Estimation of Electromagnetic Coupling Phenomena in a Vehicle Wiring Harness Using Characteristic Transfer Functions

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Abstract— **The rising number of electronic and electric systems in a modern vehicle makes automotive EMC more and more important. Due to steadily decreasing development cycles, EMC-Measurements of the whole vehicle are only possible in a relative late state of the development time. By means of measuring transfer functions in a vehicle, one can categorise different places of installation in face of their possible disturbance behaviour. The comparison of different transfer functions of vehicles can help to estimate the potential disturbance risk e.g. to the build-in radio-, TV- or mobile phone antenna.**

I. INTRODUCTION

In modern motor vehicles, many different electric and electronic components perform tasks to support the driver. This implies comfort functions like climate control or entertainment as well as safety systems like electronic stability program (ESP), airbag or motor-management systems. All these components may not disturb each other and must not exceed certain limits of electromagnetic emission. Beside the limits for emitted radiation given by law (e.g. CISPR25 [1]), a further limit is given by the radio in the car itself: a undisturbed radio reception should always be ensured. Therefore the coupling or transfer function from different locations of the cable harness to the build-in radio antenna is investigated.

Several transfer functions are measured with a network analyser in different cars. The network analyser is connected to the harness and the transfer function to the radio antenna or other antennas (e.g. of the mobile phone) is measured. Principle correlations and geometrical dependencies out of these transfer functions help to get characteristic properties to classify assembly places in respect of electromagnetic coupling, especially for estimations of EMC-disturbances in the early state of the development of new vehicles. Therewith one can find a optimal assembly place for components, depending on their emission spectrum.

II. SCATTERING PARAMETER

Scattering parameters are used to describe a two-port. Fig. 1 shows these scattering parameters and the corresponding values of current and voltage at the input and output of the two-port.

The transfer function S_{21} is defined as the transmission factor from port 1 to port 2. It describes the relation between the incoming wave at port 1 and the outgoing wave at port 2.

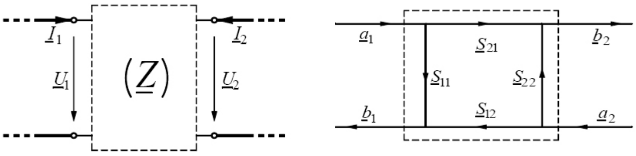

Fig. 1 Scattering parameters of a two-port and corresponding values of current and voltage

The values of the transfer function can be calculated by using the following equations shown in Fig. 2.

$$S_{21} = \left(\frac{\underline{U}_{r2}}{\underline{U}_{h1}}\right)_{\underline{U}_{h2}=0} = \left(\frac{\underline{b}_2}{\underline{a}_1}\right)_{\underline{a}_2=0} \quad (1)$$

$$S_{11} = \left(\frac{\underline{U}_{r1}}{\underline{U}_{h1}}\right)_{\underline{U}_{h2}=0} = \left(\frac{\underline{b}_1}{\underline{a}_1}\right)_{\underline{a}_2=0} \quad (2)$$

Fig. 2 Equations to assess the values of the scattering parameter S_{11} and S_{21}

Equation (1) shows the calculation of the scattering parameter S_{21} out of the terms for the incoming wave U_{h1} at port 1 and the outgoing wave U_{r2} of port 2.

Equation (2) shows the definition of the reflected part of the incoming wave to port 1. This parameter S_{11} can be used to minimize the influence of reflections by corresponding calculations.

III. MEASURING SETUP

The receiving port of the network analyser is connected to the build-in radio antenna. The diversity of the radio antenna system is shut down, to ensure that the measurement is carried out always with the same antenna (main antenna).

A switching between the different antennas during the measurement would lead to unusable results. The signal output of the network analyser is galvanically coupled to single wires of the wiring harness using a special fixture (Fig. 3).

During the measurements, the vehicle is set to different states: Radio on/off, Ignition on/off and Motor on/off and the resulting combinations. The most important difference show the states Radio on, Ignition on versus Radio off, Ignition off. The reason therefore is the active respectively inactive preamplifier of the radio antenna. Different measurements with the preamplifier in same state (e.g. Radio on, Ignition on versus Radio on Ignition off) show a very good repeatability.

Fig. 3 shows the fixture for the galvanic injection into the cable harness.

