Signal Integrity Analysis of a Super Speed Pair of a USB 3.0 Connector with Test Jig

Hyesoo Kim, Shinyoung Park, Jonghoon Kim, and Joungho Kim
TERA Laboratory
Korea Advanced Institute of Science and Technology
Daejeon, South Korea
hyesookim@kaist.ac.kr

Jung-Min Park, Un-Ho Kim, Yuck-Hwan Jeon
VEC Development Center
Korea Electric Terminal Co., Ltd.
Incheon, South Korea

***Abstract*—In this paper, we compare and analyze the signal integrity of a USB 3.0 connector depending on its pin assignment. Four pins of the connector are grouped and assigned as a differential signal pair at the center and the others as a reference. The reference can either be power and ground. Therefore, a test jig should be designed with consideration how to properly connect a power pin to the measurement reference of the test jig to evaluate the electrical performance of the connector without affecting high frequency performance of the connector. For three cases of different power pin to test jig connection, we analyze and compare their S-parameter and Z-parameter based on 3D electromagnetic simulation up to 10 GHz; for the first case, the power pin and ground pin are tied to the reference plane of the test jig by a decoupling capacitor. For the second case, the power pin is directly tied to the reference plane, and for the last case, the power pin is floated untied to the reference plane. The second case shows the most similar electrical performance to the first case.**

***Keywords*—signal integrity; test jig design; USB 3.0 connector**

I. Introduction

Todays, as automotive audio video navigation (AVN) has been commonly introduced in cars for easier in-car access to infotainment and safer and much convenient driving. As the contents provided by the AVN system has been increasing dramatically since its introduction, the volume of the data to be processed by the system has been also increasing fast. In order to achieve a high data bandwidth, the system has become requiring high-speed data transmission and high-speed connectivity [1].

With this trend, the demands for automotive Universal Serial Bus (USB) 3.0 connector has increased recently. By newly introducing Super Speed Pairs (SSPs), USB 3.0 could support the data rate up to 5 Gbps. As the data rate has increased, a USB 3.0 connector requires tighter electrical specification than a USB 2.0 connector does. For example, the frequency bound for S-parameter specifications of USB 3.0 connector cable assemblies has increased from 1 GHz to 7.5 GHz to meet the criteria for higher frequency characteristics [2], [3].

A USB 3.0 connector has three differential signal pin pairs. One of the pairs has a ground pin at the sides for a reference of

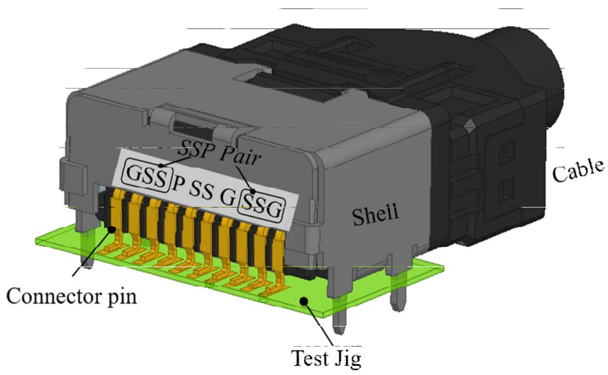


Fig. 1. The structure of USB 3.0 connector. USB 3.0 supports up to 5.0 Gbps by introducing SSP pairs

the differential signaling but it is next to a power pin as shown in Fig. 1. When we evaluate the electrical performance of a connector, we use a test jig to connect the connector and measurement instruments. Because the USB connector has an asymmetric pin assignments, it is important to connect the power pin of the connector to reference plane of the test jig with reflecting of its system environment. Depending on how to handle the power pin, the high frequency performance of the connector looks significantly different.

Therefore, in this paper, we compare, analyze and discuss three cases of different USB 3.0 connector and test jig connections based on 3D electromagnetic simulation results. One reflects the system environment by assuming that the power pin is connected to a power plane and the power plane is connected to a ground plane with a decoupling capacitor. For the other two cases, the power pins are directly connected to the reference plane of the test jig and floated, respectively.

