IEEE SW Test Workshop

Semiconductor Wafer Test Workshop

June 9 - 12, 2013 | San Diego, California

Beyond ISMI: Electric Current Capacity of Vertical Probes Under Pulses and Transient Signals

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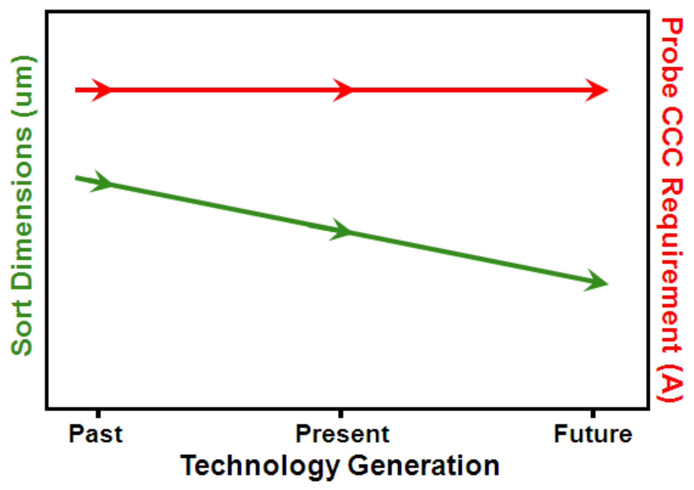
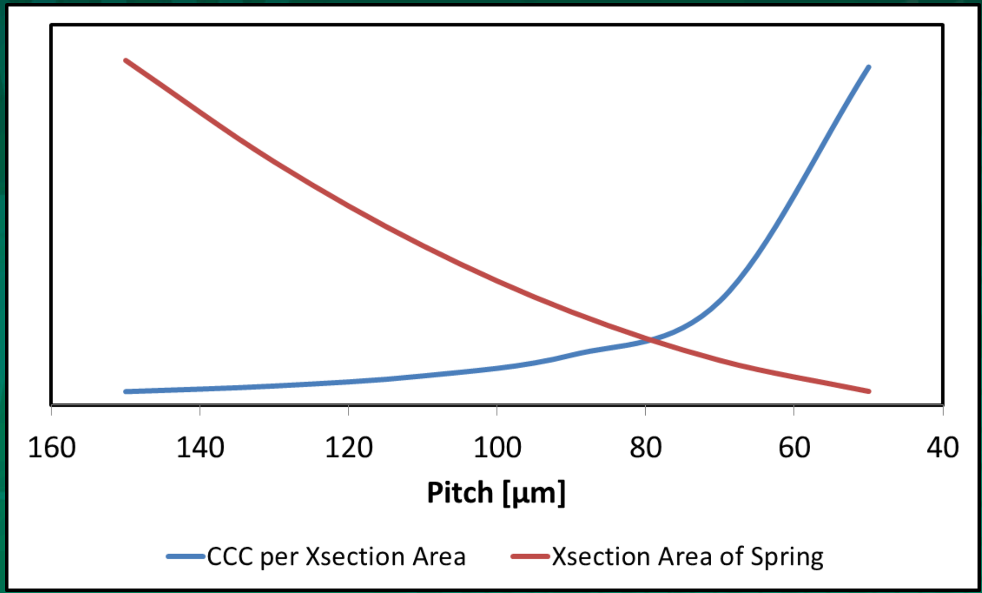
FormFactor, Inc.

Semiconductor Trends Influencing CCC



** Zeman SWTW2010 "A New Methodology for Assessing the Current Carrying Capability of Probes used at Sort"*

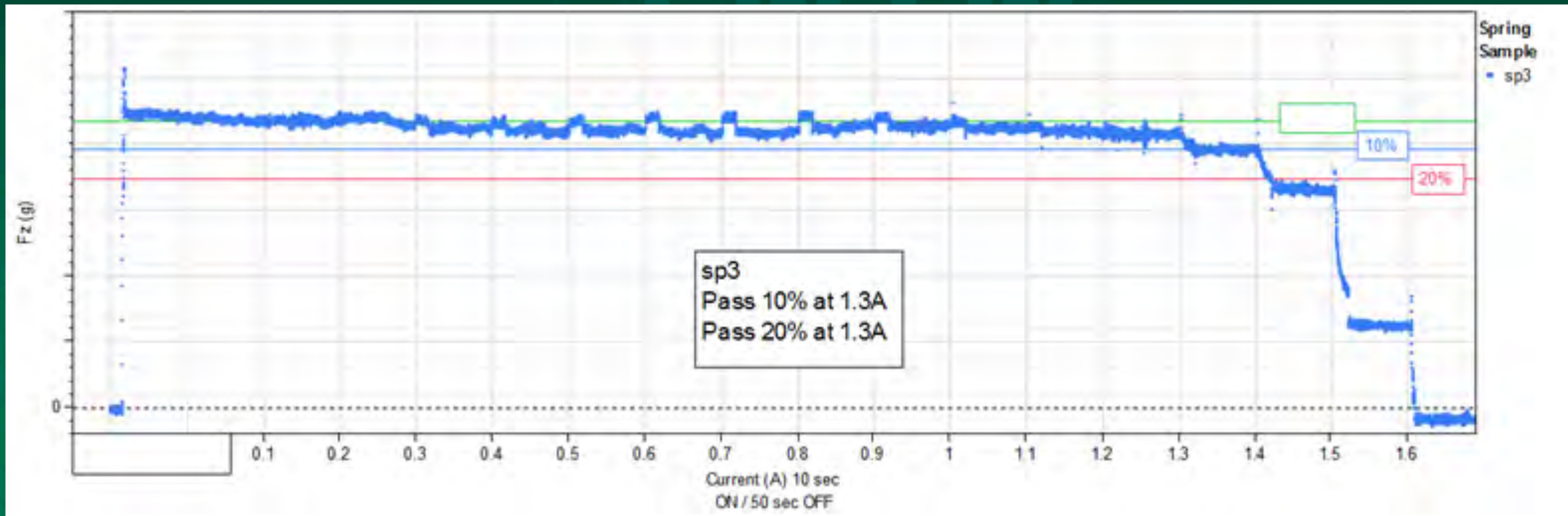


- **Keeping CCC for < 100µm Pitch is really hard**
- **Need to design efficiently to keep pace**
  - Requires smarter probe design
  - Requires smarter communication between test customers & suppliers

SWTW

How are Things Done Today?

