Impulse Noise Measurement: Initial Results

AQUANTIA®

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Overview

- **Purpose:** Create a test setup to capture, record, and analyze the characteristics of impulse noise waveforms in the enterprise environment and measure the important characteristics that could affect 2.5G/5G Base-T link quality
  - Initial set of measurements in a limited office environment (limited human activity) and a test lab area with large electrical machinery
  - Measured signal bandwidth, time span, and peak-to-peak differential voltage of impulse noise events
  - Not able to obtain useful inter-arrival interval data
- Impulse noise measurement site considerations
- Impulse noise measurement test setup and post-processing procedure
- Example captured impulse noise waveforms
- Impulse noise observations
- Observed issues with measurement test setup
- Summary of initial measurement results
- Steps for next measurement survey cycle

Impulse Noise Measurement Site Considerations

- Instrumentation must be placed at multiple locations to obtain a valid (and useful) noise profile of the enterprise environment
- Need test sites with a RH (relative humidity) down to at least 20 percent
- Each site must consider two basic equipment placement scenarios: nearby wired LAN ports (mainly in laptops) and wireless access points
- Examine two main impulse noise sources
  - ESD event induced impulse noise; mainly metal-to-metal (tool) contact events
  - On/off switch contact arc induced impulse noise; mainly switching inductive loads (e.g. motors, fluorescent lights, etc.)

Examples of Impulse Noise Sources

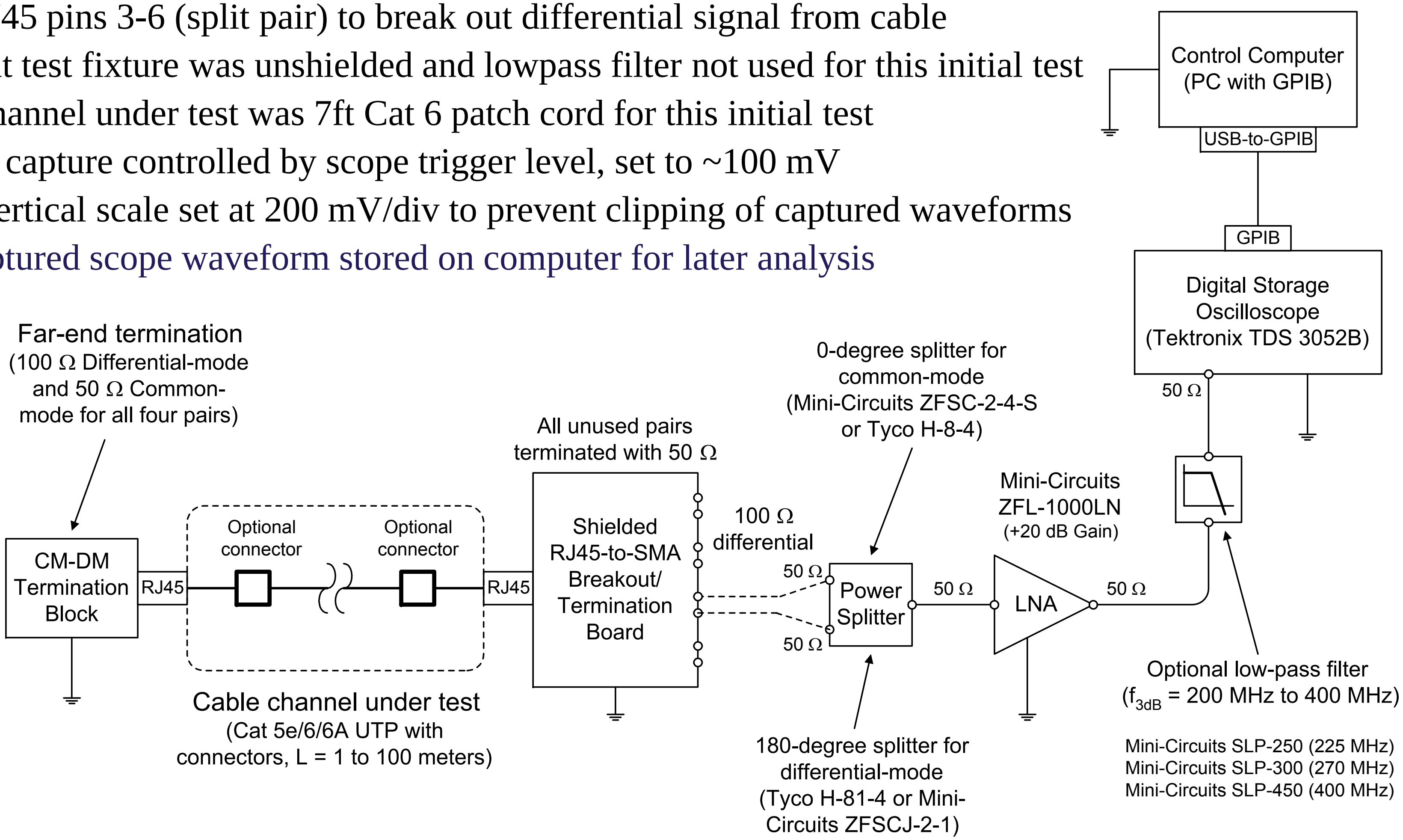
- Example sources of ESD in the enterprise environment
  - Metal-to-metal (tool) contact: Contact discharge of an isolated charged metal (conductive surface) object to ground (discharge) or contact with another “floating” metal object of different charge (charge equalization)
  - Movement of discrete metal objects in an insulating container; friction with insulating material charges metal object, contact with another metal object causes ESD event
  - Internal or external movement of furniture (e.g. opening and closing of desk drawers)
  - Sitting down or standing up in some desk chairs; these ESD events are generated internally inside the chair and grounding chains have no effect
  - Low humidity increases frequency of occurrence and intensity of ESD events
- Example sources of switch contact arc noise in the enterprise environment
  - On/off transition of light fixtures, notably desk fluorescent lights (including CFL bulbs)
  - On/off transition, plug/unplug, and operation of motorized equipment, including desk fans/heaters, paper shredders, and office HVAC

Example Measurement Sites

- Example location #1: Office “bullpen” cubicle
  - Lots of human activity in a limited area with no ESD mitigation measures
  - Potential for (tool contact) ESD induced impulse noise events near LAN ports
  - On/off switch arc induced impulse noise events (HVAC, desk fans, lighting, etc.)
- Example location #2: Local data center (other end of enterprise link)
  - Potentially less ESD events; newer installations have built-in ESD mitigation measures (probably why few problems observed with 10GBase-T)
  - CDE and PoE connect/disconnect impulse noise from inserting and removing cables
  - On/off arc induced impulse noise events from powered equipment insertion/removal
- Example location #3: Shipping/storage warehouse environment
  - On/off switch arc impulse noise events (lighting, fans, motorized equipment)
  - Potential for ESD events; lots of contact between metal tools and insulating materials

Noise Event Capture Test Setup

- Scope channel has 500 MHz bandwidth; set to 2.5 Gsps sampling rate, and 10000 samples memory capture depth (4 usec time span)
- Used RJ45 pins 3-6 (split pair) to break out differential signal from cable
- Breakout test fixture was unshielded and lowpass filter not used for this initial test
- Cable channel under test was 7ft Cat 6 patch cord for this initial test
- Impulse capture controlled by scope trigger level, set to ~100 mV
- Scope vertical scale set at 200 mV/div to prevent clipping of captured waveforms
- Raw captured scope waveform stored on computer for later analysis



