A STUDY OF ELECTRO-MAGNATIC COMPATIBILITY ABOUT ELECTRIC VEHICLE'S CHARGING MODE

Sung-Bum KIM
Jin-ju KANG, Jae-sung AN, Joong-ho BAE, Jong-Hyun LEE
Korea Automobile Testing and Research Institute
Republic of KOREA
Paper Number 13-0297

ABSTRACT

Eco-friendly car market, which involves hybrid car, electric vehicle, plug-in electric vehicle, hydrogen fueled cell vehicle is expected to be extended locally and abroad amid the high price of petroleum and the enhancement of regulations on environments. Electric vehicles (EV), called Zero Emission Vehicles (ZEV) are perceived as an alternative by using the battery due to all kinds of regulations on cars. In order to avoid problems with electromagnetic interference, Extensive Electromagnetic Compatibility (EMC) and componenets of vehicles are being developed.

As the electric cars are the ones that need recharging after driving, it may cause social problems when electromagnetic waves are over-generated while battery is being recharged at our home or work places. So the electric cars need to be evaluated by two methods. One is driving mode with no charging on the power grid which is the existing test method from old times. The other is the RESS in charging mode coupled to the power grid. Recently various researches are discussing about battery recharging methods of electric cars. However, according to vehicle's manufacture, the charging type and the position of inlet in vehicle are quite expensive. Real experiments of several electric vehicles were conducted in EMC chamber in KATRI lab. This study shows the differences in the test results of two different methods (driving & charging mode) and provides proper test setup according to the location of inlet.

INTRODUCTION

Recently, many kinds of electric & electronic devices have been equipped in vehicles. There is an Electromagnetic Compatibility in one of the test methods to improve safety of these electric & electronic devices. Due to development and propagation of Eco Friendly Vehicle (EFV), it has tightened the various regulations about these vehicles. 'Electro-Magnetic Compatibility' test can be divided broadly into two types: 'Electro-Magnetic Interference' test and 'Electro-Magnetic Immunity' test. The 'Electro-Magnetic Interference' test, in turn, can be classified into the broadband test, which measures the electromagnetic waves from the engine, the ignition system, the motor in a car, and the narrowband test, which gauges those from electronic control unit built in a car. On the broadband test, internal combustion engines are evaluated in 1500 idle RPM state, with all electronic component being operated while the electric cars and hydrogen fueled cell vehicle being fixed in 40 kilometers per hour are checked if emit electromagnetic waves are exceeding their acceptable limit. Immunity tests are used for confirming whether cars and electronic component malfunction are due to the electromagnetic waves from outside or not. Domestically, the automobile safety standard related with electromagnetic waves has been applied since 1997. [1] However, as the electric cars are the ones that need battery charging after driving, they can cause social problems as mentioned earlier.

Recently, WP.29(Working Party 29), GRE(Working Party on Lighting and Light-Signaling) and UN-affiliated organizations are discussing the battery recharging method.[2] Through this study, by analyzing the results of Electro -magnetic Interference test on neighborhood electric vehicle, electric vehicle and a large-sized electric bus in the middle of recharging, This research shows the necessity of its introduction of additional test methods about battery charging mode of EV's.

EVALUATION OF ELECTRIC VEHICLES

Test Facility and Vehicles

absorber-lined shielded enclosure

The test is performed in shielded enclosure room with internal ceiling and walls which made with radio frequency-absorbing materials. It is illustrated in Figure 1.

Figure 1. Test Facility

Chassis Dynamometer

The Chassis dynamometer can control driving and rotating condition of the test vehicle as figure 2.

Figure 2. Chassis Dynamometer

EMI Receiver and Antenna

Test Equipments are EMI receiver and broadband antenna.

FCC or CISPR prefers the use of turned and half-wave dipoles for measurement of radiated emissions. From the standpoint of rapid and efficient gathering of data over the frequency range of the radiated emission limits of 30 MHz~1GHz, the tuned half-wave dipole is not an attractive measurement antenna. Its length must be physically adjusted to provide a total length of ½λ at each measurement frequency. Also, in the measurement of the vertically polarized emissions at the lowest frequency of the limit, 30 MHz, the dipole length is 5 m. More practical measurement is the use of broadband antennas.

The infinite biconical antenna is constructed with two cones of half angle θ_h with a small gap at the feed point.

