REINHOLD ENVIRONMENTAL Ltd.

2012 APC Round Table
& Expo Presentation

July 16-17, 2012, in Baltimore, MD / Hosted by Duke Energy, Entergy, FirstEnergy, Southern Company & TVA

Challenges in Capturing Very Low to Very High Resistivity Dust

PCUG/Round Table
Reinhold Environmental

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Baltimore, July 17th, 2012

POWER | ALSTOM

Outline of the presentation

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- *Introduction*
- *Holding forces, variations in time*
- *High voltage measurements*
- *Resistivity control by means of Power Control Rapping*
- *Summary*

Topics

- ***Introduction***
- *Holding forces, variations in time*
- *High voltage measurements*
- *Resistivity control by means of*

  Power Control Rapping
- *Summary*

Principal design of Electrostatic Precipitator

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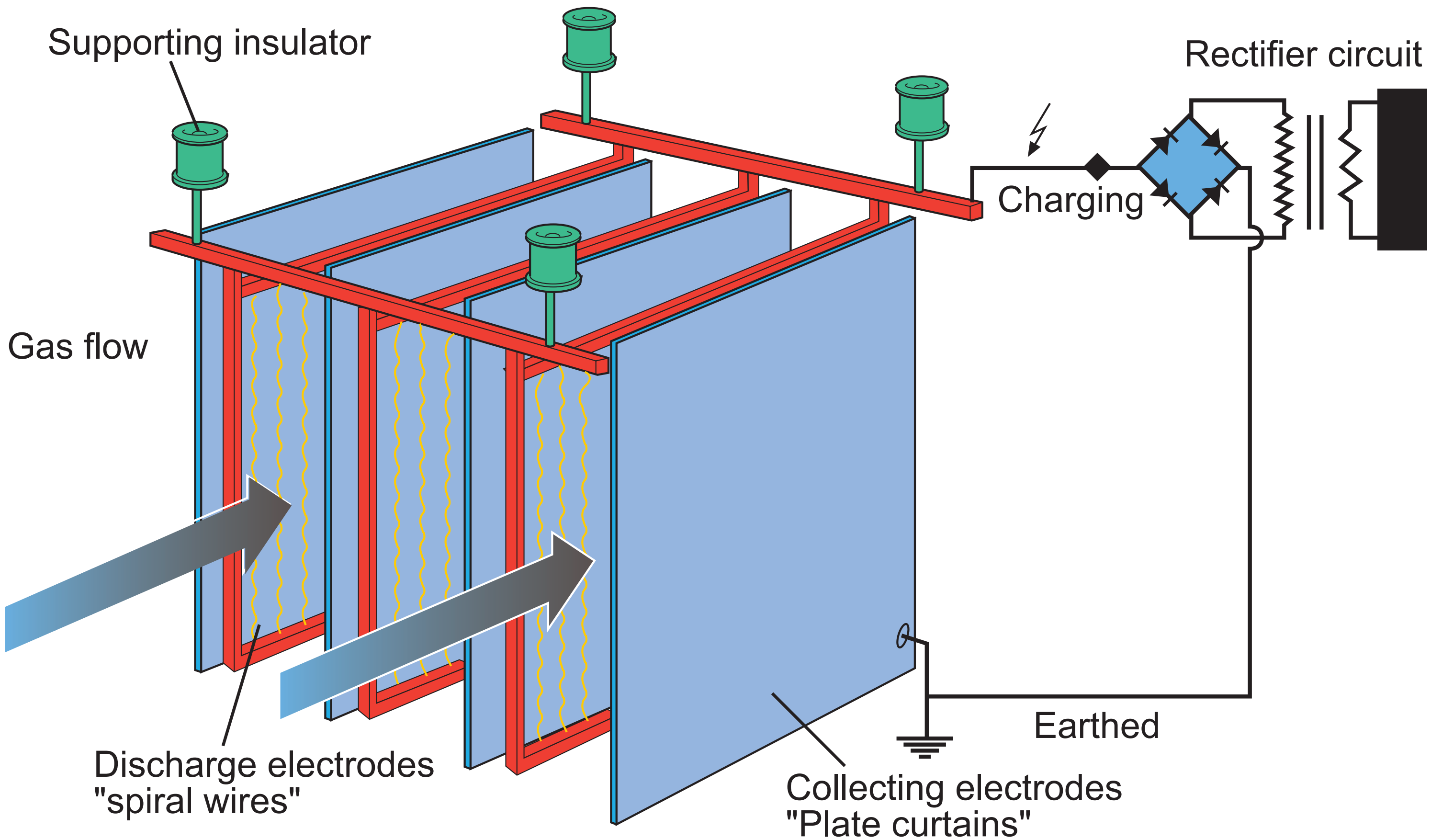
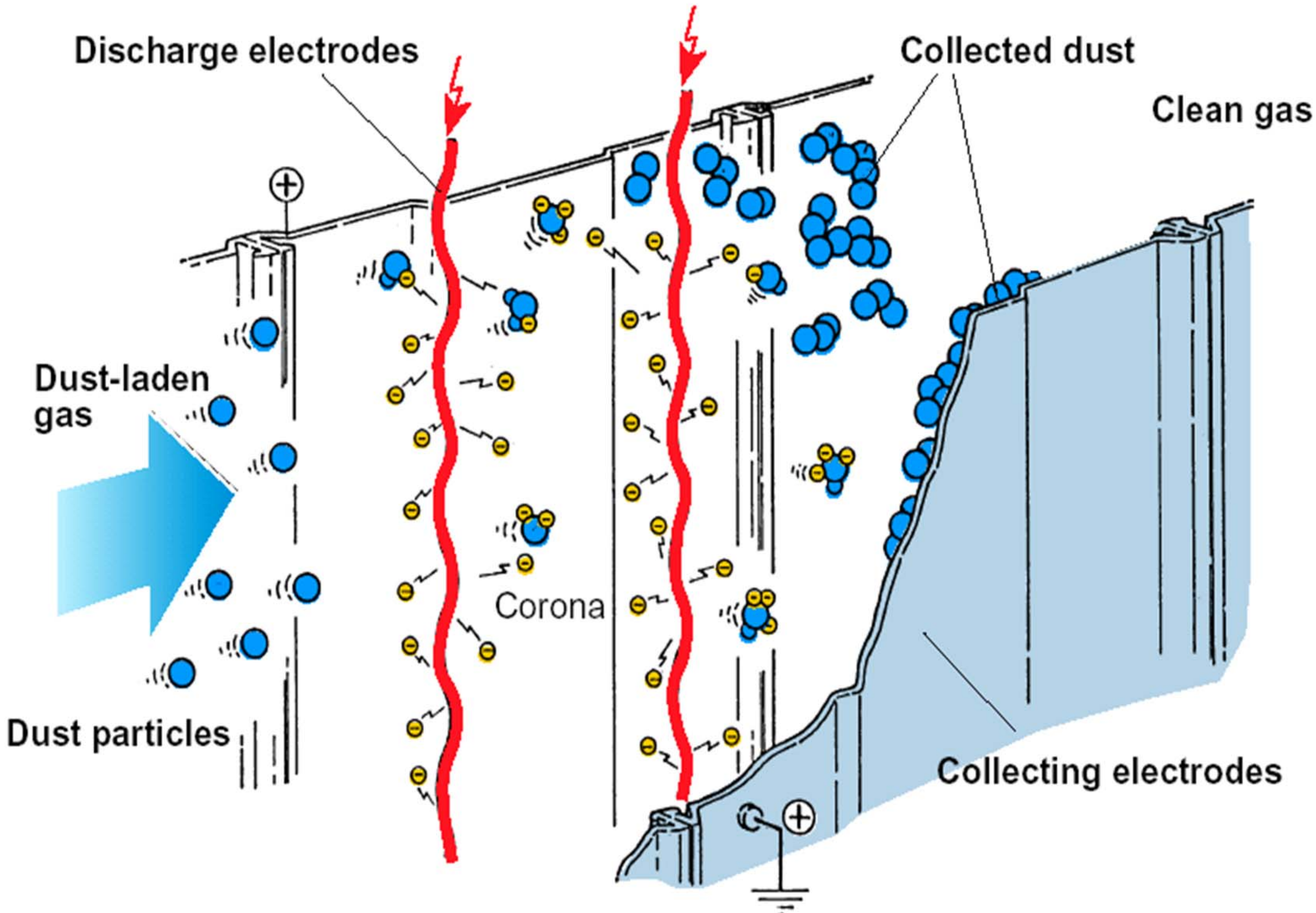


ESP dust collection



2.2

Electrical effects

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- Corona quenching
  - *Particle size distribution, 'Fine dust'*
    - *Reduced E-field at the emitting electrode*

    =>*Less Corona current*
- Back Corona
  - High resistivity dust
    - High E-field in the dust layer, spark-over

    =>Injection of positive charges into the gas
- Reentrainment
  - Low resistivity dust
    - Low E-field in the dust layer

    =>Reduced holding forces in the dust layer

Influence of fine particles

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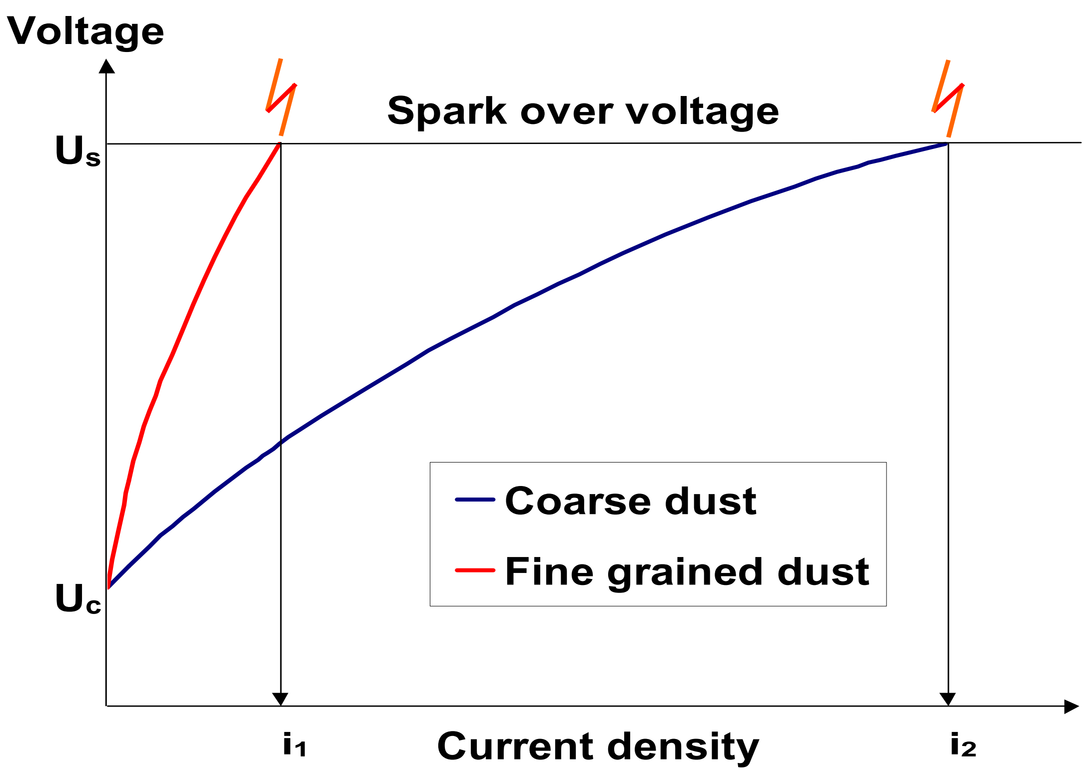
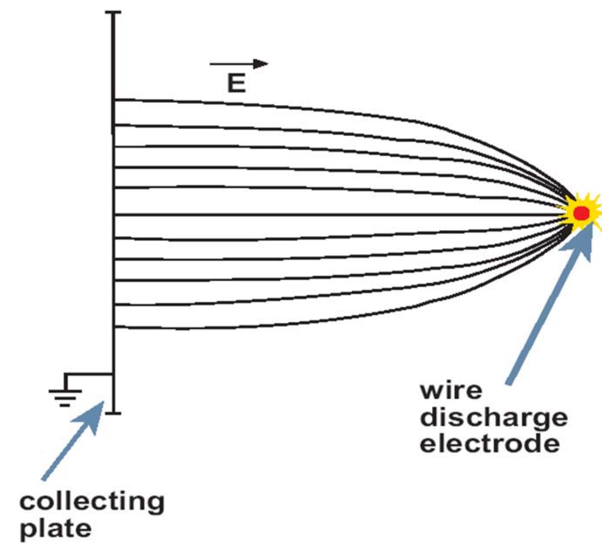
Poor Power Input





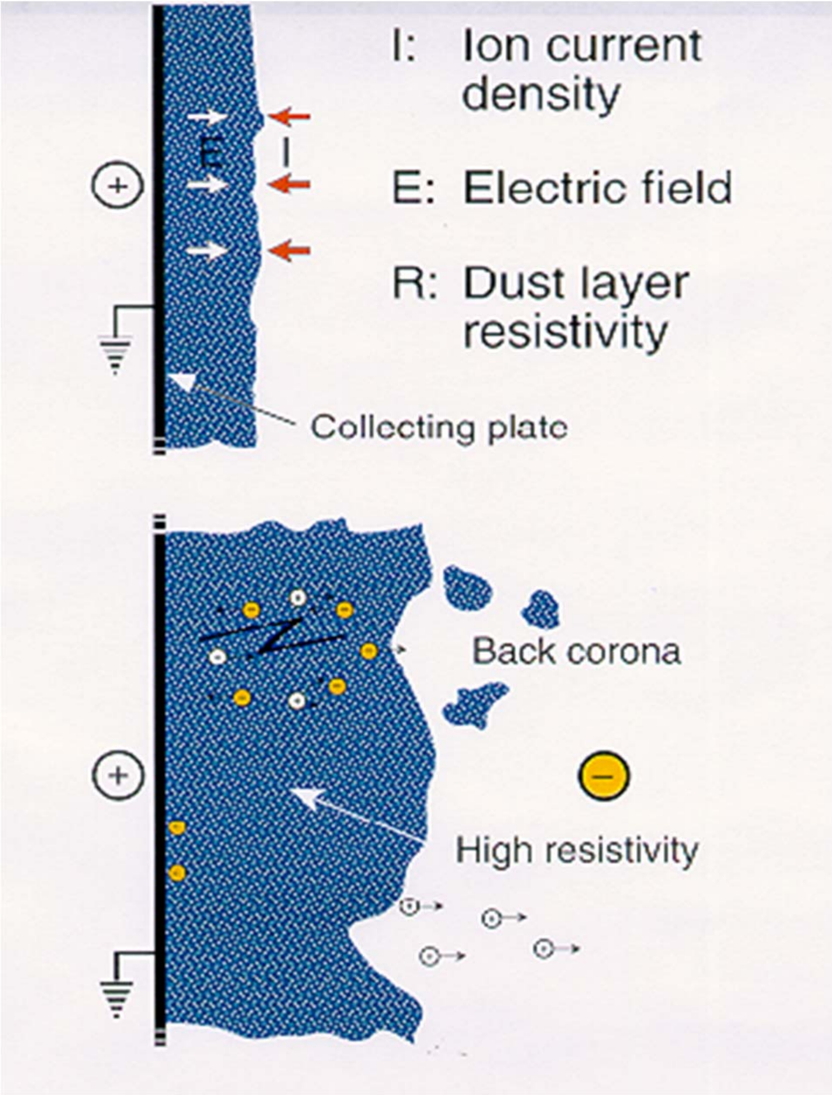
Fine grained dust increases the Space Charge Effect,

i.e. Corona Quenching

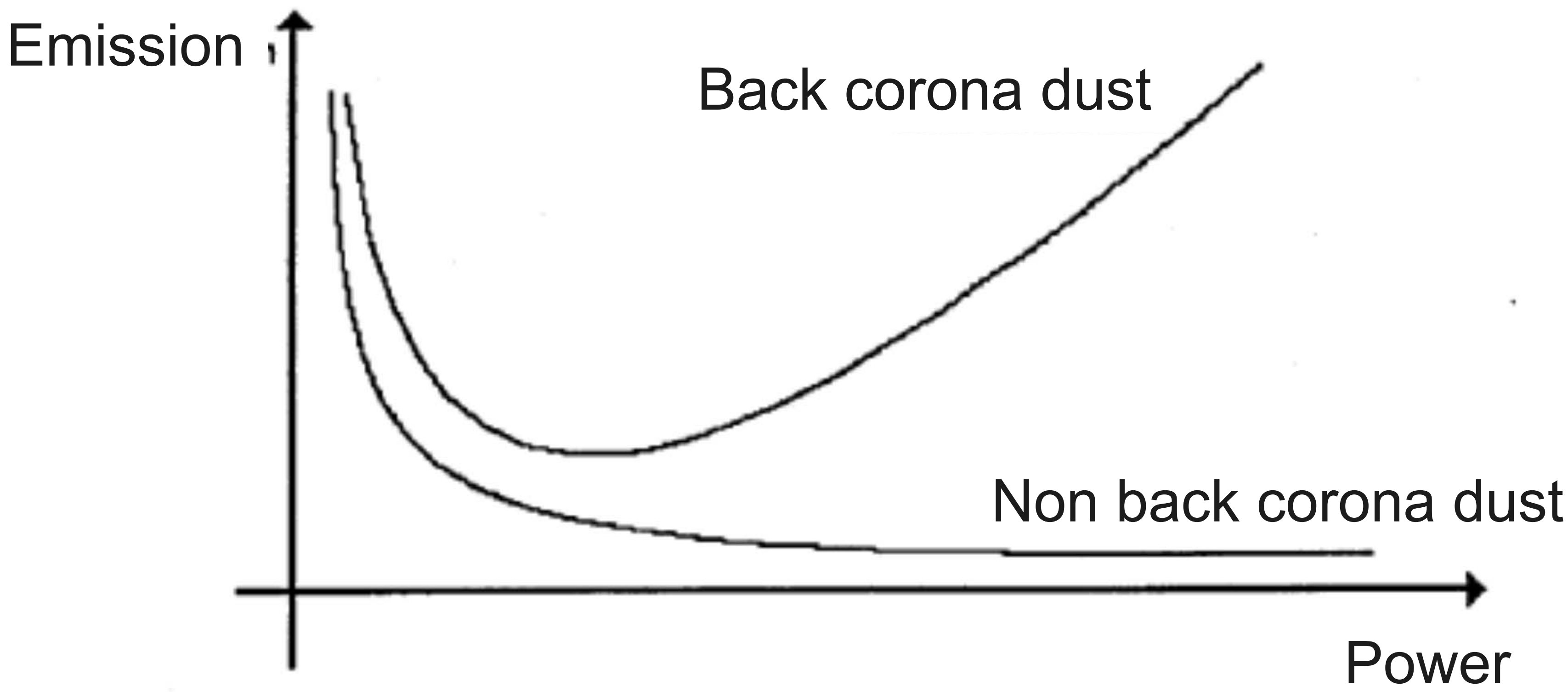
Back-Corona in ESP

$$E = j\,\rho$$

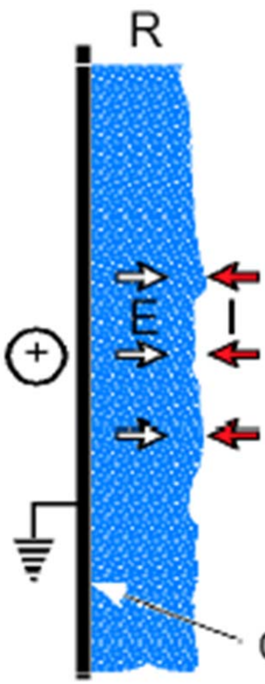
E *Field strength,* [V/m]
j *Current density,* [A/m^2]
ρ *Dust layer resistivity,* [Ωm]