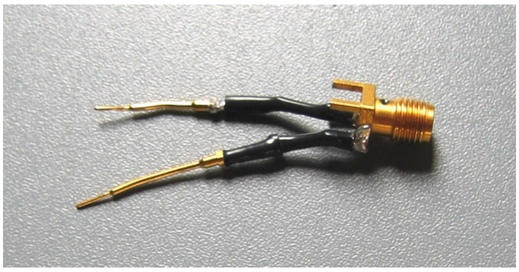

Fig. 3 Fixture for galvanic injection

The pins of the fixture shown in Fig. 3 are plugged into the pins of different control unit connectors. Before plugging the fixtures in the control unit jacks, measurements were carried out to ensure, that the ground connection of the fixture is merely plugged in pins with direct connection to vehicle ground. Therewith the influence of the additional shunting of the network analyser can be minimized and there is no risk of shorting high-voltage contact pins.

In addition to the mentioned car states (Radio on/off, Ignition on/off, Motor on/off) the injection measurement are made with the connector plugged on the control unit and also with the connector unplugged.

To protect the network analyser, both ports are equipped with dc-blocks to avoid damage through superposed dc-voltages.

The measurements are carried out with a network analyser with the maximum frequency range from 9 kHz to 4 GHz and a maximum output level of 0 dBm. The attenuation of the cables from and to the network analyser are eliminated by use of the calibration measurement.

IV. DATA REDUCTION

All measured data are processed with a algorithm to get a smoother curve progression and a better comparability. Small frequency shifts, e.g. electrical resonances displacement due to marginal geometrical changes of the harness [2] are eliminated.

The whole frequency area is divided into several sections. Adjacent sections overlap each other, so that every measuring point is at least in one section.

Within every section, the frequency information of the measurement points is discarded and the values are processed in a stochastic algorithm.

This algorithm assigns a so called “90 % value” to every section, which assures, that 90% of the measured points are below this value (worst-case estimation). Fig 4 shows the original and the processed measurement data.

In that way the data volume is reduced, while the characteristic shape of the curve remains unchanged.

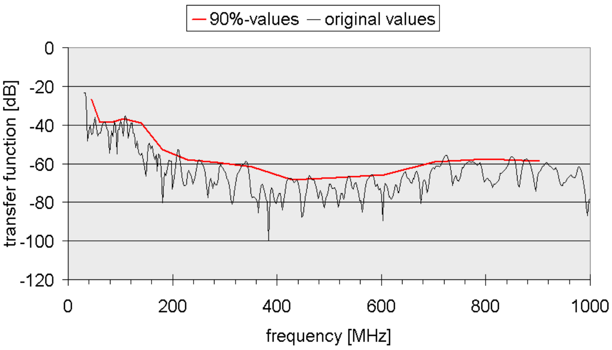

Fig. 4 Comparison of original and processed data.

The algorithm is written in Matlab. The program allows to choose different types of evaluation: e.g one coarse analysis with a larger stepsize and 30 sections or a finer analysis with 199 sections, each with the frequency area 9 kHz to 1 GHz.

V. MEASUREMENT RESULTS

A. *Influence of the radio antenna amplifier*

Most modern vehicles feature an antenna amplifier for a better radio reception. This amplifier has a frequency range of about 60 to 130 MHz. In most cases, this amplifier is active, if the radio or ignition is turned on and is inactive if radio and ignition is off-state. Comparative measurements show, that this amplifier makes a boost of about 20 dB in the corresponding frequency range. Some injection locations show a boost of less than 20 dB. This indicates, that the coupling of the injected wave occurs mostly in the region after the amplifier, whereas a boost of 20 dB shows, that the main coupling path runs over the build-in radio antenna. All diagrams shown here are recorded with active radio amplifier.

B. *Segmentation of the vehicle*

The analyzed vehicle is divided in several segments [3]. In each segment one or more transfer functions are measured and compared with each other. Fig. 5 shows the positions of the injection fixture in the car. Roughly the car can be divided in the three sections “engine compartment”, “drivers cab” and “luggage trunk”. In every section several injection points are selected to measure the transfer function to the build-in antenna of the vehicle. The red dots in Fig. 5 show the injection locations in each section.

In the second car, explored in this way, the injection points are selected at similar places, to get comparable measurements. This is doubtless difficult or unfeasible in some cases.

Despite this, it is possible to compare the transfer function of different cars. Injection points e.g. the connectors of the backlight could be used as corresponding jacks in different vehicles.

