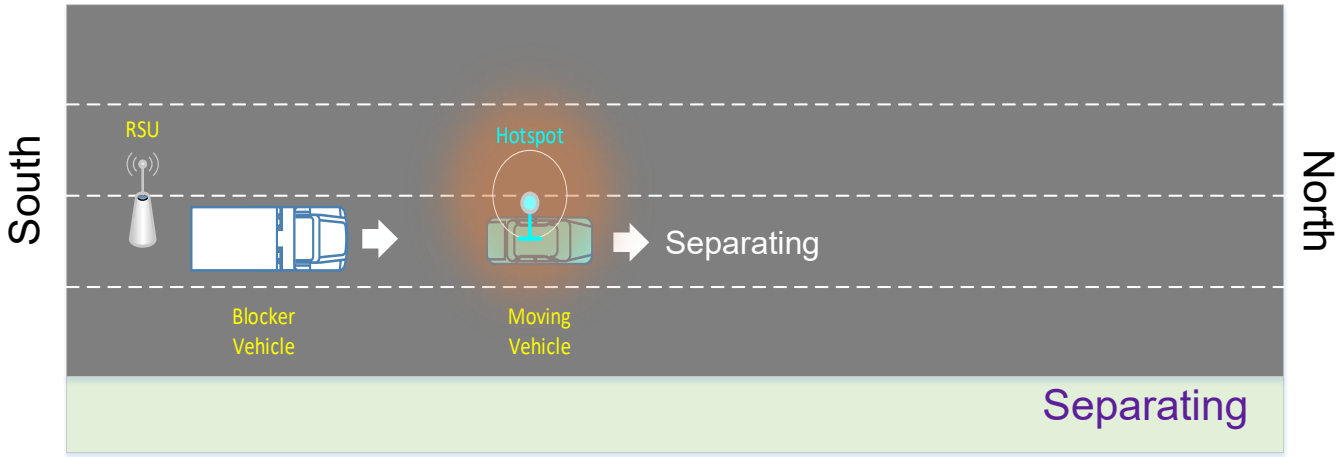
I2V Non-line of Sight (NLOS)

Test Setup: I2V NLOS

In-vehicle Hotspot

Primary Rx (Moving) → 21 [Nissan Pathfinder]
Primary Tx (Stationary) → 105 [RSU]

