ISBN: 978-3-95450-238-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2023-WE3A003

NOISE MITIGATION FOR NEUTRON DETECTOR DATA TRANSPORT*

Kazimierz J. Gofron†, Bogdan Vacaliuc, Rob Knudson IV, Steve Hicks
Spallation Neutron Source and High Flux Isotope Reactor,
Oak Ridge National Laboratory, Oak Ridge, TN, USA

Abstract

Detector events at user facilities require real-time fast transport of large data sets. Since its construction, the Spallation Neutron Source (SNS) user facility at the US Department of Energy's Oak Ridge National Laboratory successfully transported data using an in-house solution based on Channel Link low-voltage differential signalling (LVDS) point-to-point data protocol. Data transport solutions developed more recently have higher speed and more robustness; however, the significant hardware infrastructure investment limits migration to them. Compared with newer solutions, the existing SNS LVDS data transport uses only parity error detection and LVDS frame error detection. The used channel link is direct current (DC) coupled and thus is sensitive to electrical environment noise. It is difficult to maintain the same LVDS common reference potential over an extensive system of electronic boards in detector array networks.

INTRODUCTION

The SNS existing Channel Link uses LVDS [1] for data transport with a clock of about 40 MHz and a mixture of parallel and serial data transport. The 7 data bits per twisted pair in each clock cycle are transported over three pairs of typically Cat5e or Cat7 shielded cable. The maximum data rate is about 840 Mbps per cable. The DS90CR217 [2] and DS90CR218 [3] chipset pairs transport LVDS data, and SN65LVDS32 [4] and SN65LVDS31 [5] chipsets send timing-trigger, clock, and resend to lower-level boards.

Discussed herein are noise mitigation methods to improve data transport within the existing as-built infrastructure. We consider the role of shielding, ground loops, and specifically the use of toric ferrite isolation transformer [6] for radio frequency (RF) common mode noise filtering [7] on power input.

The paper investigates LVDS noise at two levels. At one level we look directly at LVDS eye diagram signals using an oscilloscope. For this work, we used Cat8 cables from FiberStore (New Castle, Delaware) [8] to identify propagation limitations. At another level, we look at the system with data loss caused by system environment noise in an extended network of detectors within the neutron beamline.

* Work supported by US Department of Energy (DOE), Office of Science, Scientific User Facilities Division under Contract No. DE-AC05-00OR22725. This manuscript has been authored by UT-Battelle, LLC, under contract DE-AC05-00OR22725 with DOE. The US government retains and the publisher, by accepting the article for publication, acknowledges that the US government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this manuscript, or allow others to do so, for US government purposes. DOE will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan (https://www.energy.gov/doe-public-access-plan).
† gofronkj@ornl.gov

EYE DIAGRAM

The SNS data collected by read-out card (ROC) are sent through the concentrator (FEM) and data system packetizer (DSP) over Cat5e cables. Reported herein are studies using higher-specification Cat8 cables from FiberStore [8]. The Cat8 shielded cables support transport frequencies up to 2 GHz.

A Tektronix MDO4104B-6 Mixed Domain Oscilloscope, 6 GHz (1 GHz, 5 GS/s) and a Tektronix TDP3500 Differential Probe 3.5 GHz, shown in Fig. 1 and Fig. 2, measured the LVDS signals for the eye diagram. The 40 MHz clock, was measured using a Tektronix TAP1500 1.5 GHz active probe. The measurement points are head-board pins soldered directly to the printed circuit board as close to the LVDS receiver as physically possible.

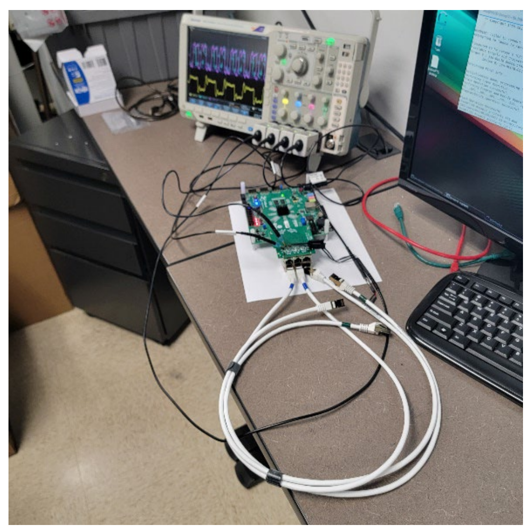

Figure 1: The eye diagram measurement setup with loop-back hex AAAA5555 test pattern signals sent from the transmit to receive connection of the ROC board.

