IEEE 802.3 FMP Ethernet Interoperability Technical Concerns and Problems to Solve

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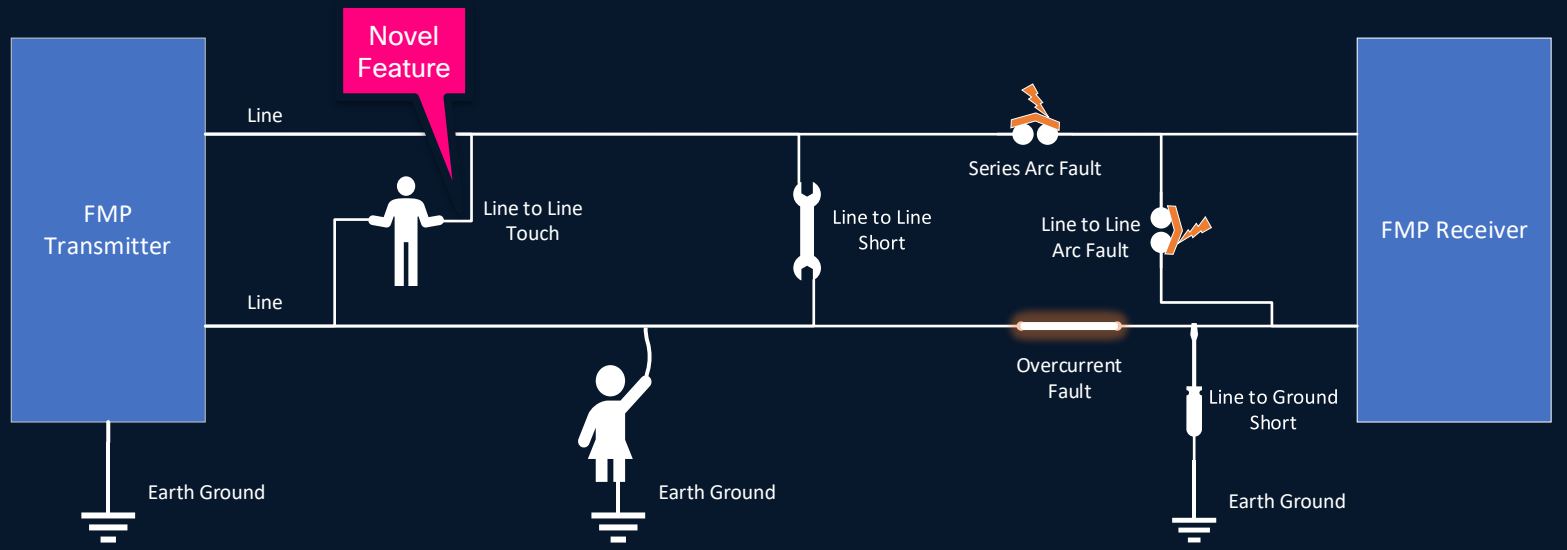
Technical Concerns

Class 4 Fault Managed Power Systems (FMPS)

Class 4 FMPS – What they are…



- FMP must protect against line-to-line and line-to-earth human touch and short circuits, series and parallel arc faults, and overcurrent faults.
- FMP devices disconnect the line from the power source before the fault can present a hazard
- Line-to-line protection is the key differentiator between an FMP system and existing electrical safety systems

Class 4 FMPS – What they are ***NOT***...

- Class 4 circuits do not have an explicit current or power limit
  - Only 450 Volt peak limit and conductor ampacity serves to limit system capacity
- Class 4 allows a multitude of fault detection techniques
  - Class 4 specifies fault detection performance, not detection methods
  - Multiple incompatible methods exist (earliest known example was in 2003 [1])
- Class 4 transmitters, receivers and cables must be listed together
  - Different Class 4 fault detection techniques may depend on different cable parameters
  - UL 1400-1 requires all permutations of cable, transmitter, and receiver to be specified at the time of listing to ensure incompatible components are not combined
  - Interoperability standards are key to relaxing this unified system listing requirement

[1] F. Frebel, M. Paque, T. Joannes and P. Bleus, "Highly safe remote power feeding system for high-power broadband networks," The 25th International Telecommunications Energy Conference, 2003. INTELEC '03., 2003, pp. 178-184.

