The Tony Davies High Voltage Laboratory

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School of Electronics and Computer Science

Local Field Enhancement in a Typical 3-Electrode System

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Outline

1. 3-electrode system for conductivity measurement
2. Maximum field in 3-electrode system
3. Evaluation of conductivity calculation method
4. Conclusion

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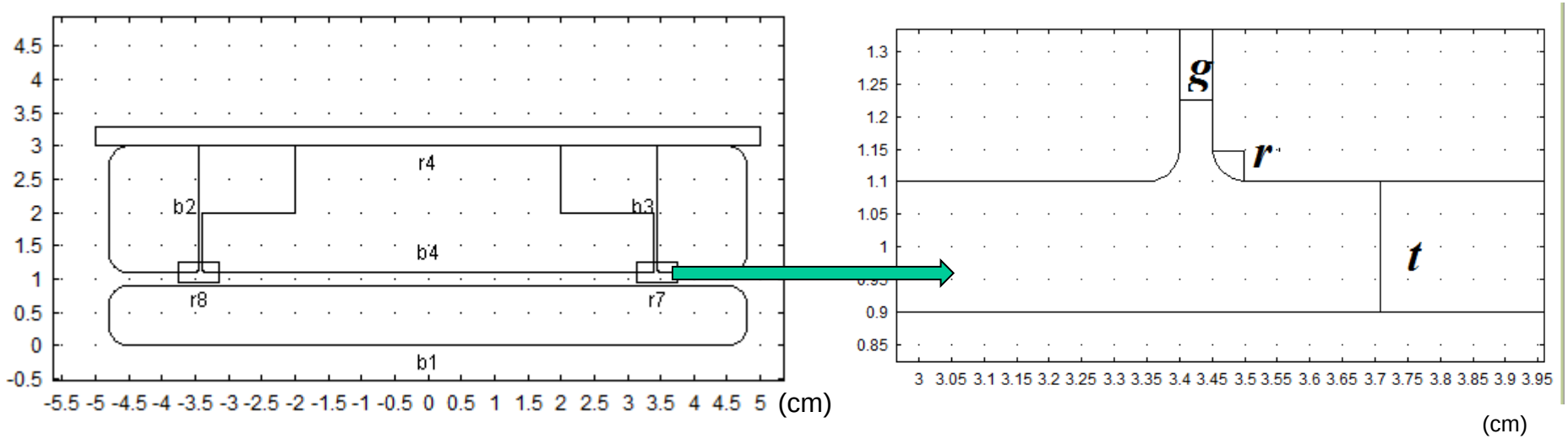
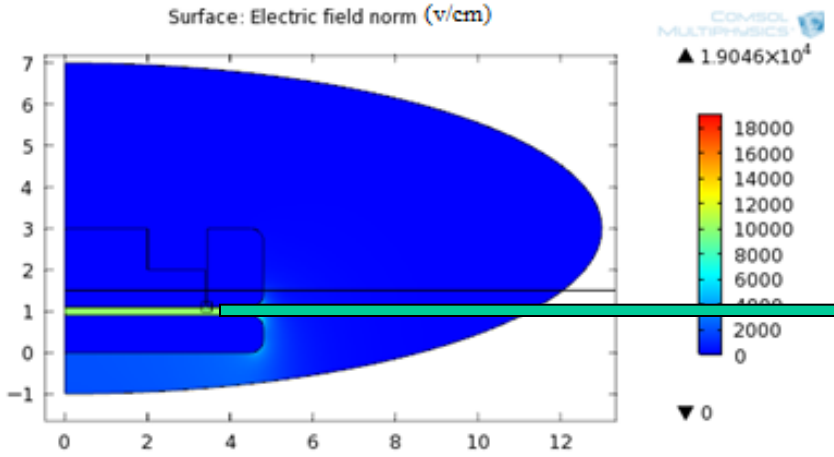
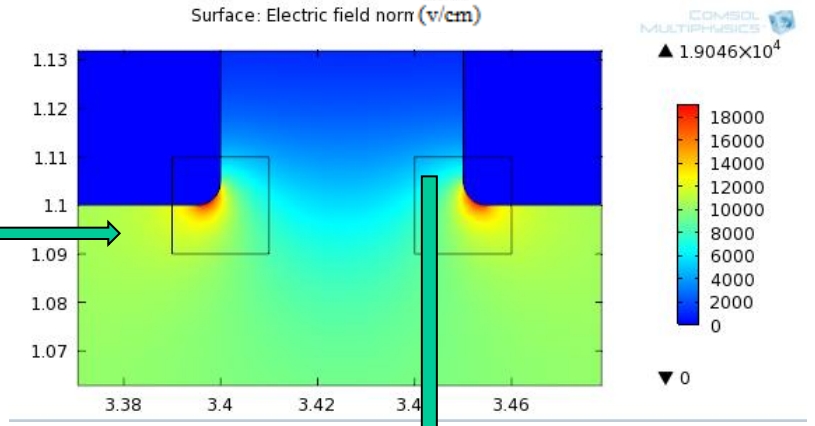
3-Electrode System

