Signaling Rate Versus Distance for Differential Buffers

Maxwell Robertson — *High Speed Interface*

ABSTRACT

This report is intended to give some estimate of the maximum transmission distances and data rates of the SN65LVDS100 and SN65LVCP4xx series devices. It provides a brief overview of the effect of transmission media on signal integrity and describes a means for measuring the maximum signaling rate for a given interconnect and total jitter requirement. The report then provides measurement results for both the SN65LVDS100 and the SN65LVCP418 transmitting over various lengths of CAT5e cable and PCB trace.

Contents

1 Introduction 2
2 Signal Degradation Over Various Interconnects 2
  2.1 SN65LVDS100 Over CAT5e Cable 3
  2.2 SN65LVDS100 Over PCB Trace 3
  2.3 SN65LVCP418 Over CAT5e Cable 4
  2.4 SN65LVCP418 Over PCB trace 5
3 Signaling Rate Versus Distance Measurements 6
  3.1 SN65LVDS100 Over CAT5e Cable 7
  3.2 SN65LVDS100 Over PCB Trace 8
  3.3 SN65LVCP418 Over CAT5e Cable 9
  3.4 SN65LVCP418 Over PCB Trace 10
4 Conclusion 10

List of Figures

1 Generic Test Setup – Single Buffer 2
2 SN65LVDS100 Output After 1-m (Left) and 20-m (Right) CAT5e Cables 3
3 SN65LVDS100 Output After 4-inch (Left) and 72-inch (Right) PCB Traces 3
4 SN65LVCP418 Output After 1-m (Left) and 20-m (Right) CAT5e Cables, No Pre-Emphasis 4
5 SN65LVCP418 Output After 1-m (Left) and 20-m (Right) CAT5e Cables, Pre-Emphasis Enabled 4
6 SN65LVCP418 Output After 4-inch (Left) and 72-inch (Right) PCB Traces, No Pre-Emphasis 5
7 SN65LVCP418 Output After 4-inch (Left) and 72-inch (Right) PCB Traces, Pre-Emphasis Enabled 5
8 Generic Test Setup – Two Buffers 6
9 SN65LVDS100/CAT5e Test Setup 7
10 SN65LVDS100/CAT5e Test Results 7
11 SN65LVDS100/PCB Trace Test Setup 8
12 SN65LVDS100/PCB Trace Test Results 8
13 SN65LVCP418/CAT5e Cable Test Setup 9
14 SN65LVCP418/CAT5e Cable Test Results 9
15 SN65LVCP418/PCB Trace Test Setup 10
16 SN65LVCP418/PCB Trace Test Results 10

1 Introduction

Some of the most common questions regarding high-speed signaling are, "How far can a signal with this data rate be transmitted?" or, conversely, "How fast of a data rate can be used with this transmission distance?" Although these questions are simple, they can be very difficult to answer. The answer depends greatly on the loss characteristics of the transmission medium. This application note is intended to provide a rough estimate of the maximum rate and distance possible for two devices: the SN65LVDS100 and the SN65LVCP418. For each device, two transmission media will be considered: CAT5e cable and printed circuit board (PCB) trace.

The SN65LVDS100 is a single-channel high-speed differential repeater capable of transmitting and receiving LVDS data at rates up to 2 Gbps. The SN65LVCP418 is an 8-channel signal conditioning buffer designed to accommodate differential signaling at a rate of 4.25 Gbps. It also incorporates receive equalization and transmit pre-emphasis to help mitigate the effects of lossy transmission lines. Measurements taken on the SN65LVCP418 will be roughly equivalent for other SN65LVCP4xx parts, such as the SN65LVCP402, SN65LVCP404, and SN65LVCP408.

Although these devices are specified for very high data rates, in applications their performance may be limited by the properties of the transmission medium. Transmission media such as CAT5e and PCB traces have a higher level of attenuation at higher frequencies and at longer lengths. This attenuation profile causes there to be more jitter at higher signaling rates due to inter-symbol interference and other factors. In general, the longer the cable or the higher the data rate, the more jitter is present. Therefore, for a particular allowable jitter threshold, the maximum achievable data rate decreases steadily with increasing transmission distance.