Control Computer (PC with GPIB)

USB-to-GPIB

GPIB

Digital Storage Oscilloscope (Tektronix TDS 3052B)

50 Ω

Far-end termination (100 Ω Differential-mode and 50 Ω Common-mode for all four pairs)

CM-DM Termination Block

RJ45

Optional connector

Optional connector

RJ45

Cable channel under test (Cat 5e/6/6A UTP with connectors, L = 1 to 100 meters)

All unused pairs terminated with 50 Ω

Shielded RJ45-to-SMA Breakout/ Termination Board

100 Ω differential

50 Ω

50 Ω

0-degree splitter for common-mode (Mini-Circuits ZFSC-2-4-S or Tyco H-8-4)

Power Splitter

180-degree splitter for differential-mode (Tyco H-81-4 or Mini-Circuits ZFSCJ-2-1)

50 Ω

Mini-Circuits ZFL-1000LN (+20 dB Gain)

LNA

50 Ω

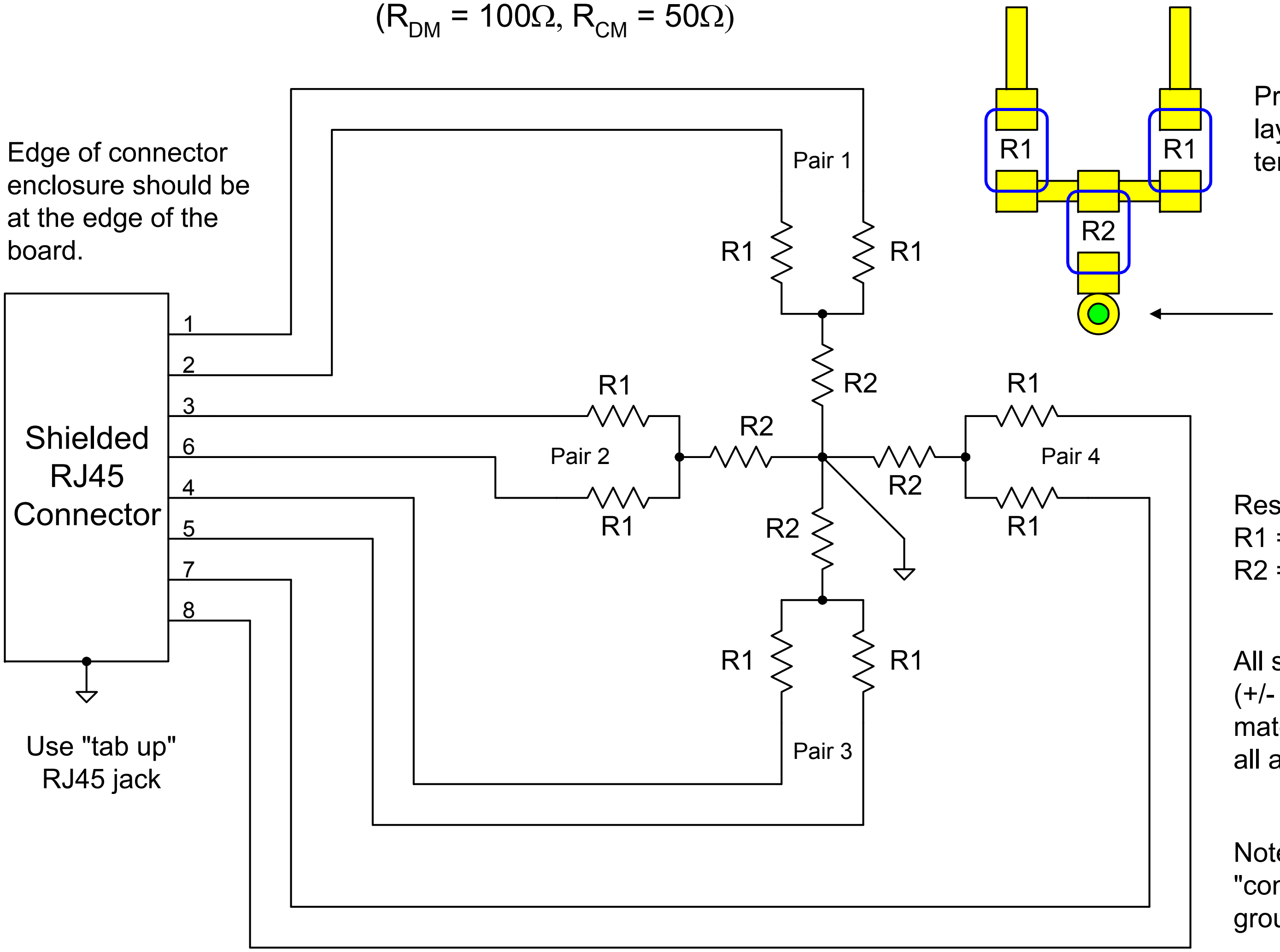
Optional low-pass filter (f_{3dB} = 200 MHz to 400 MHz)

Mini-Circuits SLP-250 (225 MHz)
Mini-Circuits SLP-300 (270 MHz)
Mini-Circuits SLP-450 (400 MHz)

Design of RJ45 CM-DM Termination Block

RJ45 Termination Block
(R_{DM} = 100Ω, R_{CM} = 50Ω)

Edge of connector enclosure should be at the edge of the board.