Dust emission vs. power consumption



Low resistivity dust, reentrainment



I: Negative charge flow

E: Electric field

R: Dust layer resistivity

<u>Tear off</u>

Gas flow (drag)

Gravity

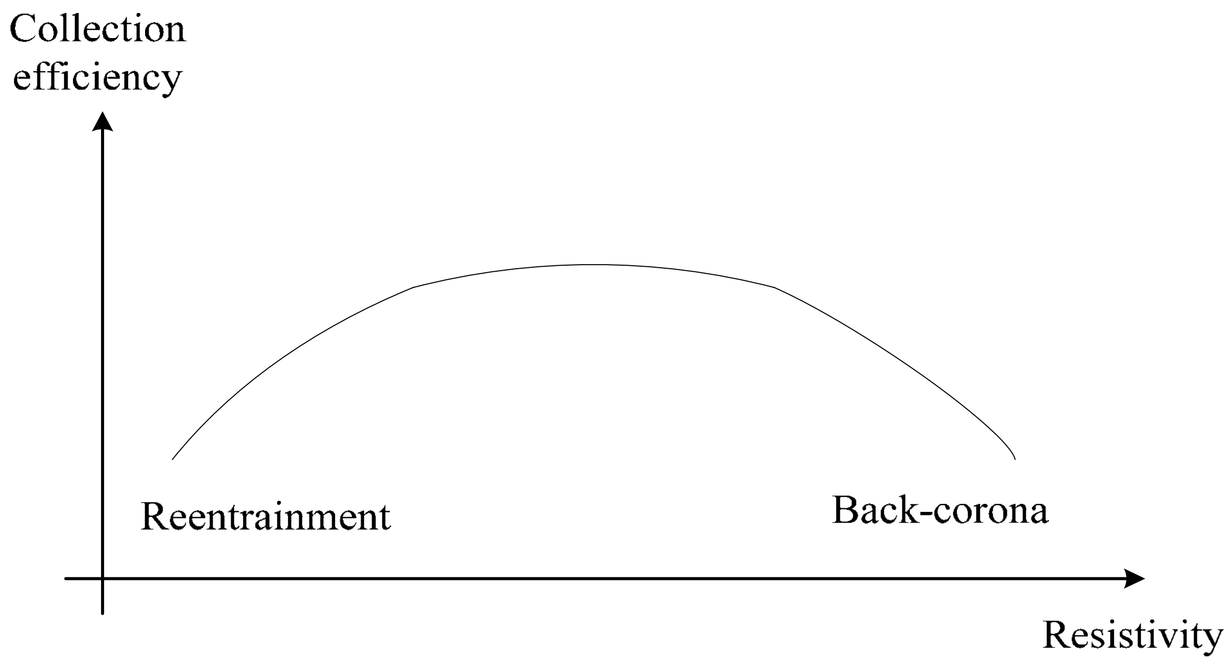
<u>Holding</u>

Electrostatic forces

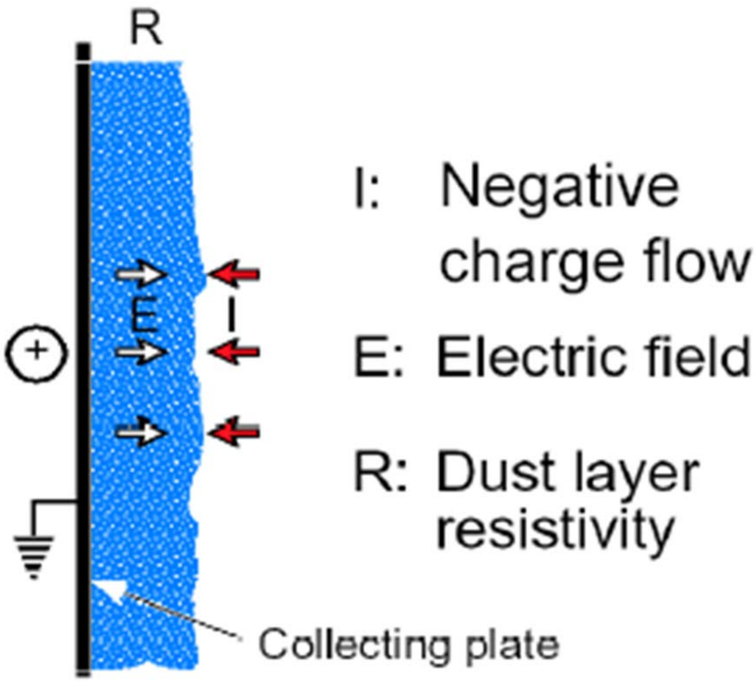
Chemical (cohesion)

Reentrainment related to low resistivity depends on the relation between dust layer <u>electrostatics</u> and <u>gas flow</u> close to the collecting electrode.

Dust emission vs. resistivity



Dust layer, resistivity



Classification 1

Conductive	10^4-10^8 Ωcm
Normal	10^8-10^{10} Ωcm
Moderate	10^{10}-10^{11} Ωcm
High	10^{11}-10^{13} Ωcm

[Parker et.al, Applied Electrostatic precipitation, 1997]

Classification 2

Low	10^7-10^9 Ωcm
Best perf.	10^9-10^{11} Ωcm
High	10^{11}-10^{13} Ωcm

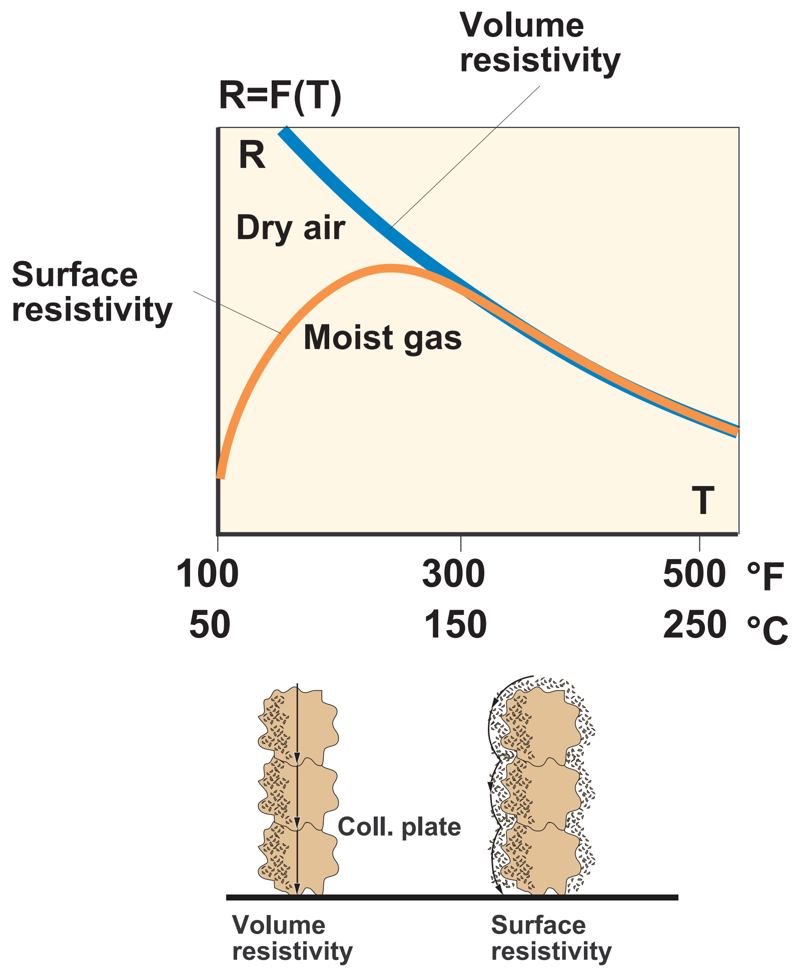
[Porle, Francis, Bradburn, ESPs for ind. Applications, 2005]

Classification 3

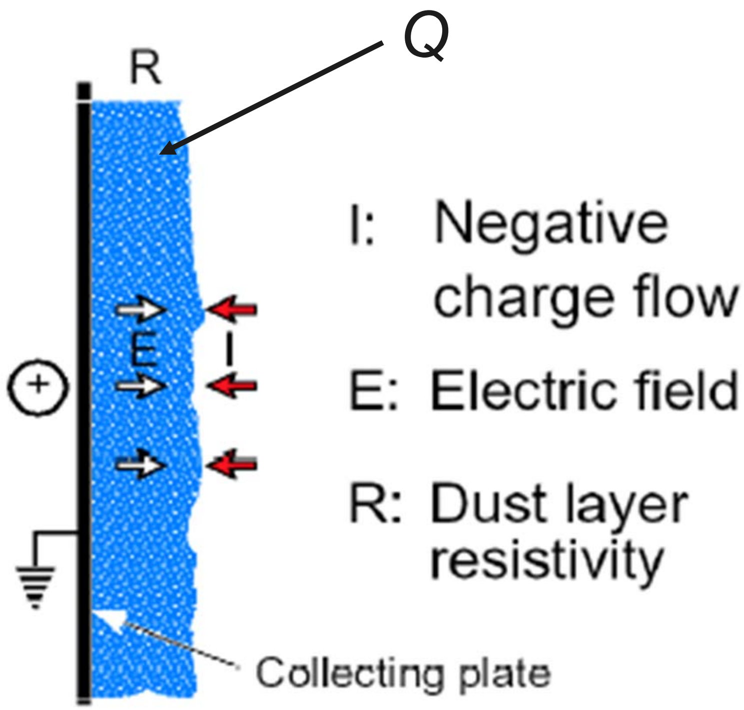
High	$>10^{10}$ Ωcm

[White, Industrial Electrostatic Precipitation, 1963]

Dust resistivity versus moisture and temp.



Dust layer, electrostatics



F=Q E

E=j ρ

=> *F=Q j ρ*

F *Force*, [N]
Q *Charge*, [C, (As)]
E *Field strength*, [V/m]
j *Current density*, [A/m²]
ρ *Dust layer resistivity*, [Ωm]

Gas flow distribution

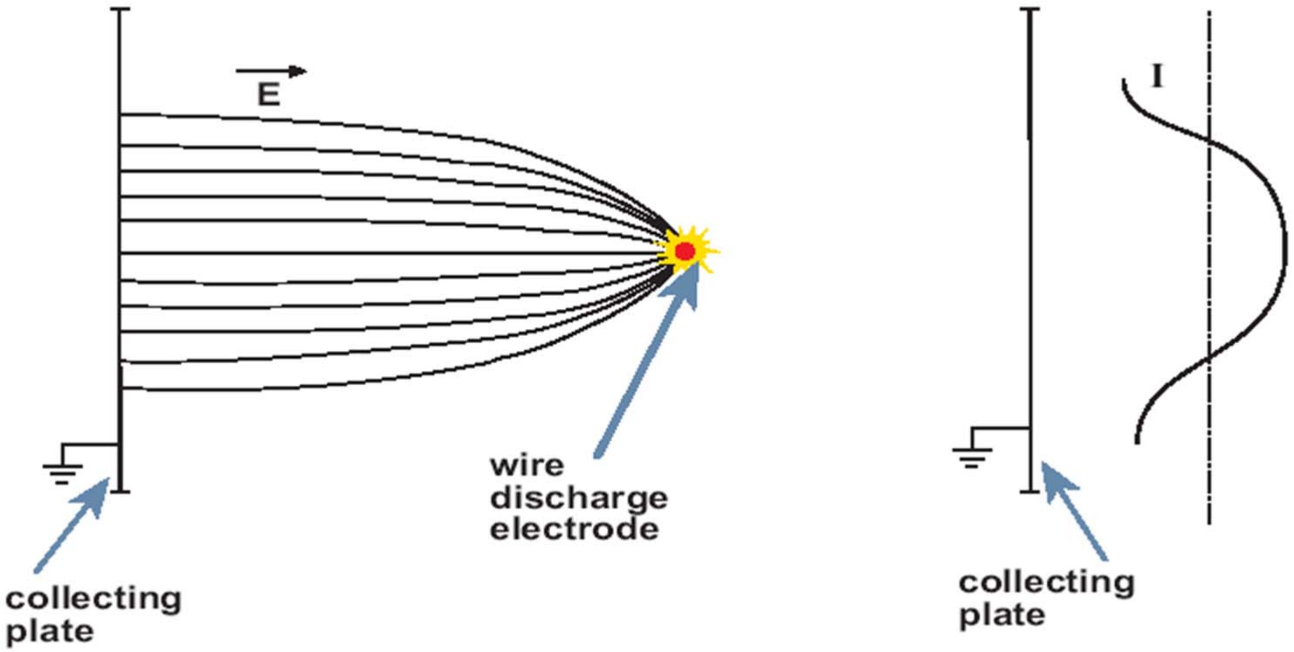
Velocities in percentage of average

Measured after the first field

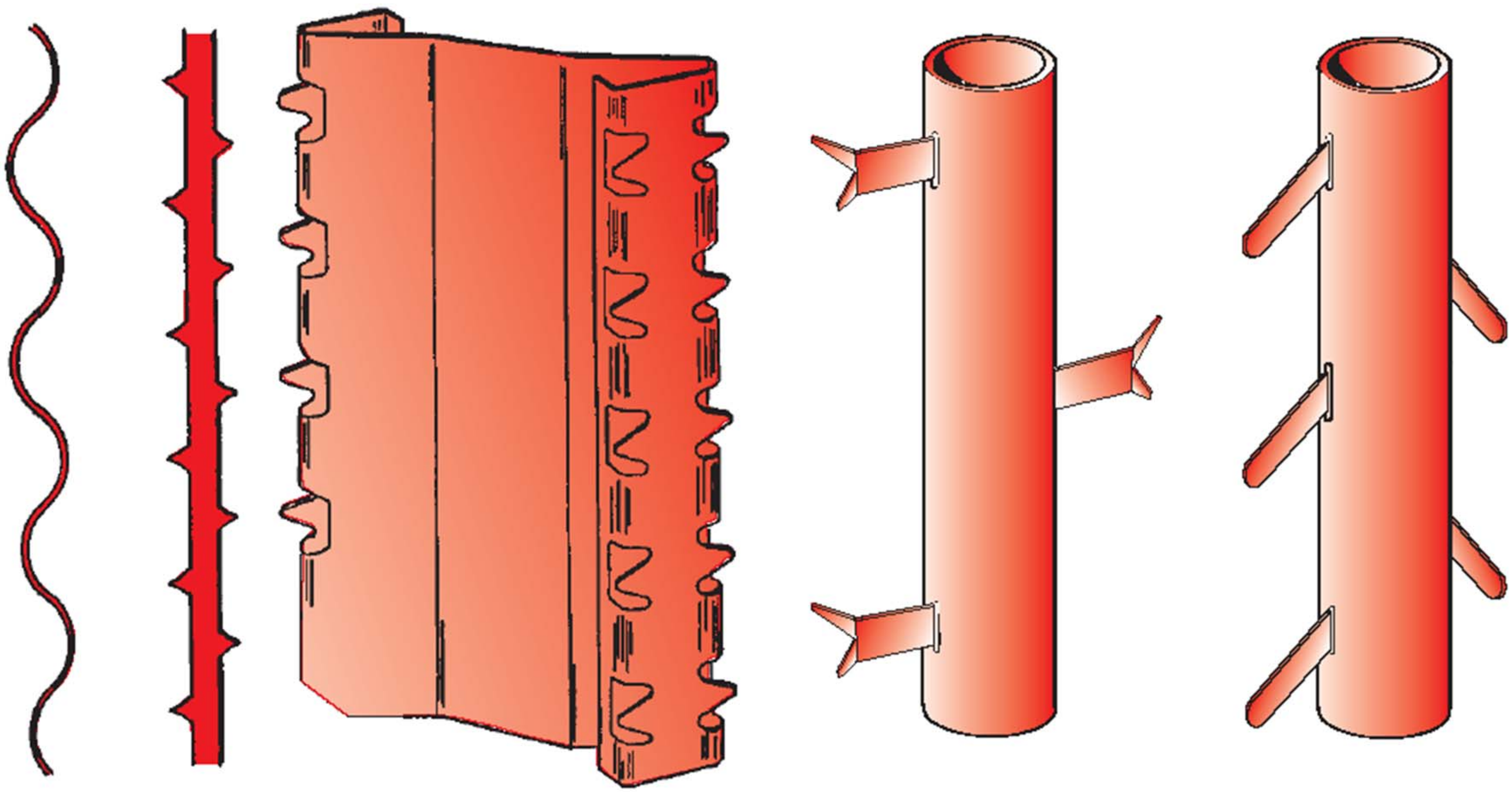
Gas flow distribution, means to minimize reentrainment

