Enterprise Environment Impulse Noise Measurements

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Why Is Impulse Noise a Problem ?

- An impulse noise event is an isolated transient interference signal that occurs :
  - Ingress of radiated energy from nearby electrostatic discharge (ESD) events
  - Switch contact arc transients from electrical appliances (e.g. lighting, motorized equipment); these events are also known as electrical fast transients (EFT)

- Main problem: Frequent impulse noise interference events can increase the bit error rate of an otherwise properly operating data link above specified limits

- Low-level ESD events (which are normally not perceptible) and low-power EFT events outside the scope of existing EMC standards can interfere with the operation of newer high-speed data links in the enterprise environment

- This presentation measures the characteristics of impulse noise from low-level ESD and EFT events in the enterprise environment and their potential problems in the deployment of 2.5G/5G Base-T systems

Why Study Impulse Noise?

- Standard EMC regulations cover compliance requirements for very large impulse noise events caused by high-voltage ESD events and large switch contact arc transients (EFT)
  - Typical ESD test levels are 4 kV contact discharge and 8 kV air discharge
  - Main intent is to insure that terminal equipment does not get damaged or destroyed by strong ESD and EFT events during normal operation
- EMC standards are not designed to verify operational integrity (Bit error degradation) of data links under normal operating conditions
  - EMC standards do not test the operational effects (Bit error degradation) of more frequent low-level ESD (or EFT) events below potentially damaging energy levels
  - ESD test waveforms are not fully representative of the interference that may be encountered in the enterprise environment under normal operating conditions
- NGEA Base-T standards should provide necessary test guidance for impulse noise interference from low-level ESD and EFT sources to ensure proper operational integrity across products from different manufacturers

What We Will Cover

- Analyze various impulse noise sources and the problems created by impulse noise in the deployment of 2.5G/5G Base-T in the enterprise environment
- Impulse noise measurement test setup and post-processing procedure
  - Examine noise from common ESD events, common office appliances on/off transients, and furniture ESD events
  - Measure signal bandwidth, time span, and peak-to-peak differential voltage of impulse noise events
- Impulse noise measurement data
  - Time-domain and frequency-domain measurement data from various sources
  - Example captured impulse noise waveforms
- Impulse noise observations, including special case of furniture ESD
- Summary of measurement results

Impulse Noise in the Enterprise Environment

- Enterprise environment includes any location that supports a wired or wireless information access network
  - Includes public libraries, restaurants, building/office lobbies, warehouses, schools, etc., not limited to just office areas and data centers
  - Scope of the enterprise environment is much wider than the data center environment; a data center environment is often tightly controlled and maintained
- Consider two basic placement site scenarios for gathering data: nearby wired LAN ports (mainly in laptops) and wireless access points
  - Nearby wired LAN ports → Few sources in close proximity (e.g. inside a cubicle)
  - Wireless access points → Potentially many sources in a limited area

Examples of Observed Impulse Noise Sources

- Examples of ESD generated impulse noise sources in the enterprise environment
  - Metal-to-metal (tool) contact discharge between isolated metal objects of different charge or one metal object to a grounded metal surface
  - Movement of furniture, specifically desk chairs or mobile file cabinets, and subsequent charge transfer (contact) to another object
  - Sitting down or standing up in desk chairs; ESD generated externally by surface friction or generated inside the chair cushion itself (special case to be discussed)
  - Cable discharge event (CDE) from plugging a network cable into a computer LAN port
  - Intensity and frequency of occurrence of all ESD events increased by low relative humidity and human activity (e.g. walking around)
- Examples of contact arc impulse noise sources 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 kitchen appliances

Special Case: Impulse Noise from Furniture Generated ESD

- Sitting down and/or standing up from some commonly used office desk chairs can generate significant impulse noise from ESD by two different mechanisms
  - ESD events generated externally by surface friction with the upholstery and subsequent body contact with another surface, including the frame of the chair
  - ESD events generated inside the chair cushion and/or by mechanical stress relief in the frame

- Special characteristics of internally generated desk chair ESD impulse noise
  - Effect first observed over 20 years ago (Ref 1), even in some "ESD safe" chairs
  - Grounding chains and standard ESD mitigation methods (e.g. dissipative flooring) have no effect on this generation mechanism
  - Impulse noise generation does not require seat occupant to contact any other surface
  - Standing up once can generate <u>multiple</u> impulse noise events over a 10-second time span
  - In Cat 5e UTP cable, resulting impulse noise events up to 40 mV ptp have been observed at 30 feet away (very significant !!)
  - Generation of internal furniture ESD events influenced by relative humidity and possibly mechanical stress between the arm rests and the body of the chair

- In locations that contain many of the above chairs and subject to frequent human activity, interfering noise events can be frequent enough to increase the bit error rate of nearby data links above the required performance limit

- 2.5G/5G links with < 200 MHz bandwidth are fairly prone to Impulse Noise events with strong content below 200MHz (more to come)

