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EMC Test for Connected Vehicles and Communication Terminals

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***Abstract*— With rapid development of intelligent connected vehicles and VANET (vehicular ad-hoc network), electromagnetic environment that vehicles are facing becomes more complex than ever. The popular multi-function on-board radio terminals include various wireless blocks, such as mobile phone, FM radio, Wi-Fi hotspot, GPS receiver and Bluetooth transceiver, etc. All these blocks are working in a circumstance full of radio energy. Both academic circles and professionals concern if the upcoming intelligent connected vehicle and the radio terminals on-board could withstand the increasingly complex electromagnetic environment, and keep a good performance under high power radiation. Unfortunately, until today, there is no commonly agreed specification for such kind of test. In this paper, the connected vehicles, together with the on-board radio terminal, are discussed to find out a solution for their EMC test, while immunity pre-test platform is designed and corresponding test schemes are presented.**

I. INTRODUCTION

Thanks to the advent of intelligence driving, vehicle makers are keen to install automotive electronics to upgrade the comfortable requirements of the consumers. The integration of communication systems for vehicles is becoming more and more important for ITS. With the inclusion of more sophisticated vehicle communications systems, the car producers have boosted the request of dedicated antennas that can operate at different frequency bands and are capable of coping with the needs of new mobile and WLAN standards, as well as with other services, such as GPS, car-to-car (C2C), or remote keyless entry (RKE) [1]. As a result, both inside and outside of vehicles are filled with electro-magnetic waves with different frequencies, causing the problem of electromagnetic interference (EMI), and bring about tremendous challenge to both vehicle and corresponding component design [2]. Several studies have reported relation between immunity performance of differential communication system [3]. As a consequence, we cannot identify the factor of the communication error by the conventional waveform measurement when immunity performance degrades. In other words, we cannot identify the noise countermeasure effect using the conventional waveform measurement.

During the market-oriented process, vehicle makers concern about overall performance of intelligence vehicle, while the parts manufacturers care about performance of specific components. Both of them are in need of EMI test schedule for multi-frequency on board systems. Moreover, trends in the Industry standard approach to the design and verification of systems for EMI/EMC compliance have become more focused on implementing broad scale unit-to system-level verification [4].

In past few years, researchers are committed to automotive EMC design and test technologies. In [5], the authors studied the vehicle electrical return paths and the impact of EMC condition on the vehicle electric systems. Moreover, electrical impedance measurements of representative on-vehicle structural elements are proposed to develop vehicle's analysis and modelling work. N. Zaman defined concepts of vehicle electronics architecture, and details the wide variety of Electronic Control Modules (ECMs) that enable the increasingly sophisticated "bells & whistles" of modern designs [6]. With the continuous development of VANET, industry insiders pay more attention to vehicles' terminal design, while the corresponding EMC test approaches are putting forward. In [7], a vehicle Internet terminal oriented EMC test setup scheme is presented. To ensure immunity performance of in-vehicle Ethernet, literature [8] proposed a mixed mode S-parameter S_{dcll} based criteria and clarified the relation between Bulk Current Injection (BCI) test results and the values of S_{dcll}. A vehicle radiated immunity testing scheme is given in [9], in which the maximum electric field (E-field) distribution in a vehicle under multipath propagation and single plane-wave exposure environments are studied.

At present, the research mainly focuses on the EMC test for vehicle terminal itself, but seldom involve its multi-frequency immunity feature. In this paper, the vehicle multi-frequency radio terminal's immunity feature is discussed, while immunity pre-test platform is designed and corresponding test schemes are presented.

The rest of the paper is organized as follows. Section 2 presents the preliminaries. The detailed test schemes are presented in section 3, and test results are analysis in section 4. Finally, conclusion is given in section 5.

II. PRELIMINARIES

A. The Electromagnetic Environment for nowadays vehicles

Fig. 1. Tthe Radio Atmosphere for nowadays Vehicles

As shown in Fig.1, the vehicle "lives" in a world of radio energy, which can be found in form of a cellular phone

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signal, a FM radio signal, a Wi-Fi hotspot, a radar signal, or a GPS signal, etc. These high-tech gadgets, not only run on the battery power, but also do require radio energy to get fully operational [6]. The presence of 'radio energy atmosphere' around vehicles plays a vital role in vehicle operation. According to legislation and regulation of CTA (China Type Approval) and State Regulation of China [10], we list related frequencies in Table 1.