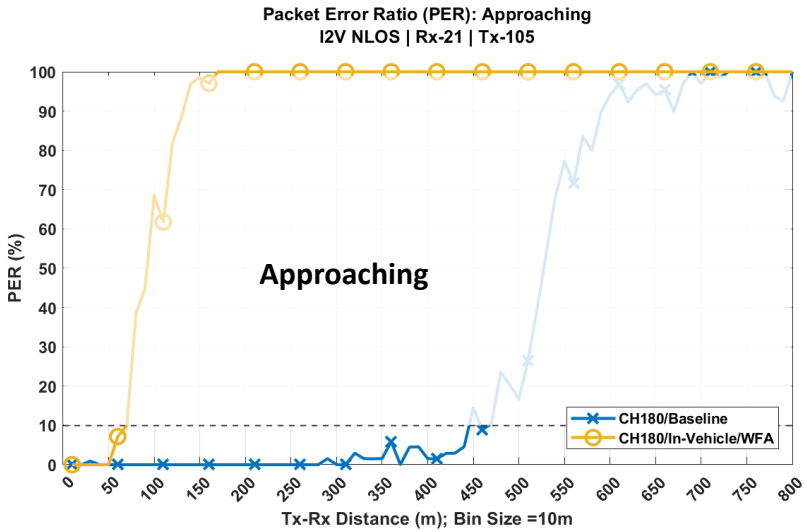


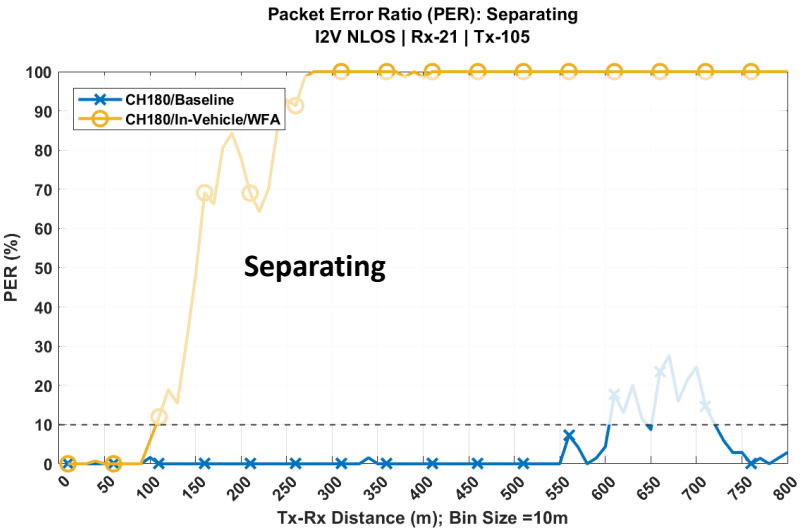


I2V NLOS (Roof-mounted C-V2X Antenna)

