Measurements of Transverse Conversion Loss for Evaluating EM Immunity of Twisted-Pair Cable

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***Abstract*—This paper presents some research works on fast and accurate measurements of a key parameter, transverse conversion loss (TCL), for characterizing the balance of a twisted-pair cable. The TCL is an important indicator of electromagnetic noise immunity and emission characteristics of a twisted-pair copper cable. Performance of a field tester for industry applications has been evaluated with reference to a 4-port vector network analyzer (with fixtures) in laboratory. The relationship between the TCL and the balance of a twisted-pair cable has also been investigated.**

I. Introduction

Recently, differential signalling over a twisted-pair copper cable has become important and popular for electronic control and communications in the automotive/automation industry [1]. This mode of signalling transmits electrical information as the difference between the voltages on a pair of wires (normally equal and opposite voltages are applied on each wire of a pair). Greater electromagnetic noise immunity can be achieved comparing to the single-ended signalling.

It has been found that, balance of a twisted-pair cable is very important for minimizing electromagnetic interferences and emissions. An imbalance twisted-pair cable with different conductor diameter, spacing or length can introduce the mode conversion to the incident signal. Such a mode conversion occurring due to the asymmetries in a cable cross-section (so called "geometrical imbalance") has recently been investigated in [2] theoretically. When the electromagnetic interference (normally in the common-mode) applies on a differential twisted-pair, the imbalance of cable will convert the unwanted interference to differential noise [3]. Another consequence of an imbalance cable is that, part of the transmitted energy through an imbalance twisted-pair will be converted into electromagnetic radiation which can induce currents in the neighbouring pairs [4]. Both the effects can decrease the signal to noise/interference ratio in a copper cable and then degrade the whole system performance for electronic control and communications.

The specifications of a twisted-pair cable therefore needs to be certified for satisfying those industry applications, through determining some key parameters as recommended in [5]. An accurate and fast measurement solution, field tester, also called as cable certifier (e.g., WireXpert developed by Psiber Data [6]) is required by the industry to track those parameters.

As a continued work of [7-8], in this paper we will focus on fast and accurate measurements of one key parameter for evaluating the balance of a twisted-pair cable, transverse conversion loss (TCL) [5, 9]. Performance comparison of a field tester against a 4-port vector network analyzer (VNA) with fixtures [10] in laboratory is also reported.

II. Theoretical Background

A. Twisted-pair Cable

Twisted-pair cable is composed of two insulated copper wires twisted around each other (forming a pair as shown in Fig. 1) and bundled together with other 3 pairs in a jacket. Different from single-ended applications (i.e., unbalanced signal referenced to the ground, or preferred as common mode), the electromagnetic signal applied to a twisted-pair copper cable is in the differential mode (i.e., balanced), normally with equal and opposite voltages are applied on each wire of a pair as shown in Fig. 1.

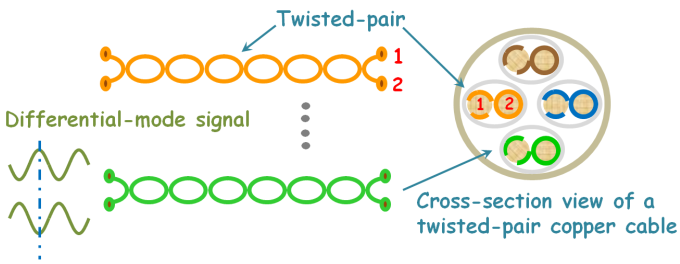


Fig. 1 Illustration of a twisted-pair copper cable with differential-mode signal applied.

B. Balance of a Twisted-pair Cable

As we introduced previously, balance of a twisted-pair copper cable is very significant for ensuring the unwanted electromagnetic interference (through mode conversion and coupling) to be minimized. The balance is directly related to the electromagnetic immunity and emission characteristics of the cabling.

As defined in [11], longitudinal conversion loss (LCL) and transverse conversion loss (TCL) are the two parameters for indicating the balance of a twisted-pair cable. They are the ratio of a voltage measured on a twisted-pair to a voltage applied to the same end of the pair. Due to the symmetry, LCL and TCL are reciprocal and therefore they have the same absolute values in dB.

In this following, we will focus on the TCL measurements which are obtained by applying a differential-mode signal to the twisted-pair and measuring the common-mode signal level at the same end. It is noted that high TCL value of a twisted-pair cable means that the cable has better electromagnetic noise immunity and lower emissions ability.