Example Chairs that Generate ESD Events

Black Chair

Mesh Chair

Green Chair

Low Cost Guest Chair

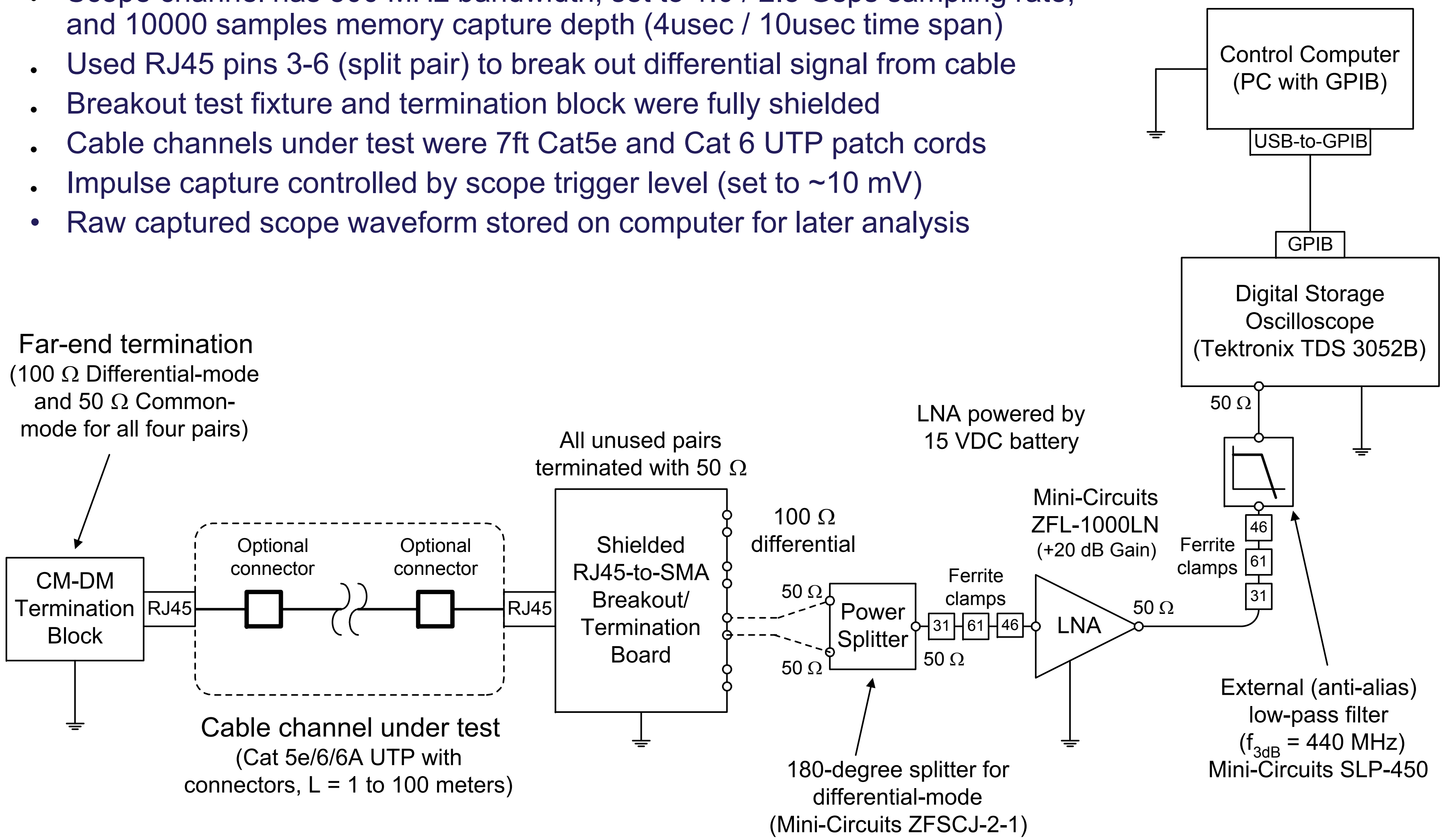
- Above office desk/task chairs were observed to generate ESD events internally within the cushion and/or frame
- The mesh chair (middle) generated the most internal noise
- ESD events can be generated inside the chair cushion or chair frame itself; chair grounding chains have no effect on this generation mechanism
- ESD events usually exhibit a band-pass shaped spectrum, often between 100 MHz and 200 MHz
- Low-cost guest chair generate lots of ESD events (from upholstery) after standing up and contacting other metal surfaces, including the chair frame itself

Example Enterprise Space With a Desk Chair ESD Problem: Public Library

- 24 stations with 24 desk chairs inside an 8m x 8m area
- Each computer station has a wired LAN port
- Room also has a wireless access point in ceiling (4 to 7m away)
- Desk chairs of this type can generate significant impulse noise events (> 40 mV ptp at 5m in Cat 5e UTP, <u>after 220 MHz (AFE) lowpass filtering</u>)
- Time limit at each station → tens or hundreds of events per hour during busy periods from the chairs alone, excluding ESD noise events from other sources

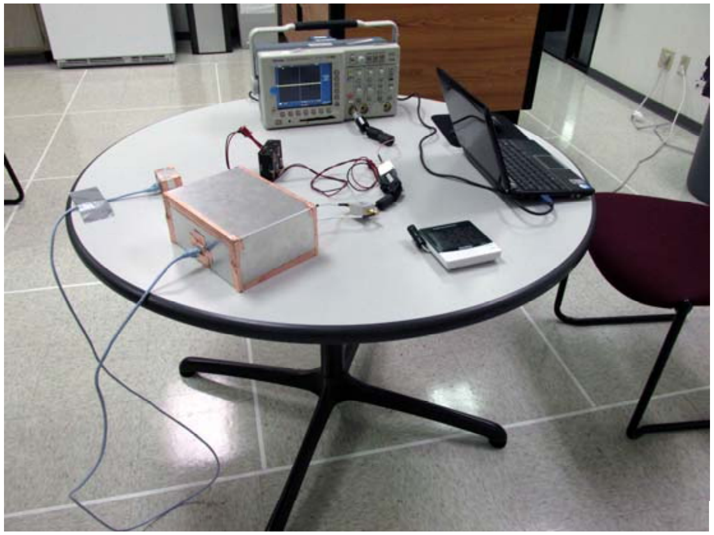
Impulse Noise Event Measurement Test Setup

- Scope channel has 500 MHz bandwidth; set to 1.0 / 2.5 Gsps sampling rate, and 10000 samples memory capture depth (4usec / 10usec time span)
- Used RJ45 pins 3-6 (split pair) to break out differential signal from cable
- Breakout test fixture and termination block were fully shielded
- Cable channels under test were 7ft Cat5e and Cat 6 UTP patch cords
- Impulse capture controlled by scope trigger level (set to ~10 mV)
- Raw captured scope waveform stored on computer for later analysis



Measurement Test Site Placement For Initial Survey

- Measurement test site #1: Inside an office cubicle to simulate environment of a computer with a wired LAN port in an office
- Measure impulse noise from common desktop electrical appliances (e.g. lamps, fans, etc) at normal operating range and nearby ESD events that may occur during daily activities



- Measurement test site #2: Office break room
- Open area used as a test range to measure impulse noise from desk chairs at various distances
- Also used to measure frequency of occurrence of common ESD events correlated with human activity; lots of foot traffic in area during meal hours

Post-Processing of Recorded Impulse Noise Data

- Record the raw captured scope waveform to allow application of various post-processing algorithms without having to repeat measurement

- 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 (differential) seen at RJ45/UTP cable interface (as seen by the AFE)
  - 180-degree splitter in test setup will transform reference impedance from 100 Ohms (differential) to 50 Ohms (single-ended), but will not add any power loss

- Compute PSD over full time span of unfiltered waveform (4.0/10.0 usec for this test setup); PSD level will be inversely proportional to length of computation time window

- Add lowpass filtering to simulate effect of AFE: 220 MHz lowpass (3rd order Butterworth) filter to simulate AFE of 5GBase-T system
  - High-pass corner to simulate line transformer supplied by AC coupling in LNA and 1 MHz lower corner frequency of 180-degree splitter

- Compute time span of impulse event (90 percent of total energy)

- Plot voltage impulse noise waveform seen at the AFE (after lowpass filtering)

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Some ESD-Based Impulse Noise Measurement Data from Cubicle (After 220 MHz Lowpass Filter)

	Cat 5e UTP		Cat 6 UTP	
Description of Event	**Peak-to-peak voltage (mV)**	**Time span (nsec)**	**Peak-to-peak voltage (mV)**	**Time span (nsec)**
Tool contact at 50 cm holding tool metal after walking on carpet	80.59	56.8	85.95	74.0
Tool contact at 50 cm holding tool handle after walking on carpet	38.38	52.4		
Tool contact at 50 cm holding tool metal after standing up from guest chair	171.89	132.8	172.17	118.8
Tool contact at 50 cm holding tool handle standing up from guest chair	93.54	41.6	65.69	81.2
Tool contact at 100 cm holding tool metal after walking on carpet	66.69	48.8	71.55	59.2
Tool contact at 100 cm holding tool metal after standing up from guest chair	88.33	79.6		
Tool contact at 100 cm holding tool handle after standing up from guest chair	119.71	70.4	68.21	66.0

