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.

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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](image)

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](image-url)

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](image-url)
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](image)

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

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.

The results are given in Figure 10.

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](image)

The results are given in Figure 12.

![Figure 12. SN65LVDS100/PCB Trace Test Results](image)

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](image)

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](image)

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 \textbf{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.

The results are given in Figure 16.

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 \textbf{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.
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