Electrical Characterization Methodology for Raw Cable up to 30 GHz

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***Abstract*—Channel loss is a dominant factor for the signaling performance of high-speed I/O's. Some platform design guides clearly specify the raw cable only loss requirement in the channel design. How to characterize the raw cable with the test fixture being de-embedded is very important for designers to select the right cable and control manufacture process control, balancing the platform performance and cost. In this study, a novel raw cable metrology is proposed for accurate and robust measurement. Delta-L de-embedding metrology is adopted with the physical fitting to report insertion loss numbers more error-resistant up to 30 GHz. The unit cable loss of different effective cable length configurations by Delta-L are very consistent to show the robustness and accuracy of this proposed metrology. Furthermore, this electrical library of different cable gauges from different suppliers was established to provide more flexibility in the cable selection during the platform design phase.**

Keywords—cable; insertion loss; electrical characterization; impedance mismatch; de-embedding; test fixture; gauge

I. Introduction

For the early stage cable selection, platform designers would like to have the accurate loss measurement to meet the channel requirement, because the cable type contributes largely to the platform cost. When the speed is going higher, cable topology is widely used because of the lower loss characteristics with the longer routing length, compared with the conventional printed circuit board. How to characterize the raw cable loss with the test fixture effect being de-embedded is very important. An improper selection of raw cable may result in either a costly over design or an increased risk of platform performance.

Currently, some industrial methods are used for the electrical characterization of twist raw cable. The conventional Thru-Reflect-Line (TRL) is well known de-embedding metrology to remove the effect of raw cable test fixtures [1]. TRL is regarded as the golden reference to move the measurement reference plane from coaxial connectors to raw cable structures. It requires various calibration structures with different routing lengths for the measurement frequency range shown in Fig. 1. The process is complicated and it is becoming less popular.

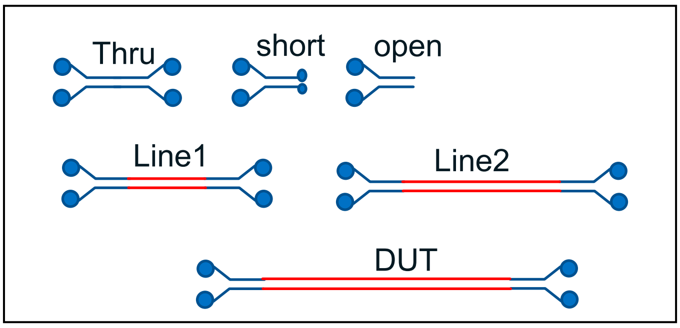


Fig. 1. TRL testing structures

2X through (2X-Thru) method was proposed with the simple testing procedure by dividing a thru calibration structure into two half portions in Fig. 2[2]. Only one 2X through structure is needed. S parameter of 1X through is mathematically calculated and it can significantly simplified calibration and de-embedding procedures. However, it need one proprietary software.

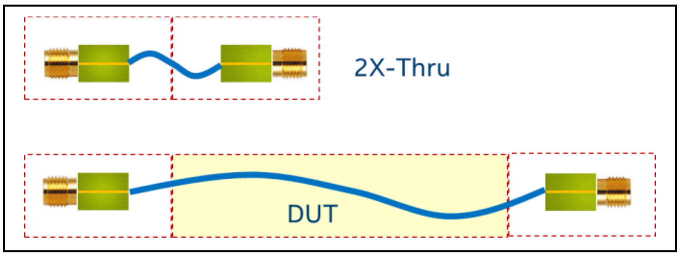


Fig. 2. 2X through strcuture

Meanwhile, there is some mismatch between the raw cable and mismatch may produce the resonance in the higher frequency and it will impact the measurement accuracy.

In this paper, the raw cable testing metrology was proposed and Delta-L with two cable lengths [3-4] was adopted to not only remove the effect of raw cable test fixtures but also mitigate the mismatch effect between raw cable and test fixture.

II. Electrical Characterization of Raw Cable

A. Test Fixture

A good raw cable fixture has low loss, good impedance matching and no resonances in the range of concerned frequencies. The adopted test fixture are well designed for different gauges of twist cables in Fig. 3. Users can easily make good connection between the ground of raw cable and the body of fixtures by the cover.

Fig. 3. Test fixture picture

B. Raw Cable Testing Flow

- Equipment Setting

  The calibration is to use electronic calibration module to move the reference plane from the instrument to the end of coaxial cable. The fixture effect can be removed by Delta-L de-embedding metrology addressed in Section III.

  The intermediate frequency (IF) bandwidth in Vector Network Analyzer (VNA) setup is set to 10 kHz for good measurement quality. The frequency range is 10 MHz to 40 GHz and the number of sampling points is 4000 with the linear frequency sweep.

- Prerequisite: Raw Cable Treatment

  The below procedure of raw cable treatment is the prerequisite of the testing.