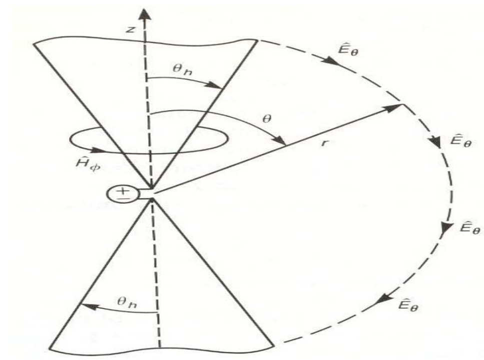


Figure 3. The infinite, biconical antenna

A voltage source feeds the antenna at this gap. A spherical coordinate system is appropriate to use for the analysis here. In the space, surrounding cones (assumed to be free space), J = 0, and symmetry suggests that the fields are Faraday's and Ampere's laws can be solved to give the forms of the fields [3]

$$\hat{H}_{\Phi} = \frac{Ho}{\sin\theta}\frac{e^{-jBor}}{r} \qquad (1).$$

and

$$\hat{E}_{\theta} = \frac{\beta_0}{\omega\varepsilon_0}\frac{Ho}{\sin\theta}\frac{e^{-jBor}}{r} = n_o\hat{H}_{\phi} \qquad (2).$$

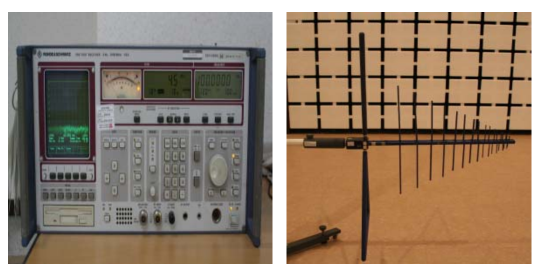


Figure 4. Test Receiver and Antenna.

Test Vehicles

The electric vehicles launched in the domestic are used to evaluate in this study. The test vehicles are EV, NEV and EV-bus. The NEV(Neighborhood Electric Vehicle) is that the maximum speed and the total weight of the vehicle never exceed 60 kilometers per hour and 1,316 kilograms respectively and they can only be driven on the road that government permitted


A Test Vehicle (NEV)


B Test Vehicle (EV)


C Test Vehicle (EV)


D Test Vehicle (EV-Bus)

Figure 5. Picture of Test Vehicles

The existing EMC test methods of the vehicles

Many countries are emphasizing their EMC(Electro Magnetic Compatibility) regulations around the world. An electronic system in vehicle that is able to function compatibly with other electronic systems and not produce or be susceptible to interference is said to be electromagnetically compatible with its environment. A system is electromagnetically compatible if it satisfies three criteria [1]

1. It does not cause interference with other systems.
2. It is not susceptible to emissions from other systems.
3. It does not cause interference with itself.

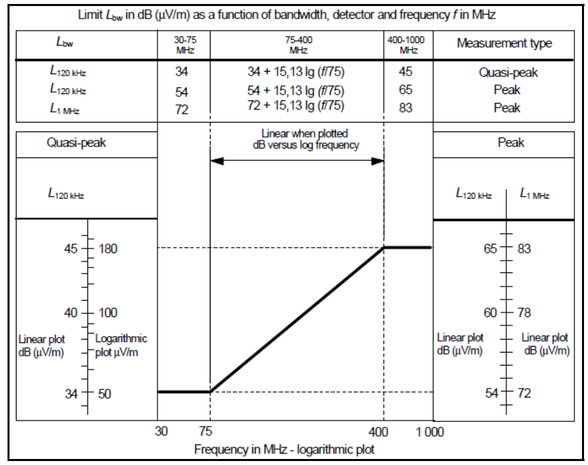
This vehicle EMC applies to components to be fitted in these vehicles with the limitation given. It covers requirements regarding the immunity to radiated and conducted disturbances for functions related to direct control of the vehicle, related to driver, passenger and other road user's protection and related to disturbances, which would cause confusion to the driver or other road users(EMS) and requirements regarding the control of unwanted radiated and conducted emissions to protect the intended use of electrical or electronic equipment at own or adjacent vehicles or nearby, and the control of disturbances from accessories that may be retrofitted to the vehicle(EMI). [4]

Emission test (EMI)

The limits in this International Standard are designed to provide protection for broadcast receivers in the frequency range of 30 MHz to 1000MHz when used in the residential environment. The vehicle shall comply with both average limits when the vehicle is in "key-on, Engine-off" mode(Narrowband test) and quasi-peak(or peak) limits when in "Engine-Running" mode(Broadband test). [5]

Table 1.