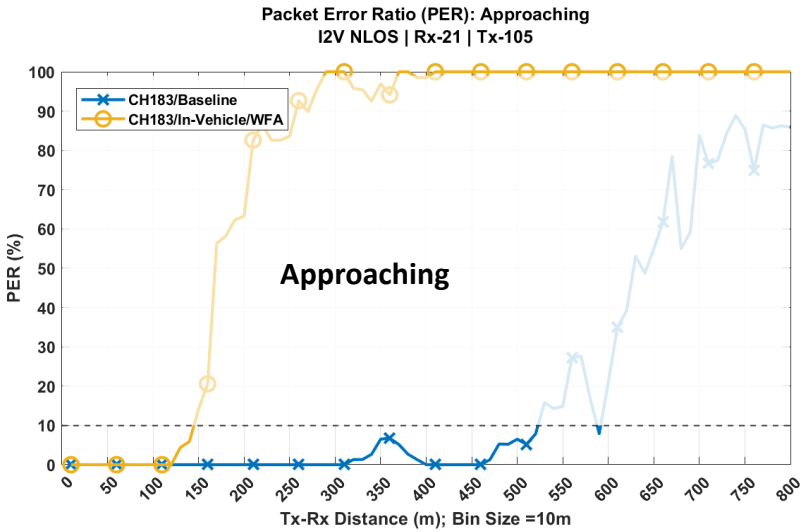
Moving Vehicle Receiving From RSU

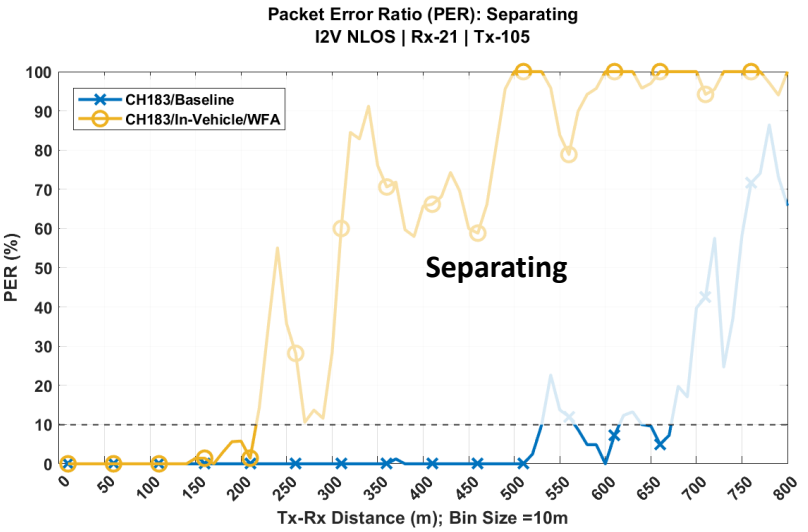
CH 180





CH 183



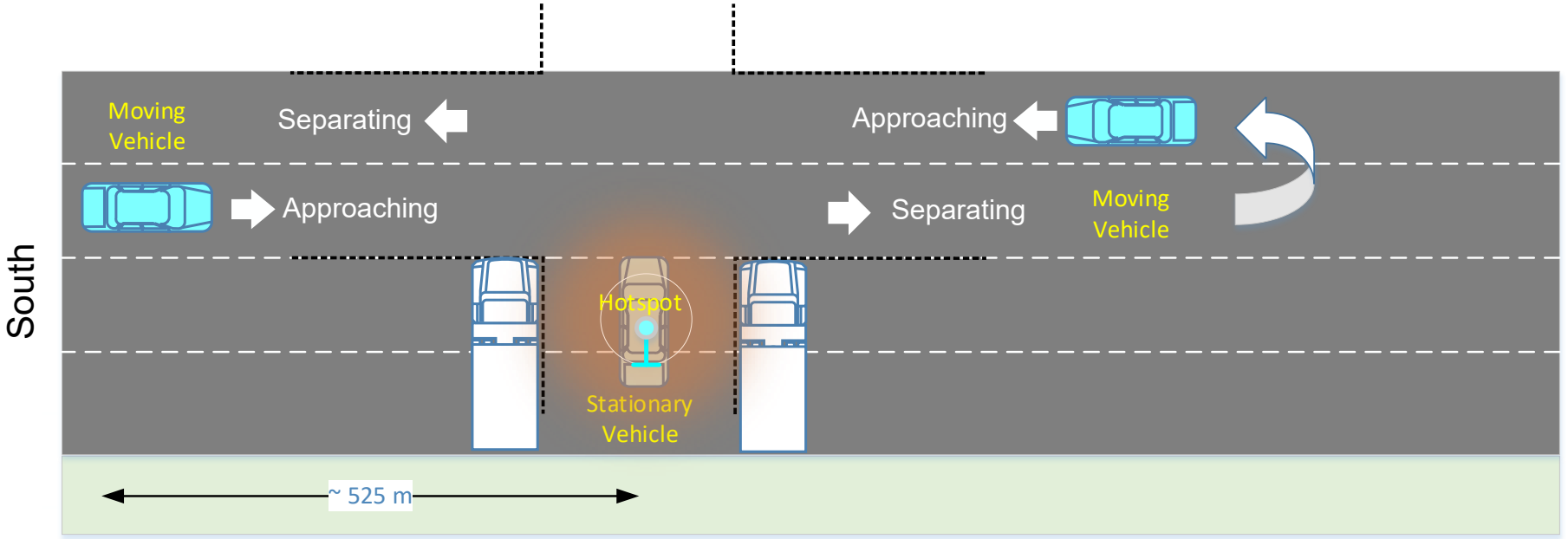


V2V NLOS Intersection

Test Setup: V2V NLOS Intersection