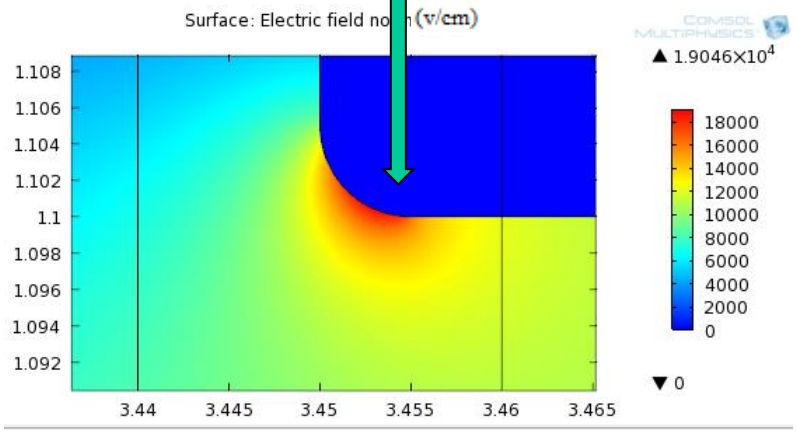
- A typical 3-electrode system contains a high voltage electrode, a measuring electrode and a guard electrode. In the international standards, there are two factors that can affect the conductivity measurement; the distance between guard and measuring electrode and the distance between the high voltage electrode and the measuring electrode.



Field Enhancement in 3 Electrode System







Here, we set the gap between upper and lower electrode is 0.2cm, the distance between guard and guarded electrode is 0.05cm, edge radius is 0.005cm and the applied voltage is 2000V

Based on the simulating results, there is a region near the edge of guard and guarded electrode that has much higher electric field.

