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Center for Pulsed Power & Power Electronics™

Interior Electromagnetic Fields of Buildings Struck by Lightning

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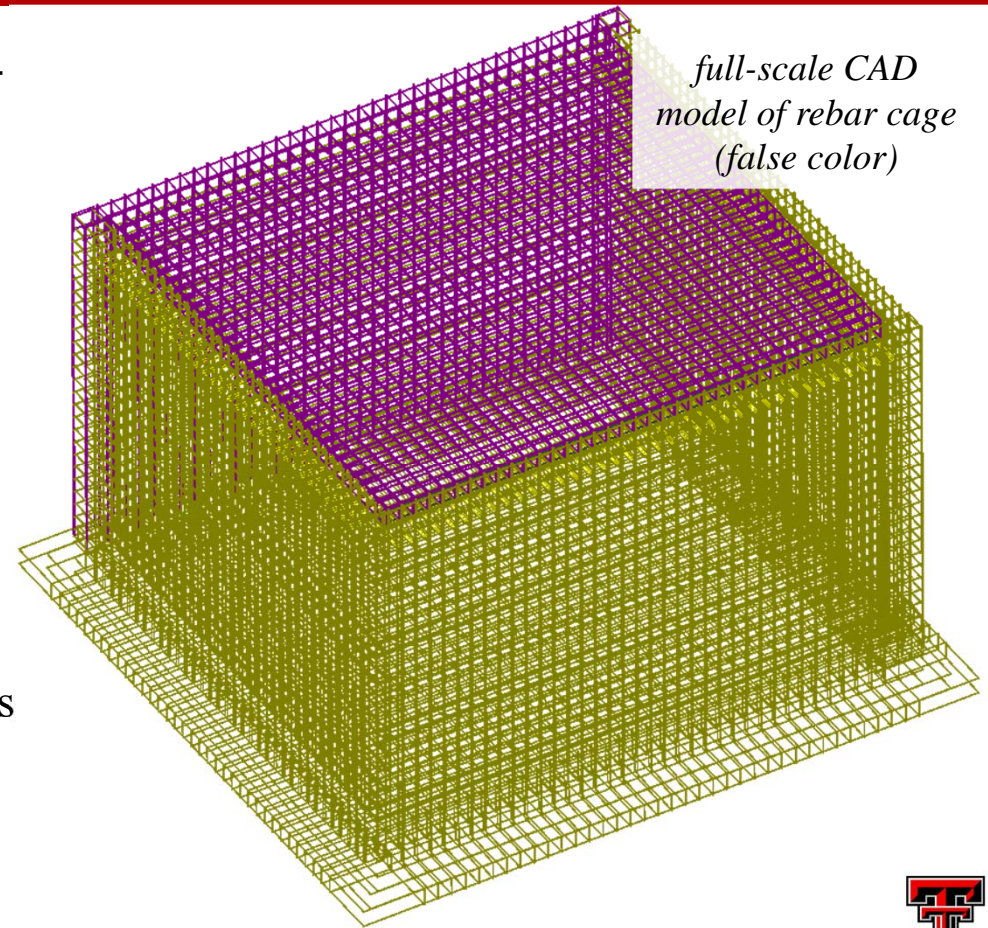
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Introduction & Building Topology

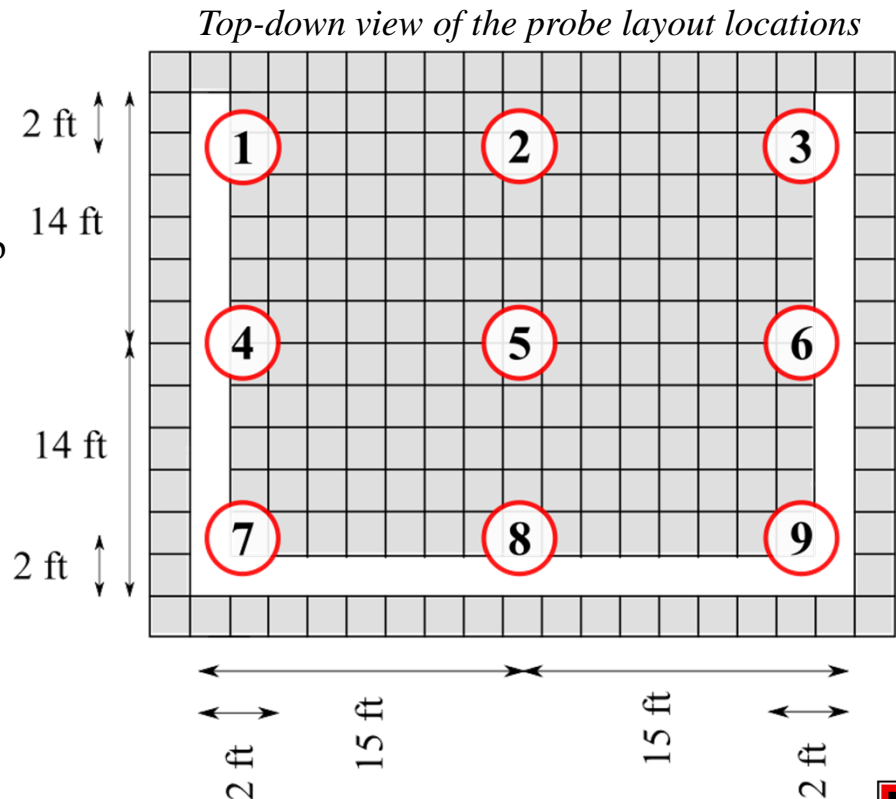
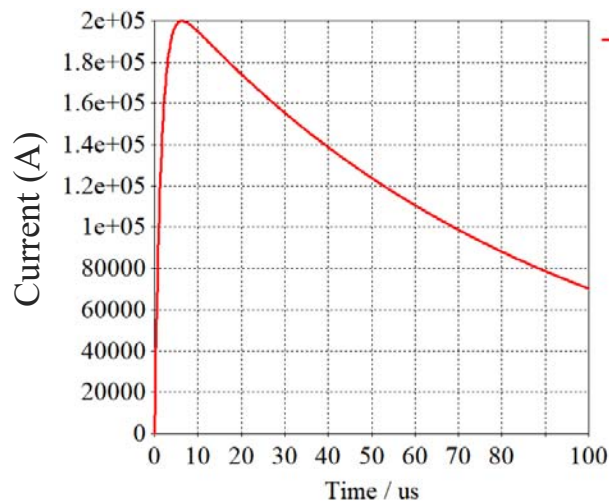
- Double-layer rebar cage, common to steel-reinforced concrete structures, generally provides adequate protection against lightning strike events
 - Analogous to a Faraday cage
- The structure on interest in this study features a blast relief
 - Three walls feature no electrical connection to the roof
 - One wall is electrically connected (i.e. a hinge)
 - Does this affect induced interior fields in lightning strike events?
 - Are there more vulnerable strike locations?