- Minimize high gas velocities
- Uniform flow distribution
- Avoid in-leakage

Current distribution, general

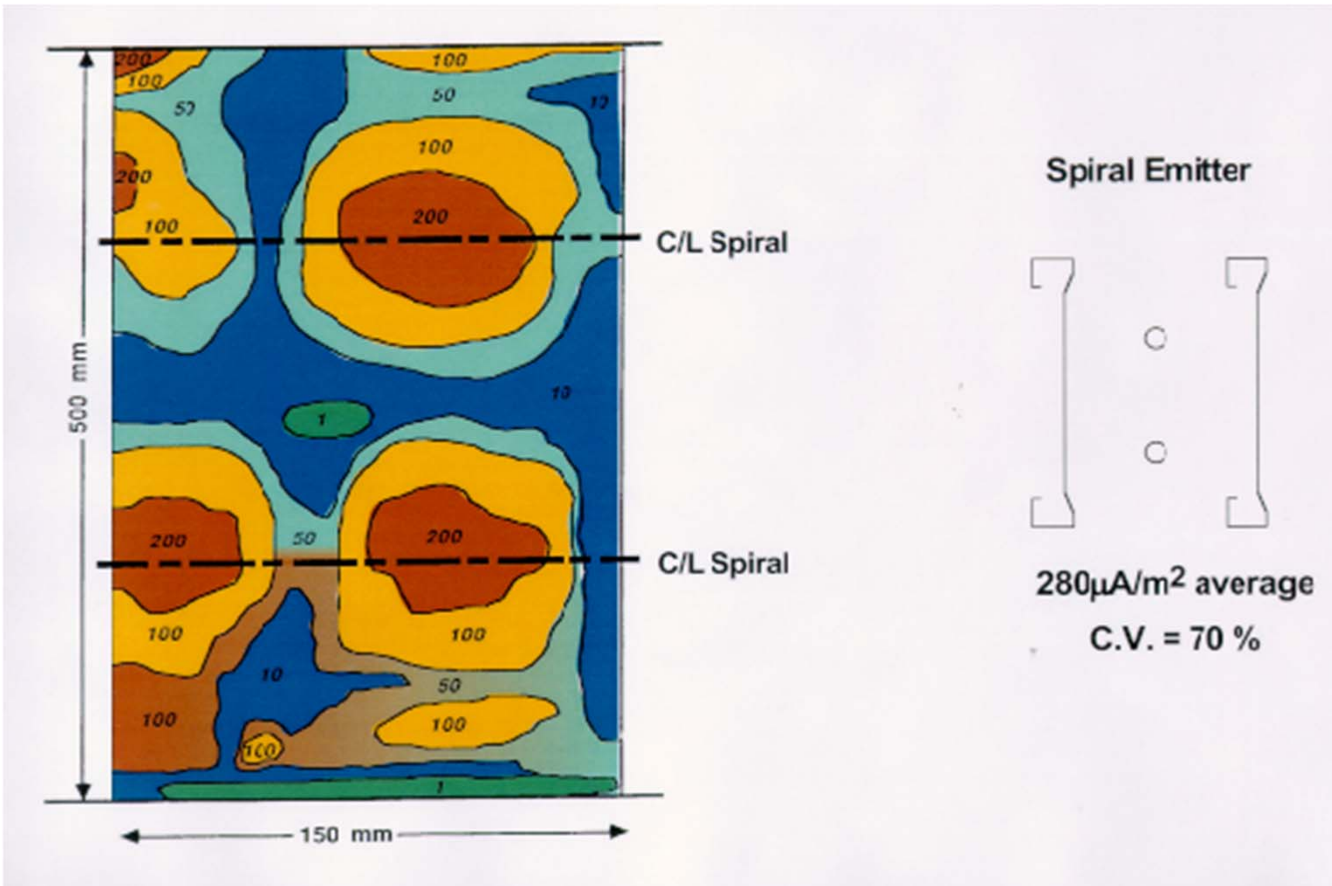


ESPs - discharge electrode



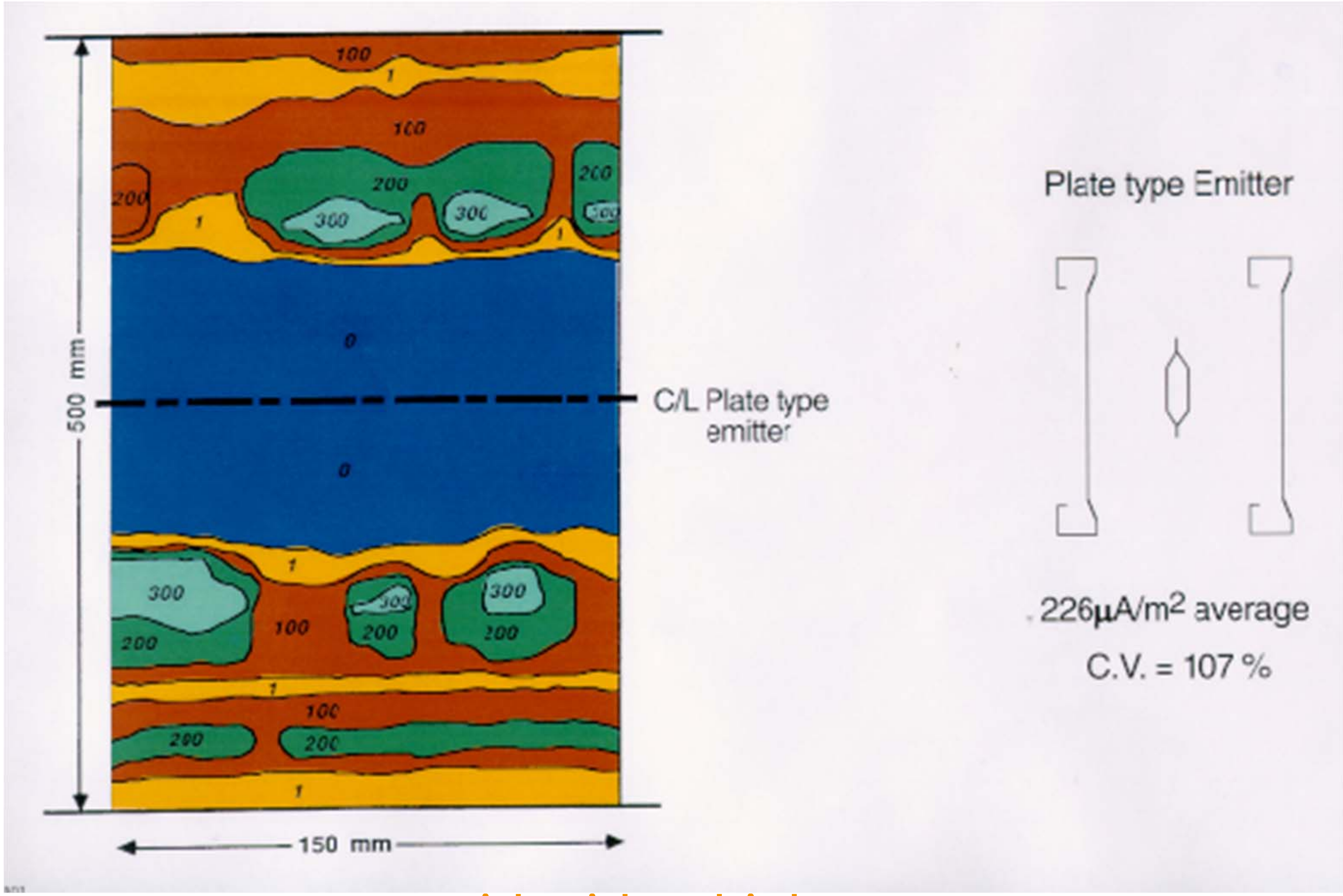
ESP - Spiral current distribution

Current distribution on collecting plates



ESP - RDE discharge electrode, current distribution

Current distribution on the collecting plate

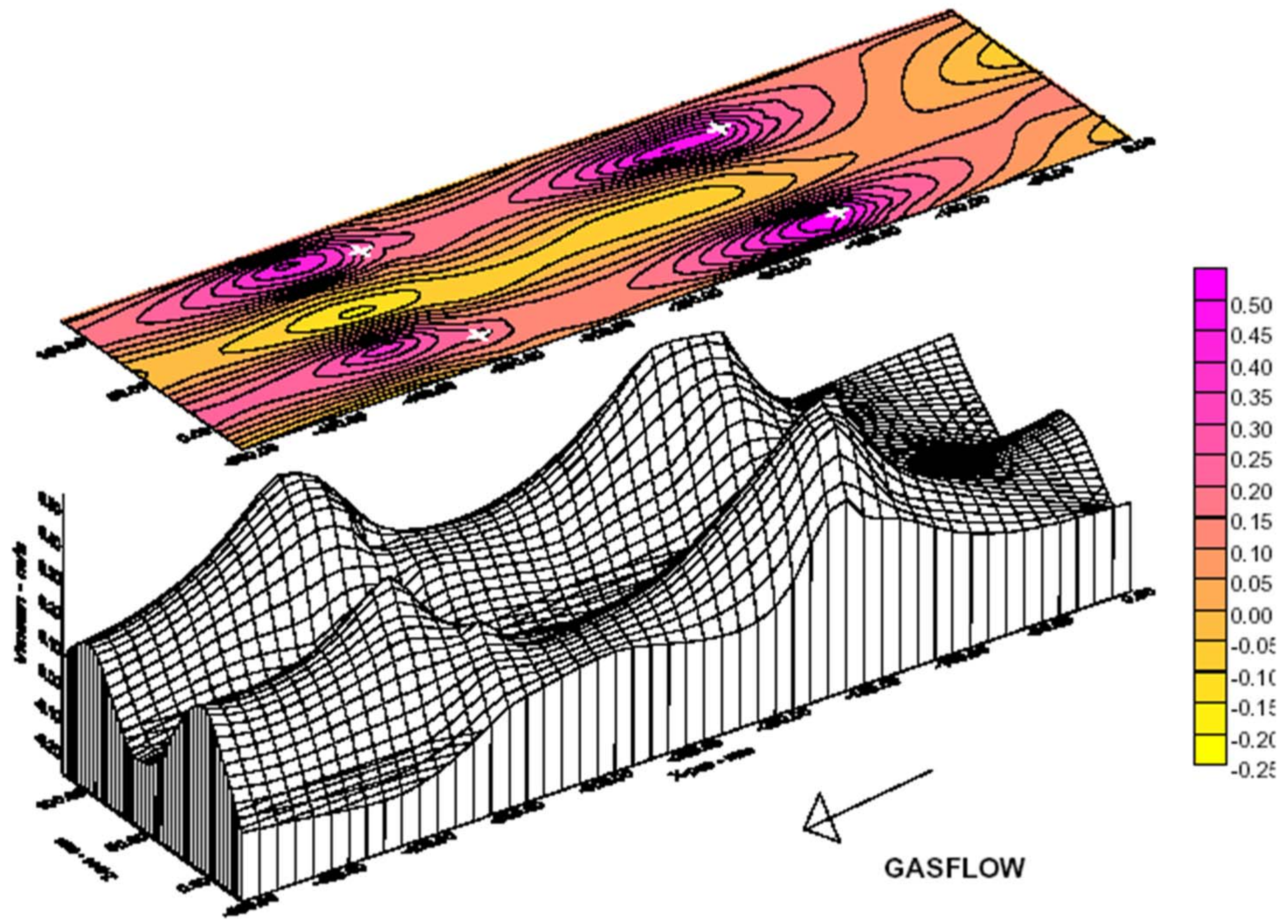


- Large areas with either high or zero current -

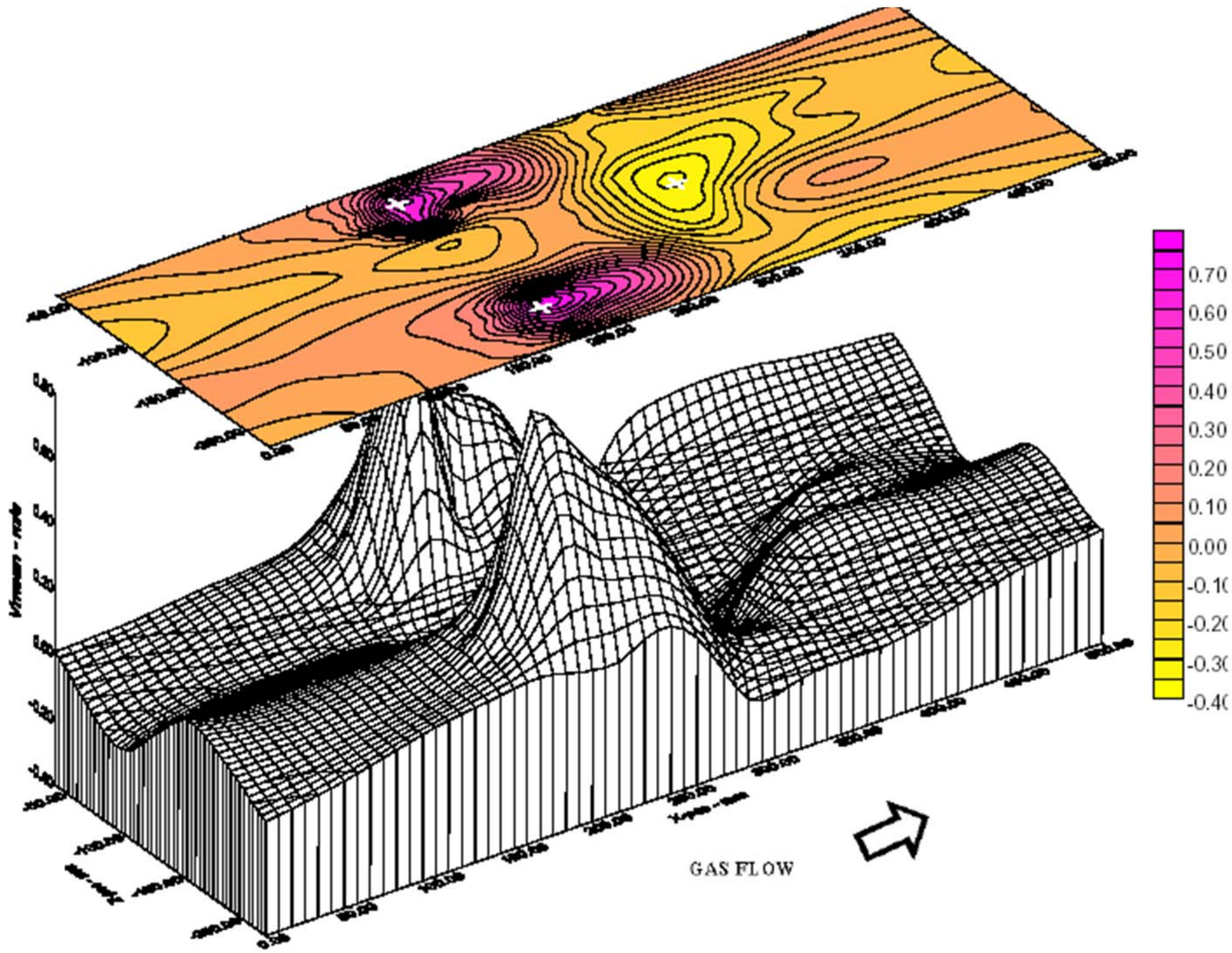
Current distribution, RDE

- Dust pattern similar to current distribution
- High CV-value in current distribution
- Poor utilisation of collecting plate
- Reentrainment

Ionic wind, spiral



Ionic wind, RDE



Current distribution

- Influenced by emitting electrode design

- Non uniform current distribution gives:
  - -Substantial areas of low current densities
  - -Negative effect from the ionic wind, high current areas

Topics

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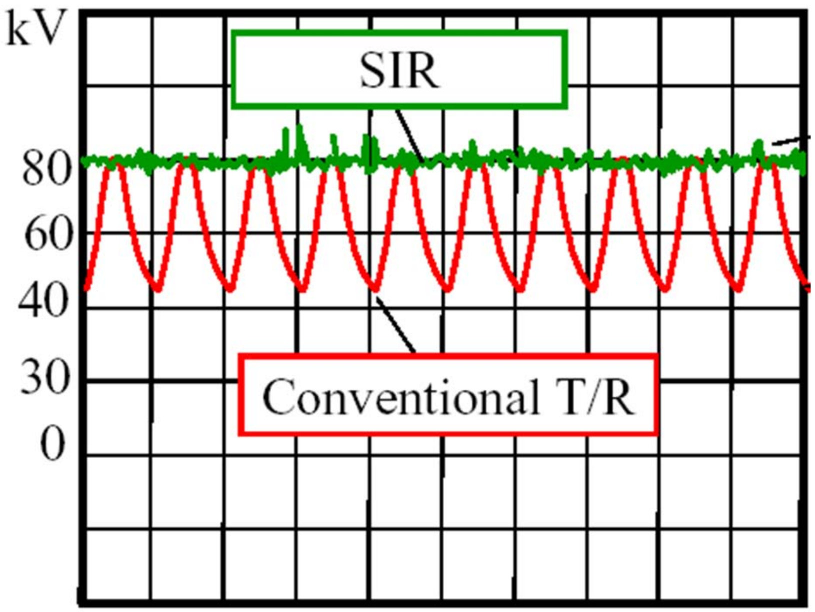
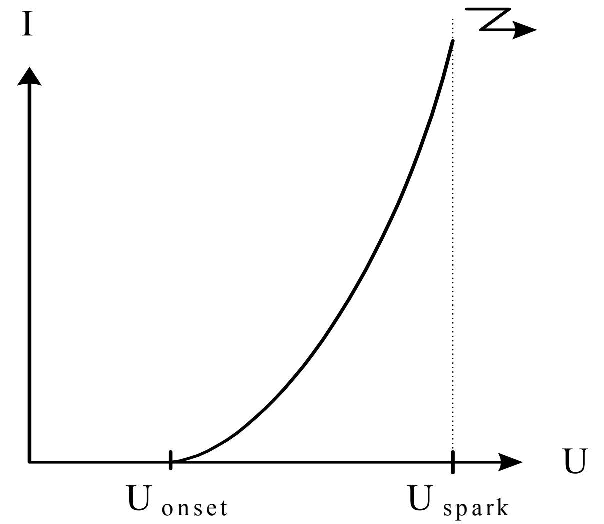
- *Summary*

Voltage ripple vs reentrainment





$$i_{Corona} = k \cdot (u - U_{Onset})^2$$

F=Q j ρ

=> F is <u>very low</u> at U_V

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Dust layer, Time Constant

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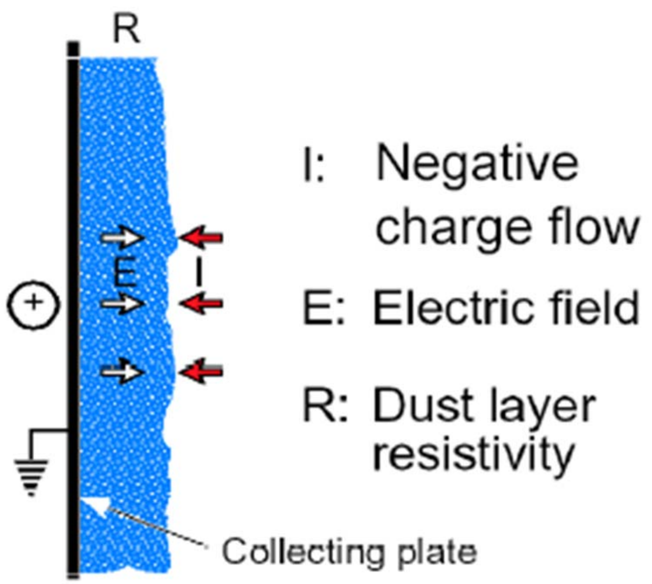
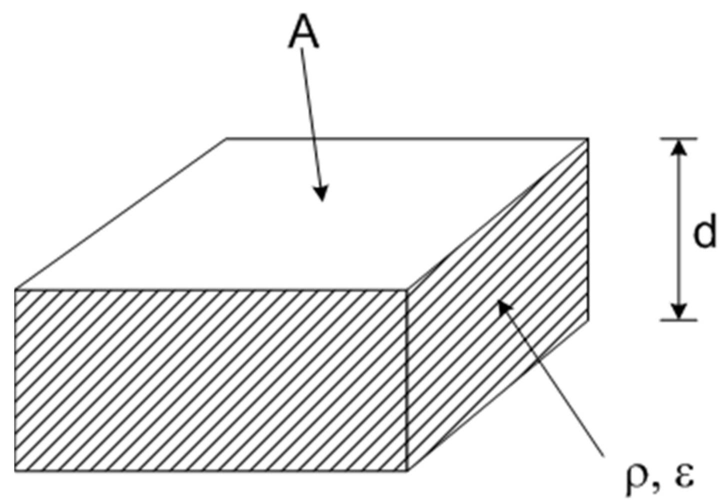




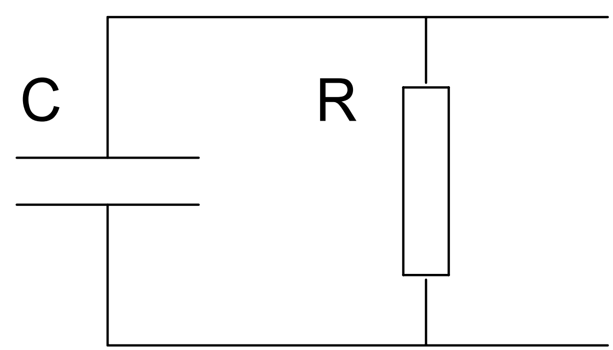
τ *Time constant* , [s]

A *Area*, [m^2]

d *Distance*, [m]

ε *Dielectric constant*, [As/Vm]

ρ *Resistivity*, [Ωm]