  Step. a: Cut off raw cable length to 80 inch.

  Step. b: Remove the shielding tape of the raw cable on the front side around 3 mm in Fig. 4.

  Step. c: Remove the insulation of the single pair on the front side around 2 mm in Fig. 4.

  Step. d: Bend the ground wire under the single pair.

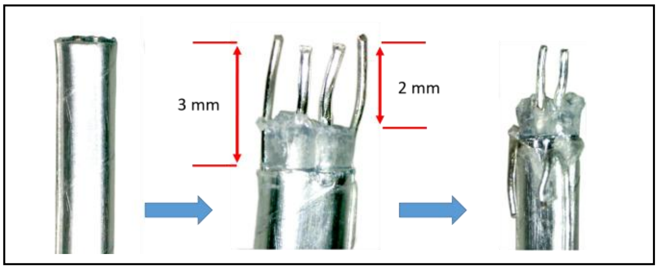


Fig. 4. Raw cable treatment

After the cable treatment, the raw cable is put into the test fixture and the ground wire is connected to the fixture ground in Fig. 5.

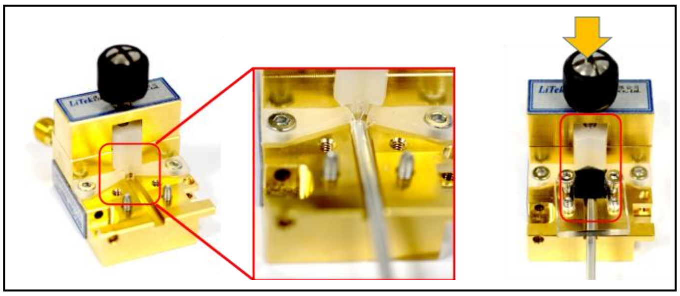


Fig. 5. Assembly raw cable to test fixture

- Testing Flow of Raw Cable Electrical Characterization

  Step. 1: Measurement of 80 inch raw cable

  The raw cable of 80 inch in the fixture is measured by VNA.

  Step. 2: 40 inch cable treatment from 80 inch

  One side of raw cable is still connected to the fixture and the other side is disconnected from the test fixture. Afterward, the cable length is cut from 80 inch to 40 inch. The raw cable treatment will be conducted and the sample will be connected to the test fixture.

  Step. 3: Measurement of 40 inch raw cable

  The raw cable of 40 inch in the fixture is measured by VNA.

  Step. 4: 20 inch cable treatment from 40 inch

  The same process will repeat as the Step 2 to cut the cable length from 40 inch to 20 inch.

  Step. 5: Measurement of 20 inch raw cable

  The raw cable of 20 inch in the fixture is measured by VNA.

Fig.6 shows the measurement setup of the raw cable with text fixture. This procedure can mitigate uncertainty by only one side specific cable treatment and different cable length with 80, 40 and 20 inch in one sample can be measured for upcoming de-embedding post-process.

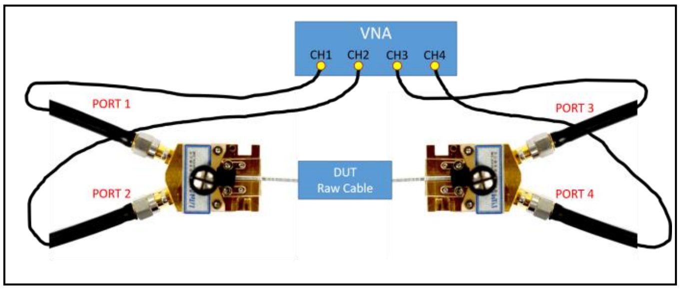


Fig. 6. Measurement setup

III. Delta-L De-embedding Metrology

Delta-L uses two different structures for the cable with the text fixture shown in Fig. 7. The reference is the short routing "B" with the length of X1 inch and the other is the longer routing "A" with the length of X2 inch. The result of structure A de-embedded by B through eigenvalue algorithm inside Delta-L is the loss of cable length (X1-X2) with the test fixture effect being de-embedded. The unit length loss can be calculated (1). Rather than reporting the raw value produced by the de-embedding algorithm, it is good to report a value that has maximal likelihood of corresponding to the real behavior of the cable. The true insertion loss profile is more likely to be typical than atypical. Typical insertion loss curves are smooth, so the reported value should correspond to a smooth insertion loss curve. Hence, the post-processing protocol with the physical fitting of advanced root omega [5] is applied to make the reported insertion loss numbers more error-resistant.