2 Signal Degradation Over Various Interconnects

As discussed above, every interconnect has a loss characteristic that will result in some amount of signal degradation. To give a qualitative sense of how much a signal changes with increasing cable or trace length, this section presents eye diagrams for a 1-Gbps differential PRBS pattern (length $2^7 - 1$) measured at the far end of an interconnect. The pattern was generated by a source, input to either the SN65LVDS100 or the SN65LVCP418, then transmitted to an analyzer over either CAT5e or PCB traces. Figure 1 illustrates the test setup used.

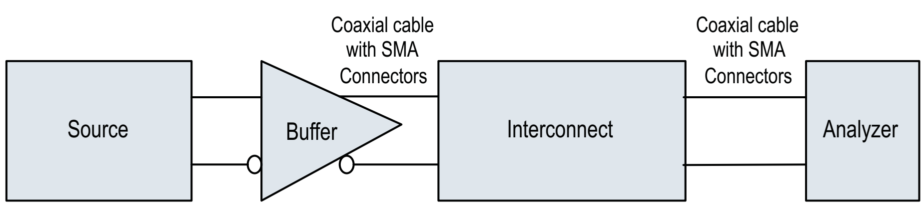

Figure 1. Generic Test Setup – Single Buffer

The interconnects used were 24 AWG unshielded twisted pair (UTP) CAT5e cables and PCB traces with 8 mil width and controlled differential impedance of 100 Ω. The traces were 1.2 mil thick and ground planes were located 8.4 mil above and below.

2.1 SN65LVDS100 Over CAT5e Cable

The following figures show the far-end eye of the SN65LVDS100 output transmitted over 1-m and 20-m CAT5e cables:

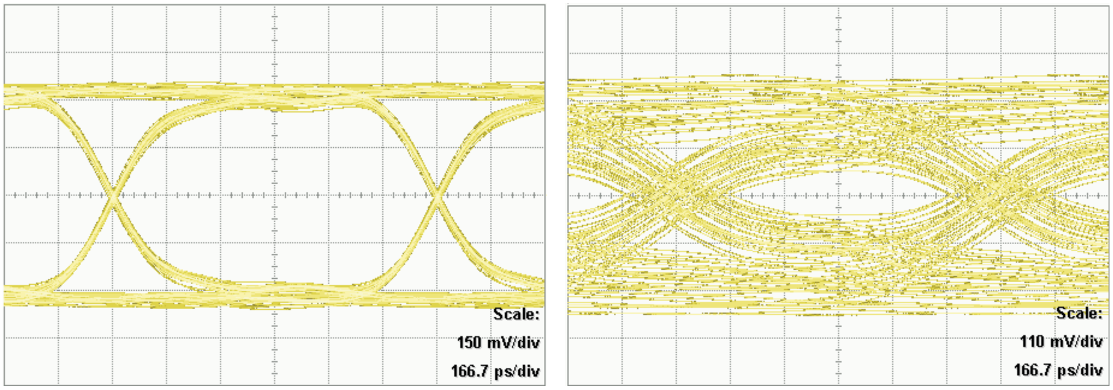

Figure 2. SN65LVDS100 Output After 1-m (Left) and 20-m (Right) CAT5e Cables

2.2 SN65LVDS100 Over PCB Trace

The following figures show the far-end eye of the SN65LVDS100 output transmitted over 4-inch and 72-inch PCB traces:

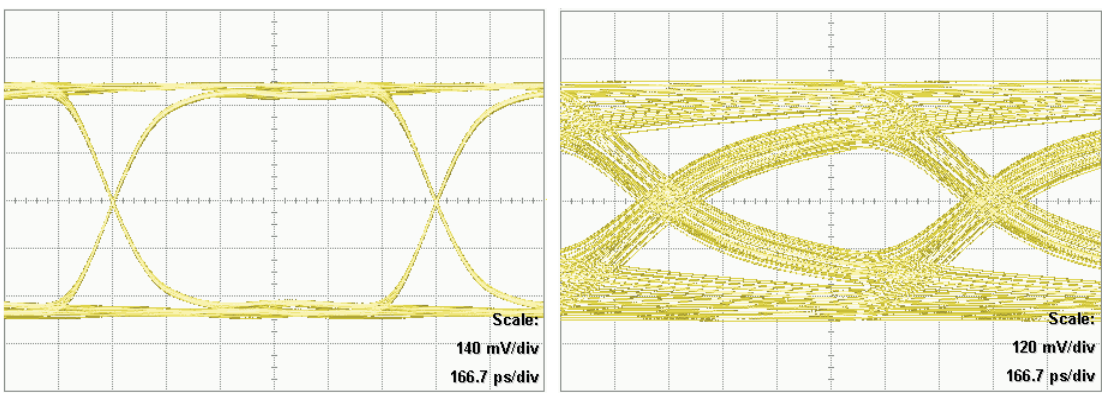

Figure 3. SN65LVDS100 Output After 4-inch (Left) and 72-inch (Right) PCB Traces

2.3 SN65LVCP418 Over CAT5e Cable

The following figures show the far-end eye of the SN65LVCP418 output transmitted over 1-m and 20-m CAT5e cables. Eye diagrams were taken with pre-emphasis levels of 0 dB (no pre-emphasis) and 6 dB.

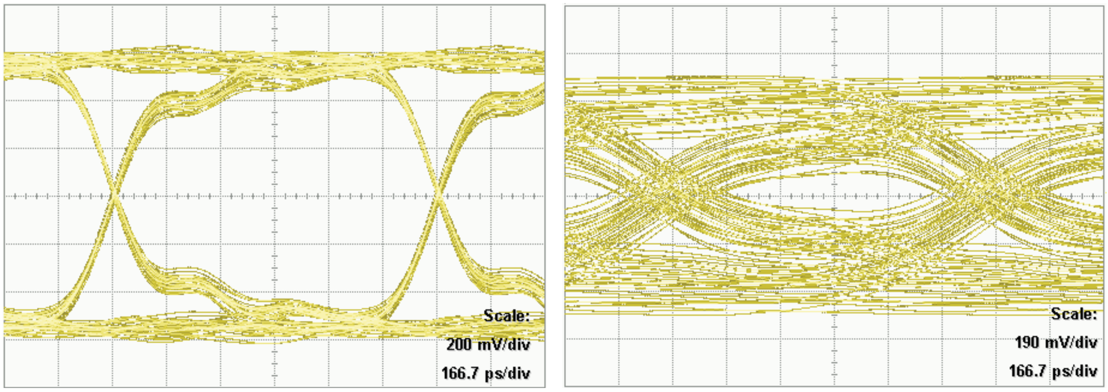

Figure 4. SN65LVCP418 Output After 1-m (Left) and 20-m (Right) CAT5e Cables, No Pre-Emphasis

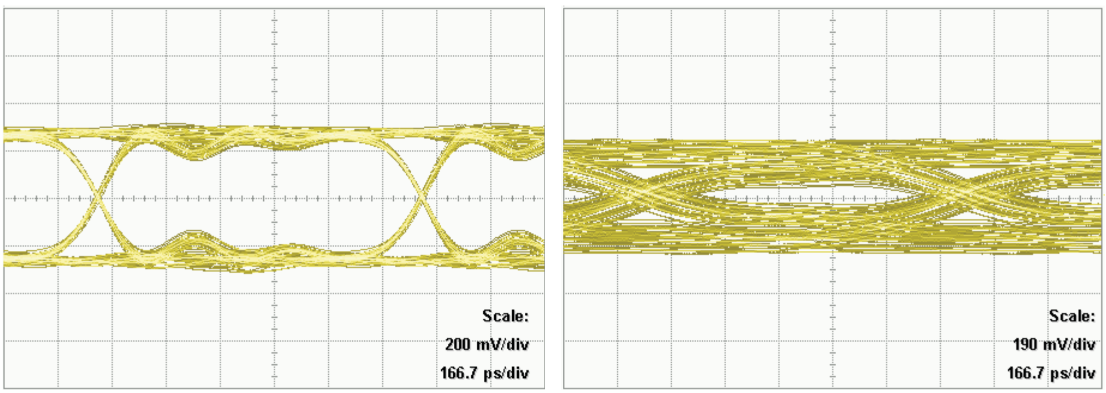

Figure 5. SN65LVCP418 Output After 1-m (Left) and 20-m (Right) CAT5e Cables, Pre-Emphasis Enabled

2.4 SN65LVCP418 Over PCB trace

The following figures show the far-end eye of the SN65LVCP418 output transmitted over 4-inch and 72-inch PCB traces. Again, eye diagrams were taken with pre-emphasis levels of 0 dB (no pre-emphasis) and 6 dB.

