Application Note:

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‘Jitter Happens’ when a Twisted Pair is Unbalanced

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Deterministic Jitter (DJ) can be caused by Differential-to-Common-Mode conversion (or vice-versa) within a Twisted Pair (STP or UTP), usually a result of twist or dielectric imbalance

1 Purpose

Despite the title, this is NOT a paper about psychiatric pathology in couples.

This paper IS about test methods to differentiate good quality twisted pair cable, from bad, for data rates >500Mb/s. Measurement examples will show that severe intra-pair delay skew introduced by a twisted pair cable can be a problem that is NOT recoverable by either equalizers or compensating skew.

The good news is that specific cable properties, such as high common-mode loss, can help mitigate intra-pair skew despite other asymmetries.

2 Test Case: Digital Video

The DVI and HDMI digital video standards refer to data transmission over long STP (Shielded Twisted Pair) cables at serial rates up to 1.65Gb/s. Ultra-long cables (e.g., 50-100ft) suffer from the accumulative effects of both skin-effect high frequency losses, and intra-pair skew.

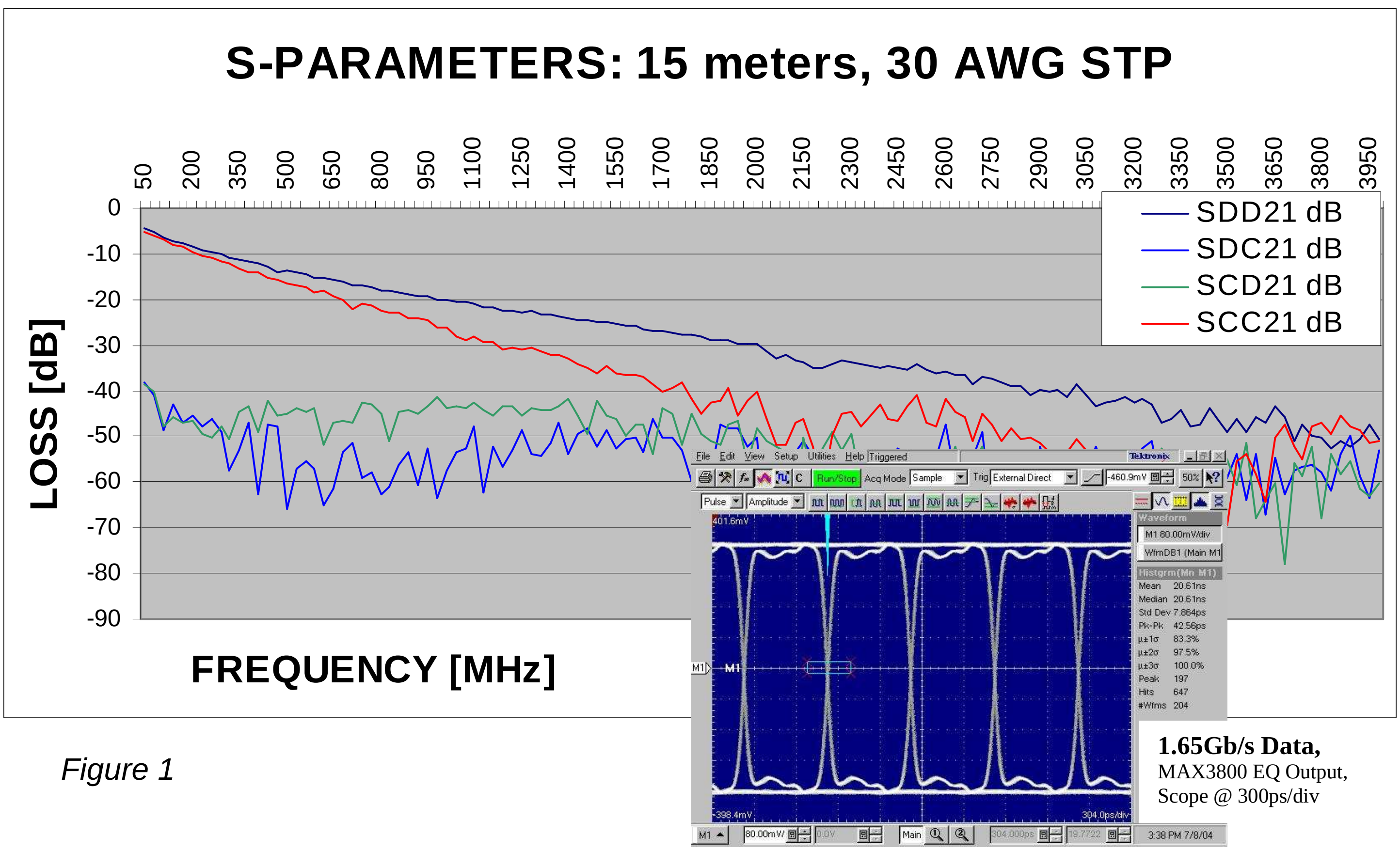


Figure 1

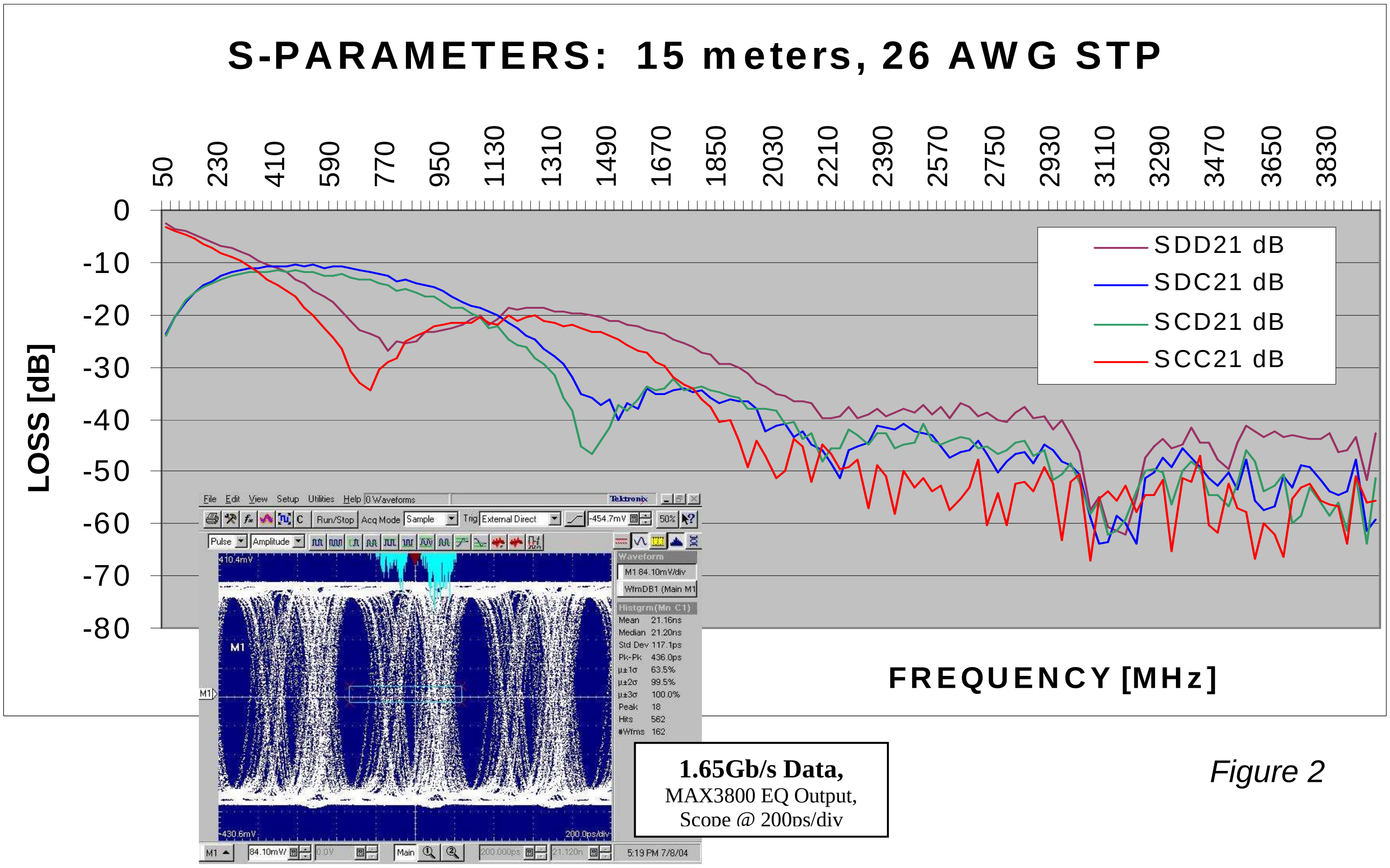


Figure 2

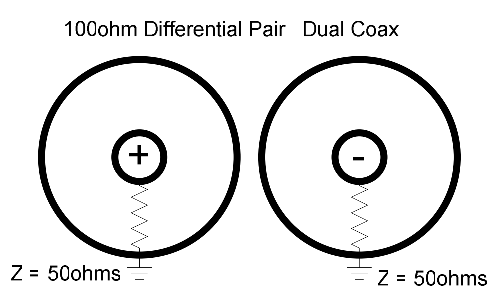