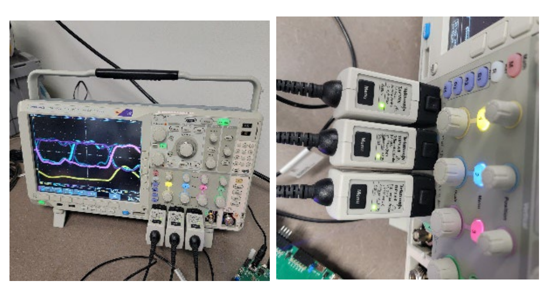

Figure 2: A Tektronix oscilloscope, with two differential probes and an active probe, is used for eye diagram measurement.

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The oscilloscope screen captured plots that show the evolution of two of the three data signals received after transmission over the Cat8 cable, using loopback. The bottom plot in Fig. 3-5 is a 40 MHz LVDS clock signal. Figures 3–5 show the 40 MHz clock from oscilloscope Channel 1, the data on Cat8 Pair [1, 2] on Channel 2, and data on Cat8 Pair [3, 4] on oscilloscope Channel 3, respectively. Figures 3–5 report results for Cat 8 S/FTP cable type having lengths from 3 to 50 ft with gauge 28 AWG.

Figures 3–5 show the evolution of the eye diagram as a function of the Cat8 cable length. The signal voltage increases in height for shorter cables. As cables get shorter, the eye diagram opens because of reduced skew, higher received voltage, and sharper rise time.

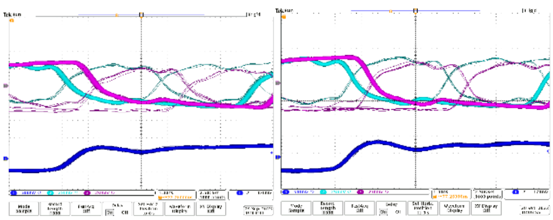

Figure 3: Received signals for (left) 50 ft Cat8 cable, (right) 35 ft Cat8 cable.

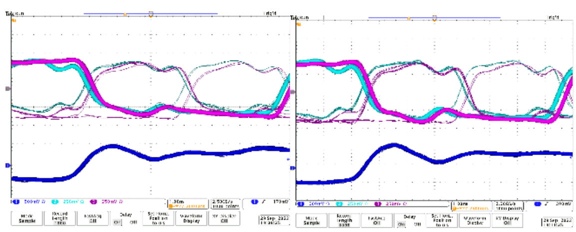

Figure 4: Received signals for (left) 25 ft Cat8 cable, (right) 16 ft Cat8 cable.

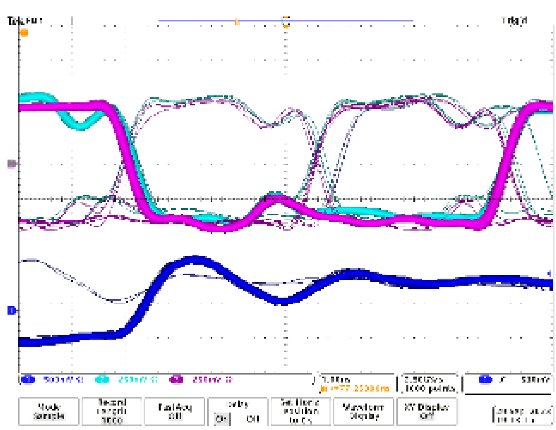

Figure 5: The eye diagram for 3 ft long Cat8 cable, with two LVDS data signals and a 40 MHz clock (bottom).

