

Scattering Parameter Approach to Insertion Loss Prediction for 40GBASE-T Systems over Structured Cabling

Olusegun Ogundapo, Alistair Duffy, Charles Nche and John Gow

Abstract-This paper applies the scattering parameters to predict the insertion loss of cascaded cables and channels for the ongoing 40GBASE-T standardization. The 40GBASE-T is a standard for 40 Gigabit/second Ethernet over copper twisted-pair undergoing development by the IEEE P802.3bq Task Force. The paper considered the draft specifications provided by the Telecommunication Industry Association (TIA) in support of the 40GBASE-T to provide insertion loss simulation that show comparison with the scattering parameter method. The research also provided a model for the connector and insertion loss deviation due to the channel using the scattering parameter. The simulation results show very good agreements with the draft category 8 cabling specifications and can be extended to observe other cable parameters in support of the 40GBASE-T system development.

Index Terms - Insertion loss, Twisted pair, Scattering parameter, 40GBASE-T, Category 8 cabling.

I. INTRODUCTION

The scattering parameter is a widely used tool for transmission line network behavior analysis and design. It also offers flexibility in design and can be used to analyze cascaded cables performance as in [1]. However, the 40GBASE-T system is proposed to consist of two connectors that have effects on the overall loss, coupled with the insertion loss deviation due to the channel. Therefore, there is the need to model and factor them into the channel insertion loss using the scattering parameter which presently does not have express provision for it. The 40GBASE-T is the next Ethernet standard for 40 Gigabits/second over copper twisted-pair cabling. The Telecommunication Industry Standard (TIA) is developing specifications for category 8 cabling systems suitable for 40GBASE-T. The International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) also has a similar project that aims to define two variants of cabling systems that will support 40GBASE-T.

The length of the channel for the proposed Ethernet

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standard has been reduced from 100m to 30m and is expected to support bandwidth of up to 2000MHz [3].

The BASE-T families of standards are regarded as one of the most successfully deployed Ethernet standards. They feature cost advantages and ease of deployment with autonegotiation. It also offers the use of the universal connector (RJ45) for seamless backward compatibility [4].

This paper therefore, provides the insertion loss predictions for different cascaded cables and channels using the scattering parameter for the proposed category 8 cabling in support of 40GBASE-T system.

II. BACKGROUND

This section deals with the theoretical knowledge needed for the research. It highlights the scattering parameters matrix approach, the draft category 8 cabling specifications, the cabling parameters to be used for the insertion loss analysis.

A. The Scattering Parameters

The S-parameters can be expressed in terms of transmission line wave propagation characteristics as presented in [2].

$$[S] = \frac{1}{D_s} \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \quad (1)$$

$$[S] = \frac{1}{D_s} \begin{bmatrix} (Z_c^2 - Z_t^2) \cdot \sinh \gamma_k l & 2 \cdot Z_c \cdot Z_t \\ 2 \cdot Z_c \cdot Z_t & (Z_c^2 - Z_t^2) \cdot \sinh \gamma_k l \end{bmatrix} \quad (2)$$

Where, Z_c is the cable or patch cord impedance in ohms depending on which of them is been considered, Z_t is the characteristics impedance of the test equipment in ohms, γ_k is the propagation constant and l is the cable length in meters.

$$D_s = 2 \cdot Z_c \cdot Z_t \cdot \cosh \gamma_k l + (Z_c^2 + Z_t^2) \cdot \sinh \gamma_k l \quad (3)$$

The propagation constant (γ_k) is derived in [6] as :

The velocity of propagation (V_{pk}) and phase constant (β_k) are given in [6] as:

$$V_{pk} = \frac{100}{\left(494 + \frac{36}{f_k}\right) \cdot 10^{-9}} \quad (\text{m/sec}) \quad (4)$$

$$\beta_k = \frac{2\pi f_k \cdot 10^6}{V_{pk}} \quad (\text{Radian/m}) \quad (5)$$