A Note on Category Cable for Class 4 FMPS

- Class 4 is fundamentally different from PoE
  - PoE is based on a Class 2 circuit limited to 60V and 100W
  - Category 5e/6/6A cables are rated for 300V
  - The 8P8C (aka RJ45) connector is rated for 150V
- Class 4 requires cable and connectors to be rated for a minimum of **450V**
  - Specified in the UL 1400-1 System and UL 1400-2 Cabling Safety Standard
  - Use of brown-field PoE structured cabling for Class 4 FMP is ***prohibited***

Fault Managed Power
vs Power over Ethernet
vs Power over Data Lines

Existing IEEE 802.3 Powering Systems vs FMPS

Key Differentiating Traits

	Power over Ethernet	Power over Data Lines	Fault Managed Power Systems
Conductor Arrangement	4-Pair	Single-Pair	Single-Pair
Current Waveform	Continuous DC	Continuous DC	Majority are interrupted DC
Installed Cable Plant	Enormous	Minimal	Virtually non-existent
Cable Performance Standards	Long history of established standards	Short history of established standards	No established standards
Cable Termination	Vast majority use one dominant connector (RJ45)	No dominant connector, many screw terminals	Vast majority use screw terminals
Power/Data-Only Interconnection Risk	High risk due to enormous install base	Medium risk due to variety of connectors and prevalence of engineered systems	Installation practice alone can ensure that wires are connected to screw terminals properly

UL 1400 – Key Compatibility Considerations

UL 1400 FMPS Safety Standards

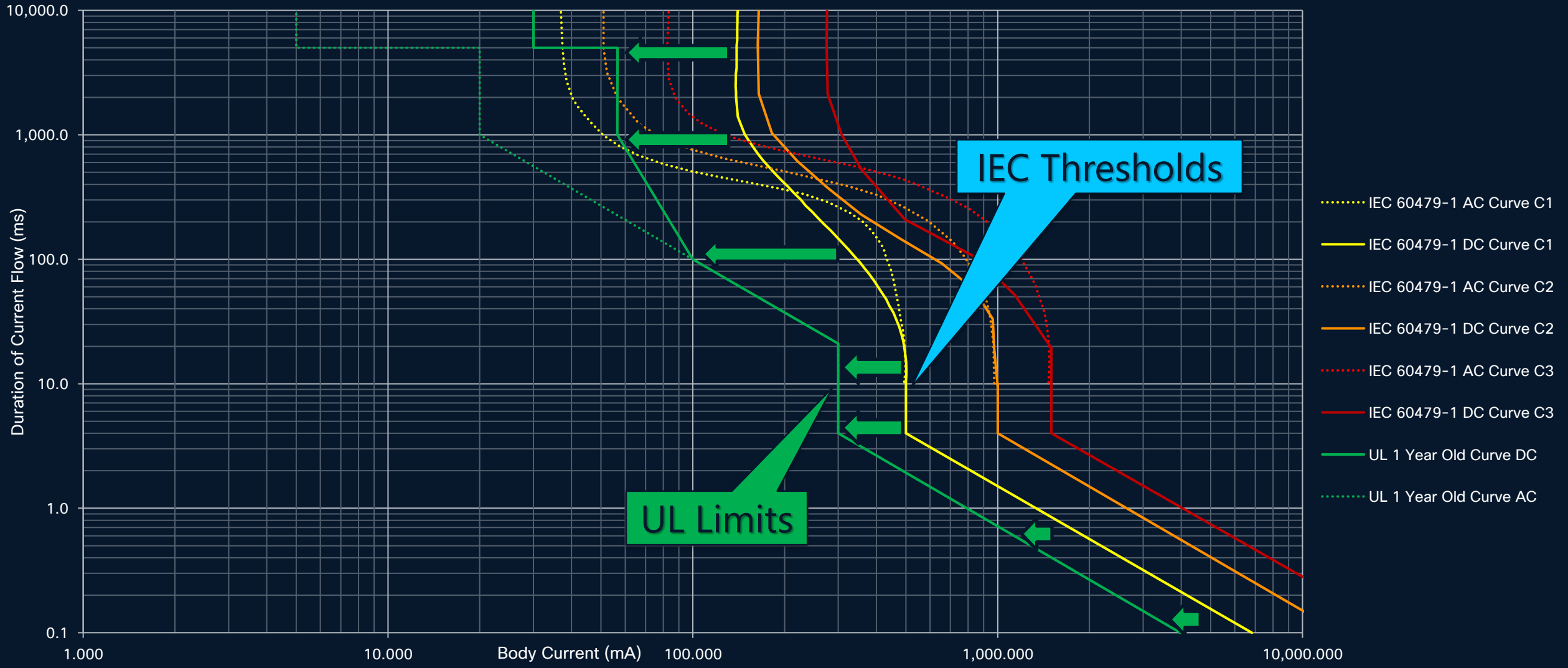
- UL has issued two safety standards governing FMPS:
  - UL 1400-1 *Outline of Investigation for Fault-Managed Power Systems, Part 1: Safety Requirements*
  - UL 1400-2 *Outline of Investigation for Fault-Managed Power Systems – Part 2: Requirements for Cables*
  - These documents are in the process of graduating from “Outline of Investigation” to “Standard” and are expected to be published any day now
- Three companies have announced obtaining UL 1400-1 listings
- Multiple cable manufacturers have listed CL4 cable under UL 1400-2

