Cost-efficient C-V2X Antenna Installation

Technical Report

June 2020

Autotalks

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1 // Introduction

1.1 // Motivation

Correct operation of V2X safety applications depends on achieving a minimal effective communication range to ensure the driver has sufficient reaction time.
3GPP specifies the usage of two RX antennas for LTE communication in general. C-V2X specification adopted this as a baseline ([5] § 7.2) regardless of vehicles' shapes and without involving carmakers, which are cost-sensitive, and would prefer to use a single-antenna where possible..
The value of C-V2X will increase with higher numbers of connected cars. By the same token, more cars would be connected if the overall C-V2X system cost would decrease.
Antenna pattern and placement, coupled with the shape of the vehicle, impacts V2X communication range. In this paper, Autotalks examines two options to reduce C-V2X system costs. The first one is using a single antenna, saving significant costs of a front antenna. The second configuration examined is removing the cable compensator. Instead of the compensator, the front antenna is connected to the ECU using a low-cost long COAX cable, introducing high attenuation, saving the cost and complexity of compensator.

1.2 // Industry Range Requirements

Minimal V2X communication range in open road varies per region:

Region	Range
USA	300m [1][2]
Europe	400m [3]
China	300m [4]

Table 1 Industry Requirements

Communication range is defined as the range for which packet-error-rate (PER) ≤10%.

2 // Testing

2.1 // Test Vehicles

The following vehicle models were used (two of each model) in the tests:

Curved Roof SUV with Sunroof: BMW X4

The BMW X4 was selected to represent a challenging vehicle shape. A large vehicle with highly curved roof, with a sunroof covering most of the roof area - minimizing the metal area of the roof and reducing the amount of reflections reaching the antenna.

Flat Roof Car: Mini Cooper

The Mini Cooper was selected to represent a common passenger vehicle shape. A small car with a flat all-metallic roof.

2.2 // Antenna Placement

Dual antenna scenarios were tested using a typical front-rear antenna installation:

Single antenna scenarios were tested using a rear antenna installation:

2.3 // Test Configuration

The following configurations were used during the tests:

Parameter	Single Antenna	Dual Antenna
Frequency	5.910GHz	
Channel Bandwidth	10Mhz	
TX Power (@EVK Port)	23dBm	
Modulation	MCS7	
Subchannels	3 (30RBs)	
Packet Size	421 Byte	
Cable attenuation to front antenna	N/A	Compensator mode: 1dB No compensator mode: 8dB
Cable attenuation to rear antenna	None (Direct connection to DUT)	Compensator mode: 1dB No compensator mode: None (Direct connection to DUT)
Antenna Gain	1dBi	
HARQ	Enabled	
Diversity	N/A	RX: MRC TX: CSD (both antennas transmitting at the same time)

2.4 // Tests Description

The tests were performed with matching vehicles (TX and RX vehicles are the same) and matching antenna configuration:

Scenario	TX Vehicle	RX Vehicle
Mini	Single Antenna	Single Antenna
	Dual Antenna	Dual Antenna
BMW X4	Single Antenna	Single Antenna
	Dual Antenna without Compensator	Dual Antenna without Compensator
	Dual Antenna with Compensator	Dual Antenna with Compensator

Table 2 Test Scenarios

2.4.1 // 360° Coverage

In order to verify the antenna installation, a "Turntable" test was performed. In this test the two vehicles were placed 200m apart. The TX vehicle remained parked while the RX vehicle was placed at 0°, 90°, 180° and 270° relative to the TX vehicle. The received signal strength (RSSI) was measured at each angle:

TX Vehicle	RX Vehicle	0°	90°	180°	270°
X4 Dual Ant.	X4 Dual Ant.	Rear: -84dBm Front: -75dBm	Rear: -70dBm Front: -73dBm	Rear: -75dBm Front: -82dBm	Rear: -70dBm Front: -70dBm
X4 Single Ant.	X4 Single Ant.	-87dBm	-84dBm	-81dBm	-81dBm
Mini Dual Ant.	Mini Dual Ant.	Rear: -70dBm Front: -64dBm	Rear: -62dBm Front: -61dBm	Rear: -65dBm Front: -70dBm	Rear: -62dBm Front: -66dBm
Mini Single Ant.	Mini Single Ant.	-67dBm	-70dBm	-72dBm	-67dBm

Table 3 200m Turntable RSSI Measurements

In addition, in order to verify that a single antenna can provide 360° coverage at the required distance, another test was performed. In this test the two vehicles were placed 500m apart. The RX vehicle remained parked while the TX vehicle drove a full small circle.

