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Cathode Modeling and Diode Performance in Planar Geometry using SCL Emission

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SCL emission and instabilities

- 1D planar SCL current density [1]:

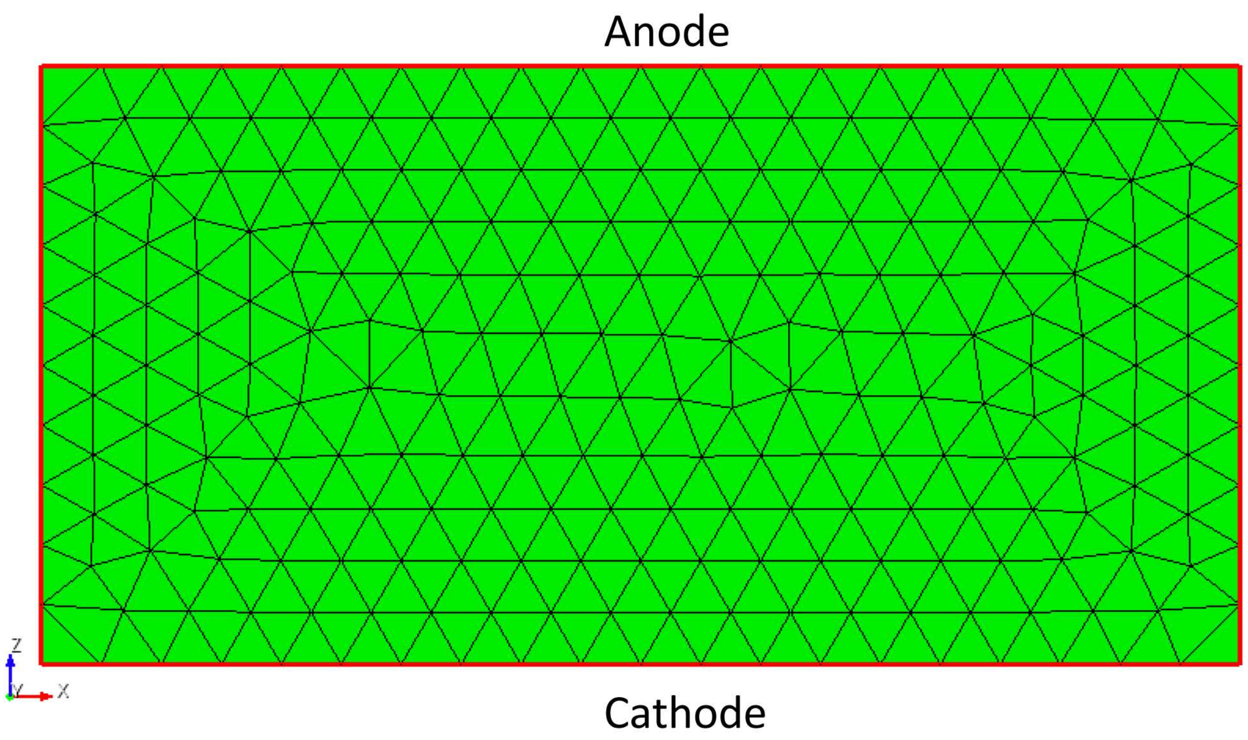
$$J_{SCL} = \frac{4\epsilon_0}{9}\sqrt{\frac{2e}{m}}\frac{V^{3/2}}{d^2}$$

- Patchy emission
  - Emission suppression of neighboring cells
- Transit time oscillations (TTOs) [2,3]

$$\frac{1}{t_{transit}} = \frac{2d}{nc}$$

- Virtual cathode oscillator formation (vircator) [4]

$$\omega_P = \sqrt{\frac{n_e e^2}{\gamma_0 m_e \epsilon_0}}$$

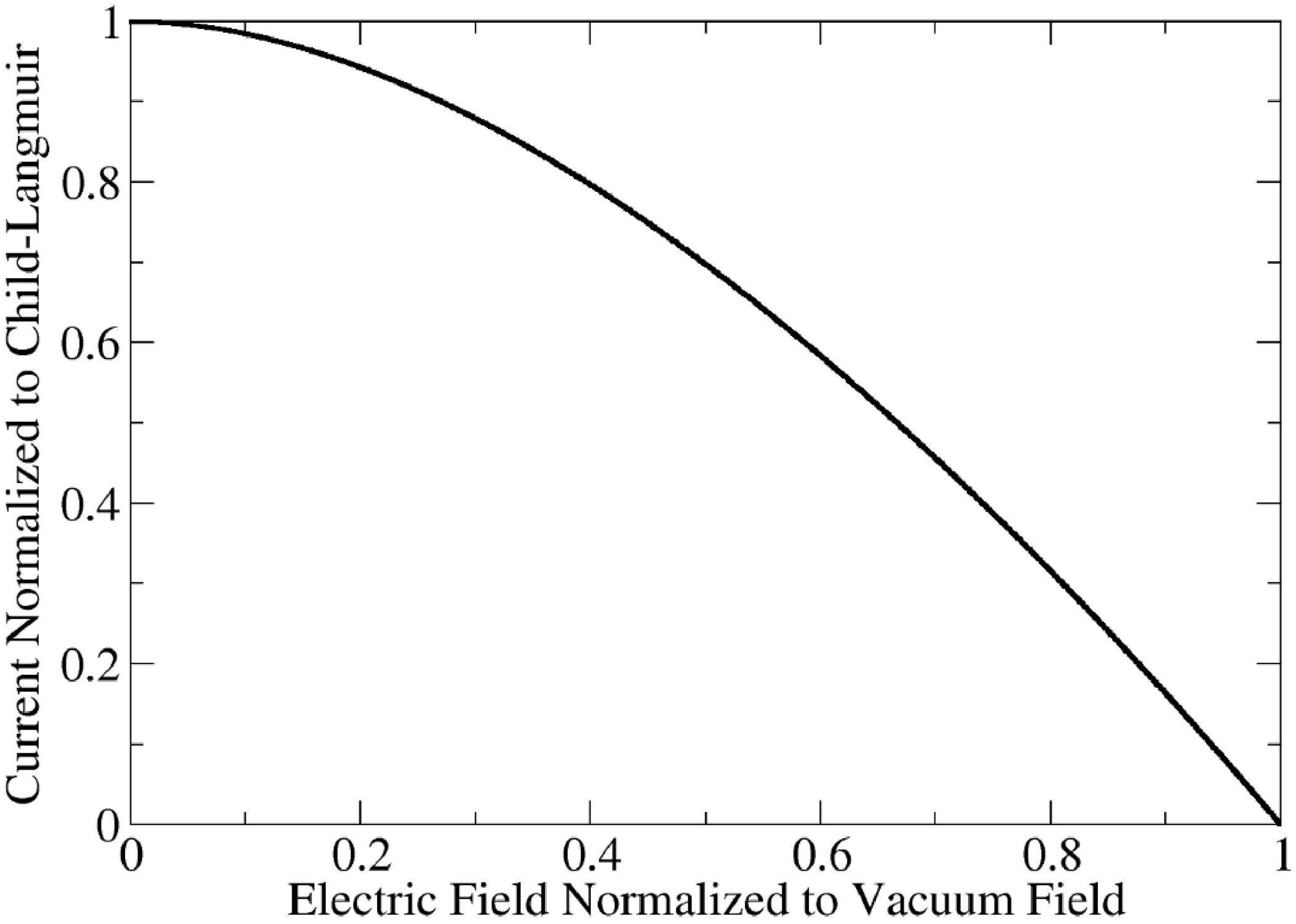


[1] - Child, C. D. "Discharge from hot CaO". *Physical Review*. Series I. 32(5): 492-511. May 1911
[2] - Luginsland, J. W., Arman, M. J., and Lau, Y. Y., "High-power transit-time oscillator: onset of oscillation and saturation" *Physics of Plasmas* 4, 4404. September 1997
[3] - Pozar, D. M., "Microwave Engineering" *Wiley*, 1998
[4] - Benford, J., Swegle, J. A., Schamiloglu, E., "High Power Microwaves" 3rd. Edition. *CRC Press*. 2016

SCL Emission and Instabilities

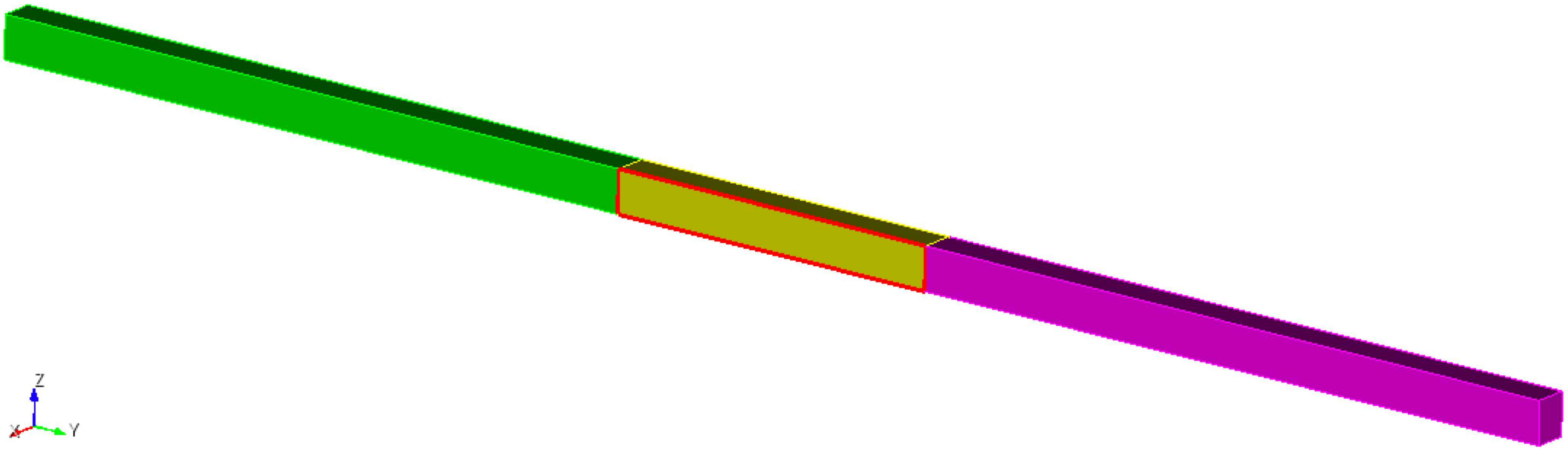
- Delay time
  - Delay cathode emission for specified time after breakdown threshold is surpassed
- Ramp time
  - Begin emission at specified initial fraction
  - Current density ramps below function over specified ramp time

