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Assessment of the Effect of a Test Setup on the Input Impedance Measurement of Cables

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***Abstract*—This paper aims at a new assessment to investigate the effect of a test setup on the input impedance of cables. The test setup includes a vertical reference plane connected to a horizontal ground plane. A connector is screwed into the vertical plane. The connector from one side is connected to a measurement device and from another side, it is connected to a cable. To assess the effect of the setup on connectors, the SMA connector and the end-launch connector are connected to the setup separately and the input impedance of the setup is measured. The results suggest that the vertical plane and the connectors have a significant impact on the test setup up to 6 GHz. This impact can be observed even by adding a 1m wire to the test setup.**

Keywords— Cable, Equivalent circuit, Input impedance, EMC, EMI, End-launch connector, MATLAB, SMA Connector.

I. Introduction

While with the advent of wireless technology, a diverse range of wireless communication systems have emerged, cables are still used in different systems ranging from motor-drive systems to medical systems [1]. These systems have to be designed to work harmoniously with other nearby devices. Cables are the principal electromagnetic interference (EMI) coupling paths for both conducted and radiated emissions [2]. They result from natural electrical unbalances present in any electronic device which propagates EMI through invisible parasitic circuits not always foreseen during functional design [3]. While a cable is a key part of any industrial installation, its placement is critical since it acts as the main actor in transporting unwanted energy through these invisible parasitic circuits [4]. Apart from cables, the contribution of connectors connected to the cables towards the propagation of EM noise is inevitable and investigation of the effect of connectors alongside the cables and their test setups can also pave the way for designing a system with a low level of EMI [5].

Several studies have been conducted on the behavior of cable above a reference ground plane [6]–[8]. In these studies, the common-mode impedance of the cable is measured above a ground plane. The test setup illustrated in Fig.1 is used in their studies as a means to connect the cable to measurement equipment. Despite the good capability of the test setup for the cables, the impact of the test setup, including the influence of the plane at which the connector is connected, on input impedance has not been investigated.

In this paper, the impact of the test setup on the input impedance is investigated up to 6 GHz. The test setup is based on that of [6] meeting the requirement of connection of the connector to VNA and the wire. In section II, the methodology for the simulation, the measurement, and their test setups are described. Section III presents the simulation and the measurement results.

II. Methodology

A step-by-step procedure is followed to investigate the effect of the test setup on the input impedance. A change in the connector can reveal its impact on the test setup. To achieve that, full-wave simulation in CST is carried out for an SMA connector and an end-launch connector [9]. Adding a wire to the connectors represents the influence of the wire on the test setup. The impact of the wire on the test setup with the SMA connector is investigated both by simulation in CST and measurement and for the test setup with the end-launch connector, simulation in CST is done. Finally, to scrutinize the impact of the reference plane and the connector on a wire, a short wire is connected to the SMA connector and by increasing its length, the length at which the effect of the reference plane on the wire is dominant is simulated in MATLAB and measured. The changes in the setup test ranging from connector type to the wire length are summarized in Table I.

A. Test setup A1& A2

The simulation setup including the reference plane and a connector is shown in Fig. 2. The reference plane is comprised of two parts: one horizontal part and one vertical part. For setup A1, the SMA connector is connected to the reference plane and the simulation is carried out in CST to analyze the input impedance of the test setup. The same procedure is adopted for setup A2, while the end-launch connector is used in this setup. The end-launch connector is shown in Fig. 2b. Considering that in the structure of the

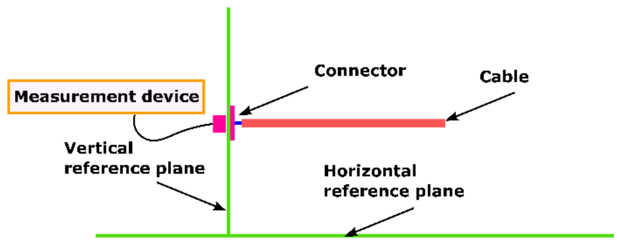


Fig. 1. The test setup in the earlier works used in this paper

end-launch connector, a printed circuit board (PCB) is used, the PCB is designed based on the schematic given in Fig. 3. The dimensions of the PCB are listed in Table II.