$$dB\ /\ unit\ loss = \text{IL (A de-embedded by B] / (X1-X2)} \qquad (1)$$

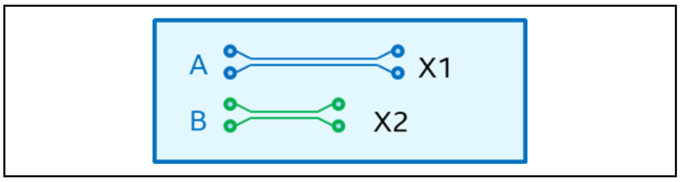


Fig. 7. Delta-L structure

IV. Result

A. Test Fixture Effect

In this section, the raw cable test fixture effect will be discussed by two de-embedding approaches. The reference plane are the coaxial connector to include the test fixture effect and the test fixture connection to the raw cable, respectively. Fig.8 shows the insertion loss result of 80 inch, 40 inch and 20 inch with and without the test fixture effect. The solid and dotted lines are the insertion loss profiles of the raw cable with and without the test fixture effect, respectively. Obviously, the insertion loss of the solid lines result with the test fixture effect is higher than the results without the test fixture effect.

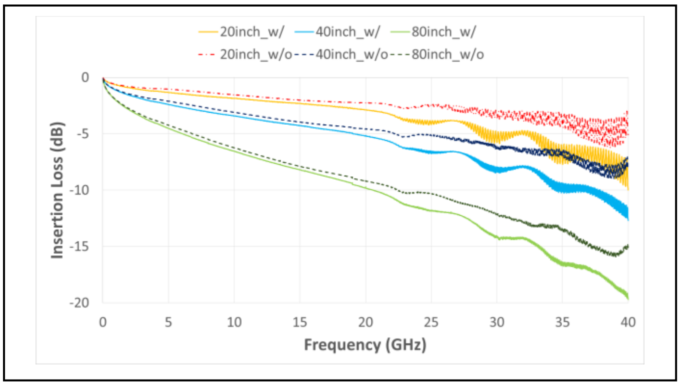


Fig. 8. Raw data with and without test fixture effect

De-embedding is very important in the accurate cable loss characterization. The frequency response of 40 inch raw cable by de-embedded the test fixture with the label of "Raw_40inch" in Fig. 9 is consistent with Delta-L eigenvalue result of 80 inch cable de-embedded by 40 inch with the label of "Raw_Delta-L_80-40" up to 30 GHz. Besides the eigenvalue de-embedding metrology insides Delta-L, it is obvious to see that the post-process by physical fitting can help make the reported insertion loss numbers more error-resistant because of mitigating the ripple in the loss profile induced the multiple impedance mismatch.

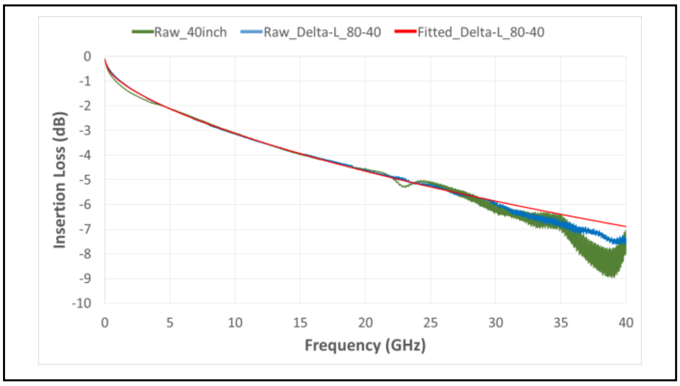


Fig. 9. 40 inch raw data comparion with 80 inch de-embeed by 40 inch through Delta-L

B. 2X-Thru v.s Delta-L

2X-Thru de-embedding is widely used in the cable characterization. In order to validate Delta-L accuracy, cross-check of results show that the de-embedding results, including Delta-L and 2X-Thru, are consistent and accurate in Fig. 10.

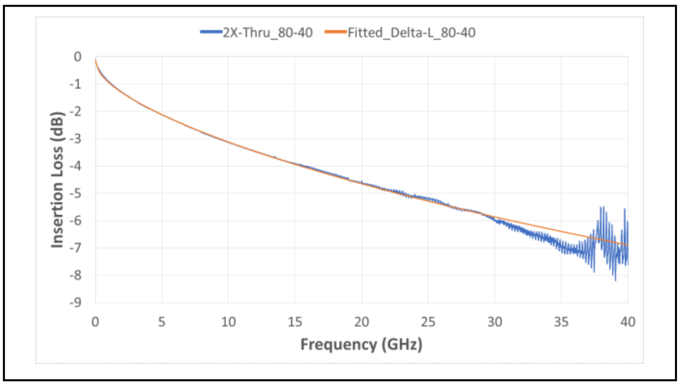


Fig. 10. De-embedding comparison between Delta-L and 2X-Thru

C. Different Cable Length De-embedding by Delta-L

Different cable length of 80 inch, 40 inch and 20 inch are measured and it can produce a variety of de-embedding combinations, such as 80 inch de-embedded by 40 inch, 40 inch de-embedded by 20 inch, 80 inch de-embedded by 20 inch. Theoretically, a good and reliable metrology can get the same unit loss in different length de-embedding configurations. The label of "40-20_w/" and "40-20_w/o" in Fig. 11 are the results of 40 inch with and without fixture effect de-embedded by 20 inch, respectively. Delta-L result in dB per inch without de-embedding the text fixture are very close to these with de-embedding. It implies that the test fixture effect by using Delta-L can be removed without moving reference plane from the end of coaxial cable to the test fixture. Meanwhile, cable loss in dB per inch of different effective cable lengths by Delta-L are very consistent to prove that the adopted metrology is good, robust and accurate.