Estimation of dust layer time constant

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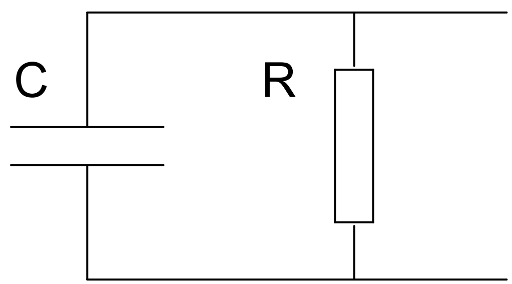
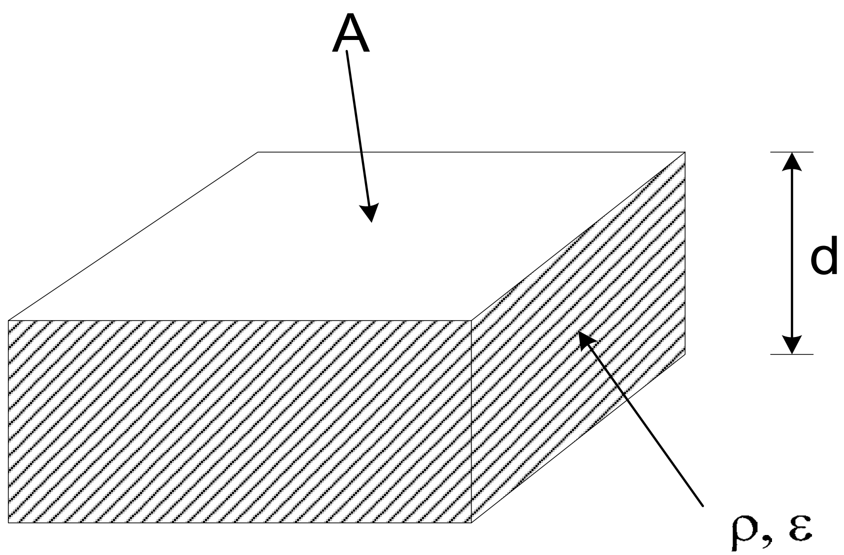


$$C = \varepsilon \frac{A}{d}$$

$$R = \rho \frac{d}{A}$$



$$\tau = R \cdot C = \rho \cdot \varepsilon$$

Estimation of dust layer time constant

$$T=RC=\rho\varepsilon$$

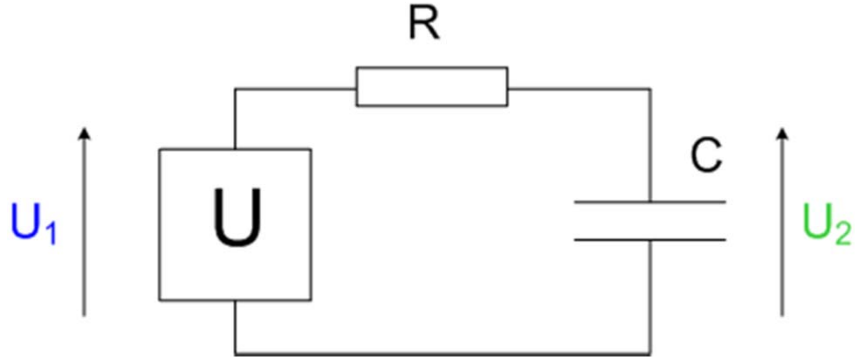
$$\varepsilon=1\cdot 8{,}85\cdot 10^{-12}\ \mathrm{As/Vm}\approx 1\cdot 10^{-11}\ \mathrm{As/Vm}$$

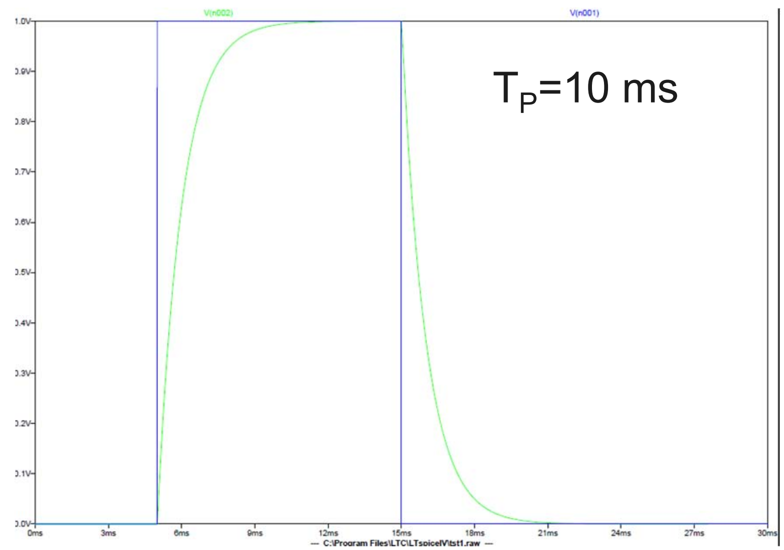
$$\rho=1\cdot 10^{10}\ \Omega cm = 1\cdot 10^{8}\ \Omega m \quad => \underline{T=1\cdot 10^{-3}\ s = 1\ ms}$$

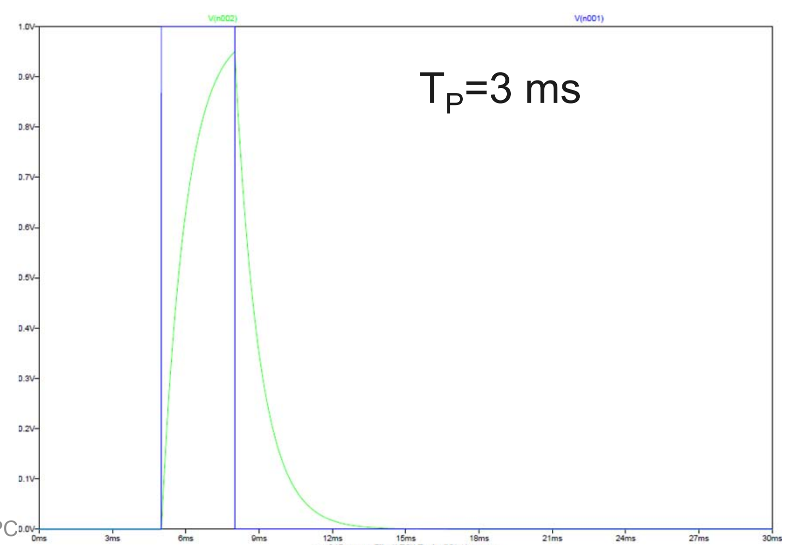
ρ [Ωcm]	T [ms]
$1\cdot 10^{8}$	0,01
$1\cdot 10^{10}$	1
$1\cdot 10^{12}$	100
$1\cdot 10^{14}$	10^{4}(=10 s)

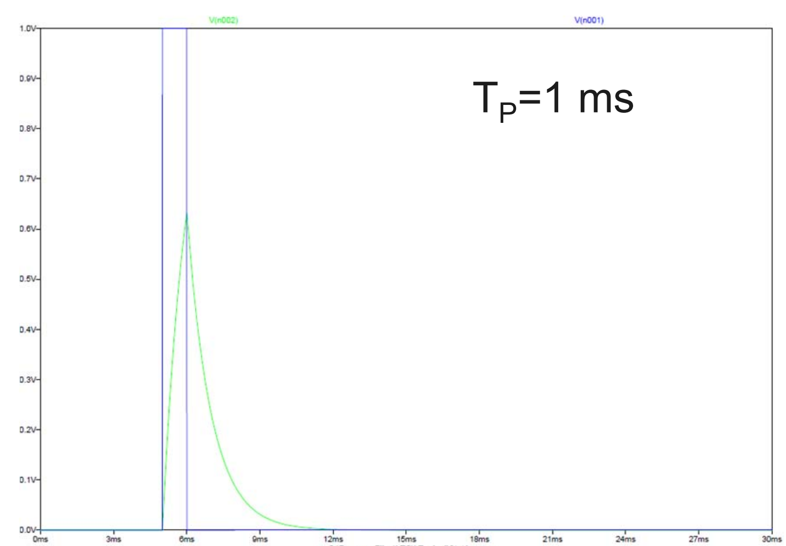
RC circuit, pulse response

$$\tau = R \cdot C = 1\ ms$$









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RC circuit, frequency response

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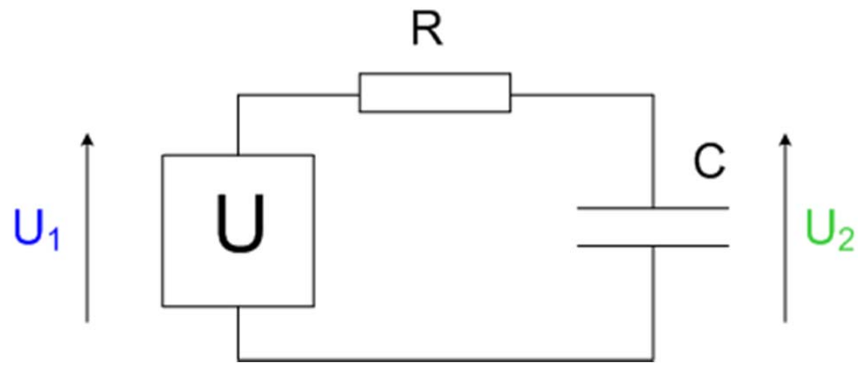
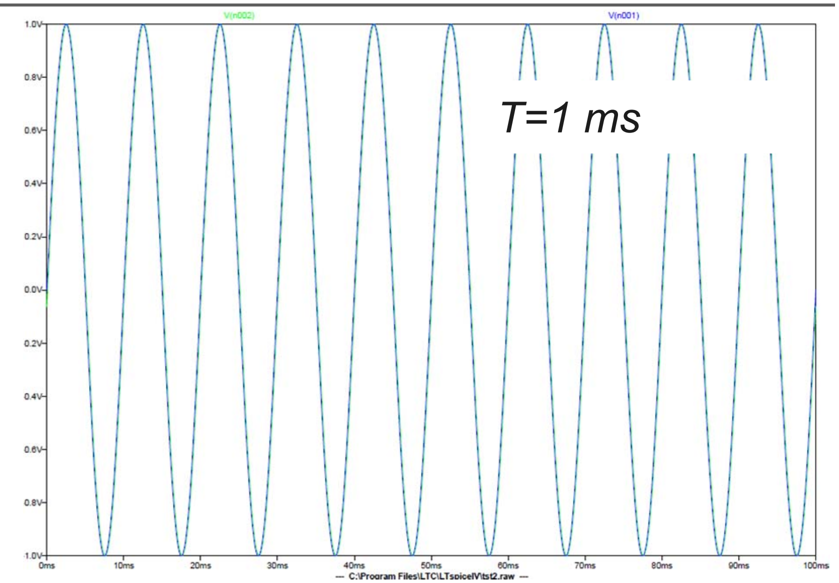
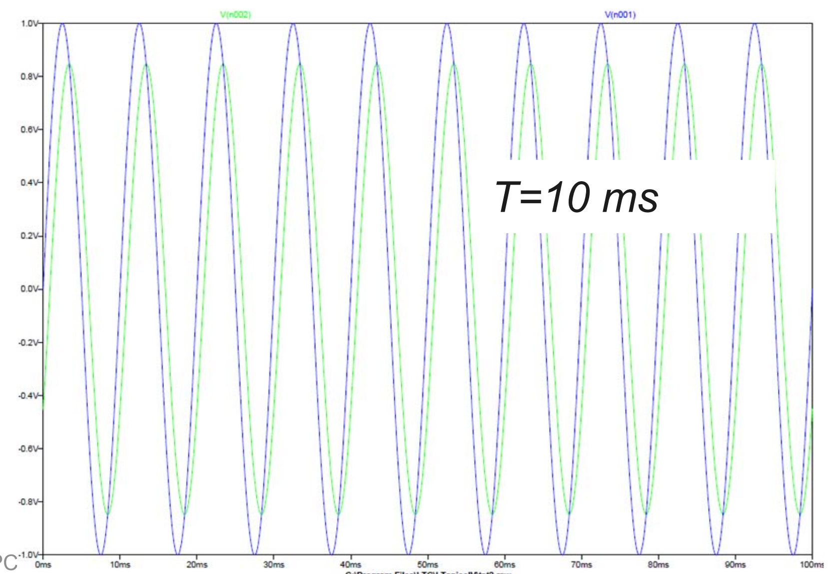
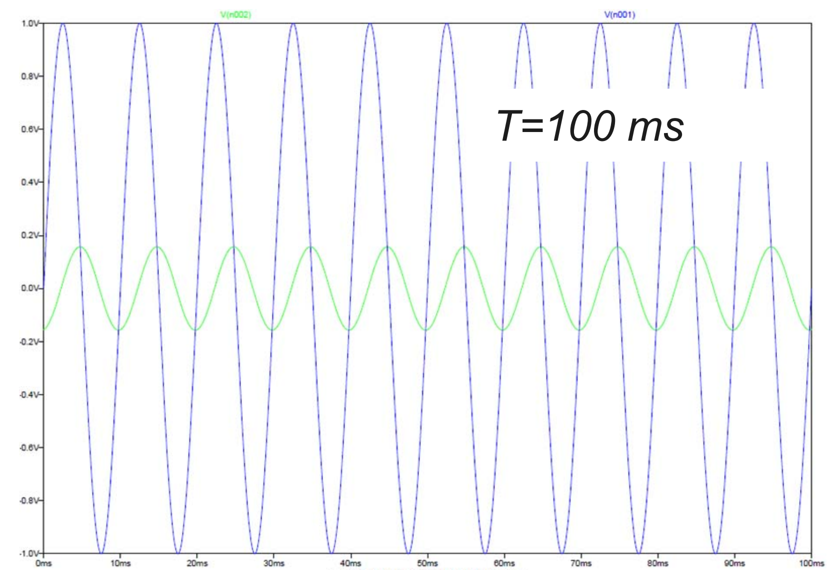
100 Hz, sine wave

$$\tau = R \cdot C$$





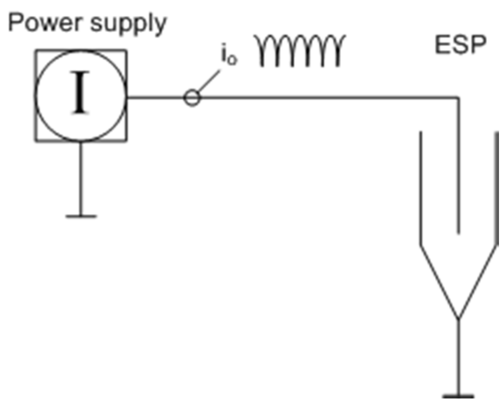




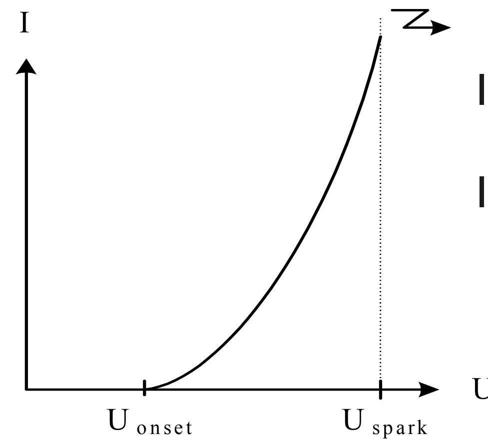
PC

Circuit modelling

Electrical system



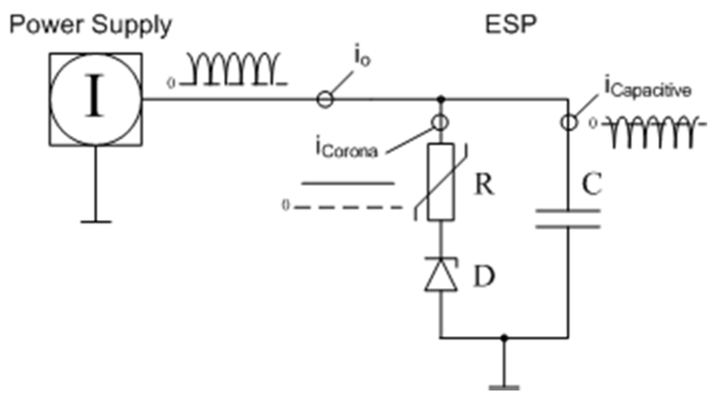
VI-curve

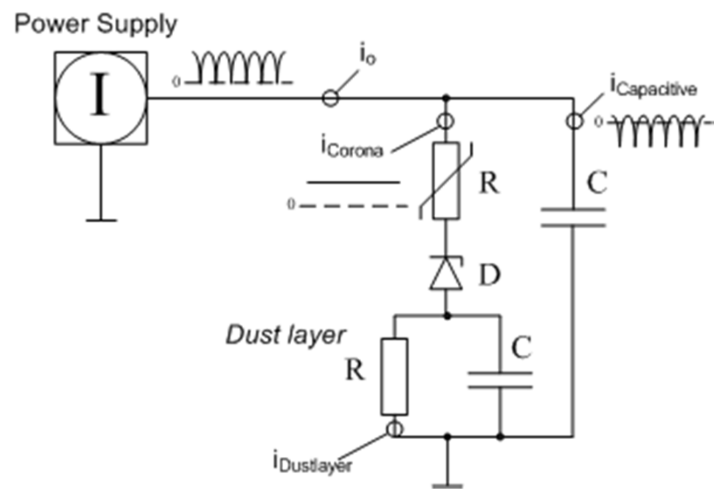


$I=0, \quad U \le U_{Onset}$

$I \approx k(U-U_{Onset})^2, \quad U > U_{Onset}$

Equivalent circuit





Conventional T/R, 1:1 operation

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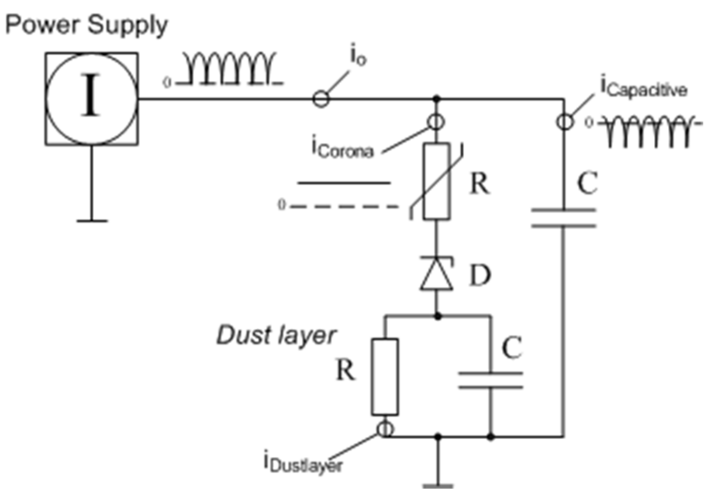
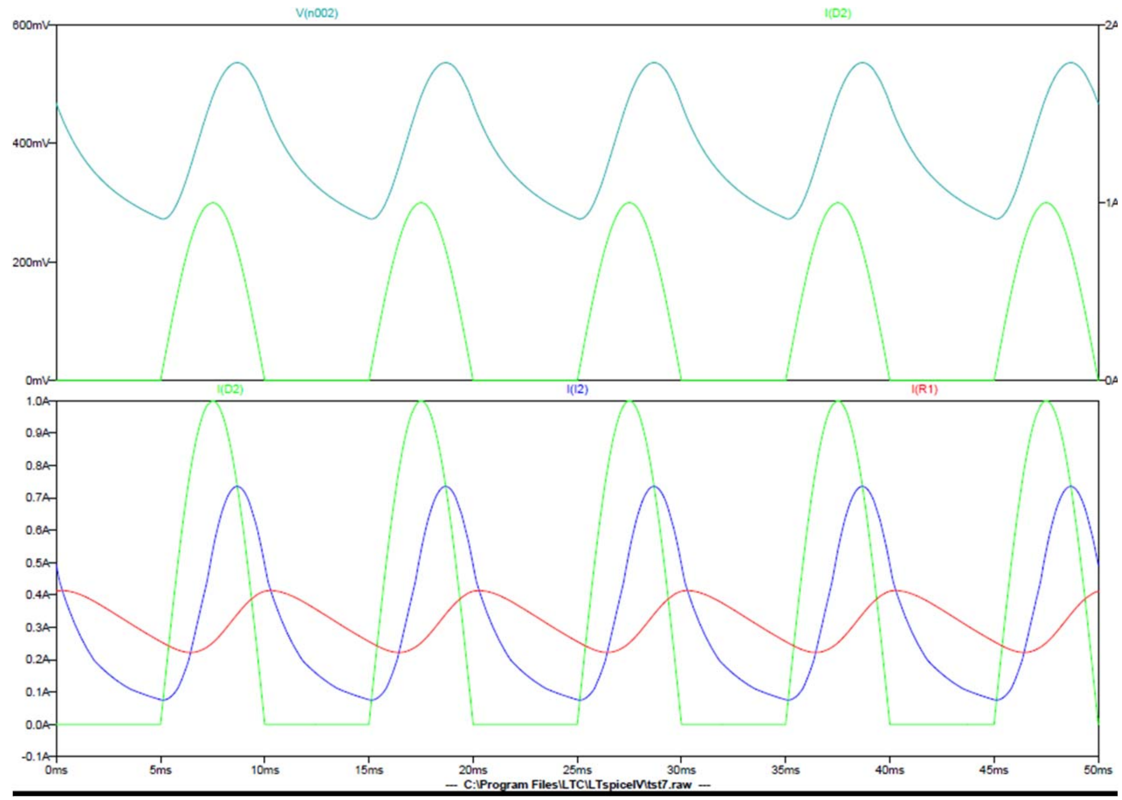
F=2*50 Hz