Biological Limits on Voltage

Body Impedance	Minimum	Typical
Line to Line (Hand to Hand)	575 Ohm	2,000 Ohm
Line to Ground (Hand to Both Feet)	500 Ohm	2,000 Ohm

The 400 Volt nominal DC voltage for FMP was chosen to align with the worst-case human body impedances and their interaction with the UL limits for risk of ventricular fibrillation

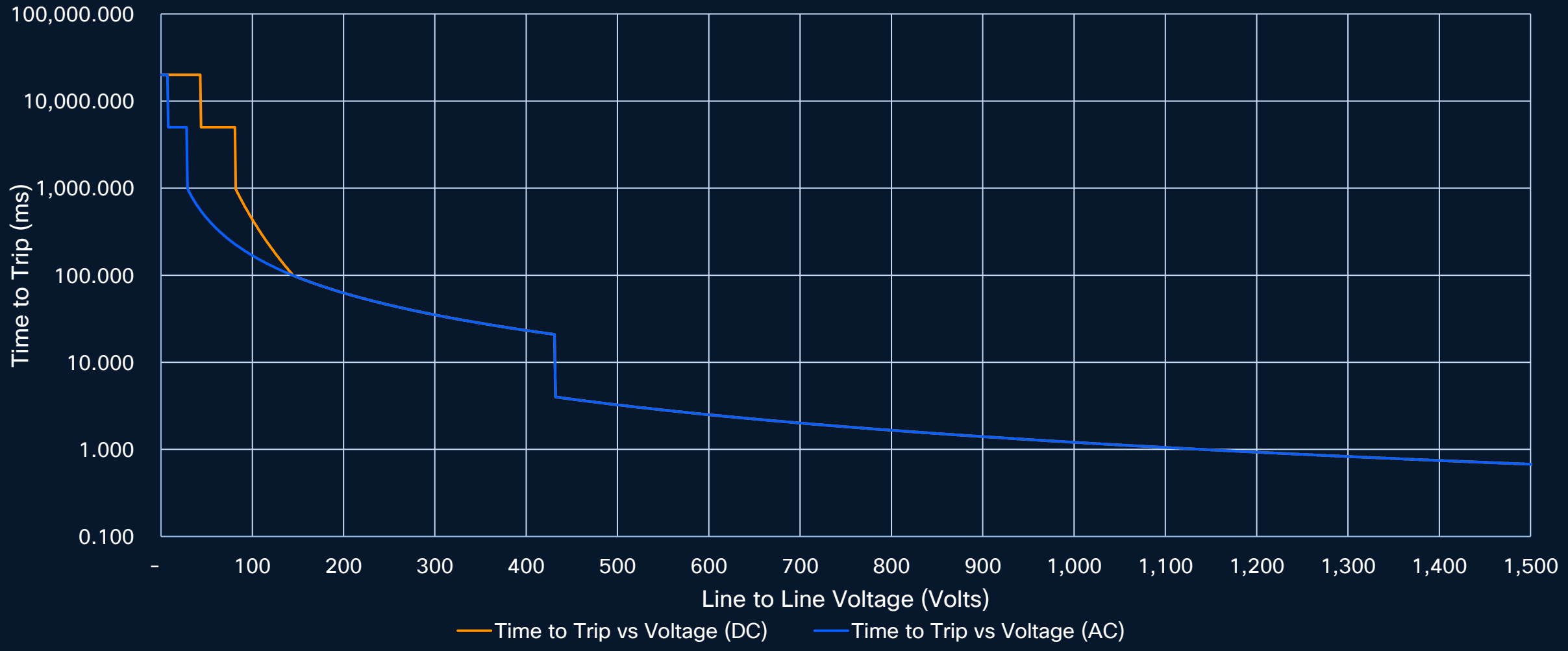
UL Shock Limit Curve



UL limit curve based on a minimum 60% derating of shock threshold curves found in IEC 60479

