COMSOL CONFERENCE 2017 ROTTERDAM

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SIMULATION OF IMPULSE ARC DISCHARGE IN LINE LIGHTNING PROTECTION DEVICES.

Alexander Chusov

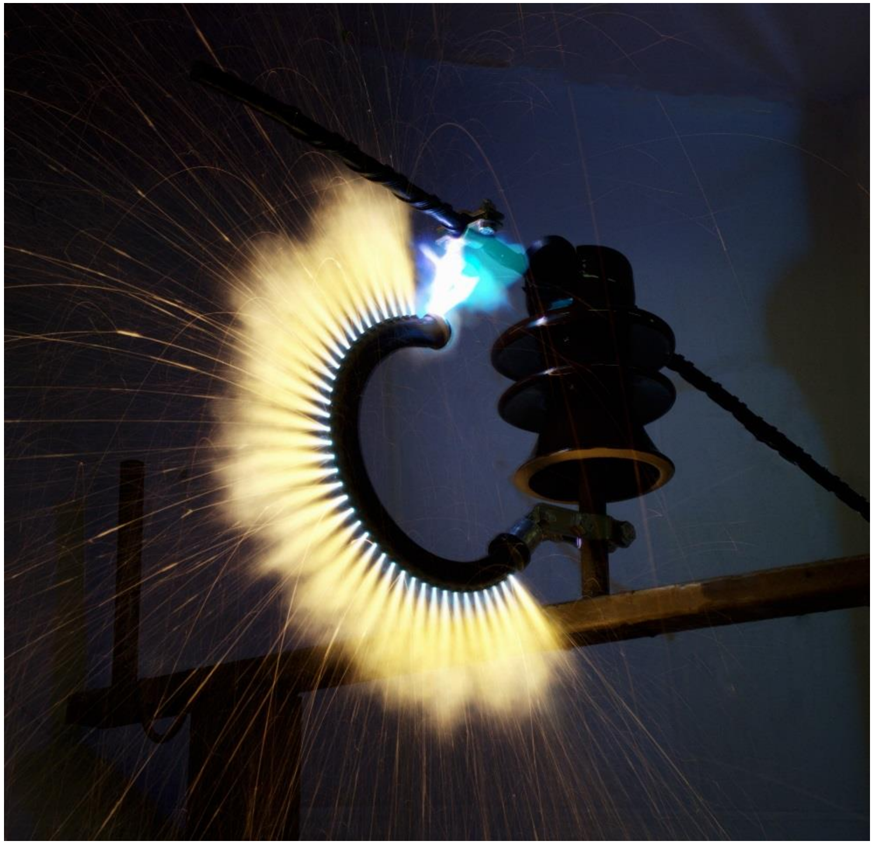
Lightning protection of overhead lines

Lightning protection of overhead lines

MULTI-CHAMBER ARRESTERS

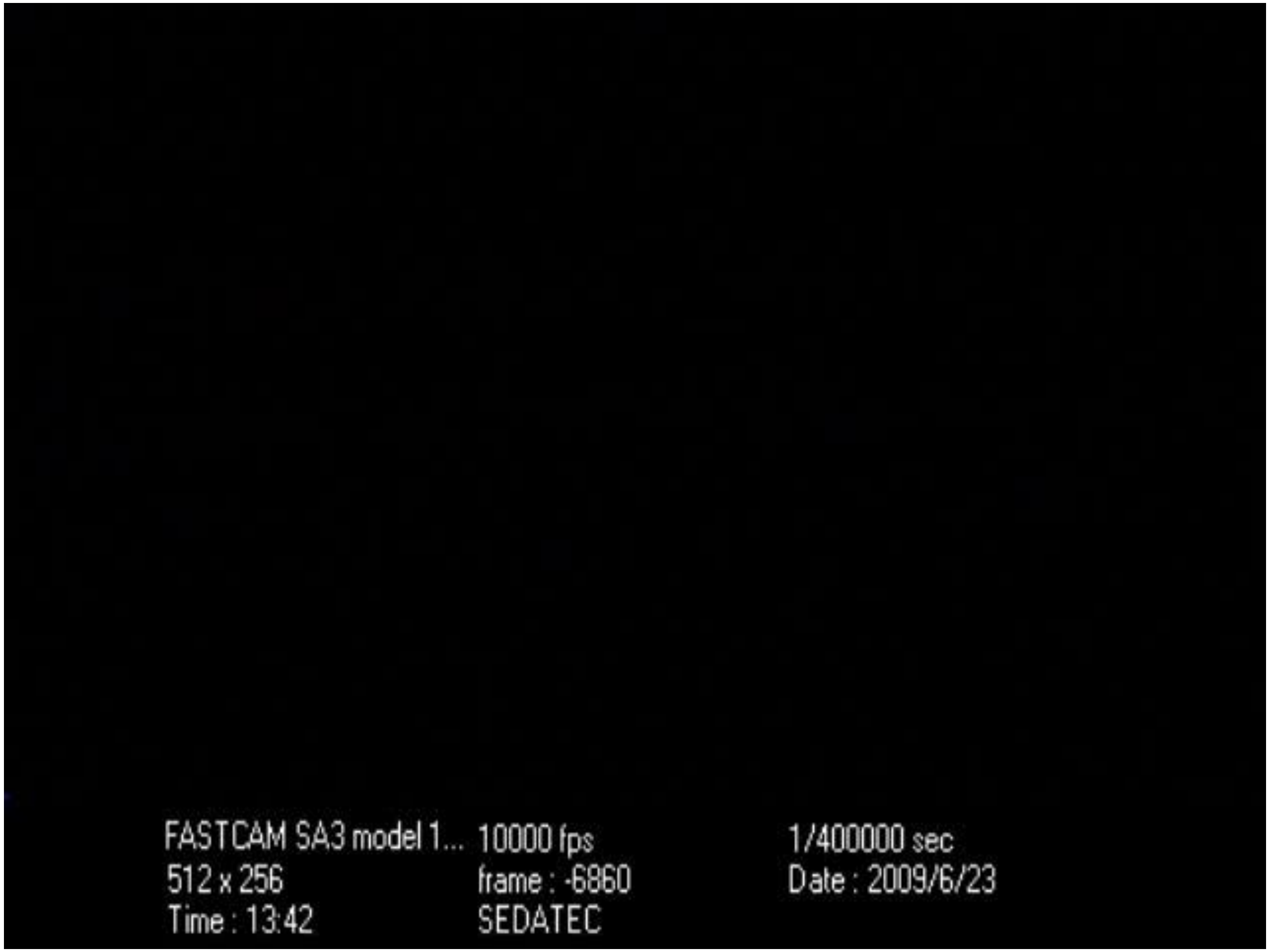
Lightning protection of overhead power lines up to 35 kV