Simulation Details and Probe Layout

- IEC 62305-001 LPL 1, positive strike waveform (200 kA, $\sim 6 \mu\text{s}$ rise)
 - Accounts for 99% of all lightning strike events
- Probes arranged in a 3x3 matrix
- Unless otherwise noted, probes are 3' above the foundation
 - Some instances of probes near the electrical gap are noted



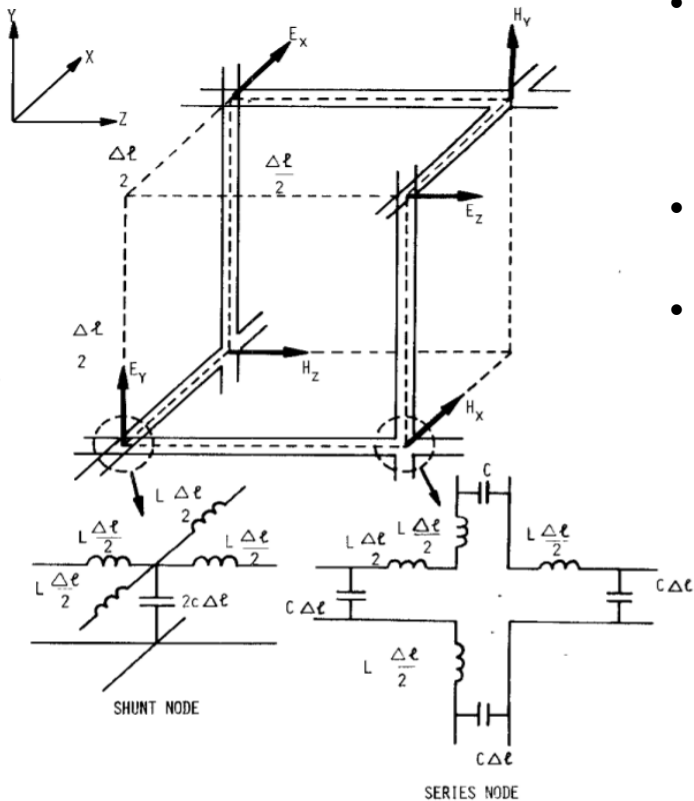
Slide 4

SZC6

What happened to negative strike?

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Algorithm and Computational Details



- Simulations incorporate a time-domain, transmission line matrix (TLM) model
 - CST Microwave Studio
- ~100M element typical mesh size
- Two, NVIDIA QUADRO RTX6000 GPUs
 - 24-48 hour typical simulation time



SPECIFICATIONS

GPU Memory	24 GB GDDR6
Memory Interface	384-bit
Memory Bandwidth	Up to 672 GB/s
ECC	Yes
NVIDIA CUDA Cores	4,608
NVIDIA Tensor Cores	576
NVIDIA RT Cores	72
Single-Precision Performance	16.3 TFLOPS
Tensor Performance	130.5 TFLOPS
NVIDIA NVLink	Connects 2 Quadro RTX 6000 GPUs ¹
NVIDIA NVLink bandwidth	100 GB/s (bidirectional)
System Interface	PCI Express 3.0 x 16

¹Source: NVIDIA QUADRO RTX6000 Datasheet

Hoefer, Wolfgang JR. "The transmission-line matrix method-theory and applications." *IEEE Transactions on Microwave Theory and Techniques* 33.10 (1985): 882-893.

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SZC1

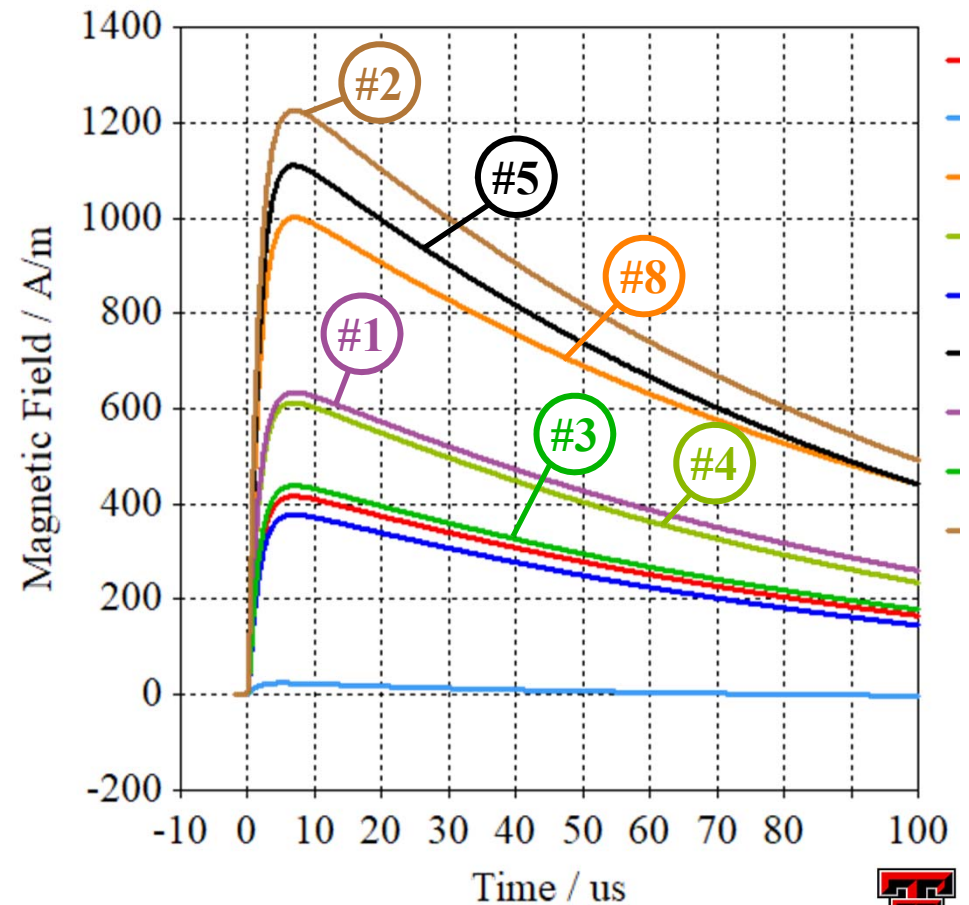
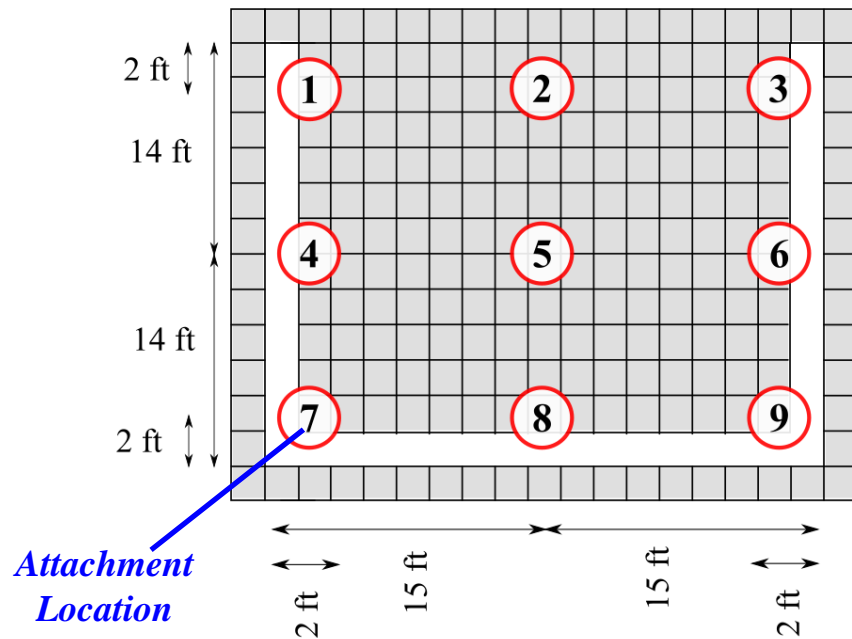
New Figure

