ABSTRACT

The use of a reference clock that is less stable than those directly driven from an oscillator may be required for some applications. In addition, some customer applications may require partnering with devices that operate outside of the IEEE 802.3 standard for transmitted jitter.

Contents

1 Introduction ......................................................... 2
2 Summary .......................................................... 2
3 Theory .............................................................. 2
4 Receiver Architecture Review ................................. 2
5 Jitter Measurement ................................................. 4
5.1 Test Setup ..................................................... 4
5.2 TEST RESULTS ............................................... 5
6 Conclusion ......................................................... 8

List of Figures

1 Transmit MLT-3 Waveform Histogram ......................... 3
2 Receiver Architecture ........................................... 4
3 Simplified Test Setup ............................................. 5
4 Transmit Signal Eye Diagram With Nominal Jitter ............... 6
5 Transmit Signal Eye Diagram With 1.4 ns Jitter (Maximum Allowed by IEEE Specification) ....................... 6
6 Transmit Signal Eye Diagram With 4 ns of Jitter .................. 6
7 Peak-to-Peak Transmit Jitter as a Function of Peak-to-Peak Short-Term Jitter (12 cycles) ....................... 7
8 Peak-to-Peak Transmit Jitter as a Function of Peak-to-Peak Long-Term Jitter (250 cycles) ..................... 8

List of Tables

1 Peak-to-Peak to RMS Jitter Conversion Factor vs. BER ................................................................. 2
2 Transmit Jitter and RX Errors as Functions of Peak-to-Peak Short-Term Jitter (12 cycles, 150 m) ............... 7
3 Transmit Jitter and RX Errors as Functions of Peak-to-Peak Long-Term Jitter (250 cycles, 150 m) .......... 7
Introduction

1 Introduction

The PHYTER family is designed for robust operation and optimized for cable length and jitter tolerance performance far exceeding the IEEE specifications.

This application report is applicable to the following products:

| DP83848C | DP83849C |
| DP83848I | DP83849I |
| DP83848YB | DP83849ID |
| DP83848M | DP83849IF |
| DP83848T | DP838460 |
| DP83848H | DP83848VYB |
| DP83848J | DP83848Q-Q1 |
| DP83848K | DP838630 |
| DP83848T | DP83620 |

2 Summary

Although Texas Instruments recommends the use of stable clock sources with a minimum of jitter to achieve the best performance, the PHYTER family is capable of error free operation using imperfect reference sources and partners with excessive amounts of transmit jitter.

With up to 3.5 ns of jitter on the reference clock, the DP83849 PHYTER is capable of error free reception from a typical partner over 150 m of CAT5 cable. The DP83849 PHYTER, with a reference with nominal jitter, can recover data from signals transmitted with over twice the maximum allowable jitter at a cable length of 150 m.

Transmit tolerance of reference clock jitter is measured against the IEEE transmit jitter specification of 1.4 ns. Based on the measured data the DP83849 PHYTER can tolerate up to 1.1 ns of reference clock jitter before exceeding the IEEE requirement.

3 Theory

Clock jitter impairs any communication system and may have a severe impact on serialized data streams. Random jitter on the reference clock results in a frequency dependent noise component with energy spread across the spectrum, which impairs signal quality through the degradation of signal to noise ratio.

For random jitter, the ratio of peak to standard deviation depends on the bit error rate (BER) at which the system must operate. For a given BER, the magnitude of the Gaussian noise, on average, will not exceed the stated peak value more often than once every 1/BER. Therefore, as the peak to peak variation of random jitter increases, the BER degrades.

In designing a system, reference clock jitter is often specified in RMS units. For a Gaussian distribution, to convert between peak-to-peak (Pk-Pk) and RMS jitter, BER must be specified. Table 1 lists common BER conversion factors from Pk-Pk to RMS.

<table>
<thead>
<tr>
<th>BER</th>
<th>(10^{-10})</th>
<th>(10^{-12})</th>
<th>(10^{-14})</th>
<th>(10^{-16})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pk-Pk/RMS Ratio</td>
<td>12.72</td>
<td>14.1</td>
<td>15.3</td>
<td>16.5</td>
</tr>
</tbody>
</table>

4 Receiver Architecture Review

When transmitting data at high speeds over copper twisted pair cable, frequency dependent attenuation becomes a concern. In high-speed twisted pair signaling, the frequency content of the transmitted signal changes significantly based on the transmitted data stream, in particular, the randomness of the scrambled data. The variation in signal attenuation caused by frequency variations must be compensated for to ensure the integrity of the transmission and accurate recovery and decoding of the received data stream.
Figure 1 illustrates the triple data histogram for a typical MLT-3 data stream. This signal would provide good BER because the tails of each distribution are far apart, providing ample room for properly decoding the three levels.