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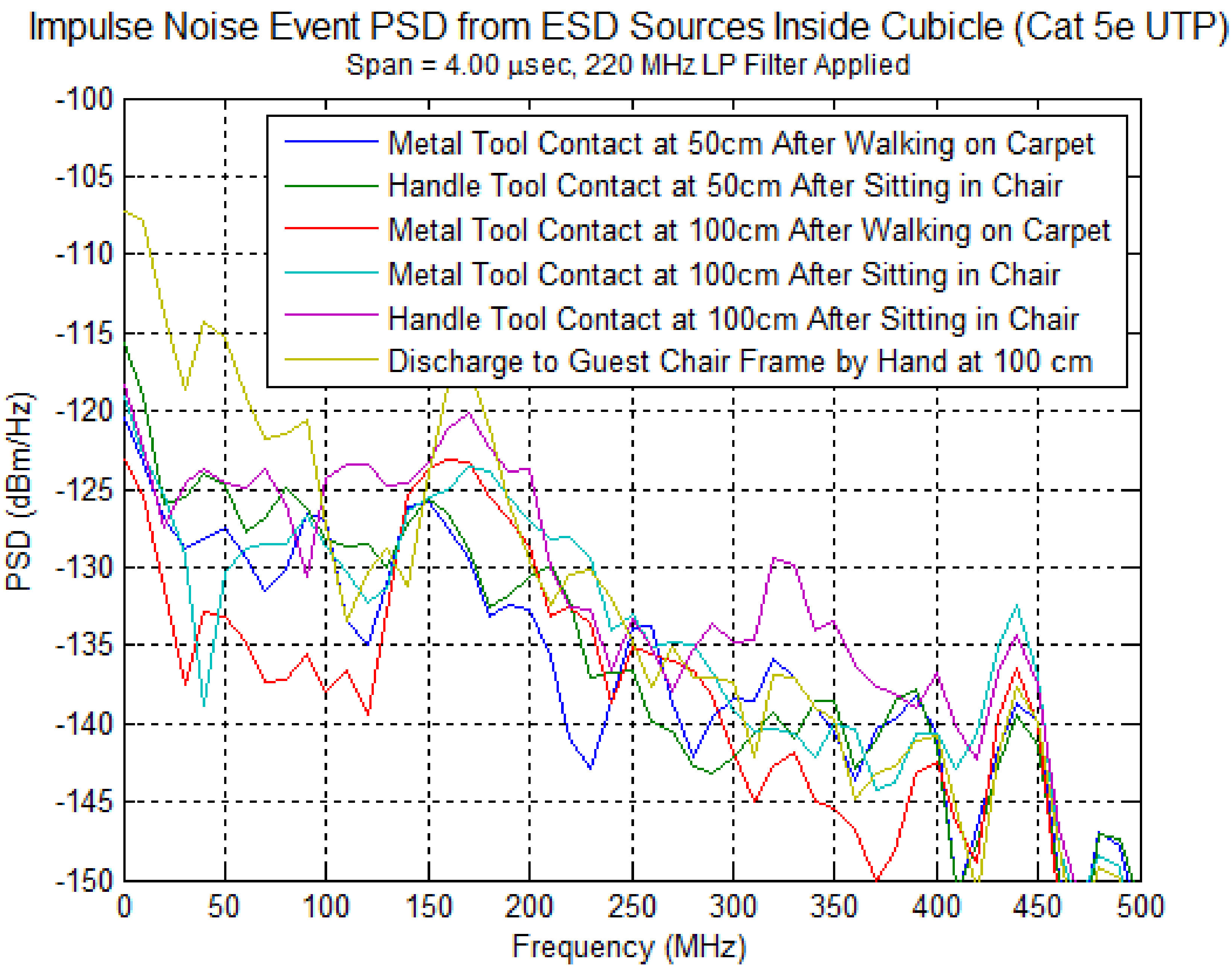
Some Switch Contact Arc Impulse Noise Measurement Data from Cubicle (After 220 MHz Lowpass Filter)

	Cat 5e UTP		Cat 6 UTP	
Description of Event	**Peak-to-peak voltage (mV)**	**Time span (nsec)**	**Peak-to-peak voltage (mV)**	**Time span (nsec)**
Desk lamp with LED bulb on/off at 50cm	31.76	222.0		
Desk lamp with CFL bulb on/off at 50cm	40.02	167.0	22.08	174.0
Under bookcase fluorescent light on/off at 50cm (short event)	135.03	743.0	55.18	2799.0
Under bookcase fluorescent light on/off at 50cm (long event)	50.19	8008.0	39.85	8048.0
Vornado desk fan on/off at 50cm (short event)	55.01	322.0	40.39	379.0
Vornado desk fan on/off at 50cm (long event)	162.91	5045.0	36.36	231.0

This data was captured using a 1 Gsps sampling rate

Some Internal Desk Chair ESD Impulse Noise Measurement Data (After 220 MHz Lowpass Filter)

	Cat 5e UTP		Cat 6 UTP	
Description of Event	Peak-to-peak voltage (mV)	Time span (nsec)	Peak-to-peak voltage (mV)	Time span (nsec)
Mesh desk chair internal ESD at 1m	143.22	54.4	107.07	90.0
Mesh desk chair internal ESD at 2m	63.40	80.8	61.15	131.6
Mesh desk chair internal ESD at 3m	50.84	208.4	54.69	166.8
Mesh desk chair internal ESD at 4m	48.89	56.8	43.62	126.0
Mesh desk chair internal ESD at 5m	38.24	57.6	18.08	74.4
Mesh desk chair internal ESD at 7m	31.51	71.2	13.37	55.6



Impulse Noise Event PSD from ESD Sources Inside Cubicle (Cat 5e UTP)
Span = 4.00 µsec, 220 MHz LP Filter Applied
Metal Tool Contact at 50cm After Walking on Carpet
Handle Tool Contact at 50cm After Sitting in Chair
Metal Tool Contact at 100cm After Walking on Carpet
Metal Tool Contact at 100cm After Sitting in Chair
Handle Tool Contact at 100cm After Sitting in Chair
Discharge to Guest Chair Frame by Hand at 100 cm
PSD (dBm/Hz)
-100
-105
-110
-115
-120
-125
-130
-135
-140
-145
-150
0
50
100
150
200
250
300
350
400
450
500
Frequency (MHz)