The attenuation (A_{tk}) for 100 meter long cable is given as:

$$A_{tk} = \left(1.80 \cdot \sqrt{f_k} + 0.005 \cdot f_k + 0.25/f_k\right) \quad (\text{dB}) \quad (6)$$

Therefore, the attenuation constant per meter is:

$$\alpha_k = \left(\frac{0.01 \cdot A_{tk}}{20 \cdot \log(e)}\right) \quad (\text{Neper/m}) \quad (7)$$

Finally, the propagation constant can now be obtained from:

$$\gamma_k = \alpha_k + j\beta_k \quad (\text{Neper, radian}) \quad (8)$$

The mathematical relationship between the S-parameters and the T-parameters that can be used for converting S-parameters to T-parameters and vice versa are presented in [5] as:

$$S = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \quad (9)$$

$$S = \frac{1}{T_{22}} \begin{bmatrix} T_{12} & T_{11}T_{22} - T_{12}T_{21} \\ 1 & -T_{21} \end{bmatrix} \quad (10)$$

$$T = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \quad (11)$$

$$T = \frac{1}{S_{21}} \begin{bmatrix} S_{12}S_{21} - S_{11}S_{22} & S_{11} \\ -S_{22} & 1 \end{bmatrix} \quad (12)$$

$$\text{Insertion loss } (\alpha_L) = -20 \cdot \log_{10} |S_{21}| \text{ dB} \quad (13)$$

B. Channel Specification

The draft schematic representation of a backbone channel configuration for the proposed category 8 cabling is shown in Fig.1.

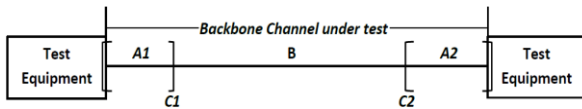


Fig. 1. Schematic diagram of a backbone channel test configuration

A1 and A2 are the equipment cords
C1 and C2 are the hardware connectors
B is the backbone cabling under test

The draft specifications to be considered for this research are presented in [7] as:

$$\text{Channel insertion loss} = 2 \times \text{connecting hardware IL} + \text{cable IL} + \text{ILD}_{\text{channel}} \quad (\text{dB}) \quad (14)$$

Where IL is the insertion loss, $\text{ILD}_{\text{channel}}$ is the insertion loss deviation due to the channel.

$$\text{Cable IL}(100\text{m}) = 1 \leq f(\text{MHz}) \leq 2000 = 1.8 \times \sqrt{f} + 0.005 \times f + (0.25/\sqrt{f}) \quad (\text{dB}) \quad (15)$$

Connecting Hardware:

$$1 \leq f(\text{MHz}) \leq 500 = 0.02 \times \sqrt{f} \quad (\text{dB}) \quad (16)$$

$$500 > f(\text{MHz}) \leq 2000 = 0.008 \times \sqrt{f} + 0.00029 \times f + 0.5 \times 10^{-6} \times f^2 \quad (\text{dB}) \quad (17)$$

$$\text{Patch cord cable(IL)} = 1.2 \times (\text{cable IL}) \quad (18)$$

$$\text{ILD(channel)} = 0.0324 \times \sqrt{f}(\text{MHz}) \quad (\text{dB}) \quad (19)$$

The insertion loss using the draft specifications for the 40BASE-T system is determined using equation (14).

III. METHODOLOGY

A. Application of the Scattering Parameter

The scattering parameter method for predicting the insertion loss of the channel shown in Fig.1 can be represented diagrammatically as shown in Fig. 2.

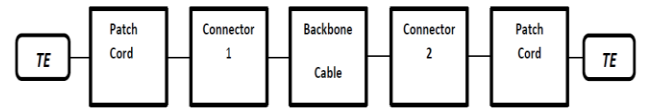


Fig. 2. Scattering Parameter Approach

The cable asymptotic impedance ($Z_{\text{cba}} = 104.5$ ohms, patch cord asymptotic impedance ($Z_{\text{cda}} = 95.5$ ohms and asymptotic impedance of the test system ($Z_t = 100$ ohms as presented in [6].