- **ISMI CCC Test standard:**



Presented at SWTW in 2009, the goal of the ISMI guideline is "*…to minimize variability in the measurement of this critical parameter… With a focus on reproducible measurements, this guideline provides CCC ratings that are inherently different from what a user will see in a production environment.*"*

- **Test suppliers/customers develop internal "rules of thumb" to convert intended chip current into equivalent ISMI rating.**

* Daniels, E Boyd, 2009. *ISMI Probe Council Current Carrying Capability Measurement Standard*. San Diego, CA, June 7-10 2009, IEEE SW Test Workshop.

Influence of CCC on Probe Design

Design "Points"

- Because the physics involved are nonlinear and start to "kick in" < 100µm pitch, the rules-of-thumb will become increasingly less useful.
- Need to elevate the level of discussion and understanding with regard to CCC between test suppliers and customers.
- Probe design is all about proper allocation of design "points"

CCC

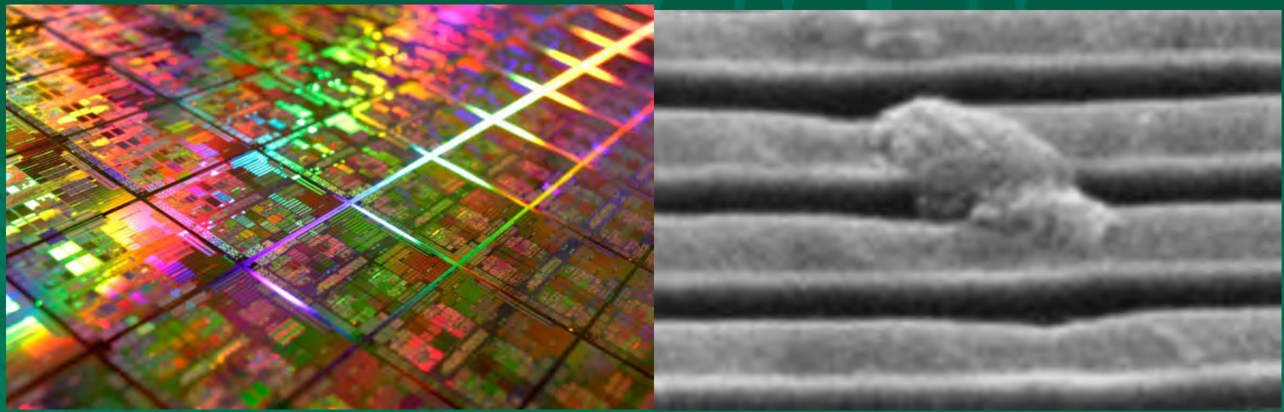
Force\K-value

Max OT

- Under-performing CCC = very bad, burnt probes
- Over-performing = still bad, comes at cost of probe stiffness & max OT

Objectives & Goals

- **Root cause of probe burns often lies in wafer-level defects causing unpredictable surges in current***

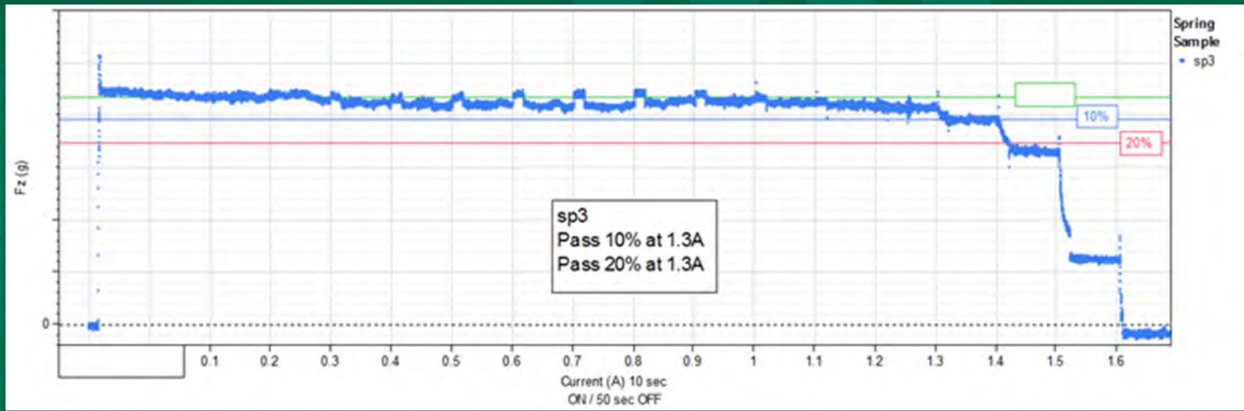


** Zeman SWTW2010 "A New Methodology for Assessing the Current Carrying Capability of Probes used at Sort"*

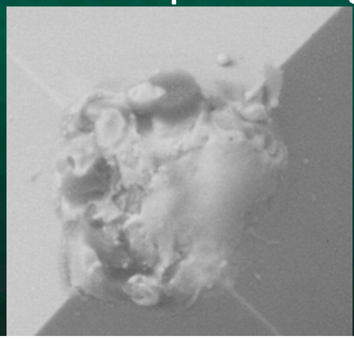
- **Goal is to understand & share learning on how CCC behaves against the full spectrum of square-wave signals.**
  - Present Day: Develop & verify a multiphysics model that can handle any type of specified signal.
  - Long Term: Construct a full multiphysics probe card model to convert Chip Requirements --> Spring Design --> ISMI Rating