Figure 2, showing PER and distance between the vehicles over time, shows that a single antenna can provide 360° coverage at 500m, exceeding the regional minimal communication range requirements:

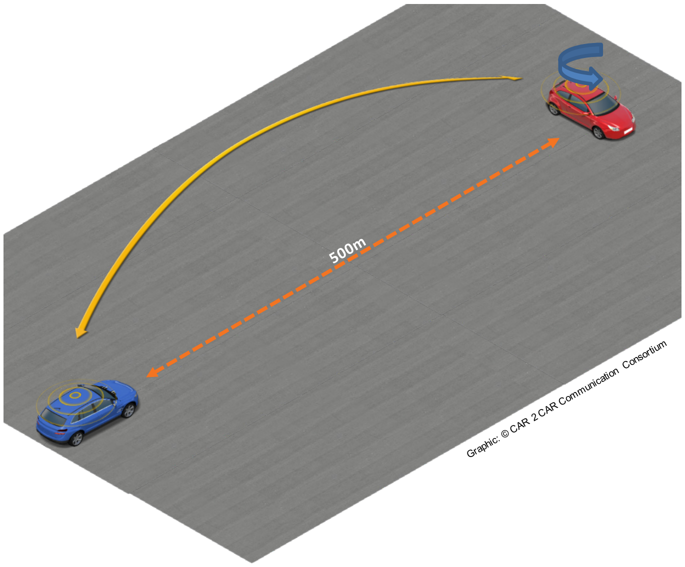


Figure 1: 500m Turntable Test

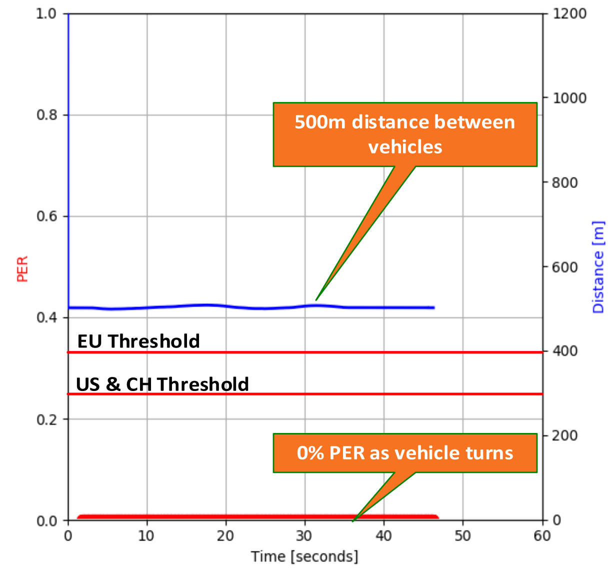


Figure 2: 500m Turntable Test Results

2.4.2 // Non Line-of-Sight

NLOS communication range was tested at a blocked-view urban intersection (T shaped junction). The tests were performed during daytime with active traffic of cars and buses on the road.
The RX vehicle remained parked 30m from the intersection while the TX vehicle approached the intersection at ~50km/h:

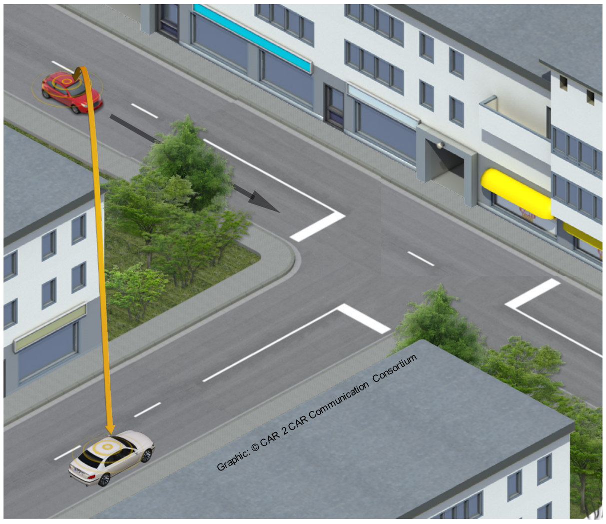


Figure 3: NLOS - Urban Intersection illustration

Figure 4: NLOS Test Location

2.4.3 // Line-of-Sight

LOS communication range was tested on an open public road with a 1.8Km of unobstructed line-of-sight conditions. The tests were performed during daytime with active traffic of cars and trucks on the road.
The RX vehicle remained parked while the TX vehicle approached from a 2Km distance at approx. 70km/h.

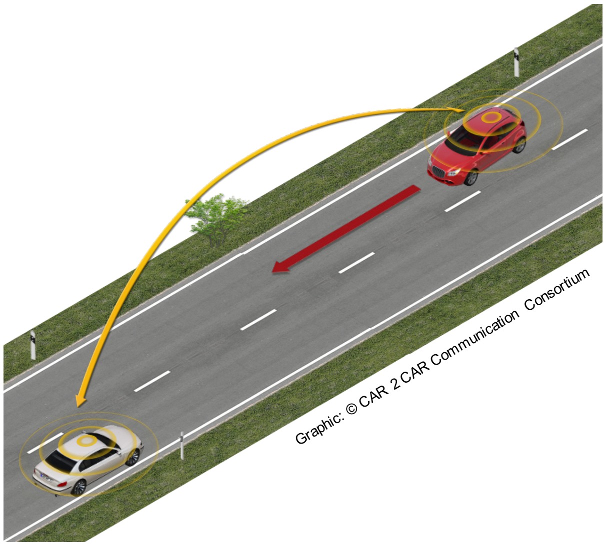


Figure 5: LOS - Open Road illustration

Figure 6: LOS Test Location

3 // Results

The following figures show Packet Error Rate (PER) (Y-Axis) vs. Distance in meters (X-Axis) results from multiple runs, each using a different line color, for all test cases.

3.1 // NLOS – Urban Intersection:

Figure 7: NLOS - Mini Cooper Single Antenna

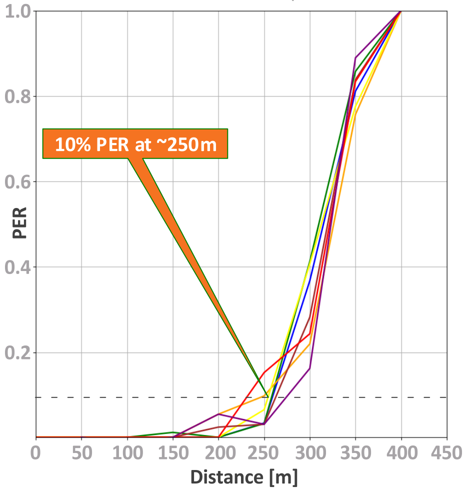


Figure 9: NLOS - Mini Cooper Dual Antenna

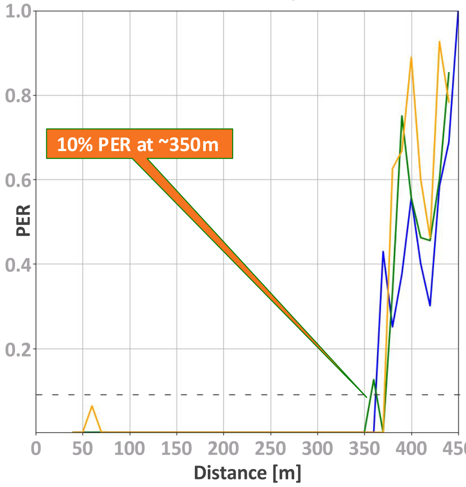


Figure 8: NLOS - BMW X4 Dual Ant. with Compensator

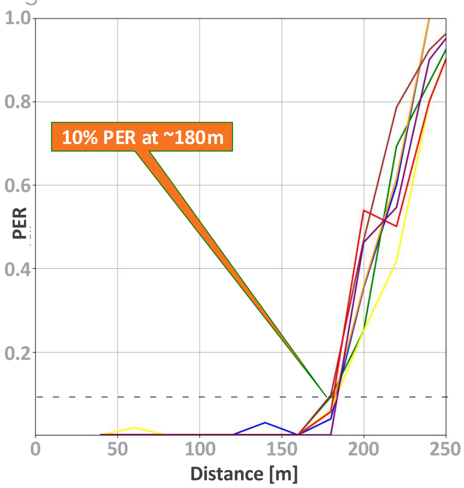


Figure 10 NLOS - BMW X4 Dual Ant. w/o Compensator

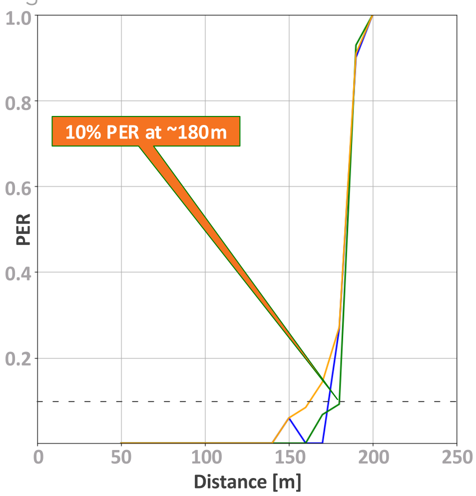
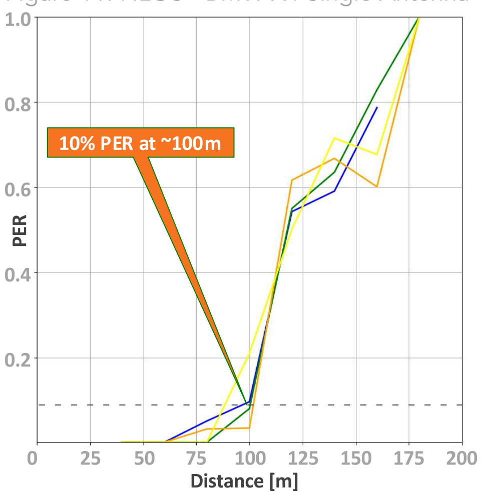


Figure 11: NLOS - BMW X4 Single Antenna



3.2 // LOS – Open Road:

Figure 12: LOS - Mini Cooper Single Antenna

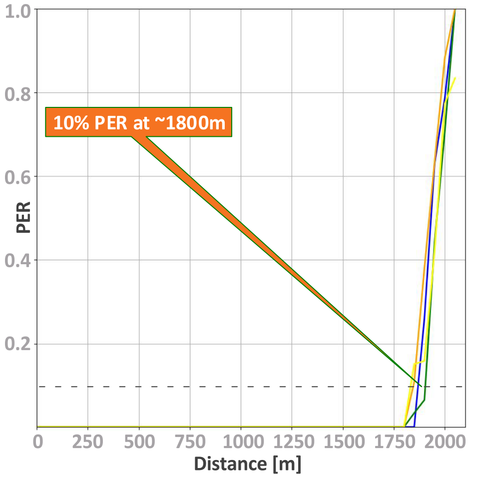


Figure 13: LOS - BMW X4 Dual Ant. with Compensator

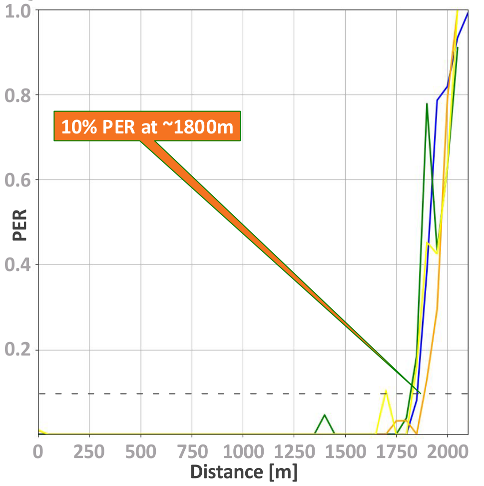


Figure 14: LOS - BMW X4 Dual Ant. w/o Compensator

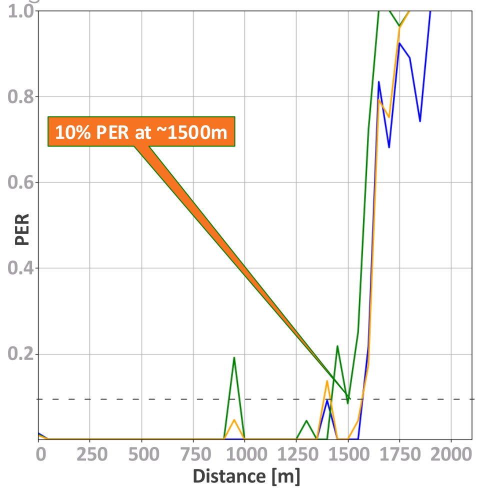
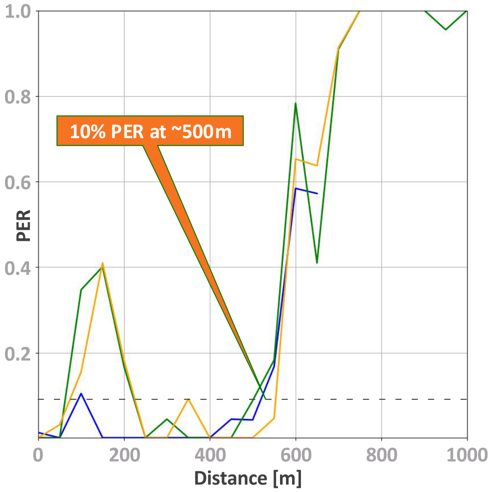


Figure 15: LOS - BMW X4 Single Antenna



4 // Conclusions

The tests measured communication range in LOS and NLOS scenarios, focusing on the ability to use a single antenna and removing the compensator when dual-antenna is used.

NLOS test observations:

> Dual antenna Mini Cooper achieved longest range (350m), yet a single antenna Mini Cooper achieved more than sufficient warning time of 18sec (250m @ 50km/h)
> The dual antenna BMW X4 surprisingly showed similar results with and without the cable compensator
> The single antenna BMW X4 reached a range of 100m. While still providing a 7sec warning time, as in the LOS scenario, this shows that vehicles with similar shapes would typically require dual antennas, considering potential usage of higher MCS and heavier road traffic

LOS test observations:

> Mini Cooper, equipped with a single antenna, achieved 1.8Km range, far exceeding all industry requirements, which may be limited only by the end of the road
> The BMW X4 equipped with dual antenna and cable compensator achieved 1.8Km as well
> Even without the cable compensator, thanks to the CSD diversity scheme, the BMW X4 reached 1.5Km effective range, exceeding all regulatory requirements
> When equipped with a single antenna, the BMW X4 reached an effective range of 500m. This shows that a large vehicle with curved non-metallic roof would typically require a dual-antenna system, considering the possible range reduction factors

The above results clearly show that in many vehicle models, a single antenna installation can achieve communication range exceeding regulatory and safety applications requirements.

Some vehicles would require a dual antenna installation. However, in most cases, implementing true TX Diversity (CSD) eliminates the need for a cable compensator.

The results are summarized in Figure 16 and Figure 17 below.