B. Test setup B1 & B2

In setup B1 a 1m wire is connected to the SMA connecter and as it is shown in Fig. 4. Simulation and measurement are done to investigate the effect of the wire on the setup. In setup B2 the 1 m wire is connected to the end-launch connector and the connector is excited by a discrete port to extract the input impedance of the structure by simulation.

C. Test setup C

As it is shown in Fig. 5, a short copper wire with an approximate length of 0.6 cm is soldered to the SMA connector. The length of the connected wire to the SMA connector is increased roughly by 1 cm. The SMA connector is connected to VNA and by increasing the length of the wire each time, the input impedance of the wire is measured. The procedure of increasing the length of the wire is adopted several times to find a length at which the impact of the vertical plane and the connector on the wire is dominant.

III. Results and Discussion

In this section, the simulation and the measurement results are presented based on the test setups that were mentioned in the previous section.

A. The impact of the change in the connectors on the input impedance

Full-wave simulation is carried out in CST for test setups A1 and A2. The horizontal plane has the dimensions of 80 cm × 50 cm × 1 mm and the vertical plane has the size of 20 cm × 20 cm × 1 mm. To expedite the simulation time the material of the planes is assigned perfect electric conductor (PEC). The conductive parts of the connectors are determined copper. The PCB substrate is Rogers RO4003 with ε_r and $\tan\delta$ of 3.5 and 0.0027, respectively. There is no wire connected to the SMA connector and the end-launch connector in test setups A1 and A2, respectively. In other words, only connectors are connected to the reference plane to merely analyze the effect of the change in the connectors on the impedance measurement of test setups A1 and A2. The results illustrated in Fig. 6 demonstrate that by changing the connectors, the input impedance response of the test setup is also changed. Considering that due to the difference in the designed structure of the connectors each of which has its own parasitic effects such as the capacitance parasitic effect, each connector has a different input impedance response.

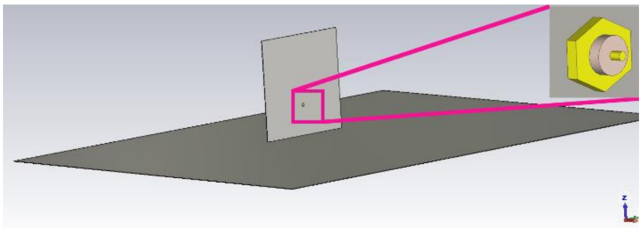
B. The influence of adding a 1 m wire to the measurement setup on the input impedance

Test setups B1 and B2 have the capability of being connected to the VNA while a wire is connected to a connector above a reference plane. As seen in Fig.7a, for test setup B1, the results demonstrate good agreement below 800 MHz, while from 1 GHz to 6 GHz a deviation between the results is observed. The deviation is likely due to the soldering part in the test setup showing its impact on the input impedance by increasing the frequency. In the frequency span of 10MHz to 6 GHz an envelope behavior is also observed. This behavior is because of the effect of the connector and the vertical plane which can be easily distinguished by comparing the curves in Fig. 7a.

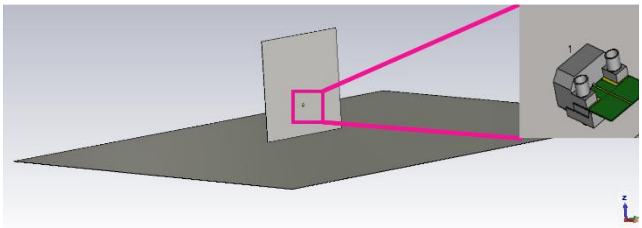
In setup B2, by changing the SMA connector to the end-launch connector the parasitic parameters of the test setup are changed. These changes can be observed in Fig.7b. For test setup B2, the first resonance is close to that of test setup B1

TABLE I. THE TEST SETUPS SPECIFICATIONS

Test setup type	Connector type	Length of wire (cm)
Setup A1	SMA	0
Setup A2	end-launch	0
Setup B1	SMA	100
Setup B2	end-launch	100
Setup C	SMA	Variable length from 0.6 to 14