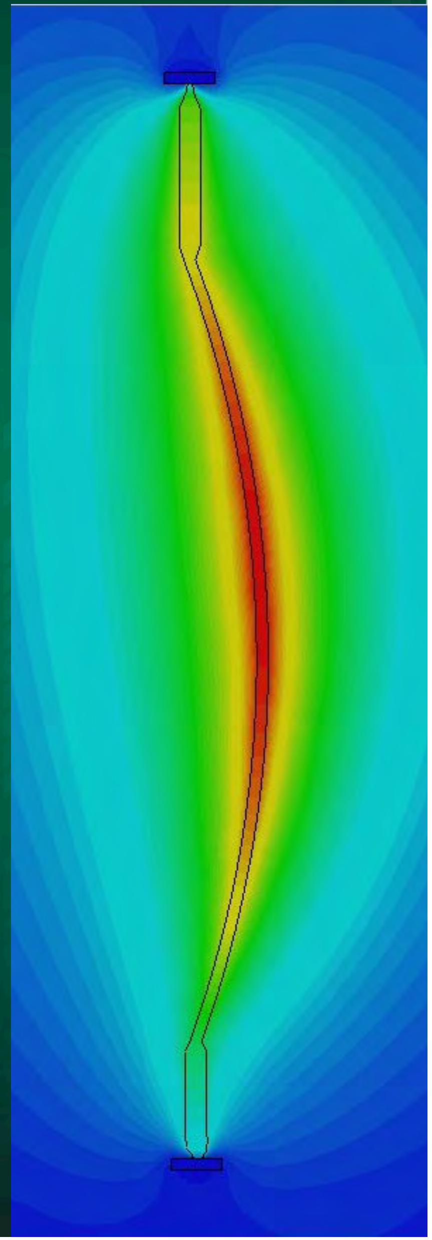
Failure Modes: DC vs Square-Wave

- **DC Failure Mode:**
  - Reduction in contact force from heating in high stress locations of spring



- **Square-Wave Failure Modes:**
  - Long Duration Pulse = Reduction in contact force
  - Short Duration Pulse = Tip melting

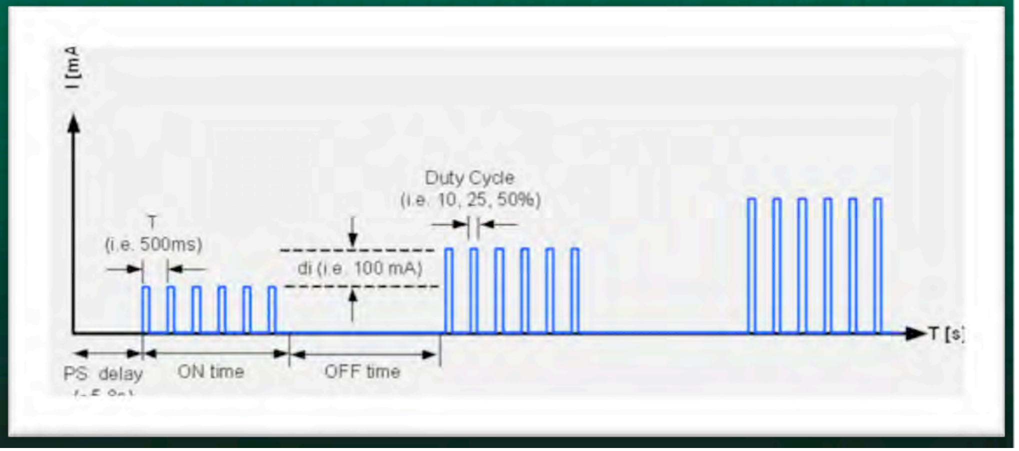




Overview of Test Methods & Procedure

- **Multiphysics Simulation Calibration Steps:**
  - Using ANSYS & Solidworks Flow Simulation, built a model that matched ISMI testing for all our probe products. This gave insight into temp rise/fall times.
  - Ran experiment for CCC vs Pulse ON length
  - Refined model to match all test cases for the same contact constraints
  - Used model to generate CCC behavior for any specified signal

- **Quantified this behavior for one of our probe products for presentation today. CCC_{ISMI} = 0.8A**