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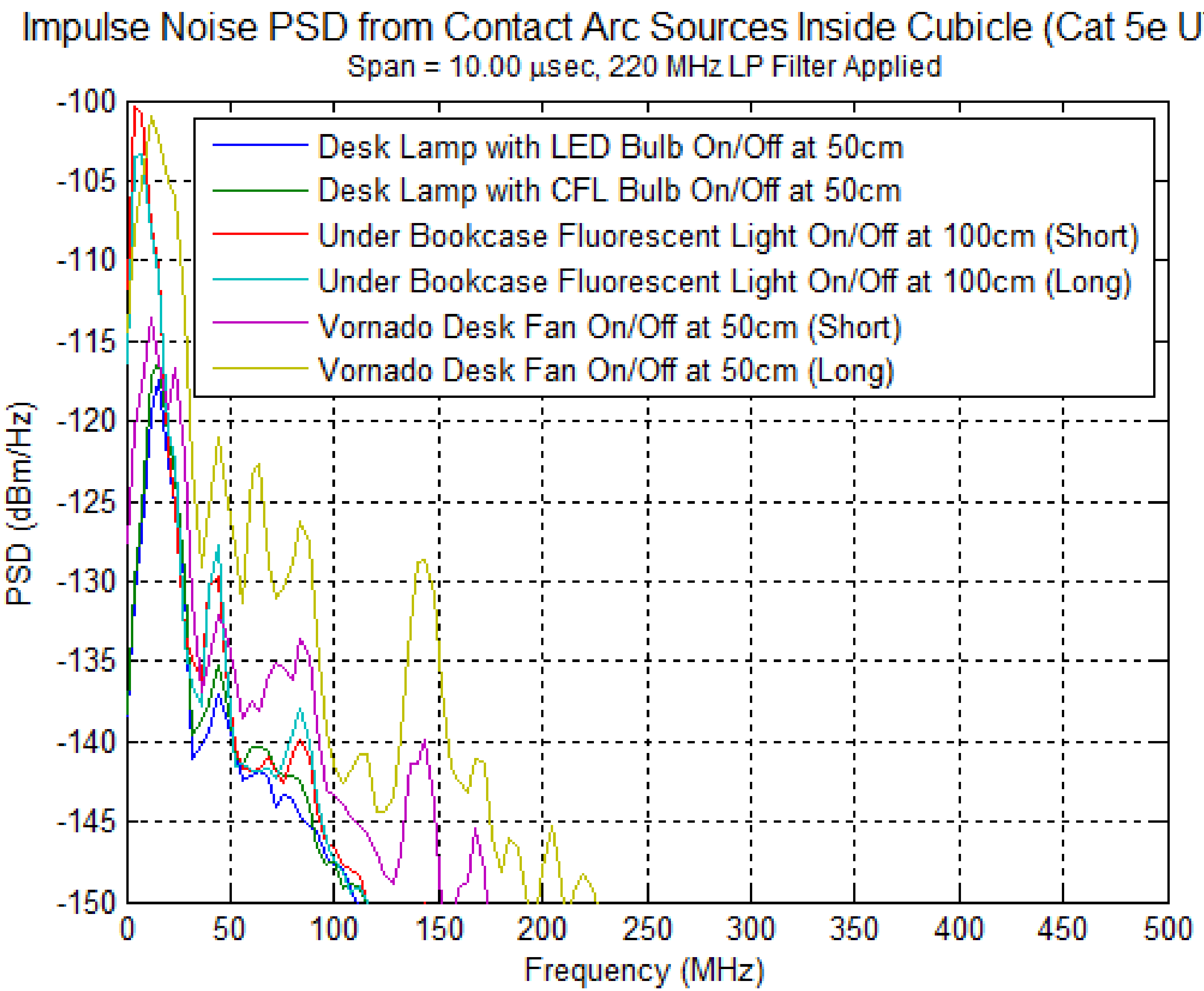
Impulse Noise PSD from Contact Arc Sources Inside Cubicle (Cat 5e UTP)
Span = 10.00 μsec, 220 MHz LP Filter Applied
Desk Lamp with LED Bulb On/Off at 50cm
Desk Lamp with CFL Bulb On/Off at 50cm
Under Bookcase Fluorescent Light On/Off at 100cm (Short)
Under Bookcase Fluorescent Light On/Off at 100cm (Long)
Vornado Desk Fan On/Off at 50cm (Short)
Vornado Desk Fan On/Off at 50cm (Long)
PSD (dBm/Hz)
-100
-105
-110
-115
-120
-125
-130
-135
-140
-145
-150
0
50
100
150
200
250
300
350
400
450
500
Frequency (MHz)

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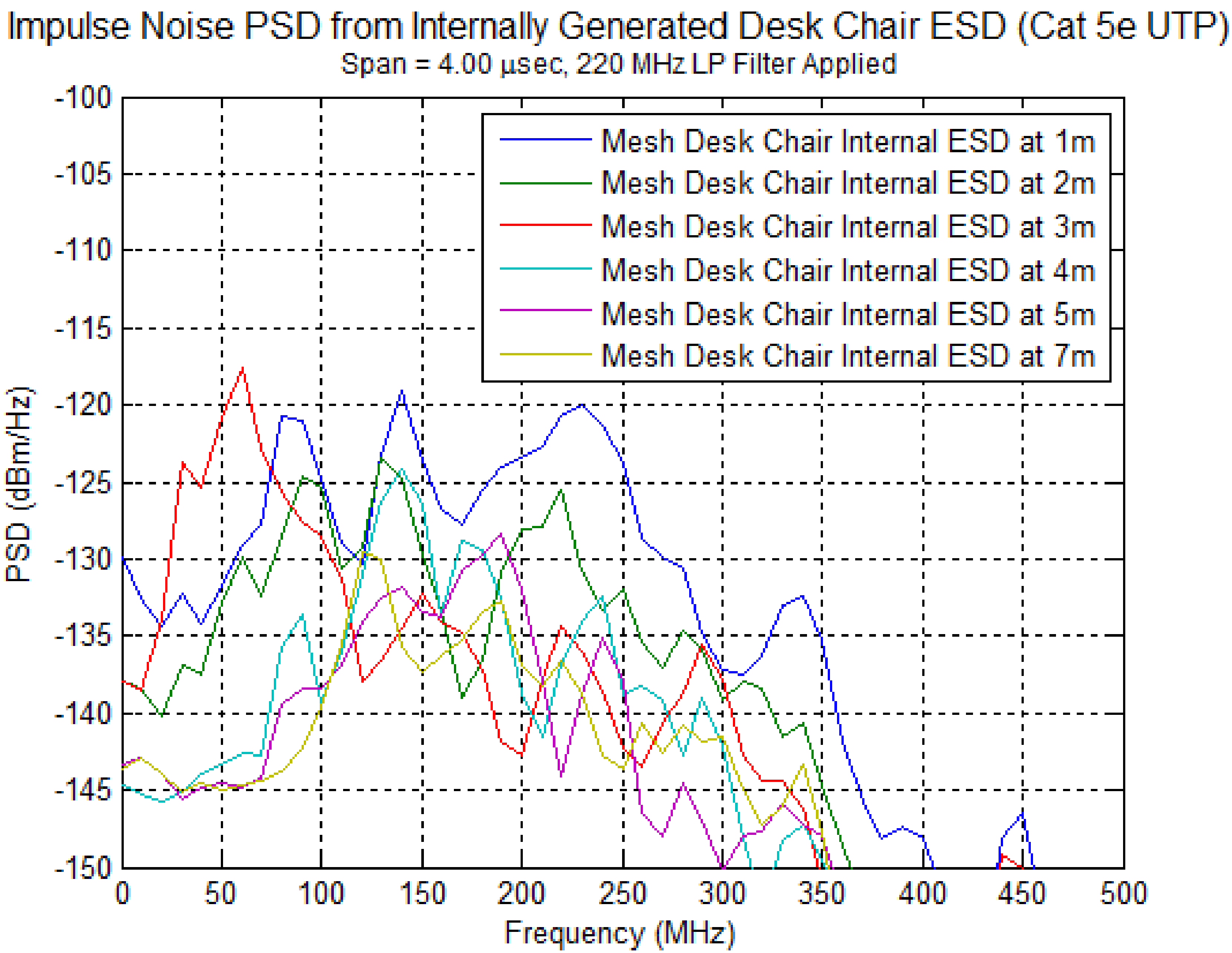
Impulse Noise PSD from Internally Generated Desk Chair ESD (Cat 5e UTP)
Span = 4.00 µsec, 220 MHz LP Filter Applied
Mesh Desk Chair Internal ESD at 1m
Mesh Desk Chair Internal ESD at 2m
Mesh Desk Chair Internal ESD at 3m
Mesh Desk Chair Internal ESD at 4m
Mesh Desk Chair Internal ESD at 5m
Mesh Desk Chair Internal ESD at 7m
PSD (dBm/Hz)
Frequency (MHz)
-100
-105
-110
-115
-120
-125
-130
-135
-140
-145
-150
0
50
100
150
200
250
300
350
400
450
500