Figures 1 and 2 show 1.65Gb/s DVI signaling over 50 feet (15m) samples of economical STP cable, the first (Fig 1) having excellent performance, and the second (Fig 2) having poor performance. Figure 1 demonstrates textbook skin-effect loss (SDD21) with low differential-to-common-mode conversion (SDC21).

Note the scope photos in Figures 1 and 2 show the state-of-the-art MAX3800 Equalizer compensating 1.65Gb/s data for accumulative skin-effect losses: Superb results are seen in Figure1, but Figure2 clearly shows the deterministic jitter (DJ) remaining after EQ due to severe differential-to-common-mode conversion, a.k.a. intra-pair skew.

3 “Simple” Intra-Pair Skew

Given a differential swept-sine-wave stimulus over a differential cable, any amount of intra-pair skew within the cable pair will manifest as a conversion from differential-mode to common-mode, and vice versa. Since conversion to common-mode varies with frequency, for a given amount of intra-pair skew, the fidelity of digital differential signaling is compromised and may be unrecoverable.

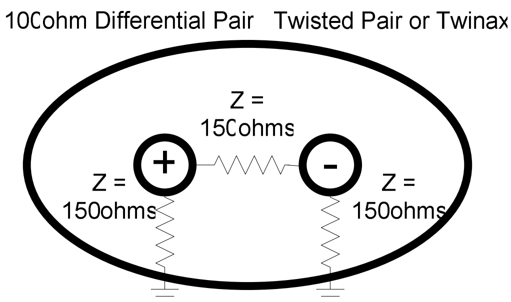
For a “simple” case to examine, consider twin coax (two separate parallel coax cables) carrying a differential signal between them, inherently having NO coupling between the signal pair. In this case, any intra-pair delay skew shows up as a “pure delay difference” at the output. Spectrally, nulls occur in the frequency response, with first differential-mode null at frequency = 1 / (2 * delaydifference). In other words, the first null occurs at a frequency where the difference in electrical delay between the two coax cables is one-half wavelength. At this same frequency there is a common-mode maximum (both signals in the pair are now in-phase).



Of course, this simple case of "pure delay difference" could be fixed by inserting a matching "pure delay" in the signal path of the shorter of the two cables. This may be easy in concept, but is not a solution for the general case.

4 Coupled Differential Pairs (STP, UTP, Twinax)

Now let's focus on the real world of coupled differential pairs, with or without shielding. These cables derive a portion of their characteristic differential impedance from coupling between the pair, in addition to coupling to ground (e.g., shield).



Any imbalance in the differential pair, such as asymmetry of length or twist or dielectric environment, results in some intra-pair skew.

Note, however, in coupled differential pairs, the intra-pair skew usually does not behave as simple skew, as was the case with the "ideal" predictable skew of dual coax in the previous section. Unlike the "ideal" dual coax case, coupled differential pairs suffer from dissimilar loss and velocities for the differential-mode and common-mode! For instance, in Figure 1, notice the different loss characteristics for the differential mode (SDD21) vs. the common-mode (SCC21). Since intra-pair skew progressively converts signal energy between these two modes, the end result is no longer an "ideal" delay difference, or skew, at cable end!