UL Shock Limit Curve for Minimum Body Impedance

Isolated Systems

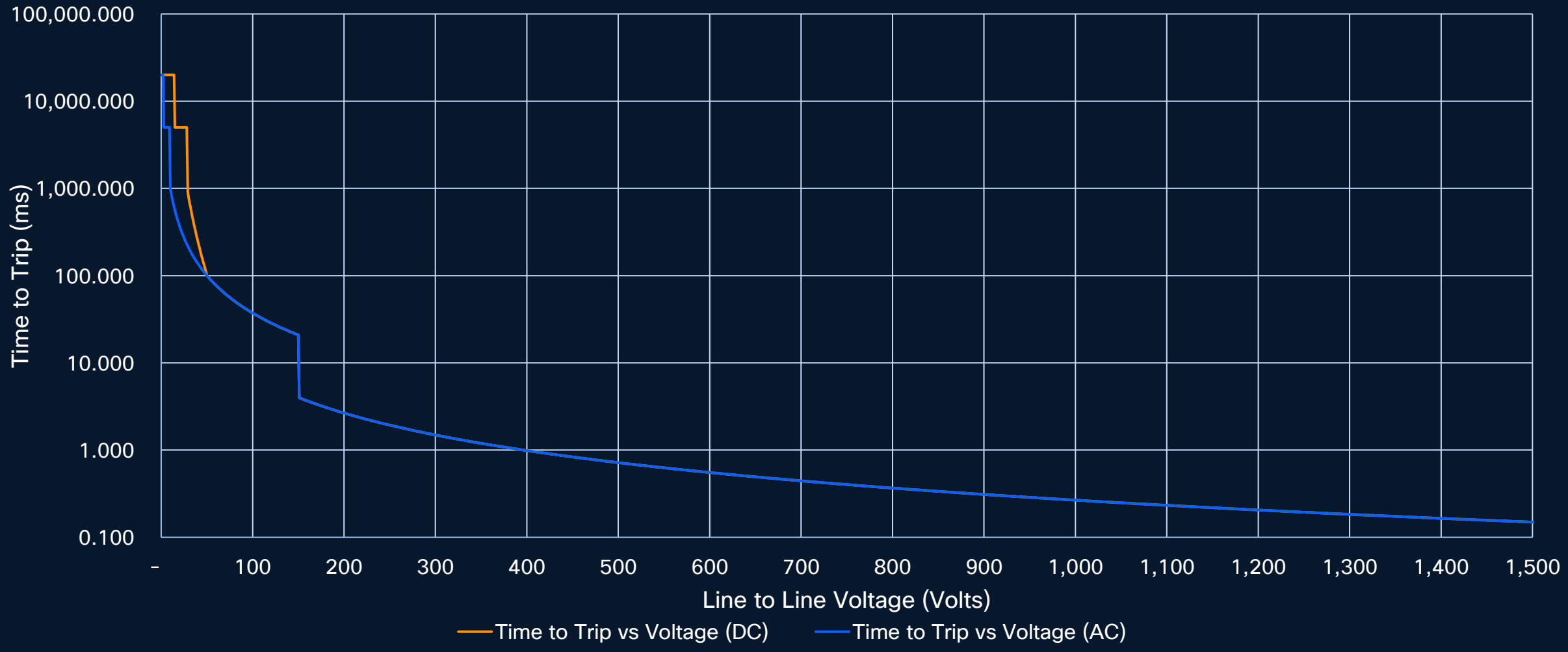


Parameters: Hand-to-Hand Fault, Heart Current Factor 0.4, Body Impedance 575 Ohm

UL Shock Limit Curve for Minimum Body Impedance