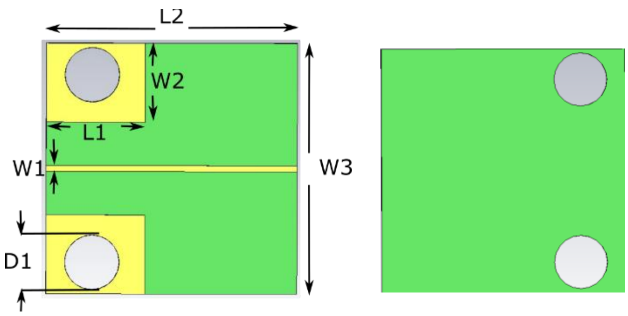


(a)



(b)

Fig. 2. The simulation setup for (a) setup A1, (b) setup A2



(a) (b)

Fig. 3. The schematic of the designed PCB for the end-launch connector (a) top view, (b) bottom view.

TABLE II. THE DIMENSIONS OF THE END-LAUNCH CONNECTOR PCB

parameter	Value (mm)
W1	0.3
W2	4
W3	12.7
L1	5
L2	12.7
D1	2.76

while its input impedance is higher. A similar envelope behavior is also observed for test setup B2 proving that the effect of the vertical plane and the connectors on the input impedance response of a wire is observable at the entire frequency bandwidth. Comparing Fig.7a and Fig.7b shows that because of the difference in the parasitic parameters of the connectors in setup B1 and B2, the envelope behavior of the test setups is also different and it is based on their connectors.

C. The effect of the vertical reference plane and the SMA connector on the wire

A wire with a 0.6 cm length is connected to test setup C shown in Fig. 5. As mentioned in the previous section, the length of the wire is approximately increased by 1 cm and measurement is carried out to extract the input impedance. The measurements are done for the wire with a length of 0.6 cm to 14 cm and the results are illustrated in Fig. 8. As seen in Fig.8, by increasing the length of the wire from 0.6 cm to 14 cm, the resonance impedances change from higher frequencies to lower frequencies. With the gradual increase of the length of the wire, the length of the wire reaches a threshold at which the most influence of the vertical plane and the connector on the wire is observable. The first resonance for the shortest wire (0.6 cm) occurs is 3.27 GHz. At this frequency, the resonance length of the 0.6 cm wire is 0.23 cm. The significantly longer wire in comparison with the resonance length of the 0.6 cm wire is the approximate threshold. This length is calculated 2.3 cm. Reaching this value indicates that at the length of 2.3 cm, the effect of the vertical reference plane on the wire is dominant. The shift observed in the results is due to the change in the length of the wire. To better investigate the effect of the reference plane on the wire, a circuit schematic is proposed and shown in Fig. 9. The circuit model is not a physical model, yet, it represents the behavior of test setup C. Consider the wire to be very short. The short wire can be modeled by a series combination of a resistance (R1) and an inductance (L1). Since there is a gap between the vertical plane and the short wire, the gap is modeled with a capacitance (C1). Therefore, for the very short

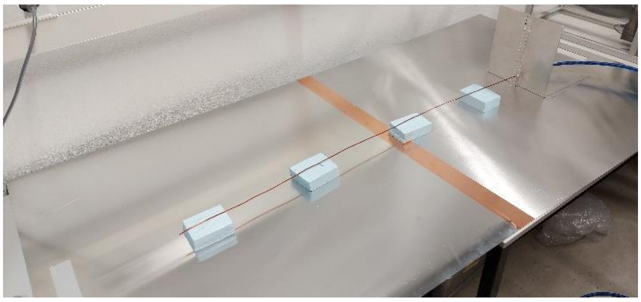


Fig. 4. The test setup to measure the effect of the wire above the reference plane on the input impedance response

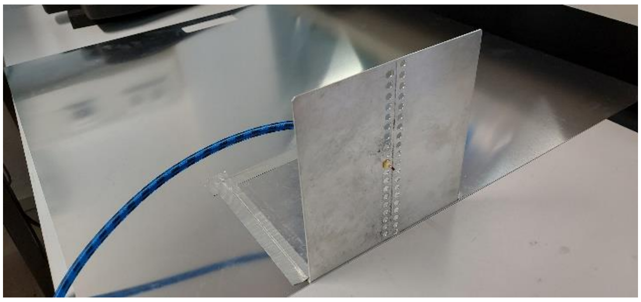


Fig. 5. The test setup to extract the parasitic parameters of the vertical plane to the wire