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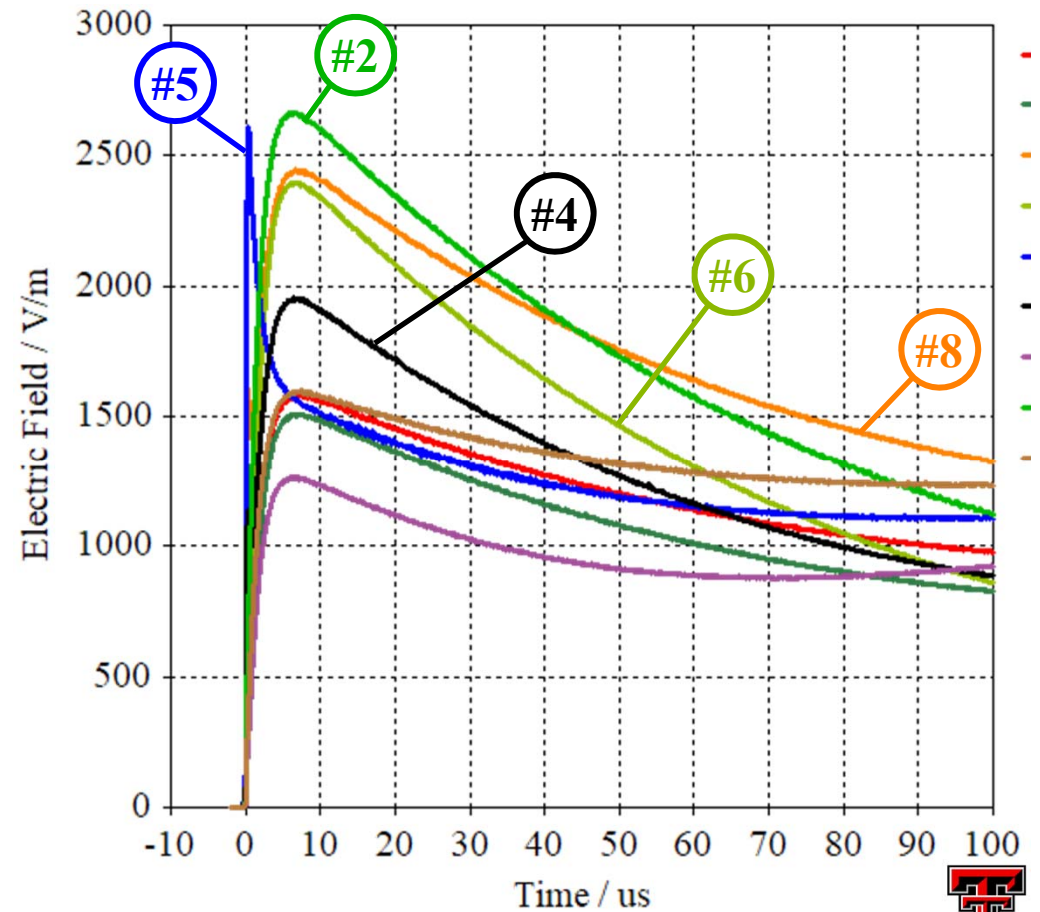
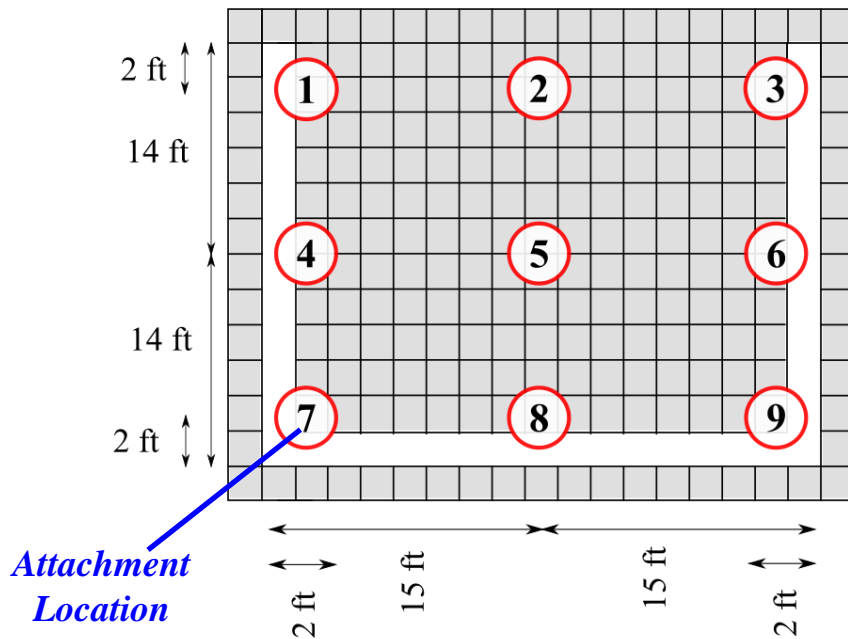
Roof-Corner Strike, H-field