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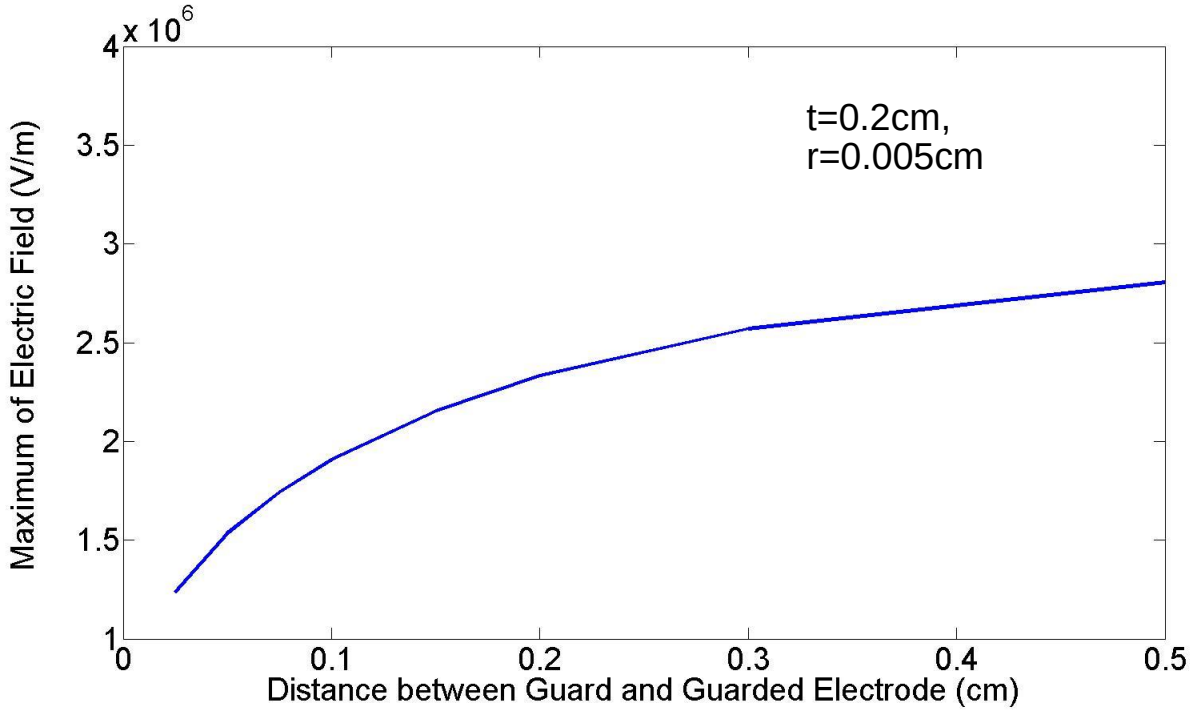
Field Enhancement in 3 Electrode System



- When the distance between the upper and lower electrode and the edge radius is constant, a larger distance between the guard and measuring electrode will result in a higher electric field.

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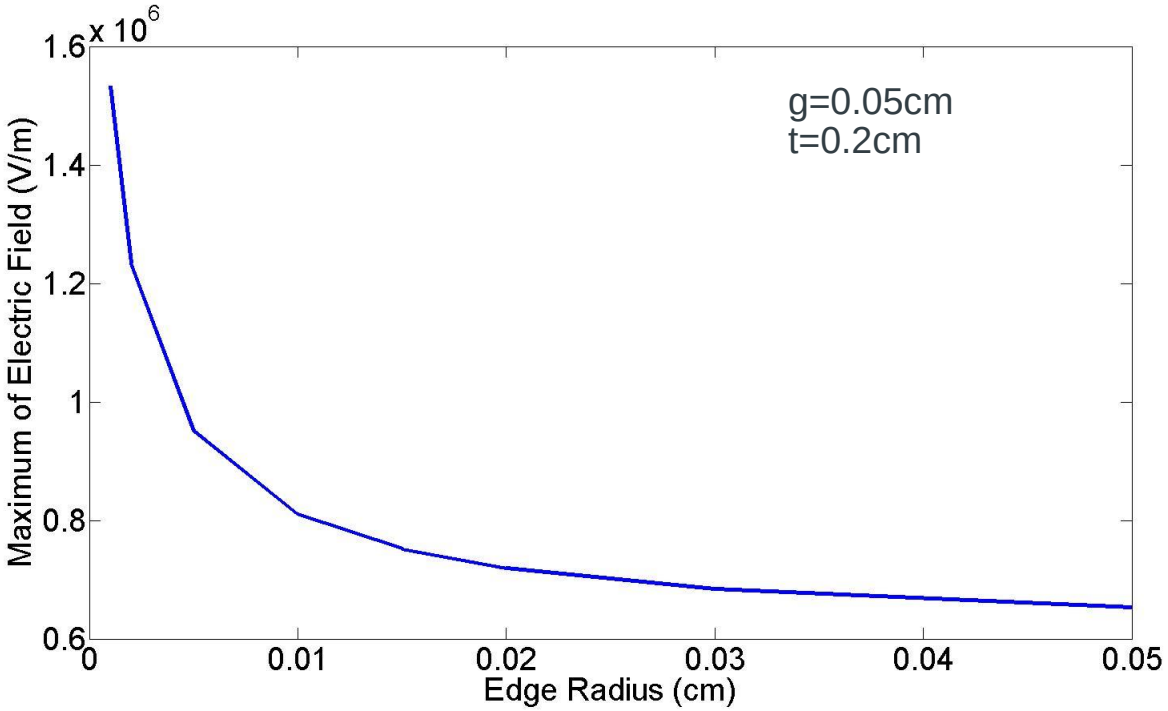
Field Enhancement in 3 Electrode System