Non-Isolated Systems

Note: Non-isolated systems are currently not permitted under UL 1400-1



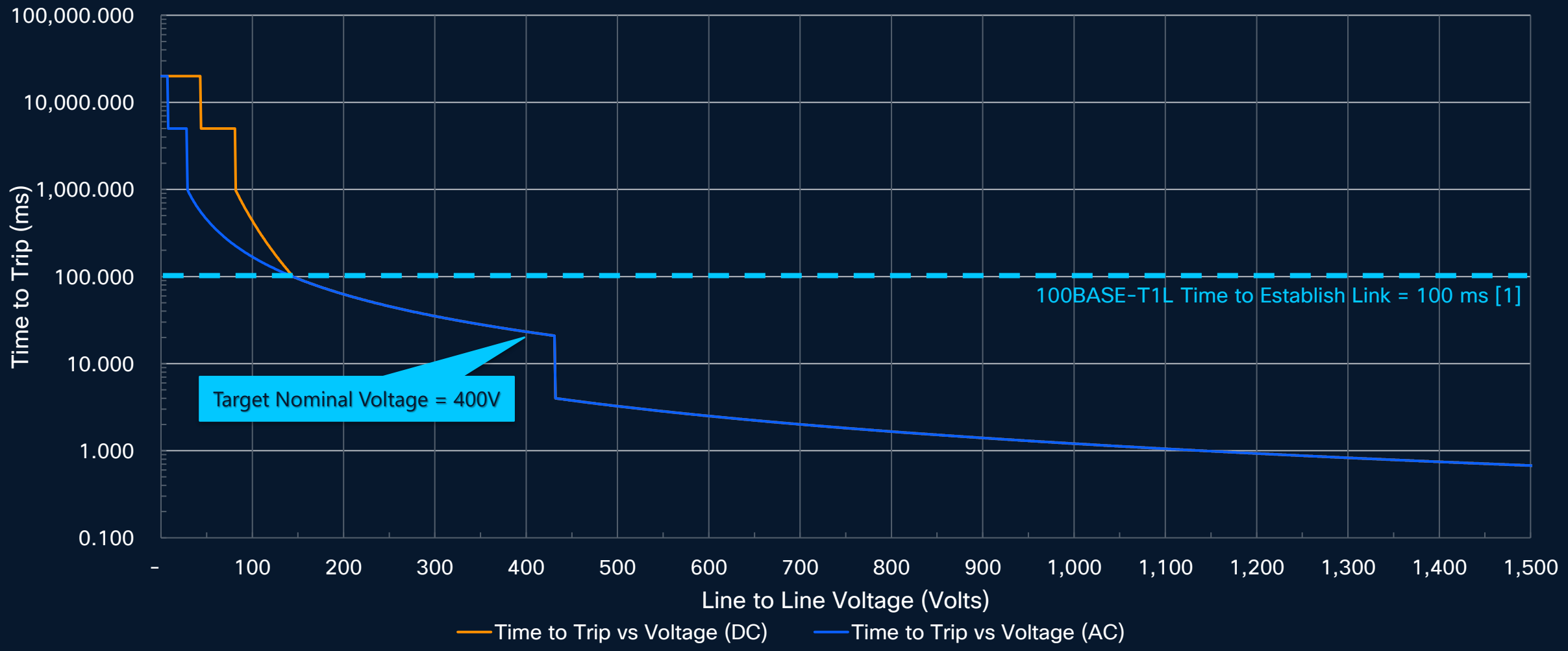
Parameters: Hand-to-Both-Feet Fault, Heart Current Factor 1.0, Body Impedance 500 Ohm