TABLE I

RELATED FREQUENCY

Equipment type	Frequency bands	Power
TPMS, RKE	314-316MHz\433.92MHz	10mW
Security system	409.75-409.8625MHz	500mW
Broadcast, MP3	87-108 MHz	100mW
Handheld Transceiver	137-144MHz\146-149.9MHz 150.05-167MHz\403-406MHz 406.1-406.5MHz 409.5-409.75MHz 409.9875-423.5MHz	25W
V2X	5.9GHz	100mW
Blue tooth	2.4-2.4835GHz	100mW
Cellular\wireless connectivity	1880-1920MHz\2010-2025MHz 2320-2370MHz\1920-1980 MHz	300mW
ACC radar	76-77GHz	400mW
RCP radar	24.00-24.25GHz	20mW
BSD radar	24.25-26.65GHz	25mW
GPS	1575.42 $\pm$ 10MHz	
Beidou Navigation System	B1:1561.098 $\pm$ 2.046MHz B2:1207.14 $\pm$ 2.046MHz B3:1268.52 $\pm$ 10.23MHz	

B. Electromagnetic Compatibility performance

Definition 1: Radiation Emission

Radiation emissions are defined as the radio frequency energy radiated by the in-vehicle module into the atmosphere due to the power electronics embedded inside the module. In order to determine the effects of radiation emissions, it is desired that emissions be measured by the measuring equipment to understand the limits of the emissions to determine their impact to the other components of vehicles. [11]

Definition 2: Radiated Immunity Against Radio Energy

The quality of absorbing radio energy without affecting the device electronics for its intended operation is defined as the immunity against radio energy that is applied on the electronic device wirelessly. [11]

Radiated Immunity is defined as the resilience of electronics module to sustain its operation undisturbed without getting impacted by the radiant energy already presented in the atmosphere. It is desired that the device resilience to the radiated immunity must be quantified by beaming the radiant energy onto the module while its key functions and features are measured, observed and recorded. This ensures that the module will perform as per design intent. It is required that when performing these tests a fully compliant calibrated specialized equipment must be used to aim radiant energy onto the module. The module must not deviate from its pre-defined operational envelope[11].

C. Vehicle on-board radio terminals

Both traffic manage department and auto industries hope that a new generation vehicle terminal, which supports various information exchange mode, such as satellite, cellular phone, V2X, and blue tooth etc., should be installed on all road vehicles in the near future.

Until today, most new model cars support cellular phone, blue tooth, WLAN and GPS function. On the other hand, the practical VANET age is just in its infancy stage, and V2X block are not assembled in most of road vehicles. Hence, no mature V2X product could be used as DUT (Device under Test).

T-box, who meets stringent car-grade requirements on reliability, working temperature and anti-interference, could delivers multiple online applications including vehicle remote monitoring, remote control, safety monitoring & warning and remote diagnosis via 4G wireless communication, GPS satellite positioning, acceleration sensing and CAN communication-boxand then is considered as a typical connected-vehicle terminal.

In this paper, we select T-box as DUT to verify the effectiveness of proposed test scheme.

III. TEST SCHEME

In this paper, we focus on the immunity feature of vehicle terminals. The aim of proposed test scheme is to evaluate operation performance of the vehicle equipped with the DUT under a circumstance of high power radio radiation. In proposed scheme, to meet EMC test demand of most vehicle OEMs, vehicle's immunity feature to radiation frequency from 30MHz to 2GHz will be tested.

As mentioned earlier, we are concern about both vehicle level and component level radio immunity performance. It is well know that all radio immunity performance identification should be done under DUT working normally condition. Hence, to fulfill vehicle onboard communication-box test, we should establish communication link firstly. However, in the EMC test environment, there's neither base station signal nor satellite signal to establish connection with DUT. To overcome this difficulty, in following section, we proposed a test environment setting method to ensure DUT working normally in the EMC test scene.

A. Basic Test Environment

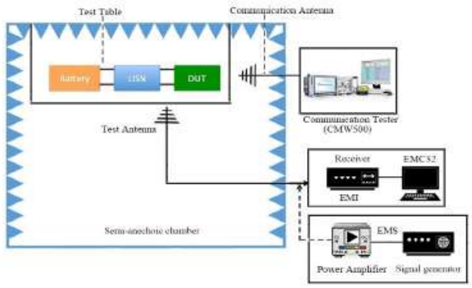
All proposed test schemes are done in a semi-anechoic chamber, which meets EMC specifications CISPR16.