RESULTS

Collected LVDS traces for different Cat8 cable lengths were analyzed for received signal voltage, skew, and rise time.

The skew is a relative delay of data transmission between one twisted pair vs. another twisted pair of the same Cat8 cable. This skew increases with cable length and reaches about 1 ns for the studied two pairs, as shown in Fig. 6. The skew is directly related to wire length of the pair and is affected by each pair's different twist pitch in Cat8 cable. Skew closes the eye diagram opening and limits the ability to decode bits reliably. Possible skew mitigation might include fixed skew adjustment between pairs at the receiving end to maintain the horizontal time opening of the eye diagram.

The signal differential voltage decreases with cable length by about 300 mV over 50 ft of Cat8 cable, as shown in Fig. 7. A possible mitigation might be boosting the voltage transmit level to keep the eye diagram open. The DC resistance of 50 ft Cat8 cable is 6.4 [Ohm], but resistance at 280 [MHz] is increased by RF skin effect conductivity to about 100 [Ohm], which reduces signal voltage for longer cables.

The rise time of the received signal increases by over 50% over 50 ft of Cat8 cables and is related to dispersion, as shown in Fig. 8.

Increasing skew, decreasing received signal voltage, and dispersion all decrease the ability to correctly read received bits over LVDS links for longer cables.

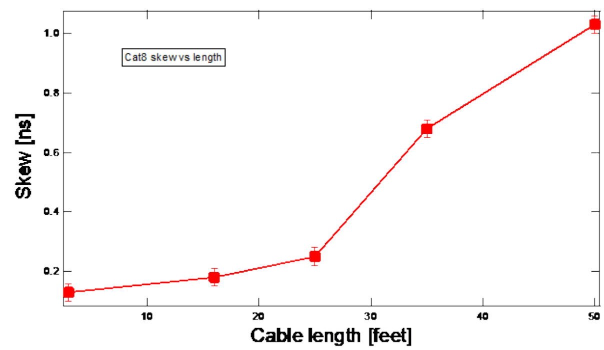

Figure 6: Signal time skew between Cat8 Pair [1, 2] and Cat8 Pair [4, 5] as a function of cable length.

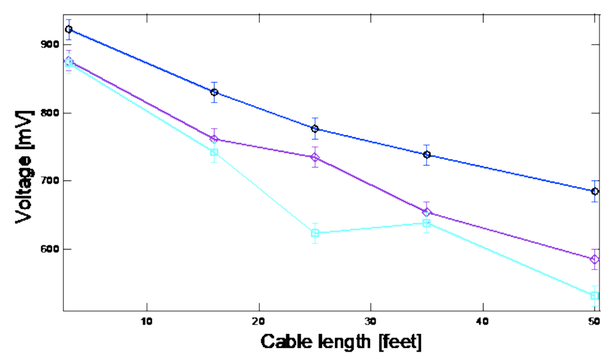

Figure 7: Signal voltage at receiver as a function of cable length.

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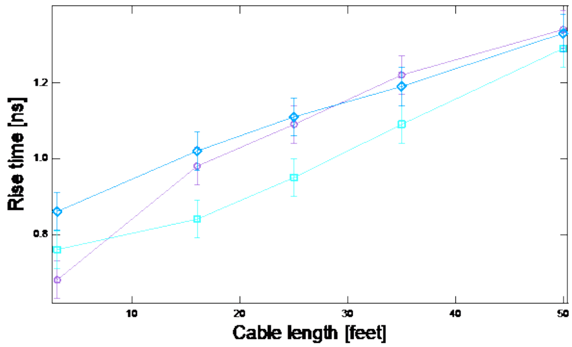

Figure 8: Rise time as a function of cable length.

NOISE SOURCES

The LVDS signals are DC coupled, are more susceptible to outside electrical noise, and have no electrical isolation from distributed power supply issues. It is difficult to maintain the same LVDS common reference potential over an extensive system of electronic boards in a neutron beamline detector array. This section discusses the effect of noise sources on LVDS signal integrity and suggests mediations [2, 5].