In-vehicle Hotspot

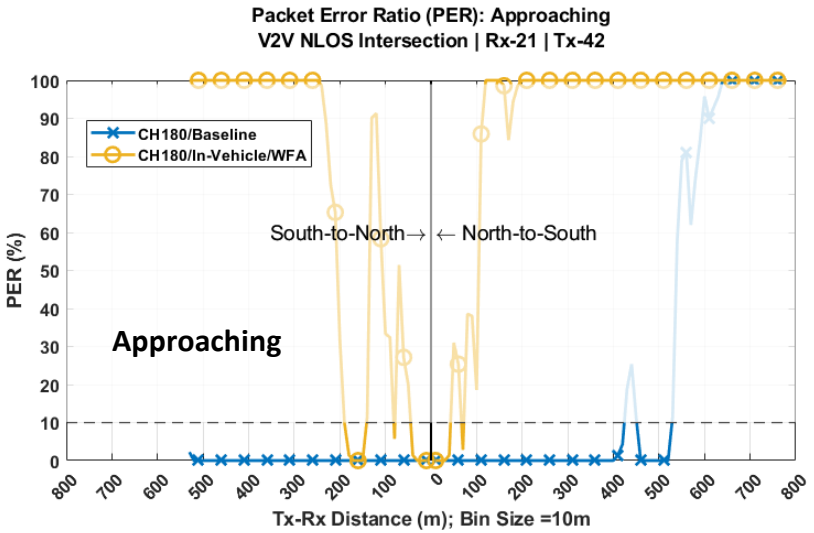
Primary Rx (Stationary) → 21 [Nissan Pathfinder]
Primary Tx (Moving) → 42 [Nissan Rogue]

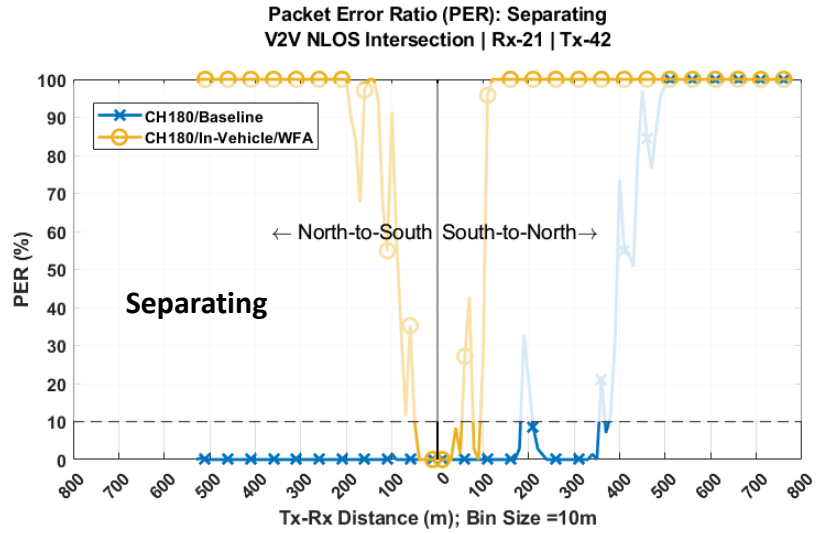


V2V NLOS Intersection (Roof-mounted C-V2X Antenna)