20 kV



35 kV

MULTI-CHAMBER ARRESTERS



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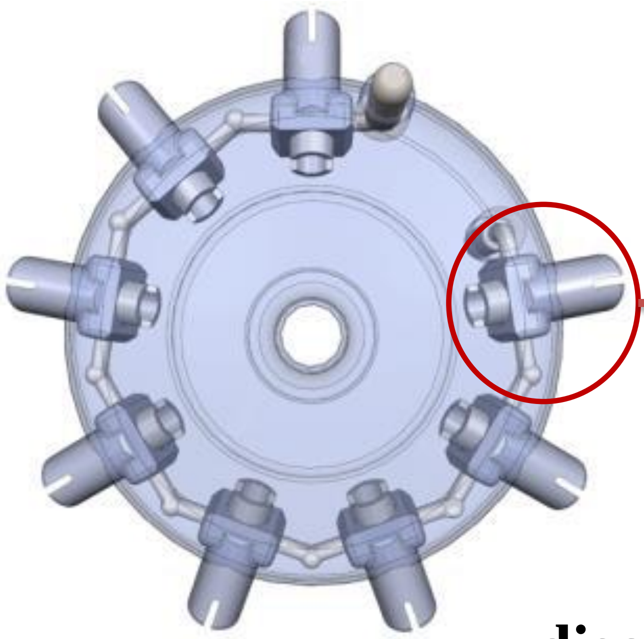
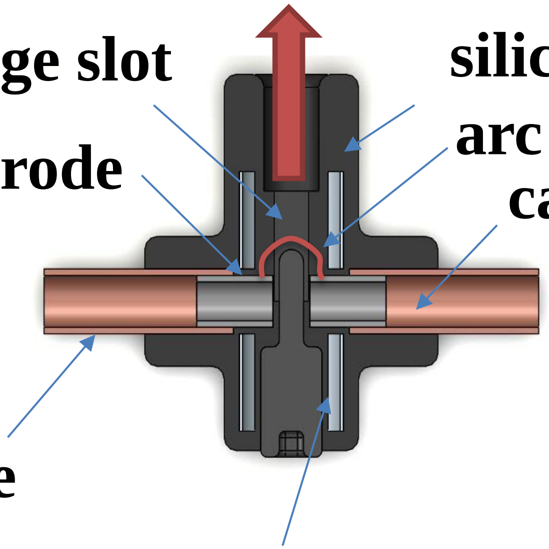
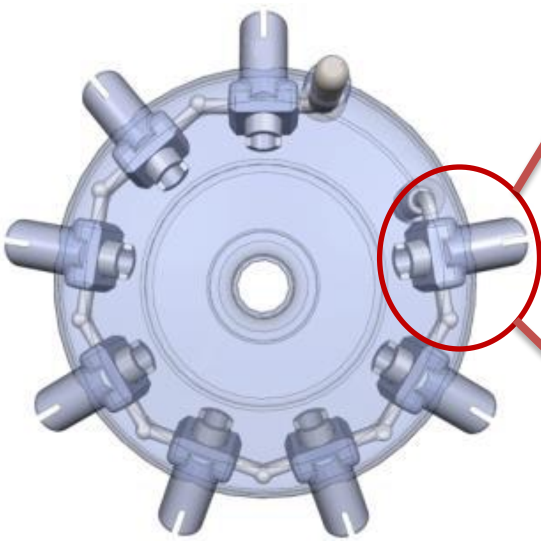
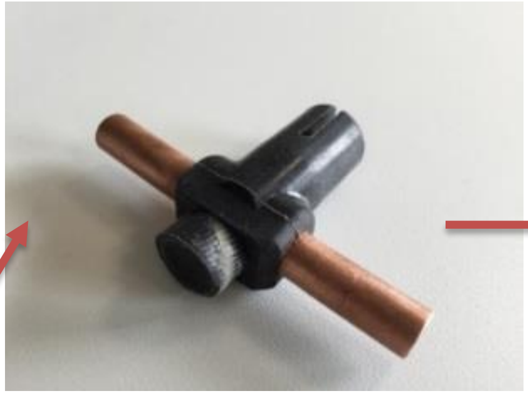
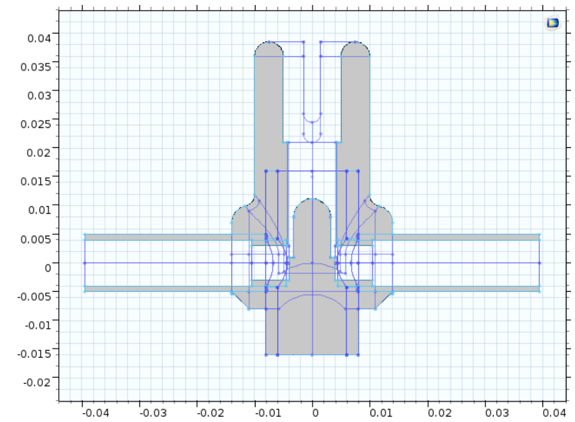






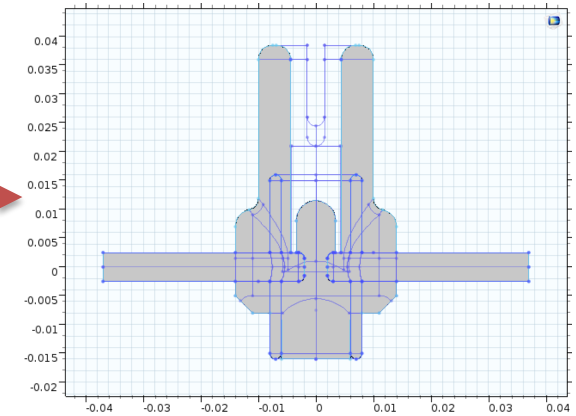


Type #1



Optimal geometry?

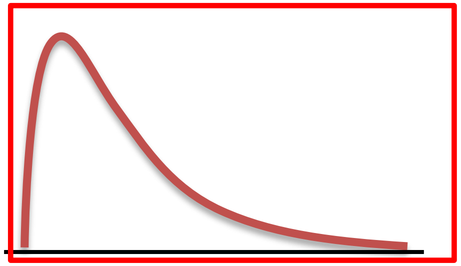
Type #2



NUMERICAL EXPERIMENT SCHEME

Chamber 3D CAD model

Lightning current impulse



Arc discharge model

Arc resistance

ARC DISCHARGE MODEL

Magnetohydrodynamics equations (MHD)

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \{\rho \mathbf{v}\} = 0$$

$$\frac{\partial(\rho \mathbf{v})}{\partial t} + \nabla \cdot \{\rho \mathbf{v} \otimes \mathbf{v}\} = -\nabla p + \nabla \cdot \mathbf{T} + \mathbf{j} \times \mathbf{B}$$

$$\frac{\partial(\rho H)}{\partial t} + \nabla \cdot \{\rho H \mathbf{v} - \lambda \nabla T\} = \frac{\partial p}{\partial t} + \nabla \cdot (\mathbf{T} \cdot \mathbf{v}) + \mathbf{j} \cdot \mathbf{E} - \nabla \cdot \mathbf{F}$$

$$\mathbf{j} = \sigma(\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{j}$$