In order to ensure quality transmission when employing MLT-3 encoding, the compensation must be able to adapt to various cable lengths and cable types depending on the installed environment. Therefore, the compensation or equalization must be adaptive to ensure proper conditioning of the received signal independent of the cable length.

The PHYTER family utilizes an extremely robust DSP equalization scheme with tightly coupled continuous analog and digital adaptive equalization. This is illustrated, along with a simplified view of the analog front end (AFE) in Figure 2.

The equalizer removes inter-symbol interference from the receive data stream by continuously adapting both the analog and digital equalizers to provide a filter with the inverse frequency response of the channel. When used in conjunction with a gain stage, the equalization enables the receive 'eye pattern' to be opened sufficiently to allow very reliable data recovery and very robust noise tolerance.

An advanced clock recovery loop ensures the data is always captured at the center of the equalized data pattern, minimizing jitter impairments that close the eye.

The equalizer is truly adaptive to any length of cable up to 150 meters.
5 Jitter Measurement

To validate the robustness of the PHYTER jitter tolerance, two DP83849 devices were linked together in 100 base-TX mode across an adjustable length cable box of CAT5 cable. Jitter was induced to the reference clock of one of the devices at various levels. The performance of both short-term and long-term jitter was characterized.

Short-term jitter, caused by high frequency noise content, is typically defined as cycle-to-cycle jitter. For the purposes of this test, short-term jitter testing was performed with a 12 cycle interval. Long-term jitter, which is low frequency in nature, is defined such that the maximum jitter occurs after a sufficiently long time such that the system can track it. In this case, that time is 10 µs.

5.1 Test Setup

To induce the jitter on the reference clock, an FM modulated signal was used. The modulation frequency was set such that the peak jitter occurred at the desired measurement point (480 ns for short-term jitter, 10 µs for long-term jitter). The FM deviation controlled the amount of peak-to-peak jitter.
For short-term jitter, the signal generator was configured with a modulation frequency of 0.99 MHz and a deviation ranging from 0 kHz to 137.2 kHz. With 1 kHz of FM deviation producing approximately 25.5 ps of jitter, the total range of short-term jitter was approximately 150 ps to 3.6 ns. Long-term jitter was induced with an FM modulation of 49.9 kHz and the deviation varied from 0 kHz to 8 kHz. This produced jitter of approximately 150 ps to 4 ns with about 500 ps of jitter for each kilohertz of deviation. In both cases, using a modulation frequency that was not an even multiple of the clock frequency prevented the jitter from becoming synchronous with the clock frequency.

Reference clock and transmit signal jitter was measured with an oscilloscope using a delayed trigger, with the delay time equivalent to 12 or 250 cycles of the reference clock. In the case of transmit jitter, the device under test (DUT) was programmed with auto-negotiation disabled and the RJ-45 connector terminated with a 100 Ω resistor between the transmit pair. A differential probe was used to capture the transmit idle waveform at the RJ-45 connector of the DUT.

For bit error rate testing, the digital packet generator configured the transmit packets and monitored packet counts on the DUT and its Partner, as shown in Figure 3. BER test results are based on 1 million packets of 1514 bytes (excluding CRC).

Several devices were tested from 3.0 V to 3.6 V and -40°C to 85°C to ensure robustness across environmental conditions.

5.2 TEST RESULTS

For reference, Figure 4, Figure 5, and Figure 6 represent actual oscilloscope waveforms showing the MLT–3 waveform eye diagram with various levels of jitter. These waveforms were taken at the DUT transmitter near end and do not include the impairments of the 150 meters of cable. Figure 5 illustrates the signal degradation with the 1.4 ns peak to peak maximum allowed by the IEEE transmit jitter specification.

The IEEE bit error rate specification for 100 Base-TX operation requires a BER of less than $10^{-7}$. Texas Instruments devices are qualified to BERs of three orders of magnitude better (BER < $10^{-10}$). Typical results from testing performed with a 150–meter CAT5 cable are shown in Table 2 and Table 3.