- When the distance between the upper and lower electrode and the distance between guard and measuring electrode is constant, a larger edge radius will result in a lower electric field.

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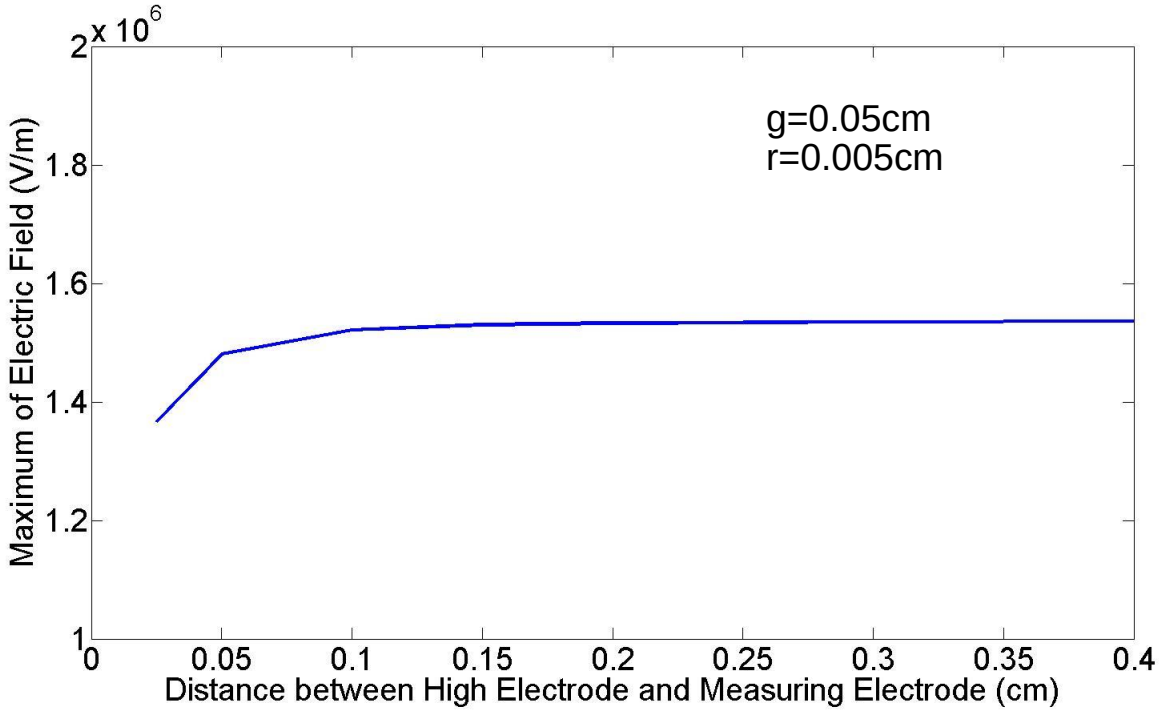
Field Enhancement in 3 Electrode System



- When the edge radius and the distance between guard and measuring electrode is constant, a larger distance between the high voltage electrode and measuring electrode will result in a higher electric field.

