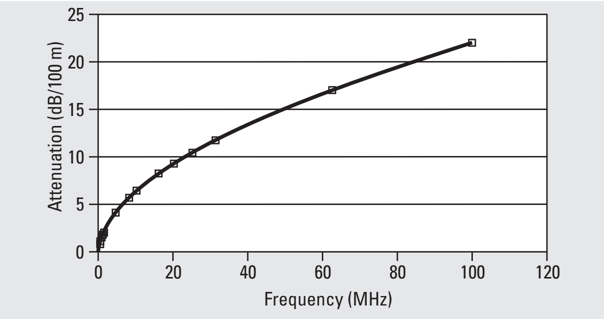
TIA/EIA-568A Category 5 cables in low-voltage differential signaling (LVDS)

By Elliott Cole, P.E.
Application Engineer, Data Transmission

This application note details the use of TIA/EIA-568A Category 5 (CAT5) cables in low-voltage differential signaling (LVDS) communication systems and includes results from tests on several CAT5 cables. These results are used to develop a "rule-of-thumb" equation for quickly estimating the distance and signaling rate that can be achieved with LVDS devices and CAT5 cables. When it comes to LVDS interfaces, designers want to send data very quickly. Unfortunately, at high data rates (>100 Mbps) the characteristics of the cable degrade the signal quality to a point where errors begin to occur. A tradeoff must be made between cable length and signaling rate. The commonly used "standard" for communications cables referred to in this note is the "Commercial Building Telecommunications Cabling Standard," or TIA/EIA-568A.

Figure 1. Permissible attenuation on a CAT5 cable



TIA/EIA-568A

TIA/EIA-568A defines the transmission requirements for commercial building telecommunication wiring. It classifies cabling into different categories based on attenuation and crosstalk losses over frequency. Twisted-pair cable is classified into different categories, abbreviated by "CATX." CAT3 is characterized up to 16 MHz, CAT4 to a maximum of 20 MHz and CAT5 for 100 MHz and above. A new revision of this standard is under development and will add categories to address the cable requirements of high-speed data communications. The higher performing cables of this shielded twisted pair (STP) specification will be called CAT7, while the unshielded twisted-pair (UTP) cables (with lower performance) will be classified as CAT6. So far, there is no "official" CAT designation, however, some manufacturers have announced availability of products capable of supporting signaling rates in the gigabit-per-second (Gbps) region. Manufacturers are using terms such as "Enhanced CAT5" or "CAT5+."

The standard does not specify a particular type of shielding, as long as the requirements given for a particular class of UTP cable are met. The following parameters are for CAT5 cable:

- The DC resistance of the cable should not exceed 9.38 ohm/100 m.
- The mutual capacitance is limited to a maximum of 5.6 nF/100 m.
- The capacitance with respect to ground must not exceed 330 pF over the frequency range of 1 kHz to the maximum specified frequency.
- The line impedance must be 100 ohms +15% for the bandwidth of 1 MHz up to the maximum frequency applied.
- The propagation delay time on the line should not exceed 5.7 ns/m (@10 MHz).

It is important to point out that the skew (created by the difference in lengths between two conductors of a pair) is not specified, even though it has a significant impact on signal quality at high signaling rates. The permissible attenuation is calculated with the formula in Equation 1.

$$\text{Attenuation}(f) = k_1\sqrt{f} + k_2 f + \frac{k_3}{\sqrt{f}} \tag{1}$$

where f is the applied frequency.

The constants that should be applied for CAT5 cables are listed in Table 1 and shown graphically in Figure 1 for CAT5 cables.

Table 1. Attenuation constants

	$k_1(\sqrt{s})$	$k_2(s)$	$k_3\left(\frac{1}{\sqrt{s}}\right)$
Category 5	1.967	0.023	0.050