Peak and quasi-peak detector limits


Limit L_{bw} in dB (µV/m) as a function of bandwidth, detector and frequency f in MHz

L_{bw}	30-75 MHz	75-400 MHz	400-1000 MHz	Measurement type
$L_{120 kHz}$	34	34 + 15,13 lg (f/75)	45	Quasi-peak
$L_{120 kHz}$	54	54 + 15,13 lg (f/75)	65	Peak
$L_{1 MHz}$	72	72 + 15,13 lg (f/75)	83	Peak

At each measurement frequency, measurements shall be taken for horizontal and vertical polarization. The horizontal distance between the reference point of the antenna and to the nearest metal part of the vehicle shall be 10 ± 0.2m, as an alternative measurement may be made at a distance of 3 ± 0.05m. For an antenna distance of 10m, the center of the antenna shall be 3 ± 0.05m above the ground surface. For an antenna distance of 3m, the height shall be 1.8 ± 0.05m. Measurements are made on the left and right sides of the vehicle. [6]

The "key-on, Engine-off" mode operating conditions are as follows:

1. The ignition switch is switched on.
2. The engine shall not be operating
3. The vehicles electronic system shall be all be in their normal operating mode.

The "Engine-Running" mode operating conditions are as below according to vehicle type.

1. Vehicle with an internal combustion engine is tested with engine operated 1,500 ± 150 rpm. (Number of cylinders >1)
2. Vehicle equipped with an electric propulsion motor is tested with the vehicle driven on a dynamometer with a constant speed of 40 km/h.

Immunity test (EMS)

This test scope specifies a vehicle test method for determining the immunity of passenger cars and commercial vehicles to electrical disturbances from off-vehicle radiation sources. The test is performed in an absorber-lined shielded enclosure, the aim being to create an indoor electromagnetic compatibility testing facility that simulates open field testing. Testing consists of generating radiated electromagnetic fields using antenna sets with radio frequency (RF) sources capable of producing the desired field strength over the range of test frequencies.

The RF power required to achieve the required field strength is determined during the field calibration phase. Calibration is performed without a vehicle in the test location. The specific test level is calibrated periodically, using an unmodulated sinusoidal wave, by recording the forward power required to produce a specific field strength for each test frequency. [7], [8]

The vehicle is in an unladen condition except for necessary test equipment and the engine normally turns the driving wheels at a steady speed of 50 km/h.

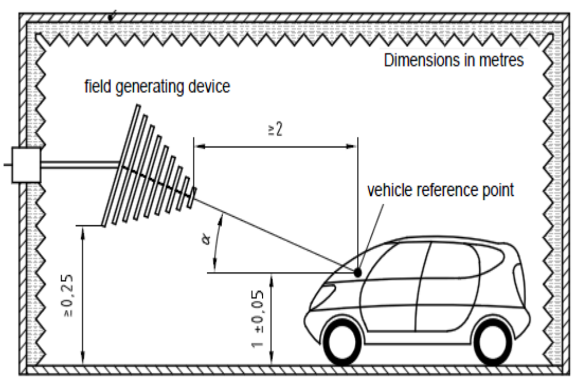


Figure 6. Example of test set-up

The EV's Charging experiment

The EMC test for EV charging mode is implemented as illustrated in Figure 6. The experiment uses the informal document of Electromagnetic compatibility for forth stage in the Directive ECE/Trans/WP.29/GRE/2010/54 [9].