- Roof-Corner strikes yield the highest interior H-fields, but not necessarily E-fields



Roof-Corner Strike, E-field

- Roof-Corner strikes yield the highest interior H-fields, but not necessarily E-fields



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SZC4

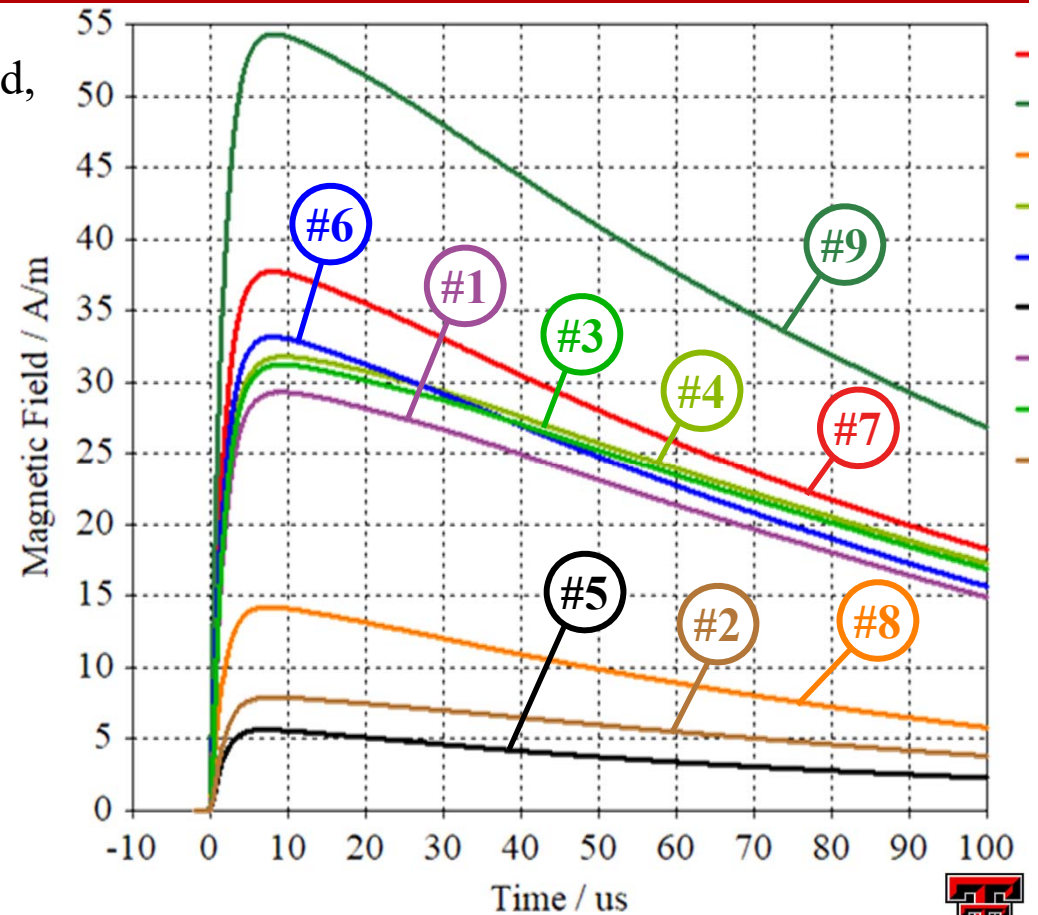
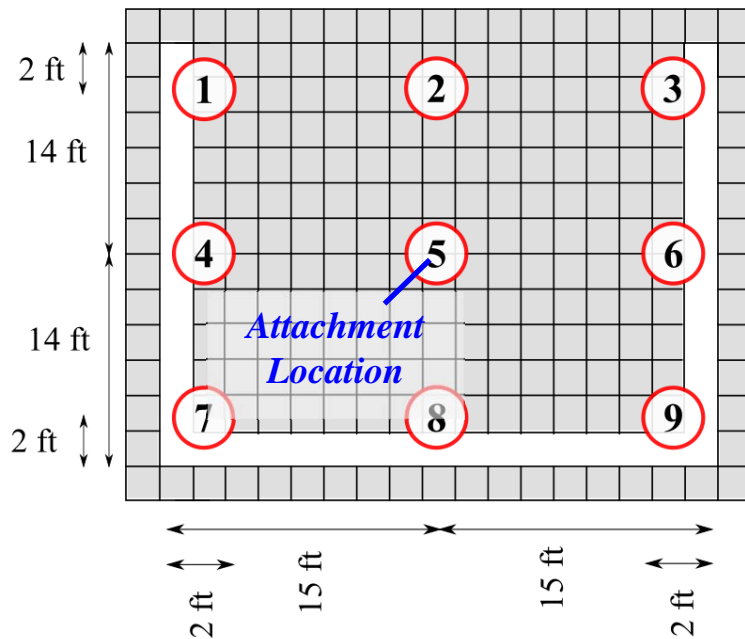
do we know why #5 does not follow the other waveforms? Interesting.