$$J = \frac{1}{4}(2 + (2 - 3E_0)\sqrt{1 + 3E_0})$$

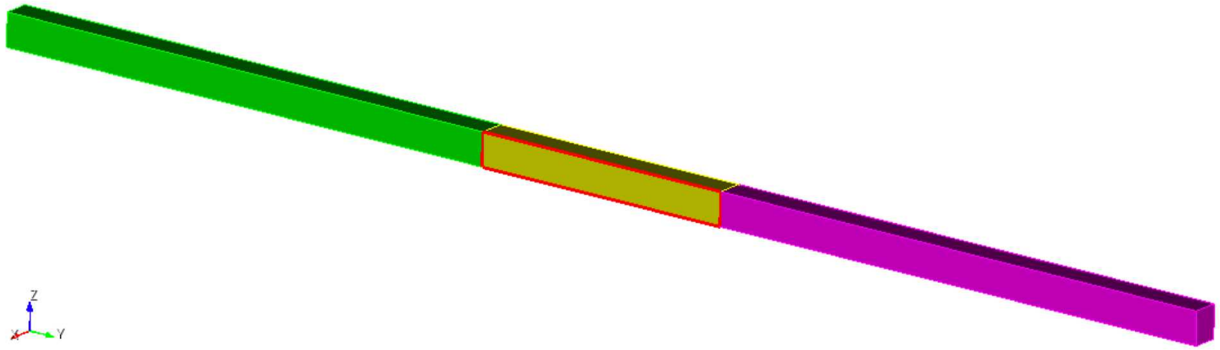


Modeling and Simulation Code

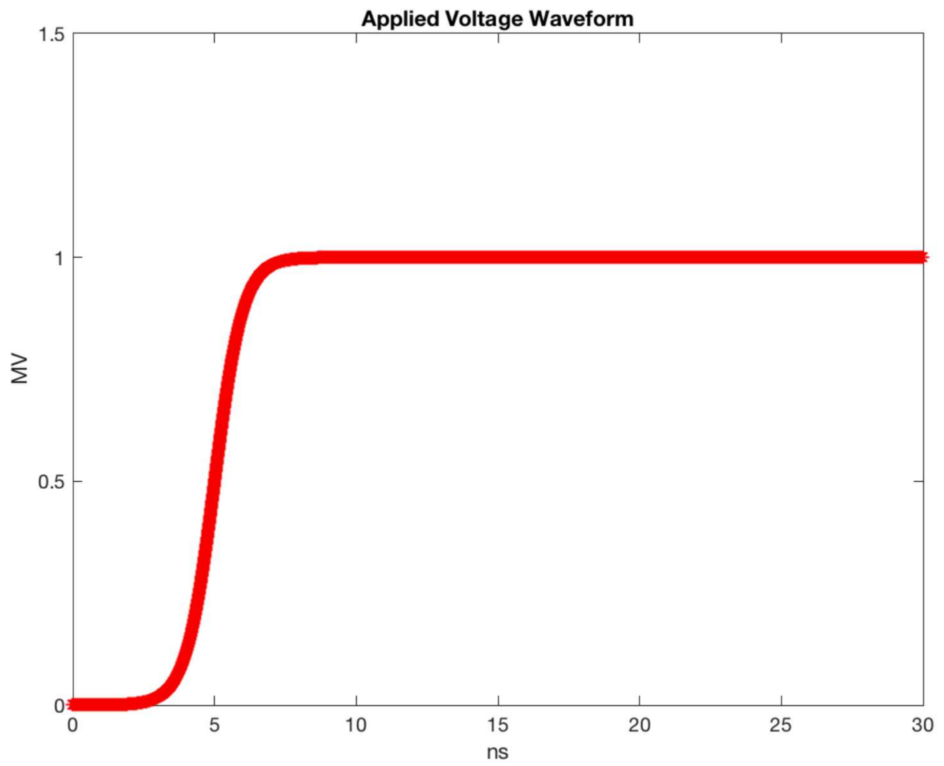
- EMPIRE – unstructured time domain electromagnetic particle-in-cell code (UTDEM PIC)
- CUBIT – code-based modelling and meshing



Modeling



- 1m transmission line BCs
- 1m model length
- 20cm diode region
- 2.5cm AK gap
- 2cm width
- Vacuum impedance[3]: 471Ω
- Steady state diode impedance[4]: 67Ω

