Institute of Energy Technology
Dept. of Power Systems and High Voltage

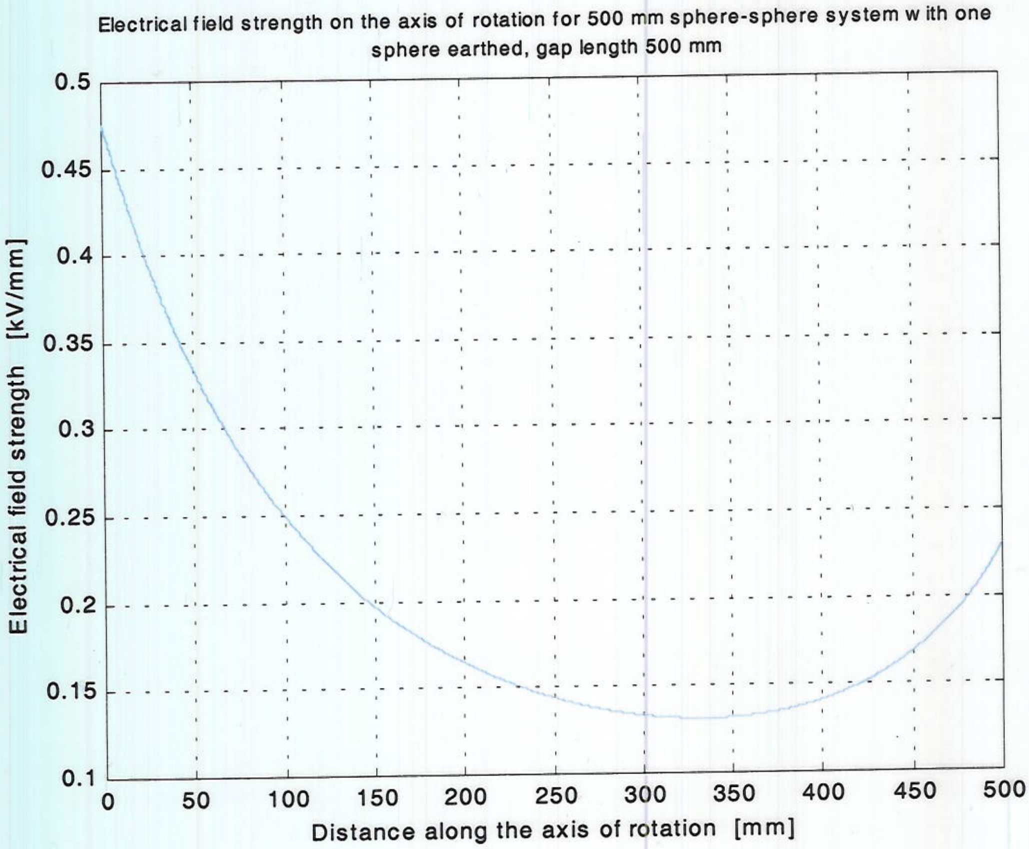
● Partial discharges

The impressing of a voltage to an insulating system will give rise to an electrostatic field. The field strength E will be determined solely by the geometry of the electrode system.

The E-field distribution is three-dimensional and given by:

$$\vec{E} = -grad(\varphi) = -\nabla\varphi = -\left[\frac{\partial\varphi}{\partial x} + \frac{\partial\varphi}{\partial y} + \frac{\partial\varphi}{\partial z}\right]$$

For a sphere gap (one sphere grounded) gives:



Several parameters decides whether one of the following happens:

✘ A noncomplete (partial) breakdown occurs = partial discharge

✚ or a complete breakdown = destruction of the insulating media forming a conductive channel with a “small” resistance.

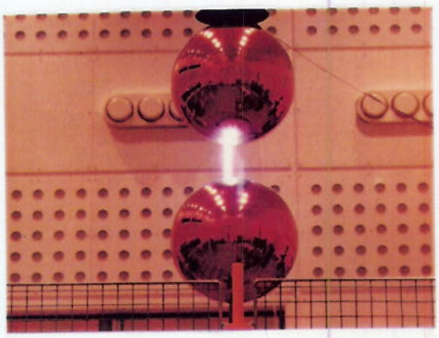
Depending of the energy content and power (short circuit power) of the supplying source this breakdown can give rise to:

- An electric arc which is a high-temperature discharge using thermoionisation of the electrode(s) as a source for the production of free, movable charge. The arc will burn steadily until it is extinguished by means of electromagnetics and/or mechanical way.