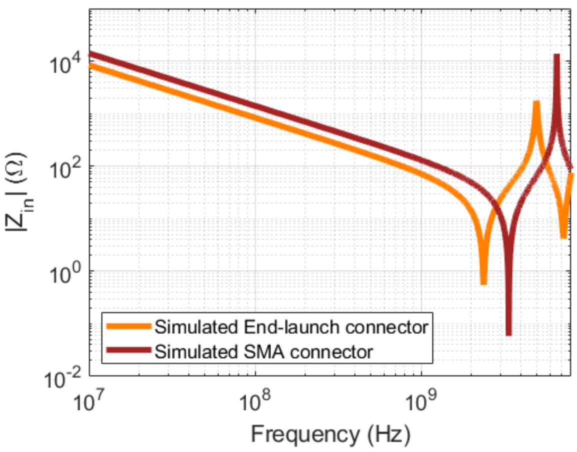
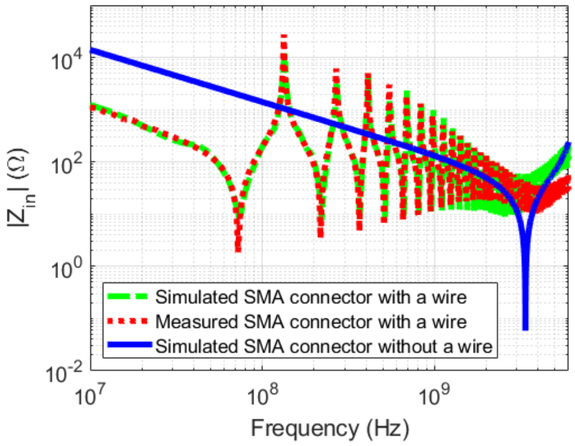
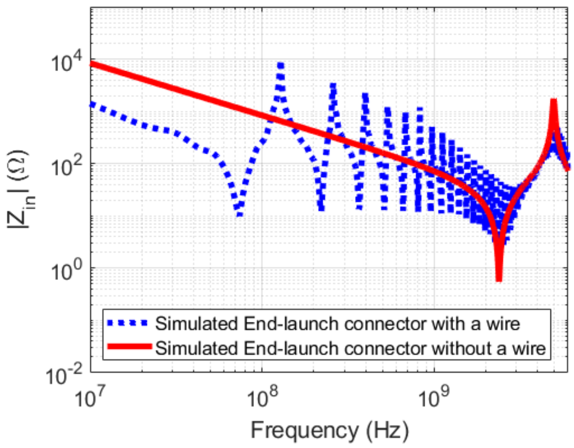


Fig. 6. The simulated input impedance of test setups A1 and A2 without wire



(a)



(b)

Fig. 7. The simulated and the measured input impedance of the wire connected to the vertical reference plane in (a) test setup B1 (b) test setup B2

wire, one stage of the equivalent circuit shown in Fig.9 including one capacitance (C1) and one inductance (L1) and a resistance (R1) is implemented. To analyze the number of stages required for a 2.3 cm wire, a circuit analysis in MATLAB is done. The results of the simulation shown in Fig. 10 indicate that for the 2.3 cm wire, a three-stage equivalent circuit is needed. It is worth mentioning that since the equivalent circuit is not a physical model, the values of the resistance are determined in order that they adjust the values of the resonance impedance at the resonance frequencies. The input impedance response of the equivalent circuit model for the values listed in Table III is closely matched with the first three measured resonances of the wire with a 2.3 cm length. there are more resonances above 6 GHz, however, the resonances do not have a prominent effect on the schematic of the equivalent circuit. In other words, while there are more stages to represent the 2.3 cm wire, the capacitance effect of the stages is so low that one can only consider a three-stage equivalent circuit.