$\hat{I}_0$=1 A

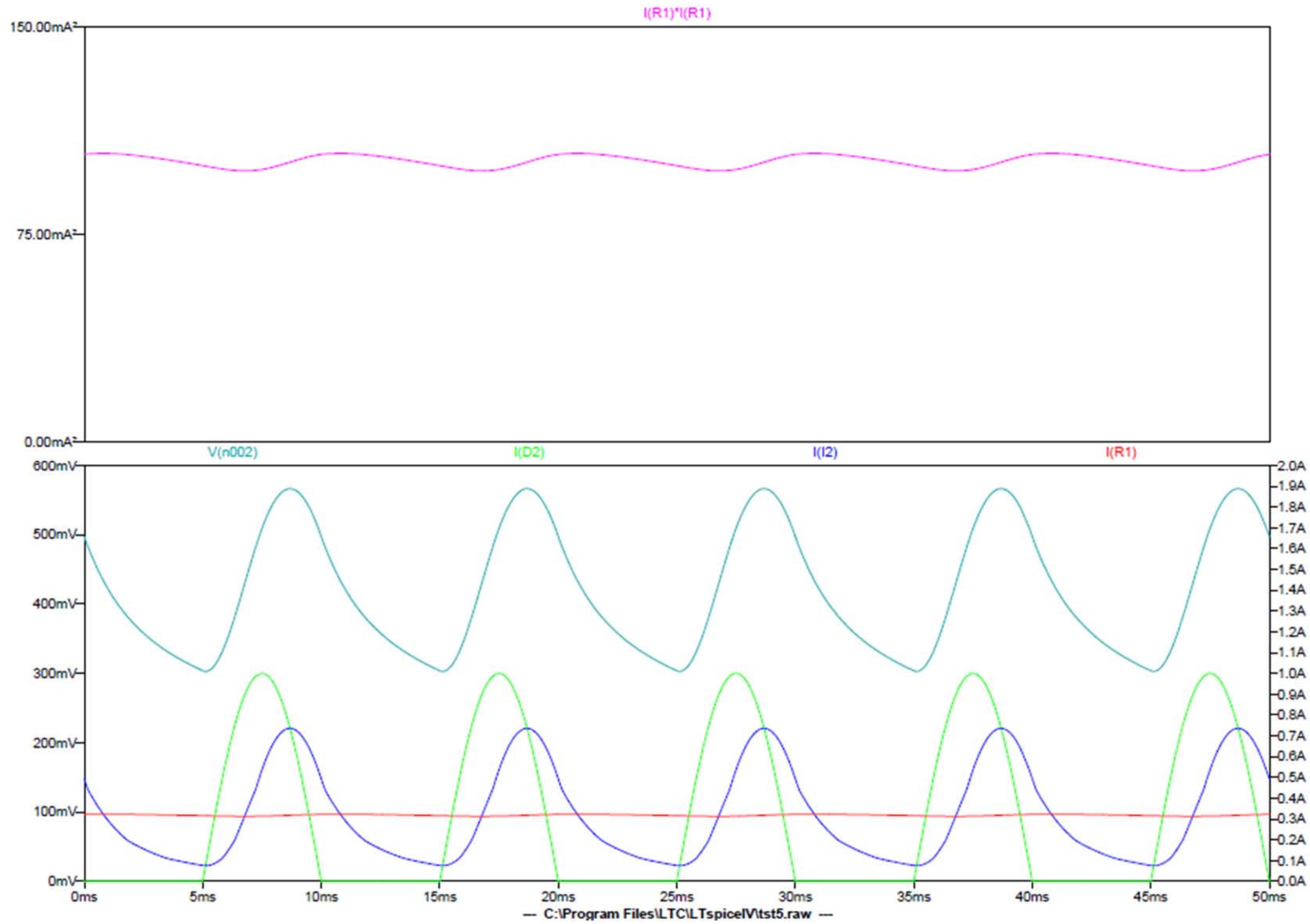
i_{Corona}(<15 kV)=0

i_{Corona}(60 kV)=1 A

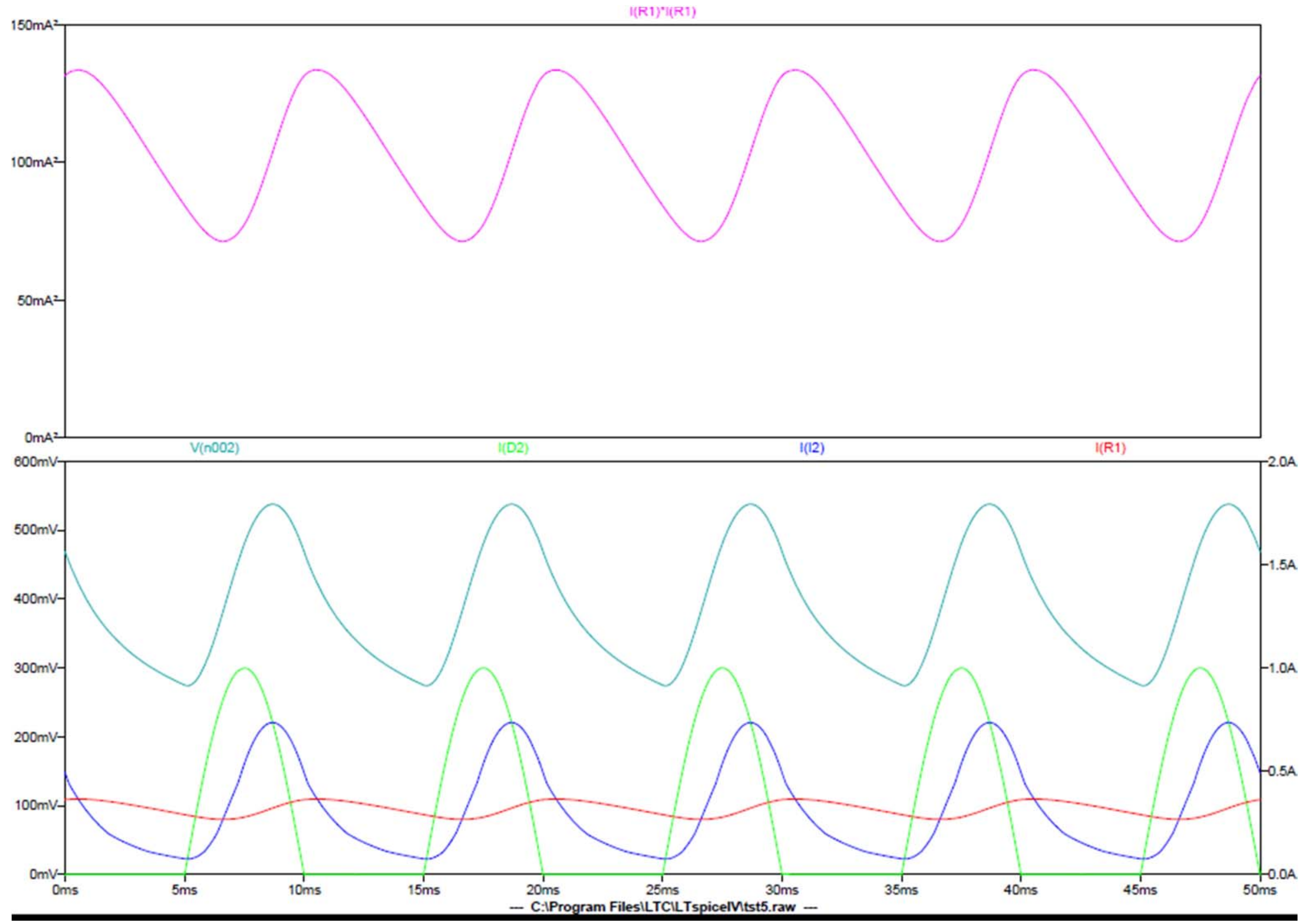




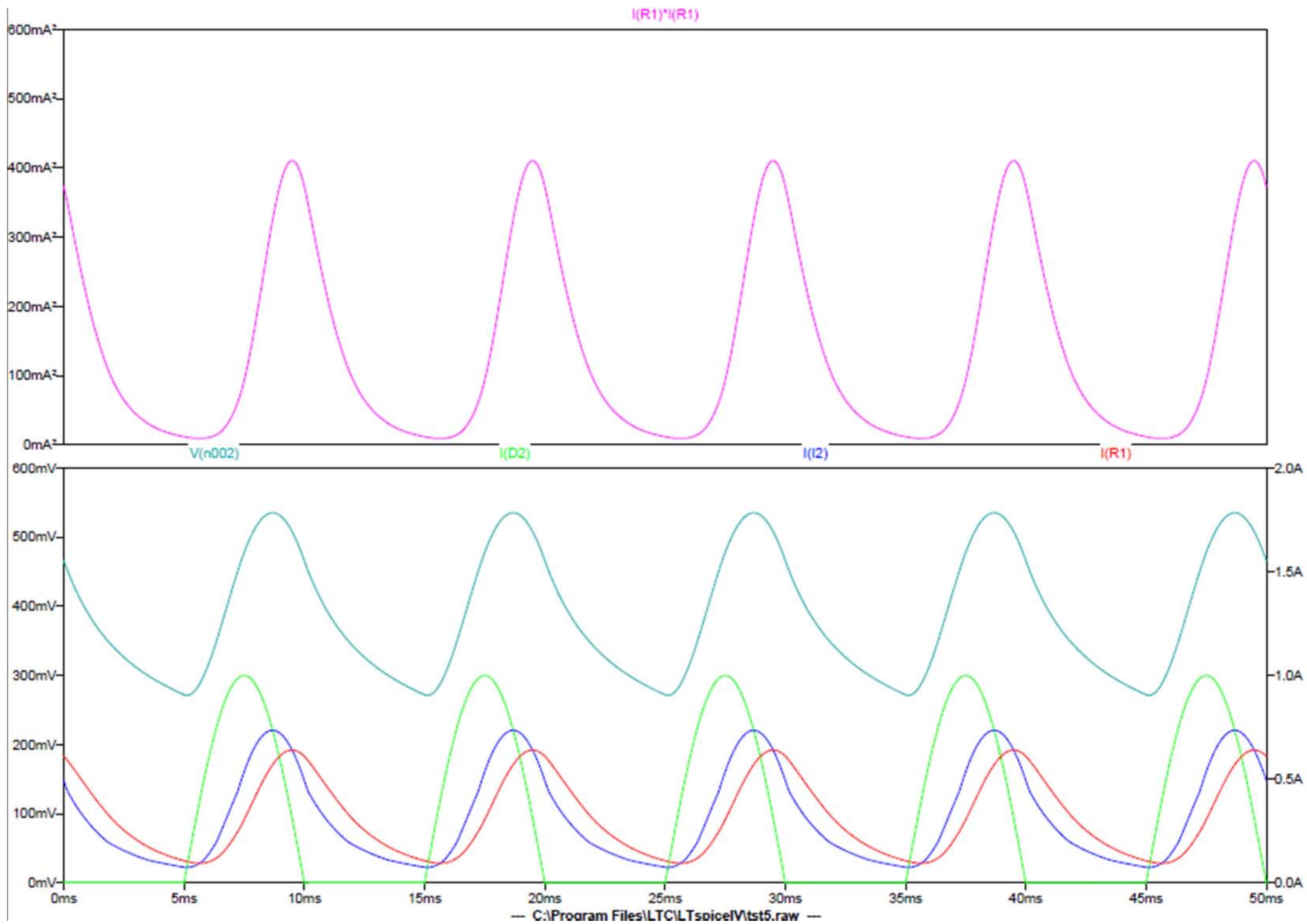
Conventional T/R, 1:1 operation
T=100 ms (10^{12} Ωcm)



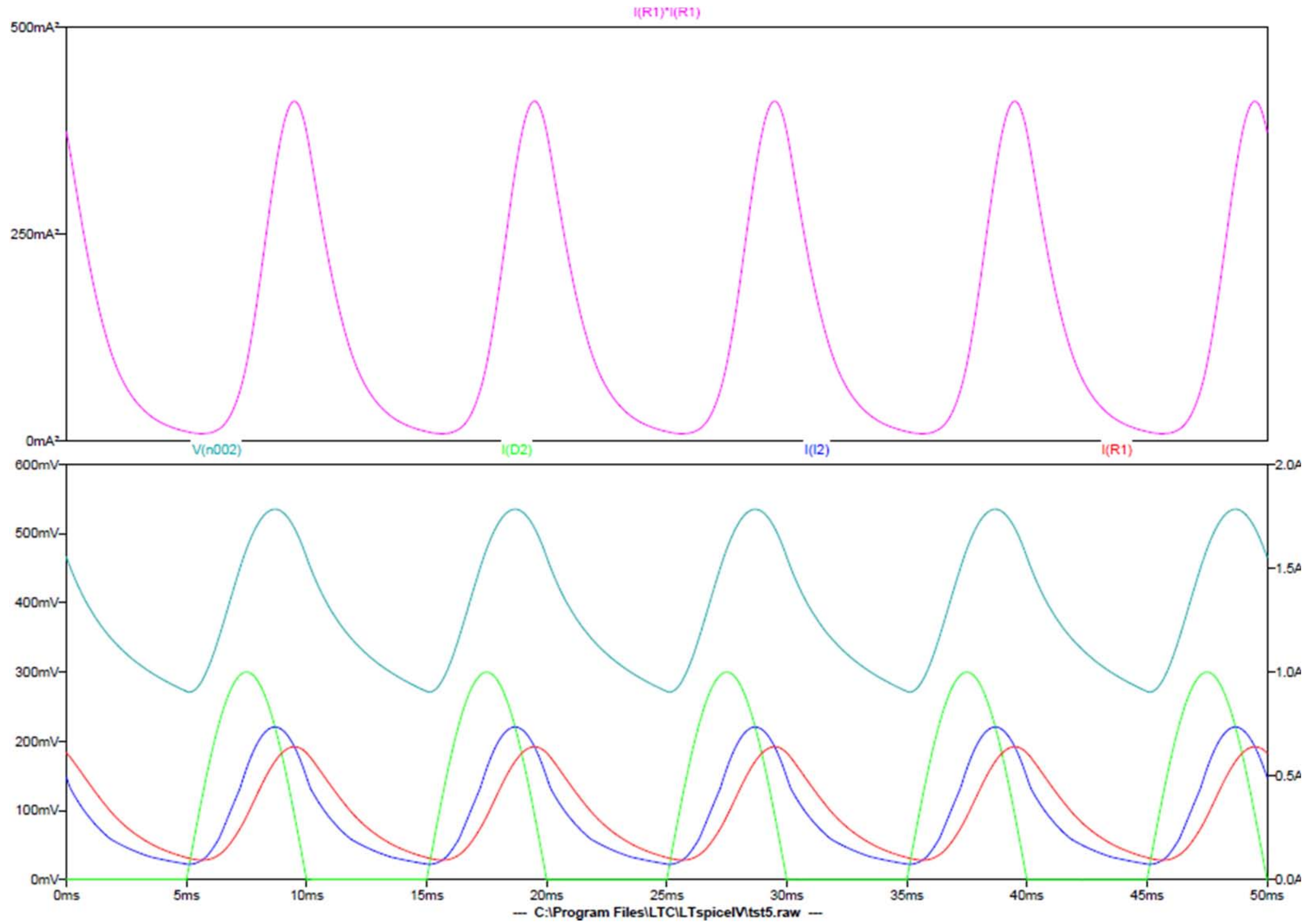
Conventional T/R, 1:1 operation
T=10 ms (10^{11} Ωcm)



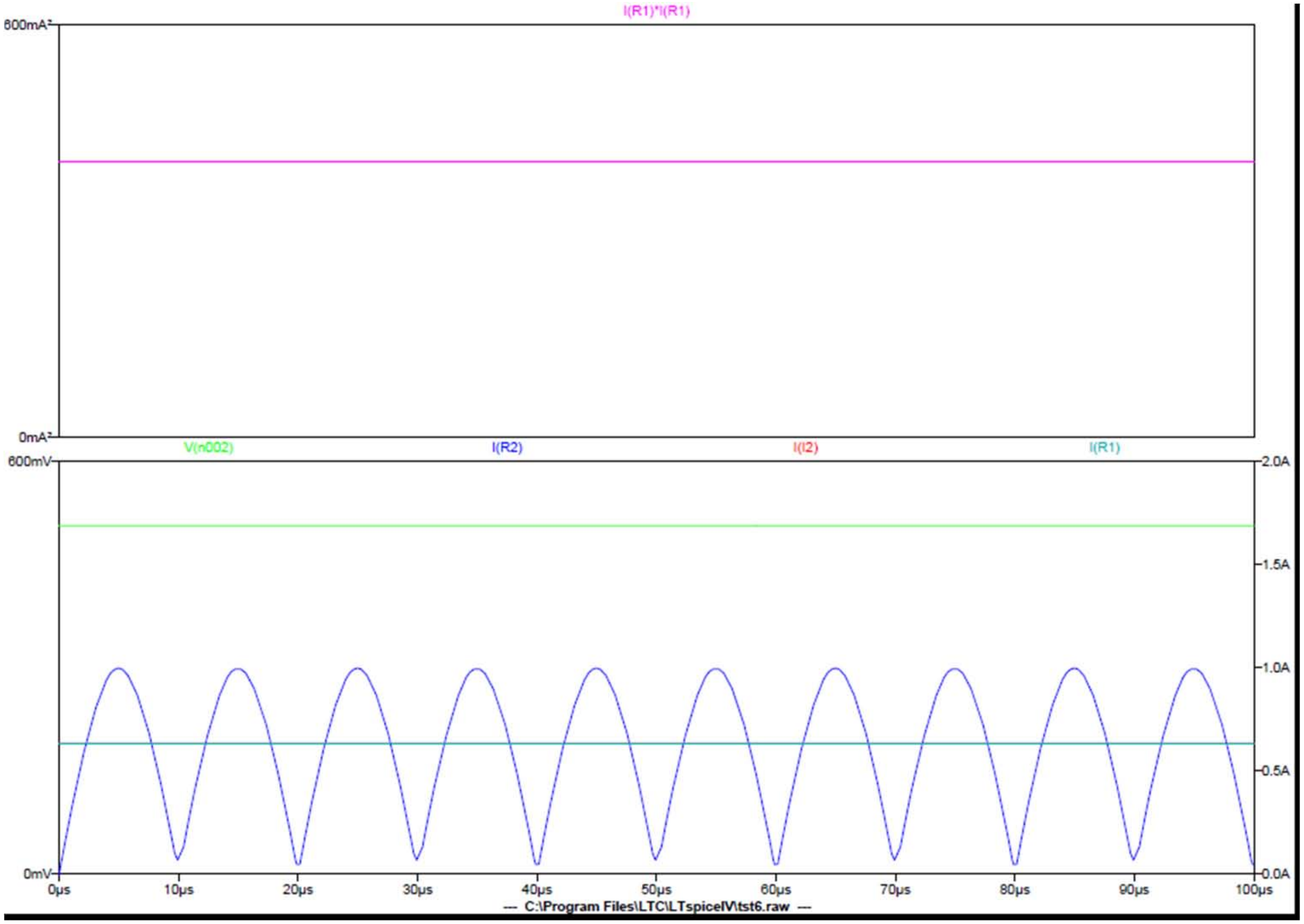
Conventional T/R, 1:1 operation
T=1 ms (10^{10} Ωcm)