The basic test environments for component level test and vehicle level test are set as Fig2.

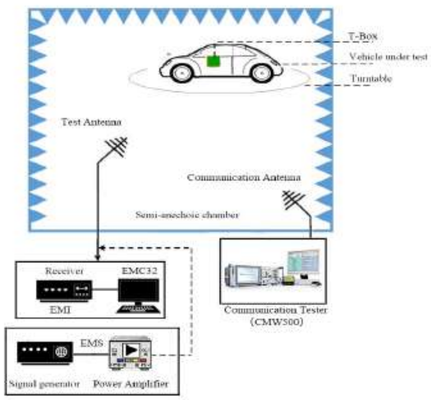
For component level test, DUT is powered by 12V battery and two LISNs (Line Artificial-Mains Network) 12V ESH2-Z6. The under-test system is placed on a test table, whose ground plate is inserted to the chamber wall. For vehicle level test, the under-test vehicle is placed on a turntable.

Before the formal test, aiming to ensure chambers full wireless signal coverage factor, a related check progress should be done firstly.

In Fig.2, a communication tester, CMW500, which connects to communication antenna, is used to establish communication link with DUT. For EMI test, the test antenna collects radiation energy and send corresponding signal to



(a) Component Level Test



(b) Vehicle Level Test

Fig. 2. Basic Test Environment

EMI receiver. Then EMC32 software is employed to analysis radiation state. On the other hand, for EMS test, signal generator, whose generating signal is controlled by computer system, is used to generate corresponding signals, whose frequencies range from 30MHz to 2GHz. The generated signal is amplified by power amplifier and sent to test antenna to produce radiation energy, which should be radiation to DUT directionally.

Fig.2's scheme is used to establish an environment, which similar to actual working condition of vehicle terminal, to ensure the efficiency of corresponding EMC test.

B. EMI test procedure

The purpose of component level EMI test is to verify that the DUT is not radiating energy harmful for other on-board electronic devices. The purpose of vehicle level EMI test is to verify that the vehicle equipped with DUT will not endanger electronic devices around it.

Both vehicle level and component level tests are done based on Fig. 2 set, and corresponding test procedures are set as follows.

- **Step 1**: Communication Tester Setting
  Here we consider GSM, WCDMA and LTE communication block. The communication tester is used to establish communication link with the DUT.
- **Step 2**: Communication Link Establishment
  In this step, communication tester is used to establish communication link with the DUT or the DUT on the vehicle, and ensure it is in normal working condition. It need to be noticed that the communication antenna connecting to the communication tester should be either very close to the DUT and radiates very low power, or far away from the DUT and the EMI test antenna. This is to ensure that the radiation from the communication antenna will not affect the EMI test result.
- **Step 3**:Radiation Energy Analysis
  When the communication link is established, the EMI test can be done either for the component or the vehicle. In EMI test, multiple antennas are utilized to capture the radiated emissions under different frequency bands:
  Rod Antenna to cover 0.15 30 MHz range $|_{SEP}^{L}|$
  Bi-conical Antenna to cover 30 200 MHz range
  Log Periodic Antenna to cover 200 1,000 MHz range $|_{SEP}^{L}|$
  Horn Antenna to cover above 1 GHz range $|_{SEP}^{L}|$
  In this step, EMI measurement equipment specified in CISPR 16-1-1 is used to collect radiation energy parameters, while EM32 software is adopted to realize parameter analysis and output testing results.

C. EMS test procedure

The purpose of EMS test is to verify that the performance of the DUT is not influenced by outside EM field, whether the outside EM field is generated by inter-vehicle communication or other external radio energy sources.

As shown in Fig.2, the outside EM field is generated by radiation antenna. The field strength needs to be calibrated first to ensure that the DUT is exposed to a field, whose field strength is strong enough to verify its radio immunity. Monitoring equipment such as cameras, oscilloscopes and communication tester are used to identify if there are any multi-functions.