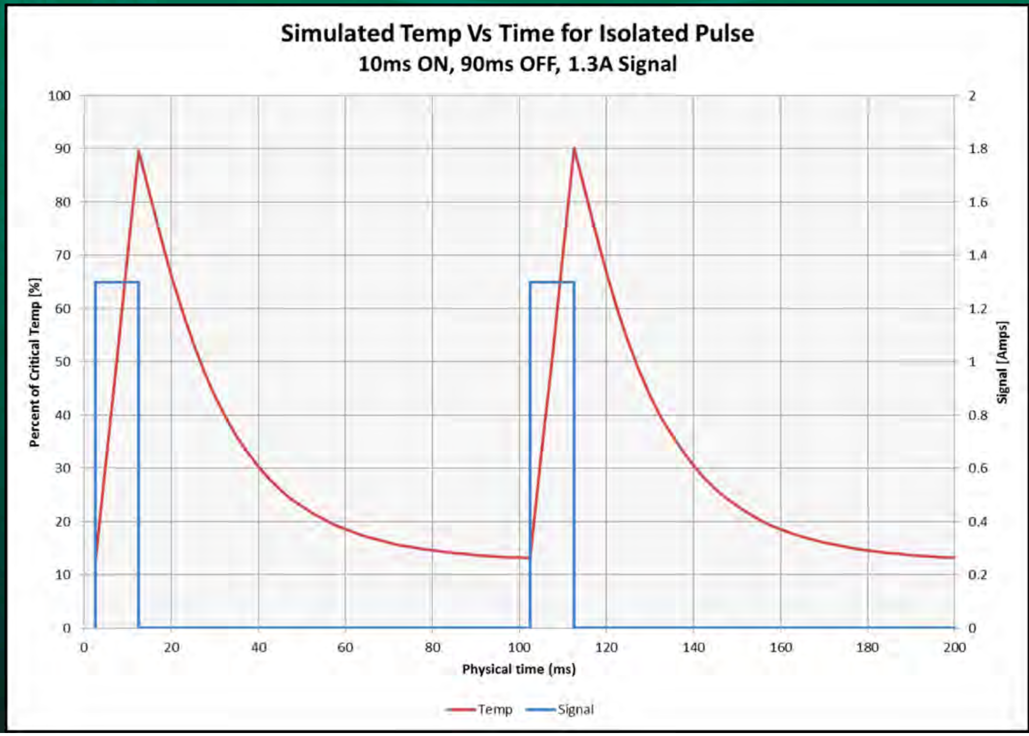


Results Overview

- **Important Insight:**
  - Probe behavior most easily understood based on the relationship between probe cooling and OFF duration between pulses.
- **For the probe presented:**
  - Time to cool ≈ 100ms *(τ = 25ms)*
- **Can classify any square wave into 3 groups:**
  - Isolated Pulses: Time between events is long enough that the probe carries no significant heat between pulses. *($f \leq 10$ Hz, $T \geq 100$ms)*
  - Hi-Speed Signals: Time between events is short enough that the probe experiences only small ΔT between pulses. *($f \geq 1$ kHz, $T \leq 1$ms)*
  - Intermediate Signals: Consists of the remainder. Time between events is such that the probe experiences large ΔT & carries residual heat between pulses. *(f = 10 Hz – 1 kHz, T = 100ms – 1ms)*

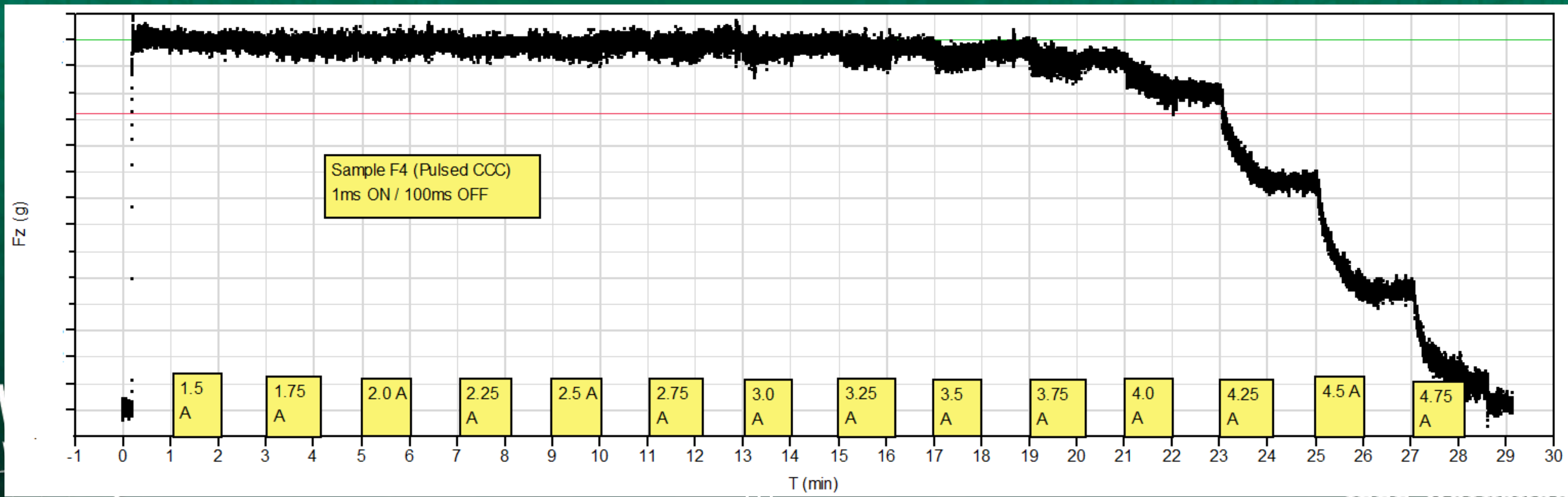
Isolated Pulses: Definition

- **Definition:**
  - Time between events is long enough that the probe carries no significant heat between pulses. *($f \leq 10$ Hz, $T \geq 100$ms)*
  - Analogous to capacitor discharge or not fully powering down between touchdowns ("hot stepping")
- **Most important signal class to understand in order to prevent burnt probes**