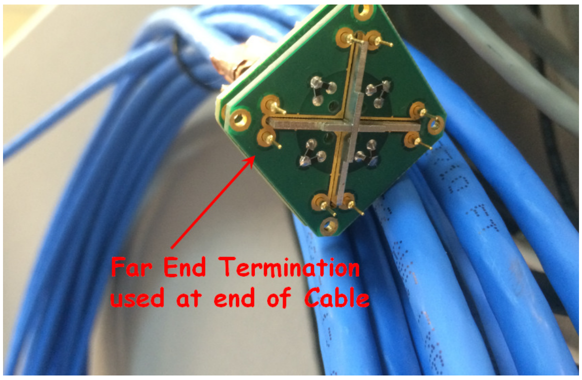
III. TCL Measurement Setups

In this paper, we mainly focus on the fast and accurate TCL measurements for evaluating the balance of a twisted-pair cable using a field tester, and its performance is compared with a 4-port VNA in laboratory. Each measurement setup is introduced below.

A. Setup with Field Tester

TCL measurements using a field tester are very simple as shown in Fig. 2. The cable is tested and measured with a device under test (DUT) adapter as shown in Fig. 2(a). The other end (far end) of the DUT cable is terminated as shown in Fig. 2(b). In order to remove the systematic errors from measurements, the field tester is calibrated at the DUT adapter interface using Open/Load/Short/Thru artefacts.

(a) Field tester measurements done with a DUT adapter



(b) Far end termination used at end of the DUT cable

Fig. 2 TCL measurement setup using a field tester.

B. Setup with VNA

A 4-port VNA has been used for performance comparison as in [8]. Its measurement setup for the balanced twisted-pair cable is configured with two TIA-1183 fixtures as shown in Fig. 3, with applying the method of mixed-mode S-parameters. It is noted that the VNA is calibrated at the TIA-1183 fixtures where both the near end and far end of the DUT cable are connected.

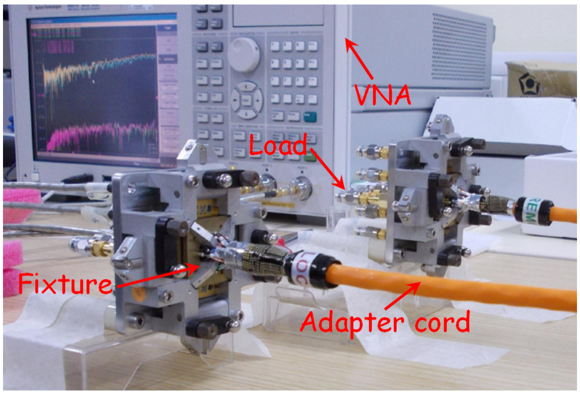
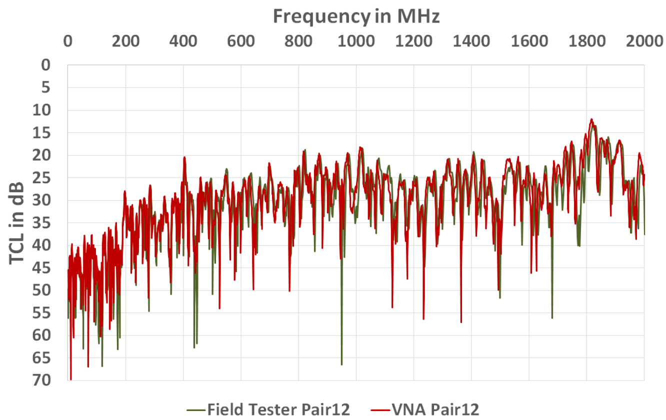
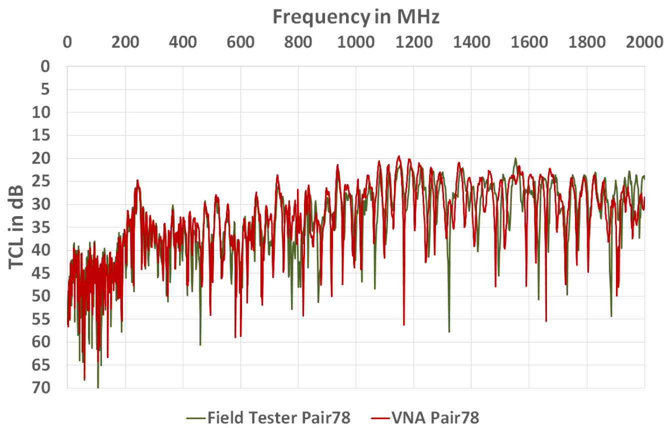


Fig. 3 Configuration of VNA measurements for balanced twisted-pair copper cable with TIA-1183 fixtures as reported in [8].