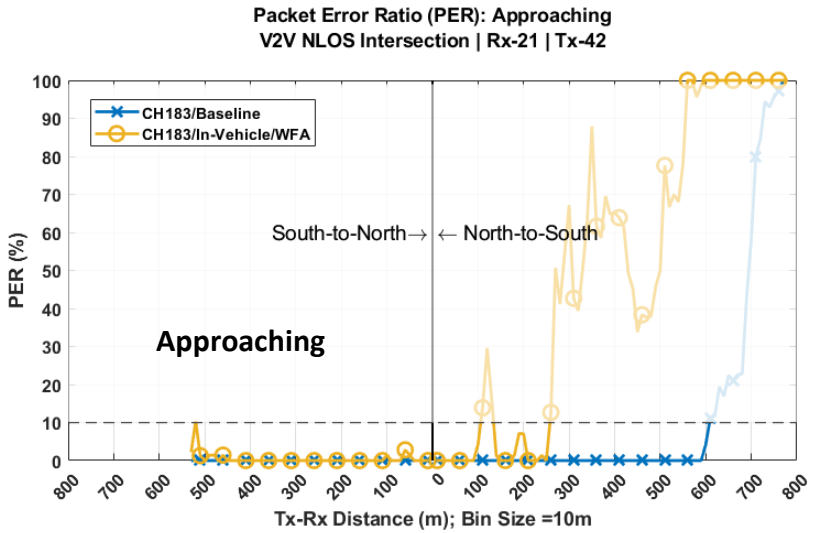
Stationary Vehicle Receiving

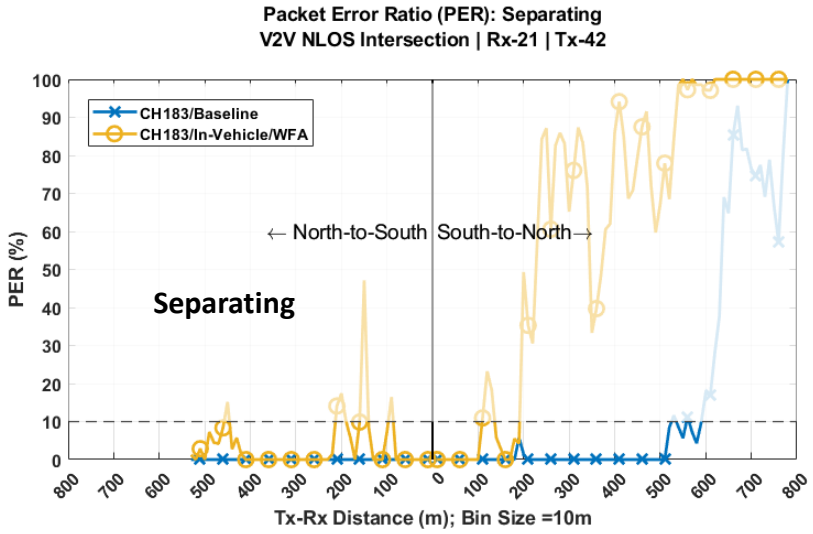
CH 180





CH 183



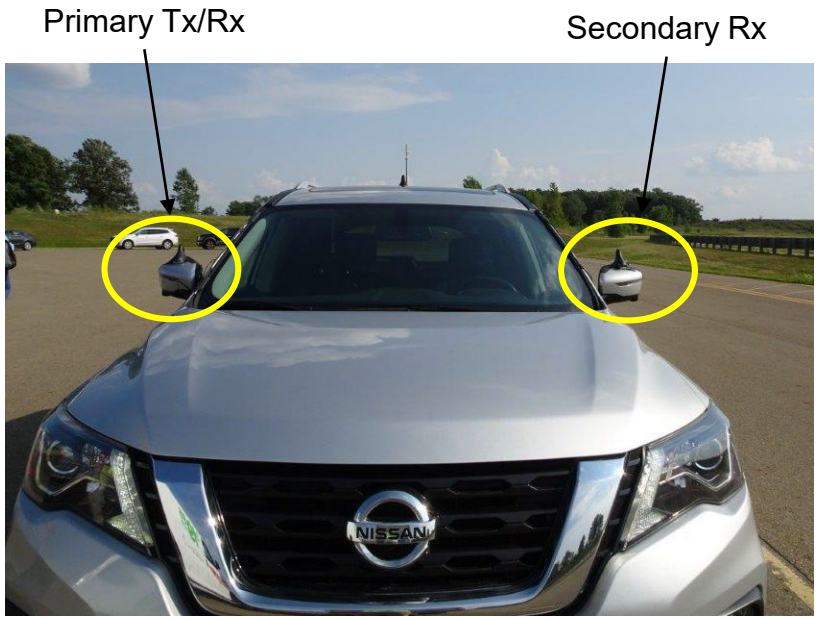


Testing Summary – In-vehicle Hotspot (Roof-mounted C-V2X Antenna)

Communication Range (@ PER < 10%)								
	Approaching				Separating			
TEST SCENARIOS	CH 180		CH 183		CH 180		CH 183	
	No Wi-Fi	In-vehicle Hotspot	No Wi-Fi	In-vehicle Hotspot	No Wi-Fi	In-vehicle Hotspot	No Wi-Fi	In-vehicle Hotspot
V2V NLOS	160 m	50 m	160 m	100 m	180 m	40 m	170 m	90 m
I2V NLOS	440 m	70 m	520 m	150 m	600 m	110 m	530 m	220 m
V2V NLOS Intersection	420 m	40 m	610 m	110 m	380 m	50 m	590 m	190 m

