Category 8 Cable Transmission Measurements Comparative Study between 4-port single wire measurements and 2-port balun measurements

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Abstract

Standards organizations are progressing in the development of test requirements and specification limits for Category 8 cabling components for frequencies up to 2 GHz.

Previous to Category 8 cabling specifications, the transmission measurement test procedures were based on 2-port Vector Network Analyzers (VNAs) and conventional balun (balanced-unbalanced) transformers. These baluns were used to interface the unbalanced ports of the VNA to the differential device under test. Conventional balun transformers use flux linkages to transmit the energy from the input circuit to the output circuit. Conventional baluns with a 1 MHz lower frequency tend to be limited at frequencies above 1 GHz.

In one method to overcome this balun limitation, 4-port VNAs are used to perform Category 8 testing to 2 GHz. On this 4-port technique, the VNA measures full 4-port, single-ended S-parameters by considering the device under test a 4-port device.

Test data acquired with the 4-port method will be compared against data acquired using a balun-based system capable of extending to at least 2 GHz the test frequency.

The scope of this paper is to:

- Compare and analyze Category 8 cable transmission data obtained from a 4-port VNA with data obtained from a 2-port VNA system with baluns. Advantages and disadvantages of the two testing methods will be reviewed.
- Show an implementation of IEC/TR 61156-1-5 (Return Loss correction procedures) on the Return Loss data obtained with the TLT baluns.

Keywords: Category 8, balun, VNA, TLT, Insertion Loss, Return Loss, Near End crosstalk, Far End Crosstalk, IFFT, LAN, Modal Decomposition. Mathematical Balun

1. Introduction

40GBase-T will transport data at a rate of 40 Gp/s over 4-pair Category 8 cabling. The test frequency for Category 8 cabling components is 2 GHz. This frequency is 4 times higher than the 500 MHz test frequency of Category 6A cabling components. Testing to 2 GHz brings challenges not encountered in testing at lower frequencies. Cable preparation, cable connecting fixtures to interface the system to the vector network analyzer, s-parameters calibration standards are some of these challenges.

Previous to Category 8 baluns were the main component used to interface the balanced twisted pairs to the unbalance output ports of the VNAs. Testing with baluns has been extensively described in the twisted pair testing documentation. With the test frequency increase to 2 GHz another approach for testing twisted pairs becomes very relevant. This other testing approach is based on the unbalanced data of the individual conductors measured with a 4-port VNA. Each end of the 2 conductors of the pair is connected to a VNA port. All other conductors of the 4-pair cable under test must be properly terminated.

In the following sections we will provide a detailed description of these two test methods. We will also test a 4-pair Category 8 cable using both methods and present the test results.

2. Balun measurements

Baluns are used to interface the unbalance ports of the VNA to the balanced twisted pairs. In addition to providing balance to unbalance interface baluns also provide impedance transformation. Therefore these baluns provide the interface between the VNA's 50 Ω unbalanced port to the 100 Ω impedance of the balanced twisted pair. There are two types of baluns: conventional winding based baluns and transmission line based transformer baluns or TLT. With conventional windings balun transformer is not possible to get the 1 MHz to 2 GHz bandwidth required to test Category 8 cables. Therefore TLT baluns are used to test Category 8 cables in the bandwidth required. The TLT used are made of coaxial transmission lines of known impedance configured to provide the 50 Ω to 100 Ω impedance matching. Fine-tuned and optimized TLT baluns operating to 2.2 GHz were used for the tests on this paper.

NDC technologies DCM cable testing products ES-2G automatic switch was used to automate the insertion loss, return loss, near end crosstalk and far end crosstalk testing of the Category 8 cables tested. The ES-2G switch was connected to a 2-port E 5071B VNA.

The ES-2G switch is specified from 1 MHz to 2.2 GHz. The noise floor level for crosstalk testing is better than 90 dB at 2.2 GHz. The ES-2G switch is capable of performing return loss measurement of up to 35 dB in the 1 MHz to 2.2 GHz frequency range.