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Roof-Center Strike, H-field

- Roof-Center strikes yield a higher E-field, but much lower H-field



Slide 8

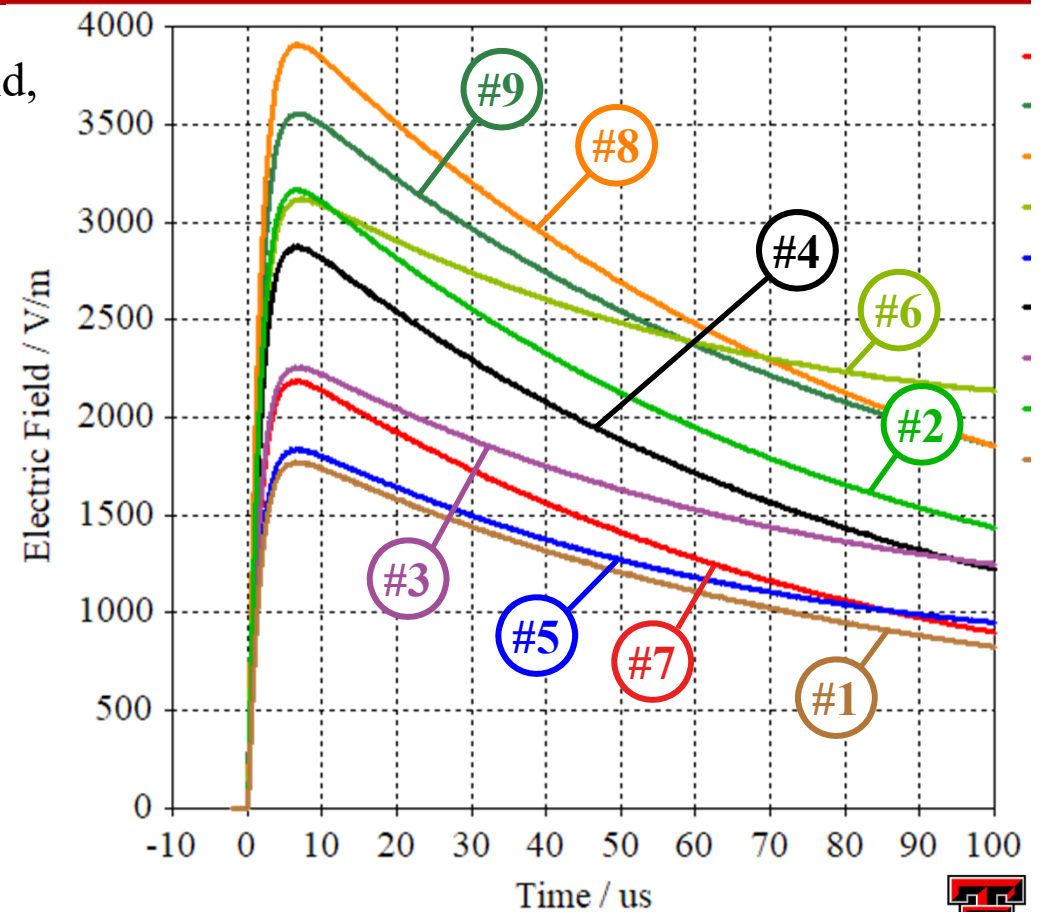
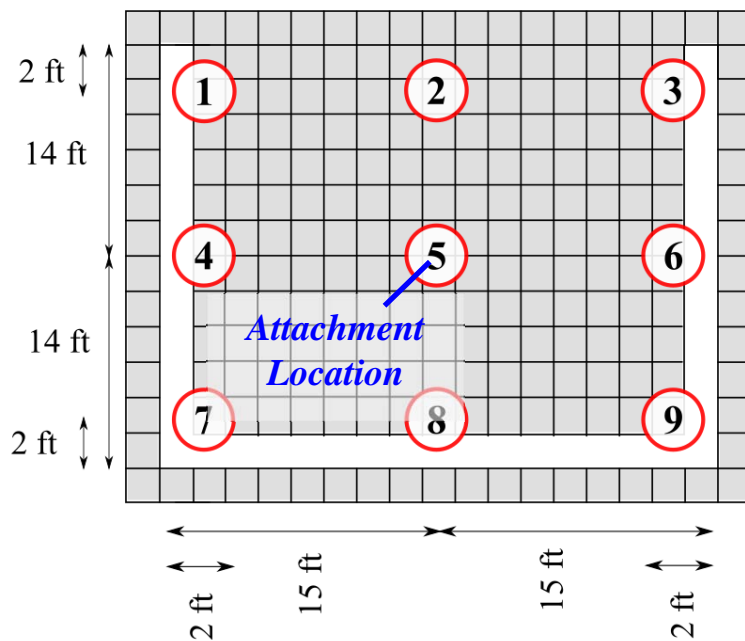
SZC3

Might recommend changing scale if there is time. At first glance this looks like this produces higher magnetic field