Use "tab up" RJ45 jack

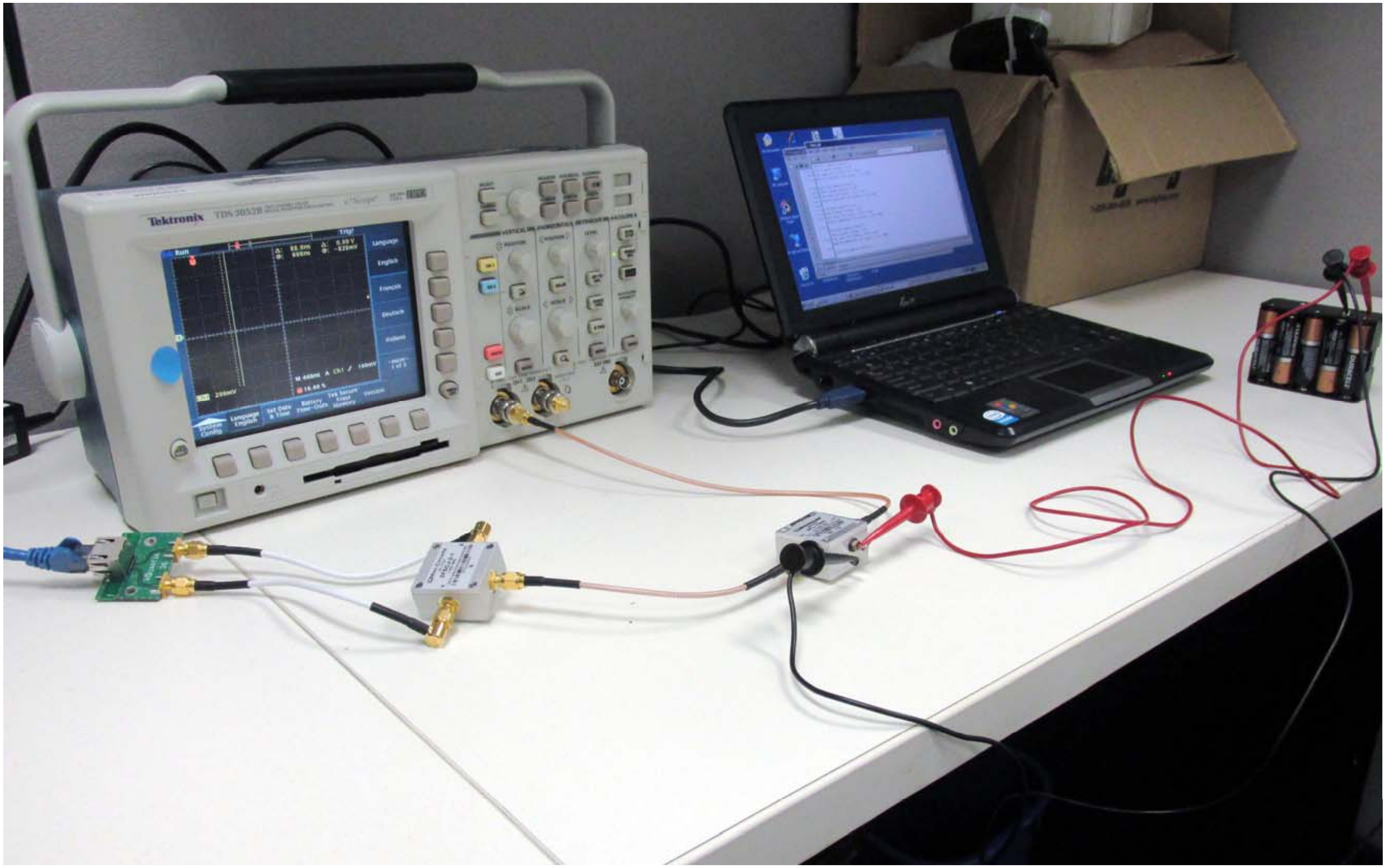
Proposed symmetrical PCB layout of resistors to preserve termination balance.

Resistor values:
R1 = 49.9Ω +/- 0.1%
R2 = 24.9Ω +/- 1%

All signal traces are 100 Ohms (+/- 10%) weakly coupled matched differential pairs, and all are the same length.

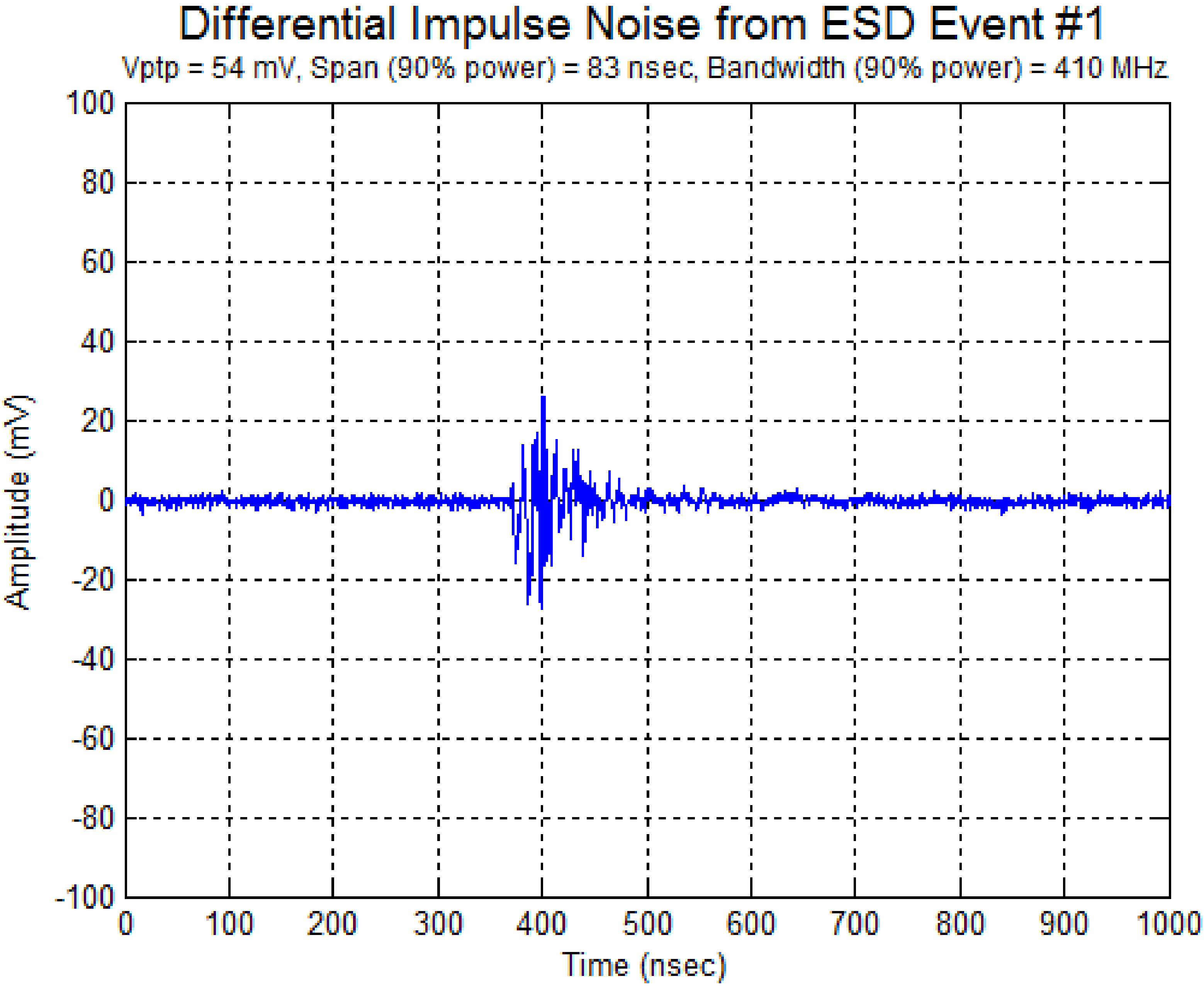
Note ground point is a "common ground", not "earth ground" and may be floating.