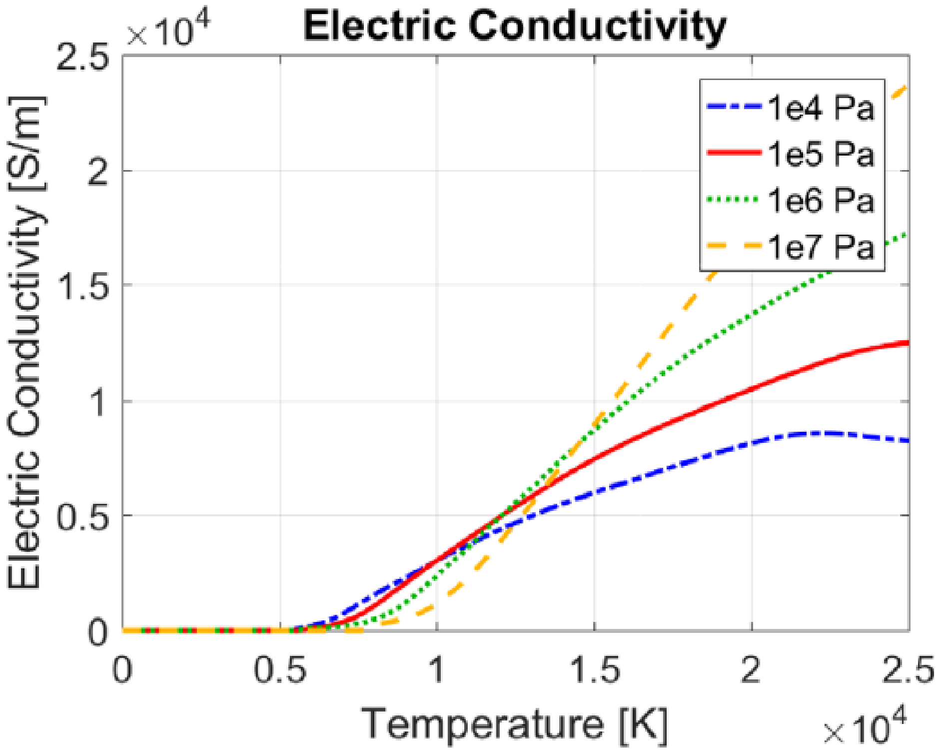
$$\partial_t \mathbf{B} + \nabla \times \mathbf{E} = 0$$

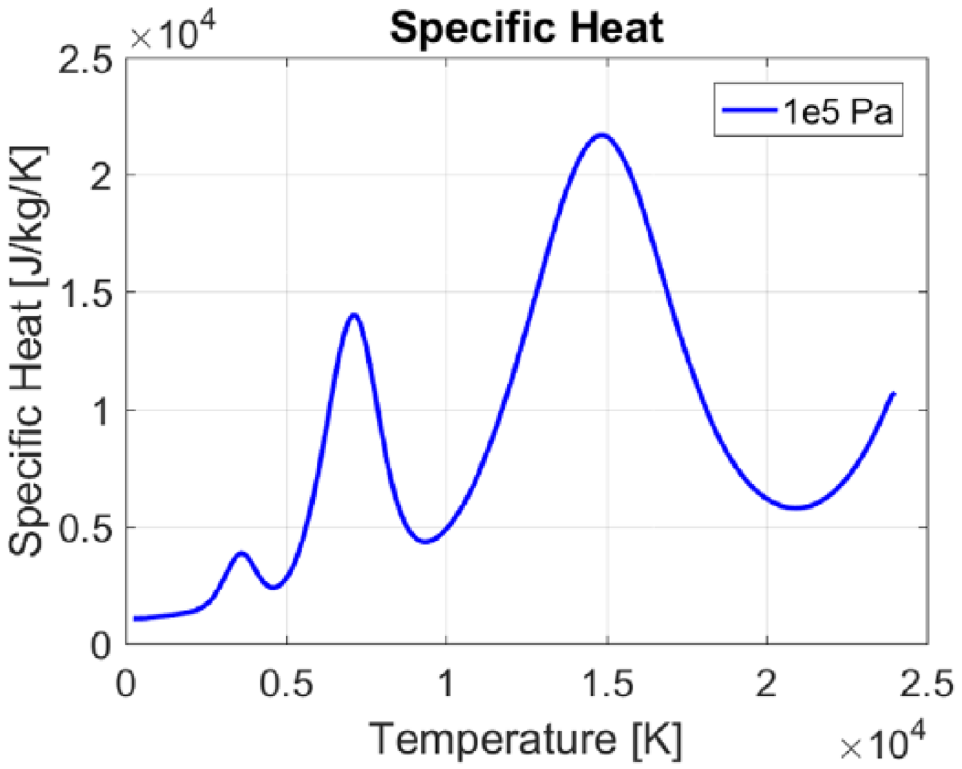
ARC DISCHARGE MODEL

Material properties

$\sigma(p,T)$

$\rho(p,T)$

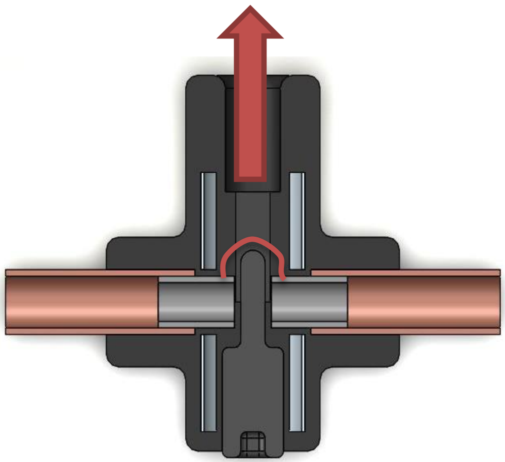




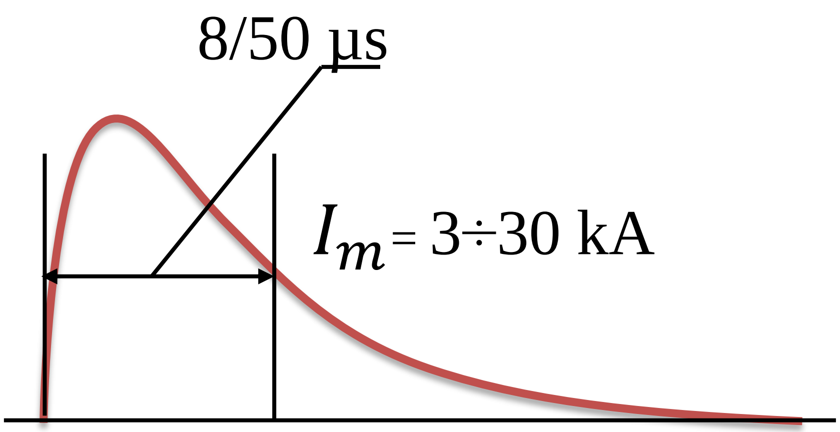
ARC DISCHARGE MODEL

Electrodynamics

terminal



ground



I_m = 3÷30 kA

$$I(t) = \frac{I_{max}}{\eta} * (e^{-\frac{t}{\tau_1}} - e^{-\frac{t}{\tau_2}})$$