The detail test steps are set as follows:

- **Step 1**: Communication Link Establishment
  In this step, communication tester is used to establish communication link with the DUT or the vehicle equipped with the DUT. Configuration of the communication tester and the communication antenna are almost the same as that of EMI test. The only different is that the placed position of communication antenna is far away from the DUT or the vehicle. In this case, we should make sure that the communication system is safe from the strong EM field when test is conducted. The communication tester sends commands to DUT, while corresponding communication antenna collects signal transmitting by DUT, and then sends it back to communication tester to demodulate data packets.
- **Step 2**: Illuminator set
  Once the communication link is established, the outside EM field can be generated. The signal generator generates predefined frequency sweeping signal, which is power amplified and radiated from the radiating antenna

to form the outside EM field, which is needed by EMS test. The radiation antennas are normally directional, which is used to simulate the scenario that there are power radiations from roadside infrastructure or other vehicles.

- **Step 3**:Communication Performance Analysis
  Whether the communication is compromised under the outside EM field will be monitored and verified in step 3. In this step, communication tester is used to monitor communication performance parameters, such as packet loss and throughput, while EM32 software is adopted to realize parameter analysis and output testing results.

IV. Experiments and Results

In the following sections, both component level and vehicle level EMC tests are conducted according to section 3. In this section, we discuss both kinds of experiment set and test results in detail.

A. Component level test

Component level tests, including EMI and EMS test, are done in a 3-meter semi-anechoic chamber.

EMI

The experimental setup is shown in Fig. 3.

Fig. 3. Experimental Setup for component level EMI test

All the experiment sets follow CISPR 25. As shown in Fig.3, the T-box under test under test is placed on the test table. The ground plate on the table is inserted to the wall of the chamber. T-Box is powered by 12V battery and two LISNs (Line Artificial-Mains Network) 12V ESH2-Z6. The communication tester CMW500 is placed in the control room, outside of the chamber. A communication antenna in the chamber pointing to the T-box under test is connected to CMW500 through cables preconfigured for signal in and out. The T-box operates in LTE/4G mode, so the CMW500 also needs to be set to operate in LTE/4G mode. The EMI test antenna, which connects to EMI test receiver ESU, is placed 1-meter away from the T-Box and it's cables.

Test parameter set is listed in Table2, while part of test results are given in Fig.4

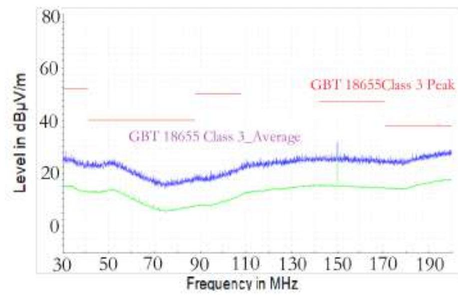
In Fig.4, the blue curve illustrates radiation test result using peak detector, while the green curve is the test result using average detector. Test result shows that the T-box under test under test meets the requirement of Chinese GB/T18655 class 3.

EMS

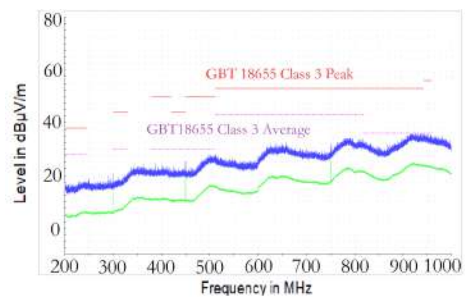
The experimental setup is shown in Fig. 5.

TABLE II
Component Level EMI Test Parameter set

Frequency band	Polarization	Communication mode
0.15-30MHz		LET
30-200MHz	H	LET
30-200MHz	V	LET
200-1000M	H	LET
200-1000M	V	LET
0.15-30MHz		WCDMA
30-200MHz	H	WCDMA
30-200MHz	V	WCDMA
200-1000M	H	WCDMA
200-1000M	V	WCDMA



(a) 30-200M H (LTE)



(b) 200-1000M H (LTE)

Fig. 4. Component level EMI test results

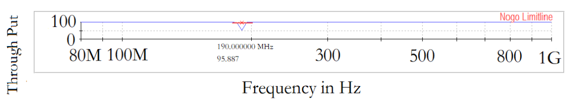
As shown in Fig.5, the T-box under test is placed on test bench, whose metal plate is earthed completely. T-Box is powered by LISN (Line Artificial-Mains Network), 12V ESH2-Z6. The interference radiation antenna, which connects to interference signal generator, is placed 1-meter distance to T-Box. T-box under test is irradiated directly by interference signal, whose field strength is programed. CMW500 LTE/4G wideband radio communication tester, whose channel mode is set as fading channel, communicates with T-box under test, and monitors related performance parameter indexes. Related test sets and results are given

