Improved Just-Before-Test Verification Methods with VNA for Conducted EMC Tests

Osman Şen, Soydan Çakır
Electromagnetic Laboratory, TUBITAK UME, Gebze, Kocaeli, Turkey
osman.sen@tubitak.gov.tr

***Abstract* — Conducted emission and conducted immunity tests are major EMC tests which are performed by using LISNs and CDNs respectively in laboratories in accordance with emission standards such as CISPR22 for conducted emission tests and immunity standards such as IEC61000-4-6 for conducted immunity tests. As per the accreditation rules stipulated by IEC17025, every laboratory must perform verifications to ensure the quality and precision of test results by means of just-before-test verifications as just-before-test verifications can detect errors beforehand in the test setup and prevent wrong testing. Although just-before-test verifications are essential for assuring the quality of test results, they are widely omitted by laboratories or inefficient verification methods are employed. There are some existing well-known methods used for verification before conducted emission and immunity tests, however they are not able detect all issues with the setup, which may result in wrong testing. In this work, we first instructively introduce the state of the art verification methods and then propose new modern just-before-test verification methods through the inclusion of network analyzers into the verification process in order to be able to detect issues, including the most insidious ones, with conducted emission and immunity test setups.**

Keywords — Conducted Emission, Conducted Immunity, EMC, Verification

I. INTRODUCTION

All equipment placed on the European Market has to fulfil the essential requirements of the European EMC Directive. The normal approach is to show compliance with basic test requirements and testing electrical and electronic products is a must before entering the market. Conducted emission and immunity tests, which are performed as per a variety of standards such as CISPR22 [1], CISPR11 [2], MIL-STD461F [3] and IEC61000-4-6 [4,5], have a very important place to fulfil the EMC requirement. On the other hand, the assurance of the quality of test results must be provided by means of just-before-test verifications and comparison tests in accordance with the quality system standards such as IEC/ISO 17025 [6]. Despite the great necessity of verifications for ensuring correct testing, they are omitted by some EMC laboratories and these laboratories only rely on instrument calibrations realized every year or every two years, which is very risky and unreliable for test quality as instrument calibrations do not prove anything about the integration of the system and connections between the test system parts such as cables, attenuators, transducers. Moreover, most of test standards do not expressly stipulate verifications to be applied before tests. On the other hand, one of the rare standards which require verification before tests is MIL-STD461F [3]. The conducted emission test called CE102 in MIL-STD461F requires the application of a known signal that is 6 dB below the limit to the input of the LISN at 10 kHz 100 kHz, 2 MHz and 10 MHz in turn as shown in Fig. 1 just before the test. At 10 kHz and 100 kHz, a signal generator is connected to the LISN power output through a coaxial “T” connector. An oscilloscope with high input impedance is used to verify the signal level and verify that it is sinusoidal via the “T” connector as the LISN impedance is not around 50 Ω at lower frequencies. At 2 MHz and 10 MHz, the signal generator is directly connected to the LISN power output as the LISN impedance is around 50 Ω at higher frequencies. Thereafter, the measurement receiver is scanned for each frequency in the same manner as a test scan and it is expected that the test software must indicate a level within ± 3 dB of the injected level. If the measured signal levels deviate by more than ± 3 dB, the test is not continued and the error must be rectified in the test system. Nevertheless, this verification method is able to only verify each LISN separately and is not able to check the whole LISN system as a unit including ground connections, 50 Ω terminators. As a consequence, this method alone is not enough to detect common mode (CM) and differential mode (DM) insidious impedance issues with the LISN system including grounding issues, defective 50 Ω terminators and coaxial cables.