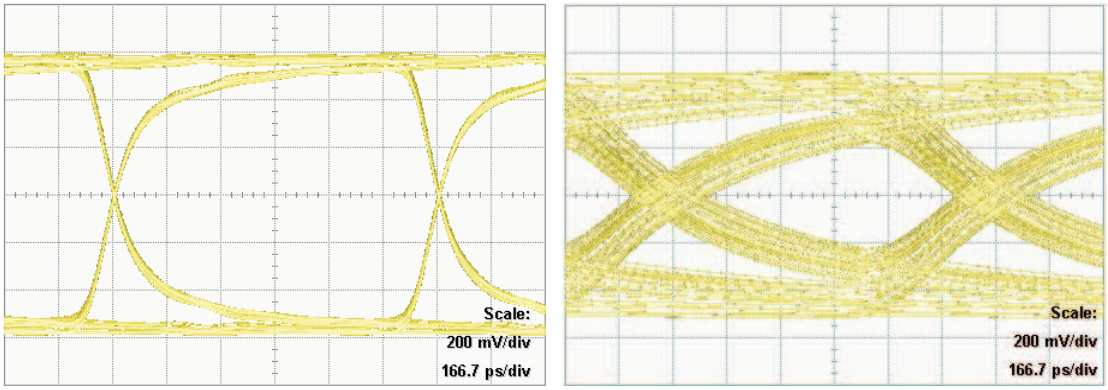

Figure 6. SN65LVCP418 Output After 4-inch (Left) and 72-inch (Right) PCB Traces, No Pre-Emphasis

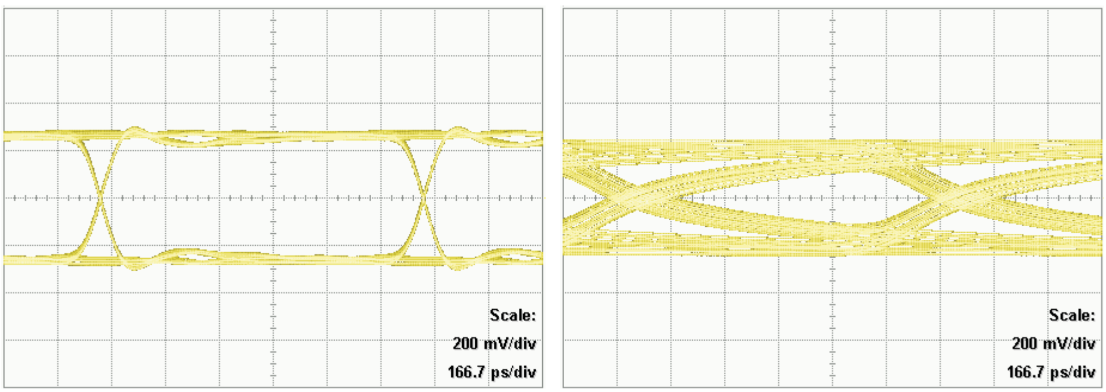

Figure 7. SN65LVCP418 Output After 4-inch (Left) and 72-inch (Right) PCB Traces, Pre-Emphasis Enabled

3 Signaling Rate Versus Distance Measurements

To determine the maximum signaling rate achievable for a particular interconnect, the following test setup was used:

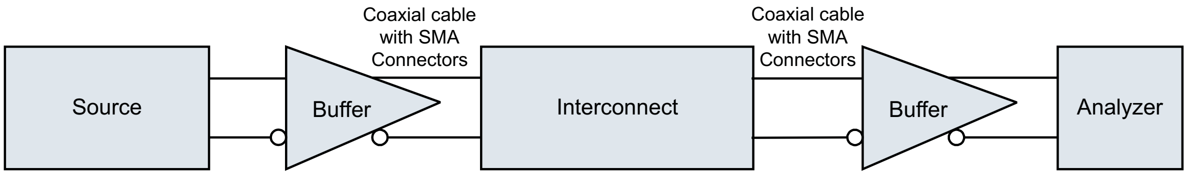

Figure 8. Generic Test Setup – Two Buffers

The source generated a differential PRBS pattern with length $2^7 - 1$. This was input to a buffer (either the SN65LVDS100 or SN65LVCP418), whose output was transmitted over various interconnects. At the far end, another buffer received the data and the amount of jitter was measured by an analyzer connected to the buffer’s output.