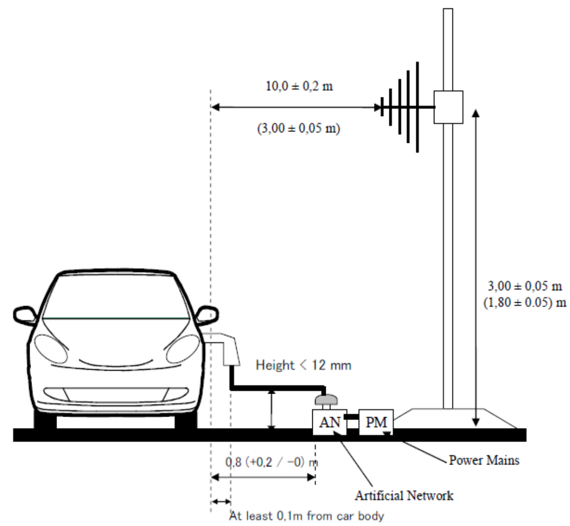


Figure 7. Vehicle in configuration "Charging mode"

In order to ensure that whether occurs in electromagnetic emission in charging mode in comparison with driving mode and how arrange test setup in case of the inlet located on the front or rear (the inlet located on the left or right is measured like figure 6) and 2 inlets in same vehicle for slow charger, we preformed the 4 kinds of EVs in the facility in Figure 1.

This study shows the differences in the test results of two different methods (driving & charging mode) and provides proper test setup according to the location of inlet and bidirectional inlet position.

Table 2.

Specifications of test vehicles

Name	A Test Vehicle (NEV)	B Test Vehicle (EV)	C Test Vehicle (EV)	D Test Vehicle (EV-Bus)
Overall L×W×H(㎜)	3,210× 1,575×1,560	3,585× 1,595×1,540	4,750×1,810× 1,460	10,995× 2,490×3,325
Curb weight(kg)	830	1,390	1,565	12,295
Seating capacity	2	4	5	51
Battery (energy)	LI-ion (9.2 kWh)	LI-ion (16.4 kWh)	LI- ion (24 kWh)	LI- ion (95 kWh)
Inlet Position	LH side	Front side	LH & RH side	Rear side
Max. Speed	60 km/h	130 km/h	140 km/h	85 km/h

Test results and analysis

Charging mode compared with driving mode

The measurement was taken from horizontal and vertical polarization of receiving antenna and on the left and right sides of the vehicle. Therefore need to perform 4 times mode for emission test. The detector of EMI receiver applies quasi-peak detector measurements and the bandwidth is 120 kHz

The horizontal distance between the antenna and vehicle is 10 ± 0.2m for test vehicle A, B & C(NEV & Passenger EV), 3 ± 0.05m for test vehicle D.(EV-Bus) For measurement at 3m antenna distance, 10 dB is added to the 10m limit. The graph presented as below shows a representative result among 4 test modes.

Figure 8 was measured from vertical polarized antenna on the left side of the test vehicle(NEV). [10]

The result is shown in Figure 8. According to the test Results, electromagnetic waves were partially measured high while driving or charging under 200MHz measurement frequency. It was not nearly emitted over 200MHz. It was measured high at the cruise driving mode except for 30~40MHz and 80~ 100MHz frequency band

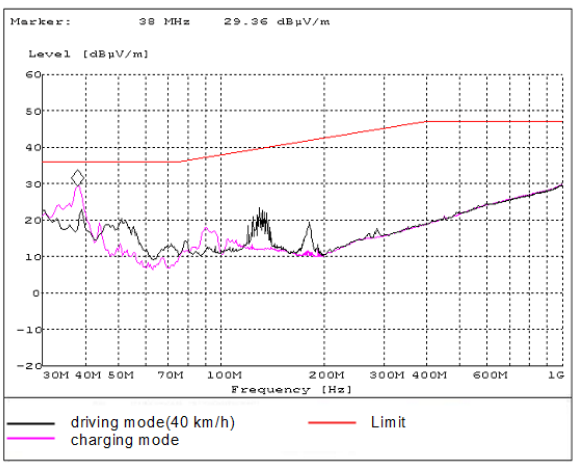


Figure 8. Test vehicle A (Left side of vehicle)

Figure 9 was measured from vertical polarized antenna on the right side of the test vehicle(EV). The result is shown in Figure 8. All measurement frequency of the 30~200MHz was measured electromagnetic waves high at charging mode. The charging mode was measured approximately 30 dB higher than the cruise driving mode. [11]