Figures 1 and 2 show the balun measurement configurations. All pairs not under test are terminated in differential and common mode.

Traditional SOLT s-parameter calibration is used for the balun measurements at the cable connecting point.

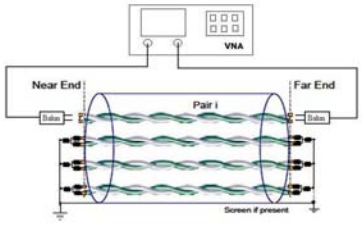

Figure 1 - IL Test Configuration –

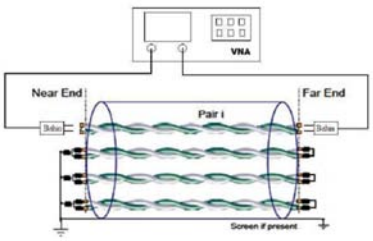

Figure 2 - RL Test Configuration –

3. 4-Pair Automatic Switch

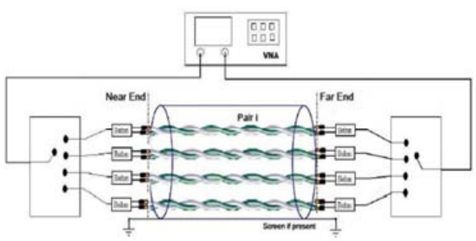

Figure 3 – 4 Pair Automatic Switch

On this test configuration each test position uses an independent balun. Each VNA port is switched to all pairs under test by means of multiple pole RF coaxial switches.

Each measurement path is calibrated using differential SOLT calibration at the cable connection point. A full 2-port calibration model in the error correction algorithm.

All differential calibration standards are verified to 2.2 GHz using an NIST traceable VNA.

Figure 4 – ES- 2G Automatic Switching System

4. Single Wire Test Configuration (4-port)

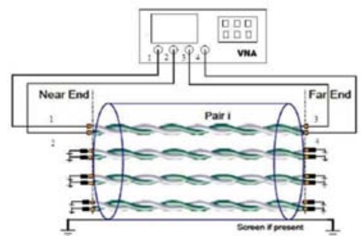

Figure 5 – Insertion Loss Test Configuration (TIA)

A 4-port network analyzer is required to perform the single wire testing. The connection between the network analyzed and the pair under test is done through two separate coaxial paths with a 50 Ohm impedance.

Each wire of the pairs not under test is terminated with 50 Ohm coaxial load. The network analyzer performs all the single wire measurements and all calculations required to provide the results in a differential format.

5. Cable Measurements

Measurement Set Up

In both cases the measurement set up was as follows: frequency range: 1 MHz to 2000 MHz

Number of points: 1601

IF Bandwidth: 300 Hz

Frequency sweep: Linear

Power Level: 10o dB

Cable temperature: 23° C

Cable Samples

U/FTP unjacketed Category 8.2 (30 meters)

F/UTP jacketed Category 8.1 (30 meters)