For each interconnect, three different maximum data rates were recorded. These correspond to the three jitter thresholds of 5%, 10%, and 20% of the unit interval (UI). In this application note, "jitter" refers to the total jitter of the signal, computed using a bit error rate of 10^{-12}. This jitter is the cumulative measurement of the deterministic and random jitter components of the entire system (source, analyzer, interconnect, and two buffers), not any one particular component.

The same interconnects described previously were used: 24 AWG unshielded twisted pair (UTP) CAT5e cables and 8-mil PCB traces with 100-Ω differential impedance.

3.1 SN65LVDS100 Over CAT5e Cable

Figure 9 illustrates the test setup used to measure the maximum data rate achievable by the SN65LVDS100 over various lengths of CAT5e cable.

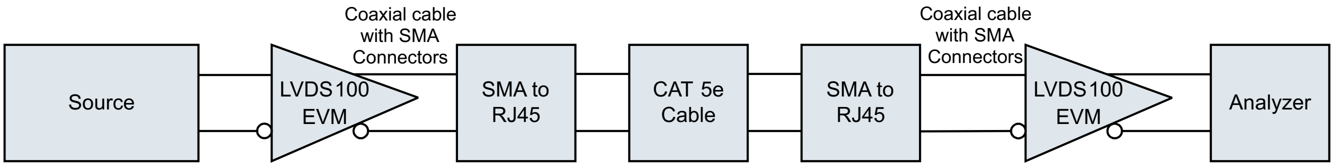

Figure 9. SN65LVDS100/CAT5e Test Setup

The results are given in Figure 10.

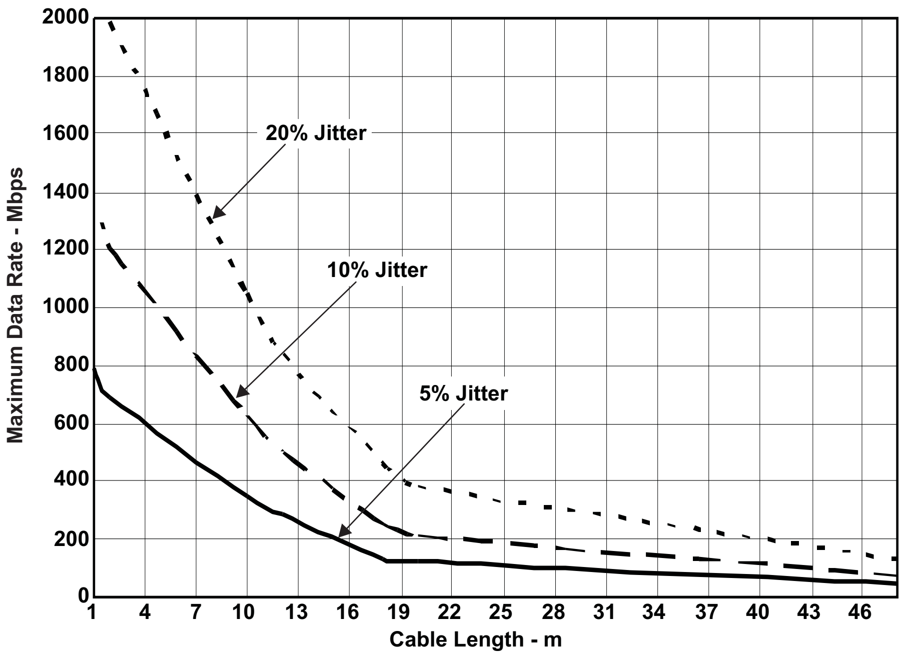

Figure 10. SN65LVDS100/CAT5e Test Results

As expected, the maximum data rate possible decreases as the cable length is increased. The SN65LVDS100 was tested at each jitter tolerance threshold with cables up to 48 m, and at this distance signals could be transmitted and received at 43 Mbps with 5% UI jitter or 130 Mbps with 20% UI jitter.