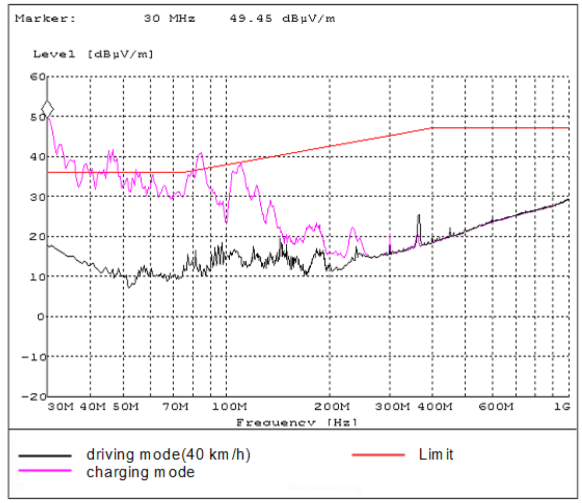


Figure 9. Test vehicle B (Right side of vehicle)

Fig. 10 was measured from vertical polarized antenna on the right side of the test vehicle.

The result is shown in Figure 10. According to the test results, all of the measurement has been measured lower than limit value and also the electromagnetic waves in driving mode was almost emitted higher than charging mode.

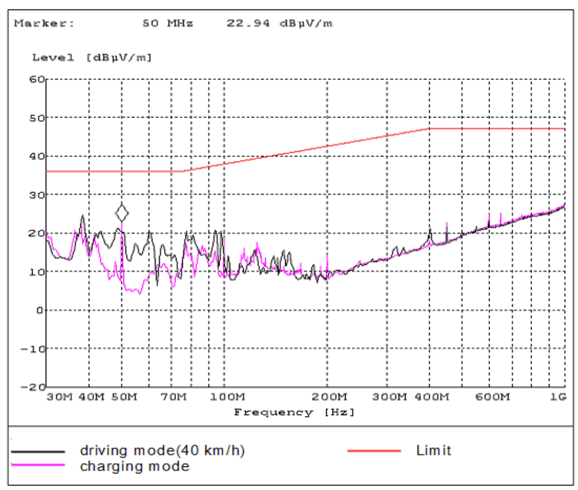


Figure 10. Test vehicle C (Right side of vehicle)

Figure 11 was measured from vertical polarized antenna on the right side of the test vehicle(EV-bus).

Most of the electromagnetic waves in driving mode were measured higher than charging mode and then the peak value in driving mode was approximately 37.8dBuv/m at 108.5MHz.

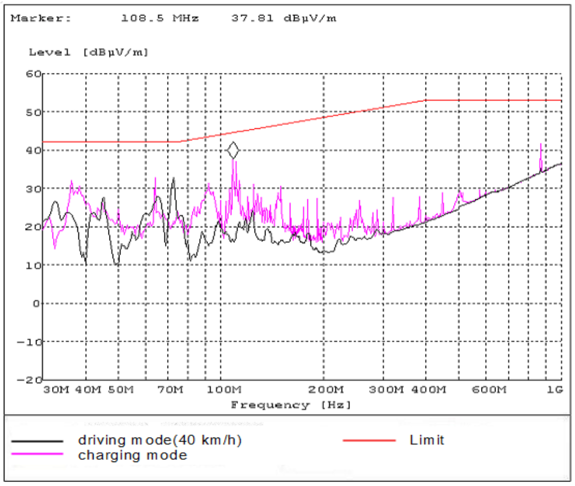


Figure 11. Test vehicle D (Right side of vehicle)

According to this experiment, the results from the two methods(drving & charging) are compared. Also the measured graphs show that electro-magnetic wave is radiated from the vehicle while charging. The results demonstrate that EV needs to be measured in charging mode including driving mode for vehicle safety.

Measurement of the inlet located on the front(or rear) on charging

According to ECE/Trans/WP.29/GRE/2010/54, as shown in Figure 7, the evaluation has to conduct both sides (left and right side of vehicle) regardless of inlet position. And the test method of inlet located on the left and right sides of the vehicle is specified but on the front and rear sides of the vehicle is not exactly stated.

The experiment results show comparisons of the left (or right) with the front (or rear) side of vehicle for emitting the electromagnetic waves.