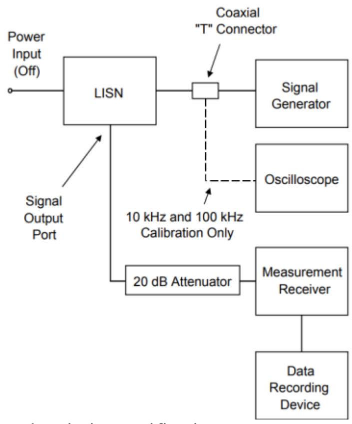


Fig 1. Conducted emission verification setup as per MILSTD461F

Another verification method used by some laboratories is the reference source method. In this method, a reference source which produces a constant broadband signal is tested just before a test and it is expected to have the same conducted emission curve per verification. This method looks more effective than the MIL-STD461F spot frequency application but it may be again inefficient for detecting all impedance issues because the emission values displayed by the test software are defined jointly by CM and DM interference sources inside the EUT, the CM and DM internal impedance of the reference source and the LISN impedance of the system. In other words, there is likelihood that some impedance issues with the LISN system, which are not detected under the current impedance combination of the reference source and the LISN system, become effective while a piece of actual Equipment Under Test (EUT) is being tested. Moreover, reference sources commonly emit only in CM or DM so that one of the impedance modes of the setup may not be checked at all.

In this paper, we proposed a just-before-test verification method which employs vector network analyzer (VNA) for a quick measurement of CM and DM impedance values of the LISN system for conducted emission tests, CM impedance of CDNs for conducted immunity tests and loop impedance of BCI tests. The proposed method reveals all possible impedance-related issues including the most insidious ones, which may not be detected by the aforementioned verifications methods, such as breakdowns inside LISNs or CDNs, problematic 50 Ω terminators or cables, weak grounding of LISNs, CDNs and EUT to the ground floor. Additionally, in this work, we also focused specially on the impact of 50 terminators used to terminate the decoupling CDNs in conducted immunity tests performed as per IEC61000-4-6. In the earlier version of the standard [5], the RF ports of all CNDs which are used for decoupling purposes are terminated with 50 Ω. However, in the new version of the standard [4], the RF port of one of the decoupling CDNs is terminated with 50 Ω and the RF ports of all the others are left unterminated. For that reason, we also investigated possible discrepancies, which may arise in the test results due to the use of the different versions of the standard, by means of loop impedance measurements and response of a piece of actual EUT chosen as an example.

II. Theory and Experimental Setup

The verification method proposed in our research is based on quick CM and/or DM impedance measurements of LISNs, CDNs and loop impedance measurements just before tests. The impedance measurement method and CM/DM impedance measurement setups that we employed in this research are given in [7] in detail and the general impedance measurement setup is simply shown in Fig. 2.

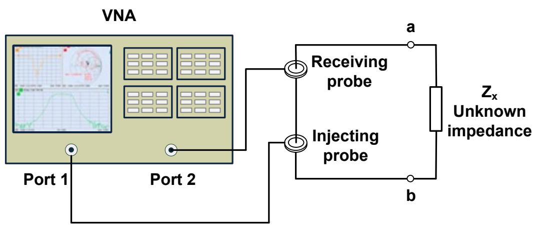
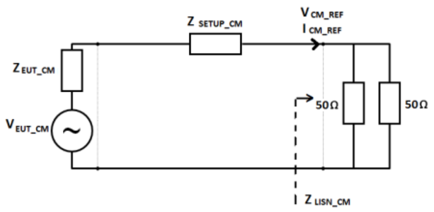
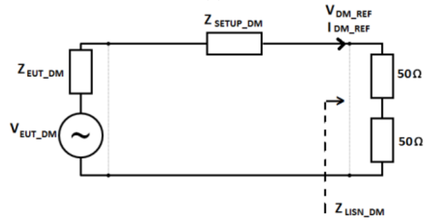


Fig. 2. Impedance measurement by using two current probes [7]