3.2 SN65LVDS100 Over PCB Trace

Figure 11 illustrates the test setup used to measure the maximum data rate achievable by the SN65LVDS100 over various lengths of PCB trace.

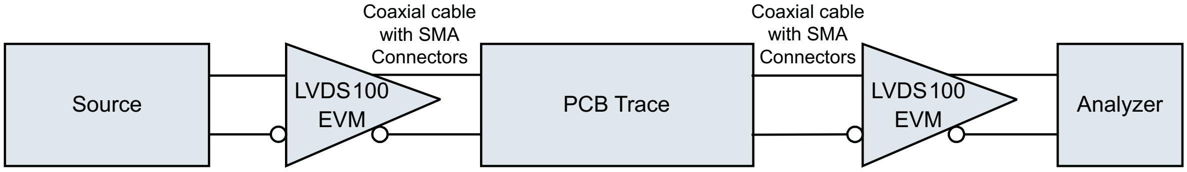

Figure 11. SN65LVDS100/PCB Trace Test Setup

The results are given in Figure 12.

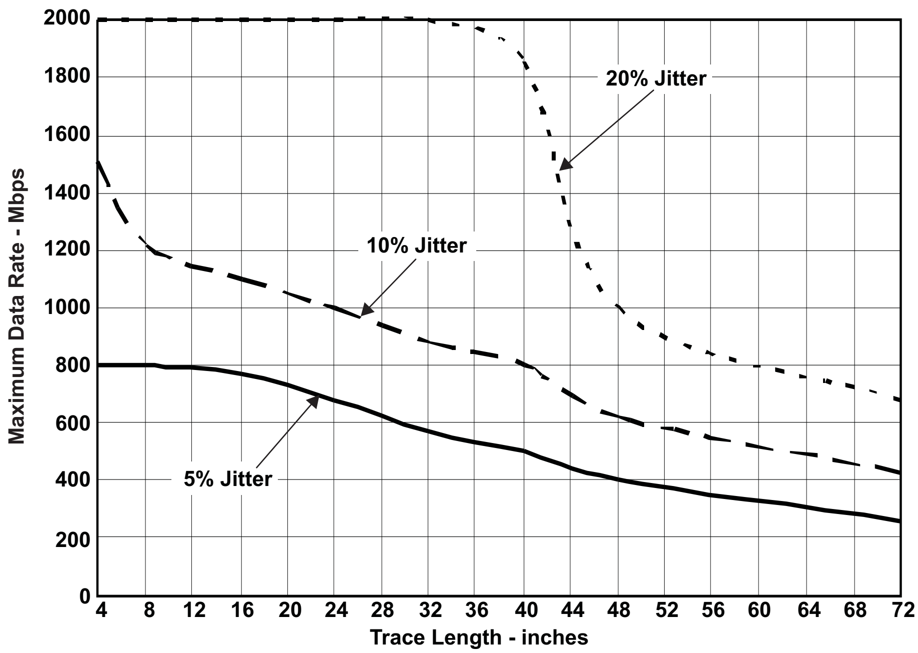

Figure 12. SN65LVDS100/PCB Trace Test Results

The SN65LVDS100 was tested at trace lengths up to 72 inches. At this distance, signals could be transmitted and received at 260 Mbps with 5% UI jitter or at 680 Mbps with 20% UI jitter.

3.3 SN65LVCP418 Over CAT5e Cable

Figure 13 illustrates the test setup used to measure the maximum data rate achievable by the SN65LVCP418 over various lengths of CAT5e cable. For each length and jitter tolerance, measurements were recorded for two conditions: (1) pre-emphasis enabled on the transmitting device and equalization enabled on the receiving device and (2) neither pre-emphasis nor equalization enabled.