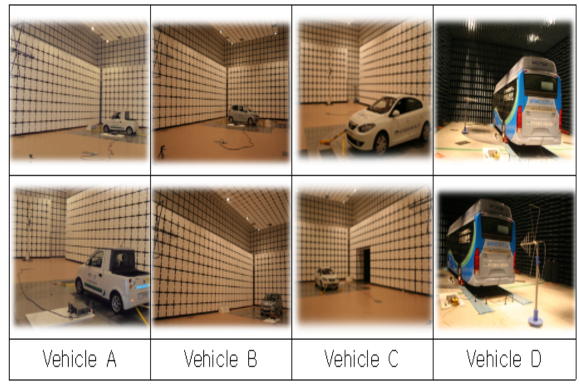


Figure 12. Test –setup between vehicle and antenna

The test vehicle A is an small electric vehicle equipped with inlet on the left side of the vehicle. Figure 13 is a result of comparing the measured value on the front and left of vehicle from the antenna while charging. The graph shows that two measured results is roughly similar because of small size car and low capacity OBC(On board charger).

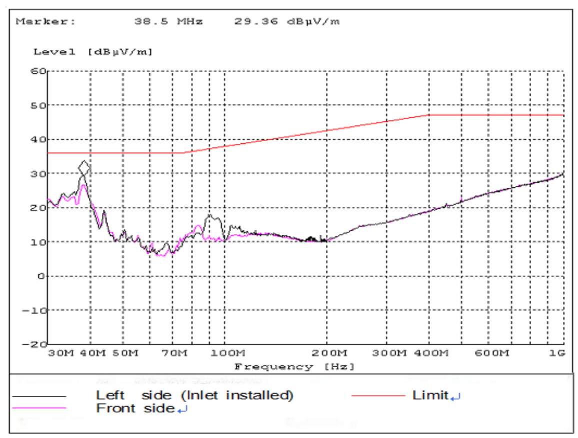


Figure 13. Test vehicle A (Left & Rear side of vehicle)

The test vehicle B is an electric vehicle equipped with inlet for AC charger on the front of the vehicle.

Figure 14 is a result of comparing the measured value on the front and right of vehicle from antenna. Below 85MHz frequency, the value on front installed the inlet has been measured greater than the side specified on standard. It is estimated that the charging device and OBC is located in front of the vehicle.

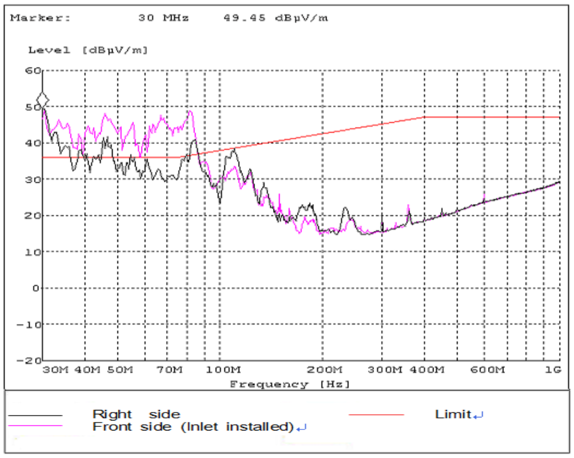


Figure 14. Test vehicle B (Front & Right side of vehicle)

The test vehicle B is an electric vehicle equipped with inlet both sides of the vehicle.

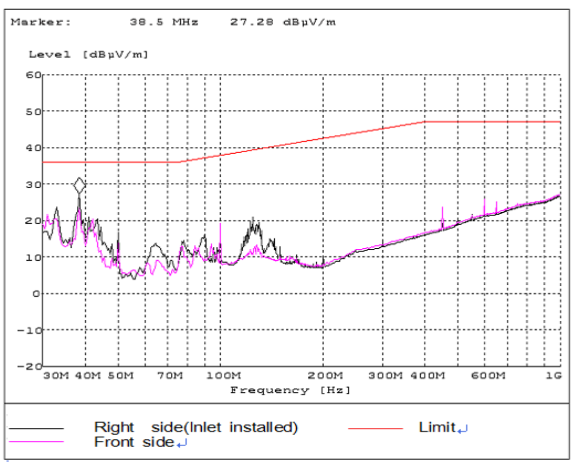


Figure 15. Test vehicle C (Right & Front side of vehicle)

Figure 15 is a result of comparing the measured value on the right and front side of the vehicle. According to the results, the right side was measured slightly higher than the front side.

The test vehicle D is an electric vehicle equipped with inlet at the rear of the vehicle. Figure 16 is a result of comparing the measured value on the rear and left side of the vehicle. According to the results, on the rear of the vehicle installed the inlet was measured higher than the left specified on standard. It seems the results of this test is caused by the charging device and OBC which are located in rear of the vehicle.