Conventional T/R, 1:1 operation
T=0.01 ms (10^8 Ωcm)



HFPS, continuous current operation *T*=0.01 ms (10^8 Ωcm)



Time variations of current, spark recovery

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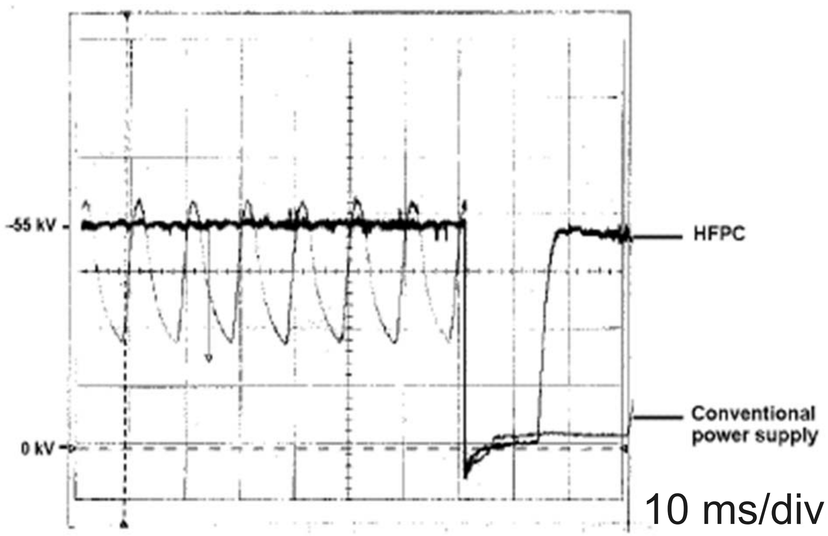
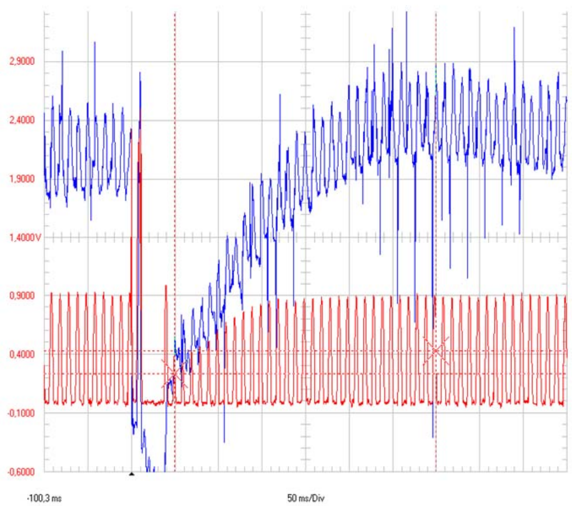


10 ms/div



50 ms/div

HFPS may have a shorter blocking time, no 50/60 Hz dependency

Superior bandwith of the control loop (faster) enables improved spark recovery.

Time variations of holding forces, means to minimize reentrainment

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- Simulations indicate risk of reentrainment
  Low and Medium resistivity

- Low Voltage ripple

- Spark over control
  - Minimize blocking time
  - Optimize voltage recover

Topics

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HFPS vs. Conventional T/R
Electrical Performance – Output Voltage

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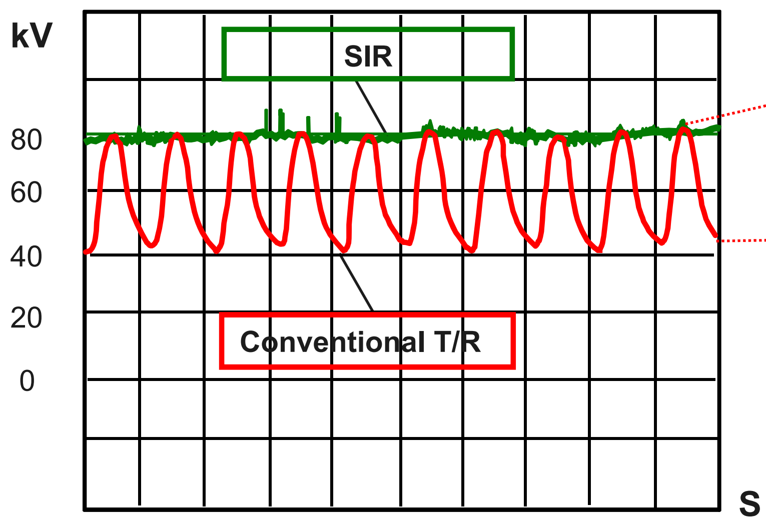
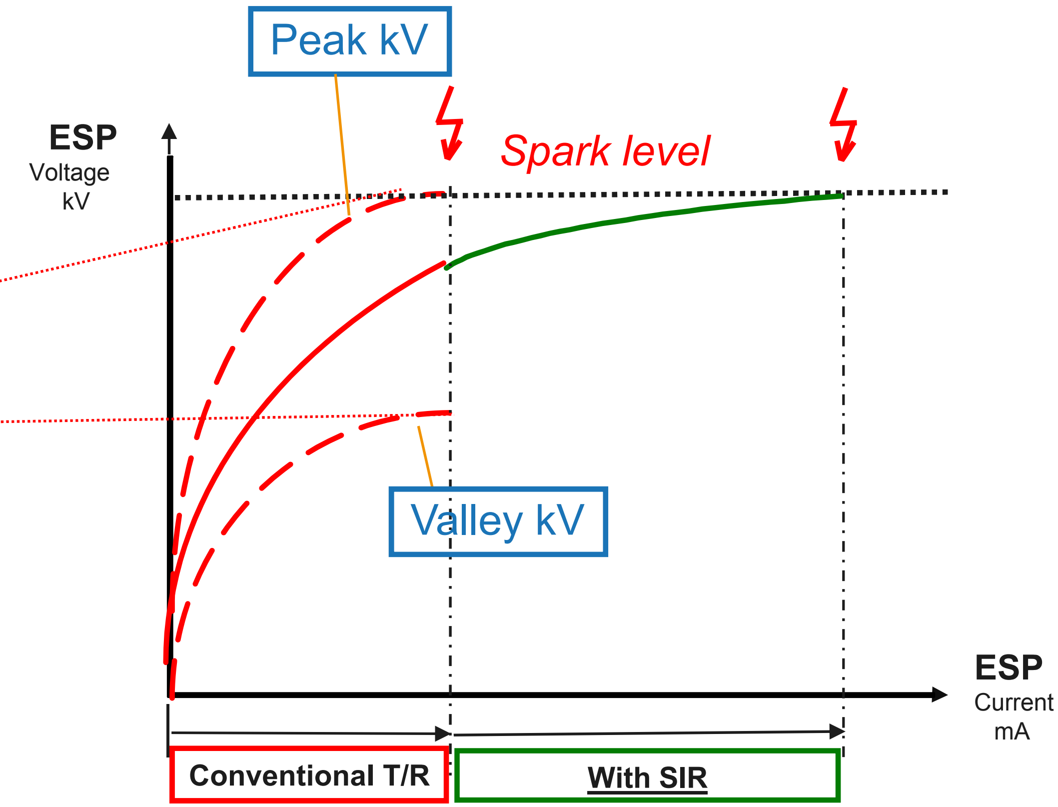
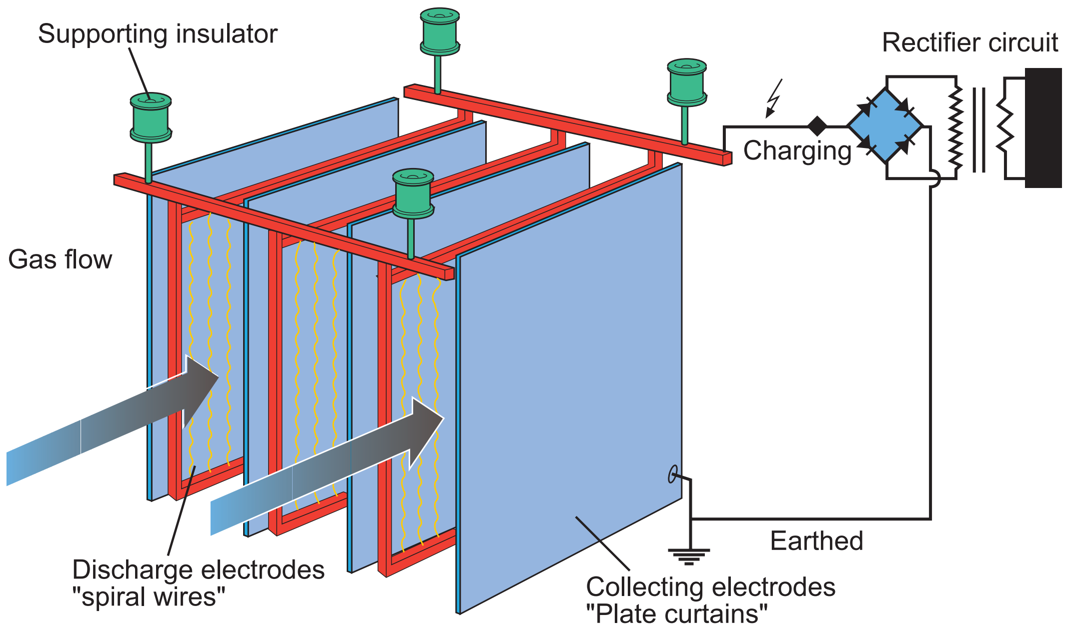




Test system set-up, Air load



Collecting Area:
A = 50 m^2

Electrode spacing:
D=400 mm

Discharge electrode:
Spiral (30/2,7)

Power Supply:
T/R set (ADOR)
HFPS (SIR)

External voltage sensor:
Wide Bandwidth Volt.Div.
15 MHz (Ross Eng.)

Oscilloscope:
Tektronix, DSO
500 MHz, 4 ch

HFPS vs. Conventional T/R Comparison – Output Voltage

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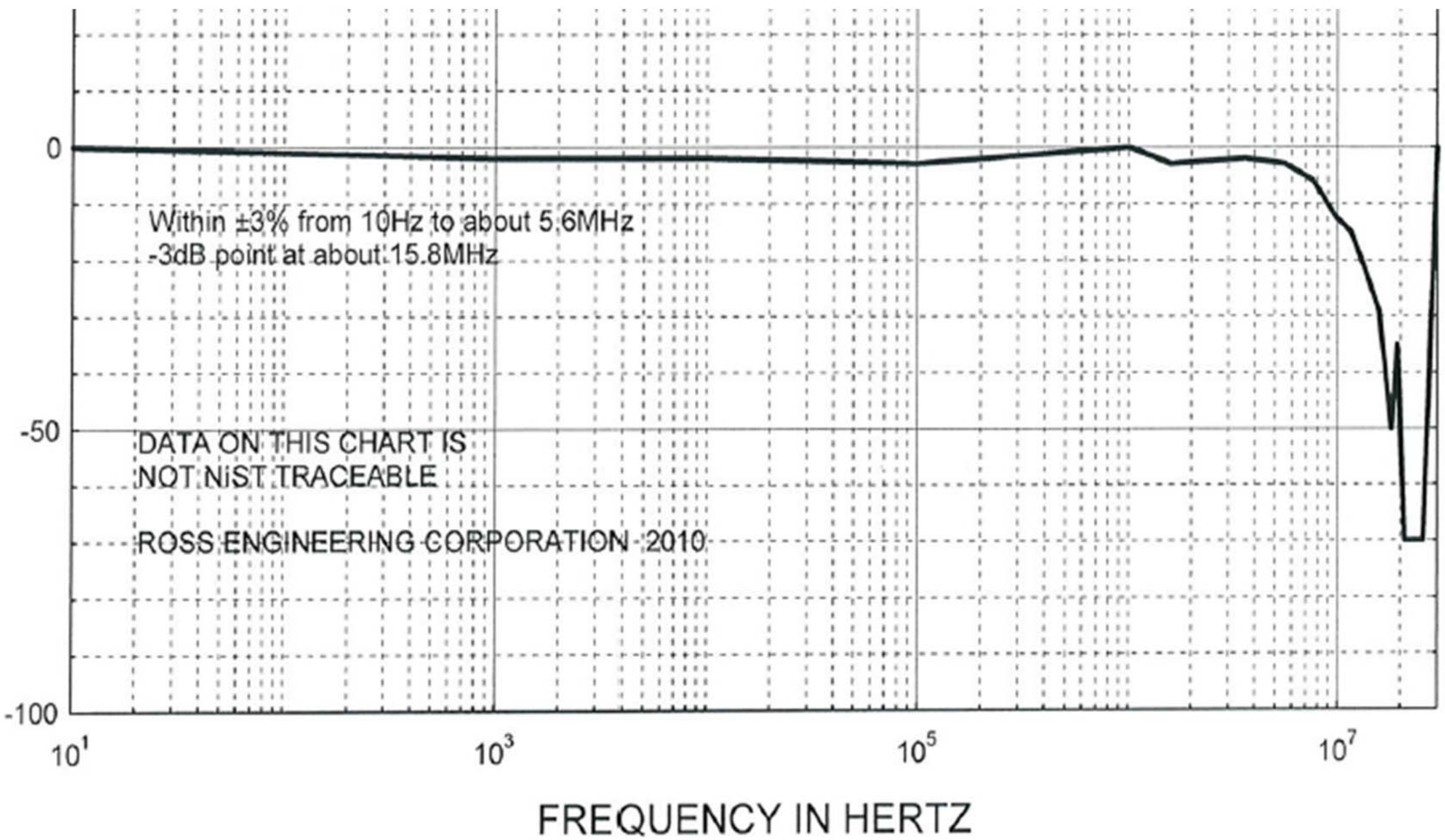
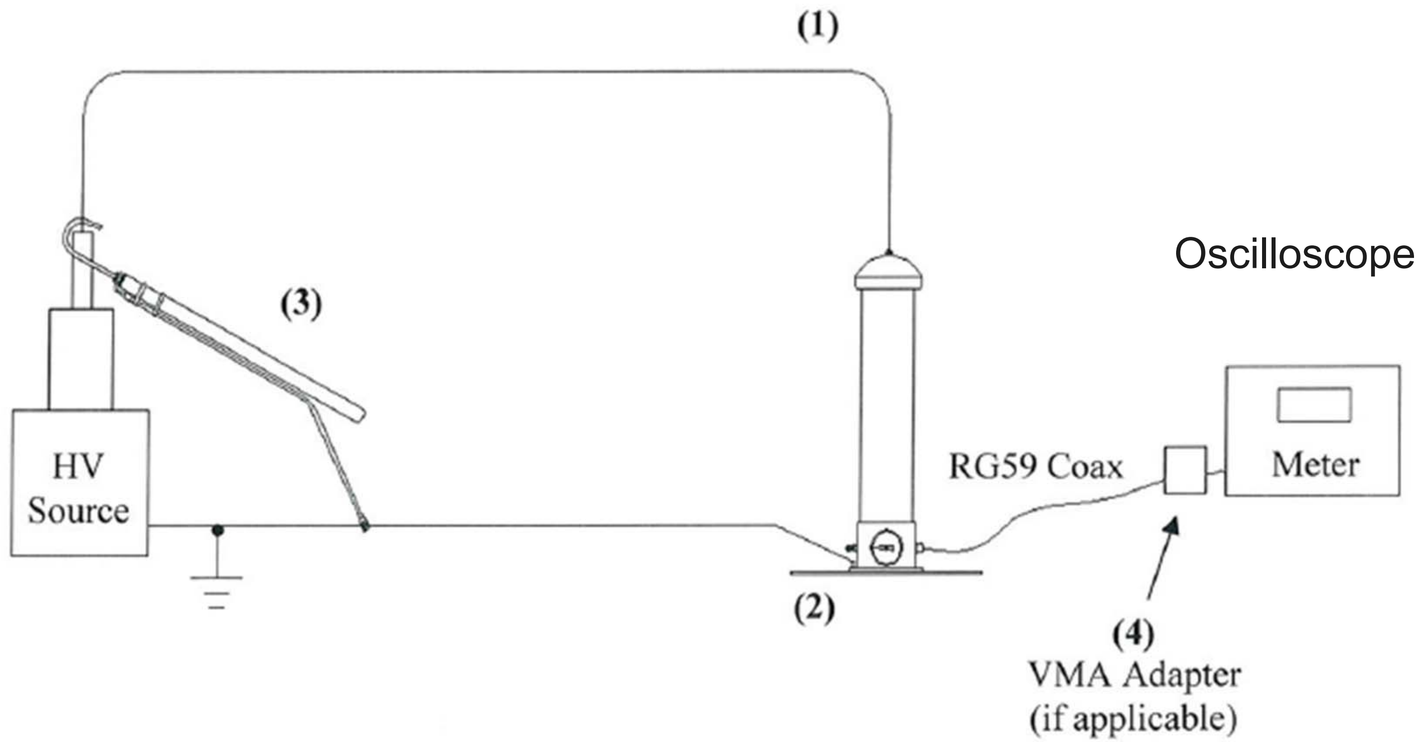


(Extract from manual)

External sensor, set-up



(Extract from manual)