Test data were generated by ROC (Fig. 9 [left], Fig. 10 [left]) detector field-programmable gate array (FPGA) firmware emulating LVDS detector data as a data source, with a rate of a few million events per second. The emulated detector data are then transported through LVDS links over Cat5e cables to DSP. The LVDS packet consistency is checked in FPGA of the DSP/FEM, where we monitor EPICS [9] Process Variable (PVs) responsible for reporting errors at the receiver (DSP or FEM). The ROC and DSP are connected through three cat5e cables, each responsible for Tx (transmit), Rx (receive), T&C (timing and control), respectively. Detector data originate at ROC and are received by DSP and use Tx Cat5e cable, Rx is used for sending commands to ROC, and T&C is used for sending timing signals. For these tests, we also used shielded Cat7 cables with a max length of 10 ft. The Cat5e cables are more prone to noise transport because they are not shielded (do not carry electrical signal common conductor), and shields do not connect LVDS common connection between boards. Typically, these tests used an analog Agilent E3648A power supply.

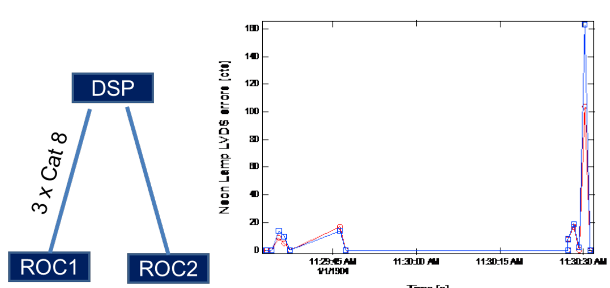

Figure 9: (left) The test setup with DSP and two ROCs. (right) The LVDS errors when the fluorescent lamp is turned on or off. ROC1 and ROC2 were both connected using unshielded twisted pair (UTP) Cat5e cables.

An induction ballast-driven fluorescent lamp (Fig. 10 [right]) served as an electronic noise source. The fluorescent lamp produces electrical noise when is switched on and off, allowing for the observation of LVDS errors (Fig. 9 [right]). The errors are produced when the lamp is powered from the same three-phase lab transformer as the noise source (i.e., test setup [DSP, ROC] in Fig. 9). When the fluorescent lamp is connected to the electrical outlet of a different transformer, no LVDS errors are detectible. Therefore, LVDS errors propagate through power lines. Double-conversion uninterruptible power supply (UPS) was effective in isolation from fluorescent lamp electrical noise.

We conclude that errors in LVDS data propagate primarily through power lines.

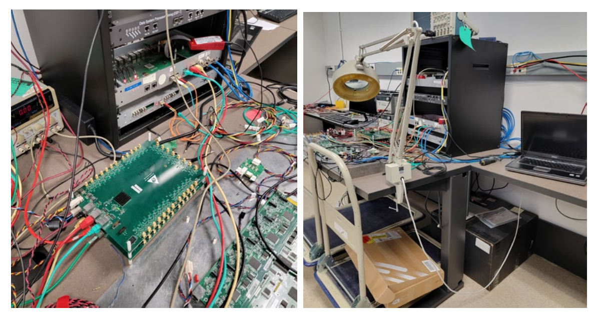

Figure 10: (left) Two ROC and DSP in the mini-RAC. (right) Fluorescent lamp is used as a source of electrical noise.

GROUNDING

Grounding (Fig. 11), for LVDS data transport, means connecting the LVDS common for all respective boards of the system to the appropriate cross-section conductor. An orange high-flexibility conductor with green tape terminal tape was used for these tests.

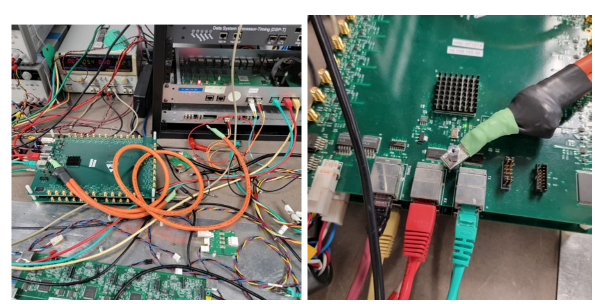

Figure 11: The grounding–connecting LVDS common of ROC (right) and common of DSP boards.