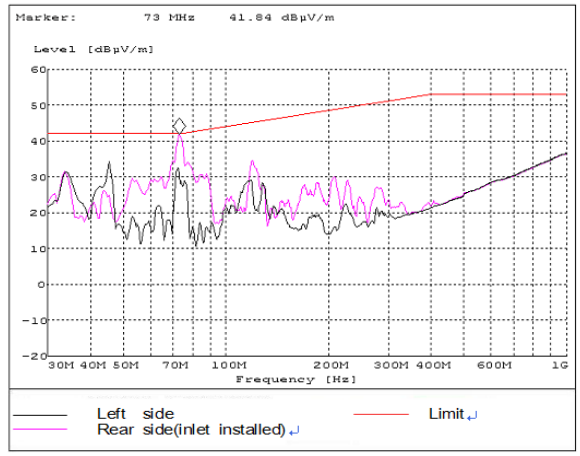


Figure 16. Test vehicle D (Rear & Left side of vehicle)

The table 3 is illustrated the difference between the two data in the frequency of 30~100MHz about 4 kinds of vehicles. The calculated values are the average of the values measured by every 10MHz for the brief analysis. It is presented that how much deviation between on both sides specified on standard and on front(or rear) position installed inlet for AC charger of vehicle

The test vehicle A is measured high approximately 5.05dB in 90~100MHz frequency band at the left side inlet mounted. The test vehicle B is measured high, about 12.56dB in 60~70MHz frequency band at the front side inlet mounted. The test vehicle D is measured high about 15.23dB in 80~90MHz frequency band at the rear inlet mounted.

Table 3.

Comparison of Measurement Orientation

	Test vehicle A (Inlet position : left)			Test vehicle B (Inlet position : Front)			Test vehicle D (Inlet position : Rear)		
Frequency Band [MHz]	Left side [dBuv/m]	Front [dBuv/m]	Deviation (Left-FR)	Right side [dBuv/m]	Front [dBuv/m]	Deviation (Right-FR)	Left side [dBuv/m]	Rear [dBuv/m]	Deviation (Left-RR)
30 ~ 40	23.99	22.71	1.28	39.48	42.96	-3.48	24.49	23.17	1.32
40 ~ 50	14.39	14.88	-0.49	36.36	44.15	-7.79	23.78	21.38	2.41
50 ~ 60	9.83	9.83	0.00	33.26	41.22	-7.96	15.57	26.54	-10.97
60 ~ 70	7.77	6.80	0.96	31.59	44.15	-12.56	17.71	29.51	-11.80
70 ~ 80	9.36	10.18	-0.82	32.49	44.21	-11.72	24.63	36.01	-11.38
80 ~ 90	13.51	12.69	0.82	36.63	41.02	-4.39	14.31	29.55	-15.23
90 ~ 100	15.80	10.75	5.05	28.55	30.21	-1.66	16.35	19.40	-3.05

Therefore, in case the inlet is located on front (or rear) of the vehicle, the measurement results in charging mode are showed that electromagnetic waves of the test vehicle B were more emitted on the front side than on the right side of vehicle. These results indicate that electromagnetic emission is dependent on the position of inlet.

Measurement of dual inlet

In the case of the inlet located on left and right of the vehicle, the measurement in charging mode was respectively taken by antenna located on the left and right sides of the vehicle.

Figure 17. Both inlets of test vehicle C

This study aims to identify which inlet is properly used for test setup if the inlets are installed on both sides as shown in figure 17.

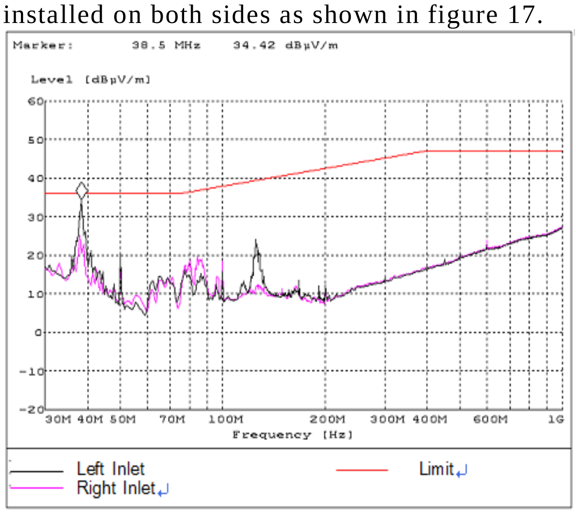


Figure 18. Result of test vehicle C (Left & Right side of vehicle)

The results of this figure 18 show that electro-magnetic waves were somewhat more emitted on the left side than on the right. The position of inlet in test vehicle is on the left side from the middle of the bonnet as shown in figure 19.