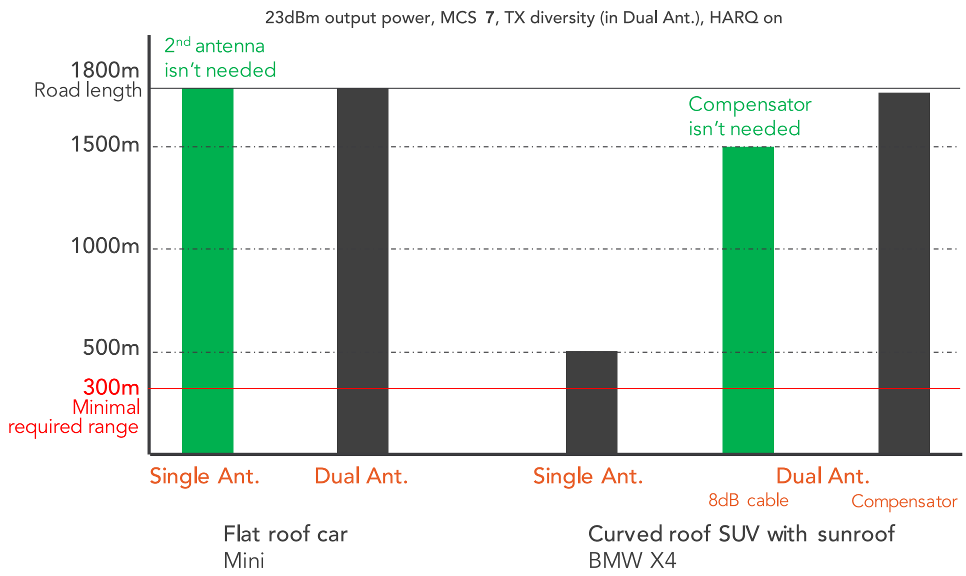


Figure 16: Result Summary – LOS

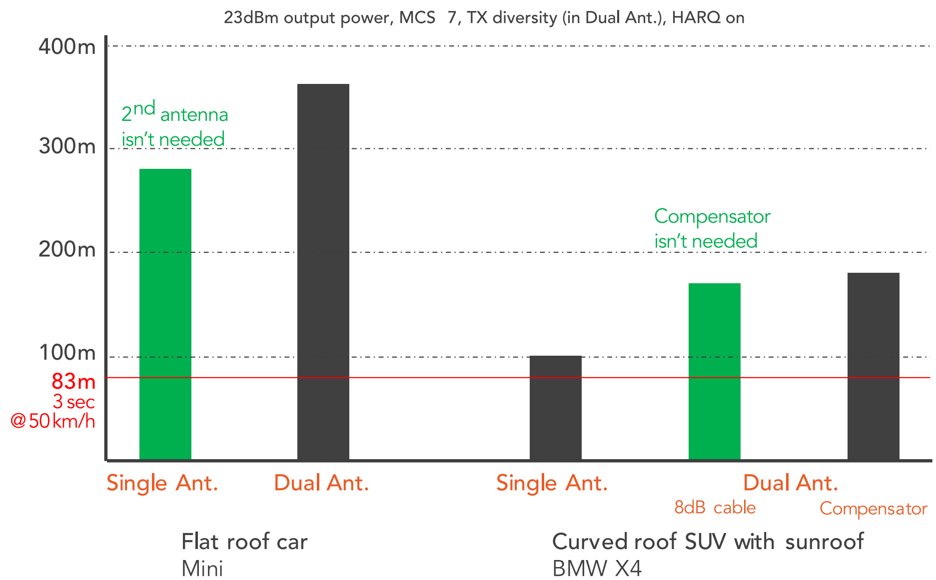


Figure 17: Result Summary - NLOS

Observation: Roof Material Effect on Reception

During the tests we observed that the roof material contributed the most to the antenna reception (more than an accurate antenna placement). The metal roof serves as a reflector, with the reflections greatly increasing the antenna reception – to the effect that opening the sunroof did not degrade the reception.

5 // Recommendations

As the results show, dual antenna installation is not required for some, if not most, vehicle models.

As lowering the cost of V2X would push forward the deployment of V2X enabled vehicles and, as a result, increase the value of V2X, Autotalks encourages the industry to collaborate with standardization and certification bodies to allow single antenna installations for C-V2X systems.

The presented results are only indicative as they represent the maximal achievable range. In mass-production vehicles, several constraints may affect performance, for example:
> Lower antenna gain
> Impact of additional RF radiators from the same antenna enclosure as V2X
> Higher cable or ECU RF losses

Installation constraints differ according to vehicle model, and therefore each OEM must run its own measurements.

Nevertheless, the results show considerable margins. The conclusions remain valid and apply to most vehicle architectures, even if the actual range is halved.

6 // Annex: Understanding TX Diversity Gain

6.1 // What is Cyclic Delay Diversity?