Test setup

The LVDS evaluation module

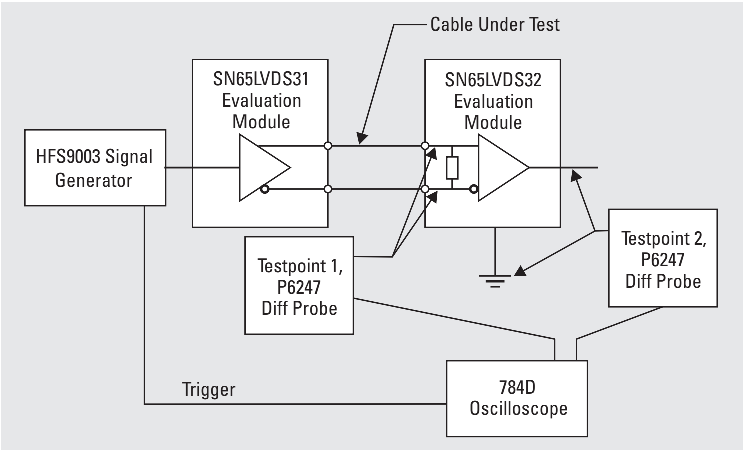
The TI SN65LVDS31/32 evaluation module (EVM) was used for these measurements. This EVM is CE-certified and available to the European community. Solder posts (terminals) were added to the EVM to facilitate changing cables and to make eye pattern measurements quickly.

Instrumentation

The input to the LVDS driver was generated by a Tektronix HFS9003 signal generator capable of generating pseudo-random binary sequence (PRBS) data patterns at up to 630 megabits per second (Mbps). The data pattern does not repeat the same sequence for $2^{16}–1$ bits or 64 kbits. The input levels to the LVDS31 driver were set to 0 V (low) and 2.7 V (high) and the transition rate (rise and fall times) set to 800 ps.

For this note a Tektronix 784D oscilloscope and Tektronix P6247 differential probes were used. Both the scope and probe have a bandwidth of 1 GHz and a capacitive load of less than 1 pF. For signals in the range of 400 Mbps and above, an even higher bandwidth is recommended. (As a rule of thumb, the fifth harmonic—i.e., 2 GHz—should be detected.) The basic test setup is shown in Figure 2.

Figure 2. Test setup



Measurements

Measurements were performed on seven CAT5 cables while varying the signaling rate and cable length. For each PRBS data measurement, non-return to zero (NRZ) formatted signals were used. The experiments were conducted in a laboratory standard environment at room temperature in an area where a considerable amount of electronic equipment was in operation. The PRBS patterns were applied and the eye pattern recorded at the end of the cable (i.e., the input of the receiver) and at the output of the receiver. Tests were carried out on each cable using eye patterns to measure the peak-to-peak jitter. System level jitter should be a function of both signaling rate and cable length. This was tested by using CAT5 cable lengths of 1 m to 20 m at signaling rates of 50 Mbps to 450 Mbps in 50-Mbps increments.

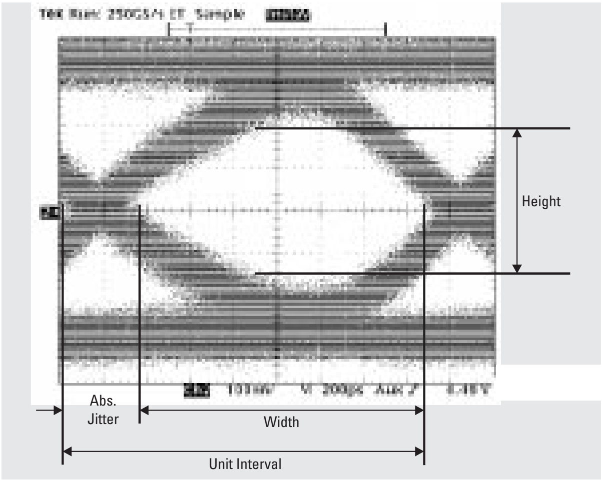
Jitter measurement

The eye pattern is a useful tool for measuring the overall signal quality at the end of a transmission line. It shows all of the effects of systemic and random distortion and shows the time during which the signal may be considered valid. A typical eye pattern is illustrated in Figure 3 with the significant attributes identified.

Several characteristics of the eye pattern indicate the signal quality of the transmission circuit. The height or "opening" of the eye above or below the receiver threshold level at the sampling instant is the noise margin of the system. The spread of the transitions across the receiver thresholds measures the peak-to-peak jitter of the data signal. The signal rise and fall times can be measured relative to the 0% and 100% levels provided by long series of low and high levels.

Jitter occurs in the time frame during which logic state transition of the signal occurs. The extreme values are caused by long sequences of one logic state preceding a transition. The jitter may be stated as an absolute number or as a percentage with reference to the unit interval. The unit interval (UI) or "bit length" equals the reciprocal value of the signaling rate. The width is the UI—i.e., the time during which the logic state "could" be valid. Percent jitter is commonly expressed as the jitter time divided by the UI (times 100) and represents the time during which the logic state should be considered invalid.