(a) Sample results measured at Pair12 of a twisted-pair cable



(b) Sample results measured at Pair78 of a twisted-pair cable

Fig. 4 Sample results measured at different pairs of a 30 m S/FTP cable.

IV. Results and Analysis

Performance evaluation of a field tester (i.e., WireXpert in this study) has been carried out with a reference to a 4-port VNA in laboratory using the setups shown in Fig. 2 and Fig. 3. The DUT cable used in the testing is a 30 m S/FTP cable. The S/FTP cable is a screened fully shielded twisted-pair network cable.

A. TCLs Measured for Different Pairs in a Copper Cable

A twisted-pair cable is composed of 4 bundled pairs in a jacket (Fig. 1), and each pair has its own TCL characteristic. Fig. 4 shows the sample results measured at Pair12 and Pair78 of the DUT cable, using the field tester and VNA.

From the results shown in Fig. 4, it can be clearly observed that good correlation has been achieved up to 2 GHz using two different measurement instruments. The slight difference is mainly from the residual measurement errors of two different fixtures used in this study (i.e., DUT adapter and TIA-1183 fixtures). Similar results have been observed for Pair45 and Pair36 (the other two pairs) of the DUT cable.

That is, the accuracy of the field tester under measurements is very good comparing to the high performance VNA in laboratory. Its portability makes it very suitable for the copper cabling in the field.

TABLE I
COMBINATION OF THE WIRE RESISTANCE OF A TWISTED-PAIR

Combination	*Wire a*	*Wire b*	*Difference*
1	50 Ohm	50 Ohm	0 Ohm
2	49 Ohm	50 Ohm	1 Ohm
3	47.5 Ohm	50 Ohm	2.5 Ohm
4	47 Ohm	50 Ohm	3 Ohm

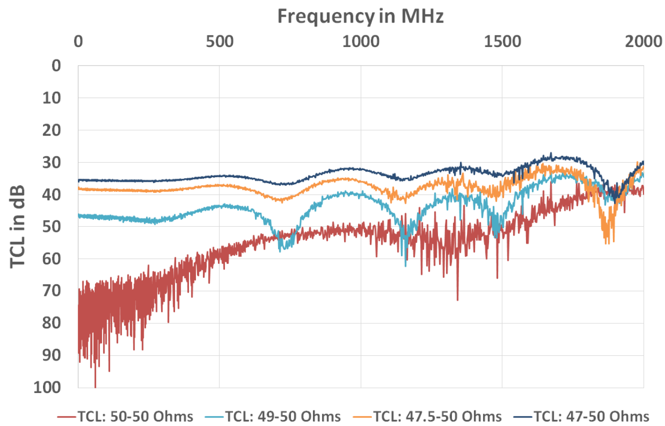


Fig. 5 TCL results measured for simulated different imbalance of a twisted-pair.

B. Imbalance Effects on the Measured TCLs

After the performance evaluation, TCL measurements are studied by varying the imbalance characteristic of a twisted-pair cable. The imbalance is simulated with different combination of wire resistance of a twisted-pair as summarized in Table I. The imbalance (so-called “termination imbalance” [12]) increases when the resistance difference between the wires increases.

The measured TCL values for each combination up to 2 GHz are shown in Fig. 5. From Fig. 5, it can be found that as the imbalance of a twisted-pair increases, generally the measured TCL value will decrease correspondingly. That is, a high TCL value of a twisted-pair cable means that the cable has a good balance, and therefore has a better electromagnetic noise immunity and lower emissions ability.

V. Conclusions

In this paper, we have reported some recent works on performance evaluation of a field tester, WireXpert, on TCL measurements.

Good correlation has been observed compared to the measurements using a 4-port VNA with fixtures up to 2 GHz. The TCL is an important characteristic of a twisted-pair cable for indicating its electromagnetic noise immunity and emissions ability.

Acknowledgment

This work was supported by the Technology for Enterprise Capability Upgrading (T-Up) Programme of Singapore, with Reference No: TI/CDS/E-AIP01/12/31.

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