- A cold discharge which will extinguish when all energy (initially a small amount) has been discharged. Gaseous dielectrics will restore their insulating properties.

Parameters affecting the above are:

- Electrode geometry (inhomogeneous field, boundaries etc.)
- Insulating media (gas, liquid or solid)
- Surface of the electrodes (roughness)
- Voltage waveform (AC, DC, polarity, impulse)



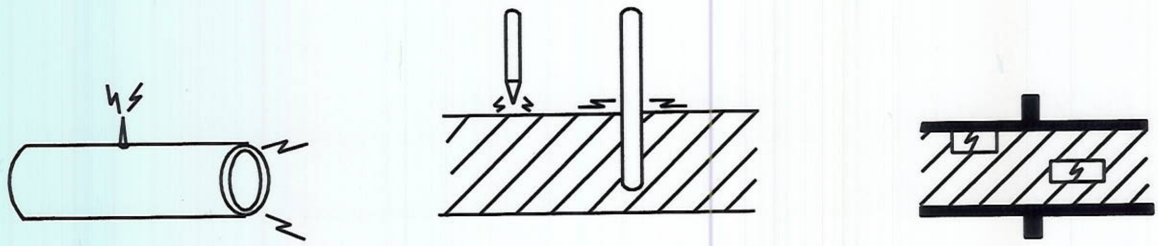
Overslag i 400 mm gnistgab mellem 500 mm kugler. 84

● Partial discharges - Definitions

Partial discharges can be defined as discharges only partially short circuiting an insulating media between two electrodes with a different potential.

Partial discharges can be subdivided into the following three cathegories:

- Internal discharges
- Surface discharges
- Corona



Corona Surface discharges Internal discharges

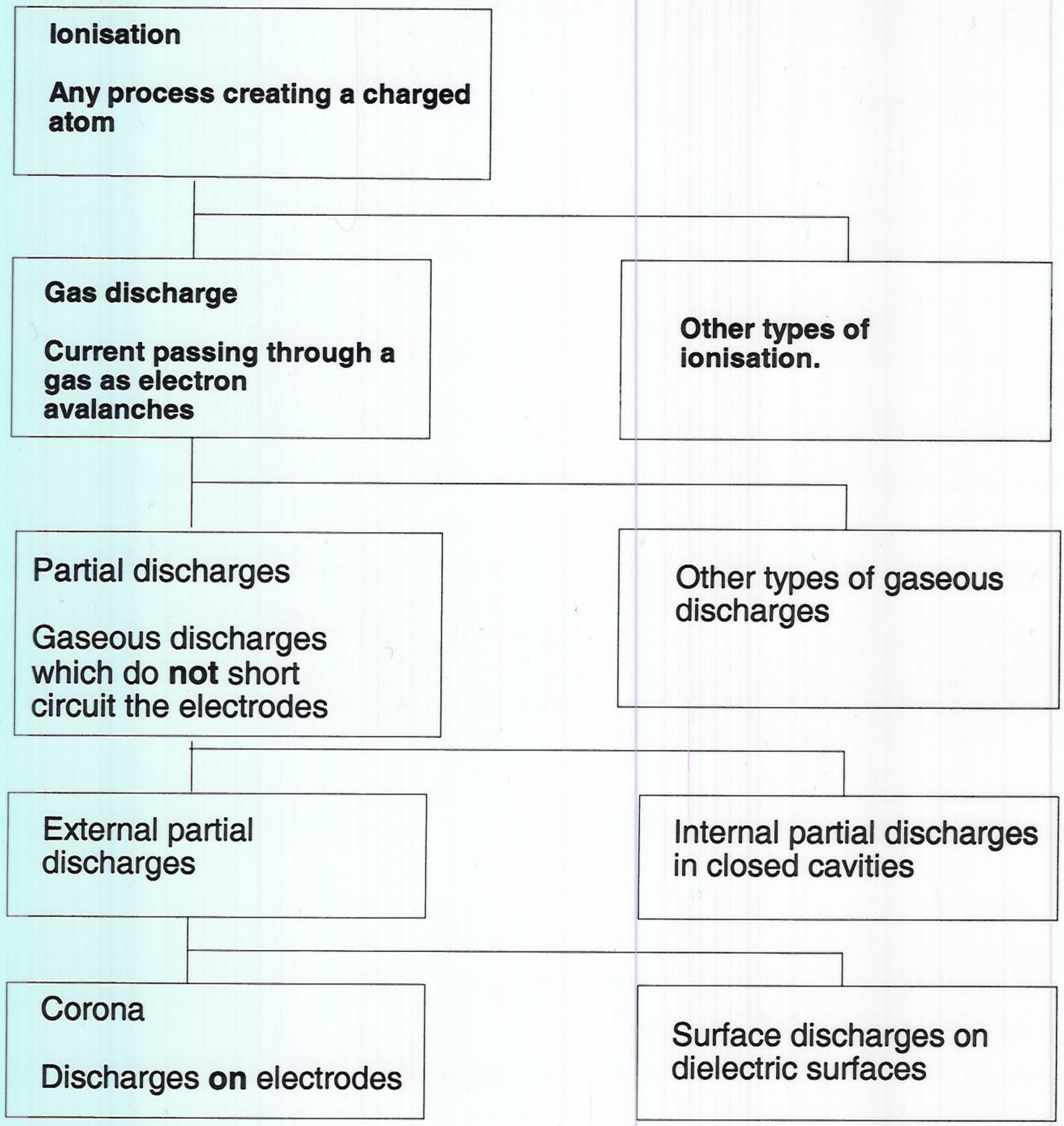
Types of partial discharges

- **Corona** is partial discharges in an inhomogeneous field (macroscopic or microscopic) in a gaseous dielectric. Example: Corona on overhead power lines.

- **Surface discharges** are partial discharges in boundaries between different dielectrics such as: gas/solid, gas/oil, oil/solid etc. Example: The transition between the HV part and the moulded plastics of a surge arrester.

- Internal discharges are partial discharges in cavities in solid or liquid dielectrics. The cavities can be limited by parts of electrodes. The cavities will mostly contain the gas which was present at the time of manufacture. Example: Small blasters (cavities) in the moulded (extruded) polyethylene of a HV PEX-cable.

● Relations between the different kinds of ionisation



● External partial discharges

- External partial discharges occurs on HV overhead power lines and is normally pronounced "Corona".