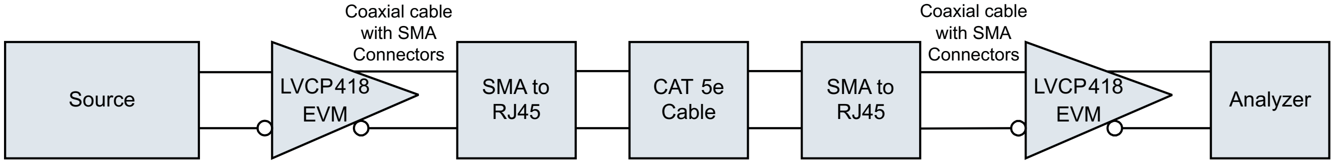

Figure 13. SN65LVCP418/CAT5e Cable Test Setup

The results are given in Figure 14. The black lines represent the results without pre-emphasis or equalization. The red lines represent the results with both pre-emphasis and equalization enabled.

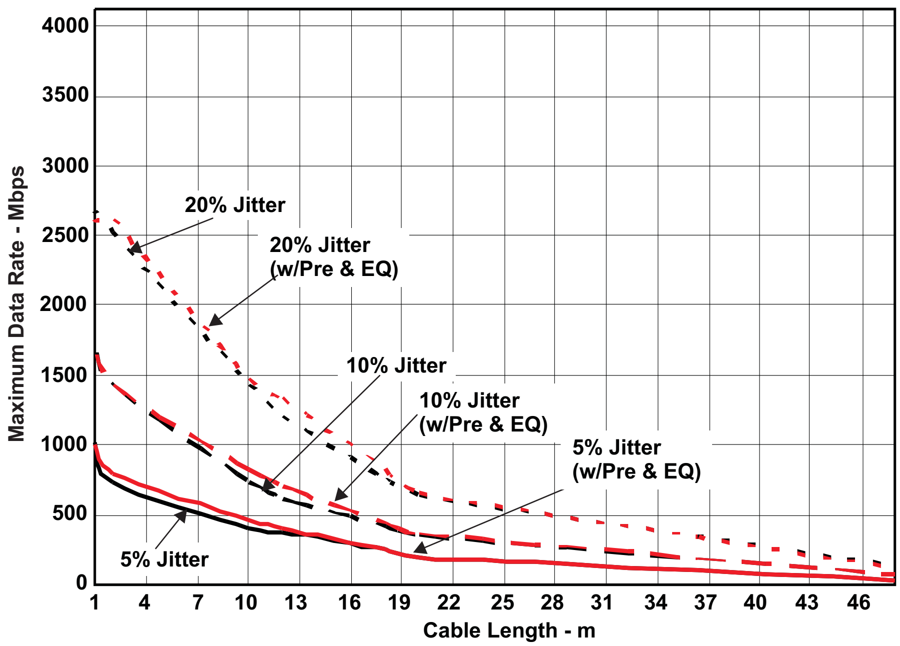

Figure 14. SN65LVCP418/CAT5e Cable Test Results

The results from this test show that higher data rates can be achieved over a CAT5e cable by the SN65LVCP418 than the SN65LVDS100, but the data rate tends to decrease with cable length in a very similar manner. It may seem from these results that pre-emphasis and equalization do not have much of an effect. This is because those features affect only the high-frequency signal components, which are heavily attenuated over CAT5e.

For a length of 20 m, the SN65LVCP418 could transmit and receive differential signals at 200 Mbps with 5% UI jitter or 650 Mbps with 20% UI jitter. For a length of 48 m, the SN65LVCP418 could transmit and receive differential signals at 35 Mbps with 5% jitter or at 130 Mbps with 20% jitter.

3.4 SN65LVCP418 Over PCB Trace

Figure 15 illustrates the test setup used to measure the maximum data rate achievable by the SN65LVCP418 over various lengths of PCB trace. As before, measurements were recorded with and without pre-emphasis and equalization enabled.

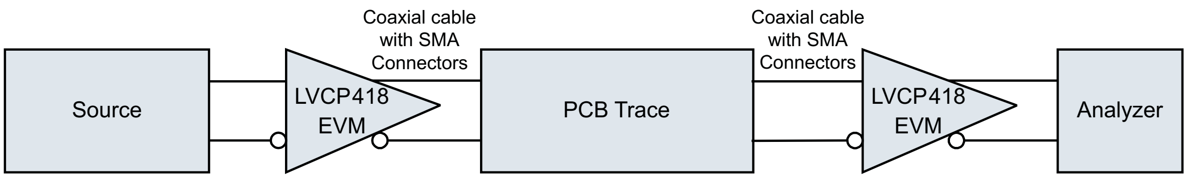

Figure 15. SN65LVCP418/PCB Trace Test Setup

The results are given in Figure 16.