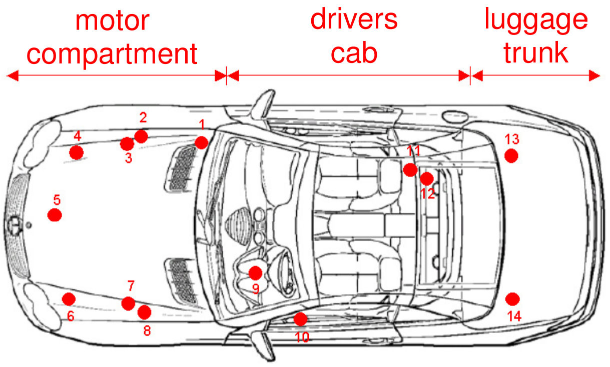

Fig. 5 Segmentation of the vehicle Nr.1, red dots show the injection locations

C. *Measurements in the motor compartment*

Measurements in the motor compartment show similar values of the transfer function, if the injection locations are near to each other. The injection locations marked with 2 and 3 are less than 10 cm far from each other. Their transfer functions differ by than 5 dB (Fig. 6)

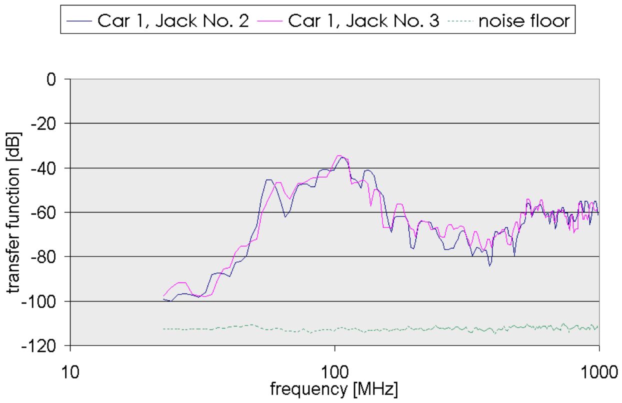

Fig. 6 Comparison of two injection locations on close proximity

Locations or injection points, which are very near to each other could be associated with one average transfer function. A similar behaviour could be found, if the injection is accomplished in different pins of a multi-pin connector. These transfer function differ also less than 5 dB. (See chapter E) The maximum deviation for distant injection points in the motor compartment are about 40 dB, especially for frequencies below 80 MHz.

Injection points with longitudinal symmetry in the motor compartment show deviation up to 10 dB and more, even if they have the same function (e.g. front left suspension and front right suspension).

In addition to this, there are also transfer functions measured at symmetric coupling points which have almost the same shape, but different absolute levels (offset of several dB).

D. *Measurements in the drivers cab and luggage trunk*

Unlike in the motor compartment, transfer functions in the drivers cab and luggage trunk show a better accordance if they are taken at injection points with symmetry to the longitudinal axis. Fig. 7 shows the run of the curves for the injection points on the right and left side of the luggage trunk of two different vehicles. Besides a few exceptions, within one car the transfer functions of coupling points symmetrical to the longitudinal axis differ by not more than 5 dB.

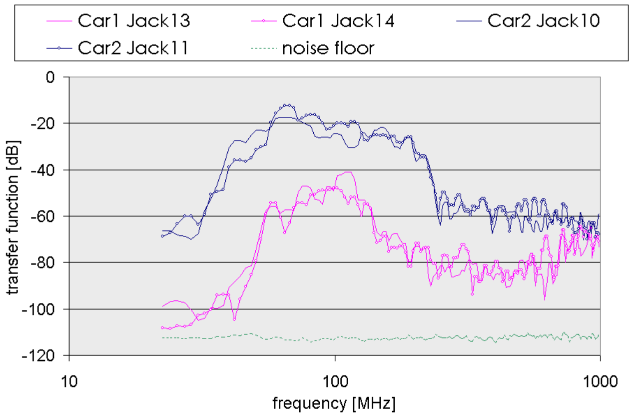

Fig. 7 Comparison of two longitudinal symmetrical injection locations in two different vehicles

Furthermore, low-lying injection points, near the floor panel, show a greater attenuation than other points. The reason therefore may be on the one hand a greater distance to the radio antenna and on the other hand a better screening or damping due to a small spacing to the electrical conductive floor panel. These points show also less influence of the radio amplifier. The difference of these transfer functions with active radio amplifier versus inactive amplifier is less than 20 dB.

E. *Injection in different pins of the same multi-pin-connector*

Measurements with different plug-in combinations are carried out on several multi-pin connectors of the vehicle.