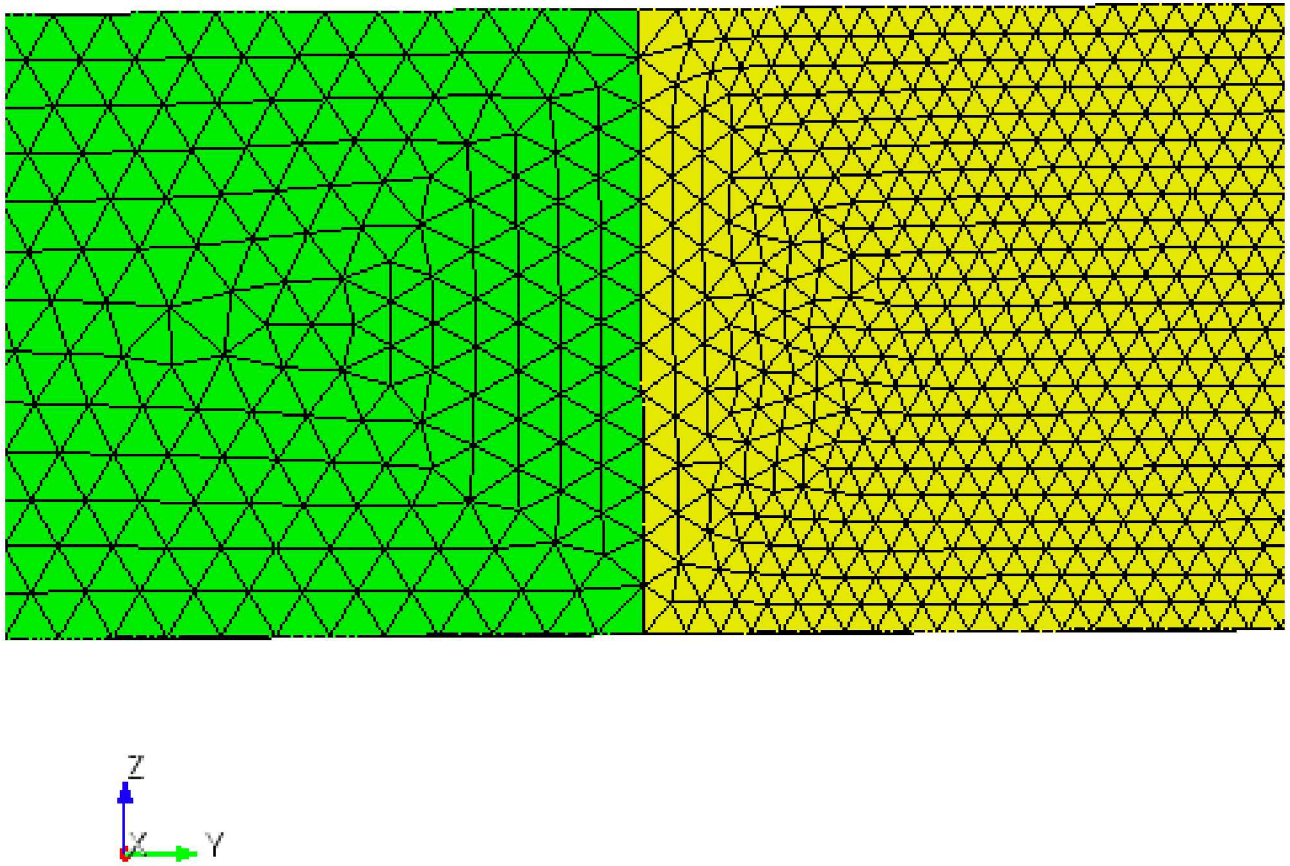


$$Z_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} \frac{d}{W}$$

$$Z_D = 429 \frac{d^2}{A} \frac{1}{\sqrt{V_0}}$$

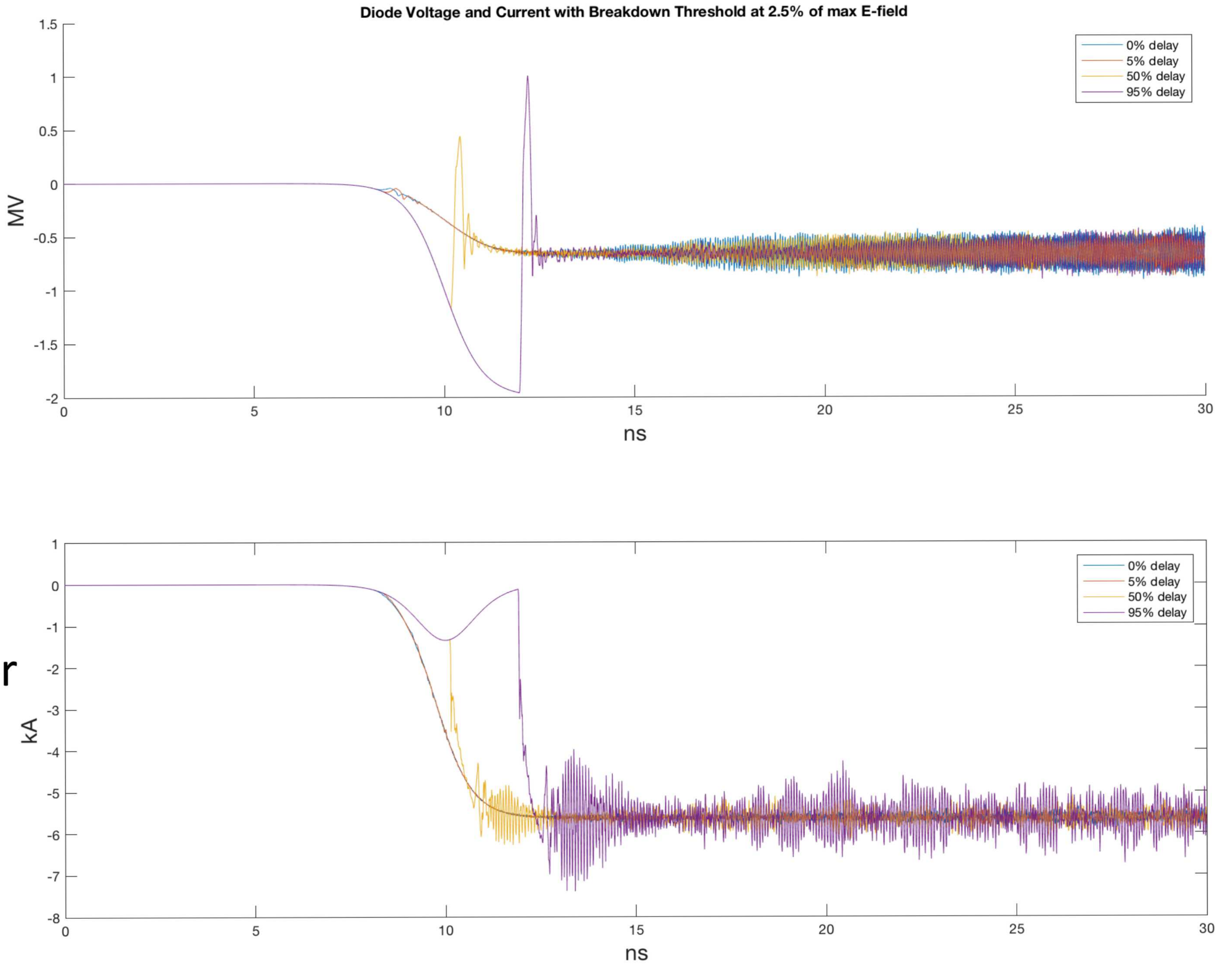
Modeling

- Vacuum wave mesh
  - dx = d/10
- Diode mesh
  - Dx = d/20
- Smooth transition between mesh sizes to minimize numerical impedance reflections



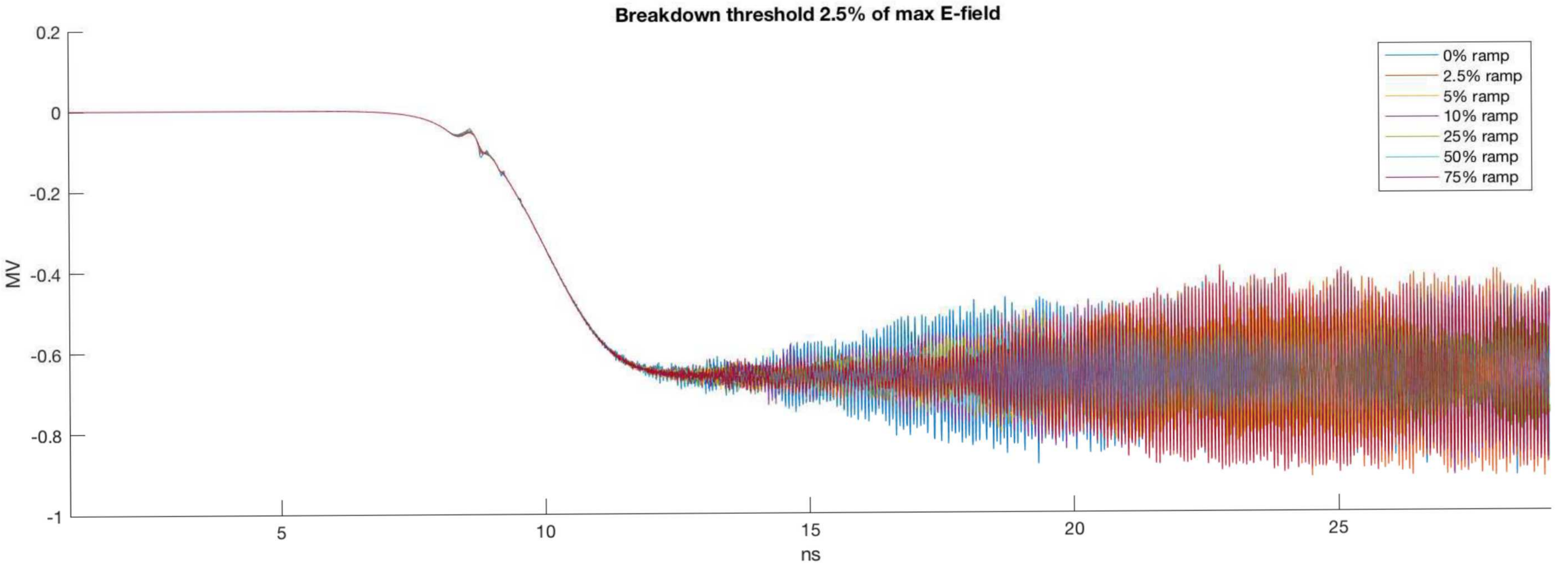
Delay Time

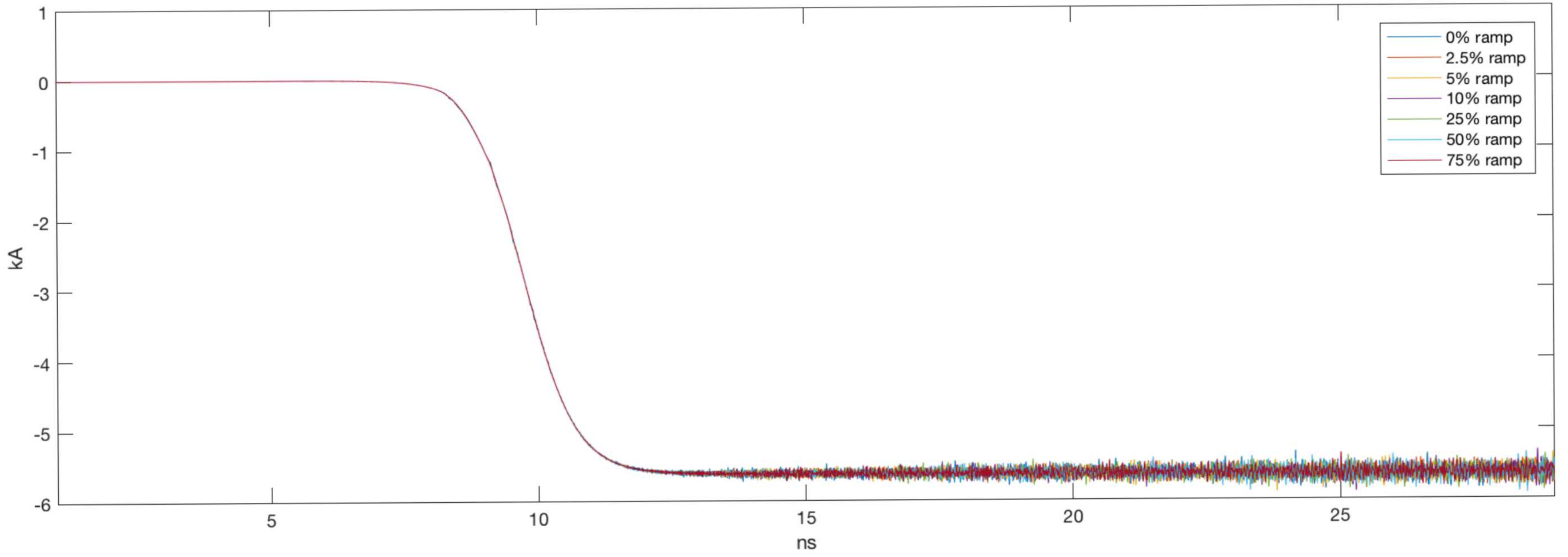
- Delay performs as expected
- Behaves similarly to simply increasing the breakdown threshold
- Primary benefit lies in tens of timesteps after breakdown
- dt = 1ps