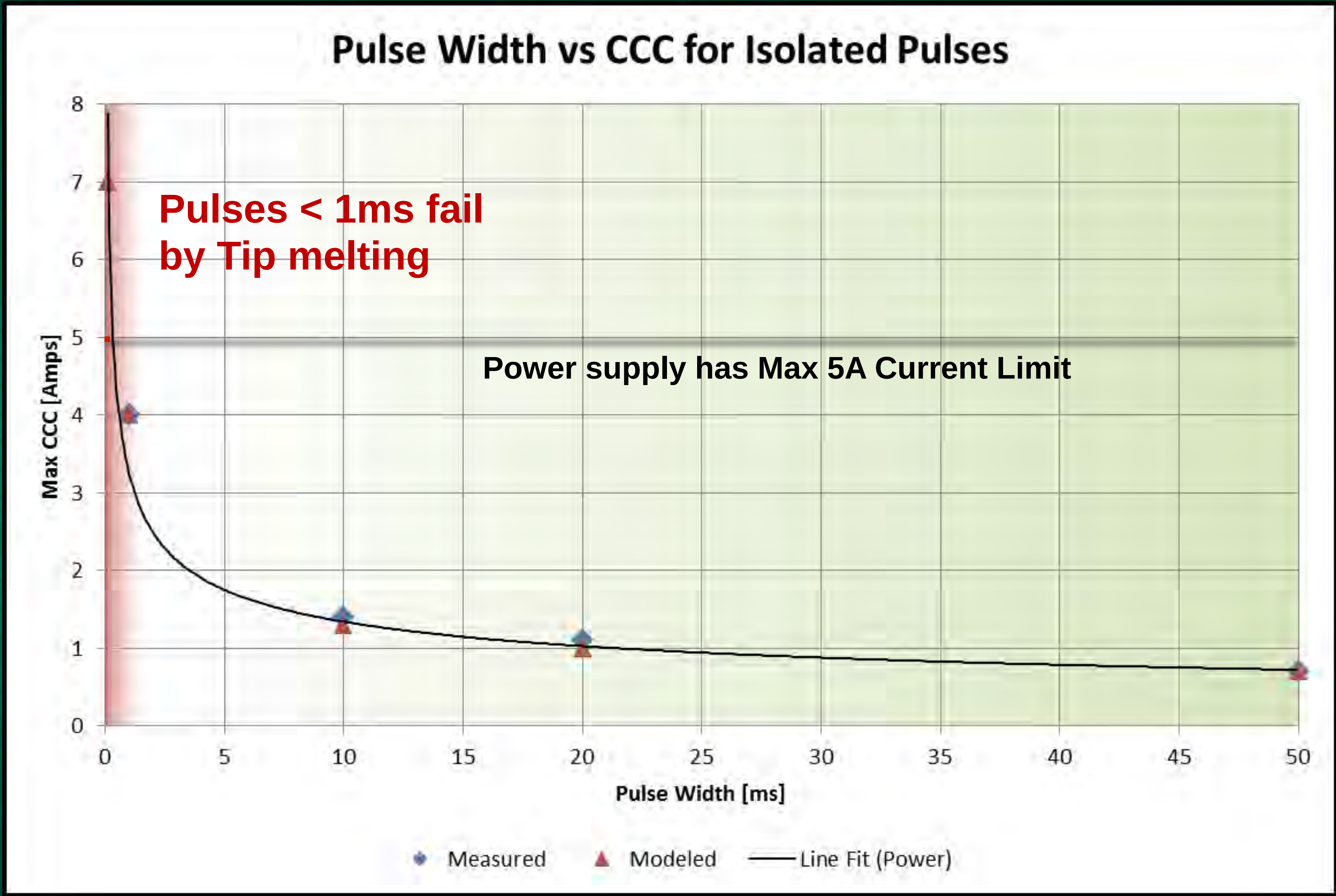


Isolated Pulses: Procedure

- **Experimentally measured CCC for Isolated Pulses:**
  - ON Duration: 20ms, 10ms, 1ms, 0.1ms
  - OFF Duration: 100ms
  - Procedure:
    - Signal Run for 1min → Check Force → Increase Current → Repeat Until Failure
  - Probe subjected to ~545 pulses at each current level before re-checking force and increasing current further