To obtain the complex characteristics impedance as a function of frequency, a heuristic impedance equation which has been proven extensively to describe very well the mean characteristics impedance values is stated in [1],[6] as:

$$Z_k = \left[1 + 0.055 \cdot \frac{(1-j)}{\sqrt{f_k}} \right] \quad (20)$$

Therefore, the characteristics impedance of the cable and the patch cords are given respectively as:

$$Z_{\text{cbak}} = Z_{\text{cba}} \times Z_k \quad (\Omega) \quad (21)$$

$$Z_{\text{cdak}} = Z_{\text{cda}} \times Z_k \quad (\Omega) \quad (22)$$

The S-parameters of the cable and patch cords can be individually determined using equation (2).

B. The Concatenation of Cables

This involves the concatenation of cables by converting their S-parameters into T-parameters and multiplying them sequentially as:

$$T = T_1 \times T_2 \times T_3 \times \dots \times T_n \quad (23)$$

The resultant T-parameters from equation (23) are then converted into S-parameters to obtain the insertion loss using equation (13). This method was applied to obtain the insertion loss for four different concatenations of cables: two 15m, three 8m, four 7m and five 6m cables. The cables were simulated at an asymptotic characteristics impedance of 104.5 ohms.

C. Connector and Insertion Loss Deviation Modeling

The connectors and insertion loss deviation were modeled by the attenuation constant that provided good agreement with the 40GBASE-T system. The attenuation constant was determined from the connecting hardware and insertion loss deviation for channel specifications with some modifications as:

$$1 \leq f(\text{MHz}) \leq 500 = (0.02 \times \sqrt{f} + 0.0162 \times \sqrt{f}) \times 0.1 \quad (\text{dB}) \quad (24)$$

$$500 > f(\text{MHz}) \leq 2000 = [0.008 \times \sqrt{f} + 0.00029 \times f + 0.5 \times 10^{-6} \times f^2 + 0.0162 \times \sqrt{f}] \times 0.11 \quad (\text{dB}) \quad (25)$$

Equations (21) and (22) can be simplified as:

$$1 \leq f(\text{MHz}) \leq 500 = 0.00362 \times \sqrt{f} \quad (\text{dB}) \quad (26)$$

$$500 > f(\text{MHz}) \leq 2000 = 2.662 \times 10^{-3} \times \sqrt{f} + 3.19 \times 10^{-5} \times f + 5.5 \times 10^{-8} \times f^2 \quad (\text{dB}) \quad (27)$$

The S-parameters of the each connector can now be determined using equation (2).

D. Concatenation of Channel Components

The concatenation of channel components involves converting the S-parameters obtained for the two patch cords, the backbone cable and the two connectors into T-parameters and then multiplying them sequentially as:

$$T = T_1 \times T_2 \times T_3 \times T_4 \times T_5 \quad (26)$$

The T-parameters obtained from equation (26) is then converted back to S-parameters. The S-parameters obtained from the conversion can be used to determine the insertion loss in decibels using equation (13).

The insertion loss is simulated in MATLAB and compared with the insertion loss generated from the proposed category 8 cabling specifications stated in section II. This method of concatenation was applied to determine the insertion loss of the following channels: 3m-24m-3m, 1m-3m-1m, 2m-10m-2m, 1m-24m-5m, 0.5m-3m-0.5m and 1m-26m-3m.