Cyclic Delay Diversity (CDD), enables to transmit from both antennas the same information at the same time and on the same frequency resources (without wasting more time or bandwidth). CDD applies a different phase delay to each antenna in order to prevent destructive interference between the two antennas.

6.2 // CDD vs. Switching Diversity

Alternative diversity scheme is Switching Diversity. With Switching Diversity, the transmitter alternates the transmissions between the two antennas: For example, transmitting the 1st HARQ copy from the first antenna and the HARQ retransmission from the second antenna.

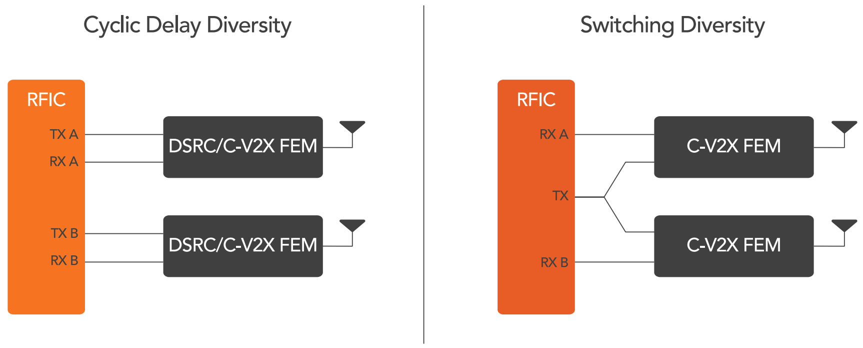


Figure 18: TX Diversity Comparision

While switching diversity scheme utilizes both antennas, when one transmitting antenna is badly received, alternating the transmissions will result in a loss of 50% of the transmissions. Each message would be received once in a given direction, resulting in no HARQ gain (3-6dB).

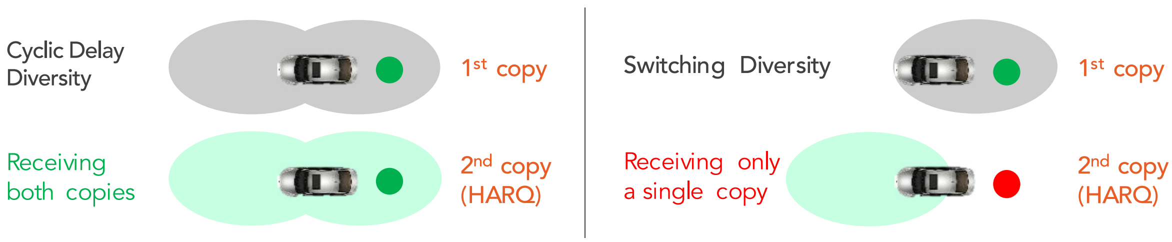


Figure 19: CSD Diversity HARQ Gain

6.3 // Diversity Schemes & Cable Compensator

As explained above, CDD diversity scheme improves system gain, and thus compensates for the attenuation of the coaxial cable to the remote antenna.

Hence, in most cases, CDD diversity eliminates the need for cable compensator in dual-antenna systems.

Contrary to the above, since switching diversity does not add such system gain, dual antenna vehicles equipped with switching diversity modems might require cable compensator to overcome the insertion loss caused by the second antenna cable (depending on cable length).

Reference Documents

[1] SAE J9245/1 On-Board System Requirements for V2V Safety Communications

[2] SAE J3161/1 On-Board System Requirements for LTE-V2X V2V Safety Communications

[3] C2C-CC TF Antenna & Wireless Performance – Whitepaper

[4] YD/T 3400-2018 General technical requirements of LTE-based vehicular Communication

[5] 3GPP TS36.101 User Equipment (UE) radio transmission and reception

Abbreviations

3GPP	3rd Generation Partnership Project
CDD	Cyclic Delay Diversity
CSD	Cyclic Shift Diversity
C-V2X	Cellular V2X
HARQ	Hybrid Automatic Repeat Request
LOS	Line of Sight
NLOS	Non Line of Sight
RSSI	Received Signal Strength Indicator
RX	Reception
TX	Transmission
V2X	Vehicle to Everything

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