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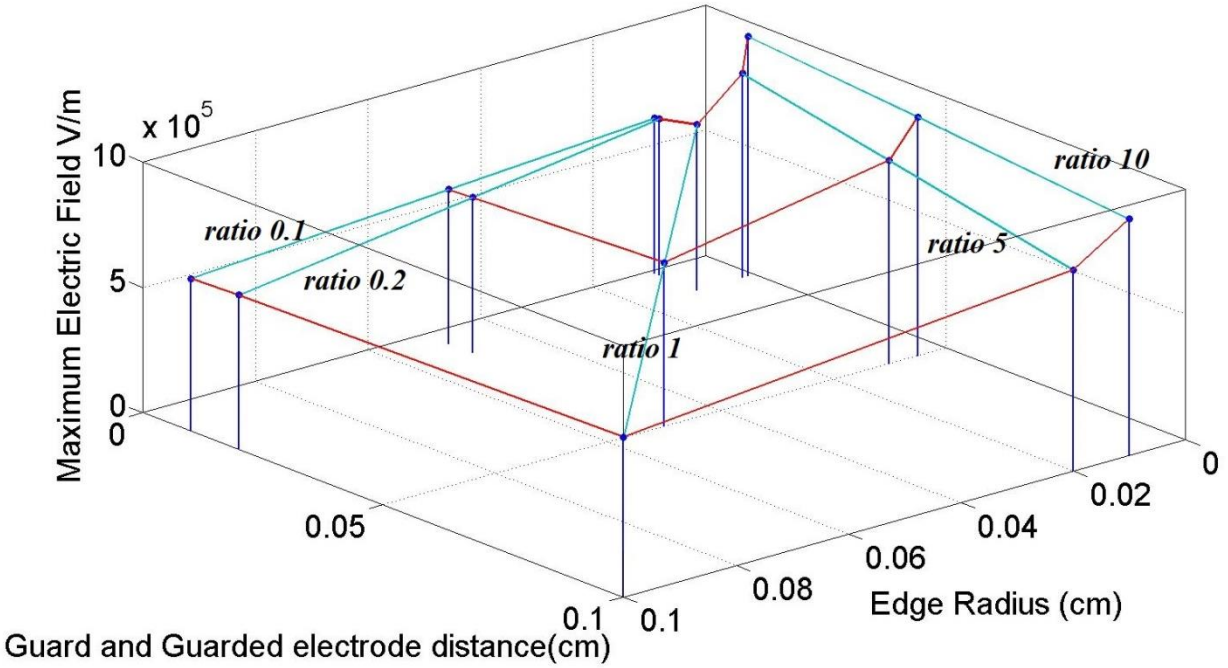
Field Enhancement in 3 Electrode System