Implementation of Test Setup



Post-Processing of Recorded Data

- Record the raw captured scope waveform to allow application of various post-processing algorithms without having to repeat measurement
- Plot voltage impulse noise waveform seen at the attached UTP cable (what the AFE will see) and plot the PSD of the impulse with respect to background noise
- Initial post processing of impulse noise event
  - Remove DC component of captured waveform: v(t) – mean{v(t)}
  - Scale voltage data by –17 dB (-20 dB for LNA gain, +3 dB for change of Z_{REF} from 50 Ohms at scope to 100 Ohms at RJ45/UTP cable interface
  - No lowpass filtering for any data sets
- Additional post-processing of ESD impulse noise event
  - Compute PSD of ESD impulse noise event inside a 1.0 usec localized time span; note PSD level will be inversely proportional to length of computation time window
  - Compute background noise PSD from second half (2.0 usec time span) of captured impulse noise data; for most short ESD events this section contains no impulse noise
- Additional post processing of switch contact arc impulse noise event
  - Compute PSD of ESD impulse noise event over full time span of waveform (4.0 usec)
  - Use computed background noise PSD from ESD event as reference level

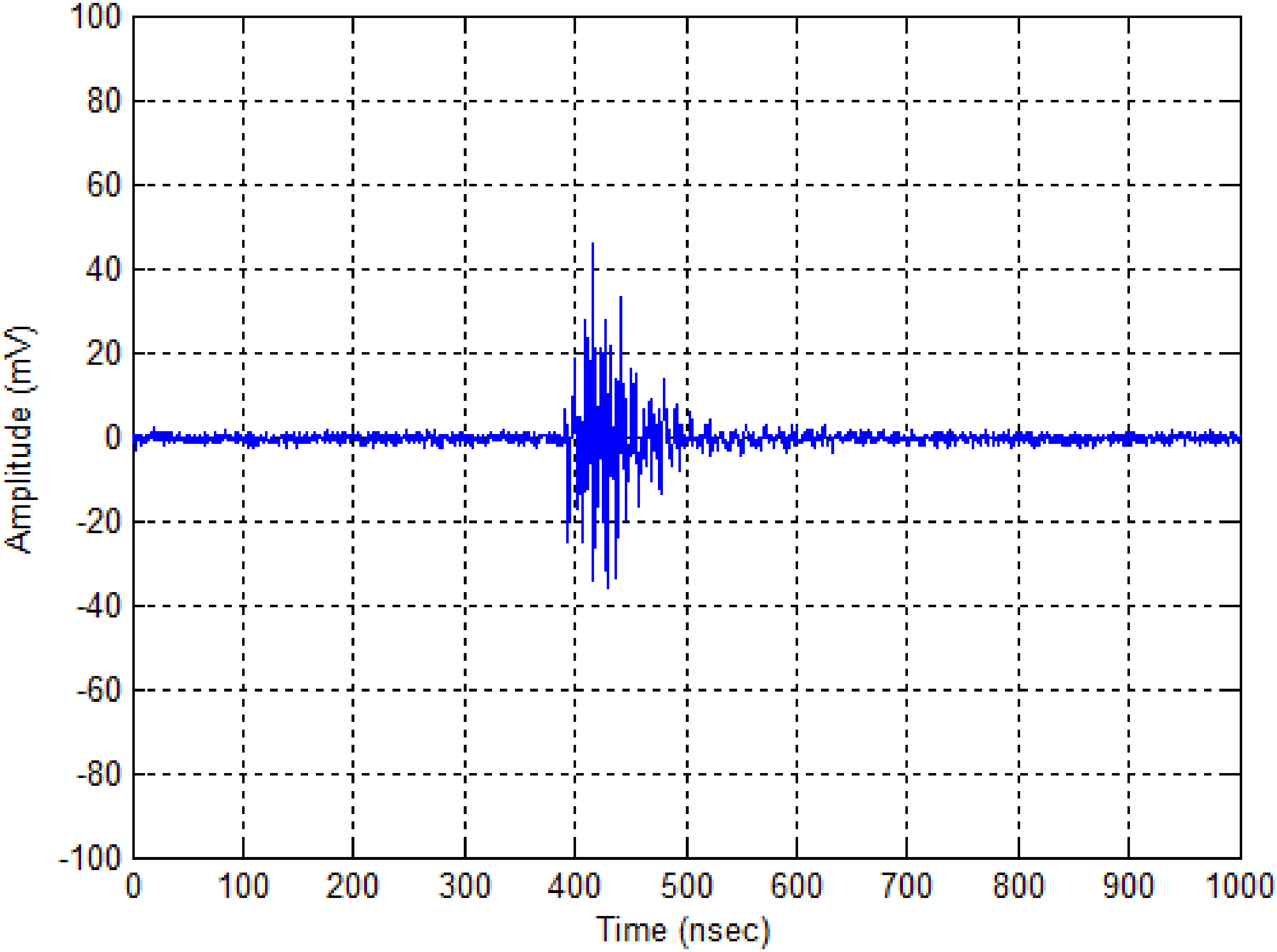


Differential Impulse Noise from ESD Event #1

Vptp = 54 mV, Span (90% power) = 83 nsec, Bandwidth (90% power) = 410 MHz

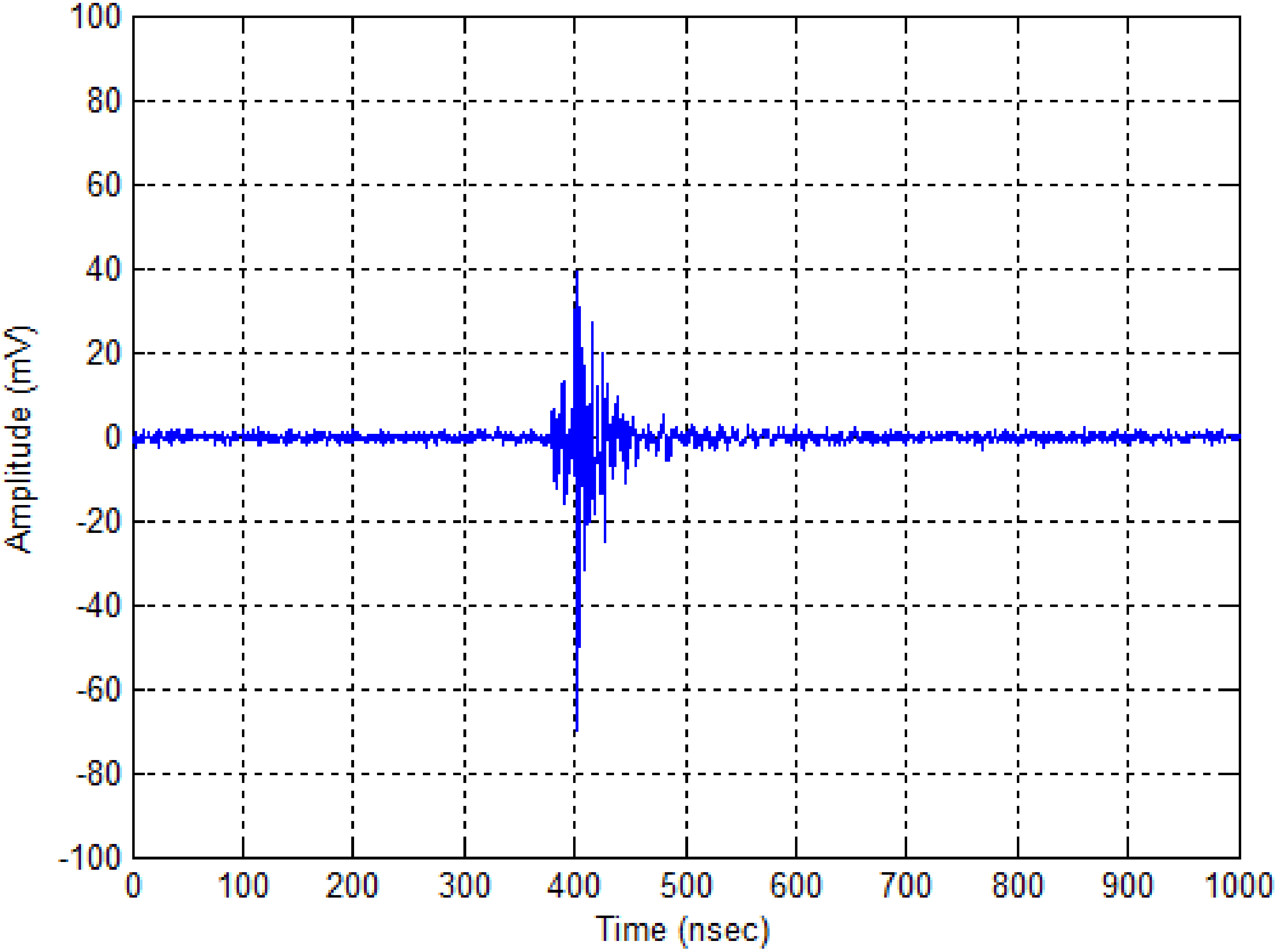
Differential Impulse Noise from ESD Event #2