Conventional T/R, 1:1 operation
I=50 mA, 25 mA, external sensors

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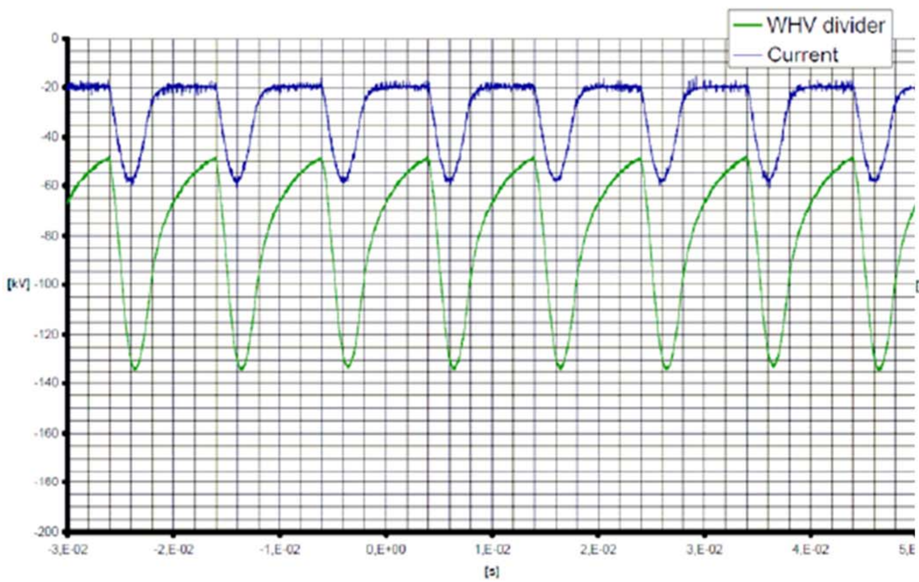
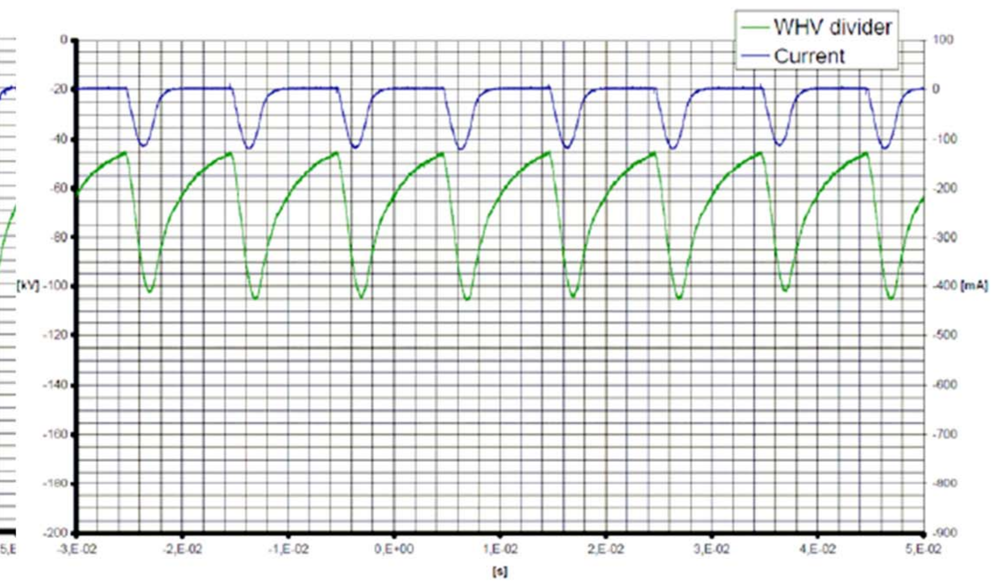
50 mA (1 mA/m²)



25 mA (0,5mA/m²)



20 kV/div, 100 mA/div,
10 ms/div

Conventional T/R, 1:1, 1:3
T/R signal vs External sensor

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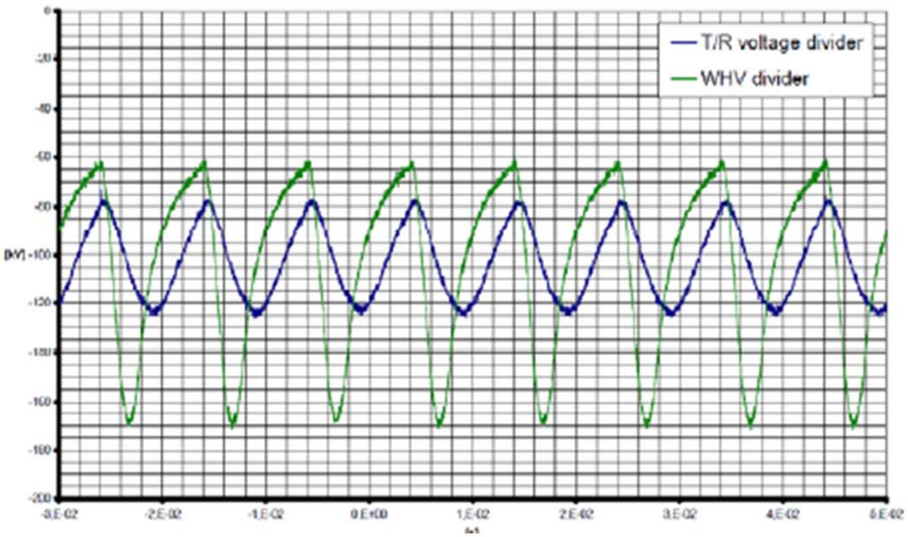
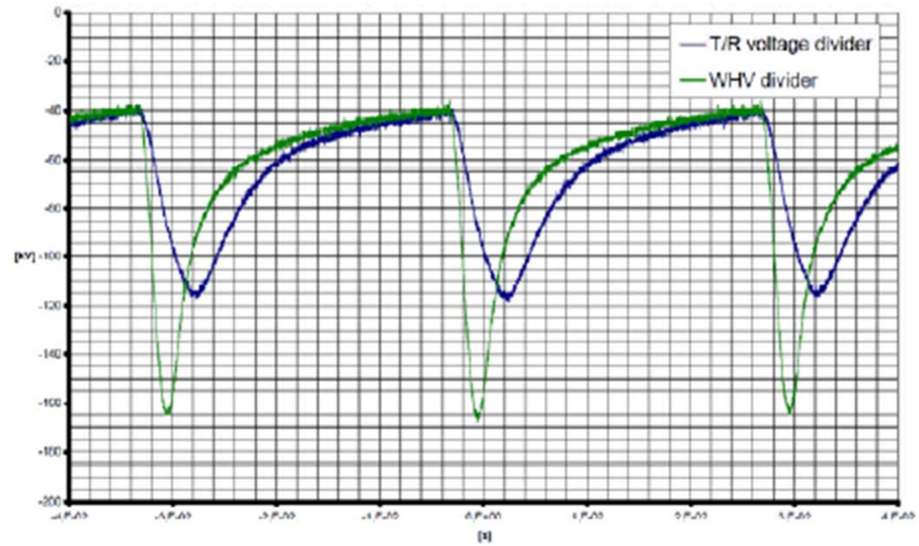
1:1



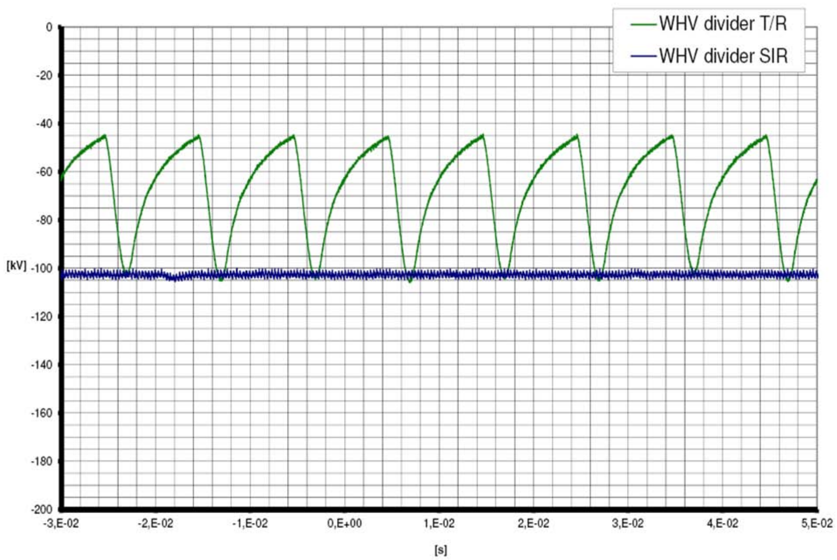
1:3

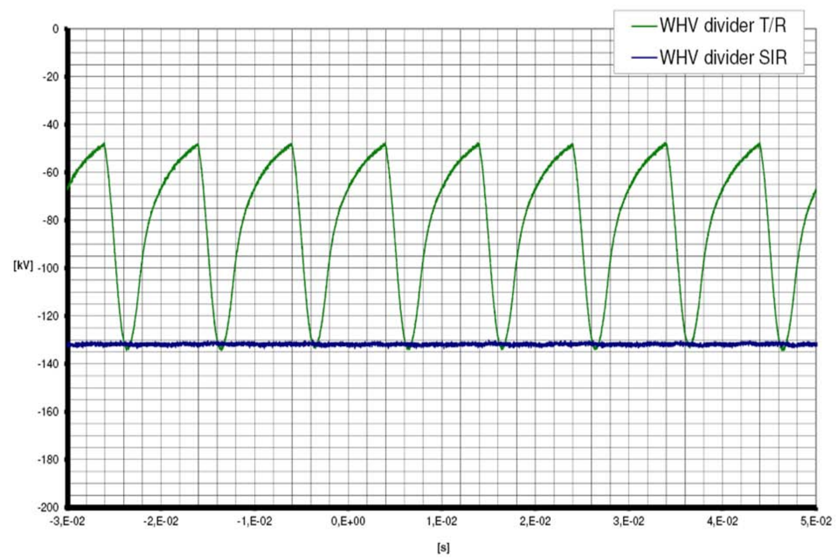


20 kV/div, 10 ms/div

HFPS vs. Conventional T/R
Same peak voltage

Conventional T/R:	25 mA	Conventional T/R:	50 mA
HFPS:	75 mA	HFPS:	150 mA





20 kV/div, 10 ms/div

HFPS vs. Conventional T/R
Same current (average), 50 mA

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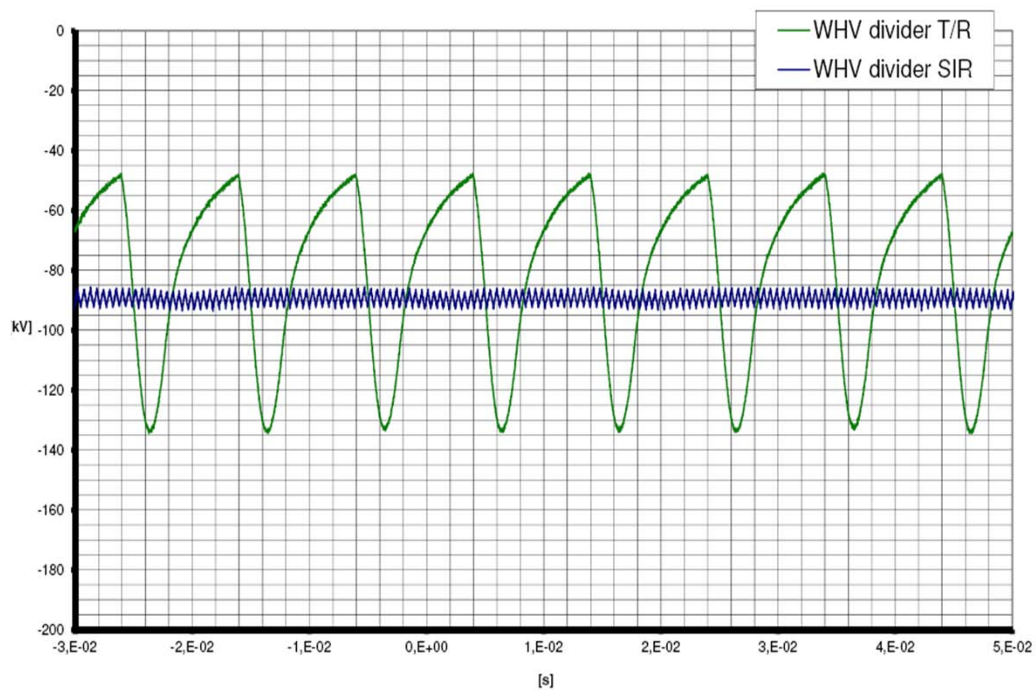
Conventional T/R: 80 kV_{AVG}

HFPS: 90 kV_{AVG}



20 kV/div, 10 ms/div

HFPS vs. Conventional T/R Comparison – Spark recovery

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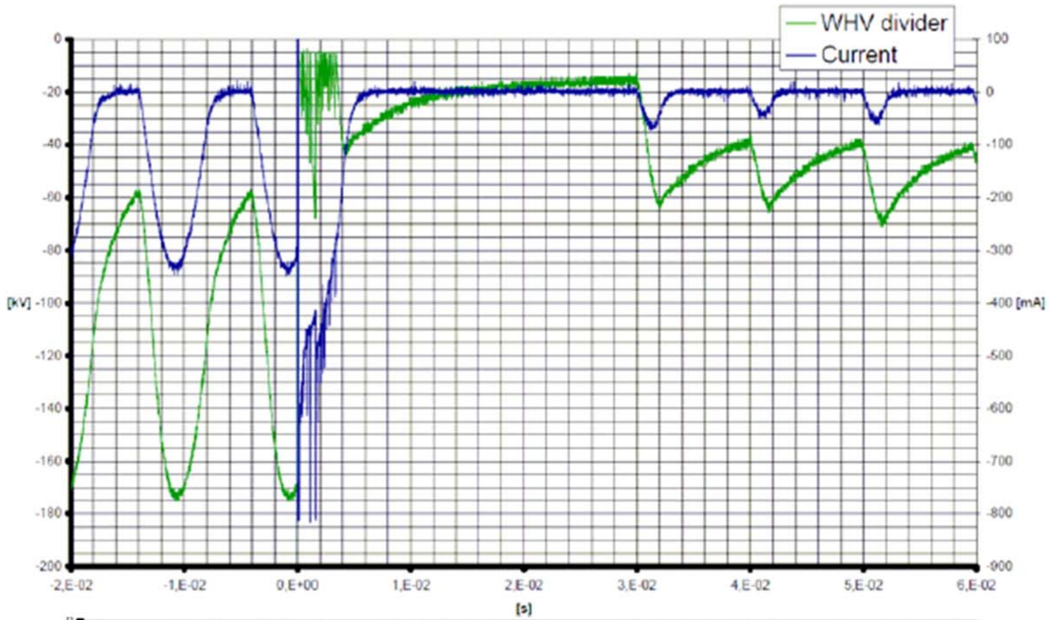
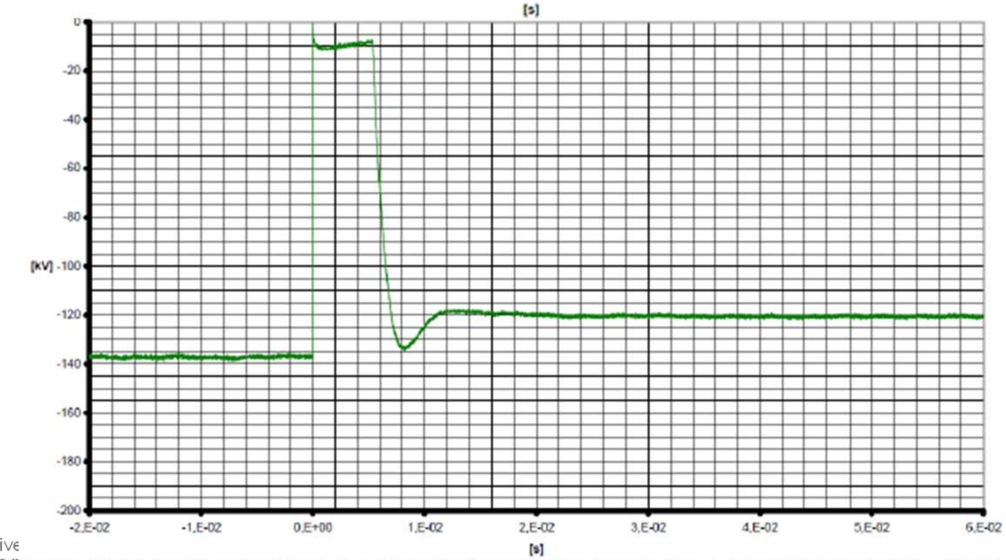
Conventional T/R



HFPS



20 kV/div, 10 ms/div

High voltage measurements

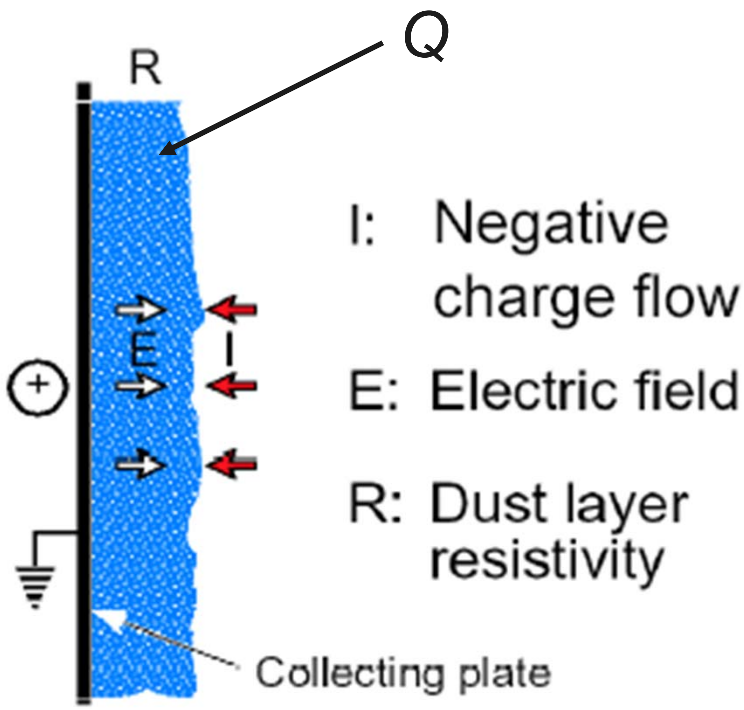
- For precise measurement use
  Wide Bandwidth Voltage Dividers

- Peak voltage may be higher than expected

Topics

- *Introduction*
- *Holding forces, variations in time*
- *High voltage measurements*
- ***Resistivity control by means of Power Control Rapping***
- *Summary*

Dust layer, electrostatics



$F = Q\,E$

$E = j\,\rho$

$\Rightarrow F = Q\,j\,\rho$

F *Force*, [N]
Q *Charge*, [C, (As)]
E *Field strength*, [V/m]
j *Current density*, [A/m^2]
ρ *Dust layer resistivity*, [Ωm]

Strategy

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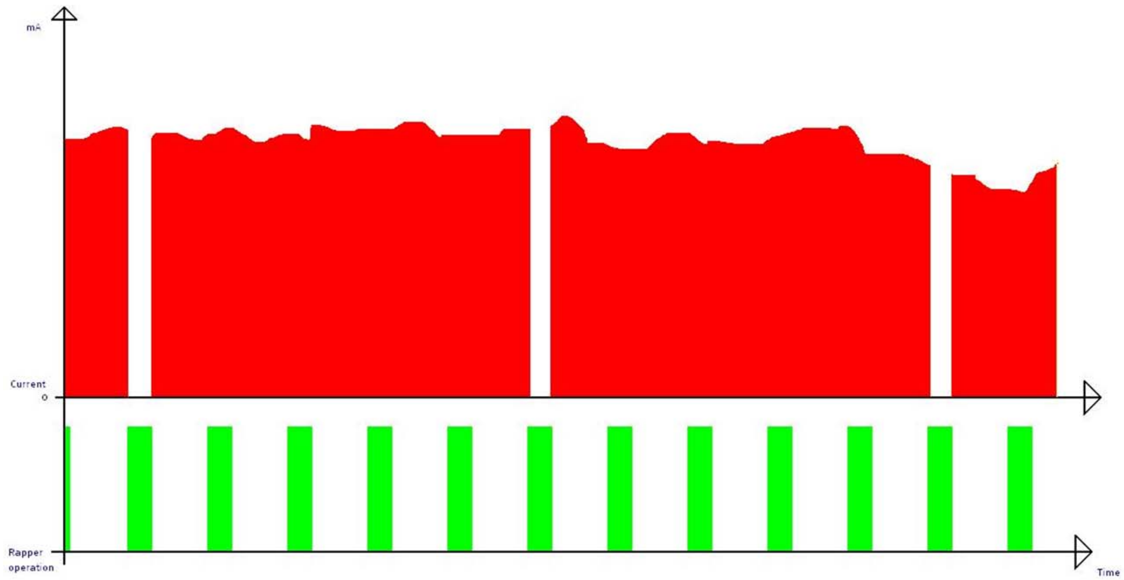
Power Control Rapping