This impedance measurement method uses VNA (Manufacturer: Keysight Technologies, Model: E5061B in our case), two current probes and precision known impedance. A typical VNA, which can cover the frequency range of interest and can provide a received signal which is at least 15 dB above the noise floor, is enough for this impedance measurement. This method yields the value of the unknown impedance which is depicted in Fig.2 as well as the cable impedance that includes the effects of the used current probes and, if any, other measurement components. Emissions coming from EUT are classified as CM and DM and measured in laboratory environment with the use of LISNs. The circuit models of conducted emission measurements for CM and DM are simply presented in Fig.3. As seen in Fig.3, the interference sources inside the EUT are indicated as V_{EUT_CM} and V_{EUT_DM} for the CM and DM circuit models. Z_{EUT_CM} and Z_{EUT_DM} are the internal impedance values of the EUT for the CM and DM circuit models respectively. Z_{SETUP_CM} and Z_{SETUP_DM} are the impedance values of the used cables including employed measurement components such as current probes and so on. These figures show the reference setup installed with two LISNs in laboratory environment. The impedance of each LISN is depicted as 50 Ω. The LISNs become parallel in the CM circuit model and series in the DM model [8]. The flowing CM current and the induced CM voltage just at the LISN system in Fig.3(a) are depicted as I_{CM_REF} and V_{CM_REF} respectively for the CM model. Likewise, for the reference DM model, the flowing DM current and the induced DM voltage just at the LISN system in Fig.3(b) are depicted as I_{DM_REF} and V_{DM_REF} respectively.



(a)



(b)

Fig 3. Circuit models of conducted emission measurements in laboratory environment (a) CM circuit model, (b) DM circuit model

In this paper, the just-before-test verification for conducted emission tests is based on the measurement of CM and DM impedance of the LISN system at its mains input as seen in Fig.4(a). The measurement results are then compared with the expected reference curves. This verification directly reveals, if any, issues with internal structure of LISNs or with used 50 terminators or with grounding of LISNs, which may not be detected through the other known verification methods. To be able detect all possible issues related to the grounding in addition to the internal LISN and termination issues; the ground cable of the impedance measurement setup must be connected to the ground floor in front of the LISNs, not to the ground of the LISN EUT power outlet.

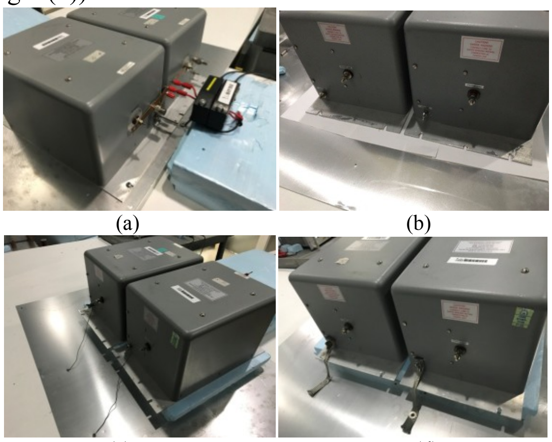
To demonstrate the effectiveness of the verification method, while the reference was the case in which the LISNs and their terminators were healthy and the LISNs were securely bonded to the ground floor, we formed the following issue scenarios by means of military LISNs (Manufacturer: Solar Electronics, Model: 9233-50-TS-50-N) seen in Fig.4(a);

LISN and termination issue scenarios:

- One of the LISNs is defective
- Both of the terminators are defective (open-circuited).
- Both of the terminators are defective. One of the terminators is open-circuited and the other is short-circuited.
- Both of the terminators are defective (short-circuited).
- One of the terminators is defective (short-circuited). The other is healthy.