Vptp = 82 mV, Span (90% power) = 85 nsec, Bandwidth (90% power) = 695 MHz



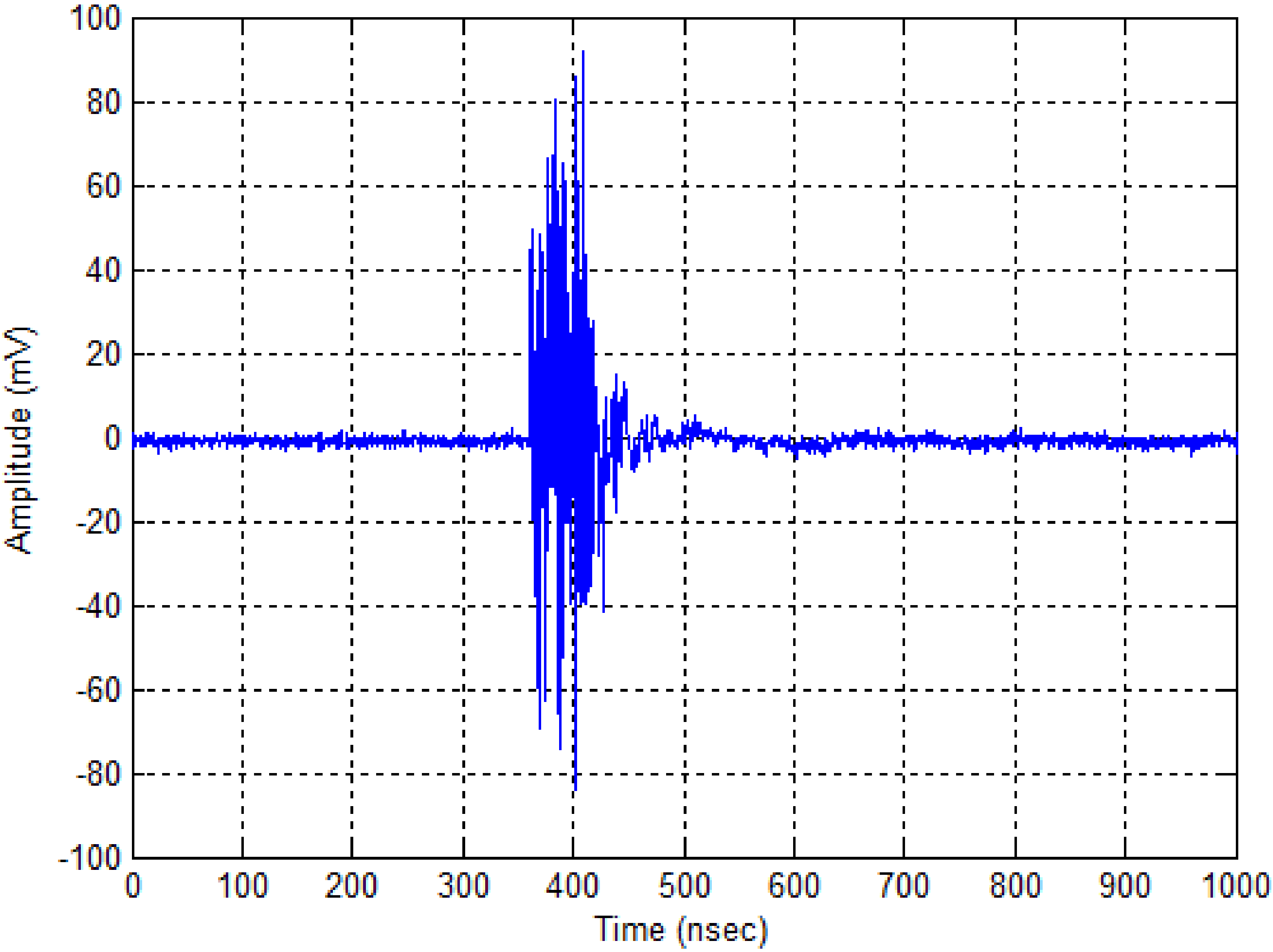
Differential Impulse Noise from ESD Event #3

Vptp = 109 mV, Span (90% power) = 44 nsec, Bandwidth (90% power) = 545 MHz



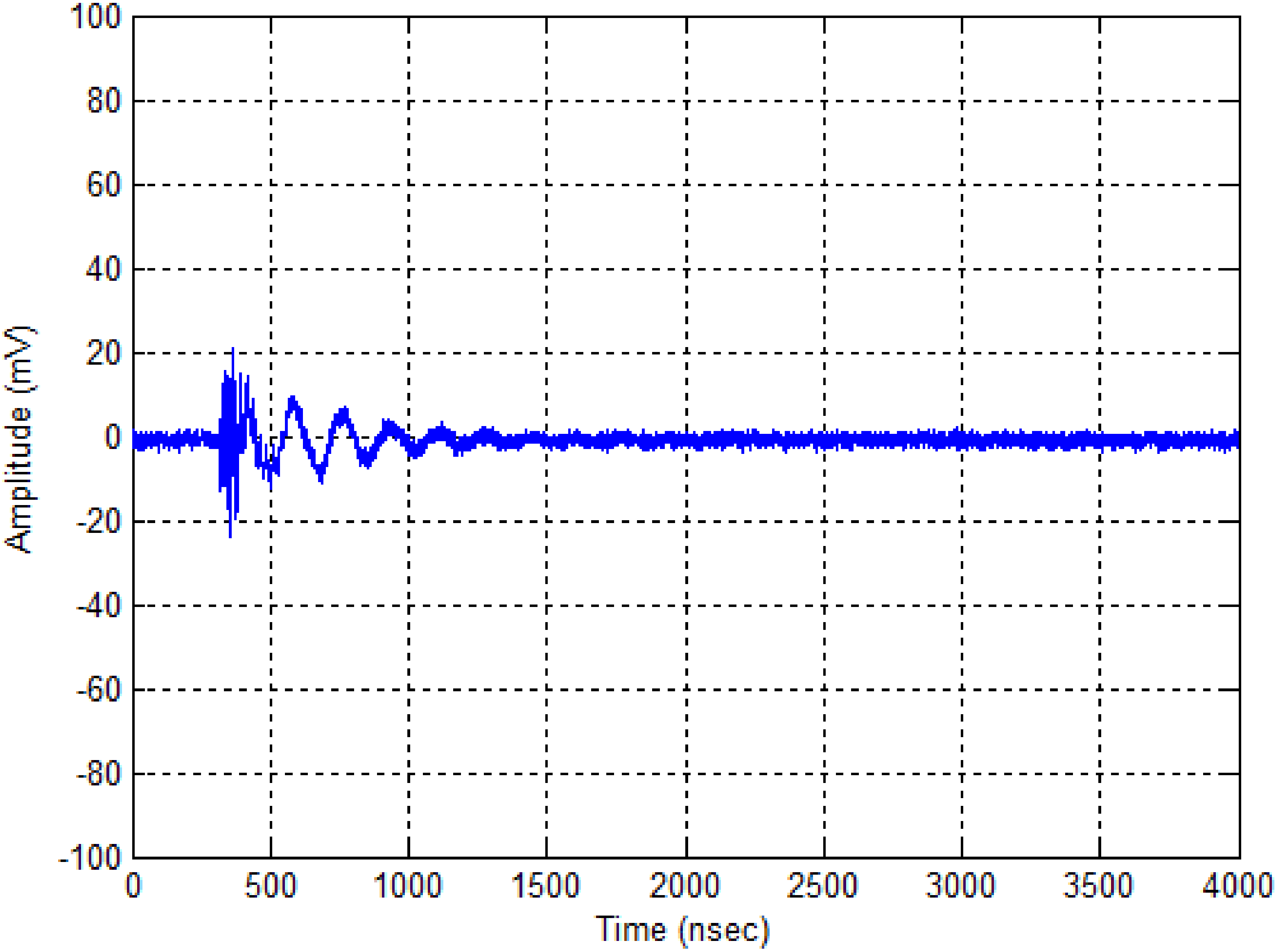
Differential Impulse Noise from ESD Event #4