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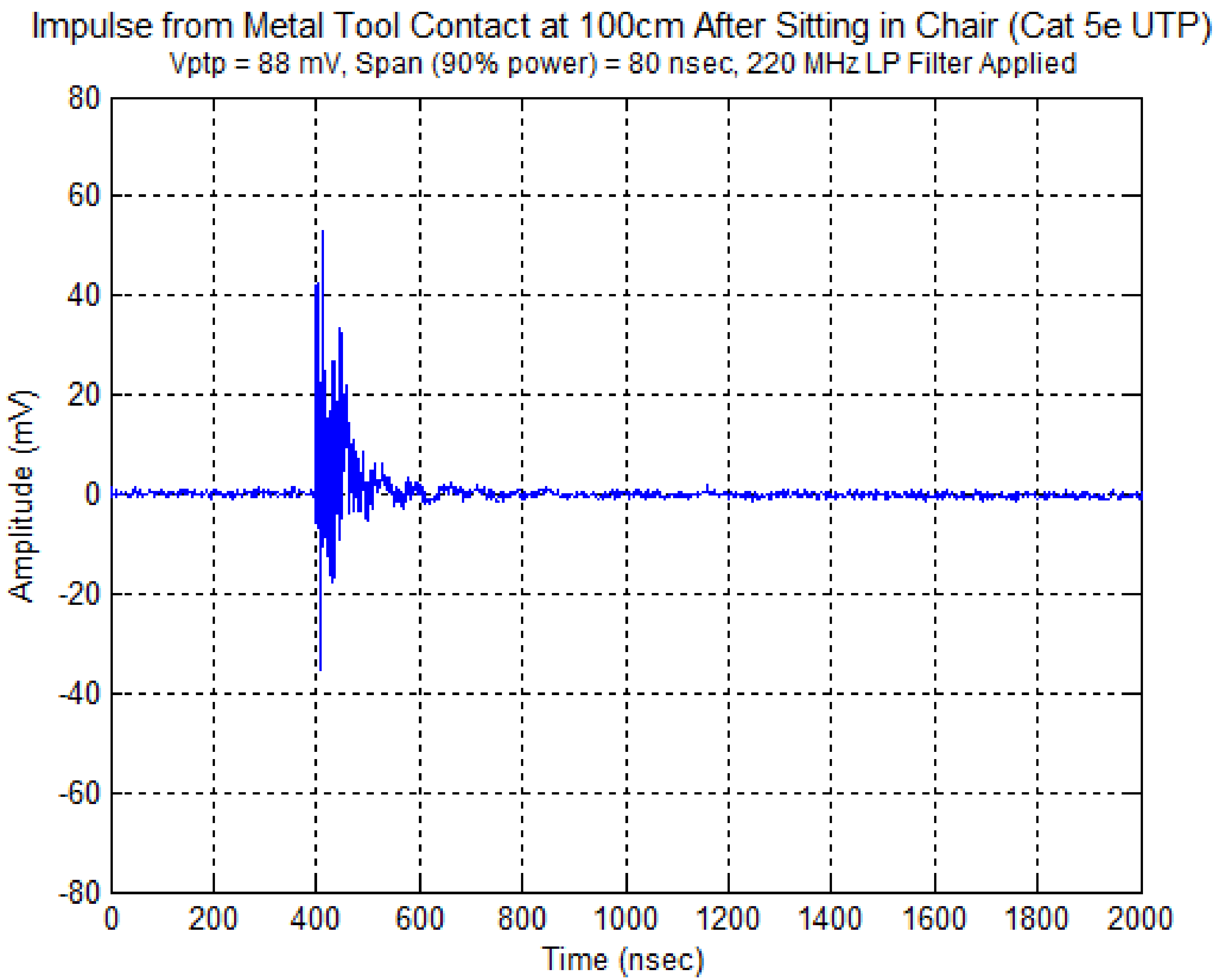
Impulse from Metal Tool Contact at 100cm After Sitting in Chair (Cat 5e UTP)
Vptp = 88 mV, Span (90% power) = 80 nsec, 220 MHz LP Filter Applied
Amplitude (mV)
80
60
40
20
0
-20
-40
-60
-80
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Time (nsec)