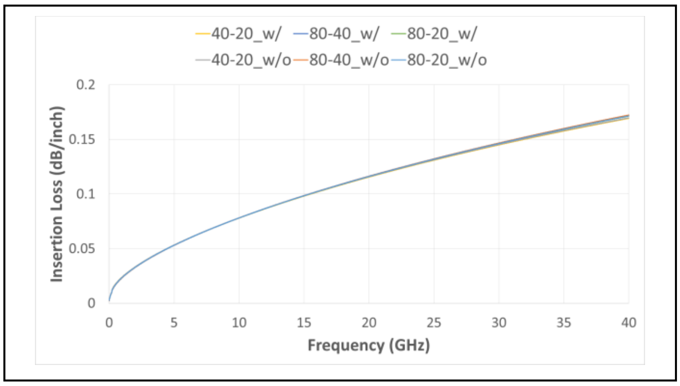
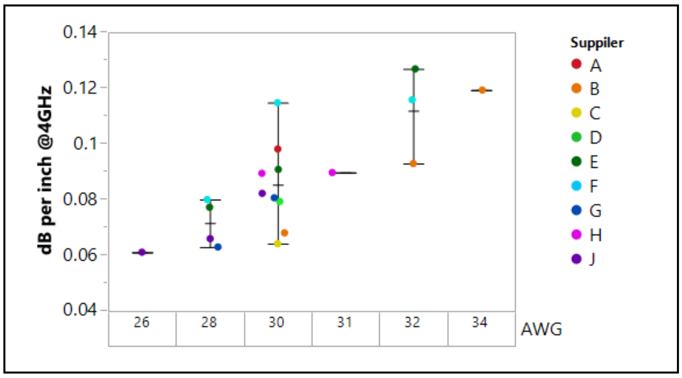


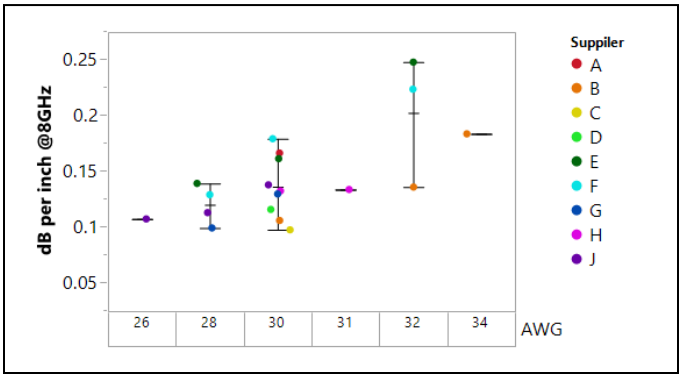
Fig. 11. Delta-L results for different effective cable lengths

D. *Electrical Library of Different Cable Wire Gauge by Different Suppliers*

The cross-sectional area of each gauge is an important factor for determining its electrical performance and increasing gauge numbers denote decreasing wire diameters. Total 20 raw cables from 9 vendors with 6 gauge types were collected and validated to establish this electrical library for the platform designers' use. For the same design, raw cable with larger gauge usually has more loss by the decreasing wire diameters in Fig. 12. It is very interesting to see that the loss of different suppliers with the same gauge of 30 are from around 0.06 dB/inch to 0.118 dB/inch at 4 GHz and these difference are from insulation material, grounding, the manufacture process and etc. Users can easily use this approach and library to select the corresponding raw cable to meet the channel design requirement.



(a) 4 GHz



(b) 8 GHz

Fig. 12. dB per inch of insertion loss at 4 GHz and 8 GHz

V. SUMMARY

The raw cable metrology was proposed for accurate, robust and efficient electrical characterization. The testing procedure of raw cable validation was clearly addressed in this paper and Delta-L de-embedding methodology is adopted for the accurate insertion loss analysis with physical fitting approach up to 30 GHz. The unit cable loss in dB per inch of different effective cable length configurations by Delta-L are very consistent to show robustness and accuracy of this proposed metrology. Cross-check of results show that the de-embedding results, including Delta-L and 2X-Thru, are consistent and accurate. The electrical library of different raw cable gauges from different suppliers was established to provide more design flexibility in the cable selection.

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