Cable Test Results

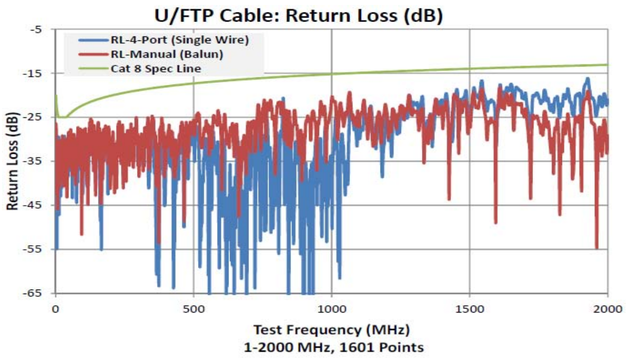

Figure 6 – Return Loss Balun vs Single Wire

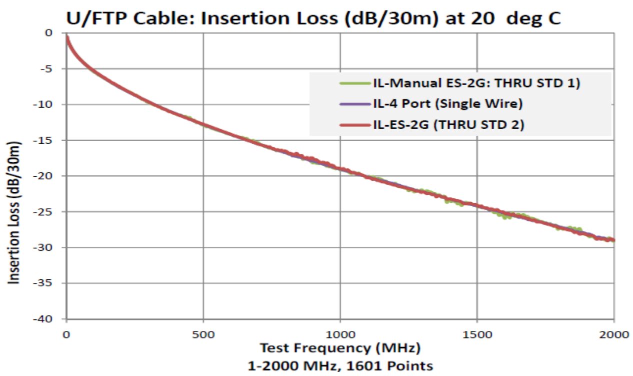

Figure 7 – Insertion Loss Balun vs Single Wire

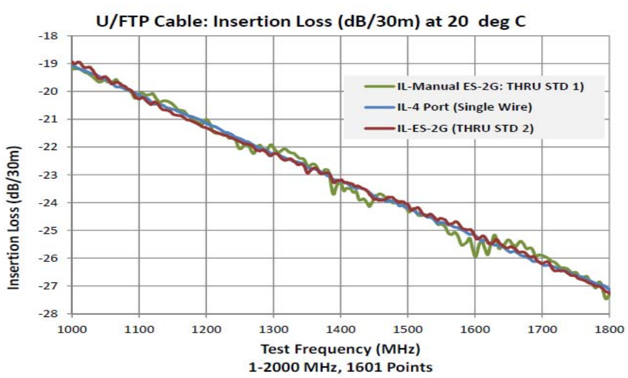

Figure 8 – Exploded IL view showing thru standard effect

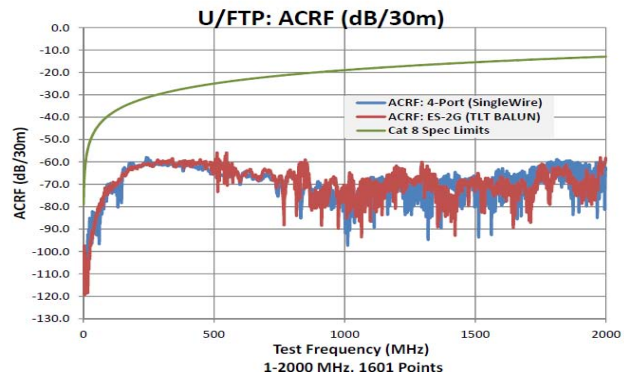

Figure 9 – ACR FEXT Balun vs Single Wire

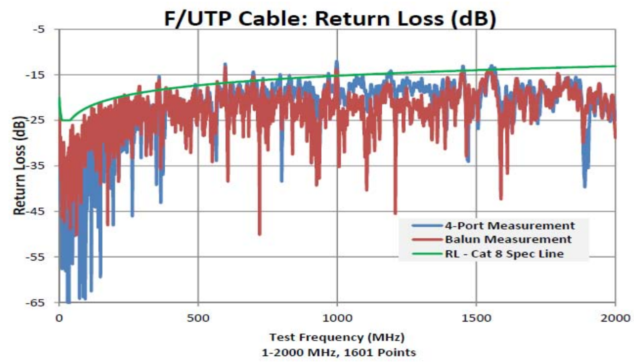

Figure 10 – Return Loss Balun vs Single Wire

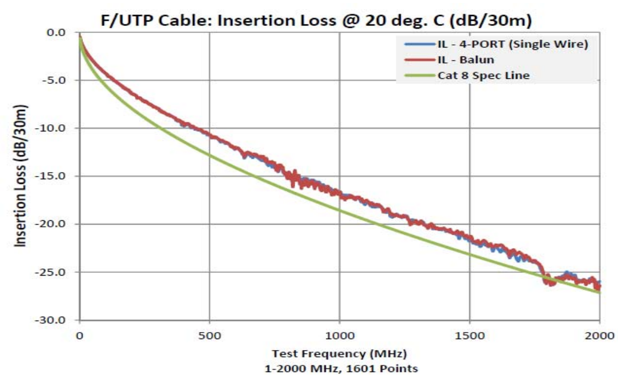

Figure 11 – Insertion Loss Balun vs Single Wire

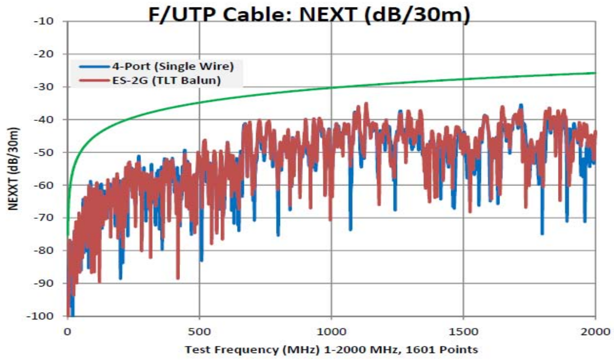

Figure 12 – Near End Crosstalk Balun vs Single Wire

6. Evaluation of Test Results

Sample preparation

Direct balun measurement:

- Followed typical laboratory LAN cables test techniques.
- Cable connection was performed using a printed circuit board (PCB) assembly attached directly to the TLT balun with SMB connectors.
- Impedance matched PCB traces connected the IC sockets to the SMB connectors.

Automatic balun measurements:

- Requires spreading of the pairs under test
- Connection of the pair under test is performed by using terminating cubes that connect directly to 50 Ohm contact path.
- Shielded cups are used to obtain high isolation between test positions

Single wire measurements:

- A 50 Ohm impedance controlled printed circuit assembly (PCA) with SMA connectors connects directly to the 4-port VNA.
- IC type sockets were used to connect the pair under test to the PCA.

S-parameter calibration

Direct balun and automatic balun measurements:

- Full 2-port differential SOLT were used.
- Different Thru cables were used to analyze the effect of the transmission calibration on the insertion loss measurements

Single wire measurements:

- A 4-port Ecal was used to perform the s-parameter calibration on the 4-port VNA.

Insertion Loss:

- Single wire insertion loss measurements and balun based insertion loss measurements show good correlation.
- Selection of the thru standard is critical to obtain a smoother and wave free insertion loss measurement.