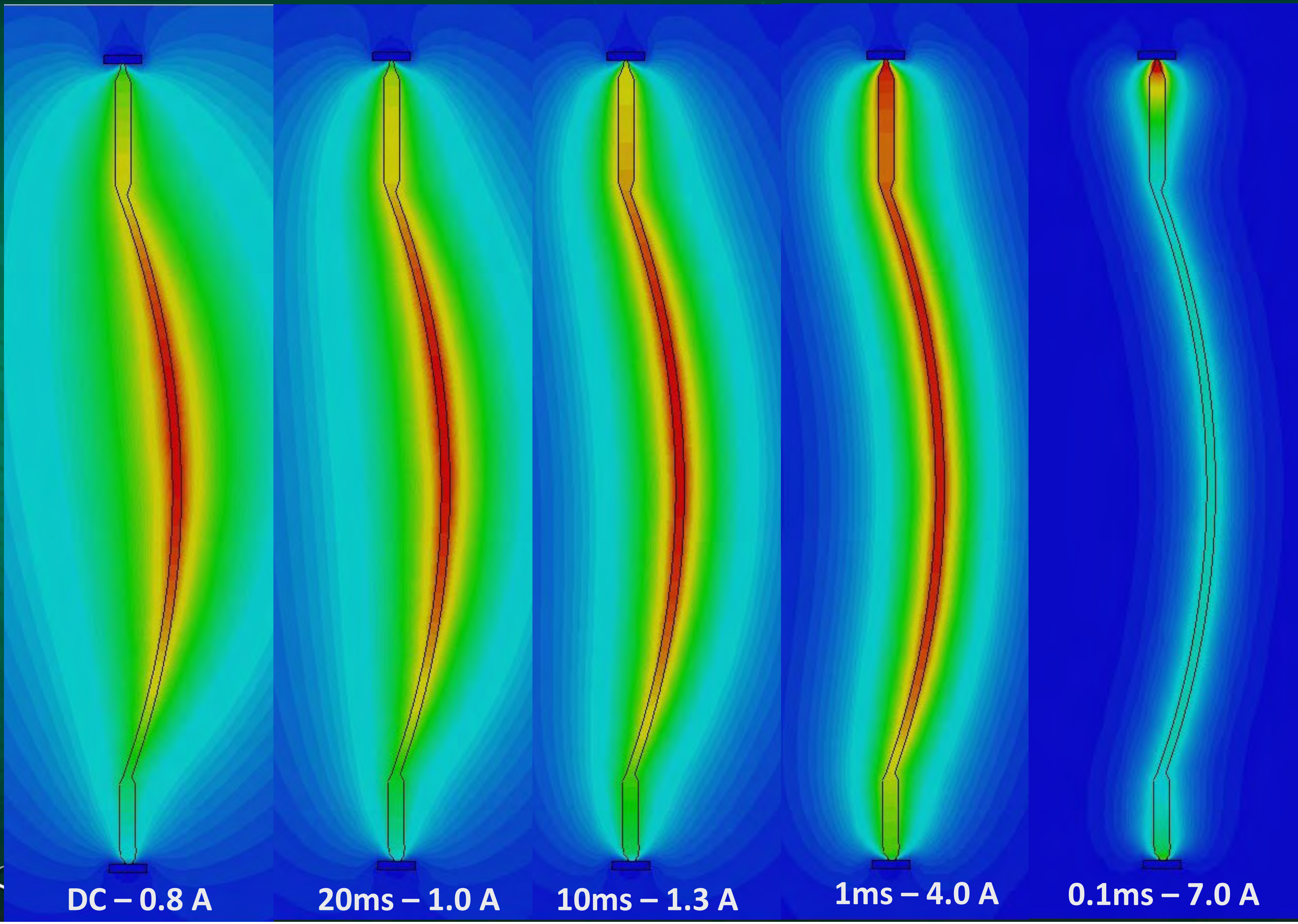


Isolated Pulses: Results



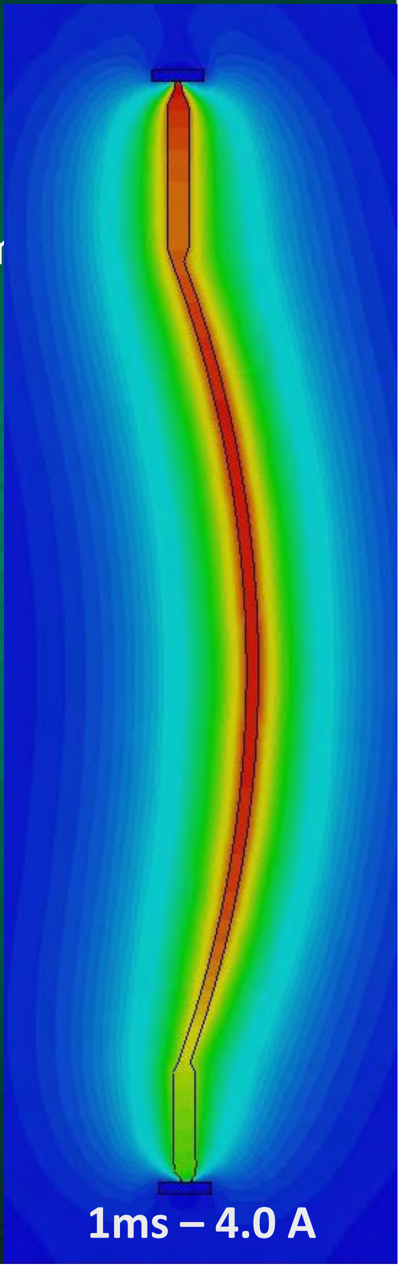
- Probes survived 550 pulses at 4.0 A, if duration is ≤ 1ms.
- 400% increase in CCC over ISMI rating of that product!
- Starting at ~5.0 A, 0.1ms pulse we start seeing melted tips

Isolated Pulses: Behavior



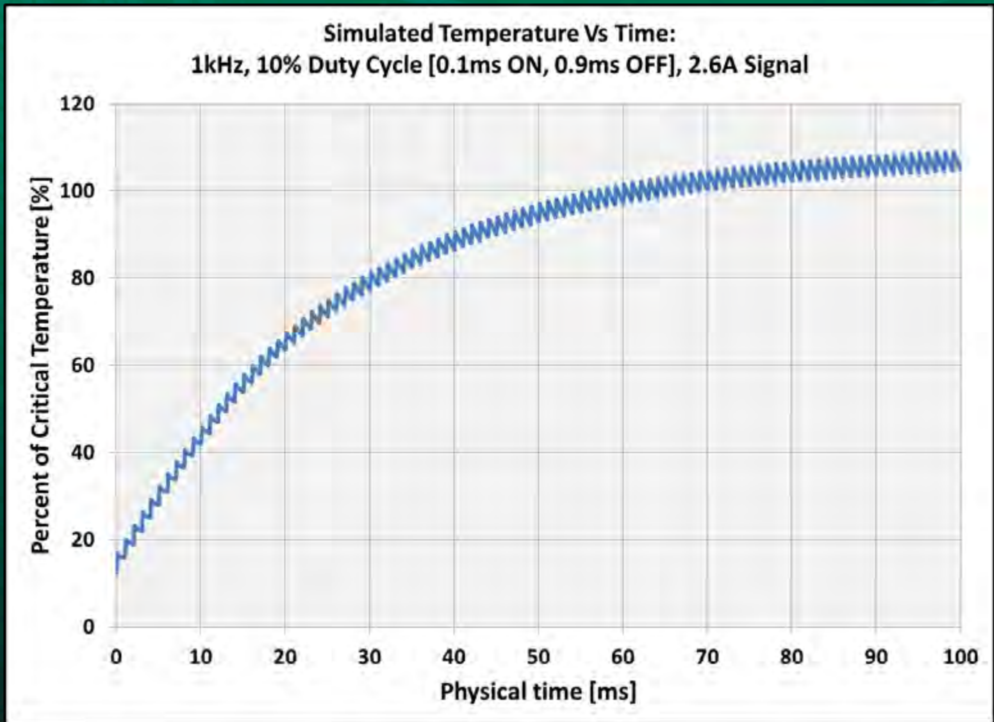
Isolated Pulses: Comments

- **There exists a practical limit on CCC for isolated pulses where max current can no longer be increased by a decrease in pulse length due to instantaneous melting at the tip.**
  - For the product shown this practical limit is ~5.0 A for a 0.1m pulse
- **There exists a transition point where the probe failure mechanism changes from loss of contact force to tip melting.**
  - For the product shown here that point is a 4.0 A, 1ms duration pulse.
- **Dominating factors:**
  - Pulse Width & Spring Design
- **Isolated pulses can be successfully predicted and understood using a multiphysics simulation software**