ARC DISCHARGE MODEL

Radiation transport

$$\mathbf{s} \cdot \nabla I_\nu(\mathbf{r}, \mathbf{s}) = \kappa_\nu \left[I_\nu^b(T) - I_\nu(\mathbf{r}, \mathbf{s}) \right]$$

$$I_\nu^b(T) = \frac{2h}{c^2} \frac{\nu^3}{\mathrm{e}^{h\nu/k_\mathrm{B}T} - 1}$$

Two-band model

from zero up to $\lambda = 120$ nm

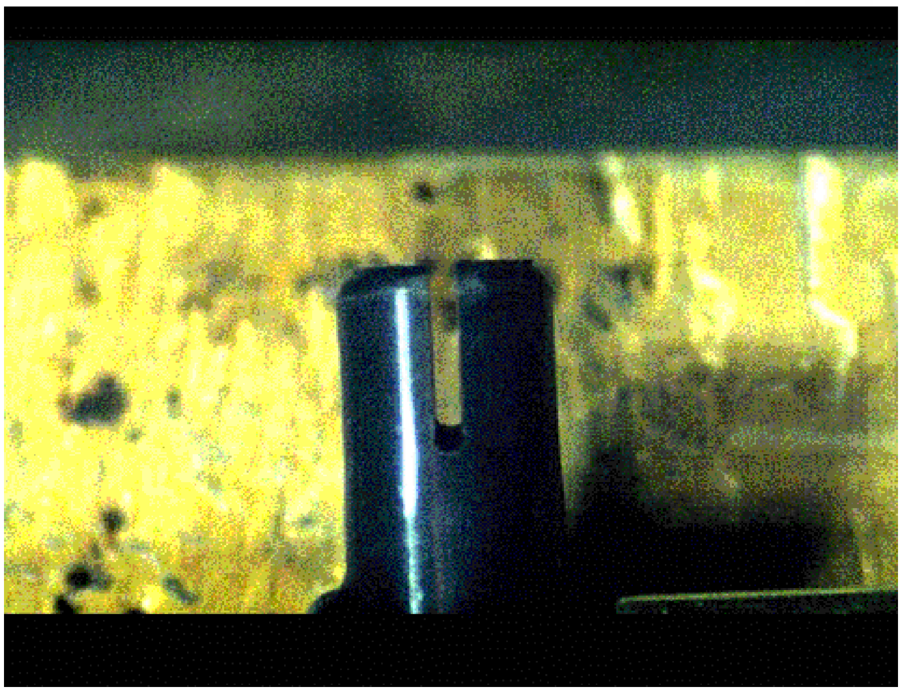
$$\alpha = 2000 \text{ m}^{-1}$$

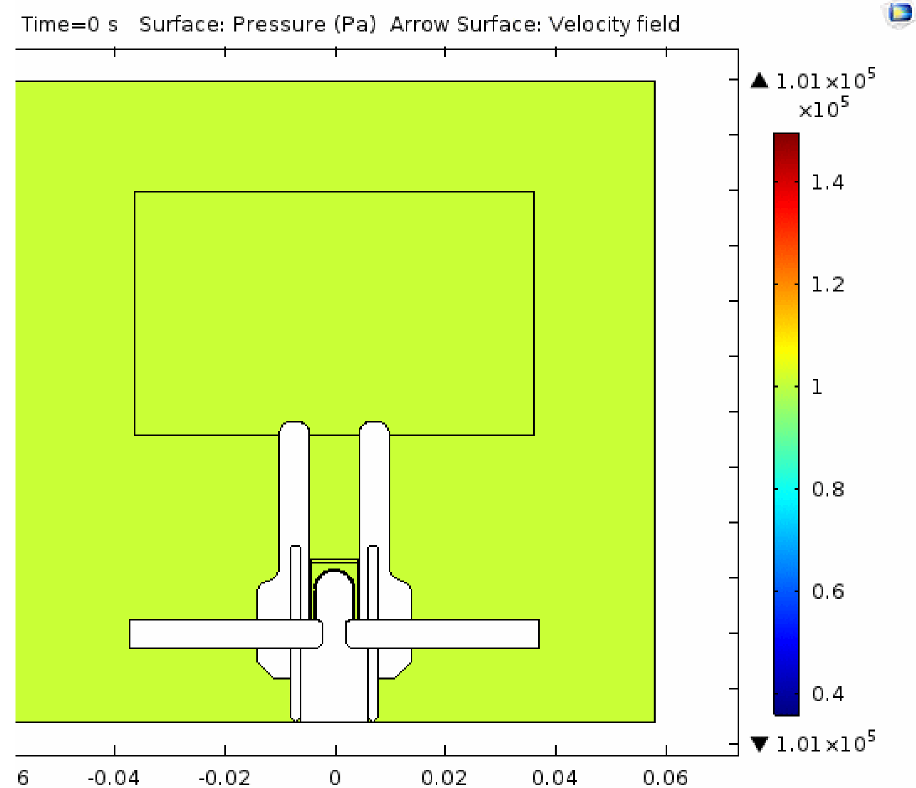
from $\lambda = 120$ nm up to $\lambda = 1$ mm