- The effect of the return loss on insertion loss is more evident on shorter cables

Return Loss:

- The results are comparable in both methods**.**
- Cable preparation and handling is very important especially in automatic measurements.
- This effect is easily removed using DSP techniques

Crosstalk:

- Care must be taken in manual measurements to maintain proper isolation between pairs.
- Proper termination of unused pairs is critical for accurate results.
- Proximity to ground of the pairs under test affect the results especially at lower frequencies**.**

7. Category 8 Alien Crosstalk Test Set Up

Figure 13 - ES-2G AXT Head

An ES-2G modified test head with 4 isolated measurement positions and 24 terminated positions is used for connecting 7 cables for an six-around-1 alien crosstalk test. To simplify the connecting and disconnecting the pairs under test Wago plugs and receptacles are fitted on all 28 pairs. A utility program guides the user on the different pair connections to obtain the crosstalk results.

The test results populate an Excel spreadsheet as the measurements are taken. Once the spread sheet is filled all the power sum required are automatically calculated.

Alien crosstalk heads are interchangeable with ISTP and UTP heads.

(ANEXT and AFEXT Test results were not available at the time of this paper publication)

8. Removal of cable end preparation effects from reflection tests

It is well known that the length of jacket removed during LAN cable preparation for testing affects the impedance and return loss test results. As the frequency increases a tail up/down effect is seen on these reflection measurements

As the length of jacket removed shortens, the frequency at which the tailing up/down effect is seen increases. However, it will always be necessary to remove some of the cable jacket; therefore there will always be a tailing- up/down effect due to the length of jacket removed. This may be very confusing to the cable manufacturers since they may reject good cable or pass bad cable due to failures on the reflection test results.