Ramp Time

- Early TTO excitation?
- Perform FFTs to see what this is





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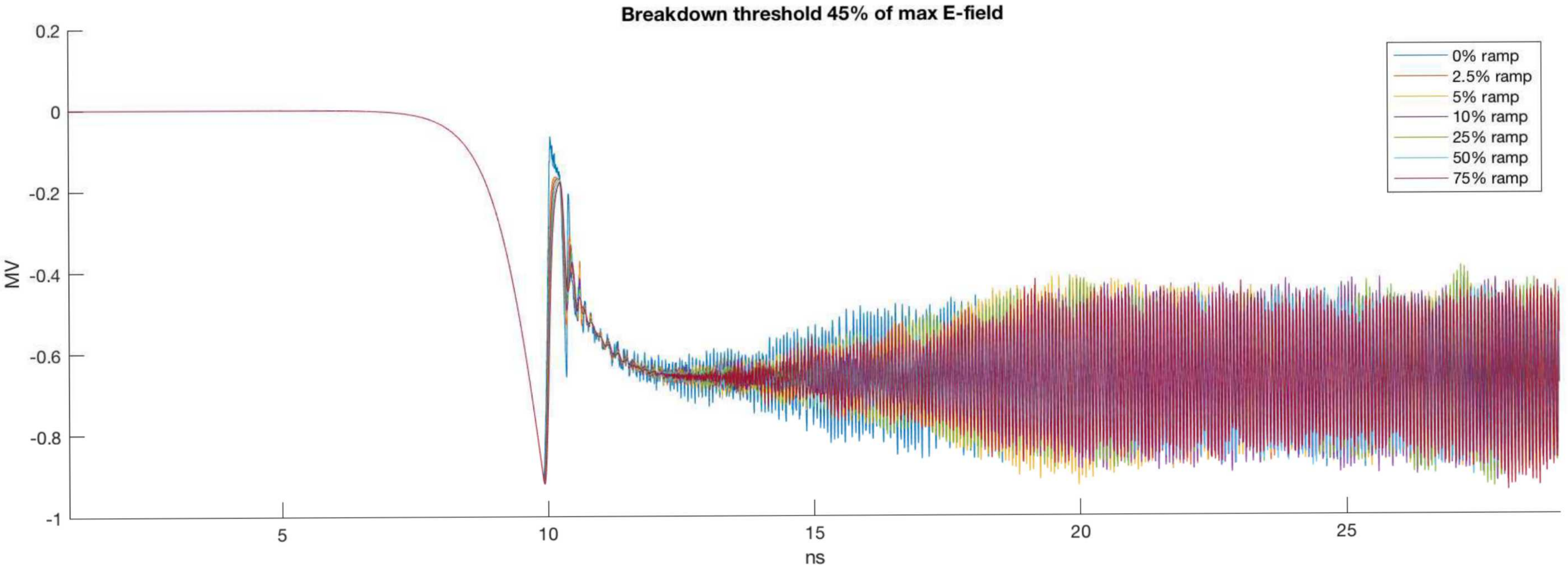
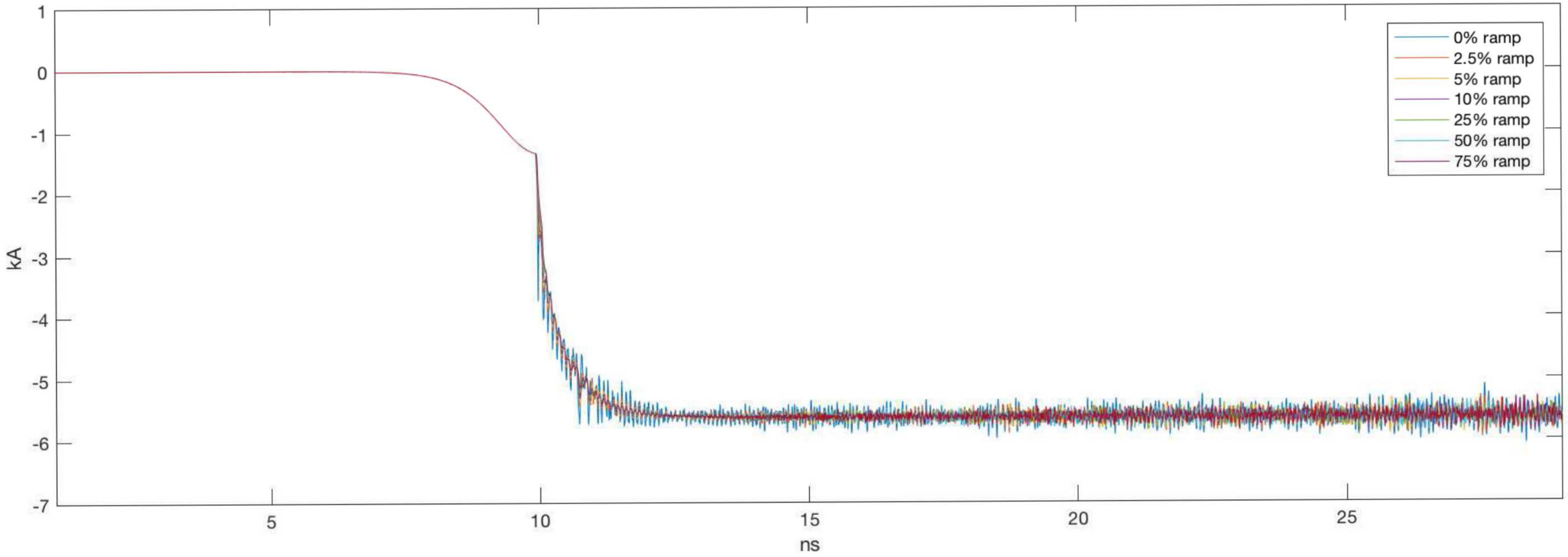
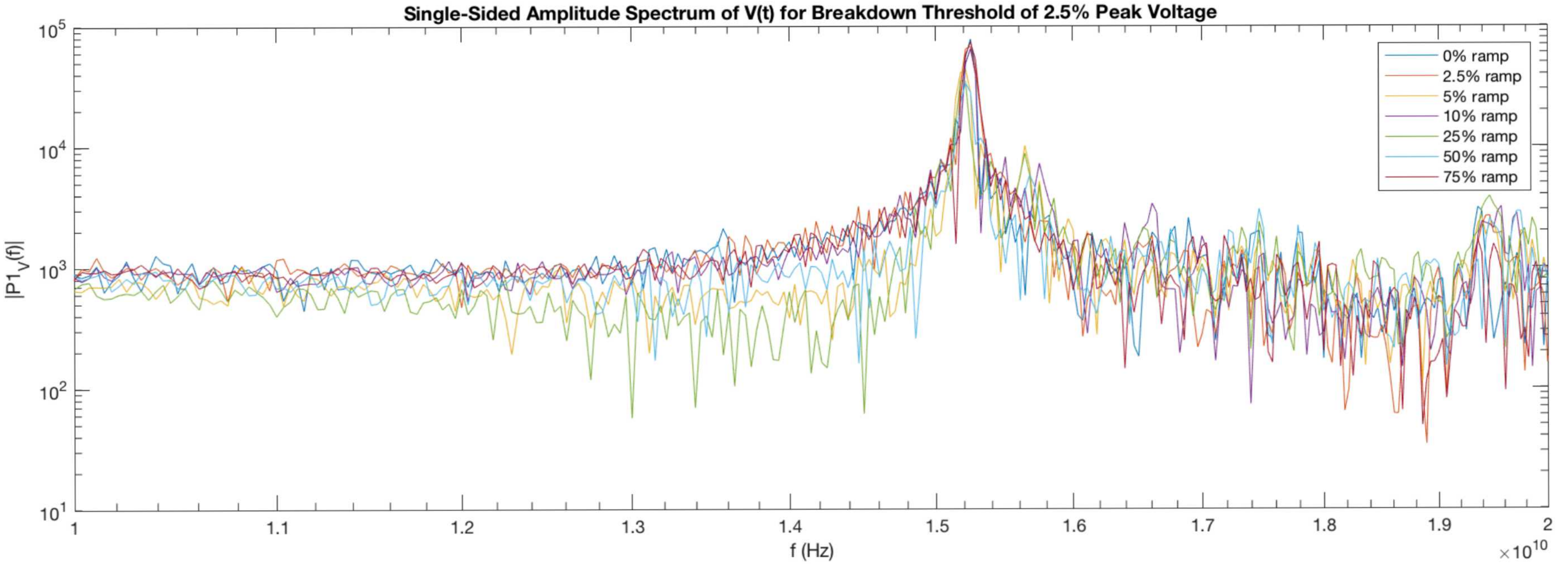