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Roof-Center Strike, E-field

- Roof-Center strikes yield a higher E-field, but much lower H-field



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SZC5

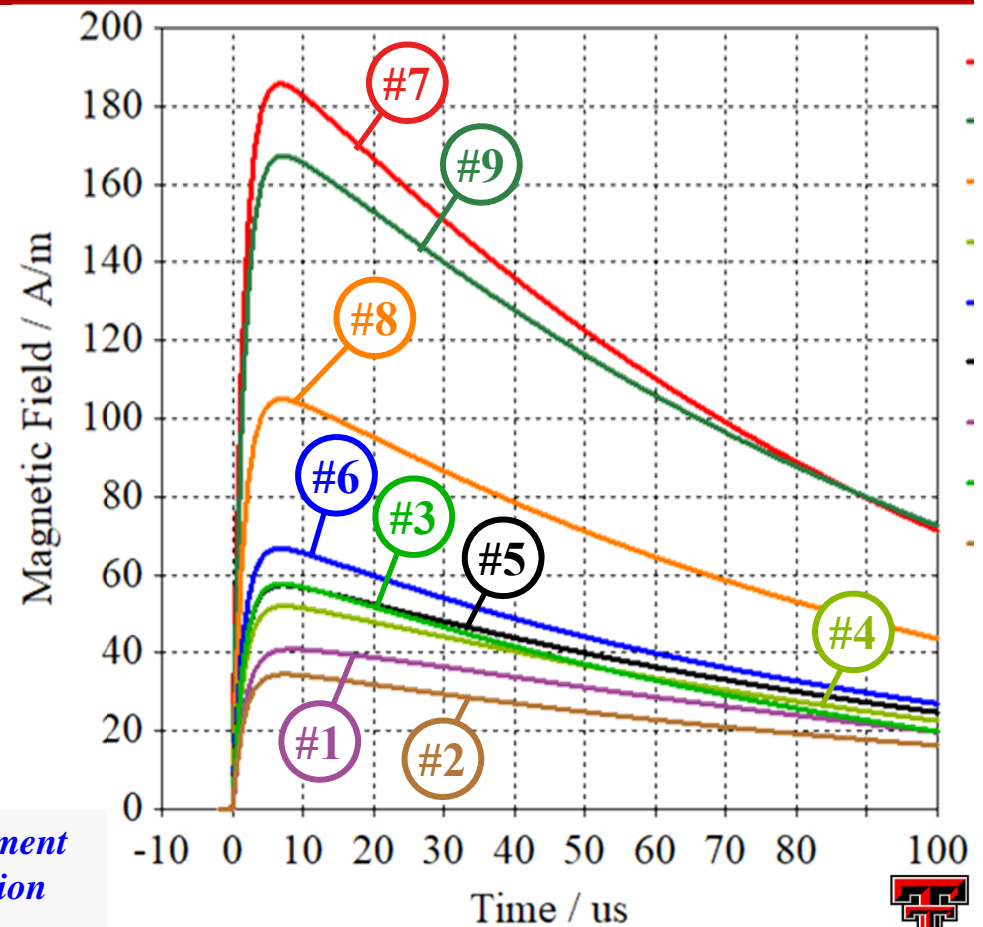
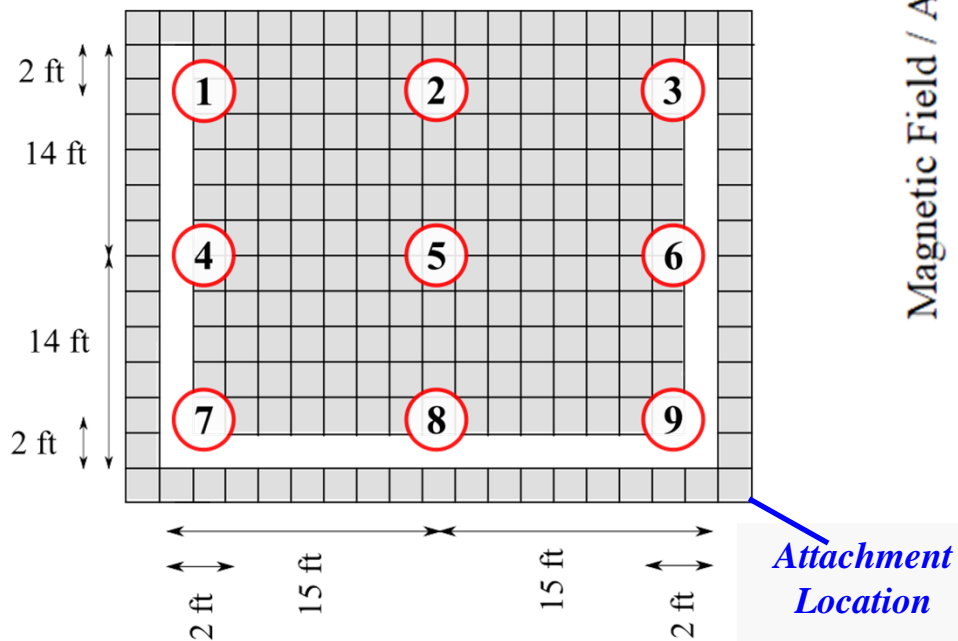
No figures here follow what #5 did on corner strike. Interesting.

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Wall-Corner Strike, H-field

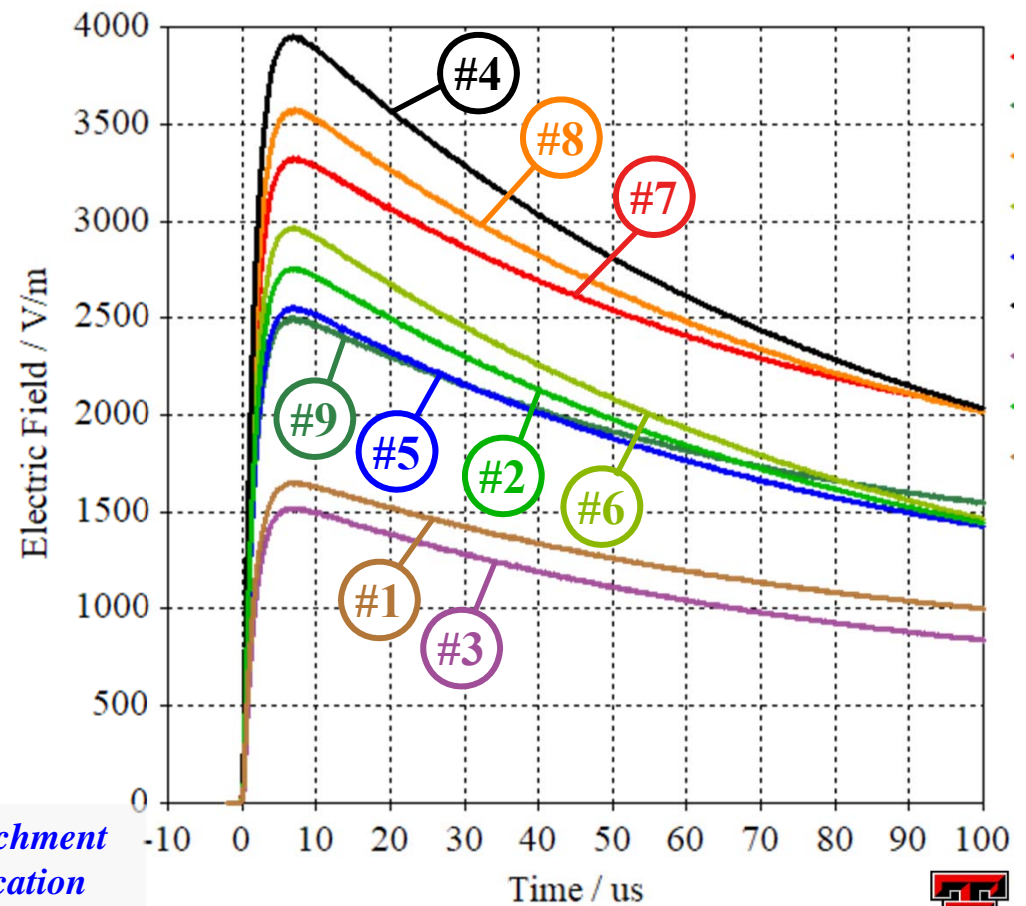
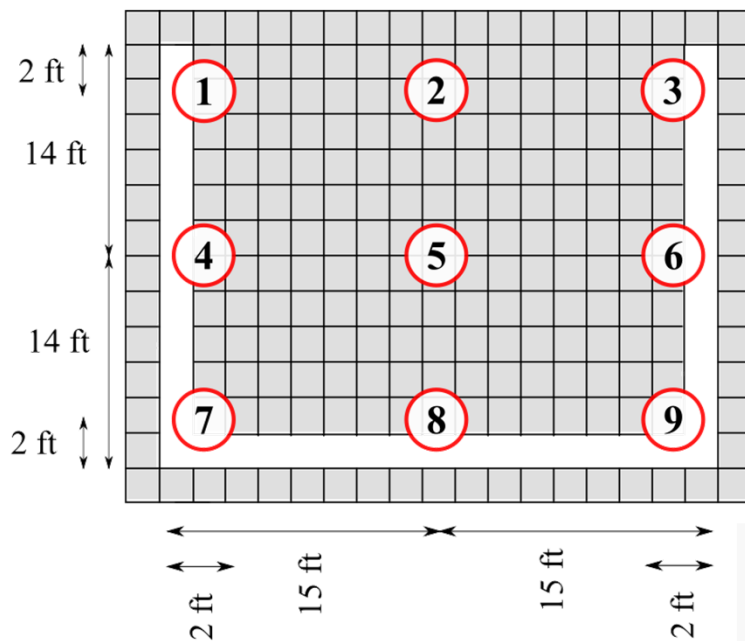
- Wall-Corner Strike yield moderate H-fields and higher E-fields