Hi-Speed Signals: Definition

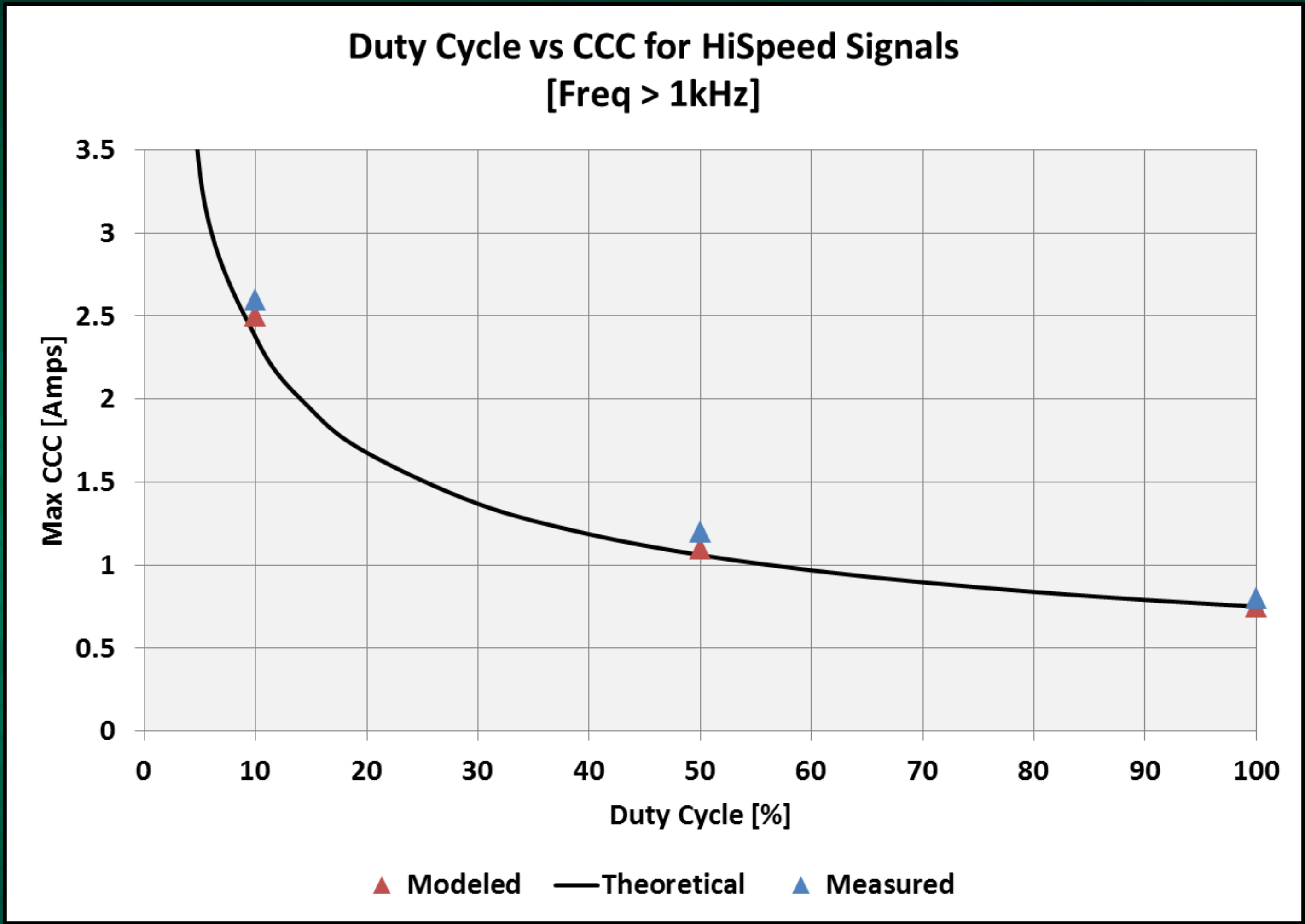
- **Definition:**
  - Time between events is short enough that the probe experiences only small ΔT between pulses. *(f ≥ 1 kHz, T ≤ 1ms)*
  - Analogous to a fast logic signal
- **Hi-Speed signals represent the most common intended signals**
  - Understanding CCC behavior for signals operating at speeds > 1 kHz will help tailor probe designs used at these locations.

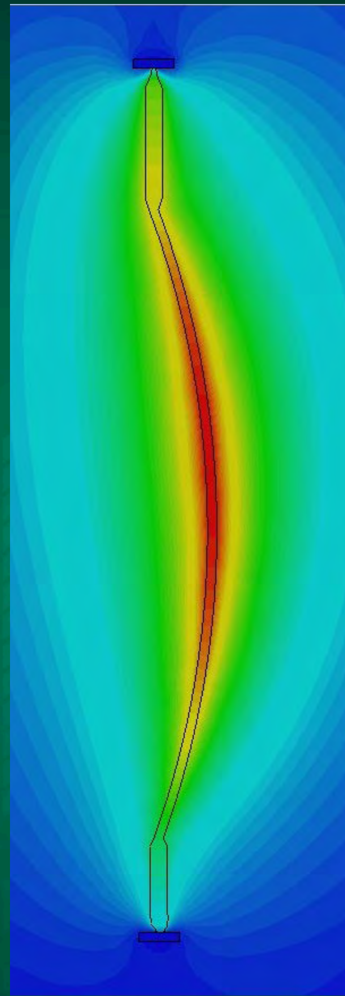


If we assume small ΔT between pulses, CCC for any duty cycle should follow the equation:

$$CCC_{HiSpeed} = \sqrt{CCC_{ISMI}}$$

Hi-Speed Signals: Results





- Simulation & Experimental tests closely follow theoretical equation for equivalent energy input $CCC_{HiSpeed} = \sqrt{CC}$
- Significant increase in CCC for Duty Cycles < 30%
- Behaves thermally like a DC input