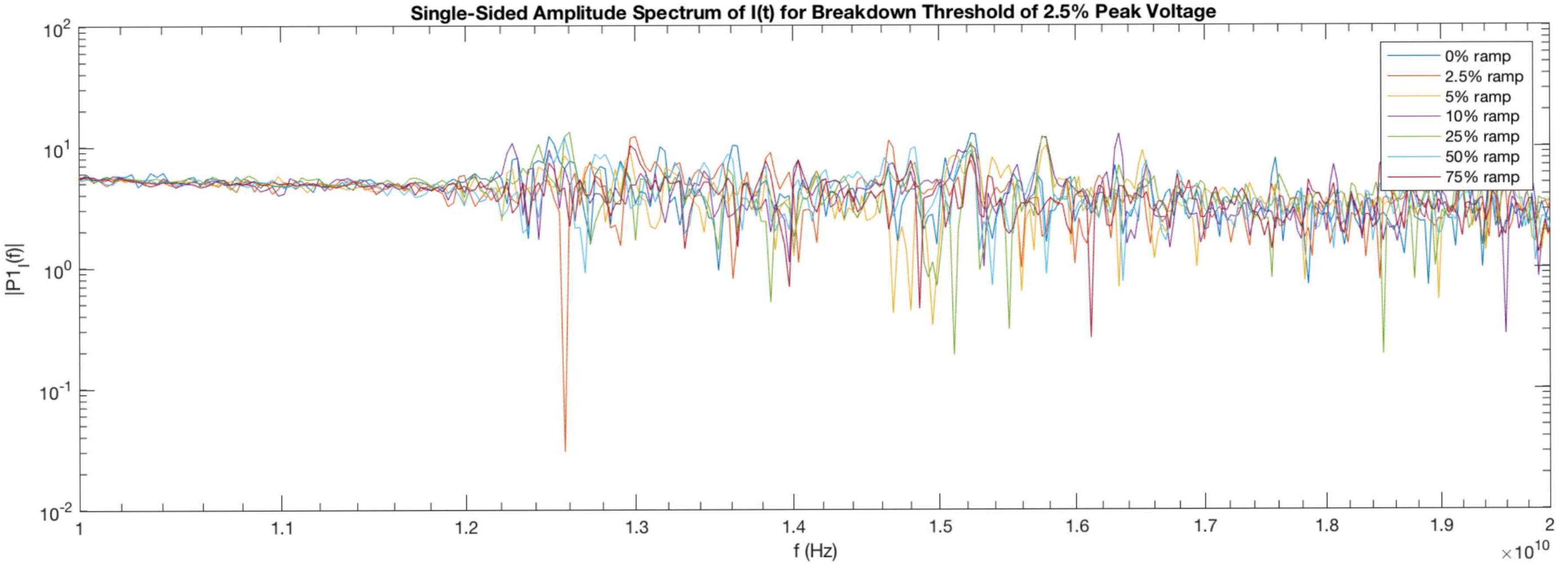


Ramp Time FFTs

- Oscillations are primarily in voltage waveform
- 15GHz oscillation

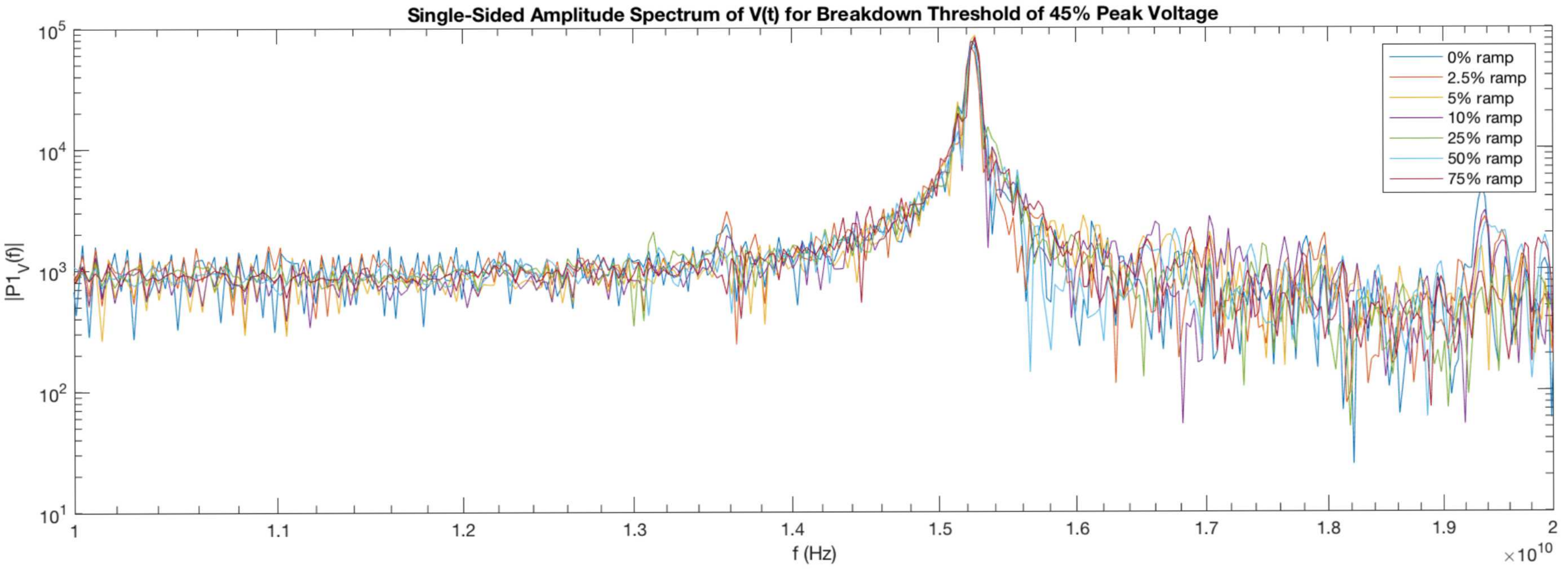
$$\frac{1}{t_{transit}} = \frac{2d}{nc}$$

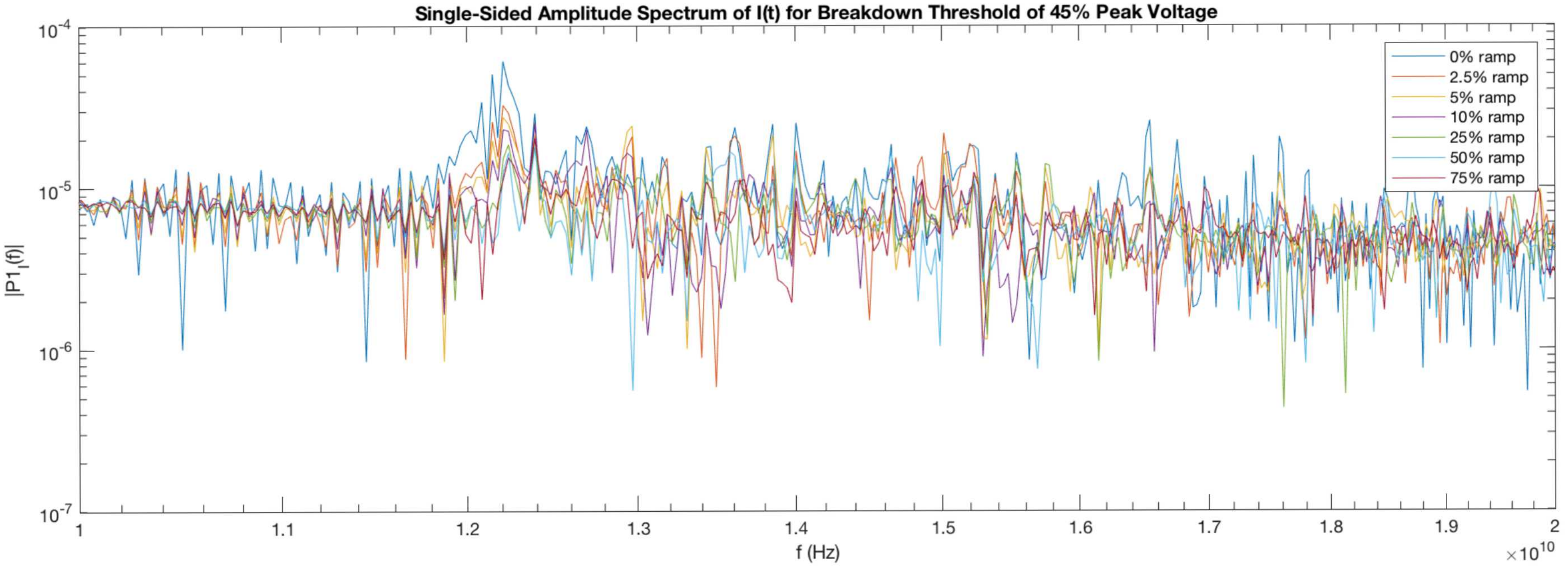




Ramp Time FFTs

- Oscillations are primarily in voltage waveform
- 15GHz oscillation
- Current has small 12GHz oscillation