$$\alpha = 50 \text{ m}^{-1}$$

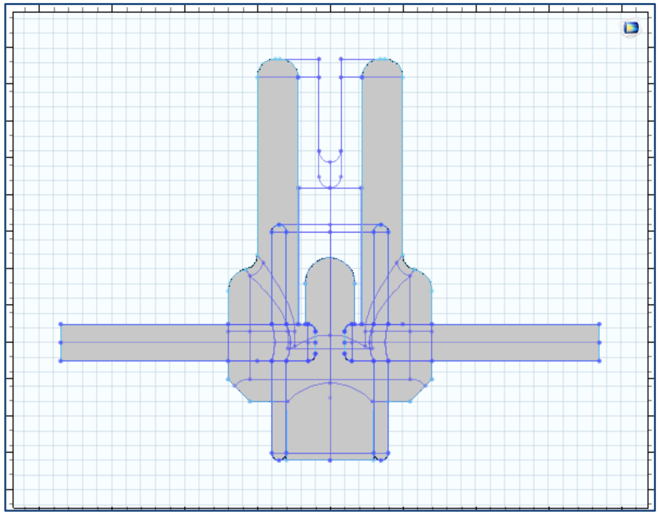
SIMULATION RESULTS

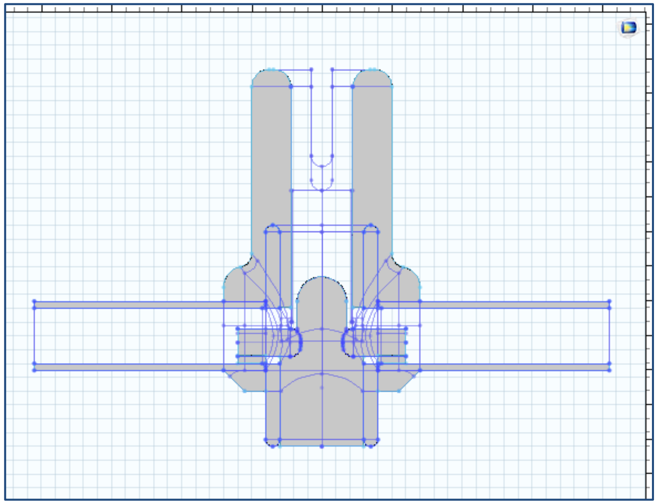
Fast-imaging record of plasma jet

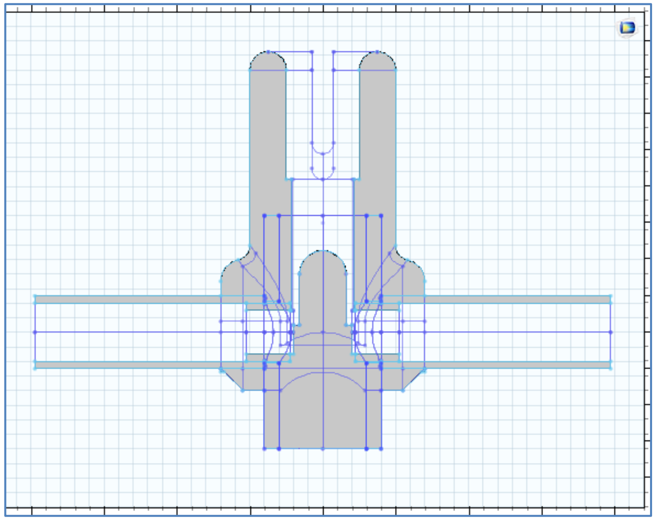


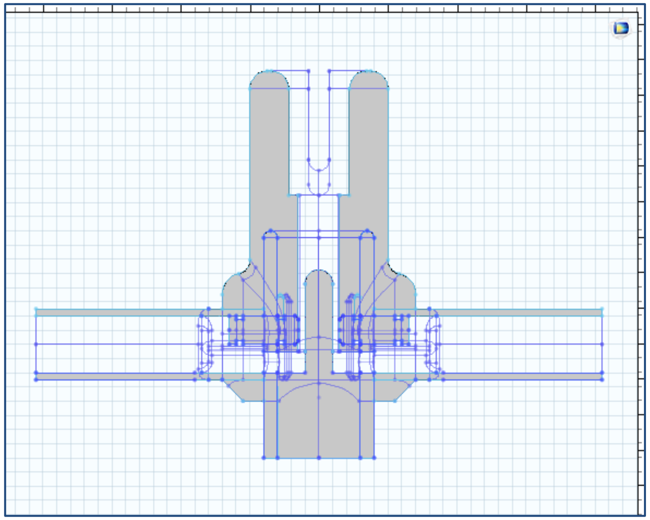


SIMULATION RESULTS

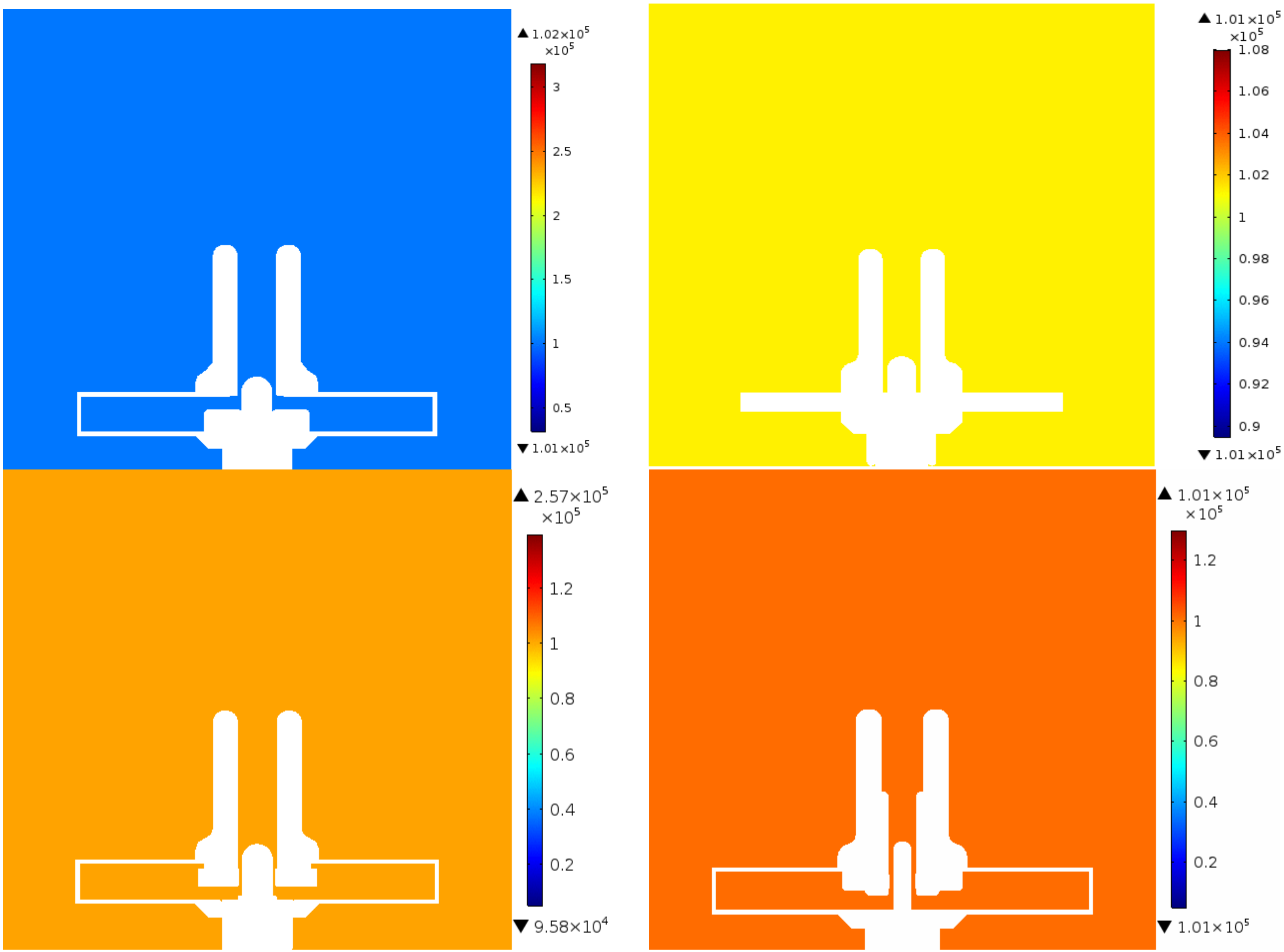