Wall-Corner Strike, E-field

- Wall-Corner Strike yield moderate H-fields and higher E-fields





Summary of Full-Scale Computational Results

- Calculated E-field and H-field magnitudes are generally consistent with published literature for conventional structures*
- Roof strikes, near the discontinuity induce significantly higher H-fields, while E-fields less dependence on the strike location

Table: Maximum field values observed for the 3x3 matrix of field probes, 3' above the foundation surface

	Peak H-field	Peak E-field
Roof-Corner Strike	1200 A/m	2600 V/m
Roof-Center Strike	54 A/m	3900 V/m
Wall-Corner Strike	185 A/m	4000 V/m

* I.A. Metwally, F.H. Hiedler, W.J. Zischank, "Magnetic Fields and Loop Voltages Inside Reduced and Full-Scale Structures Produced by Direct Lightning Strikes" IEEE Trans. Electromag. Compat. **48**, 414 (2006).



Slide 12

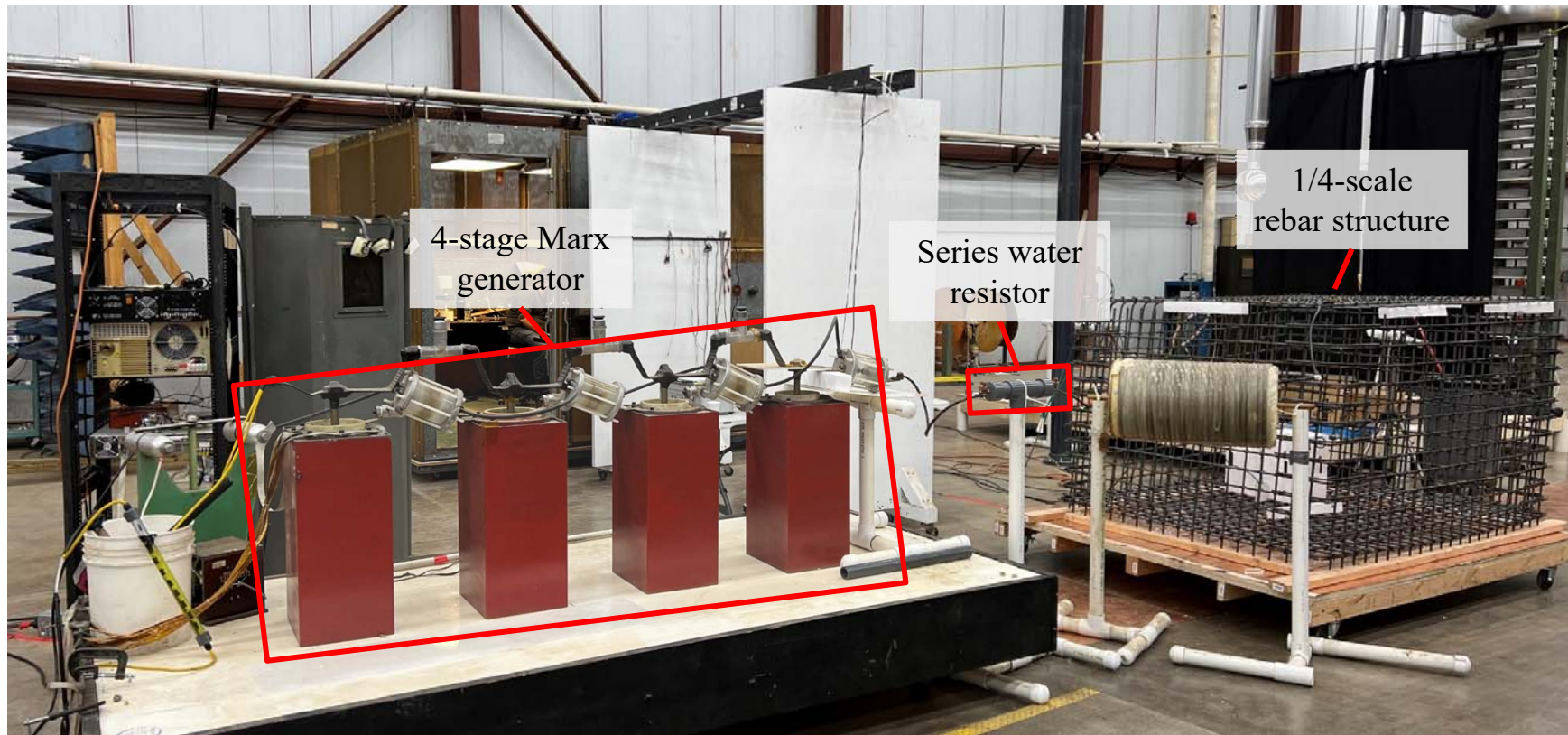
SZC7

Are there any conclusions/equations that can be drawn from this so far? Seems pretty empirical at the moment.