Functional Safety Considerations

- UL 1400-1 requires a functional safety evaluation of each system
- Multiple Functional Safety Standards can be utilized
  - IEC 61508 for example, is permitted with a minimum Safety Integrity Level (SIL) of SIL 2
- Functional Safety drastically increases the development complexity of any product
- For this reason, our standard should avoid bringing the Ethernet data link into the scope of the UL 1400-1 functional safety analysis if at all possible

Potential PHY Timing Interactions

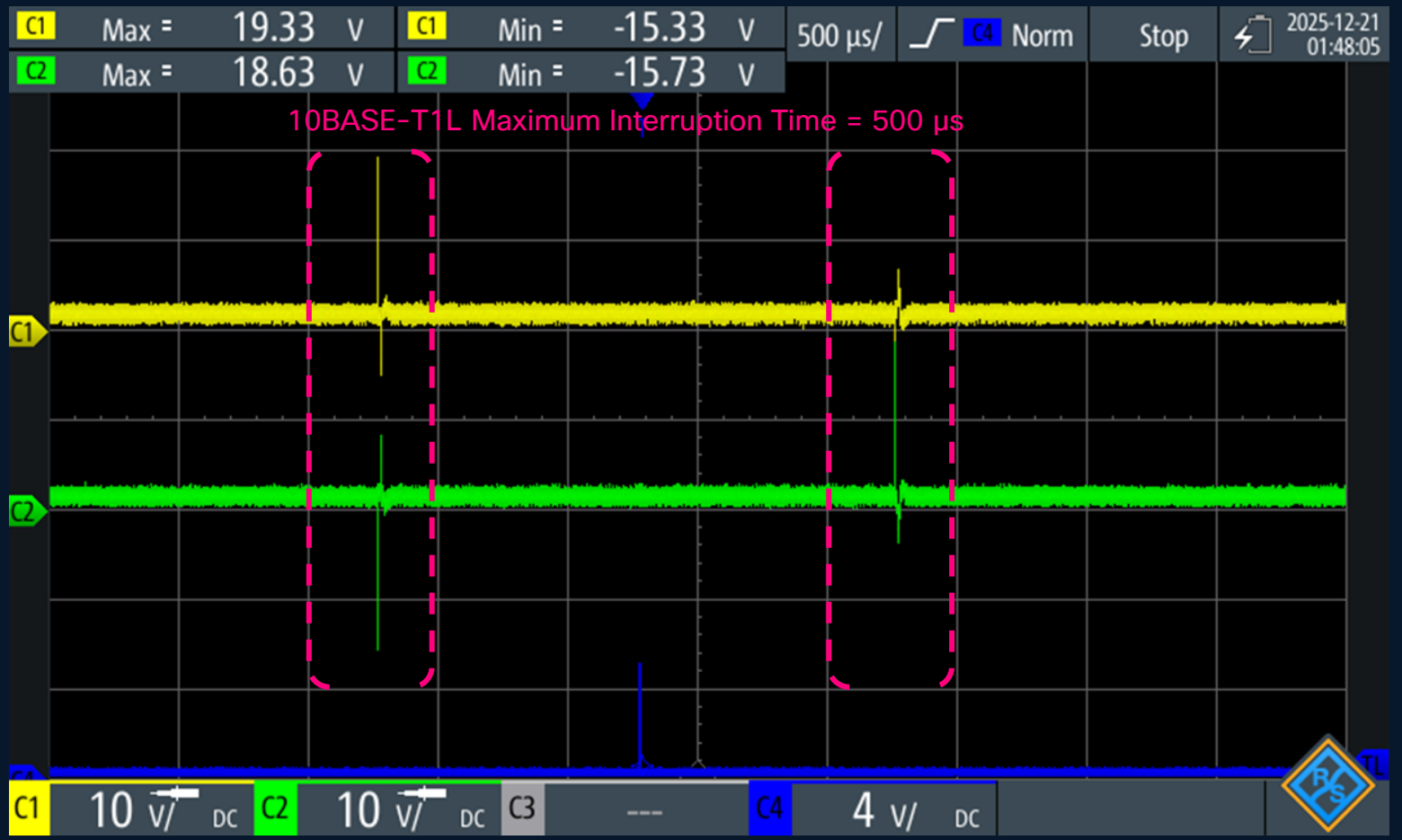
UL Shock Limit Curve Timing vs Key PHY Parameter