LISN grounding issue scenarios:

- The LISNs' grounding to the ground floor is broken and the LISNs are placed on pieces of paper, which simulates very poor grounding (see Fig. 4(b))
- The LISNs are elevated by 5 cm from the ground floor and connected to the ground floor by thin and weak ground cables (see Fig. 4(c))
- The LISNs are elevated by 5 cm from the ground floor and connected to the ground floor by thick cables (see Fig. 4(d))



(a) (b) (c) (d)

Fig 4. Conducted emission grounding issue scenarios (a) reference setup, (b) very poor grounding with paper, (c) grounding with thin cable, (d) grounding with thick cable

Fig 5. Civil LISN with VDE/CISPR switch circled in red

Finally for the conducted emission just-before-test verification, we also investigated the impact of the "protective ground simulation circuit" switch which exists on some civil LISNs as per VDE0877 Part1 [9] because it may be left ON accidentally during the test while intending to perform a test as per CISPR standards. For this part of the research, we employed a civil LISN (Manufacturer: Schaffner, Model: MN2050D) that includes a VDE/CISPR switch on it (see Fig. 5). To be able detect the issues related to this special switch; the ground cable of the impedance measurement setup must be connected specifically to the ground of the EUT power outlet of the LISN, not to the ground of the test table.

In the second step of the research, we focused on just-before-test verifications of conducted immunity testing. The standard IEC61000-4-6 requires a setup presented in Fig.6. The conducted immunity test setup circuit model installed in laboratory is shown in Fig.7 [10].

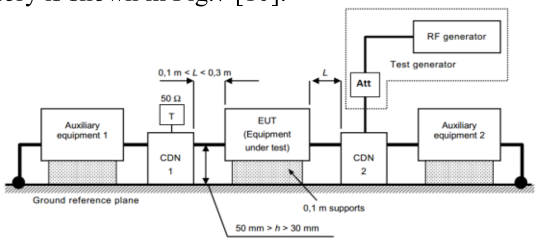


Fig 6. Conducted immunity test setup with CDNs [4]

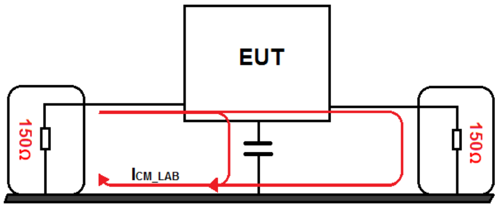
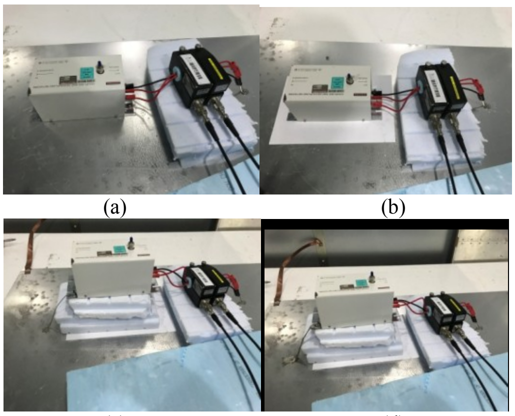


Fig 7. General conducted immunity test setup equivalent circuit

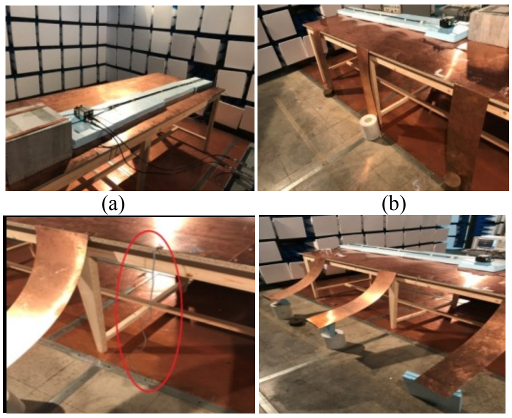
As seen in Fig.7, the test loop includes two pieces of 150 Ω impedance and EUT. Unlike the conducted emission testing, the just-before-test verification for conducted immunity testing is based only on the CM loop impedance measurement of each CDN seen in the test setup in Fig.6. Through this verification setup, similar to the conducted emission verification, CDN-related or grounding issues can be easily detected. While the ideal setup was a well-grounded CDN with a proper 50 Ω terminator as seen in Fig.8(a), the issue scenarios were formed as follows;