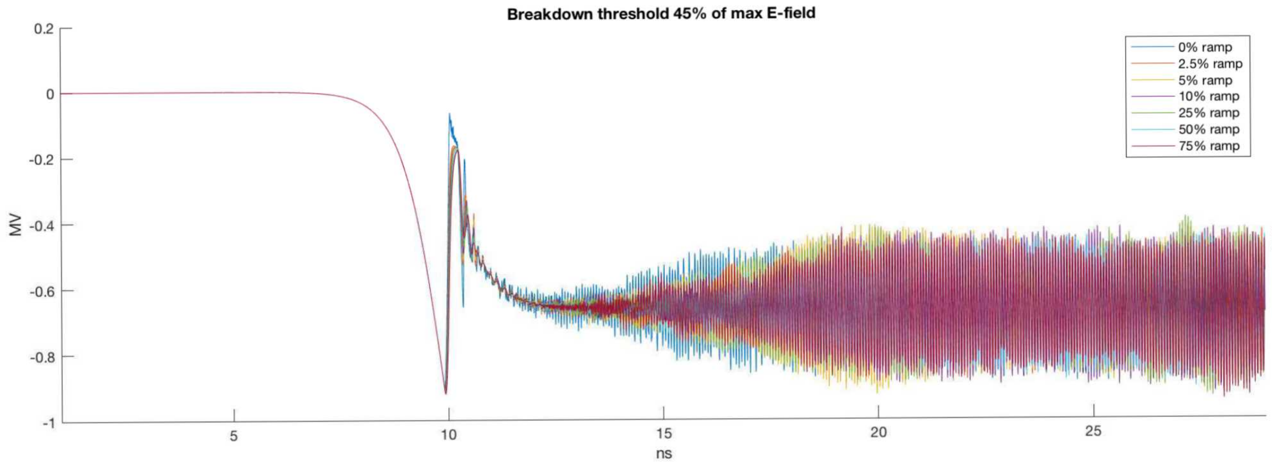


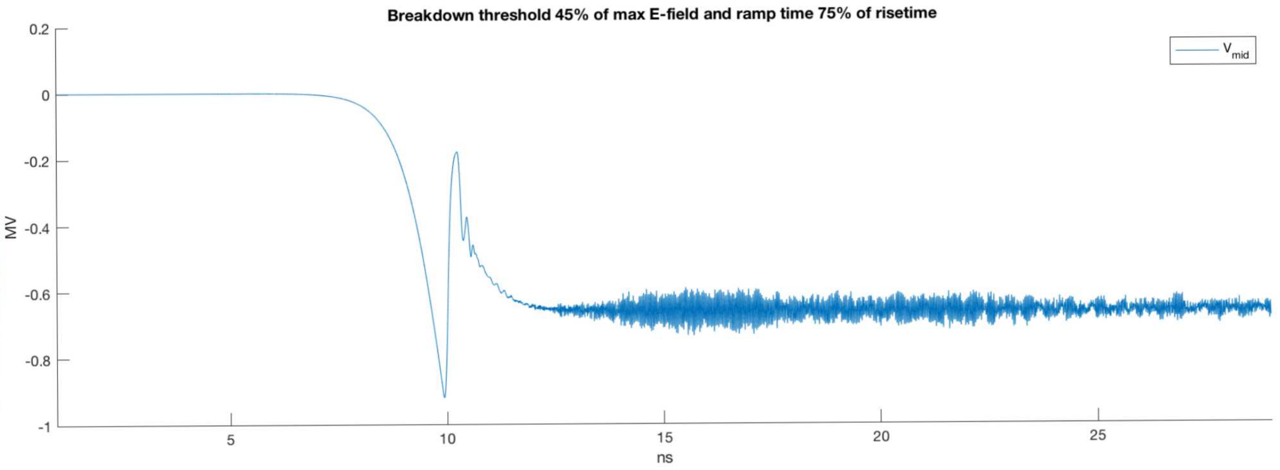


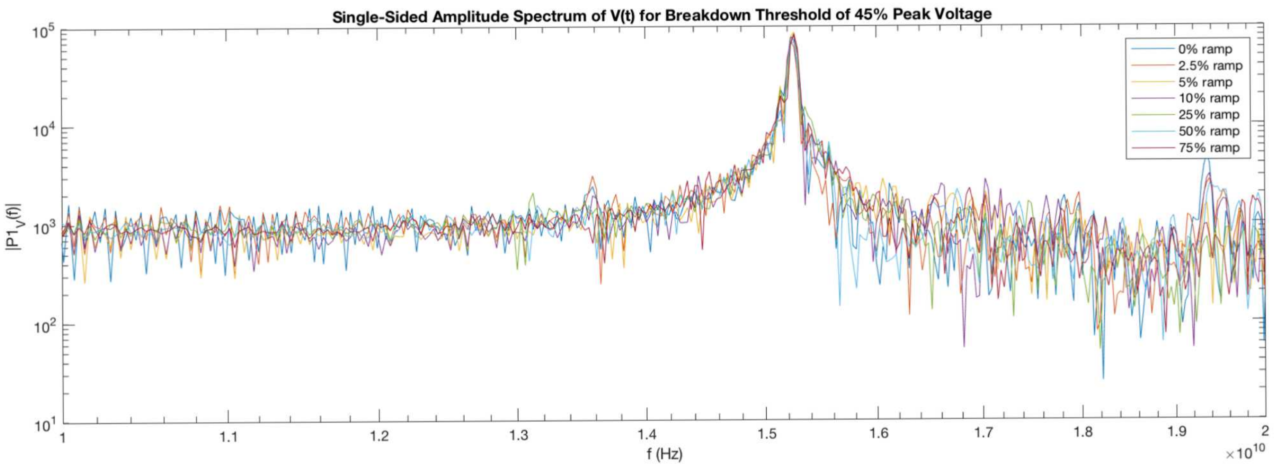
PMC ringing

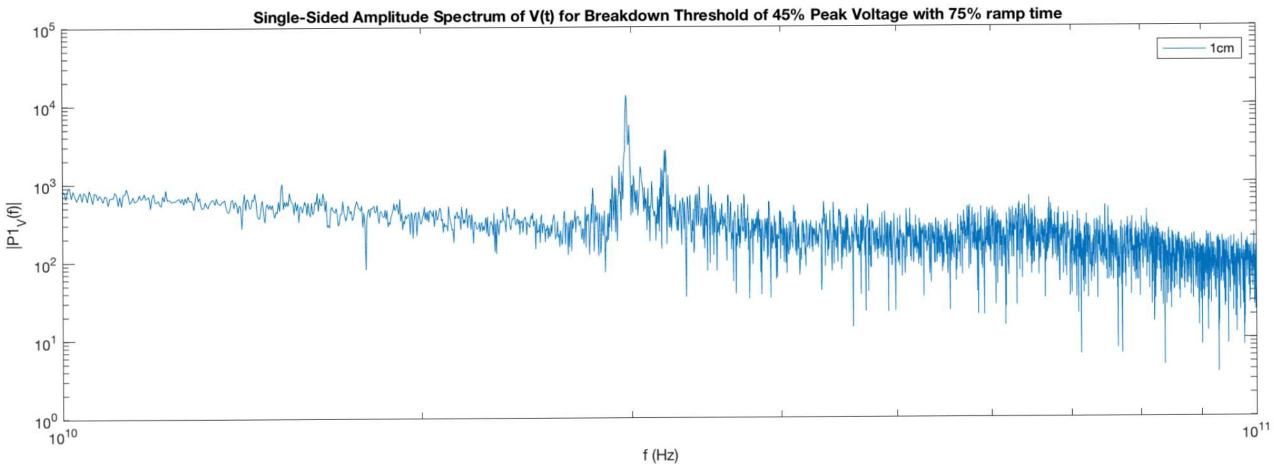
2cm width

1cm width

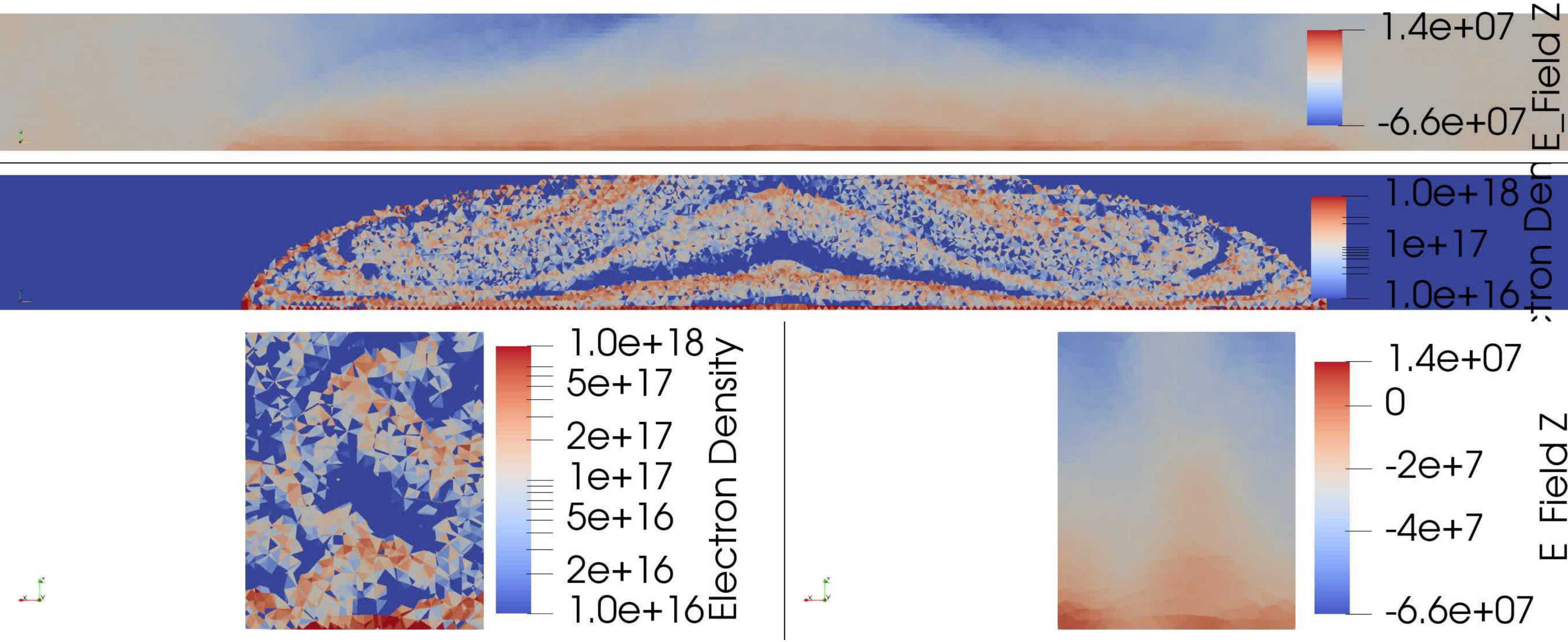






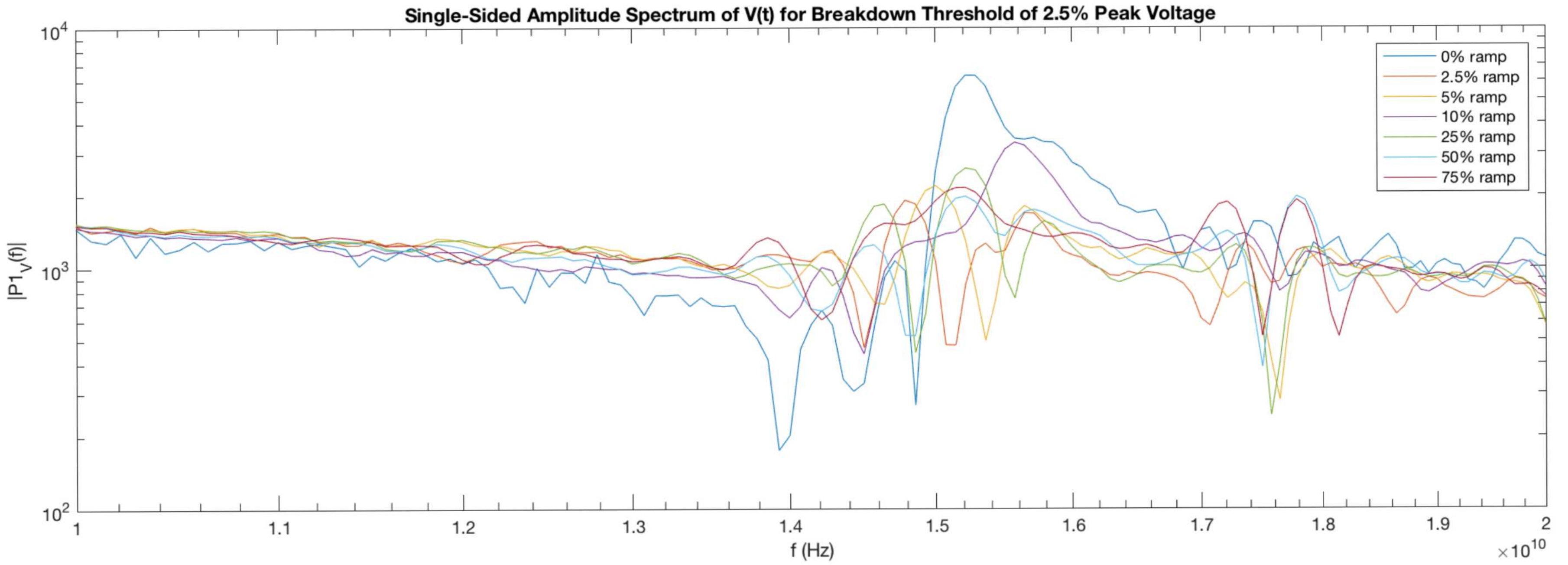


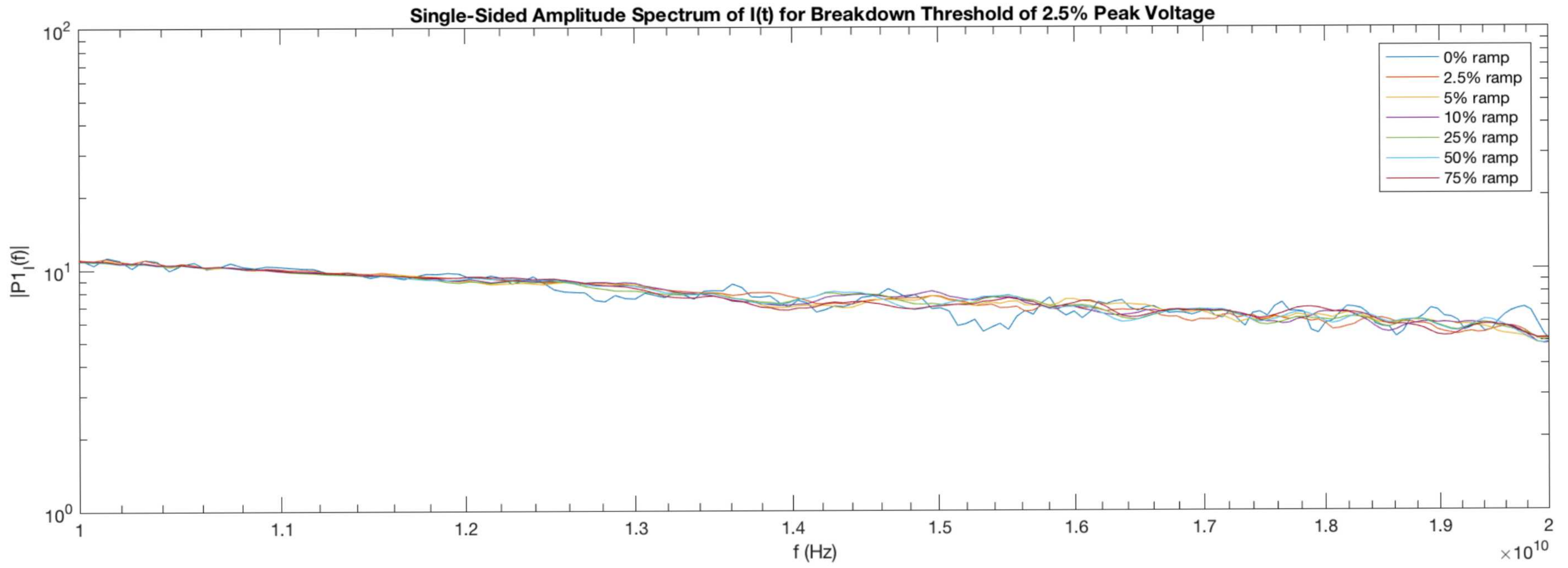
PMC ringing


1.4e+07
-6.6e+07