The lab test involved connecting the ROC LVDS common with DSP LVDS common (Fig. 11) and studying LVDS errors using a power distribution board (PDB), discussed in the following section.

PDB

The SNS beamlines are migrating to a power distribution board (PDB), a power supply that uses DC–DC conversion, with the benefit of providing electrical isolation.

19th Int. Conf. Accel. Large Exp. Phys. Control Syst. ICALEPCS2023, Cape Town, South Africa JACoW Publishing
ISBN: 978-3-95450-238-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2023-WE3A003

The PDB provides power for ROC, FEM, and DSP. Noise originates in "common mode," which propagates along power connections to ROC detector LVDS links. This common noise mode is eliminated by passing detector power conductors through a toric ferrite transformer core.

However, DC–DC conversion generates hundreds of kilohertz of RF noise that propagates through an air interface. For dedicated ground not connecting ROC and DSP, when the metal shield around the PDB board was connected to a large metal plate, many LVDS errors (Fig. 12) were generated on UTP Cat5e LVDS links between ROC and DSP (Fig. 9 [left]).

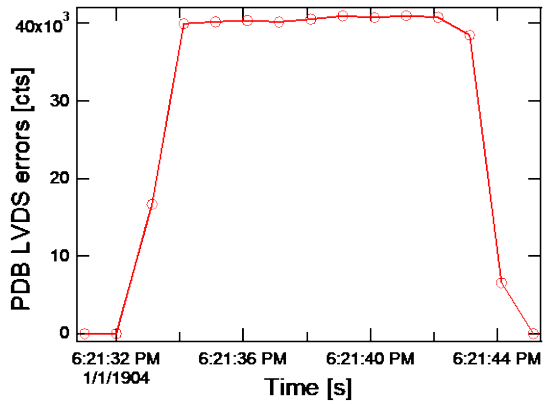

Figure 12: UTP Cat5e cable generates many LVDS errors when the ground of Fig. 10 is disconnected. The noise signal was generated by attaching a PDB shield to a large 40 × 90 cm metal plate, which behaves as an RF antenna.

For UTP Cat5e cables, connecting the PDB shield to a large (40 × 90 cm) metal plate introduced a much larger number (40k) of LVDS errors.

These LVDS errors were eliminated for UTP Cat5e LVDS links only by grounding ROC and DSP, as discussed in the "Grounding" section. Here, grounding means connecting LVDS common of the ROC and DSP. This finding indicates that the shield conductor of Cat8 is functioning as a good common-mode ground. These findings guide the PDB installation while minimizing the DC–DC conversion noise source.

FPGA FIRMWARE

The FPGA firmware through the Experimental Physics and Industrial Control System (EPICS) provides information on the LVDS status, including parity errors (Fig. 13), LVDS frame errors (Fig. 14), and dropped frames (Fig. 15); selected neutron event distributor (nED) [10] PVs are listed in Table 1. Using test firmware to remove known miscount issues, no LVDS errors were observed on LVDS links between FEMs and ROCs for a period of 5 days. Therefore, LVDS error events are not frequent events.

The LVDS errors appear as bursts, as shown in Fig. 13, where parity errors are plotted.

Table 1: The nED PVs That Monitor LVDS Link Errors

Metric PV	DSP link
UpFrameErrCnt	Uplink
DownRxFrameErrCnt	Downlink
UpRxParityCnt	Uplink
DownRxParityCnt	Downlink

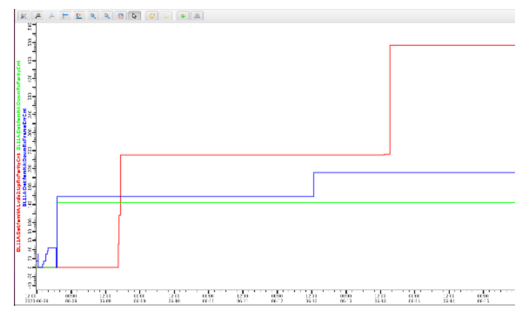

Figure 13: Parity errors for POWGEN beamline LVDS links.