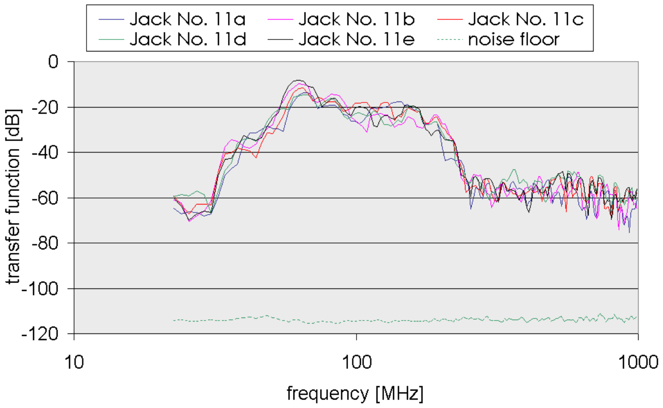

Fig. 8 Comparison of different injection combinations of a multi-pin connector in car 2

Fig. 8 shows the result of 5 different combinations of injections in one multi-pin connector. The measurements are marked as a, b, c, etc. which represents each a different plug-in position of the fixture in one connector (jack no. 11). The transfer functions of the different plug-in combinations differ less than ± 5 dB.

F. Measurements with the mobile phone antenna

To investigate the frequency area from 500 MHz to 2,5 GHz, transfer function measurements to the mobile phone antenna were carried out. Fig. 9 shows the transfer function of two injection points in the motor compartment, symmetrical to the longitudinal axis of the vehicle. The injection locations are the same as used with the radio-antenna measurements (Fig. 5).

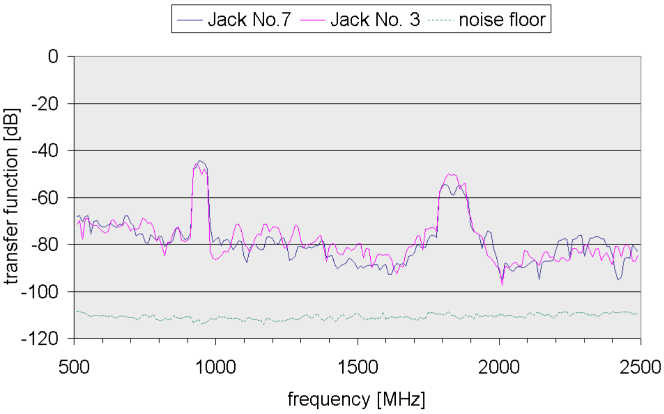

Fig. 9 Transfer function of two injection points in the motor compartment to the mobile phone antenna

Like the measurements with the radio antenna as receiving antenna, most of the transfer functions to the mobile phone antenna show also a symmetry to the longitudinal axis of the vehicle. This symmetry is remarkable, because the mobile phone antenna is placed on the left side of the car.

Despite this, the difference of injection locations with symmetry to the longitudinal axis show a similar behaviour, even if one injection point is fairly on the left and the other fairly on the right side of the car, e.g. connectors in the two front doors.

VI. CONCLUSIONS

Transfer functions of different injection points are a good tool for the classification of different assembly areas in respect of the vehicle's EMC-performance (emission). Injection locations which are close to each other show the same or at least a very similar transfer function.

More investigations of transfer functions in different vehicles are necessary to show the dependence of similarities in respect of size, shape, antenna locations and other EMC-relevant characteristics (e.g. metal or plastic car body components) of a car. This knowledge can be used to estimate transfer functions of a vehicle even in the pre-build phase of the development cycle. Another method to estimate useful transfer functions are electromagnetic field calculations of a vehicle [4] which are possible as soon as CAD-data of the car body and the basic wiring harness characteristics are available.

The result of this can be used especially in the early development phase of new vehicles to find suitable locations to place electric and electronic components and the also the wiring harness. By this procedure, EMC disturbances and interferences of the whole vehicle can be minimised.

REFERENCES

[1] CISPR 25: *Limits and methods of measurement of radio interference characteristics for the protection of receivers used on board vehicles*

[2] M. O'Hara, J. Colebrooke, *"Automotive EMC test harnesses: Standard lengths and their effect on conducted emissions"*, York EMC 2003

[3] M. Richter, S. Frei, C. Lippert, *"EMV-Prozesse und Tools für eine baureihenübergreifende Elektronikentwicklung",* GMM-Fachbericht Nr. 48, Ingolstadt 2005

[4] R. Neumayer, A. Stelzer, F. Haslinger, G. Steinmair, M. Tröscher, J. Held, B. Unger and R. Weigel, *"Numerical EMC Simulation for automotive applications"*, IEEE 2003