Vptp = 176 mV, Span (90% power) = 63 nsec, Bandwidth (90% power) = 710 MHz



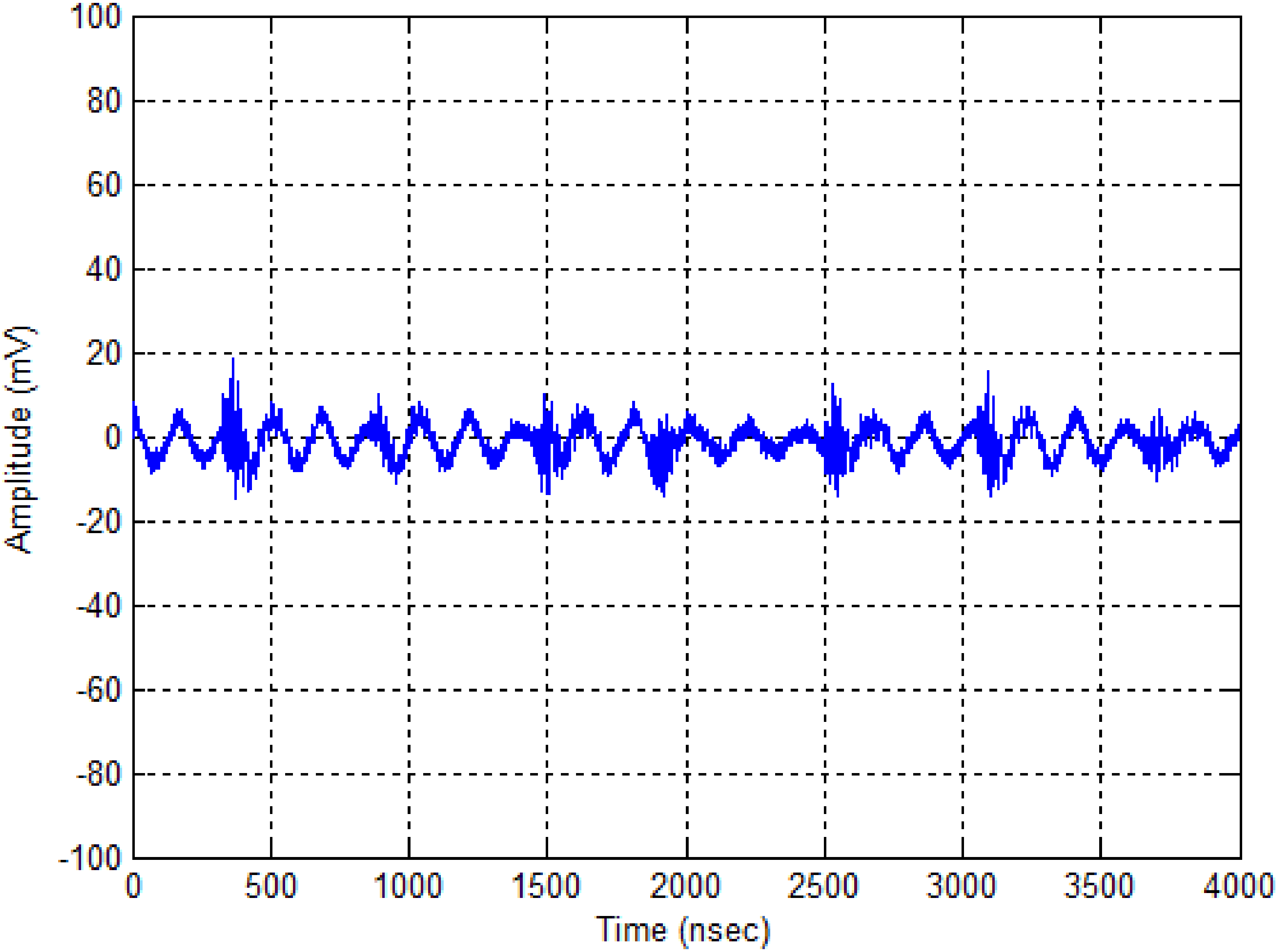
Differential Impulse Noise from Fluorescent Light Event #1