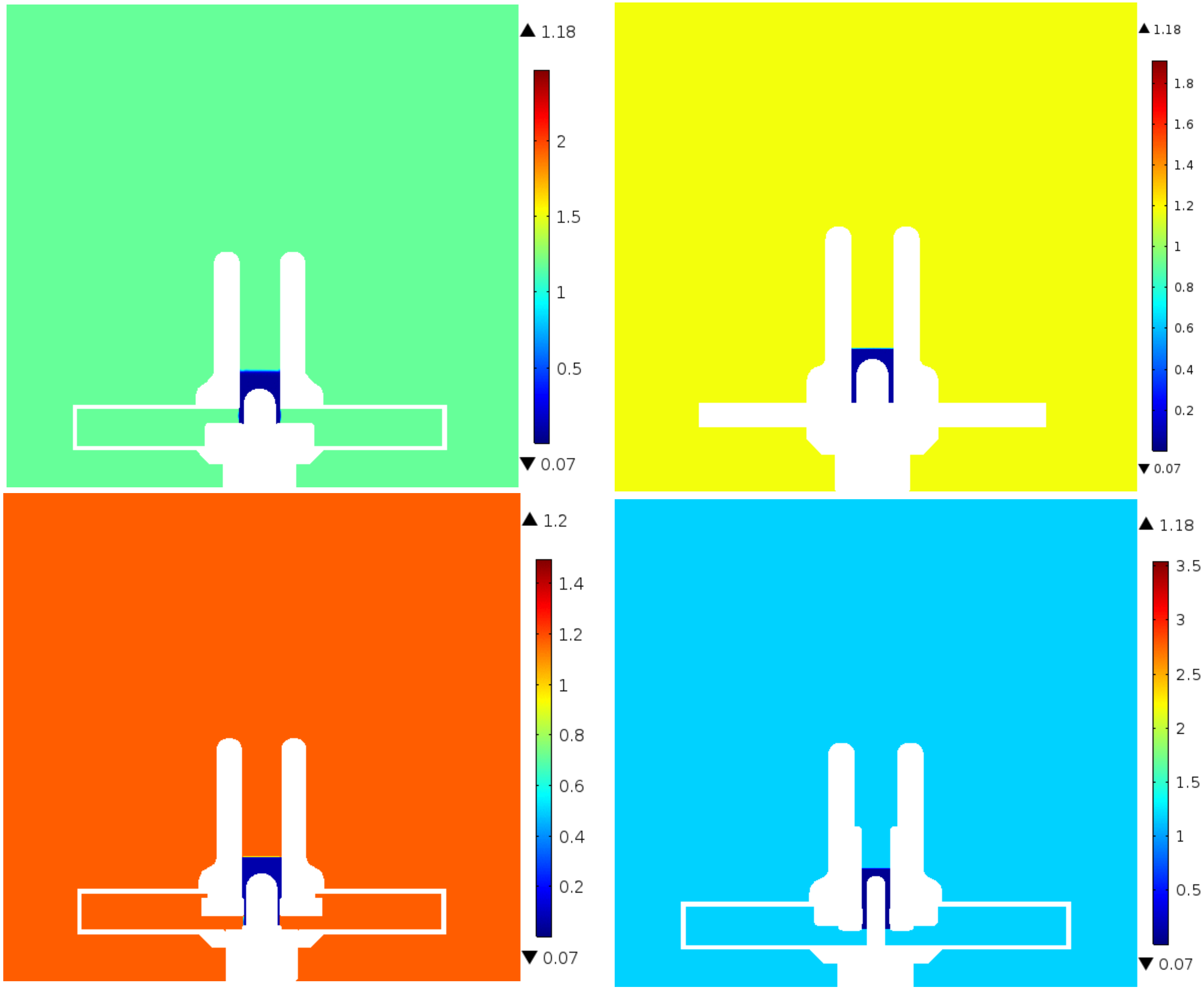




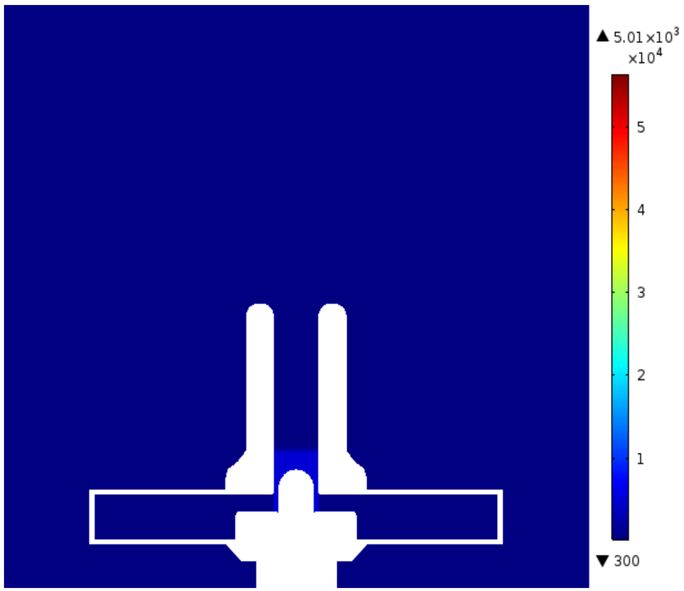
SIMULATION RESULTS:PRESSURE

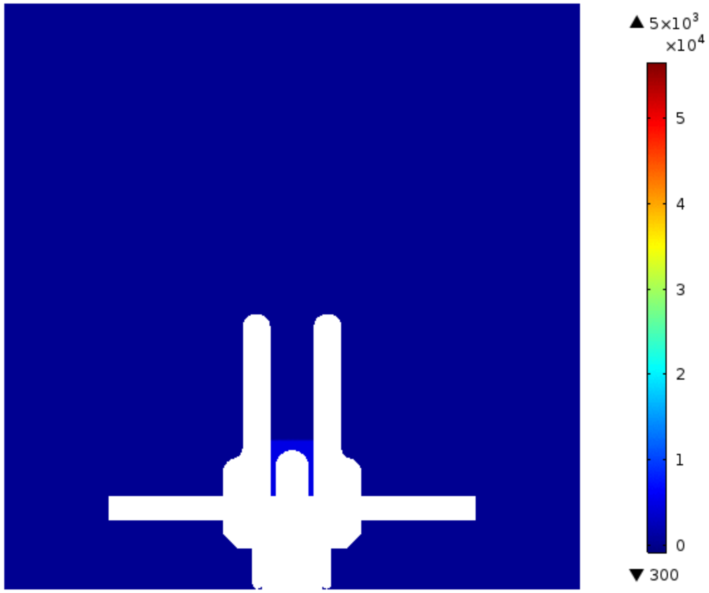


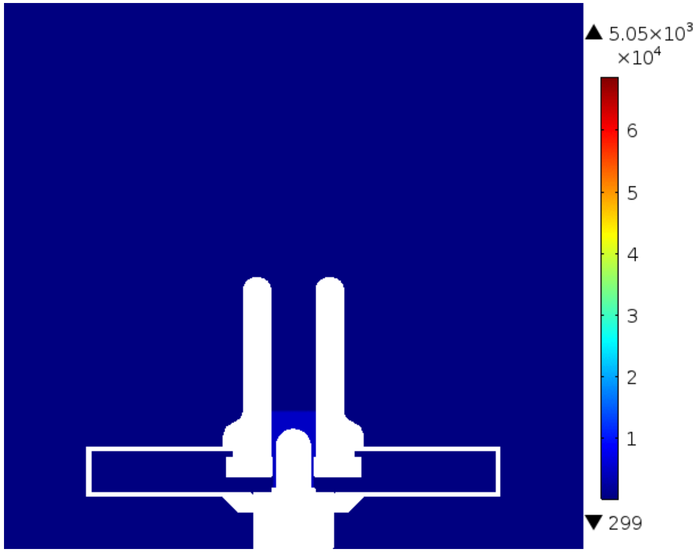
SIMULATION RESULTS:DENSITY

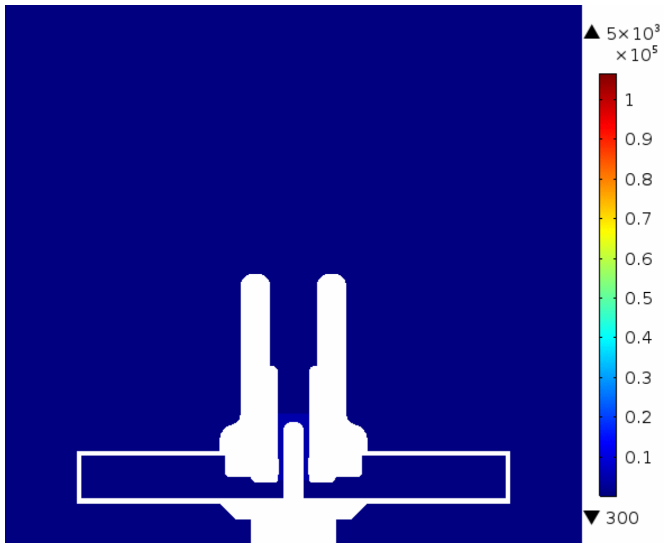


SIMULATION RESULTS:TEMPERATURE

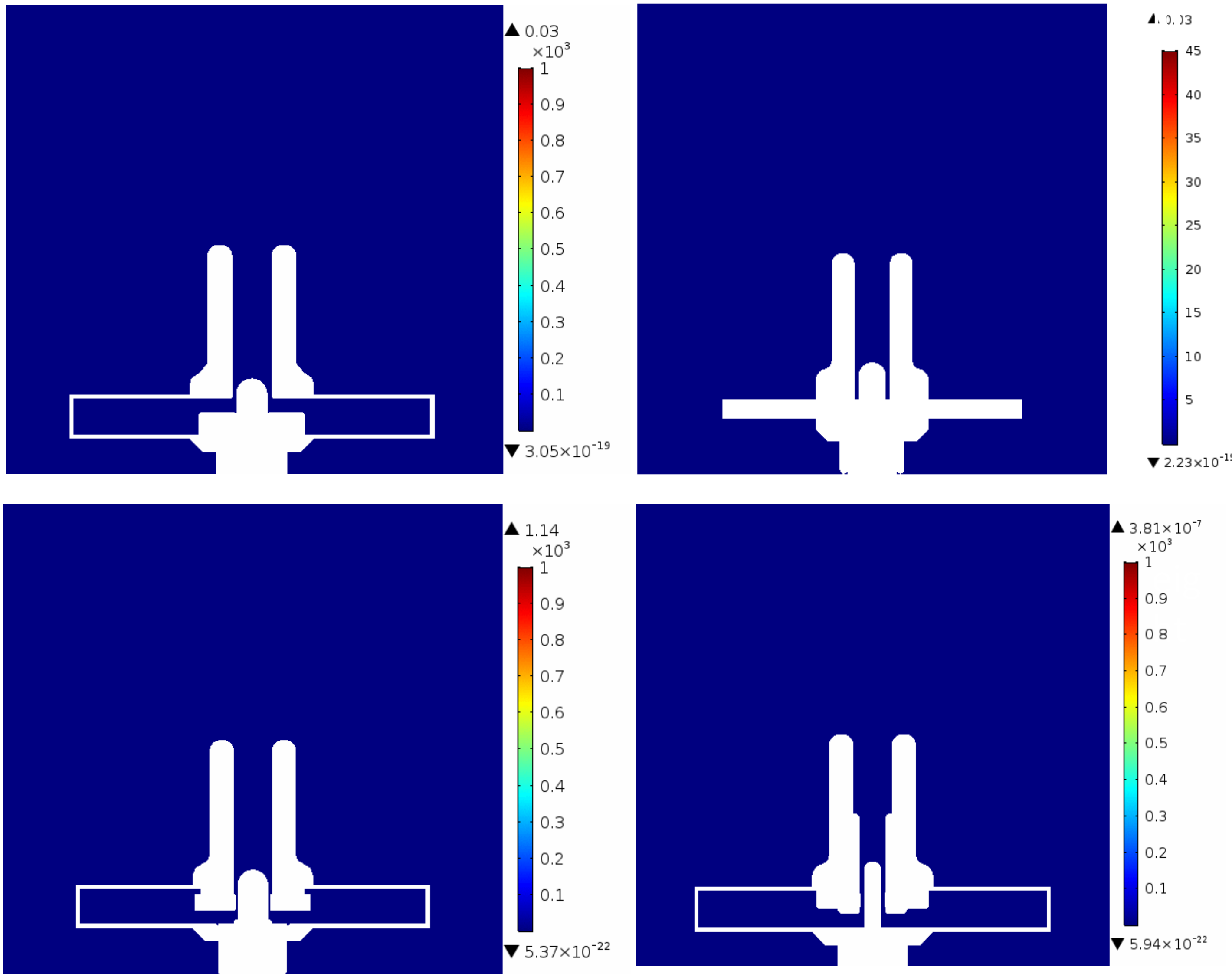