Fig. 5. Experimental Setup for component level EMS test

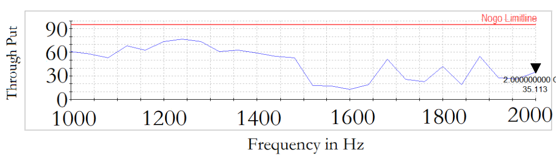
in Table 3, while part of test curves are given in Fig.6.

TABLE III
COMPONENT LEVEL EMS TEST PARAMETER SET AND TEST RESULTS

Frequency band	Polarization	Modulation	Field strength	Mode	Index	Results
80-1000M	V	CW	100V/m	LTE	Throughput	Normal
80-1000M	V	AM	100V/m	LTE	Throughput	Normal
80-1000M	V	CW	100V/m	WCDMA	BER	Abnormal on 190MHZ
80-1000M	V	AM	100V/m	WCDMA	BER	Normal
80-1000M	H	CW	100V/m	LTE	Throughput	Abnormal on 190MHZ
80-1000M	H	AM	100V/m	LTE	Throughput	Normal
80-1000M	H	CW	100V/m	WCDMA	BER	Abnormal on 190MHZ
80-1000M	H	AM	100V/m	WCDMA	BER	Abnormal on 190MHZ
1-2G	V	CW	100V/m	LTE	Throughput	Abnormal on 190MHZ
1-2G	V	AM	100V/m	LTE	Throughput	Abnormal on 190MHZ
1-2G	V	CW	100V/m	WCDMA	BER	Abnormal on frequency band above 1.5GHz
1-2G	V	AM	100V/m	WCDMA	BER	Abnormal on frequency band above 1.6GHz
1-2G	H	CW	100V/m	LTE	Throughput	Abnormal
1-2G	H	AM	100V/m	LTE	Throughput	Abnormal
1-2G	H	CW	100V/m	WCDMA	BER	Normal
1-2G	H	AM	100V/m	WCDMA	BER	Normal



(a) 80-1000M H CW 100V/m LTE



(b) 1-2G H CW 100V/m LTE

Fig. 6. Component level EMS test results

As shown in Table 3 and Fig.6, interference radiation from the outside EM field deadly influences T-Boxs communication performance, such as throughput and BER, especially on the frequency band above 1GHz.The test results show that external interference will lead to a lot of problems, such as throughput decline, packet loss, and etc., which bring a bad influence on communication performance, and furthermore lead to a series vehicle application functional failure, such as video interrupt, navigation update failed, which should guide the user to a wrong way.

B. Vehicle level test

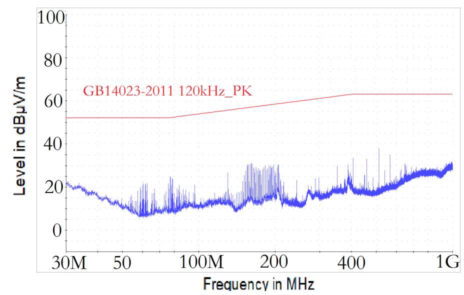
In this paper, vehicle level test is done in a 10m-range semi-anechoic chamber, and a SUV with on-board T-Box is selected as the vehicle to be tested. Here both EMI and EMS tests are involved.

EMI

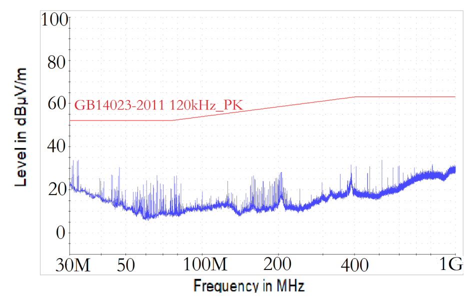
All the experiment sets follow CISPR 12. The vehicle under test is first set to ”Key-On, Engine off” and then ”Engine- Running w” state. The experimental setup is shown in Fig. 7.