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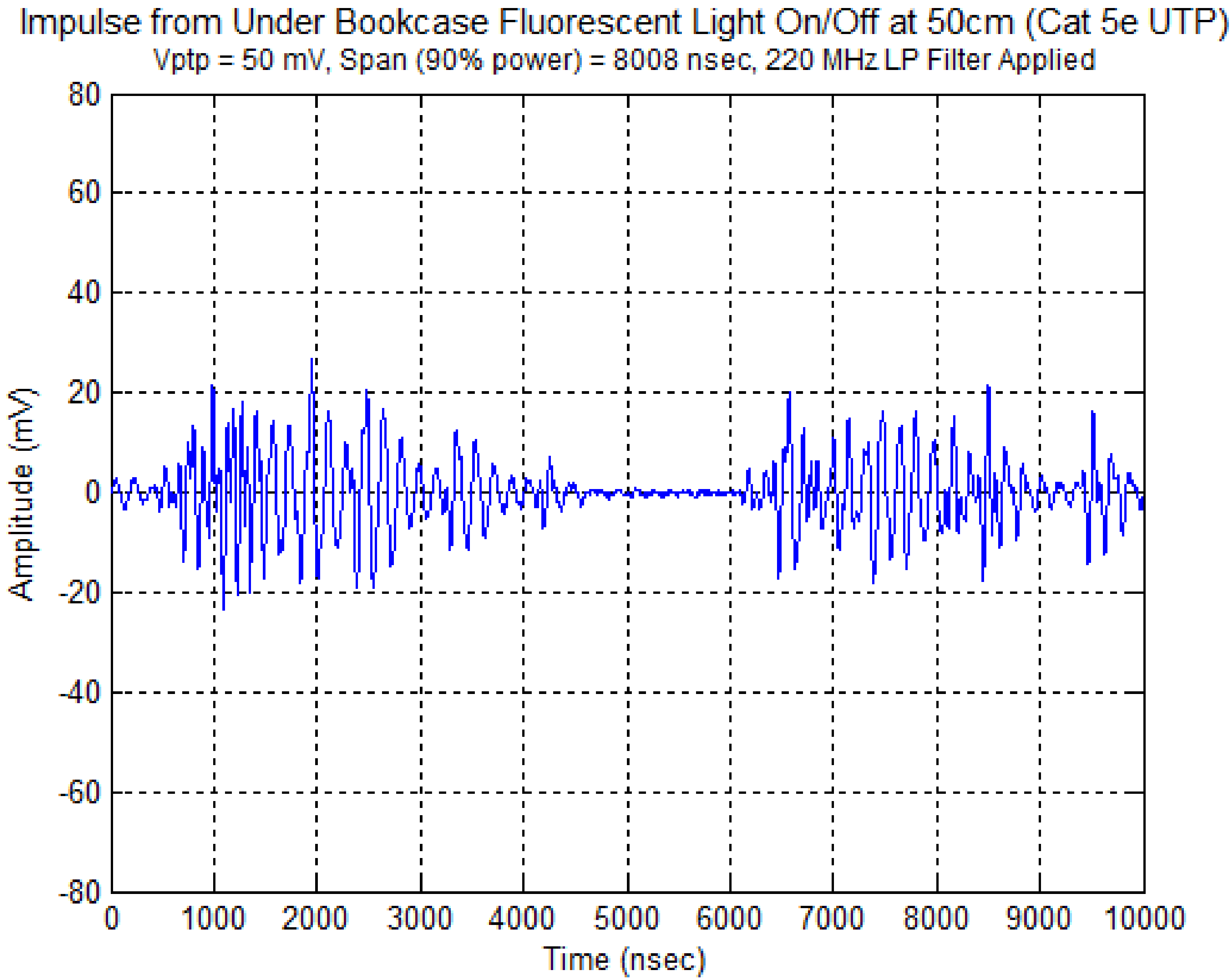
Impulse from Under Bookcase Fluorescent Light On/Off at 50cm (Cat 5e UTP)
Vptp = 50 mV, Span (90% power) = 8008 nsec, 220 MHz LP Filter Applied
Amplitude (mV)
80
60
40
20
0
-20
-40
-60
-80
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Time (nsec)

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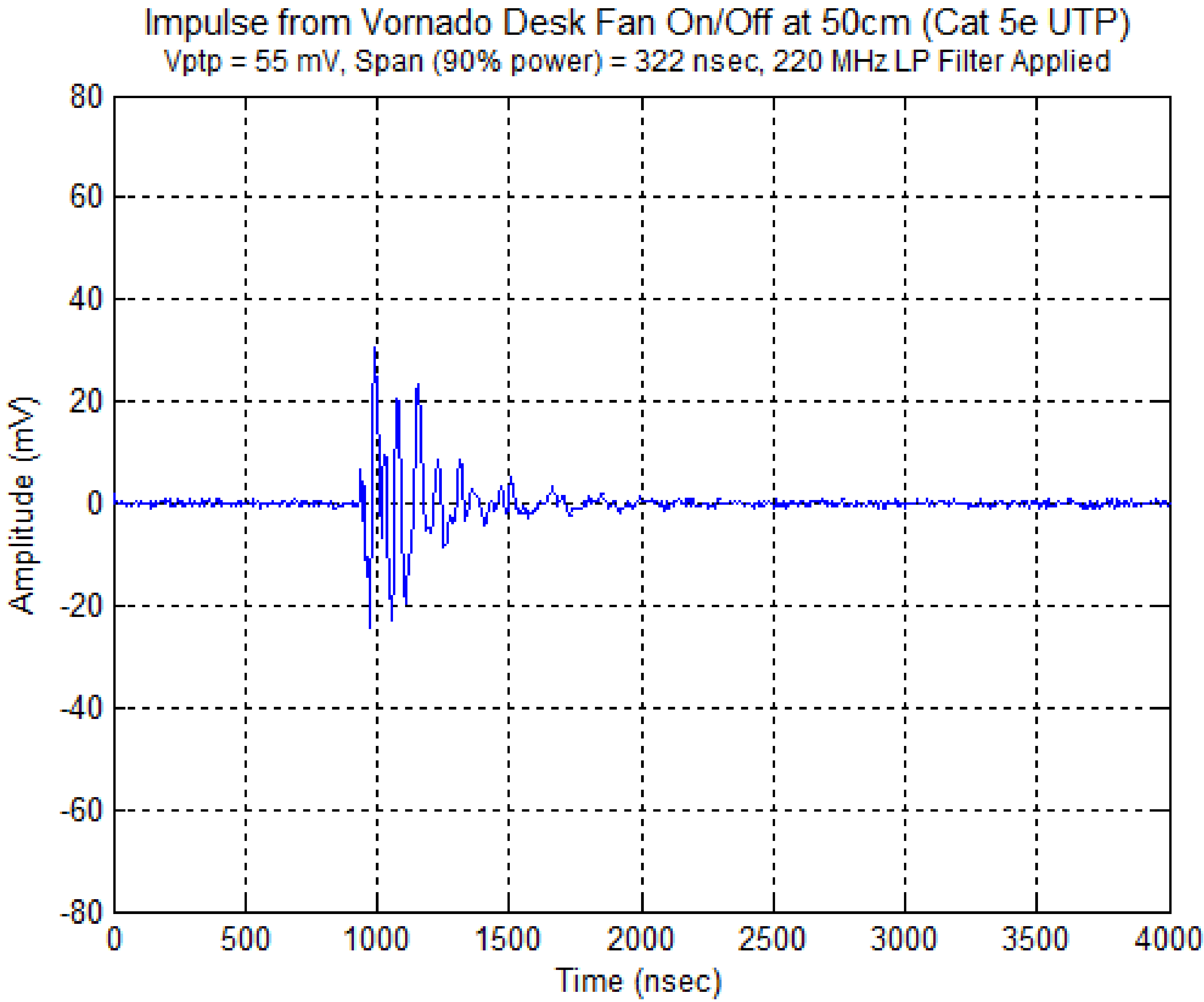
Impulse from Vornado Desk Fan On/Off at 50cm (Cat 5e UTP)
Vptp = 55 mV, Span (90% power) = 322 nsec, 220 MHz LP Filter Applied
Amplitude (mV)
Time (nsec)
80
60
40
20
0
-20
-40
-60
-80
0
500
1000
1500
2000
2500
3000
3500
4000