- The RF port of the CDN is left open
- The terminator of the CDN RF port is defective (short-circuited)
- The CDN is placed on the ground floor through a piece of paper that simulates very poor grounding. (See Fig.8(b))
- The CDN is elevated by 10 cm from the floor and connected to the ground floor with a thin and weak ground cable. (See Fig.8(c))
- The CDN is elevated by 10 cm from the floor and connected to the ground floor with a thick regular ground cable. (See Fig.8(d))



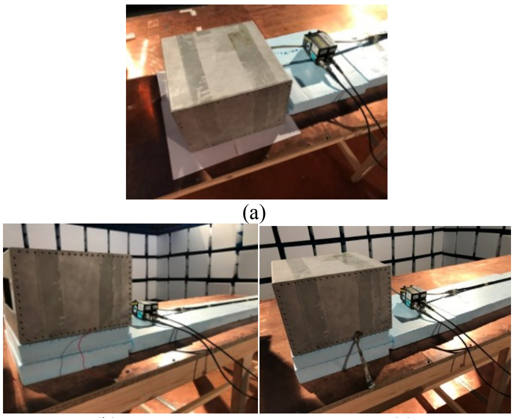
(a) (b) (c) (d)

Fig 8. Conducted immunity grounding issue scenarios (a) reference setup, (b) very bad grounding with paper, (c) grounding with thin cables, (d) grounding with thick cables



(a) (b) (c) (d)

Fig 9.Test table grounding issue scenarios (a) reference setup (front view), (b) reference setup (rear view), (c) grounding with ordinary cable circled in red, (d) broken ground



(a) (b) (c)

Fig 10. EUT grounding issue scenarios (a) very poor grounding with paper, (b) grounding with thin cable, (c) grounding with thick cable

In the third step of the research, we focused on the effects of possible issues with metallic tables used in some conducted immunity tests such as MIL-STD461 CS114 [3] tests, and automotive BCI testing. For example, in the CS114 test, the military EUT is placed on a metallic plate on the table and securely bonded to it. The metallic ground floor on the table is expected to have a surface resistance no greater than 0.1 milliohms per square. The DC resistance between the metallic ground plane and the shielded enclosure must be 2.5 milliohms or less. The metallic ground plane must be electrically bonded to the floor or wall of the basic shielded room structure at least once every 1 meter. The metallic bond straps must be solid and maintain a five-to-one ratio or less in length to width. To investigate the possible effects of the failure to meet these requirements in CS114 tests, we installed a CS114 setup seen in Fig.9(a) by means of a piece of dummy EUT that is a metallic box with a coaxial connector on it, a coaxial cable that connects the EUT to the wall of the chamber and a metallic table that is connected to the chamber floor. Subsequently we formed a large loop that contains the dummy EUT, the coaxial cable, the shielded chamber and the metallic table along with its bond straps. While the reference setup was installed with this very well grounded table and the securely grounded dummy EUT as seen in Fig.9(a)-9(b), we formed the following issue scenarios in turn;

The metallic test table grounding issue scenarios;

- The bond straps are disconnected from the floor and the metallic surface of the table is connected to the chamber floor via an ordinary banana cable (see Fig.9(c))
- The grounding of the metallic surface of the table is completely broken (see Fig.9(d)).