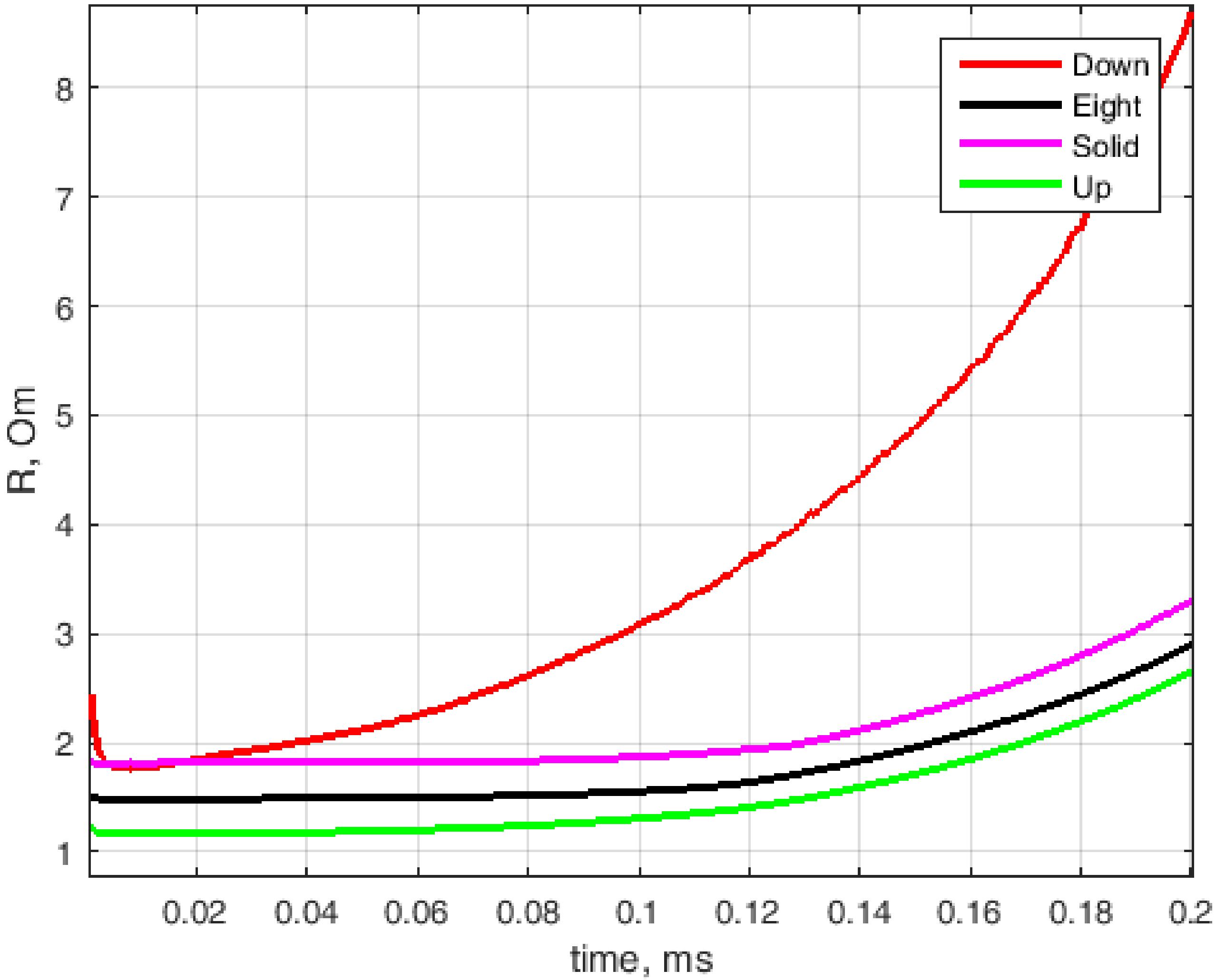




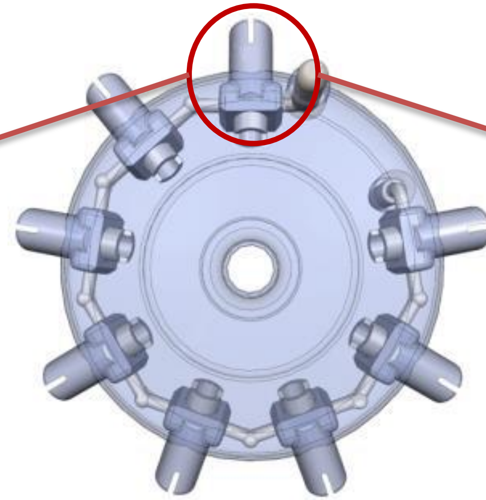
SIMULATION RESULTS:VELOCITY



SIMULATION RESULTS

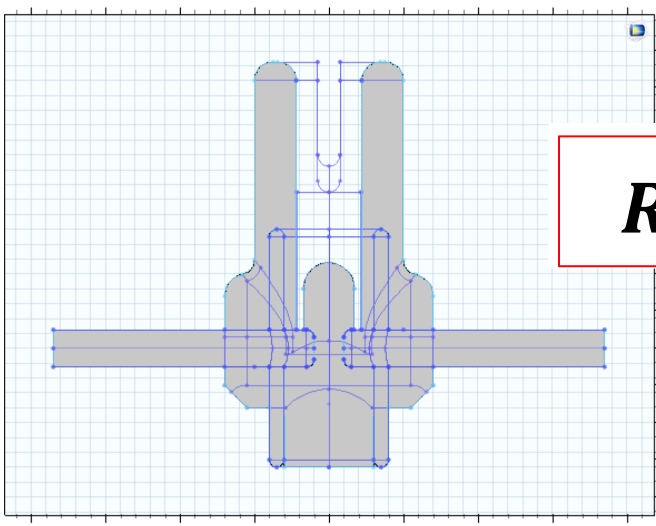


SIMULATION RESULTS

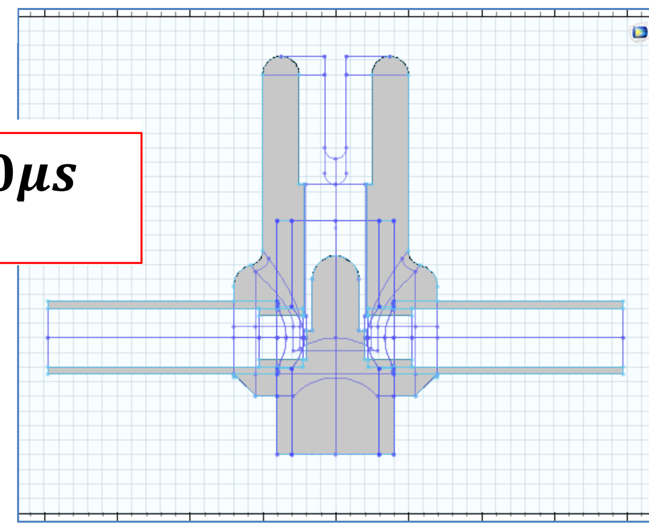


Type #1

Type #2



$$R_1^{t=200\mu s} < R_2^{t=200\mu s}$$



Type #1 is better than Type #2

CONCLUSIONS:

- **Predictions of certain type chamber performance are in qualitative agreement with experimental knowledge**

- **Numerical simulation is a promising design tool for future lightning protection devices**

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Thank you for your attention!