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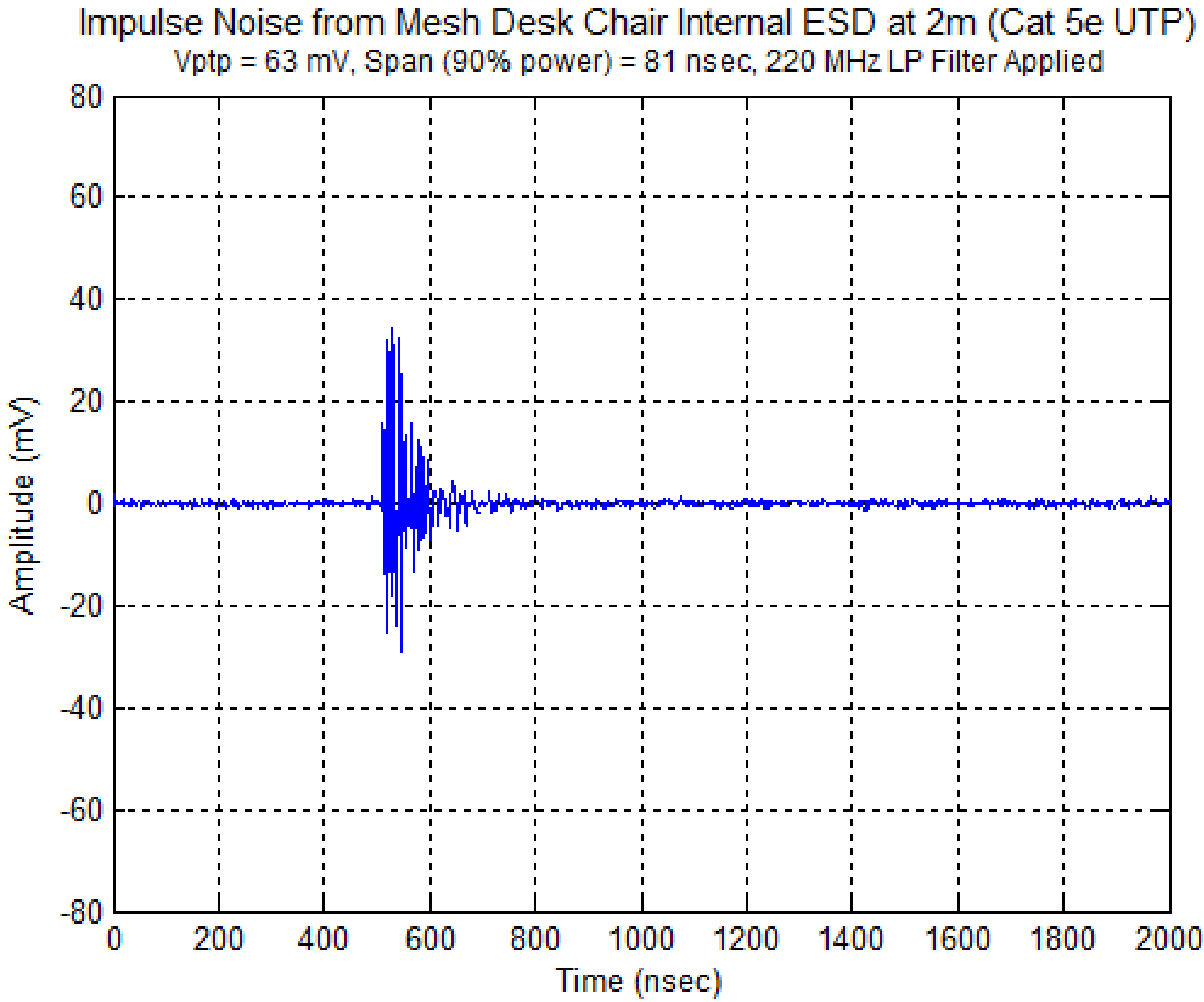
Impulse Noise from Mesh Desk Chair Internal ESD at 2m (Cat 5e UTP)
Vptp = 63 mV, Span (90% power) = 81 nsec, 220 MHz LP Filter Applied
Amplitude (mV)
80
60
40
20
0
-20
-40
-60
-80
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Time (nsec)

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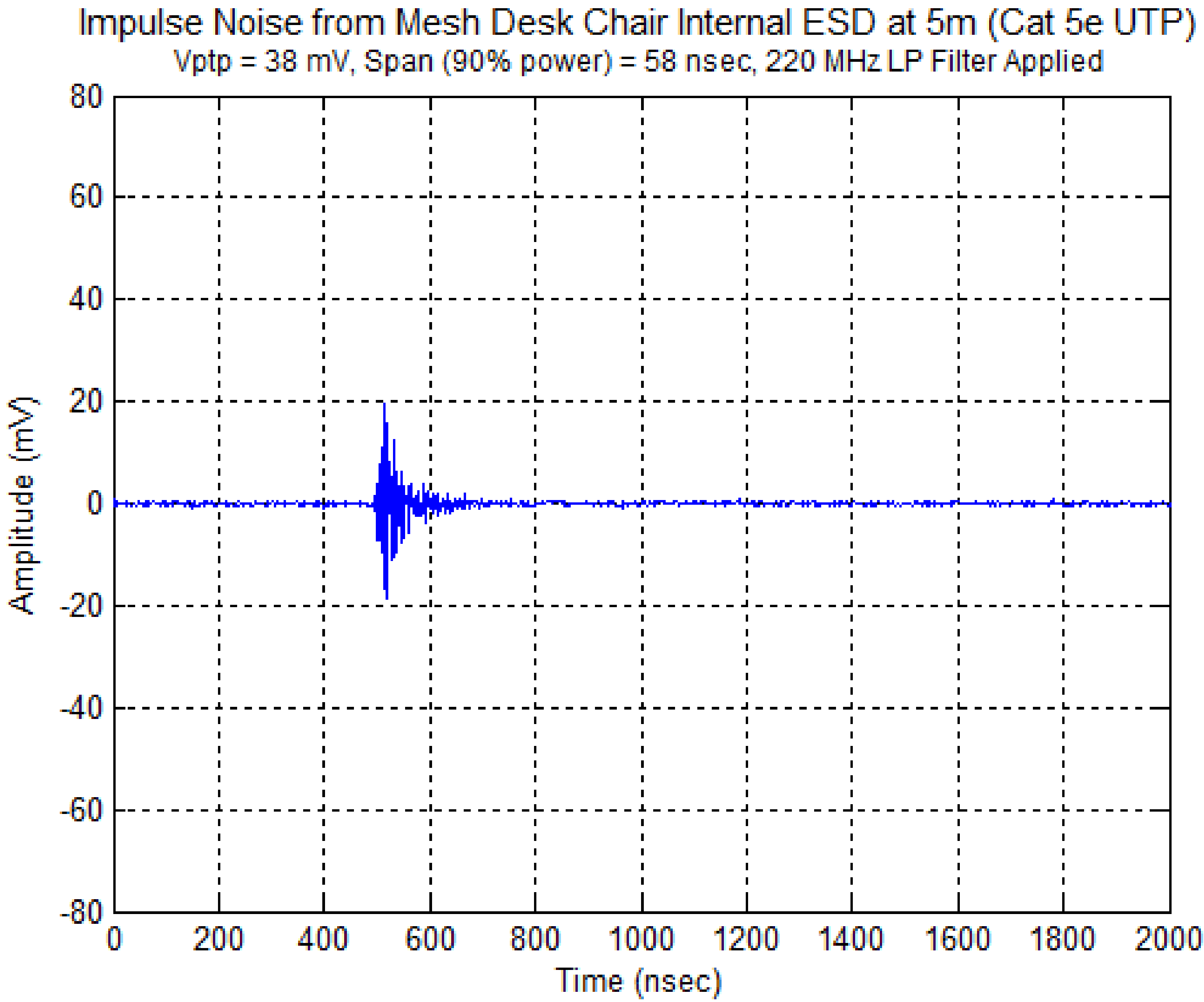
Impulse Noise from Mesh Desk Chair Internal ESD at 5m (Cat 5e UTP)
Vptp = 38 mV, Span (90% power) = 58 nsec, 220 MHz LP Filter Applied
80
60
40
20
0
-20
-40
-60
-80
Amplitude (mV)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Time (nsec)