Figure 7 and Figure 8 are plots of the transmit jitter relative to the reference jitter.
Figure 4. Transmit Signal Eye Diagram With Nominal Jitter

Figure 5. Transmit Signal Eye Diagram With 1.4 ns Jitter (Maximum Allowed by IEEE Specification)

Figure 6. Transmit Signal Eye Diagram With 4 ns of Jitter
Table 2. Transmit Jitter and RX Errors as Functions of Peak-to-Peak Short-Term Jitter (12 cycles, 150 m)

<table>
<thead>
<tr>
<th>Reference Clock Jitter (ns)</th>
<th>Transmit Jitter (ns)</th>
<th>DUT RX Errors</th>
<th>Partner RX Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.16</td>
<td>0.35</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.64</td>
<td>0.79</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1.12</td>
<td>1.39</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1.64</td>
<td>2.01</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2.12</td>
<td>2.59</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2.64</td>
<td>3.21</td>
<td>0</td>
<td>2 CRC</td>
</tr>
<tr>
<td>3.16</td>
<td>3.84</td>
<td>0</td>
<td>21 CRC</td>
</tr>
<tr>
<td>3.64</td>
<td>4.36</td>
<td>2 CRC</td>
<td>148 CRC</td>
</tr>
</tbody>
</table>

Table 3. Transmit Jitter and RX Errors as Functions of Peak-to-Peak Long-Term Jitter (250 cycles, 150 m)

<table>
<thead>
<tr>
<th>Reference Clock Jitter (ns)</th>
<th>Transmit Jitter (ns)</th>
<th>DUT RX Errors</th>
<th>Partner RX Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.14</td>
<td>0.35</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.60</td>
<td>0.77</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1.10</td>
<td>1.25</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1.62</td>
<td>1.75</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2.12</td>
<td>2.27</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2.63</td>
<td>2.79</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3.16</td>
<td>3.30</td>
<td>0</td>
<td>4 CRC</td>
</tr>
<tr>
<td>3.66</td>
<td>3.81</td>
<td>0</td>
<td>33 CRC</td>
</tr>
<tr>
<td>4.19</td>
<td>4.31</td>
<td>1 CRC</td>
<td>277 CRC</td>
</tr>
</tbody>
</table>

Figure 7. Peak-to-Peak Transmit Jitter as a Function of Peak-to-Peak Short-Term Jitter (12 cycles)
Figure 8. Peak-to-Peak Transmit Jitter as a Function of Peak-to-Peak Long-Term Jitter (250 cycles)

6 Conclusion

The PHYTER receiver architecture’s DSP equalization scheme with tightly coupled continuous Analog and digital adaptive equalization and advanced timing recovery loop is designed to tolerate both short-term jitter and long-term jitter. It is also capable of adapting to channel impairments up to 150 meters of CAT5 cable. The system ensures data is captured at the center of the open eye, providing extremely reliable data recovery and jitter tolerance well beyond the IEEE limits.

Based on the measured data shown in Table 2 and Table 3, at a BER three orders of magnitude better than IEEE specifications, BER < $10^{-10}$, a DP83849 PHYTER with nominal reference jitter can detect signals with over twice the maximum allowable transmit jitter at 150 m of cable length. Even with 3.5 ns of jitter on the reference clock, the DP83849 PHYTER is capable of error free reception over 150 m of CAT5 cable from a typical partner. Increased amounts of jitter can be tolerated at shorter cable lengths.

For the transmit path the reference source is not filtered. As a result, the transmit jitter tracks the increase in the jitter of the reference. It can be seen from the plots in Figure 7 and Figure 8 that as the reference jitter exceeds 1 ns the transmit jitter approaches the IEEE specification limit of 1.4 ns.
IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as “components”) are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

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

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license 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 significant portions 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. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

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

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have not been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products
Audio www.ti.com/audio
Amplifiers amplifier.ti.com
Data Converters dataconverter.ti.com
DLP® Products www.dlp.com
DSP dsp.ti.com
Clocks and Timers www.ti.com/clocks
Interface interface.ti.com
Logic logic.ti.com
Power Mgmt power.ti.com
Microcontrollers microcontroller.ti.com
RFID www.ti-rfid.com
OMAP Applications Processors www.ti.com/omap
Wireless Connectivity www.ti.com/wirelessconnectivity

Applications
Automotive and Transportation www.ti.com/automotive
Communications and Telecom www.ti.com/communications
Computers and Peripherals www.ti.com/computers
Consumer Electronics www.ti.com/consumer-apps
Energy and Lighting www.ti.com/energy
Industrial www.ti.com/industrial
Medical www.ti.com/medical
Security www.ti.com/security
Space, Avionics and Defense www.ti.com/space-avionics-defense
Video and Imaging www.ti.com/video
E2E Community e2e.ti.com