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A critical analysis of the bulk current injection immunity test based on common-mode and differential-mode☆

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ABSTRACT

The bulk current injection with substitution method is applied to the electromagnetic compatibility (EMC) test of automotive components. In this paper, the experimental characteristics of the device under test (DUT) with differential- mode bulk current injection and common-mode bulk current injection are studied. Also, the effects of the location of the bulk current injection probe are studied briefly. The test setup is in compliance with the ISO 11452-4 standard and the applicable frequency range is 1 MHz to 400 MHz. The results show that, due to the resonance phenomenon, the current coupled into the wiring harness in the common-mode bulk current injection test is sometimes less than the current coupled into the wiring harness in the differential-mode bulk current injection test. Moreover, the current coupled into the wiring harness is related to the location of the current injection probe, and the effects of the location are different in different frequency bands. However, in the ISO11452-4 standard, only common-mode bulk current injection test is considered in the bulk current injection immunity test. Therefore, in order to accurately reflect the true immunity level of the DUT, the differential-mode bulk current injection test should be considered in the ISO 11452-4 standard.

1. Introduction

MODERN automobiles work in an increasingly harsh electromagnetic environment. Due to the requirements of automotive safety, the bulk current injection (BCI) immunity test based on the substitution method is applied to the electromagnetic compatibility test of automotive components. The ISO11452-4 standard has specified the bulk current injection immunity test [1].

In recent years, scholars at home and abroad have done a lot of researches on the EMC [2–5]. In the vehicle level EMC, the link between the electromagnetic radiation from the motor drive system and the electromagnetic radiation from the electric vehicle was analyzed in detail. A simplified model of vehicle common-mode interference has been proposed [6]. In the automotive components level EMC, devices used in BCI test mainly include bulk current injection probe, current measurement probe and calibration fixture. Meanwhile, shielded wiring harness and optical fiber are used to BCI test widely. Electromagnetic disturbance is injected into the wiring harness connected to DUT by bulk current injection probe. It is due to the importance of bulk current injection probe that some studies about it have been developed in some literatures. The lumped parameter circuit model and distributed transmission line circuit model of bulk current injection probe were established [7–10]. An improved lumped circuit model of probes has been established [11]. The effect of the port impedance of calibration fixture has been analyzed [12]. A 3D electromagnetic model created by CST and a circuit model built by SPICE have accurately simulated the phenomena associated with the probe ferrite core. An circuit model of probe has been developed for the frequency band 1 MHz–500 MHz. A transmission line circuit model of injection probes was developed [13–15]. Equivalent circuit model of bulk current injection probe and equivalent circuit model of monitoring probe have been developed. New lumped-parameter models of current clamps were discussed [16]. Calibration fixture is usually used in the BCI test to ensure the accuracy of the test. Generally, according to the ISO 11452-4 standard, the injection probe is preliminary calibrated by a calibration fixture. Therefore, some studies have been done on calibration fixtures [17]. Coaxial shielded cable is a kind of transmission line and its circuit model has been developed to evaluate its effects in BCI test. Moreover, an accurate model of braided coaxial cables has been developed to predict transfer impedances [18–19]. Transmission line equation of a bundle of

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shielded coaxial cables has been established. A circuit model considering the transmission impedance and the transfer admittance was proposed [20]. In order to test the immunity of CAN-Bus Lines, according to automotive EMC Standards, an accurate model of bulk current injection probe has been developed [21].

In order to predict the bulk current injection (BCI) test results, it was found that the model was suitable for simulating the bulk current injection test. A new common approach to develop accurate models of different system-level EMC test has been proposed. And it can be accurately simulated in the time and frequency-domain [22–26].

In summary, almost all of the related studies focus on the modeling of the current injection probes, the calibration fixtures, etc. But very little research has paid much attention to the influence of the current injection probe's common mode and differential mode, location, as well as resonance phenomenon in the actual testing process, which also are important to accurately reflect the true immunity level of the device under test (DUT). Moreover, some interesting results are summarized in this paper.

2. BCI test

In this section, firstly, the substitution BCI method in compliance with the ISO 11452-4 standard is introduced in detail to evaluate the susceptibility level of automotive electronic equipment to continuous wave (CW) electromagnetic interferences. After a brief introduction for differential-mode BCI (D-BCI) and Common-mode BCI (C-BCI), a test bench is implemented. The basic working principles of the bulk current injection probe and calibration fixture are described.

2.1. BCI test bench

The BCI test bench in compliance with ISO 11452-4 standard is shown in Fig. 1. The device under test (DUT) is a car headlight. Actually, there are two electromagnetic interference modes. All wires of the DUT wiring harness are routed inside of the injection probe, which is called common-mode BCI (C-BCI). Only ground wires that are power returns directly or indirectly (through load box/simulator) are routed outside of the injection probe and the others are routed inside of the injection probe, which is called differential-mode BCI (D-BCI). BCI tests should be conducted in a shielded room and in the BCI tests, the DUT is connected to its power by a 1.5-m-long wiring harness which is located 50 mm above a copper plane that is a system ground plane. A low relative permittivity support ($\varepsilon r \leq 1.4$) is located between the DUT wiring harness and the copper plane [1]. Generally, since the characteristic impedance of the wiring harness used in vehicle is usually 50-Ω, the two artificial networks (ANs) with 50-Ω impedance which provide matching impedance and RF line impedance stabilization are connected between battery and DUT by wiring harness. One is connected to the positive supply line and the other one is connected to the power return line so that they can dissipate the coupled HF power [26].