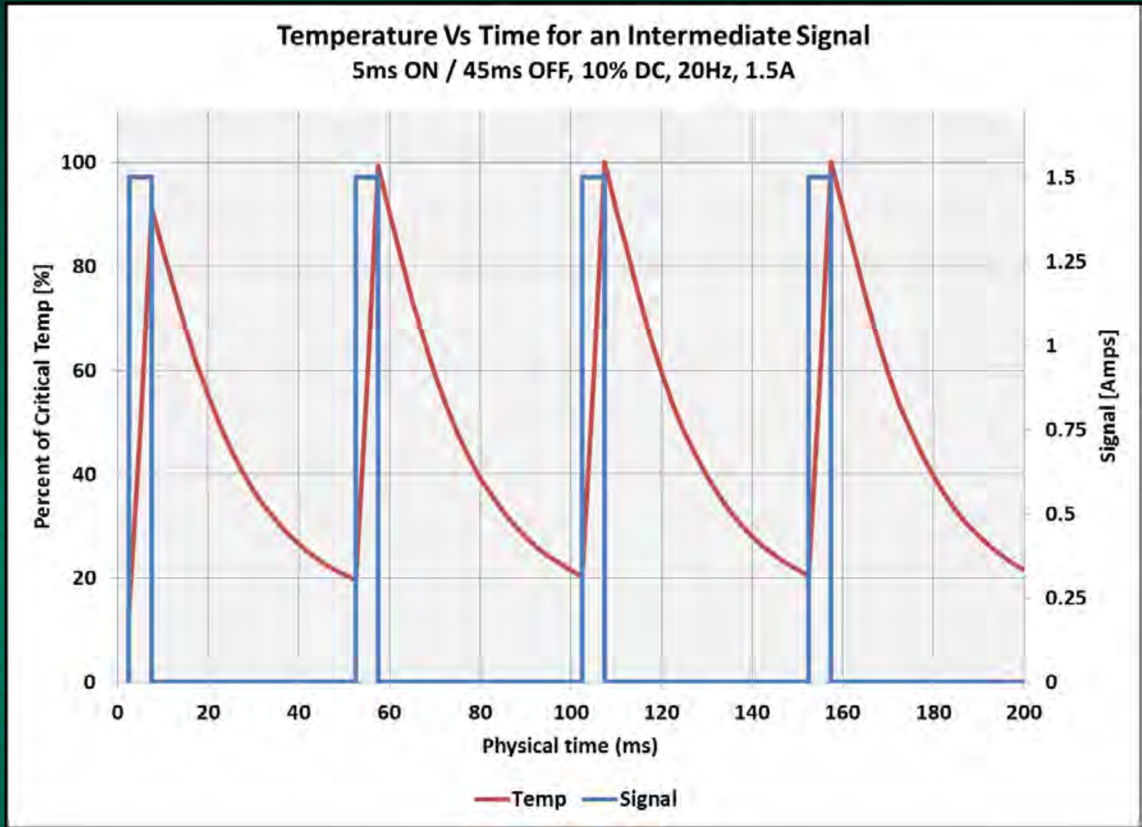
Intermediate Signals: Definition

- **Definition:**
  - Consists of the remainder of signals that do not qualify to be either "isolated" or "Hi-Speed."
  - Time between events is such that the probe experiences large ΔT & carries residual heat between pulses. *(f = 10 Hz – 1 kHz, T = 100ms – 1ms)*

- **Most complex to analyze:**
  - Temperature "walks upward" with each pulse, but at a rate unique to that signal condition & probe design.
  - Number of pulses to reach steady-state can range from just a handful to several hundred

- **<u>Thankfully these are the least likely signal types to be used on a probe card</u>**

Intermediate Signal: Results



- **This particular signal condition reaches steady-state in 3 cycles**
  - Max CCC for 5ms ON / 45ms OFF = 1.5 A
- **Intermediate signals will always have a lower CCC than the equivalent Isolated Pulse or Hi-Speed Signal**
  - 5ms pulse width for Isolated Pulse = 1.75 A
  - 10% Duty Cycle for Hi-Speed = 2.5 A

Summary & Conclusion

- CCC can be greatly influenced by the specific signal used on a probe
- Shown that CCC of a probe can be increased by as much as 400% given the proper signal condition
- The CCC of any arbitrary signal can be modeled successfully using a multiphysics simulation software
- For vertical probe cards to continue to advance < 100um Pitch:
  - Probe card suppliers should better understand their CCC capabilities for unpredictable surges in current
  - Probe card customers can aid by providing as much information about the test conditions as possible
- Communication will become increasingly important for matching probe technology to product

Future Work

- **Collect additional experimental data to continue to validate the multiphysics simulation**
- **Consider defining a CCC characterization test for isolated pulses**
  - Would need to better understand what a typical discharge event looks like
- **Increase overall robustness and value of simulation to account for any combination of:**
  - Heat from neighboring springs
  - Testing at elevated or reduced temperatures
  - Cres Variation
- **Allow FormFactor/MicroProbe to evaluate very quickly:**
  - Product Needs → Spring Design → Equivalent ISMI → Test → Ship