- Significant communication range degradation in the presence of U-NII-4 Wi-Fi in-vehicle Hotspot
- Both CH 180 and CH 183 are impacted, with higher harmful impact on CH 180

Side-mirror C-V2X Antenna Setup

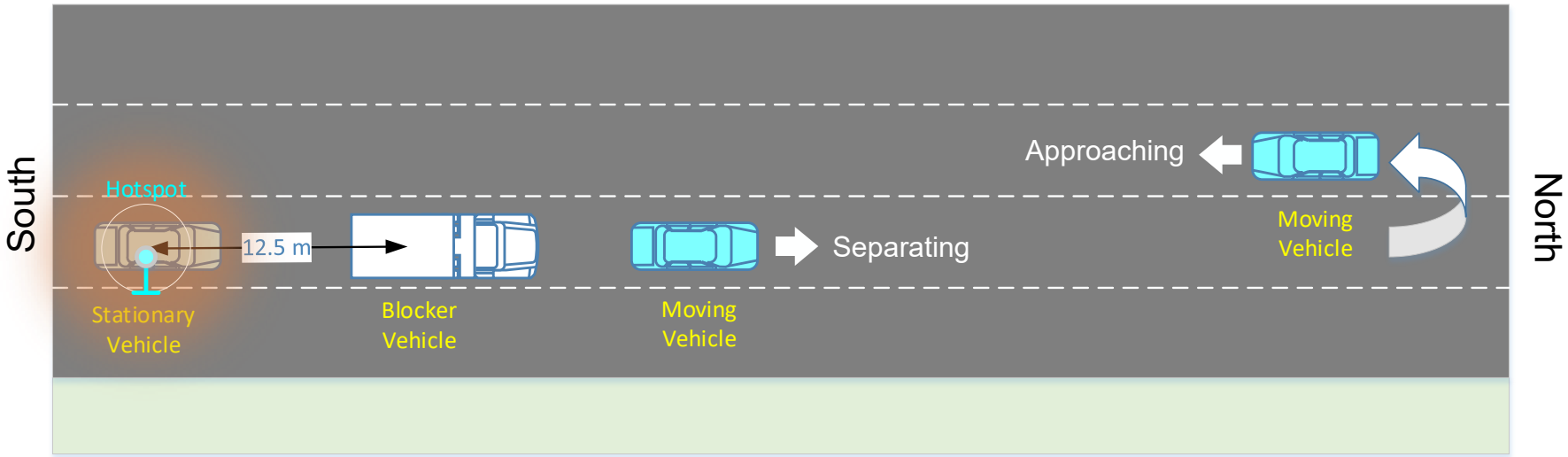


- Side-mirror C-V2X antennas were placed only on the stationary vehicle
  - Moving vehicle still had roof-mounted C-V2X antennas
- The isolation between the in-vehicle hotspot and the primary and secondary V2X antennas was measured at 52 dB and 60 dB, respectively