II. Simulation Set-up for USB 3.0 Connector Assembly with Test Jig Assembly

Fig. 2 describes the simulation environment that includes test jigs, USB 3.0 connectors and cables. For simple simulation, the connector pins are modeled to have a uniform thickness. In

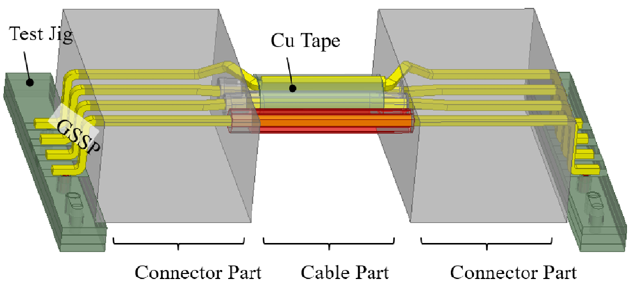


Fig. 2. Simulation environment for simplified assembly structure of USB connector terminal and cable wire.

case of the cables, a cooper tape shields the two signal wires and ground wire. The power cable is isolated from them. The following three cases are simulated with HFSS, a 3D field solver from Ansys.

We name the case 'Case A', which the power pin is connected to the reference plane of the test jig through a power plane and a decoupling capacitor as illustrated in Fig. 3 (a) likewise the configuration of the PCB and the connector in the actual system. The power pin is connected to the power plane by the via. We name the case 'Case B', which the power pin is directly connected to the reference plane by a via. A through-hole via is used considering cost issues. In other words, the power pin is connected as the differential signal pairs perform Ground-Signal-Signal-Ground (GSSG) signaling. For the case, which the power pin is floated without any linkage to the reference plane, we name it 'Case C'.

III. Signal Integrity Ananlysis and Discussion of Simulated USB 3.0 Connector Assembly with Test Jig

Fig. 4 shows the waveforms comparing the differential insertion loss of Case B and that of Case C to the 'Case A' up to 10 GHz. It was confirmed that both differential insertion loss (Sdd_{21}) of Case B and that of Case C are different from that of Case A. For a detailed analysis, we observed the self-impedance (Z_{11}) for single-ended signal pins of the Case B, Case A and Case C as shown in Fig. 5 (a), (b) and (c), respectively.

For Case B, the impedance curve of the two signal pins are not perfectly matched even though it has GSSG symmetric pin assignments as shown in Fig. 5 (a). The signal wire of the cable nearer to the ground wire sees the ground wire and the ground shield as a reference. Since the power wire is separated from the ground wires, the signal wire nearer to the power wire sees the different reference. However, since the power pin of the connector is directly tied to the ground plane of the test jig, on the connector side, the both the signal pins see the same reference. Therefore, the signal wire on the power side of the cable sees a different reference from the connector. In other words, the signal on the power side undergoes a reference change, which results in different impedance from that of the signal on the ground side.

As described in Fig. 5 (b), Compared with the Case B, the Case A has slightly larger inductance [4]. For the Case A, even if the power is tied to the ground with a decoupling capacitor, a current loop appears still larger than Case B. Consequently, relatively considerable parasitic inductance occurs. For the Case C, although charges are applied to the floating line by the coupling, current does not flow through the line. Therefore, the loop inductance becomes apparently larger than Case A. As a result, impedance curve of Case C looks different from Case A as illustrated in Fig. 5 (c).