In the BCI test, the current injection probe and the current measurement probe are located as shown in Fig. 1. According to the ISO 11452-4 standard, the current measurement probe is placed at 50 mm from the connector of the DUT and the current injection probe is located at 150 mm, 450 mm and 750 mm from the connector of the DUT respectively in test. But in this paper, when the effect of common-mode and differential-mode on the experimental characteristics of BCI test is analyzed, the current injection probe is only located at 450 mm, because it is enough to analyze the test characteristics between D-BCI and C-BCI. The current injection probe is connected to the output terminal of attenuator, whose input terminal is connected to the dual directional coupler that is connected to the output terminal of an RF power amplifier, whose input terminal is connected to a CW RF signal generator. Actually, two power sensors are connected between power meter and

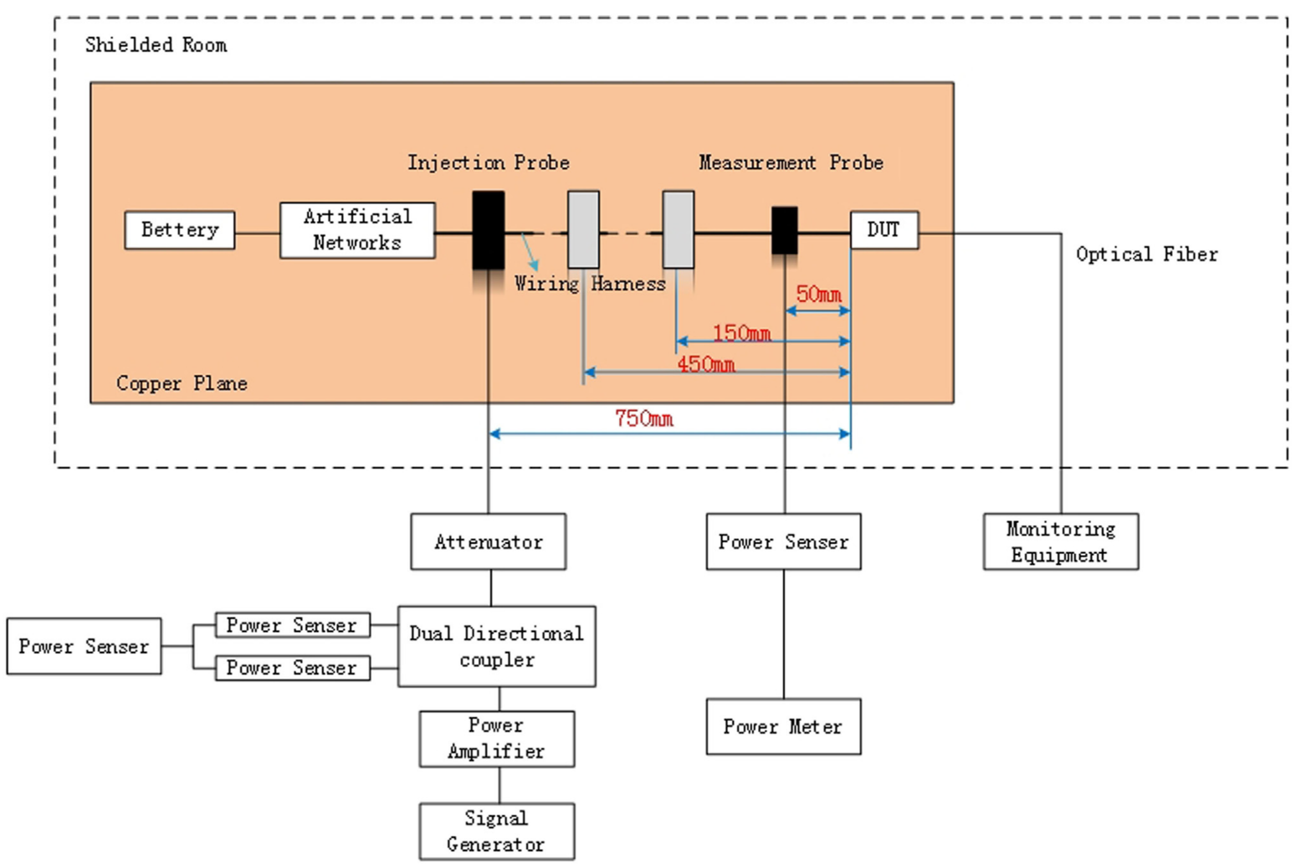

Fig. 1. BCI test bench.