The EUT grounding issue scenarios;

- The dummy EUT is placed on pieces of paper without grounding. (See Fig. 10(a))
- The dummy EUT is elevated by 10 cm from the metallic surface of the table and connected to the metallic surface with a weak and thin cable. (See Fig.10(b))
- The dummy EUT is elevated by 10 cm from the metallic surface of the table and connected to the metallic surface with a thick cable. (See Fig.10(c))

Finally, in the last step, we investigated discrepancies between the two versions of the civil immunity standard “IEC61000-4-6” in terms of the RF port termination style of decoupling CDNs as there is a major difference between the 1996 and 2008 versions of the standard. While RF ports of all decoupling CDNs are terminated with 50 Ω in the version 1996, only one of them is terminated with 50 Ω and all the others are left unterminated in the version 2008. To experimentally detect the effects of the difference in the termination style on test results, we firstly installed a conducted immunity setup by means of a piece of actual EUT as seen in Fig.11, which is a hygro-thermometer that was intentionally made EMC-susceptible by revision on it, and four CDNs.

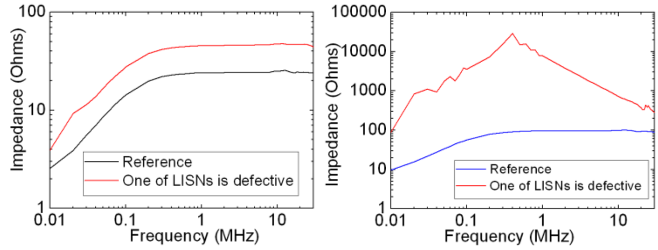
(a) (b)

Fig 11. Conducted immunity test setup (a) general view, (b) close-up of CDNs

The first CDN was a M2 type and used for supplying the EUT with 220 VAC, 50 Hz and for the interference injection. The other three CDNs were decoupling CDNs each of which was connected to a CM point of the EUT to simulate an actual test setup. With this setup, we performed two tests in sequence as per the 1996 and 2008 versions of the standard respectively and the response of the EUT along with the injected current was recorded per chosen frequency at which the EUT was very susceptible. In the first test as per the 1996 version, the RF ports of all the decoupling CDNs were terminated with 50 Ω. In the succeeding test, while only one of the decoupling CDNs was terminated with 50 Ω, all the others were left unterminated as required by the version 2008. Before each test, the CM loop impedance measurement was carried out at the power input of the power CDN (M2 type) as seen in Fig.11(a). Thereafter, the loop impedance results were compared with each other and a link was sought between the response of the EUT and the impedance curves and ultimately the detected discrepancies between the two versions of the standard were emphasized.

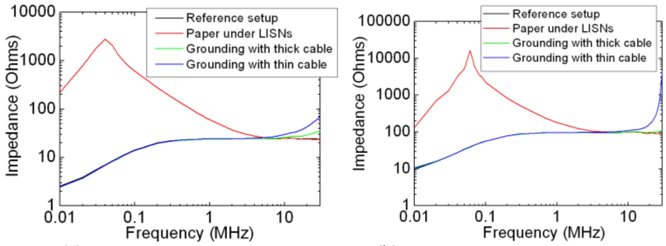
III. EXPERIMENTAL RESULTS AND DISCUSSIONS

The CM and DM impedance curves of the LISN system in the issue scenarios are given between Fig.12 and Fig.15. As seen in these figures, the CM reference curve starts from a value below 10 Ω and increases to 22 Ω as the LISNs become parallel to each other as shown in Fig.3(a) and one of the military LISNs has impedance of around 45 Ω. On the other hand, the DM reference impedance is around 90 Ω as the LISNs become serial as seen in Fig.3(b). In the first issue scenario in which one of the LISNs is internally defective, in Fig. 12, while the CM impedance of the LISN system is two times higher than the CM reference impedance, the DM impedance of the same issue scenario in Fig.12(b) is markedly higher than the DM reference impedance. Consequently, any LISN breakdown can be easily detected with the VNA just before a test. In the second issue scenario, when pieces of paper are placed under the LISNs, the grounding issue is remarkably detected for frequencies up to 10 MHz and the obtained curve settles on the reference curve beyond 10 MHz in CM as seen in Fig. 13(a). Similarly, in DM, the effect of the paper is also significantly detected. When the LISNs are elevated and grounded through ordinary thin and thick cables in turn, the CM impedance values seen in Fig.13(a) deviate from the reference curve especially beyond 10 MHz. The effect is more significant in the use of the thin grounding cables than the thick cables. In Fig.13(b) for DM, the effects of the thin and thick cables occur again beyond 10 MHz in a similar manner. Subsequently, all the grounding issues can be detected by the proposed just-before-test verification method using two current probes. The results of the termination-related issues are given in Fig.14. The curves here reveal that all the termination-related issues can be detected very easily just before a test in CM and DM. Finally for LISN issues, the impact of the grounding switch forgotten in the VDE position while intending to perform a test as per CISPR standards is presented in Fig.15. The curves in Fig.15 show that its tangible effects are detected only in CM but cannot be detected in DM.