Figure 3. Typical eye pattern

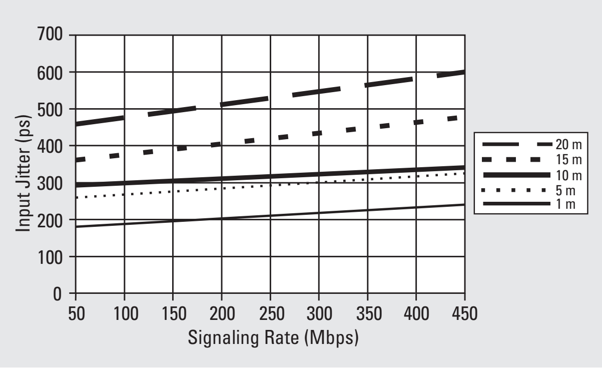


Results

As expected, system jitter is a function of both cable length and signaling rate. The first set of measurements taken determined the extent which these two parameters effected system level jitter. Jitter was recorded at the input and output of the LVDS32 receiver with different test cables. The jitter results for each cable type and length were averaged for each specific signaling rate.The average input jitter measurements are shown in Figure 4.

Continued on next page

Figure 4. Input jitter vs. signaling rate for CAT5 cables



Continued from previous page

Jitter did increase with cable length. Note that although each cable provided a linear jitter response over the entire range of signaling rates, the positive slope for each increase in length means that jitter effects are more pronounced at longer cable lengths. Also, note that the input jitter, even at shorter cable lengths, may have a significant impact on system performance.

For example, the input jitter measured on the 1-m cable at 400 Mbps was 225 ps, which already represents 5% jitter at 220 Mbps and does not include jitter added by the LVDS receiver.

The receiver also amplifies jitter in the system as can be seen in Figure 5. It shows two important factors: 1) jitter increases with cable length, and 2) additional jitter introduced by the receiver is a function of the signaling rate. In fact, it turns out to be about 1 ps per Mbps.

The “rule of thumb”

Based on the information contained in Figures 4 and 5, system (cable plus receiver) jitter can be estimated closely as a function of both cable length and signaling rate. Equation 2 has been developed from the data in Figure 4 and 5 to approximate the jitter out of an LVDS receiver given a specific length of CAT5 cable and signaling rate. Since it is an average, based upon several CAT5 cables, it is fair to assume that better cables will yield better results. Notice that it is based on cable lengths of 1 m to 20 m and signaling rates of 100 Mbps up to 400 Mbps. No assumptions should be made about performance of either the cable or LVDS receiver outside these bounds.

Figure 5. Jitter increases through a receiver

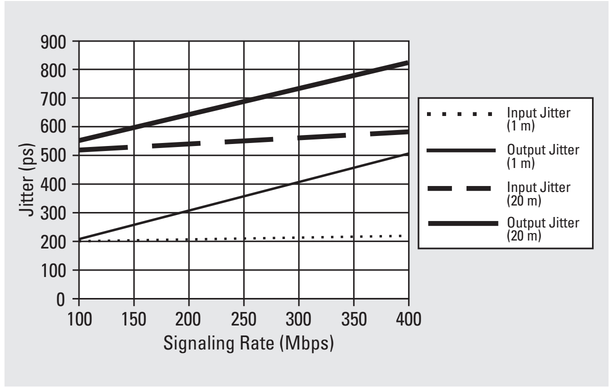
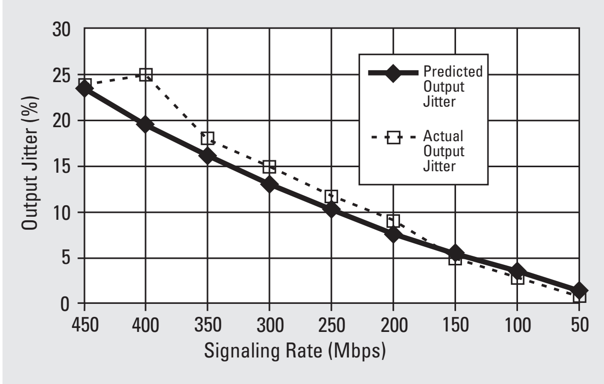


Figure 6. Actual vs. predicted jitter (5-m CAT5 cable)



Output jitter

$$= \frac{\left\{1+\left[\dfrac{0.0023\times S.R.}{1+\dfrac{(C.L.-1)}{7.63}}\right]\right\}\times\{[200+(15\times C.L.)]\times S.R.\}}{10{,}000} \qquad (2)$$

where $S.R.$ is the signaling rate in Mbps and $C.L.$ is the cable length in meters.