IV. RESULTS AND DISCUSSION

The research provided insertion loss predictions for four different cable concatenations of two 15m, three 8m, four 7m and five 6m cables as presented in Fig. 3 to 6. The results show good agreement with the 40GBASE-T specified insertion loss specification. Similarly, the insertion loss prediction plots for different channels are shown in Fig.7 to 12. The simulation provided insertion loss prediction of 35.3418 decibels as against 35.5618 decibels generated from the channel specifications for 3m-24m-3m configurations at 2000MHz. The simulation procedure can be extended to simulate and observe other cable parameters behavior.

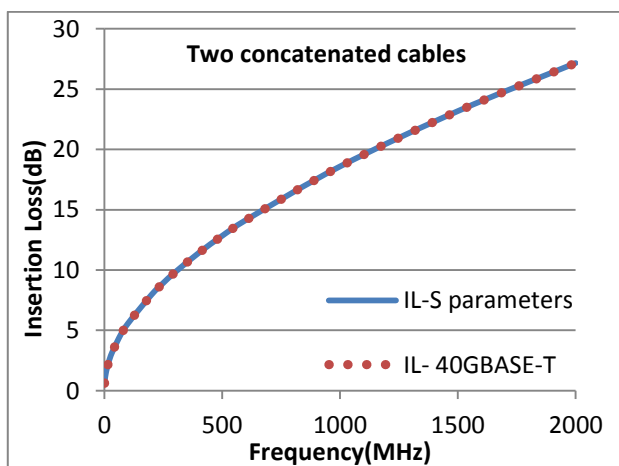


Fig. 3. Insertion loss for two 15m cables