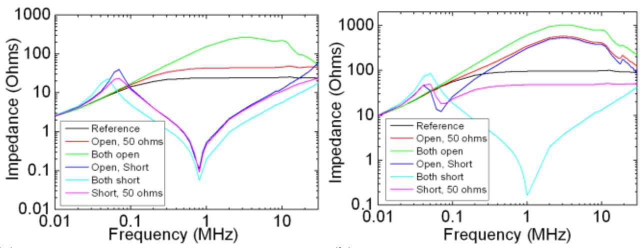
(a) (b)

Fig 12. Results of the issue scenario in which one of the LISNs is internally defective (a) CM, (b) DM



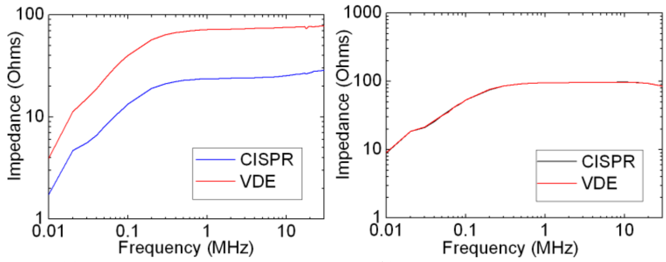
(a) (b)

Fig 13. Results of LISN grounding-related issues (a) CM, (b) DM



(a) (b)

Fig 14. Results of termination-related issues (a) CM, (b) DM

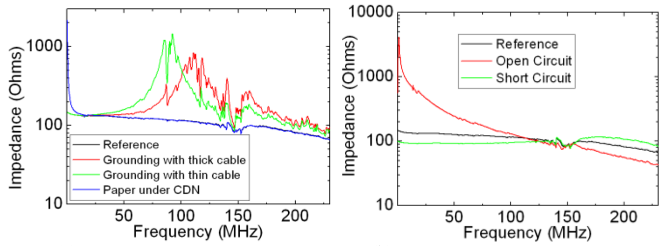


(a) (b)

Fig 15. Results of the issue with CISPR/VDE Switch left in the VDE position (a) CM, (b) DM

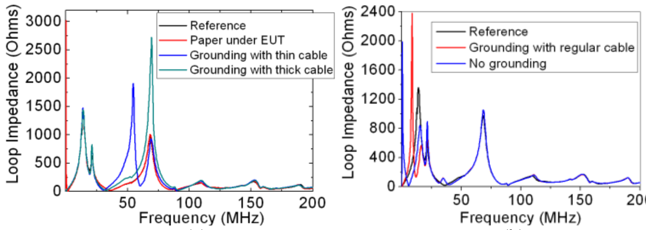
The results of the CDN related issues are presented in Fig.16. As seen in Fig.16, while the reference loop impedance that includes the well grounded CDN is around 150 Ω, all the issue scenarios give remarkable deviations and they are easily detectable through the proposed verification method. Similarly the results of the test table and EUT grounding issue scenarios are given in Fig.17. Surprisingly, with the proposed method, the issues related to the table/EUT grounding can be detected and the deviations from the reference curve arise only for frequencies up to 100 MHz. Beyond 100 MHz, the issues cannot be detected through the proposed verification method.