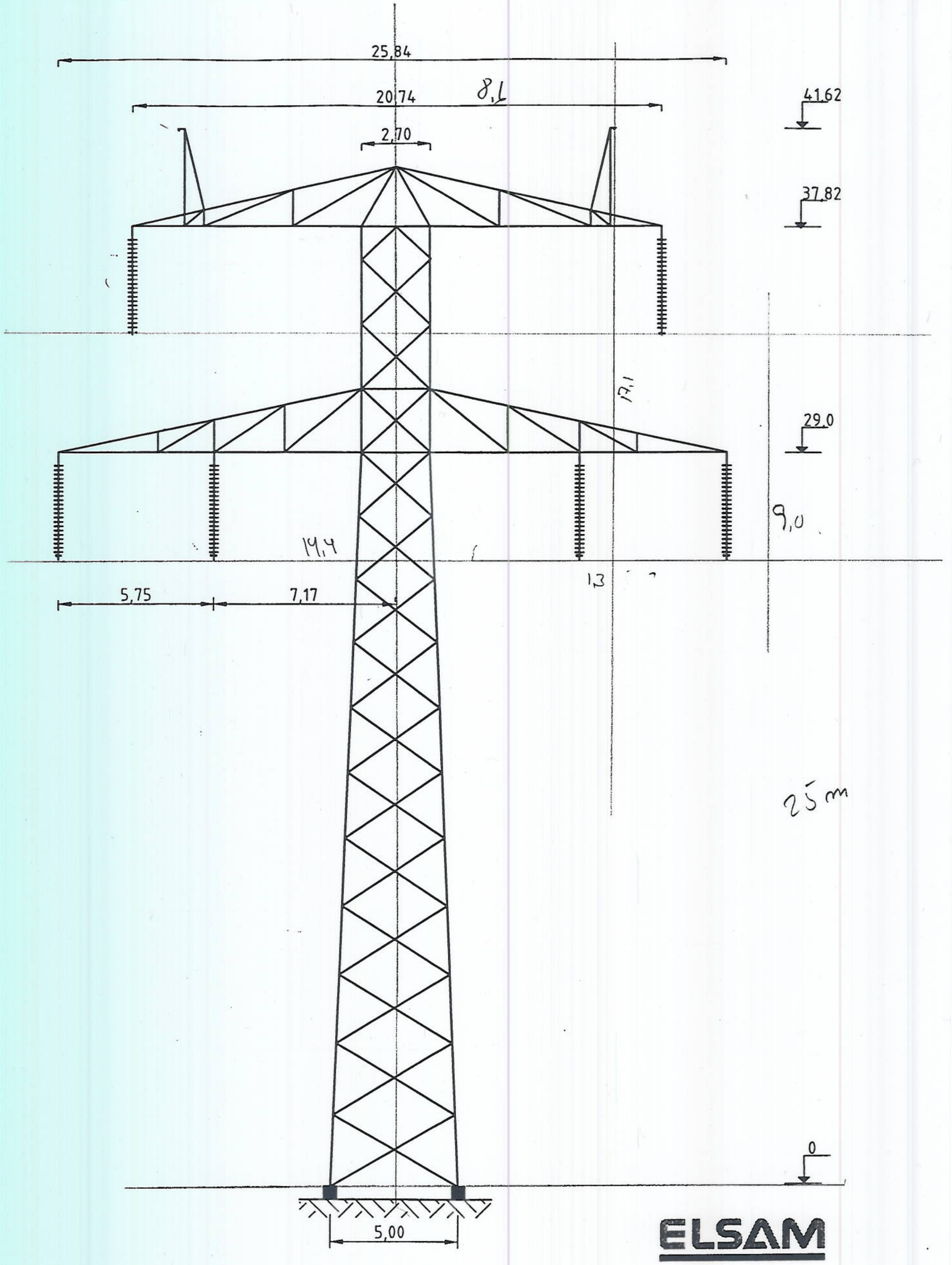
- The corona is caused locally by exceeding the critical field strength (for practical cases) of app. 12-15 kV/cm. This gives rise to elastic collission ionisation caused by accelerated charge carriers in the E-field.

- A state of corona uses energy ➜ corona losses

- The partial discharges of the corona around the the E-field stressed portion of the HV system will cause HF electromagnetic waves which causes radio interference. + AUDIBLE NOISE

- External partial discharges on an experimental setup disturbs the measurement of internal partial discharges. Test setups are optimized so they produced a minimum of corona.