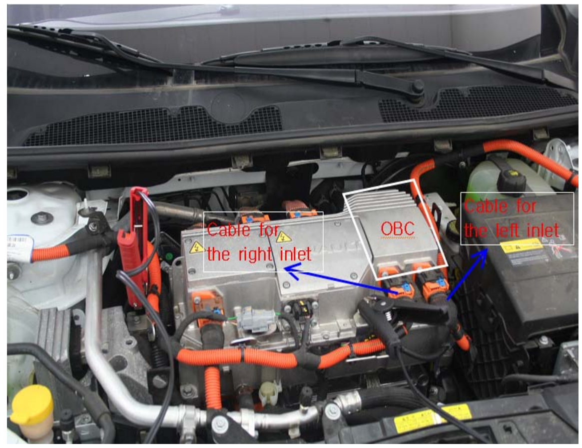


Figure 19. The position of OBC in bonnet

In conclusion, if the inlets for AC charger are located on both sides of the vehicle, the study has proposed that it would be more appropriate to consider the test setup as the position of the on board charger in vehicle.

CONCLUSIONS

The automobile standard for EMC evaluates only in driving mode. From the result of the test, the electromagnetic waves of driving mode is mostly measured high, but partial frequency bands are occurred in the charging mode. Some of the vehicles in the charging mode emit more electromagnetic waves by comparison with driving mode. The results show that EV needs to be measured in charging mode including driving mode for vehicle safety.

Based on the ECE/Trans/WP.29/GRE/2010/ 54, the measurement of charging mode has to conduct both sides similar to the driving mode. The existing test method reflects to provide protection for residential environment which locates on both side of the road in condition of vehicle driving. But EV's charging condition is static mode (no driving state). The test results show that electromagnetic emission is dependent on the position of inlet. This study suggest that antenna is required to be positioned on either the front(or rear) side of a vehicle including on the left and right sides, case of the vehicle with inlet located front(or rear).

The measurement of dual inlet shows that which inlet is properly used for test setup, in the case of the inlet located on left and right of the vehicle. This research is to propose that it would be more appropriate to consider test setup position on board charger in vehicle. More researches need to see if this proposal satisfies in other duel conditions.

REFERENCES

[1] Motor Vehicle Safety Standard of Korea, Article 111-2 “Electromagnetic Compatibility”

[2] UNECE/TRANS/WP.29/GRE/2010/54, "Proposal for the 04 series of amendments to Regulation No. 10" http://www.unece.org/trans/main/welcwp29.htm, 2010.

[3] Clayton R. Paul., Introduction to Electromagnetic Compatibility, John Wiley & Sons, Inc., 1992.

[4] UNECE/TRANS/WP.29 “Regulation No. 10 Revision 3” http://www.unece.org/trans/main/wp29/wp29regs1-20.html

[5] IEC, CISPR 12 Ed. 6 “Vehicle, boats and internal combustion engines – Radio disturbance characteristics – Limit and methods of measurement for the protection of off-board”, 2009

[6] IEC, CISPR 25 Ed. 3 “Vehicle, boats and internal combustion engine driven devices – Radio disturbance characteristics – Limit and methods of measurement for the protection of on-board receivers”, 2000

[7] ISO 11451-2 Ed. 3 “Road vehicles - Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy - Part 2:Off-vehicle radiation sources”, 2005

[8] SAE J551/2 “The limit and methods of measurement of radio disturbance characteristics of vehicles, Motor boat and spark-ignited engine driven devices”, 1994

[9] “United Nations Economic Commission for Europe", UN/ECE, Proposal for the 04 series of amendments to Regulation No. 10, July 2010.

[10] Kim, S. B., "Considerations for Electromagnetic Compatibility from NEV's Charging mode", KSAE, 2011.

[11] Kim, S. B., “A study of EMC about EV’s Charging mode”, KSAE, 2012.