E_Field Z
1.0e+18
1e+17
1.0e+16
1.0e+18
5e+17
2e+17
1e+17
5e+16
2e+16
1.0e+16
Electron Density
1.4e+07
0
-2e+7
-4e+7
-6.6e+07
E_Field Z

PMC Ringing and TTO Growth

- Cut off FFTs at 15ns





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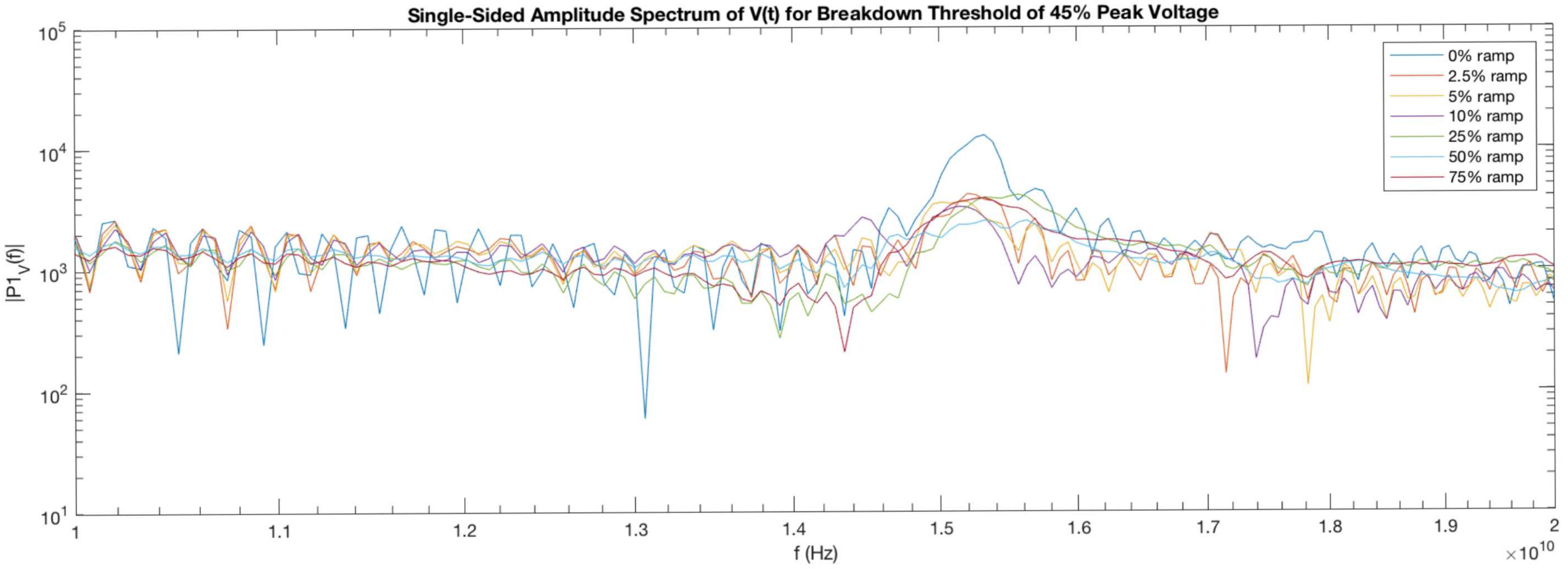
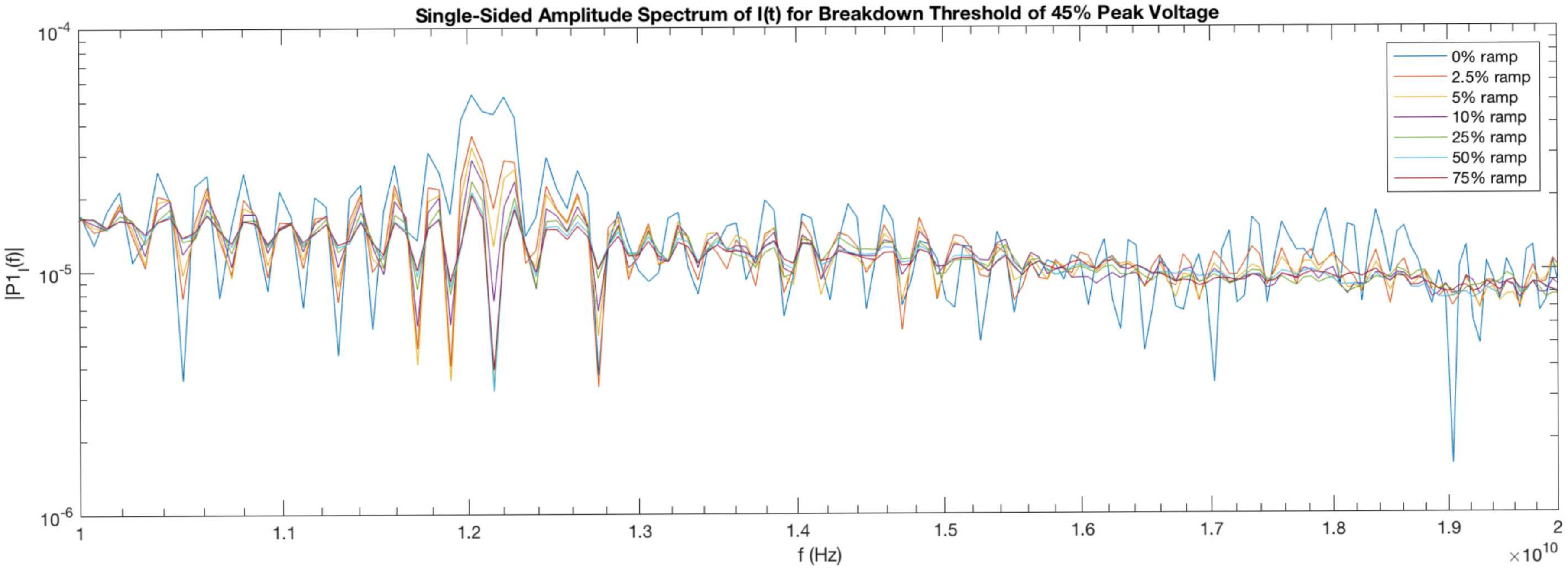
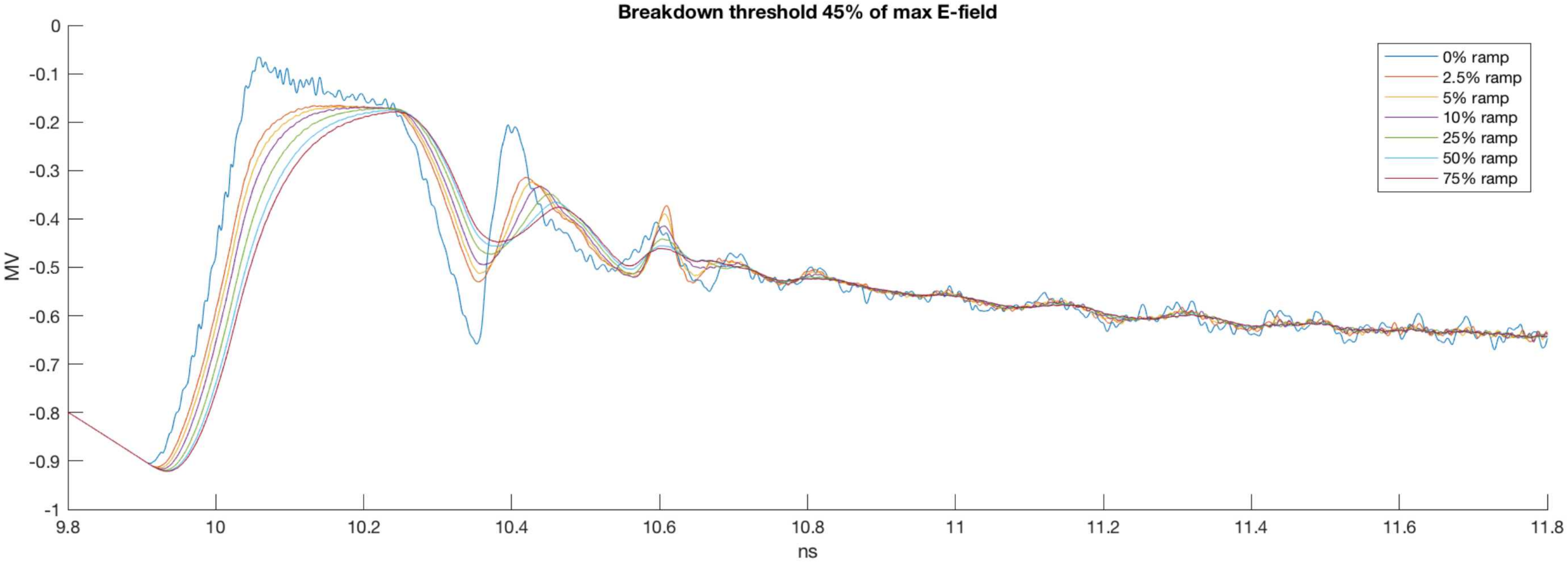