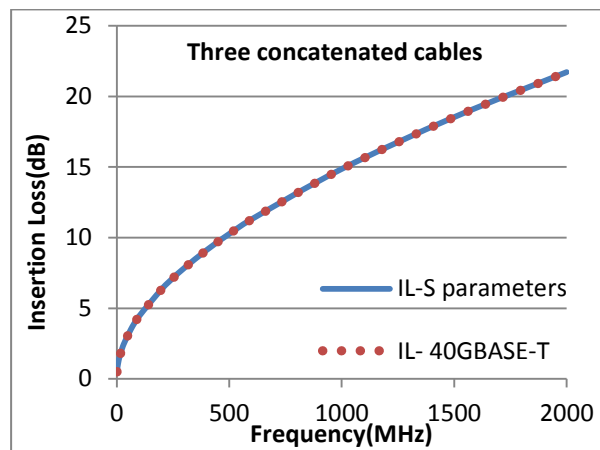


Fig. 4. Insertion loss for three 8m cables

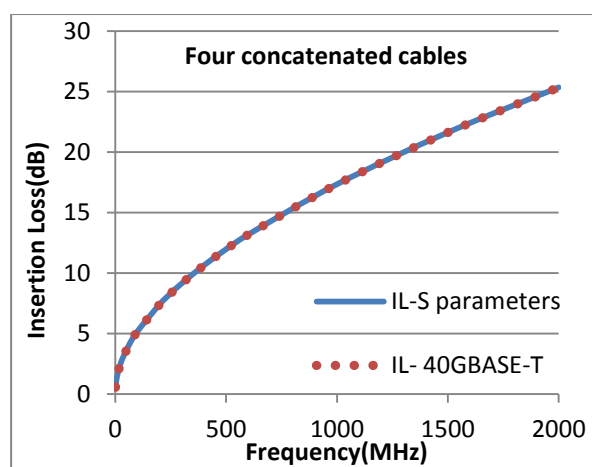


Fig. 5. Insertion loss for four 7m cables

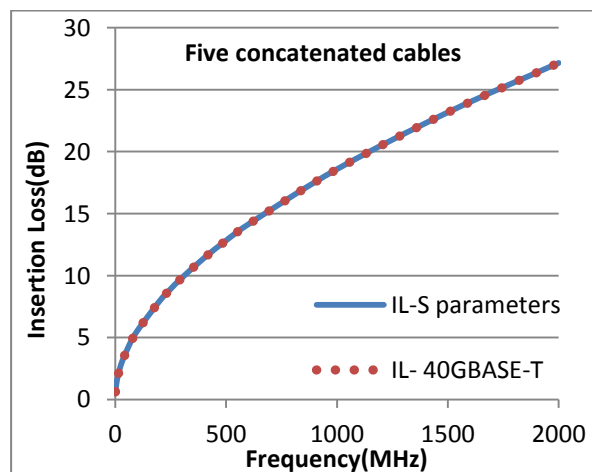


Fig. 6. Insertion loss for five 6m cables

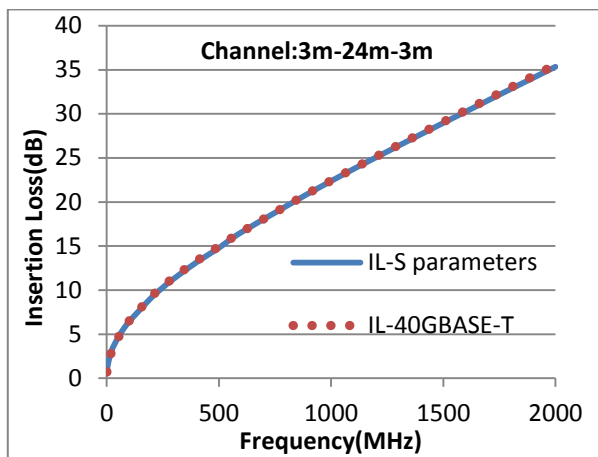


Fig. 7. Insertion Loss for 3m-24m-3m channel

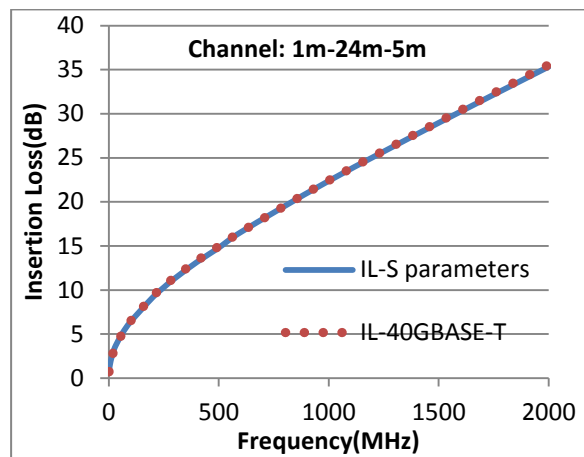


Fig. 10. Insertion loss for 1m-24m-5m channel

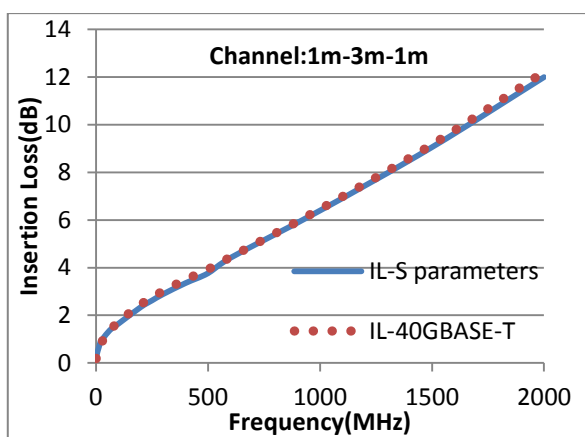


Fig. 8. Insertion loss for 1m-3m-1m channel

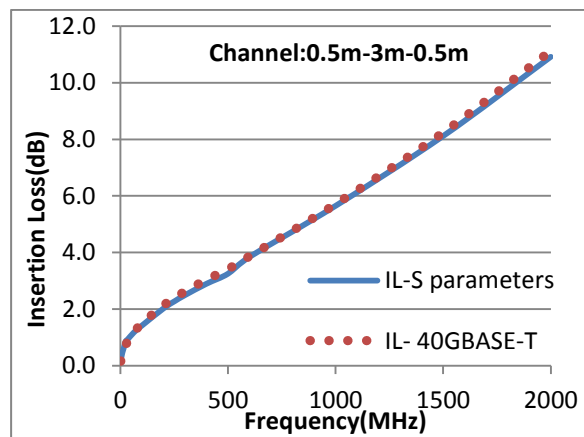


Fig. 11. Insertion loss for 0.5m-3m-0.5m channel

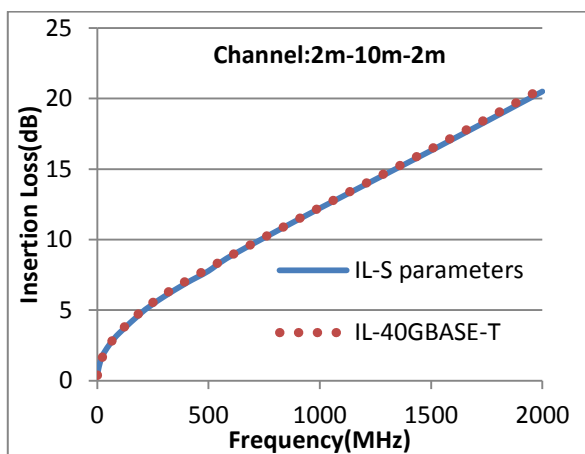


Fig. 9. Insertion loss for 2m-10m-2m channel