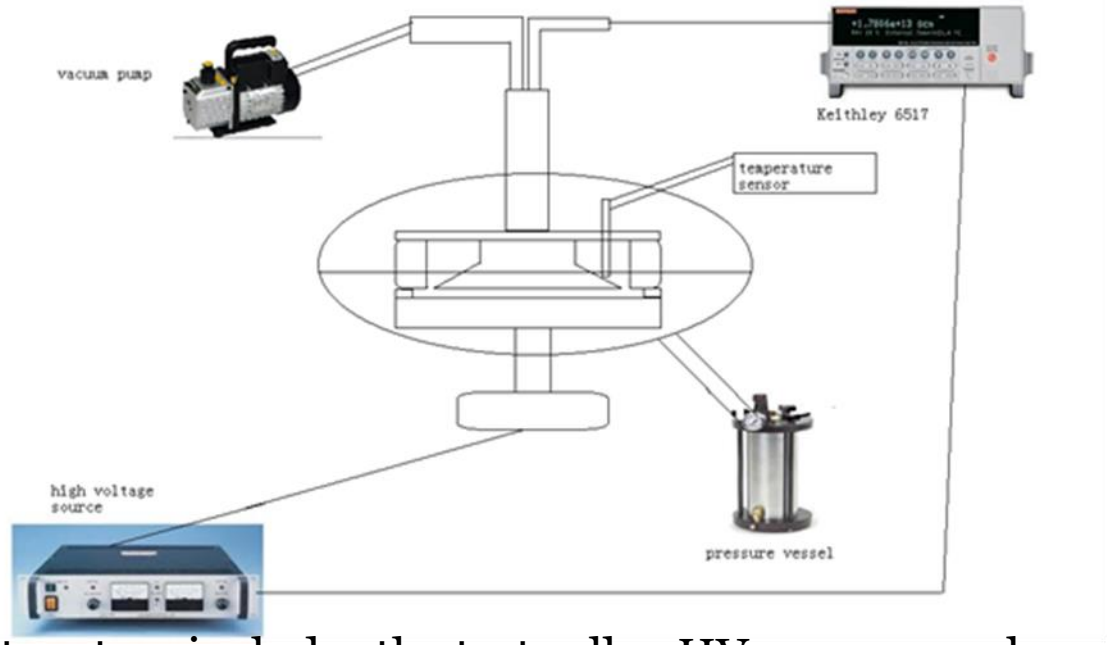


If assuming the distance between upper and lower electrode is far larger than the gap distance and radius, it is obvious that it is the ratio of the distance between the guard and guarded electrode and the edge radius that determines the maximum electric field in the oil test cell. For a further recommendation, this ratio should never surpass 1.

Confirmation from Experiment

- Three different types of mineral oil will be used in the DC polarization test. Shell ZX-I (fresh oil), Hydro Quebec (aged for 10 years), Terna (aged over 50 years)

- The electrification time will be 3 hours.



The test system includes the test cell, a HV power supply, a vacuum pump, a Pico-ammeter and a fan-assisted oven.

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Confirmation from Experiment

- As seen from the maximum field at which the sample can sustain at least 3 hours, a low ratio allows a higher measuring field applied. (The electric field ranges from 1kV/mm to 5kV/mm)

Ratio =g/r

Oil in our lab	30℃	90℃
Terna	Below 1kV/mm	Below 1kV/mm
Hydro Quebec	2kV/mm	1kV/mm
ZX-I	5kV/mm	5kV/mm

Ratio is around 10

Oil in our lab	30℃	90℃
Terna	2kV/mm	2kV/mm
Hydro Quebec	5kV/mm	5kV/mm
ZX-I	5kV/mm	5kV/mm

Ratio is around 1

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Effective Radius from the International Standards

- Fringing current in the region of the electrode edges may effectively increase the electrode dimension, therefore, the edge of the guarded electrode will be extended.
- ASTM D257 states that the effective radius of the guarded electrode should be denoted as:

$$R = R_0 + \frac{g}{2} - t\{(2/\pi)\ln\cosh[(\pi/4)(g/t)]\}$$

- IEC60093 defines the effective radius as:

$$R = R_0 + g/4$$

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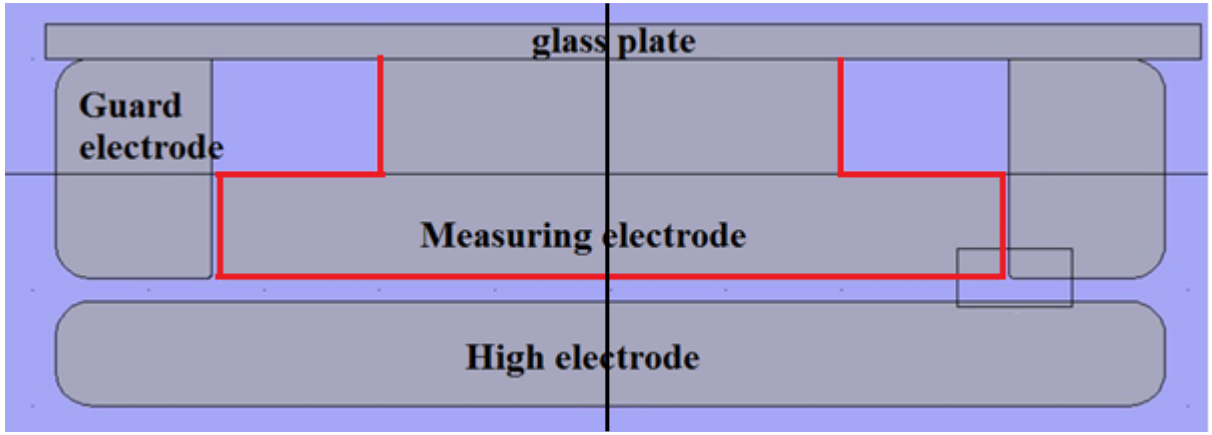
Calculation of the Effective Radius



- If we assume that there are no space charge formed in the bulk and the conductivity is constant all the time, then we can obtain the effective radius using the following equation:

$$R = \sqrt{\frac{t}{U}\int_{l} E(r) r dr}$$

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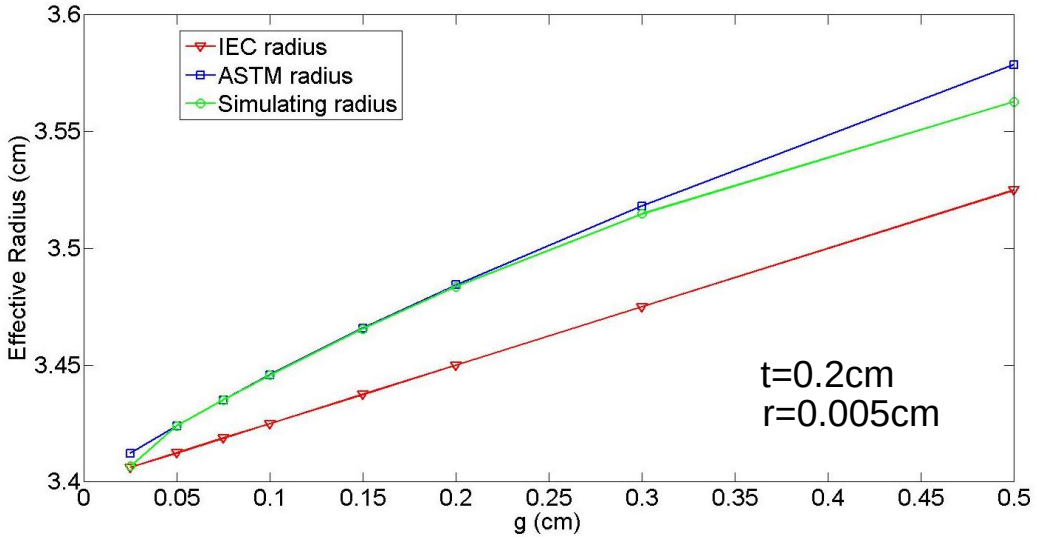
Effective Radius



- When the distance between the high voltage electrode and measuring electrode and the edge radius are constant, the calculated the effective measuring electrode radius is close to the value calculated from ASTM standard. However, the difference between the radius calculated from the current standards is not significant.