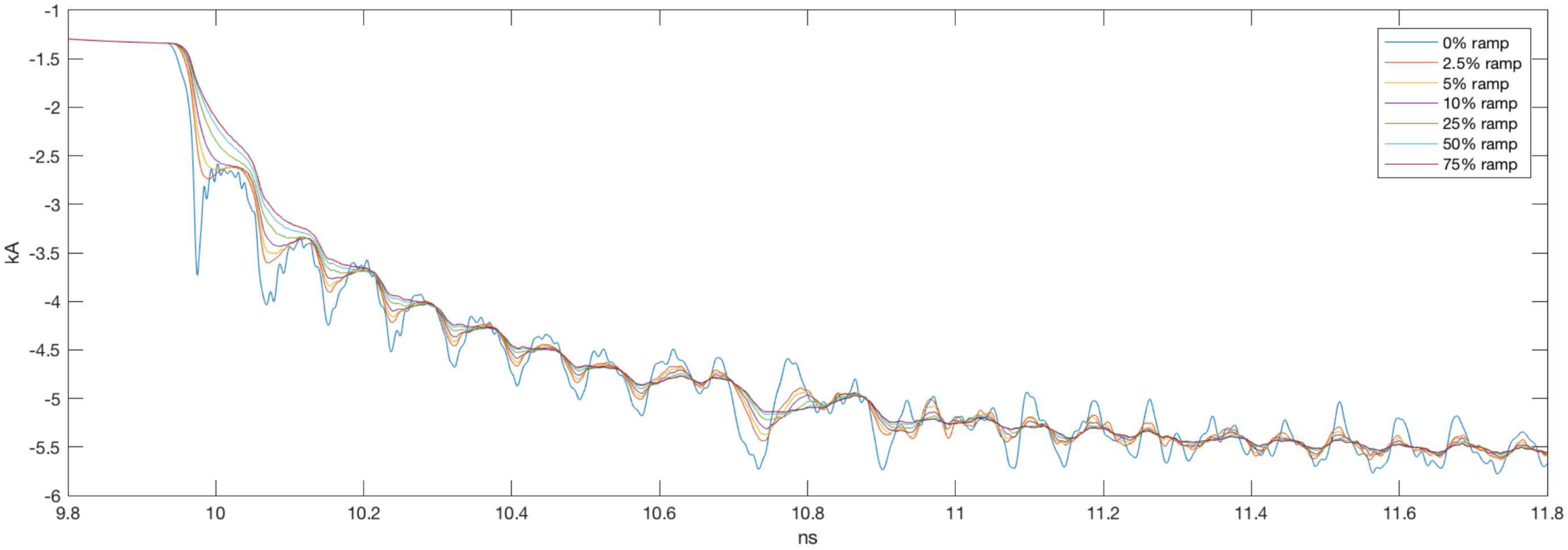


Possible Vircator

- Flat FFTs
- f ~ 1.1GHz
- n_e ~ 5e16

$$\omega_P = \sqrt{\frac{n_e e^2}{\gamma_0 m_e \epsilon_0}}$$





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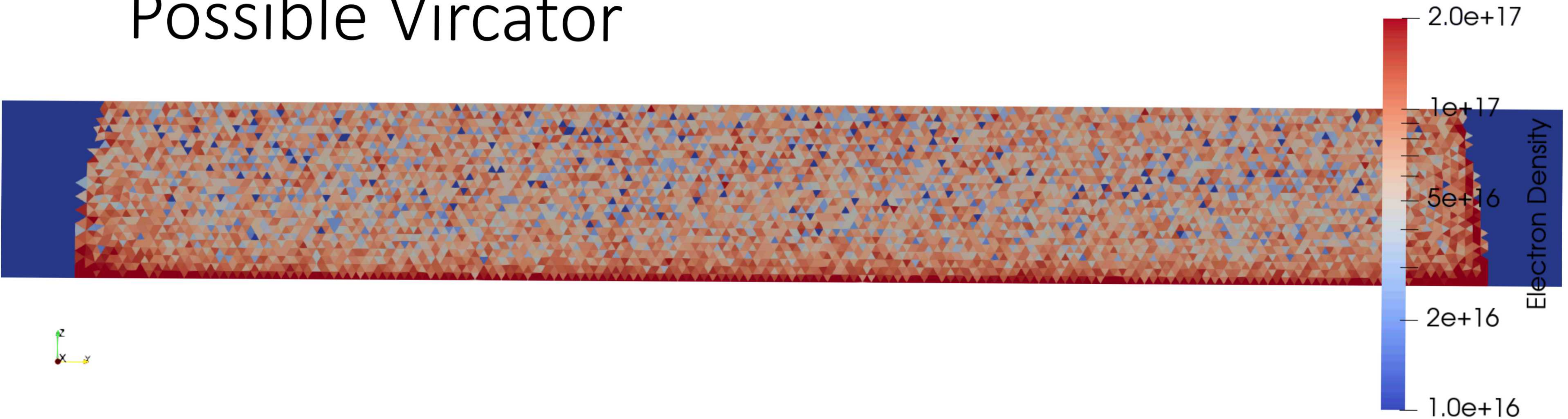

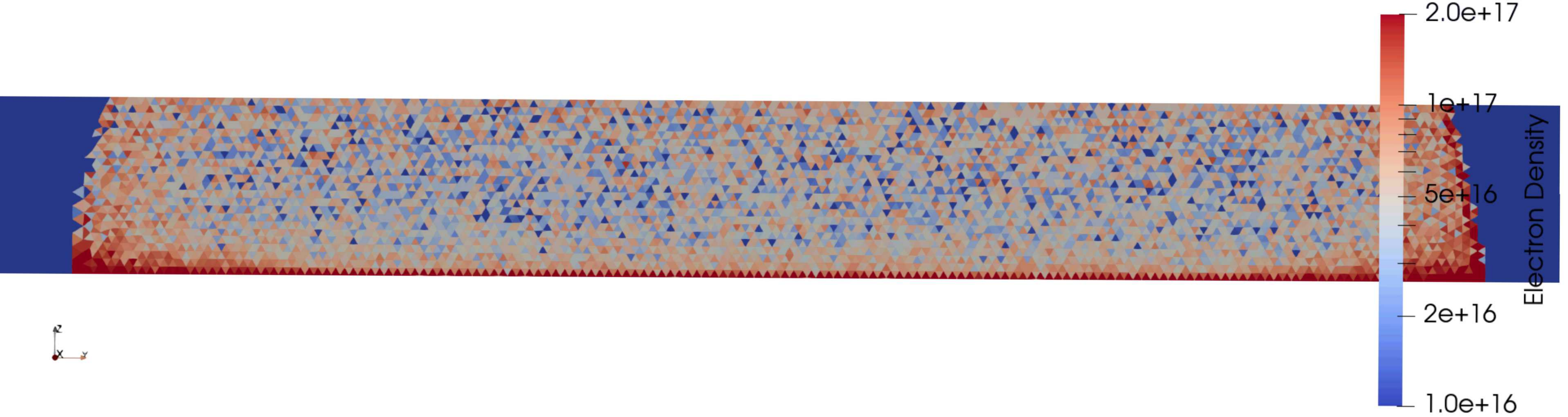

Conclusions and Future Work

- Problems with PMC boundary conditions
  - Change to periodic BCs
- Possible vircator
  - Plot in phase space
- Non-planar solutions
  - Increase impedance
  - Lower injected current (electrostatic problem with injected beam?)
- Meaningful ramp time definition
  - Increase timestep
- Run 90% breakdown case