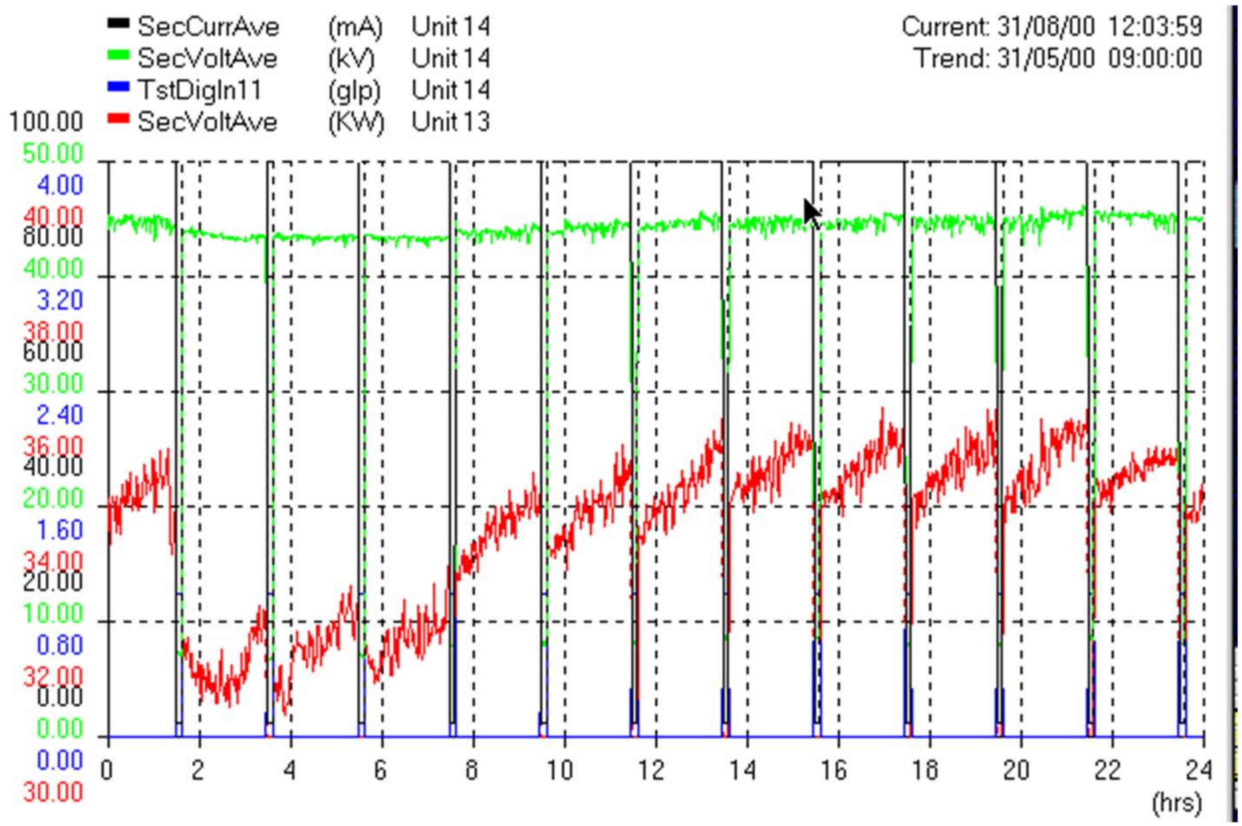
- Reduces electrical holding forces
- Important at back-corona situations where accumulation of high resistivity dust over time increases the dust difficulty
- Normally PCR is not necessary every cycle. Often every 5 (difficult) or less frequent is enough
- Preferably do exit field PCR at night when ambient temperature impact is low and boiler load is low
- If the control system is upgraded for more power, the need for PCR will be more likely, i.e. SIR.

Power Control Rapping



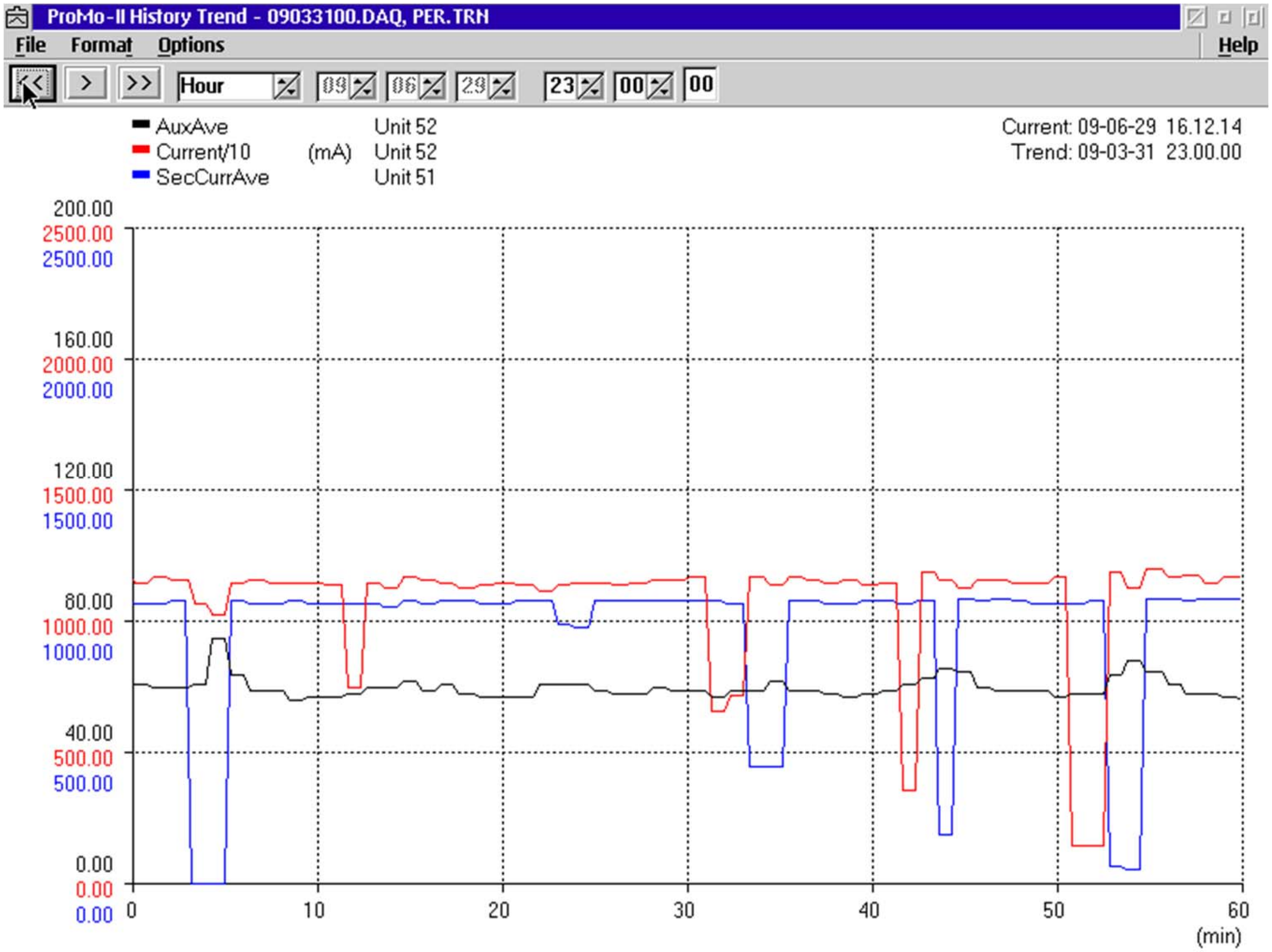
- Red is secondary current. Green is rapper operation. mA drop is PCR

Tuning Rappers-PCR

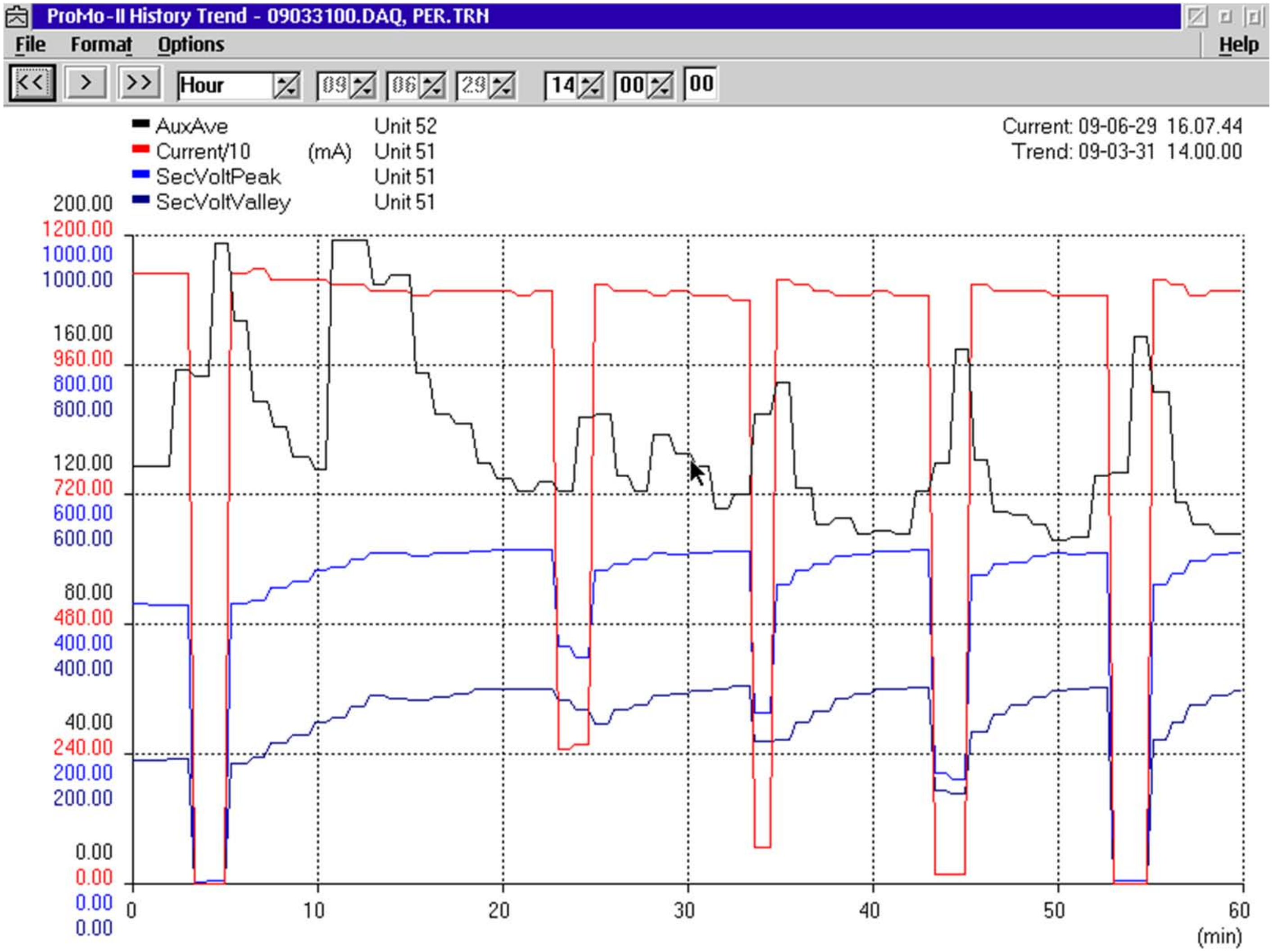


- **Note the drop in kV after PCR every two hours. This is a second field and this drop is a good**
- **Sign of working Power Control Rapping**

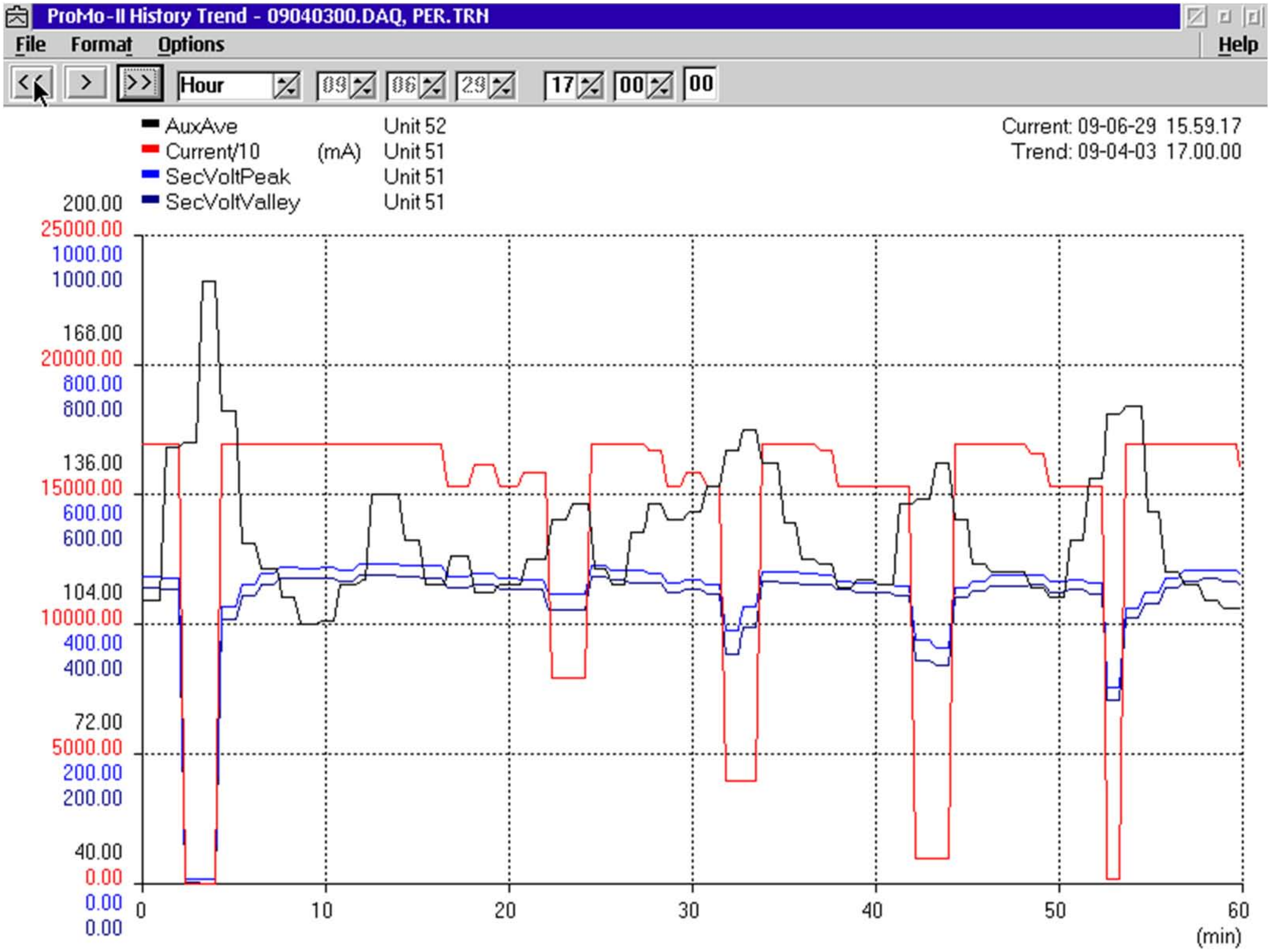
PCR Rapping sequence



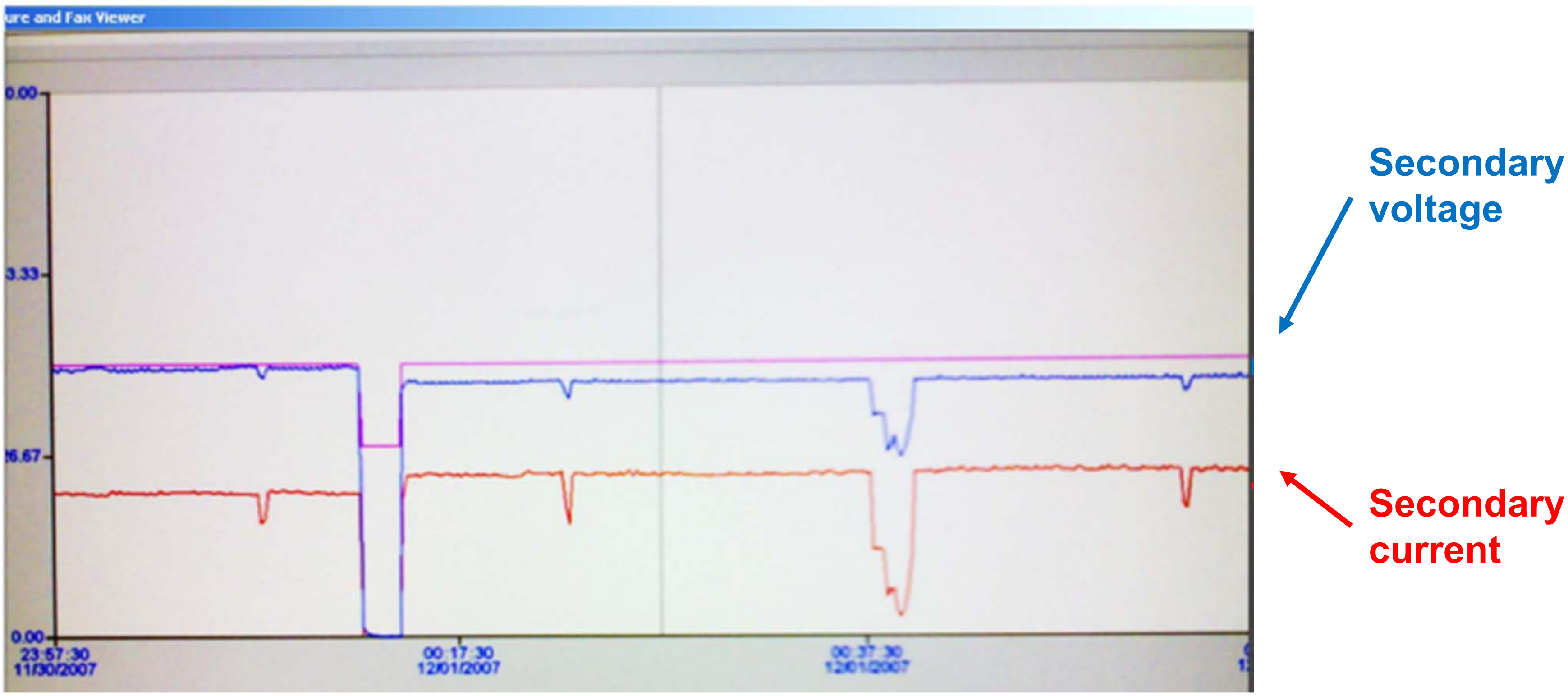
PCR Rapping sequence



PCR Rapping sequence



PCR with EPOQ optimization



Topics

- *Introduction*
- *Holding forces, variations in time*
- *High voltage measurements*
- *Resistivity control by means of Power Control Rapping*
- ***Summary***

Summary

- Low resistivity calls for higher current, $F=Q \cdot j \cdot \rho$
- Time variation of Corona current
  Risk of reentrainment for
  Low and Medium resistivity ash
- Use external voltage sensors for
  precise measurements
- Back Corona is influenced by rapping sequence
  Improved operation at high resistivity with PCR

Thanks for your attention !

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