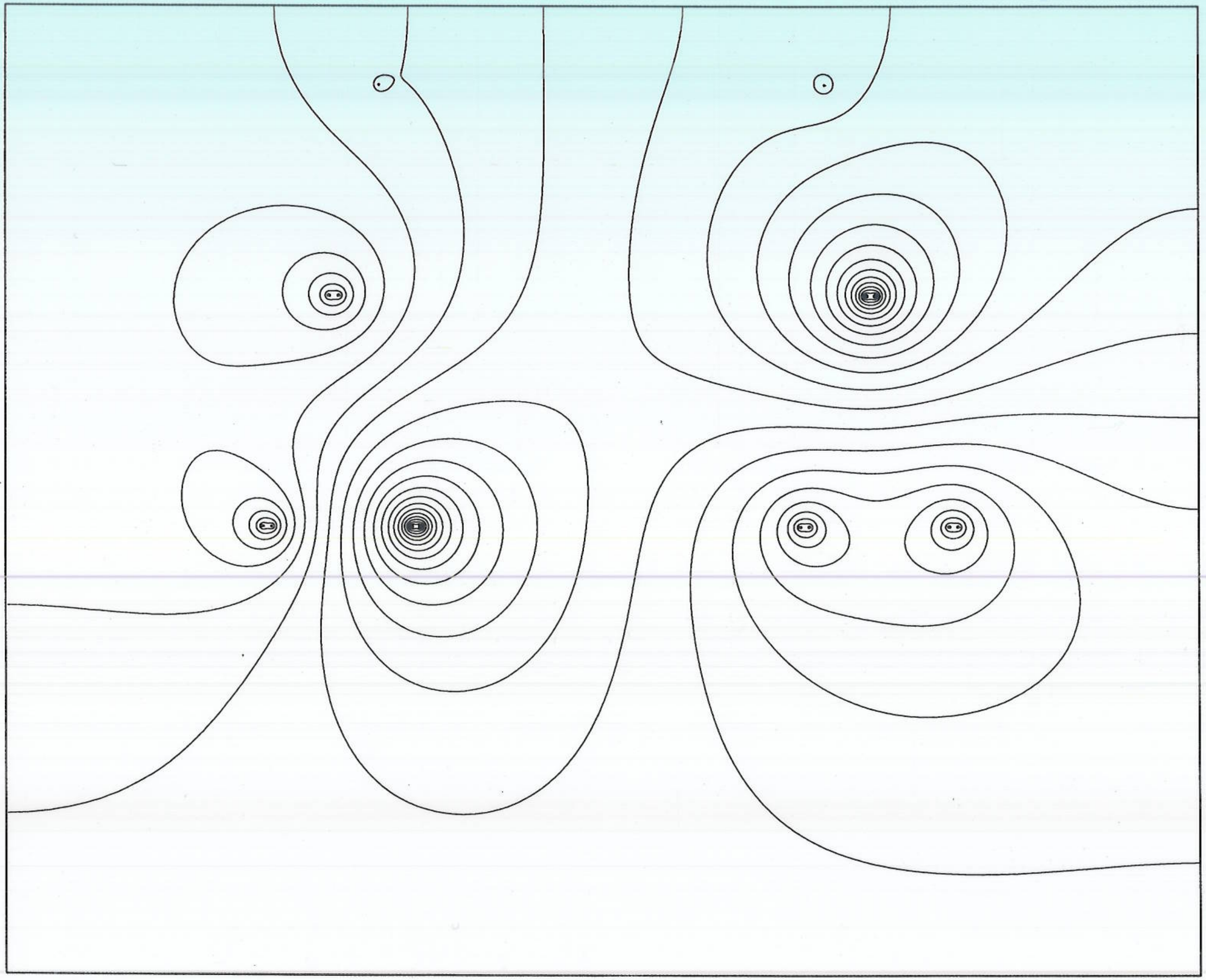
- Surface discharges in dielectric boundaries gaseous/liquid/solid will cause erosion of the insulation, which in long terms will cause a complete breakdown..