Finally, the research results about the effects of the different versions of the IEC61000-4-6 standard are presented between Fig. 18 and Fig. 19. Fig.18 shows the loop impedance curves of the test setups that include the EUT, cables and CDNs for the two versions of the standard. As mentioned earlier, while all the decoupling CDNs are terminated with 50 Ω as per the 1996 version, only one of the decoupling CDNs is terminated with 50 Ω as per the 2008 version. The effects of the use of the different standard versions are clearly observed between 100 MHz and 150 MHz in terms of loop impedance. Due to the high scale of the graph, it is not easily observable but there is also slight difference between the two curves of Fig.18 in the rest of the frequency range.



(a) (b)

Fig 16. Results of CDN-related issues in CM (a) grounding issues, (b) termination issues



(a) (b)

Fig 17. Results of EUT and table grounding issues (a) EUT, (b) table

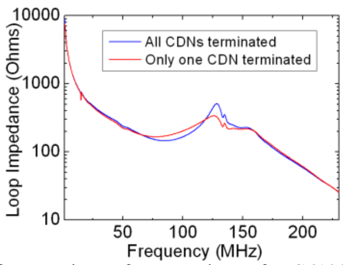


Fig 18. Results of comparison of two versions of IEC61000-4-6 in terms of loop impedance

As the EUT was intentionally made susceptible by modification, it notably responded to the frequencies in the ranges 70 MHz - 120 MHz and 150 MHz - 230 MHz. For that reason, we specially focused on these frequency ranges in the succeeding step of the research and investigated the response of the EUT in the tests as per both of the versions of the standard. In the Fig. 19, while the curves in (a) and (c) indicate the injected current into the test loops in both of the cases per frequency range, (b) and (d) show the EUT response which is the deviated value indicated on the EUT display due to the injected interference signal. All the curves in Fig.19 clearly reveal that different termination styles of the decoupling CDNs cause different injected currents and different EUT responses under the same injected calibrated power. In Fig 19. (b) and (d), while the displayed temperature is 37 degrees in the absence of interference, the deviations on the displayed value on the screen arise in a different manner in the different versions of the standard subsequently the failure to meet the specific requirements of each version may lead to different test results or wrong testing.

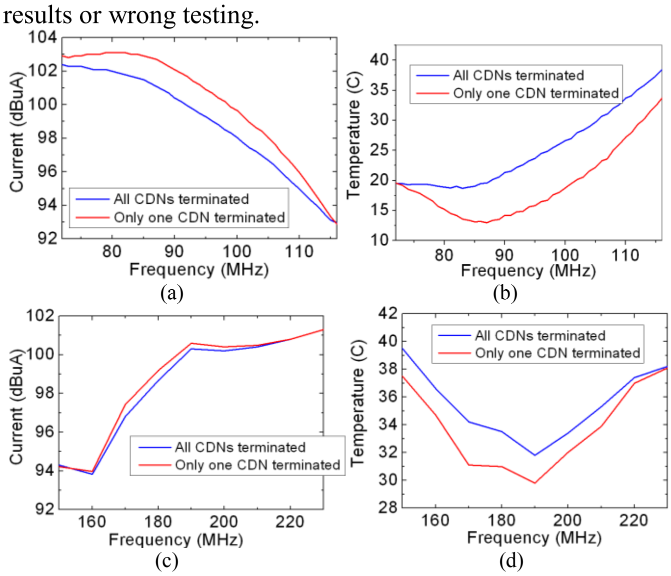


Fig 19. Results of comparison of two versions of IEC61000-4-6 in terms of injected current and EUT response (a) injected current between 70 MHz-120MHz, (b) EUT response between 70 MHz-120 MHz, (c) injected current between 150 MHz-230MHz, (d) EUT response between 150 MHz-230MHz

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