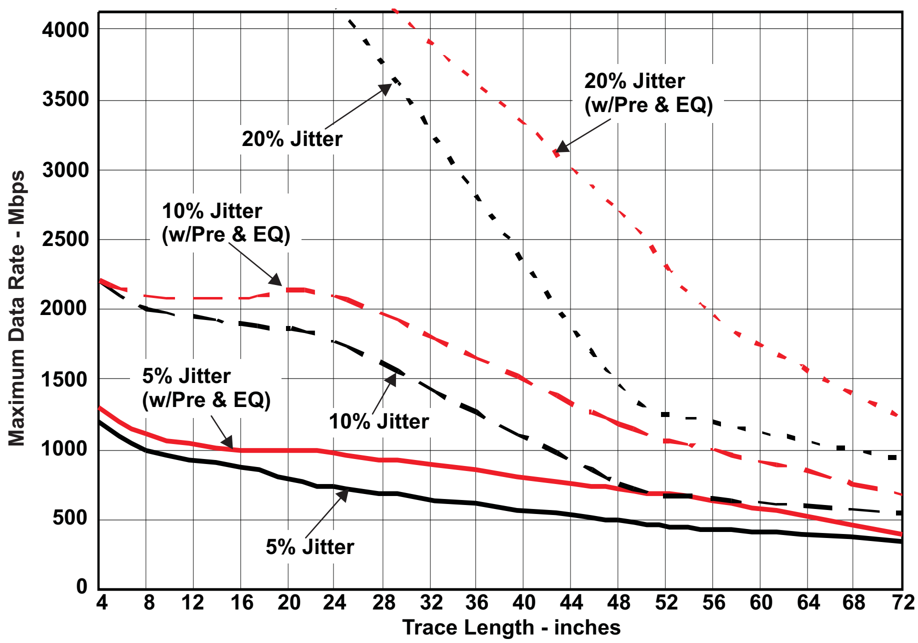

Figure 16. SN65LVCP418/PCB Trace Test Results

With PCB traces used as the transmission medium, pre-emphasis and equalization have a much greater benefit. In most cases, enabling pre-emphasis and equalization nearly doubled the maximum transmission distance achievable for a given data rate.

Trace lengths of up to 72 inches were tested. At this length, the SN65LVCP418 could transmit and receive differential signals at 390 Mbps with 5% UI jitter or at 1220 Mbps with 20% UI jitter.

4 Conclusion

Because of the multitude of factors affecting these results, this application note should not be regarded as a definitive measure of the maximum transmission distances of these devices. Rather, it should be used as a starting point for further, more detailed analysis or as a quick aid in estimating how fast and how far signals can travel.

Because this testing focused on a single-channel simplex connection, only first-order cable effects (e.g. loss) were taken into account. In applications involving many signals along a bus, other second-order effects such as skew and crosstalk must also be considered. Other concerns arising from the use of long cables are insufficient eye height due to signal attenuation and increased coupling of common mode noise.

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 TI 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. Information of third parties may be subject to additional restrictions.

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.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

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

Products		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DLP® Products	www.dlp.com	Communications and Telecom	www.ti.com/communications
DSP	dsp.ti.com	Computers and Peripherals	www.ti.com/computers
Clocks and Timers	www.ti.com/clocks	Consumer Electronics	www.ti.com/consumer-apps
Interface	interface.ti.com	Energy	www.ti.com/energy
Logic	logic.ti.com	Industrial	www.ti.com/industrial
Power Mgmt	power.ti.com	Medical	www.ti.com/medical
Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
RFID	www.ti-rfid.com	Space, Avionics & Defense	www.ti.com/space-avionics-defense
RF/IF and ZigBee® Solutions	www.ti.com/lprf	Video and Imaging	www.ti.com/video
		Wireless	www.ti.com/wireless-apps

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