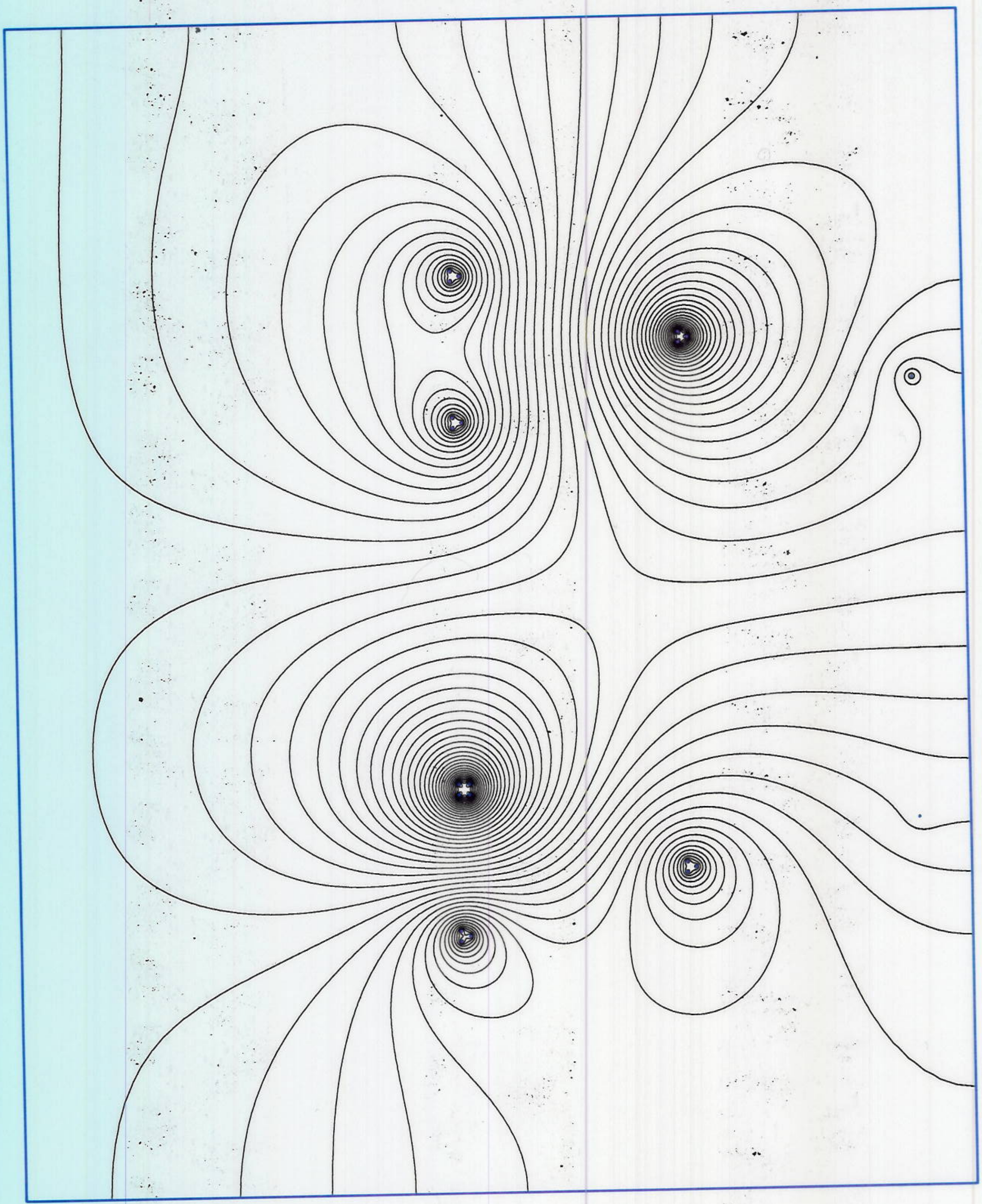


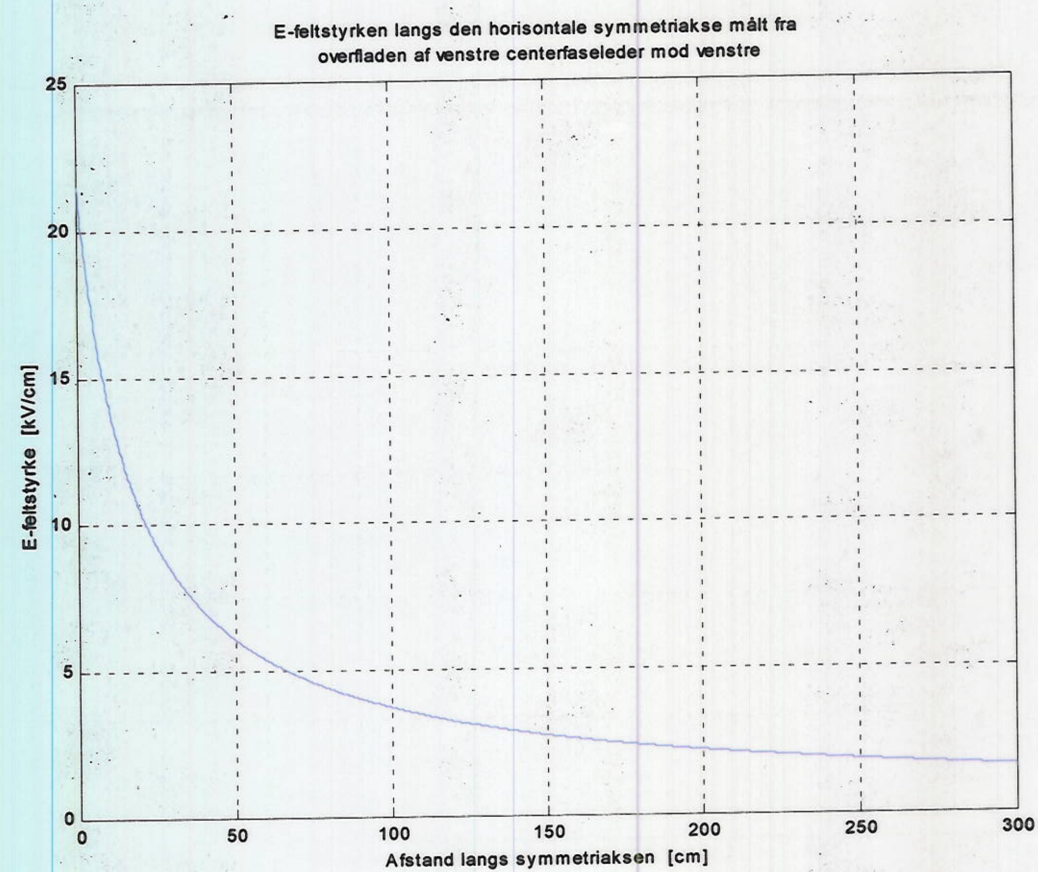
ELSAM