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Observed Characteristics of ESD Induced Impulse Noise

- ESD induced impulse noise events are mainly generated by human activity; high frequency of occurrence in areas with lots of human foot traffic
- ESD based impulse noise events may have large amplitudes (> 100 mV ptp) but are usually very short (< 100 nsec) in duration
- Lower voltage events generate a wider bandwidth impulse because of the fast rise time of the ESD current; most common source of impulse noise
  - Generally from tool (metal-to-metal) contact ESD; usually not perceptible
  - These events have been observed to cause errors in existing 10GBase-T links
- As voltage increases, the ESD event creates a longer spark gap which increases the rise time of the ESD current; skews energy distribution towards lower frequencies
  - Generated from tool contact, body contact, or furniture ESD
  - ESD energy level often still too low to be perceptible or cause discomfort to touch
  - More likely to affect 2.5G/5GBase-T links
- Interfering impulse noise from “higher voltage” ESD events are more frequent during low relative humidity conditions (common during winter months)

Observed Characteristics of Switch Contact Arc (EFT) 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, but lower peak-to-peak voltage than ESD impulse noise
  - Most energy below 50 MHz (for small inductive loads) and below 10 MHz for large inductive loads
  - Inductive loads generate higher contact arc voltages and longer arc discharge paths, which increases arc current rise time and low frequency energy
  - Low frequency interference can potentially affect many different types of data links

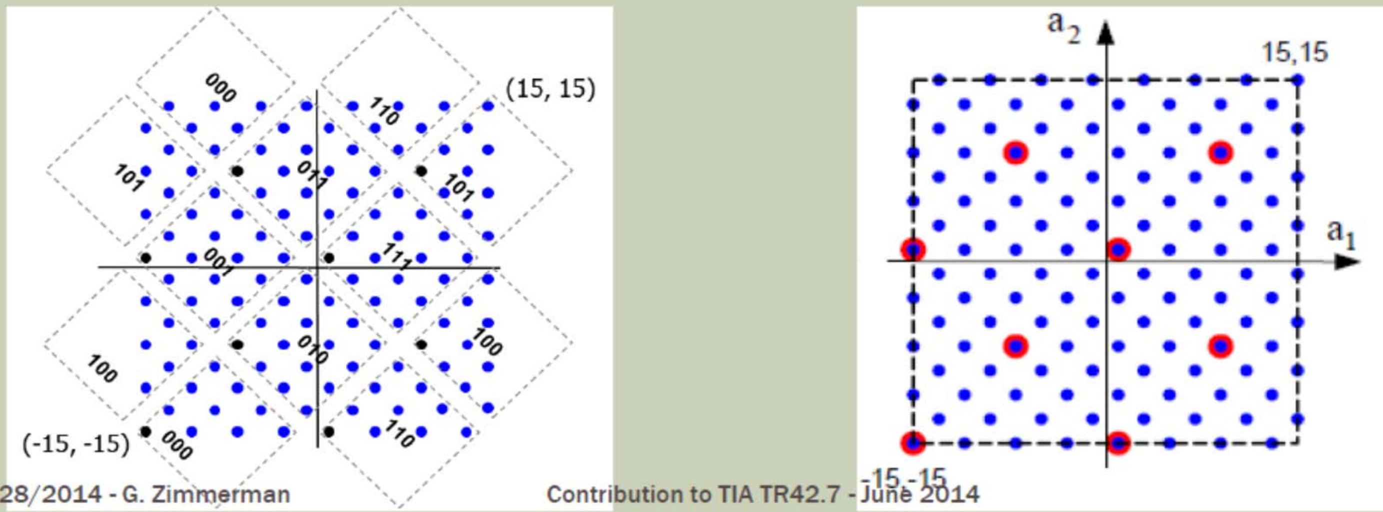
- Can produce long impulse noise events that may wipe out several received symbols, but frequency of occurrence is much lower than ESD based events
  - Strength of impulse noise event often depends upon the point in the 60 Hz power cycle where the contact arc (switching event) occurs; impulse noise may be weak if switching occurs near a zero crossing

- Impulse noise threat from contact switch arc discharge is likely lower than ESD impulse noise because the frequency of occurrence for strong events is much lower

Unprotected Bits and Impulse Noise

- Insufficiency of 128DSQ coding in presence of impulse noise due to it's FEC unprotected bit scheme has been discussed and understood by 40GBase-T, 25GBase-T and TIA forums
- One of many examples: (see below TIA presentation 5/2014)

- Most common observed source of impulsive errors – electrostatic events, corrupting the unprotected bits in 10GBASE-T



- Error thresholds are:
  - Double: 33 mV to 65 mV
  - Single: 46 mV to 93 mV

Short Cable

- Error thresholds are:
  - Double: 25 mV to 35.5 mV
  - Single: 35 mV to 50 mV

Long Cable

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Summary and Findings

- Some common office furniture, specifically desk chairs, can generate significant impulse noise through internal ESD generation
  - Because of the bandpass spectrum shape, this impulse noise directly falls in the 2.5G/5G bandwidth (100MHz, 200MHZ)
  - Areas with large numbers of these chairs can generate frequent impulse noise events
  - Grounding chains and standard ESD mitigation methods (e.g. dissipative flooring) have no effect on this generation mechanism

- Impulse noise events from switch contact arc discharge (EFT) are broader in time domain but less of a problem than ESD because they occur less frequently

- Impulse noise's ability to easily corrupt uncoded bits will cause issues not only at long cable lengths or SNR restricted scenarios, but also in short and medium length links

- The choice of 2.5G/5G coding should avoid un-coded bits

References

1. D. Smith, “A New Type of Furniture ESD and Its Implications”, *Electrical Overstress/Electrostatic Discharge Symposium Proceedings*, 1993, pp. 3-7.
2. M. Mardiguian, Electrostatic Discharge: Understand, Simulate, and Fix ESD Problems 3rd Edition, IEEE Wiley, 2009.