Of course, intra-pair skew can be minimized by attention to equal length and twist symmetry, plus balance in the dielectric and shield environment. This can be a difficult requirement for economical consumer-grade cables. For instance, a 100 ft (30m) DVI digital video cable, at 1.65Gb/s data rate, need only have a 1" asymmetry in electrical length to have a 0.25 unit interval (UI) error.

Fortunately, there are tactics in the construction of economical cable to mitigate inherent intra-pair skew. One approach is to increase common-mode loss, as compared to differential-mode loss (while maintaining EMI shielding performance). Note, in Figure 1, that the common-mode loss is somewhat greater than the differential-mode loss. Other low-cost cables have been observed with even higher common-mode loss and predictably excellent differential-mode behavior. The construction of the foil shield and dielectric are the root of this behavior.

5 Cable Measurements: Differentiating Good from Bad

Several methods have been used to measure intra-pair skew. A frequency domain method is suggested here, in preference to typical step-delay methods.

Determining intra-pair skew by measuring the difference between two single-ended step-delay measurements can be misleading. A single-ended step stimulus (stimulating only one side of differential pair at a time) launches both differential-mode and common-mode energy. Due to the different propagation velocities and loss between the modes, the resulting delay numbers do not apply to the case with a differential-mode-only source! Further, long cable performance cannot be predicted from these short cable measurements.

5.1 FREQUENCY DOMAIN METHOD: DVI Example

For the DVI application, the testing of a given "long" cable assembly can be made at 2 or 3 selected frequencies (e.g. ½-max-bit-rate: 800MHz sine, and ¼-max-bit-rate: 400MHz sine), sensing either the differential-to-common-mode (SCD21) or common-mode-to-differential (SDC21) conversions. Experience shows that measuring only at a few spot frequencies is permitted because "poor" SCD21 or SDC21 occurs over a broad frequency range (i.e, hard to miss). Either SCD21 or SDC21 response will give the same result and the choice can be made by equipment availability (See Table 1).

The objective is the SCD21, or equivalently the SDC21, should be at least 12dB below the primary differential-to-differential response (SDD21) at all frequencies up to bit-rate. You will note this to be true of the 30AWG cable (Fig 1), but violated miserably by the 26AWG cable (Fig 2). The SDD21 should not have to be measured as it is a known quantity (skin-effect loss) at these frequencies, for a given cable AWG.

6 Stay Tuned for More …

As MAXIM introduces more solutions for these cable challenges, this topic will be developed further in the form of articles and application notes.

Table 1

RECOMMENDED CABLE QUALIFICATION FOR LONG DVI CABLES:

1) **Measure common-mode-to-differential conversion of a DVI cable assembly:**
   a. *Apply Single-Ended sine-wave generator for frequencies 800MHz and 400MHz, and a 50ohm-Power-Splitter, so that the (+) and (-) of the differential STP cable can be driven together (in common-mode).*
   b. *View Differential Scope or Power Meter to measure cable conversion output at these two frequencies, where the (+) and (-) of the differential STP cable are sensed differentially.*
   c. *"PASS" a cable demonstrating it has output conversion measurement (SDC21) at least 12dB below the expected differential skin-effect loss (SDD21) at both 800MHz and 400MHz, respectively. (i.e., note Figure 1 passes easily, and Figure 2 fails)*

OR

2) **Measure differential-to-common-mode conversion of a DVI cable assembly:**
   a. *Apply Differential sine-wave generator for frequencies 800MHz and 400MHz, where the (+) and (-) of the differential STP cable are driven differentially.*
   b. *View Single-ended Scope or Power Meter to measure cable conversion output at these two frequencies, and a 50ohm-Power-Splitter, so that the (+) and (-) of the differential STP cable can be sensed for the common-mode signal.*
   c. *"PASS" a cable demonstrating it has output conversion measurement (SCD21) at least 12dB below the expected differential skin-effect loss (SDD21) at both 800MHz and 400MHz, respectively. (i.e., note Figure 1 passes easily, and Figure 2 fails)*