The “rule of thumb” was tested against one of the cables selected at random. The actual jitter performance versus the “rule of thumb” predicted jitter performance with a 5-m cable is shown in Figure 6.

Conclusion

As expected, the “rule-of-thumb” equation works better at the lower signaling/data rates. Less jitter was apparent from the cable and the LVDS receiver at low signaling rates where CAT5 cables are specified. It’s important to realize that all of the cables tested were developed before the LVDS standard was released. It’s fair to assume that none of these CAT5 cables were developed to support signaling/data rates of 400 Mbps.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products	
Amplifiers	**amplifier.ti.com**
Data Converters	**dataconverter.ti.com**
DSP	**dsp.ti.com**
Interface	**interface.ti.com**
Logic	**logic.ti.com**
Power Mgmt	**power.ti.com**
Microcontrollers	**microcontroller.ti.com**

Applications	
Audio	**www.ti.com/audio**
Automotive	**www.ti.com/automotive**
Broadband	**www.ti.com/broadband**
Digital control	**www.ti.com/digitalcontrol**
Military	**www.ti.com/military**
Optical Networking	**www.ti.com/opticalnetwork**
Security	**www.ti.com/security**
Telephony	**www.ti.com/telephony**
Video & Imaging	**www.ti.com/video**
Wireless	**www.ti.com/wireless**

TI Worldwide Technical Support

Internet

TI Semiconductor Product Information Center Home Page
support.ti.com

TI Semiconductor KnowledgeBase Home Page
support.ti.com/sc/knowledgebase

Product Information Centers

Americas

Phone	+1(972) 644-5580	Fax	+1(972) 927-6377
Internet/Email	support.ti.com/sc/pic/americas.htm		

Europe, Middle East, and Africa

Phone			
Belgium (English)	+32 (0) 27 45 54 32	Netherlands (English)	+31 (0) 546 87 95 45
Finland (English)	+358 (0) 9 25173948	Russia	+7 (0) 95 7850415
France	+33 (0) 1 30 70 11 64	Spain	+34 902 35 40 28
Germany	+49 (0) 8161 80 33 11	Sweden (English)	+46 (0) 8587 555 22
Israel (English)	1800 949 0107	United Kingdom	+44 (0) 1604 66 33 99
Italy	800 79 11 37		
Fax	+(49) (0) 8161 80 2045		
Internet	support.ti.com/sc/pic/euro.htm		

Japan

Fax			
International	+81-3-3344-5317	Domestic	0120-81-0036
Internet/Email			
International	support.ti.com/sc/pic/japan.htm		
Domestic	www.tij.co.jp/pic		

Asia

Phone			
International	+886-2-23786800		
Domestic	Toll-Free Number		Toll-Free Number
Australia	1-800-999-084	New Zealand	0800-446-934
China	800-820-8682	Philippines	1-800-765-7404
Hong Kong	800-96-5941	Singapore	800-886-1028
Indonesia	001-803-8861-1006	Taiwan	0800-006800
Korea	080-551-2804	Thailand	001-800-886-0010
Malaysia	1-800-80-3973		
Fax	886-2-2378-6808	Email	tiasia@ti.com
Internet	support.ti.com/sc/pic/asia.htm		ti-china@ti.com

C011905

Safe Harbor Statement: This publication may contain forward-looking statements that involve a number of risks and uncertainties. These "forward-looking statements" are intended to qualify for the safe harbor from liability established by the Private Securities Litigation Reform Act of 1995. These forward-looking statements generally can be identified by phrases such as TI or its management "believes," "expects," "anticipates," "foresees," "forecasts," "estimates" or other words or phrases of similar import. Similarly, such statements herein that describe the company's products, business strategy, outlook, objectives, plans, intentions or goals also are forward-looking statements. All such forward-looking statements are subject to certain risks and uncertainties that could cause actual results to differ materially from those in forward-looking statements. Please refer to TI's most recent Form 10-K for more information on the risks and uncertainties that could materially affect future results of operations. We disclaim any intention or obligation to update any forward-looking statements as a result of developments occurring after the date of this publication.

Trademarks: All trademarks are the property of their respective owners.

Mailing Address: Texas Instruments
Post Office Box 655303
Dallas, Texas 75265