Figure 14: Using side-loaded test FEM firmware to remove known miscounts, no UpFrameErrCnt LVDS errors were observed during a 5 day test run at the beamline.

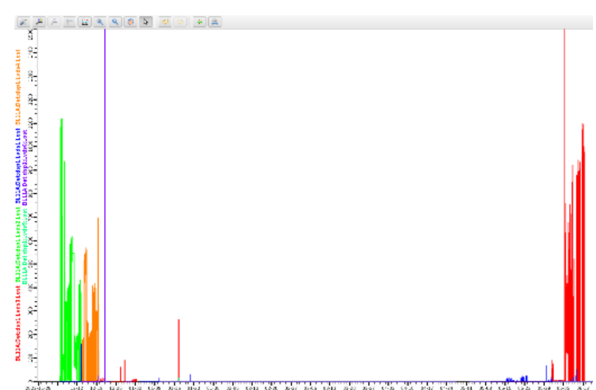

Figure 15: Many LVDS errors on the DSP port connecting to POWGEN's north FEM chain were observed once in a few months.

This work involved investigating the sources of LVDS errors in the Channel Link data transport. Shielded twisted pair Cat7 or Cat8 cables provide good immunity to electronic noise. For better robustness to LVDS errors of beamline system, reference common grounds of all links should be connected to clean ground.

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During a beamline inspection, several possibly damaged Cat7 cables were found at the POWGEN Beamline, and other cables were bent beyond the minimum bend radius, which is four times the cable diameter for Cat5e cables (i.e., ~ 1 in.). Such excessive bending might have contributed to signal transmission failure.

The POWGEN beamline lacks the connection to clean ground. The lab tests indicated that a dedicated ground connection is important when using PDB power supplies.

CABLES UPGRADE

In accordance with eye diagram studies, the Cat7 cables were replaced with significantly shorter Cat8 cables, as shown in Fig. 16. The shorter cables have higher received voltage, smaller skew, and faster rise time (less dispersion). Furthermore, the specifications for Cat8 cables are higher in terms of transport frequency, thereby minimizing dispersion.

The Cat8 cables shown in Fig. 16 (right) transport LVDS data between scintillation wavelength shifting fiber detectors (blue) and 1-U FEM in the rack.

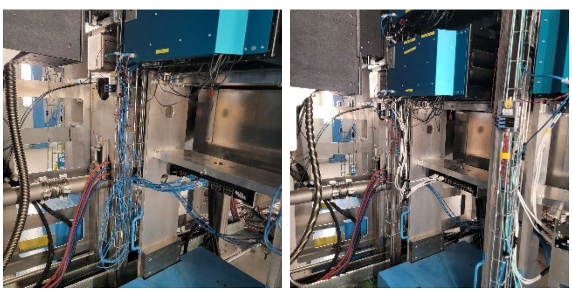

Figure 16: Cat7 (blue) data cables replaced with Cat8 (white) cabling of as short lengths as possible for POWGEN beamline at SNS.

SUMMARY

Longer Cat8 cables cause the eye diagram to close, hindering the receiver's ability to correctly decode the bits transmitted using LVDS Channel Link signalling and simple data protocol. For shorter cable lengths, the eye diagram opens by means of the larger received signal voltage, decreased relative signal skew between twisted pairs, and faster rise time (smaller dispersion). Using the shortest possible Cat8 cables is a good practice. Additional mitigation techniques, such as adjusting receiver skew opens eye diagram, and makes transmission more robust.

Proper grounding (i.e., the connection of LVDS common for all detector devices using Channel Link signaling) is crucial for immunity to electrical noise. Double-conversion UPS isolated the detectors from many external electrical noises.

ACKNOWLEDGEMENTS

Much appreciation to Starra Lyons and Charles Ndo for help with the cabling upgrade of POWGEN beamline.

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