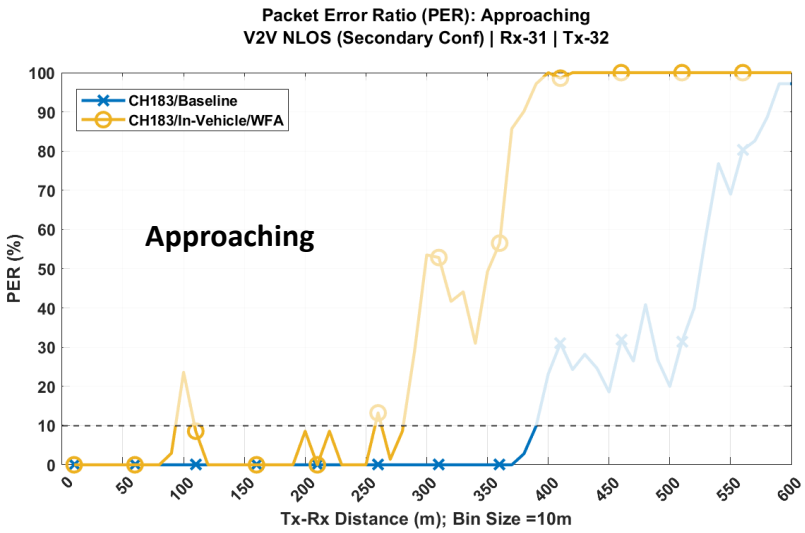
Test Setup: V2V NLOS

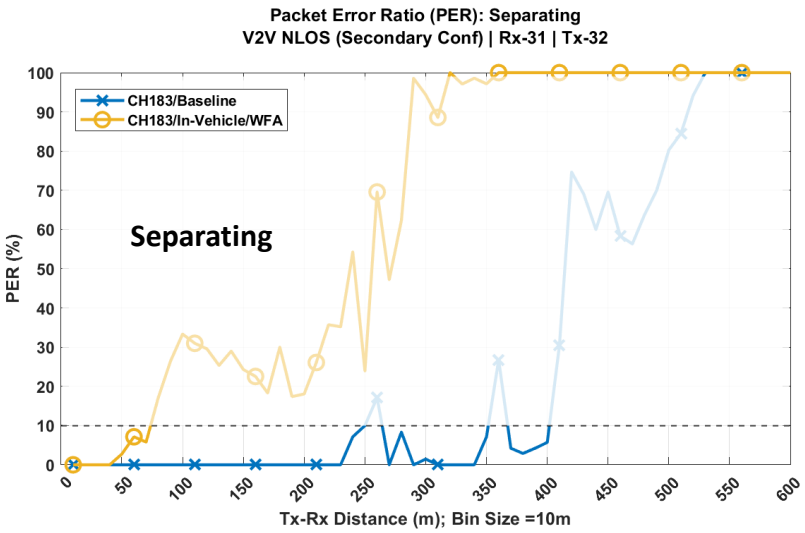
Primary Rx (Stationary) → 21 [Nissan Pathfinder]
Primary Tx (Moving) → 42 [Nissan Rogue]

In-vehicle Hotspot



V2V NLOS (Side-mirror C-V2X Antenna)
Stationary Vehicle Receiving
CH 183





Testing Summary – In-vehicle Hotspot (Side-mirror C-V2X Antenna)

Communication Range (@ PER < 10%)			
Approaching		Separating	
No Wi-Fi	In-vehicle Hotspot	No Wi-Fi	In-vehicle Hotspot
390 m	100 m	400 m	70 m

- Side-mirror C-V2X antenna configuration is tested in V2V NLOS Scenario with the same placement of the in-vehicle Wi-Fi antenna as in the previous tests
  - Only CH 183 was tested
- Significant communication range degradation in the presence of In-vehicle Hotspot U-NII-4 Wi-Fi operation
- With less spectral separation, interference to CH180 is expected to be greater than observed in CH183

Conclusions

- Field tests of three (3) V2X safety use cases have clearly shown harmful interference when U-NII-4 Wi-Fi devices operate in-vehicle
- Depending on the choice and positioning of the Wi-Fi antenna in-vehicle the interference to C-V2X can be even higher
- For that reason, additional protection of V2X safety applications is required

Backup

C-V2X Device Parameters

	20 MHz (CH 183)		10 MHz (CH 180)	
Packet Size	MCS	Num Sub Channels	MCS	Num Sub Channels
365	11	2	11	2
1400	7	10	7	5

Sub-Channel Size = 10 Resource Blocks (RB)
HARQ Enabled