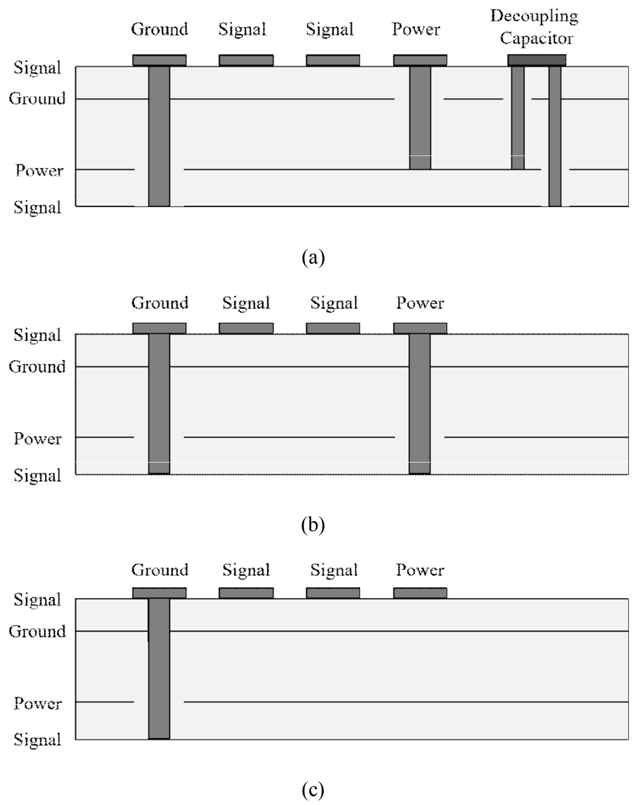


Fig. 3. Conceptual figures for three cases depending on how to handle the power pad. (a) Case A; ground and power pads are connected by decoupling capacitor. (b) Case B; the power pad is considered as ground. (c) Case C; the power pad is floating.

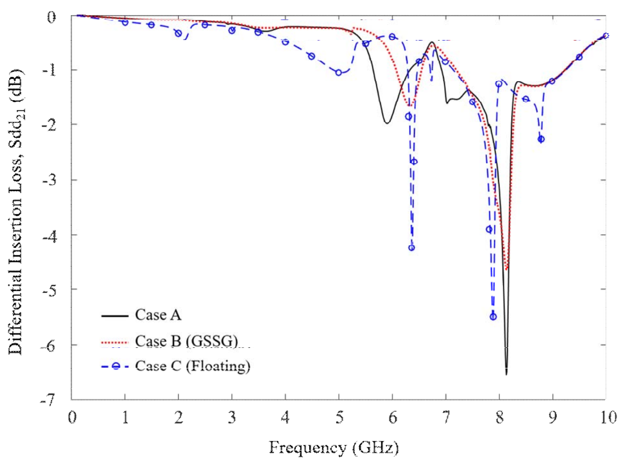
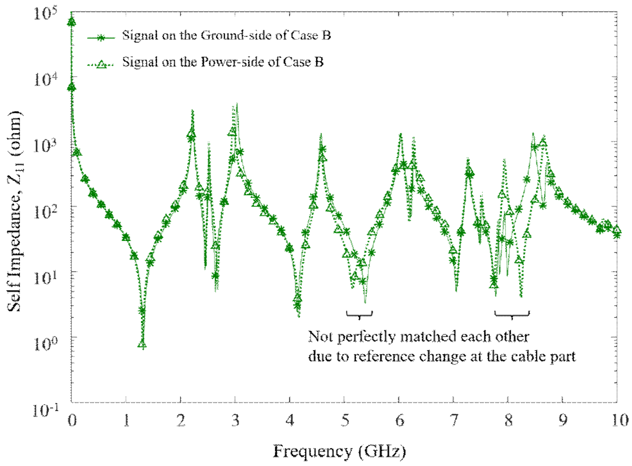
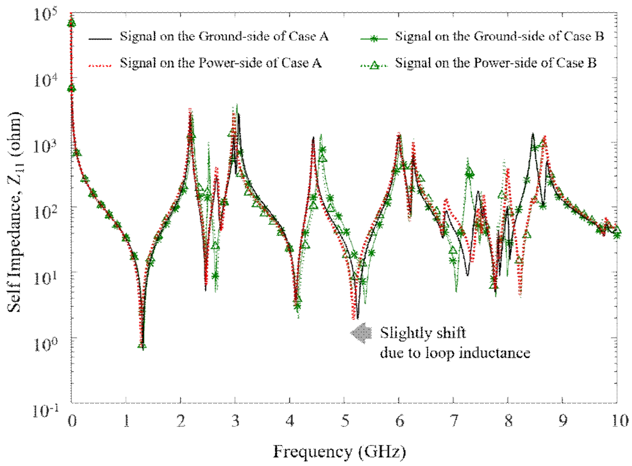