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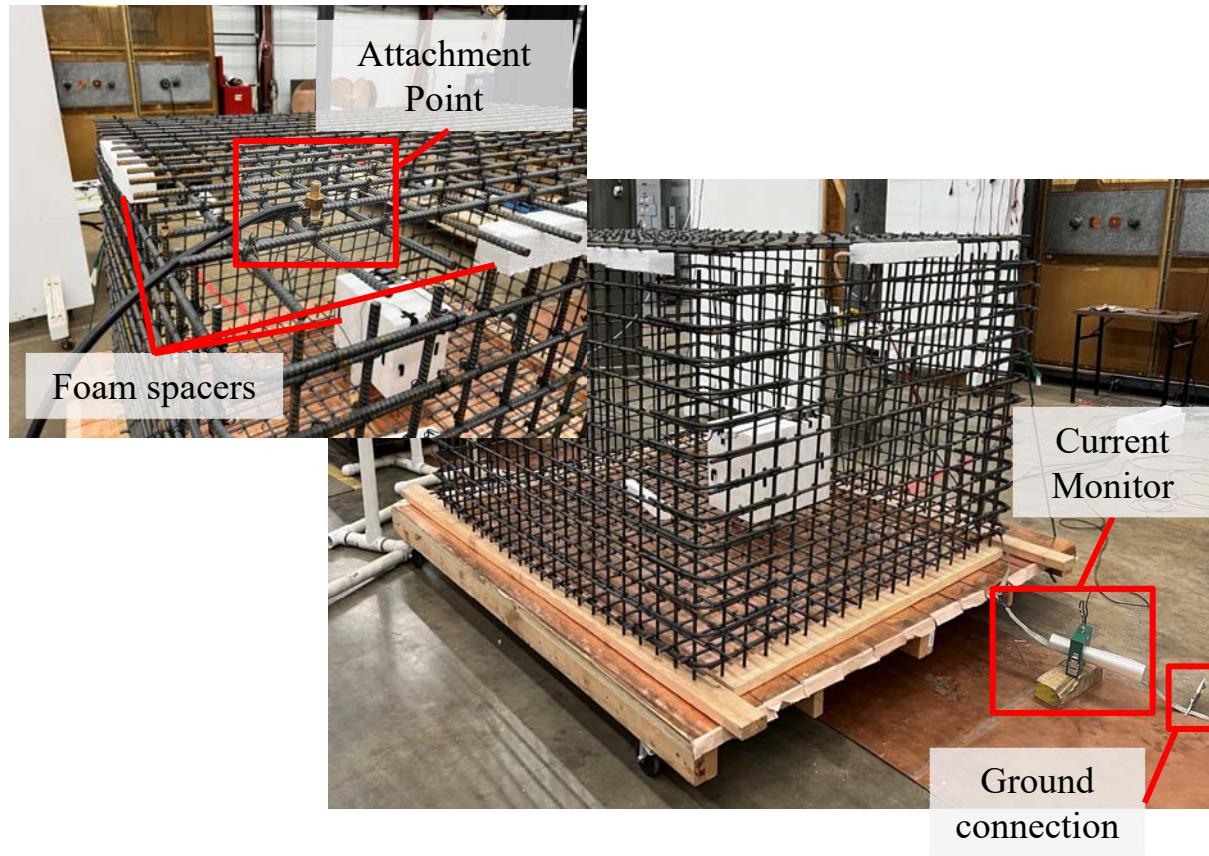


Experimental Setup





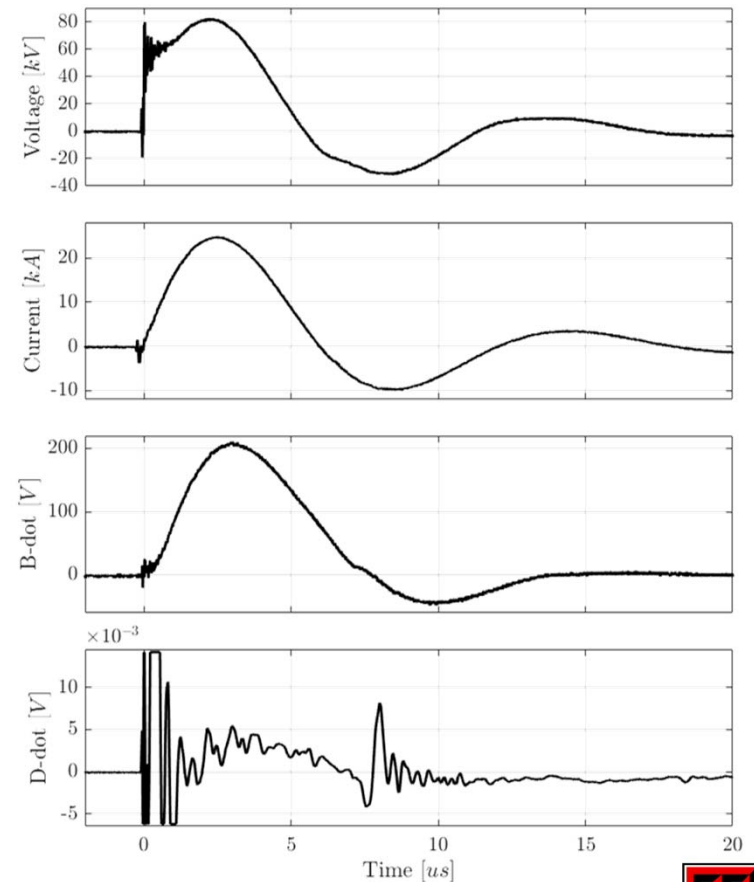
1/4-Scale Rebar Structure





First Experimental Shots

- Example shot for 30 kV marx charge voltage (~ 120 kV) output
- Currently collecting experimental data with varying current waveforms and strike locations
 - Voltage, Current, E-fields, B-fields





Conclusion & Future Plans

- Continue modeling effort to better understand induced fields
 - Varying attachment location, strike type (positive, negative, etc.), grounding details, etc.
- Revision of our Marx generator to provide 1/4-scale relevant peak current and pulse risetime
 - Measurement of interior magnetic and electric fields
- Reconciliation of experimental and computationally modeled fields
 - Improved confidence in computational model results