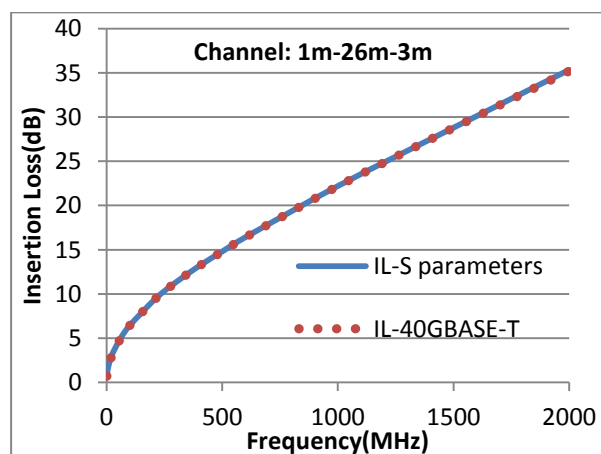


Fig. 12. Insertion loss for 1m-26m-3m channel

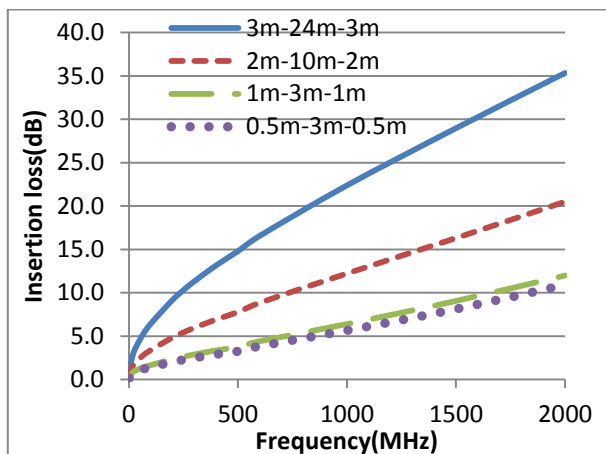


Fig. 13. Channel Insertion Loss Comparison

V. CONCLUSION

The paper has provided the scattering parameter approach to predict the insertion loss for the proposed category 8 cabling with two connectors in support of 40GBASE-T. The predictions by the scattering parameter show good agreement with all the channels considered. A comparison of the insertion loss for the channels indicates that the insertion loss increases with length and frequency.

The procedure can be extended to predict the insertion loss of other cable behavior necessary for the 40GBASE-T systems.

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