The reproducibility of the reflection test results is also affected since the end of cable prepared by different individuals provides different reflection test results.

IEC Technical report IEC/TR 61156-1-5 describes a process to eliminate this jacket removal effects. The process is based in a conversion of the frequency domain results to time domain were digital signal processing (DSP) techniques are used to remove the jacket effect of the results. Once the effects are removed the data is converted back to the frequency results. The conversion of the data from frequency domain to time domain and back to frequency domain is performed using Inverse Fast Fourier Transformation (IFFT) and the conversion back to frequency domain is performed using Fast Fourier Transformation (FFT). Correction procedure for the measurement results of return loss and input impedance.

Test Results

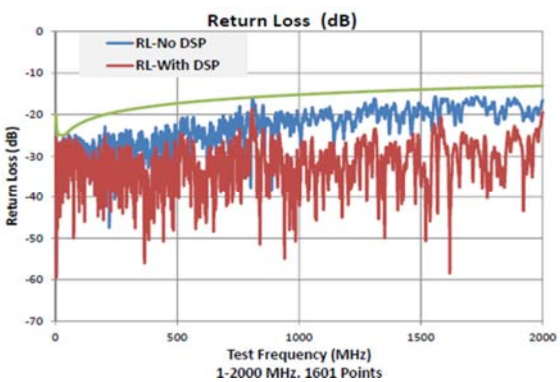

Figure 14 – Return Loss with DSP and without DSP

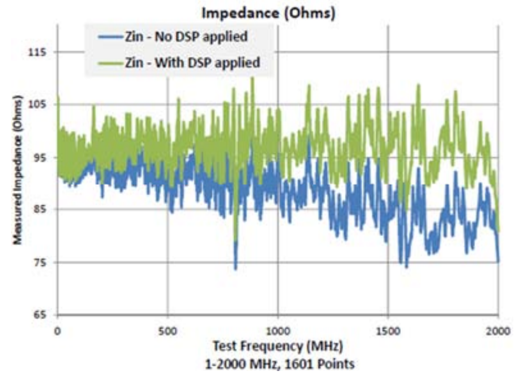

Figure 15 – Tail Down effect removal with DSP

8. Conclusions

It is well known that the 4 port technology allows the capability of testing balanced pairs without the frequency range limitations of baluns. However, baluns with TLT technology can offer bandwidths that are capable of covering the range of frequencies of the Category 8 proposals. As the standards for the Category 8 cables continue to progress towards ratification, there is also the need for further advances in the testing requirements and guidelines to meet the needs of those higher frequencies.

A significant technical requirement for accurate measurements is fixturing and calibration. And with the comparison testing completed for this paper, it was the calibration and fixturing that caused the some of the most visible effects and differences between the balun and 4 port measurements with this set of tests. E-cal type of calibration offers simplicity and accuracy, but is difficult to implement with a switched system and still requires additional procedures to remove effects of the test fixture. Some more complex E-cal type calibration techniques may require a higher level of network analyzer as well.

Short/Open/Load/Through calibration techniques also present challenges of their own. In particular, the calibrated load resistor must be both carefully chosen and characterized, and the quality of connection of the resistor to the fixture plays a measurable role in measurements such as Return Loss. And the through measurement, particularly at these higher frequencies requires care in choosing the design for the through device.

Anomalies inherent in test fixtures do affect the test results for all parameters, but most significantly with RL measurements. And it is the effects on RL measurements that are the most difficult to minimize. Another separate effect on RL measurements is the preparation of the cable itself. Whether shielded or unshielded pairs, the small length of exposed conductor at the test fixture does affect the impedance at the test terminals, with the effect tending to be more pronounced with unshielded pairs under an overall shield. The results in this paper demonstrate the ability to remove some or most of the fixture effects with software. The implementation of this DSP technique for the 4-port single wire measurements should be investigated further, and will likely play an important role in test standards as the frequency of testing expands.

9. References

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10. BIO

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- The laboratory space and technical assistance for performing the cable testing.