Vptp = 45 mV, Span (90% power) = 676 nsec, Bandwidth (90% power) = 593 MHz



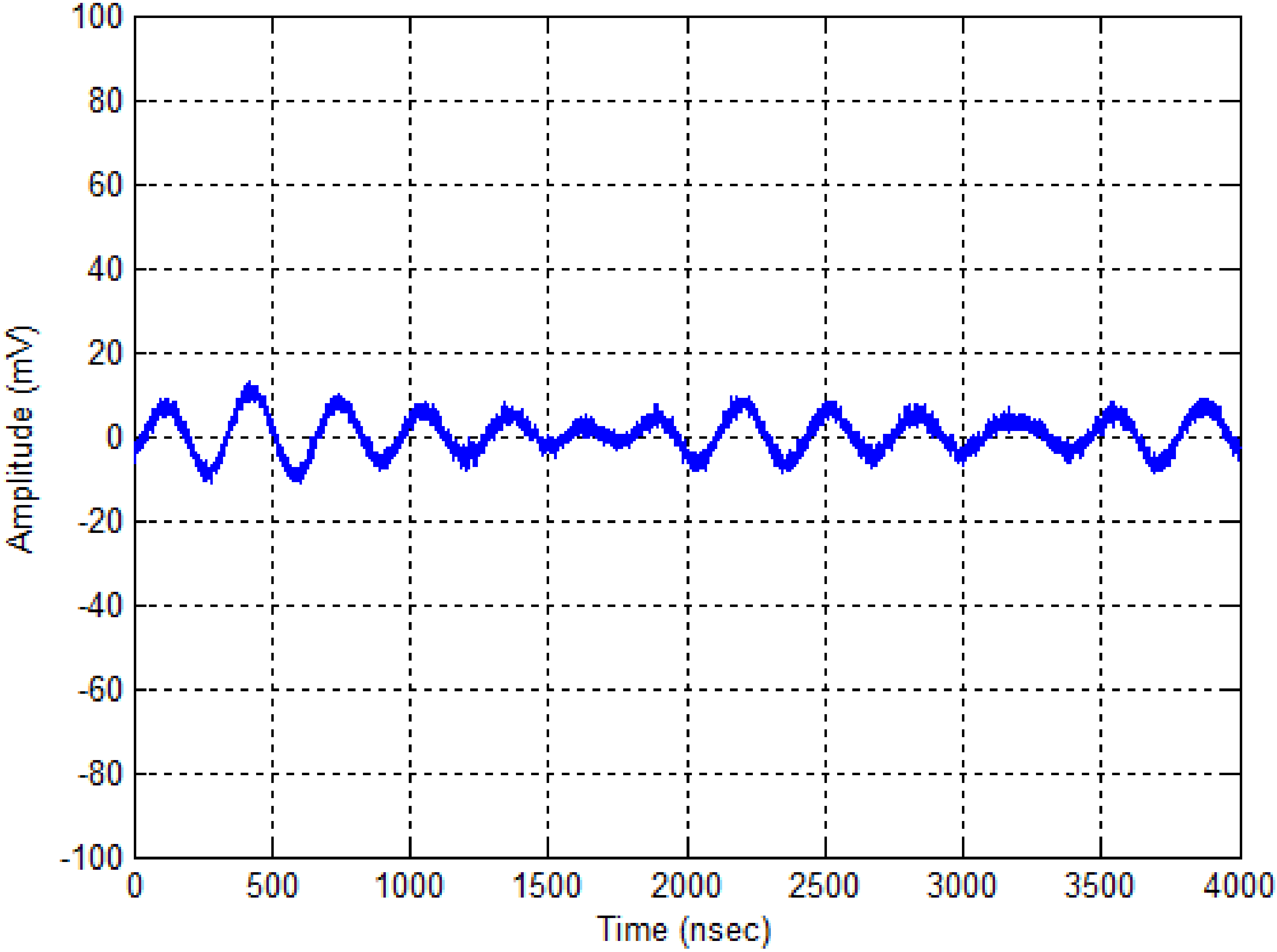
Differential Impulse Noise from Fluorescent Light Event #2

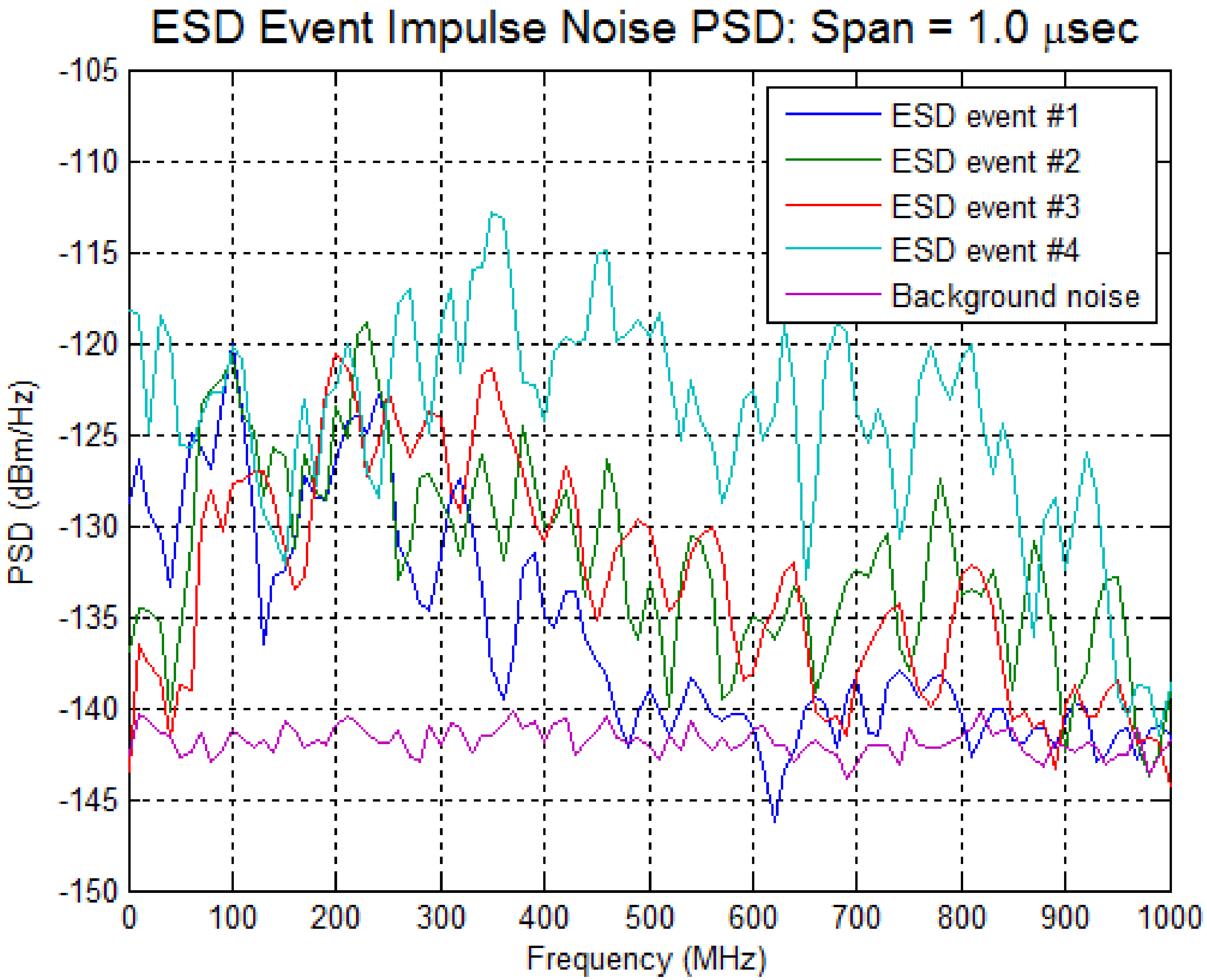
Vptp = 33 mV, Span (90% power) = 4000 nsec, Bandwidth (90% power) = 306 MHz