Fig. 7. Experimental Setup for vehicle level EMI test

As shown in Fig.7, a wideband antenna serves as measurement antenna, which connects to EMI test receiver ESU, and is placed 10-meter away from the vehicle under test. The height of measurement antenna is adjustable with variation range of 1 to 4 meters. Radiation from the left, right, front and back side of the vehicle is tested. Part of the test results is given in Fig.8.



(a) Horizontal polarization



(b) Vertical polarization

Fig. 8. Vehicle level EMI test results

Fig.8 shows the test result under ”engine running” mode, which conforms to the requirement of CISPR 12.

EMS

All the experiment sets follow ISO 11451-2 standard. The interference radiation antenna, which connects to interference signal generator, is placed 10-meter distance to under-test vehicle, which is placed on turntable. Under test vehicle is irradiated by interference signal, whose field strength is programed. A running turntable is used to change the radiation direction. CMW500 LTE/4G wideband radio communication tester, whose channel mode is set as fading channel, communicates with T-box under test, and monitors related performance parameter indexes.

The experimental setup is shown in Fig. 9. Related test sets and results are given in Table 4, while part of test results are given in Fig.10.

Fig. 9. Experimental Setup for vehicle level EMI test

TABLE IV

VEHICLE LEVEL TEST SET AND RESULTS

Frequency band	Pola-riza-tion	Modul-ation	Field strength	Mode	Index	Results
20-220M	V	CW	50V/m	LTE	Throughput	Normal
20-220M	V	AM	50V/m	LTE	Throughput	Little worse on190MHz
20-220M	V	CW	50V/m	WCDMA	BER	Normal
20-220M	V	AM	50V/m	WCDMA	BER	Normal
20-1000M	V	CW	50V/m	LTE	Throughput	Normal
20-1000M	V	AM	50V/m	LTE	Throughput	Normal
20-1000M	V	CW	50V/m	WCDMA	BER	Normal
20-1000M	V	AM	50V/m	WCDMA	BER	Normal
1-2G	V	CW	50V/m	LTE	Throughput	Abnormal on 1960MHz
1-2G	V	AM	50V/m	LTE	Throughput	Abnormal on 1960MHz
1-2G	V	CW	50V/m	WCDMA	BER	Normal
1-2G	V	AM	50V/m	WCDMA	BER	Normal

As shown in Table 4, EMS test results of vehicle level perform better than that of component level. That is said, reasonable vehicle level EMC design could improve immunity level of component, and then improve related performance. However, corresponding communication performance decline also lead to function failure of vehicle.

V. CONCLUSIONS

This paper proposed an EMC test method for connected vehicles and the on-board radio terminal, T-Box. In proposed method, both EMI test and EMS test are considered, while both component level test and vehicle level test are involved. Related tests are done in EMC laboratory of Chinese Automotive Engineering Research Institute. Test results show that the on-board radio communication system has little influence on the EMI performance of the vehicle. However, in EMS tests, external interference may decline communication performance in some frequency bands, which may lead to functional failure. This suggests that EMS performance of the on-board radio communication systems and vehicles that are equipped with those should draw enough attention. Otherwise, malfunction of these systems under strong outside interference could lead to critical errors. In further work, EMC test method will be studied on ADAS systems and autonomous driving systems, so as to ensure better reliability of intelligent connected vehicles.

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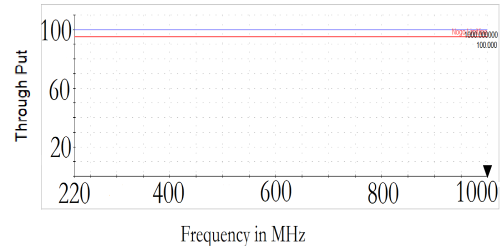
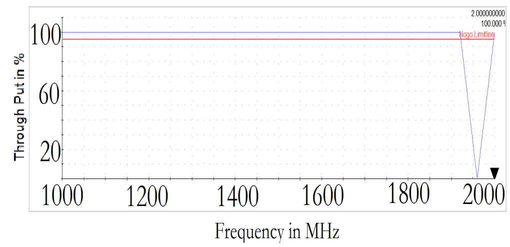


(a) Throughput of 220-1000M LTE, Vertical polarization 1-2G LTE V CW 50Vm



(b) Throughput of 1-2G LTE, Vertical polarization

Fig. 10. Vehicle level EMS test results

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