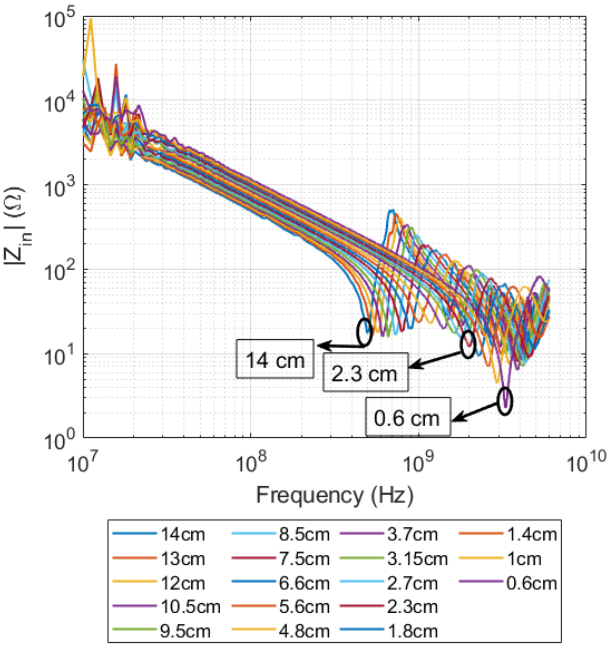


Fig. 8. The measured input impedance of the wire connected to the vertical reference plane for different lengths of 0.6cm – 14cm.

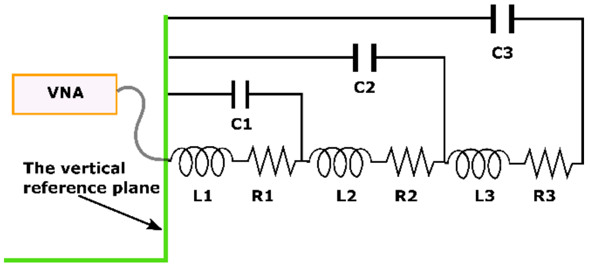


Fig. 9. The circuit equivalent of the short wire connected to the vertical reference plane

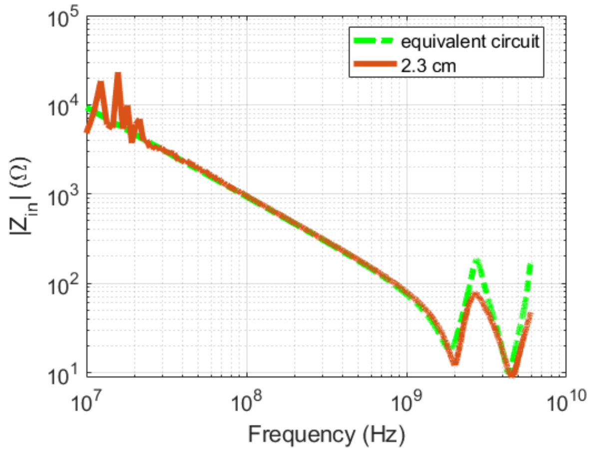


Fig. 10. The comparison of the input impedance calculated in MATLAB with that of the measured for the 2.3 wire

TABLE III. THE VALUES OF THE EQUIVALENT CIRCUIT COMPONENTS

Components	values
L1	1.2 nH
L2	3 nH
L3	8 nH
C1	1.5 pF
C2	0.9 pF
C3	1 pF
R1	6 Ω
R2	6 Ω
R3	20 Ω

IV. CONCLUSION

In this work, the influence of the test setup incorporating vertical and horizontal reference planes on the input impedance is investigated. A change in the connector types reveals that the input impedance of the test setups changes due to the difference in the parasitic parameter of the connectors. Comparing the simulation and the measurement results of the test setup with the SMA connector connected to the 1m wire shows that the results are close to each other up to 1 GHz, while above 1 GHz, the difference between the results is on the increase which might be because of the effect of soldering part in the measurement setup showing its effect on the response at the high frequencies. Moreover, there is the envelope behavior in the input impedance response of the setups with the 1m wire which is the result of the influence of their connectors and the vertical plane on the input impedance response. The circuit model proposed in this paper describes the effect of parasitic as well as no-parasitic components of the test setup with a 2.3 cm wire length. According to the measurement and simulation results, the wavelength of the resonances is increased by adding to the length of the wire and the wire reaches a threshold at which the effect of the vertical plane and the connector on the wire is dominant.

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