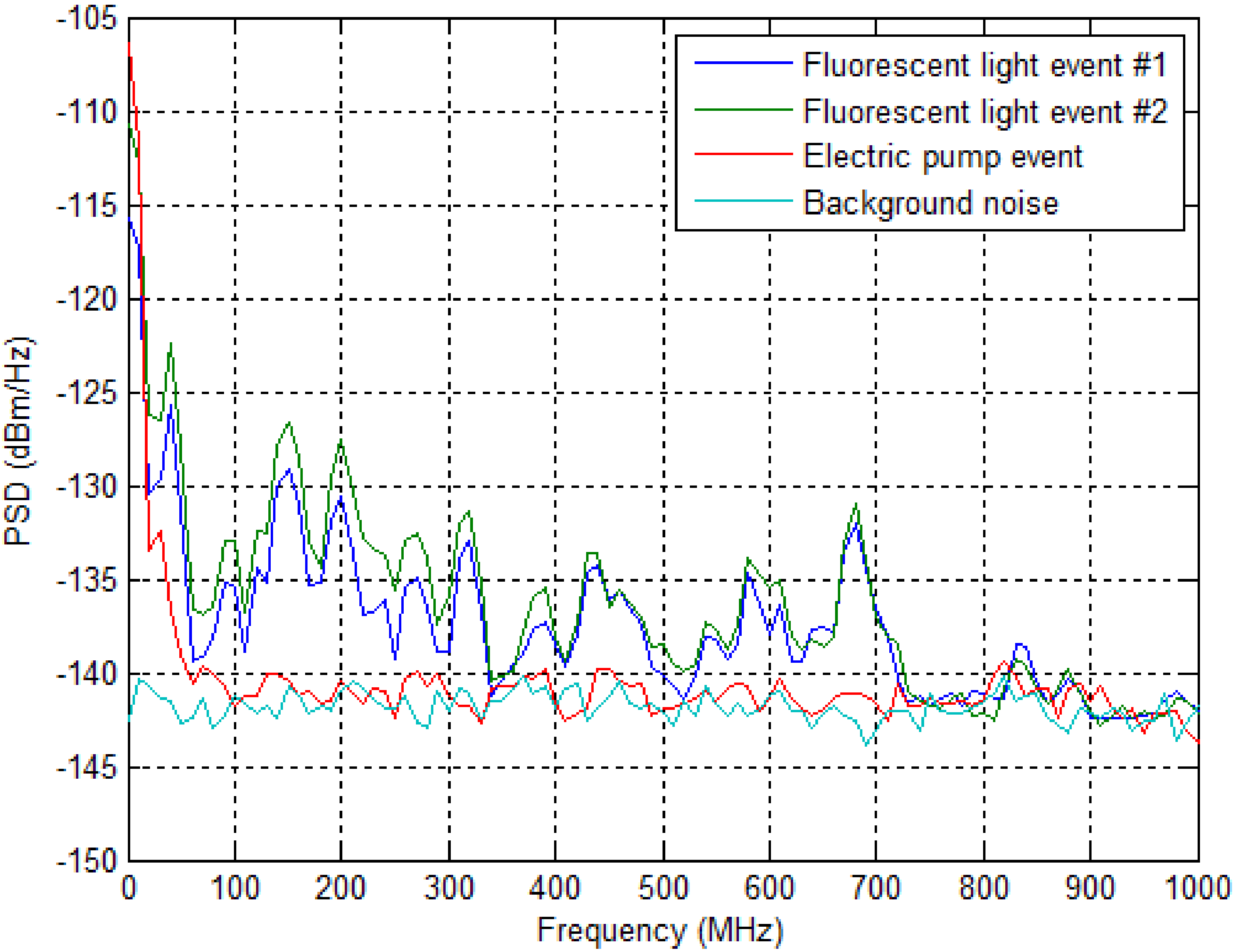
Differential Impulse Noise from Electric Pump Event

Vptp = 24 mV, Span (90% power) = 4000 nsec, Bandwidth (90% power) = 3 MHz




ESD Event Impulse Noise PSD: Span = 1.0 μsec
-105
-110
-115
-120
-125
-130
-135
-140
-145
-150
PSD (dBm/Hz)
0
100
200
300
400
500
600
700
800
900
1000
Frequency (MHz)
ESD event #1
ESD event #2
ESD event #3
ESD event #4
Background noise

Switch Contact Arc Impulse Noise PSD: Span = 4.0 μsec



Observed Characteristics of ESD Induced Impulse Noise

- ESD induced impulse noise events are mainly generated by human activity; high event occurrence is where human occupancy and activity is high
- Lower voltage events generate a wider bandwidth impulse because of the fast rise time of the ESD current; most common source of impulse noise
  - These events are known to cause errors in 10GBase-T links
  - Generally from tool (metal-to-metal) contact ESD
- High voltage events produce a longer spark gap which increases the rise time of the ESD current; skews energy distribution towards lower frequencies
- Impulse noise from lower voltage events have a slight “highpass” shaped PSD with most energy above 200 MHz
  - RF ingress in UTP increases as frequency increases (depends upon cable length and orientation with respect to the radiation source)
  - Less impulse noise energy below 200 MHz may explain why 1000Base-T operation is not degraded by the occurrence of ESD events

Observed Characteristics of Switch Contact Arc Induced Impulse Noise

- On/off switch contact arc induced impulse noise generated mainly by switching inductive loads (e.g. motors, fluorescent light ballasts)
- Much longer duration and lower peak-to-peak voltage than ESD impulse noise; needs a longer capture window
- Strong low frequency content, minimal high frequency energy
  - Most energy below 50 MHz (for small inductive loads) and below 10 MHz for large inductive loads
  - Larger inductances generate higher arc voltages creating longer arc discharge paths causing a longer arc current rise time and increasing lower frequency emissions
- Need more measurement data from different sources to determine if switch contact arc impulse noise is a problem for 2.5G/5G Base-T systems
  - Measure impulse noise generated by specific equipment (e.g. desk fans, desk lamps, paper shredders, etc.)
  - Determine frequency of occurrence of such events in the enterprise environment

Observed Issues with Measurement Test Setup

- Need a longer capture window for contact arc impulse noise events; slower sample rate and/or larger capture memory depth
- Disconnecting termination block in test setup increases impulse noise ingress
- Need to use shielded RJ45-to-SMA breakout test fixture; a shielded fixture more accurately replicates the environment of a real product
- Scope vertical sensitivity may limit resolution of differential-mode waveforms since the scope V/div must be high enough to prevent waveform clipping and associated artifacts
- Potential for intra-pair delay skew (mismatched cables and breakout board trace mismatch) to introduce significant common-mode to differential conversion that limits differential signal resolution
  - Total delay skew must be <10 ps to limit C2D to -36 dB at 500 MHz (-30 dB at 1 GHz)
  - Must have tight trace length matching on SMA breakout test fixture (< 70 mils with perfect cables)
  - Use short matched cables for test setup as the shorter length limits total delay skew
- Accuracy may be slightly improved by gain scaling with actual measurement data from the test fixturing (splitter, LNA, and all cables); –20 dB correction for LNA and test fixture is approximate

Summary of Results from Initial Measurements

- Initial set of measurements was in a limited office environment with insufficient human activity level to obtain useful inter-arrival interval data of impulse noise events
- Gathered a set of impulse noise samples from common ESD and switch contact arc events that could occur in a typical desk cubicle
- Examination of impulse noise waveforms and PSDs from various ESD and switch contact arc impulse noise samples
- The impulse noise spectrum from some ESD events show a slight highpass shape which may explain limited ESD effects on 1000Base-T systems
- A longer capture window is required for contact arc impulse noise events; slower sample rate and/or larger capture memory depth

Steps for Next Measurement Survey Cycle

- Measure data from office area with more human activity to obtain inter-arrival time and energy distribution statistics on impulse noise events; need at least one location with low relative humidity
- Measure impulse noise from plug/unplug, on/off, and operation of common office devices: small fans, paper shredders, desk lamps (both CFL and LED bulbs)
- Test setup issues
  - Increase capture window time span for on/off switch contact arc impulse noise events
  - Use a shielded RJ45-to-SMA breakout test fixture
- Define a standard post-processing procedure for captured impulse noise data (e.g. set time span window length for PSD computation, lowpass filtering)
- Record relative humidity of each measurement site