Detection of EMI Issues Caused by Differential-Mode Voltages on an Electric Scooter

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***Abstract*—Typically, the most anticipated coupling to sensitive components of an electric scooter is through common mode. However, it is shown that such scooters can be susceptible to the differential mode voltage at the input of the controller, which is often neglected. In this paper, susceptible-to-electromagnetic-interference frequencies due to differential mode voltages are identified on a real case of an electric scooter. After an initial risk assessment using basic equations, the resonant frequencies are determined. Then the response is verified on the electric scooter using a VNA measurement with the direct injection technique.**

Keywords—coupling, DPI, EMC, scooter, VNA

I. Introduction

Any equipment under test (EUT) is usually evaluated for its conducted and/or radiated immunity/emissions in accredited test sites following designated standards. This way, electromagnetic interference (EMI) issues can be identified and overcome. Example measuring methods applied for conducted susceptibility tests are the bulk current injection (BCI) (typically for common mode (CM) testing) and the direct power injection (DPI) (typically for differential mode (DM) testing) methods. A quick and effective way to detect EMI disturbances on automotive components regarding CM has been presented and applied in [1]. However, although CM is known to be the most common and troublesome form of coupling, sometimes it is the DM that causes EMI, especially in systems where the DM voltage defines its functionality. In this paper, an EMI issue occurring on an electric scooter [2] due to differential mode (DM) voltages is investigated for quick verification of the preliminary (EMI risk) analyses. A vector network analyzer (VNA) is used to identify the potential susceptible-to-EMI frequencies based on the resonant behavior of the EUT. Then the EUT is tested for susceptibility using the DPI method with more emphasis on the resonance frequency band.

II. Case Study

The EUT addressed in this paper is an electric scooter. The sensitive part of this scooter consists of a potentiometer connected with a long unshielded cable to a controller. The potentiometer acts as voltage divider for different speed modes, providing a DC voltage between two wires in an unshielded cable bundle, which is connected to the controller. The controller is in charge of the proper operation of the scooter based on the received DC voltage. However, a high-frequency field coupled onto the wires can enter the controller, be rectified due to the internal electronics, and seen at the input as DC voltage, causing unwanted operation.

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III. Detection of Defect

A. Verification measurement using a VNA

After a basic risk analysis using the standard equations [3], a verification measurements to confirm the EUT's susceptible frequencies was performed using a VNA. The VNA was connected at the two wires of the potentiometer, in the close vicinity from the controller. The susceptibility of the EUT can then be anticipated at the resonant frequencies where the impedance of the scooter is significantly high. In the case applied in this paper, the high impedance values are detected mostly in the frequency range of 40 MHz to 250 MHz, compared to the complete swept spectrum. Therefore, this frequency band can be considered as the most suspicious to cause EMI. This operation requires a single sweep of the VNA, which is very quick.

B. Susceptibility using the DPI method

To validate the susceptibility of the EUT at the previously found suspicious frequency band, the DPI method is applied, using the same test setup. The test setup is as described in MIL-STD 461C, methods CS02 [4]. A continuous wave (CW) from a signal generator (25 dBm) is injected via a high pass filter (or DC block) onto the cable harness. By injecting the DM signal directly to the EUT, EMI defects have been easily detected regarding the scooter speed (e.g., acceleration, deceleration) at 180 MHz, which lies within the band where the impedance is the highest as can be seen in Fig. 1.

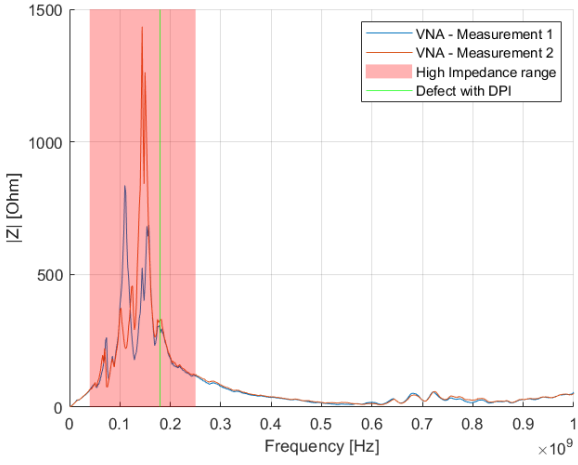

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Fig. 1. Input impedance measured a couple of milimeters away from the controller of an electrical scooter in the frequency range of 1 MHz to 1 GHz.

IV. Conclusion

A correlation between a simple VNA measurement and the DPI method has hinted a quick and efficient way to detect the susceptible-to-EMI frequencies. As shown, the VNA technique can allow to find very fast the susceptible frequency band such that a detailed analyses can be focused on that band, making use of the a priori knowledge. This saves not only a

lot of time, but also reduces the risk of missing the susceptibility of the electric scooter.

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