[1] Clause 190.3.4 “Training”, IEEE, IEEE Std 802.3dg-2026 (Amendment to IEEE Std 802.3-2022), 2026.

PHY Transient Tolerance

Data presented in “Impact of Interrupted DC Current Flow on 10BASE-T1L Communications” [1] showed that the duration fo the turn-off and turn-on transients for a 2.5 A constant-current load did not exceed the 500 µs 10BASE-T1L interruption limit determined experimentally by Brunner and Ostertag [2].



Parameters: 10 ms period, 2 ms off, 2.5 A CC load

[1] https://www.ieee802.org/3/EFMP/public/260513/Potterf_FMPE_PhyTransients_2026-05.pdf
[2] K. Brunner and M. Ostertag, “10BASE-T1L micro interruptions : importance of good cabling between moving parts,” in Proceedings of the 2024 Embedded World Conference, Apr. 2024, vol. Proceedings of Embedded World Conference 2024, pp. 560–565, doi: 10.21256/zhaw-32171.

Problems to Solve

Problems to Solve – Power Channel

- Define target cable parameters
- Establish reach targets
- Identify supported cabling topologies
- Noise environment for power delivery monitoring

Problems to Solve – Data Channel

- Choose PHYs to target
  - Align with power delivery reach targets
  - Align with power cable topology and conductor count
- Noise environment for data channel
- Mitigate issues caused by non-DC power channel
- Specify key power / data coupling parameters
- Solve interruption resiliency
- Solve link establishment challenges
- Establish synchronization method between PHY and FMP subsystem around FMP-induced transients

Problems to Solve – Receiver Behavior

- Determine minimum set of receiver behavior specifications to enable interoperability of fault detection schemes
- Determine voltage compatibility specifications
- Agree on supported topologies

Problems to Solve – Transmitter Behavior

- Determine minimum set of transmitter behavior specifications to enable interoperability of compliant receivers
- Establish turn on, turn off, and fault recovery behaviors that support any PHY limitations

Problems to Solve – Packet Flow

- Specify methods for minimizing packet loss
  - Consider packet interruption at lower rates (≤ 10 Mb/s)
  - Not necessary at higher rates (≥ 100 Mb/s)
- Establish synchronization method between MAC and FMP subsystem around FMP-induced transients

Questions and Discussion