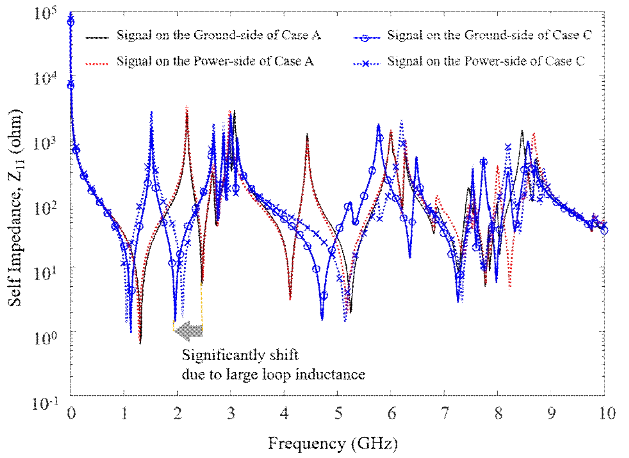
Fig. 4. Simulated differential insertion loss for Case A, B and C.



(a)



(b)



(c)

Fig. 5. Simulated self impedance of single-ended signal for Case A, B and C. (a) Case B. (b) Comparison between Case A and B. (c) Comparison between Case A and C.

Based on aforementioned analysis, it could account for Fig. 4. For Case B, due to the relatively smaller loop inductance, the resonance at the 6 GHz of the Case A is slightly moved backward thus, appears at the 6.3 GHz. On the other hand, for Case C, the overall shape of the waveform differs from others due to the large parasitic inductance making impedance distorted. For all cases, the resonance at the 8 GHz occurs due to the connector length.

In conclusion, it is best to design a test jig similar to the actual system operating environment. A decoupling capacitor, which connects power and ground in real system, lowers the impedance between them, secures the return current path for the signal input. However, if it is not available, grounding the power could be the second best. When grounding power, it has similar inductance to the real system because power is connected to ground. For floating power, on the other hand, since the return current path is not formed on the power pin, a larger loop inductance is formed. Consequently, a completely different performance appears. Therefore, in order to achieve similar performance to the actual system, power should be designed as grounding and not floating.

IV. Conclusion

In this paper, we compare and analyze the cases which the power pins of a USB 3.0 connector are connected to either the ground plane of a test jig by the decoupling capacitor or a via, and the case which the power pin floated. Based on the simulation result, we could conclude that when evaluating the connector of differential pin pairs with non-symmetry reference pins such as USB 3.0 connector, the power pin should be connected to its test jig as the ground pin is.

Acknowledgment

We would like to acknowledge the technical support from ANSYS (ANSYS HFSS) and the financial support from Korea Electric Terminal Co., Ltd. This work was also supported by the MKE through the International Collaborative R&D Program, “Glass interposer based RF FEM for Next Generation Mobile Smart Phone”, under Grant N0000899. Additionally, this research was supported by the MSIT(Ministry of Science and ICT), Korea, under the ITRC(Information Technology Research Center) support program(IITP-2017-2016-0-00291) supervised by the IITP(Institute for Information & communications Technology Promotion).

References

[1] Universal Serial Bus Revision 2.0 specification [Online], Available: http://www.usb.org/developers/docs/usb20_docs/

[2] Universal Serial Bus Revision 3.0 specification (including errata and ECNs through May 1, 2011) Revision 1.0, June 2011

[3] E. B. Rosa, The Self and Mutual Inductance of Linear Conductors, Bulletin of the National Bureau of Standards, vol. 4, no. 2

[4] Global Automotive Connectors Market 2016-2020, 2016 [Online], Available: http://www.usb.org/developers/docs/usb20_docs/