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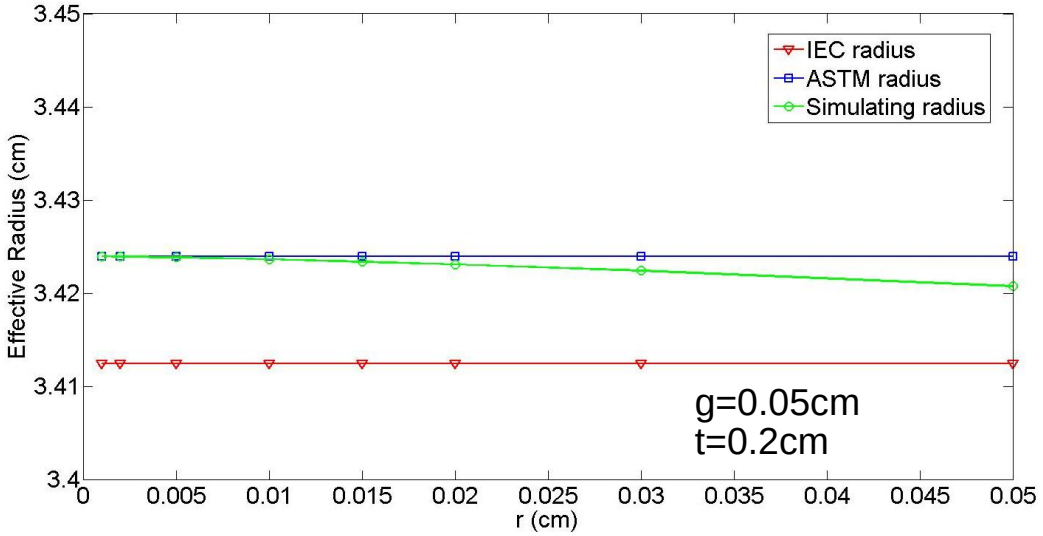
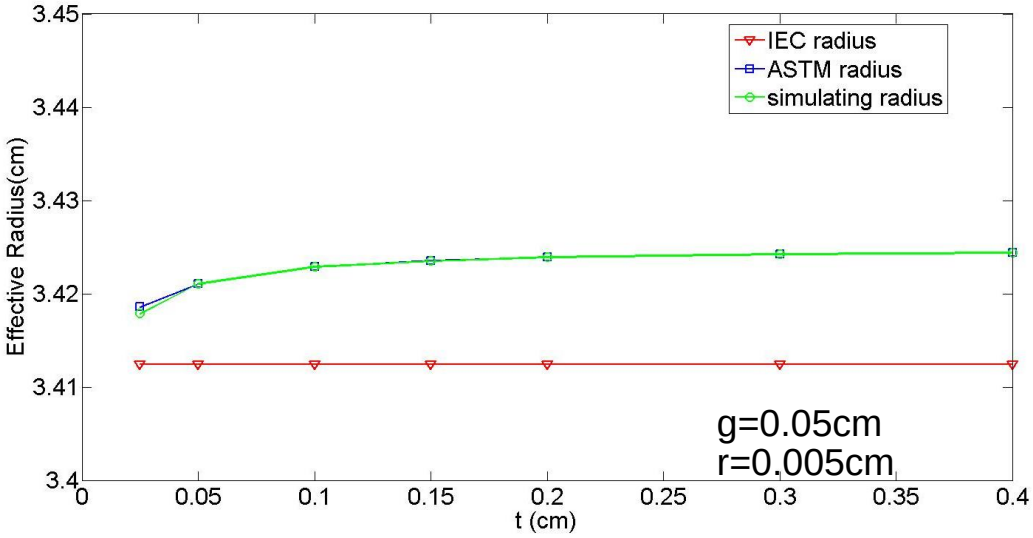
Effective Radius





- As seen from the simulating result, the effective radius calculated from simulation is close to the value calculated according to the ASTM standard and a little higher than that obtained from the IEC standard. The difference between the radius calculated from those two standards are not notable.

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Conclusion

- There is a region with higher electric field near the edge of the guard and measuring electrode in a 3-electrode system.
- Decrease the ratio between the distance of the guard and measuring electrode and the edge radius can reduce the maximum electric field between the upper and lower electrode.
- This new parameter, edge radius, do not affect the effective radius very much. For a daily measurement, IEC standard is recommended for its simplicity.

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Thank you