Donau bæremast
2 x 400 kV
Mål 1:200
D. 8.11.1996

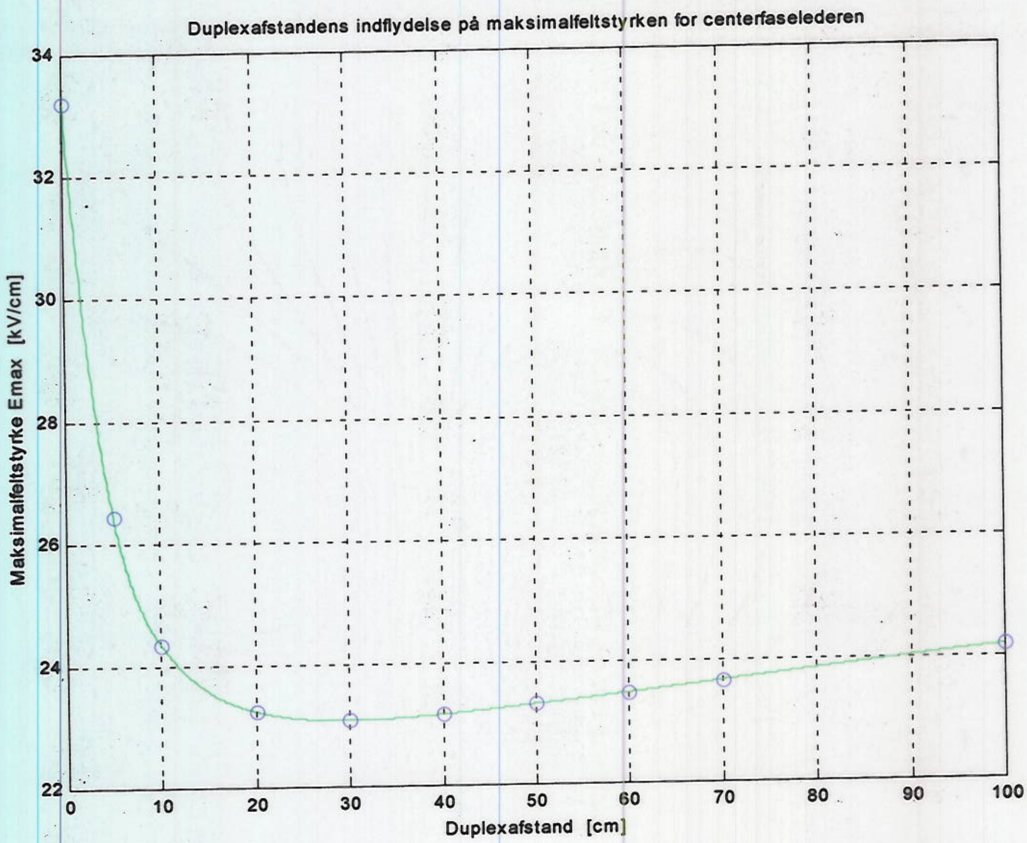
[illegible]



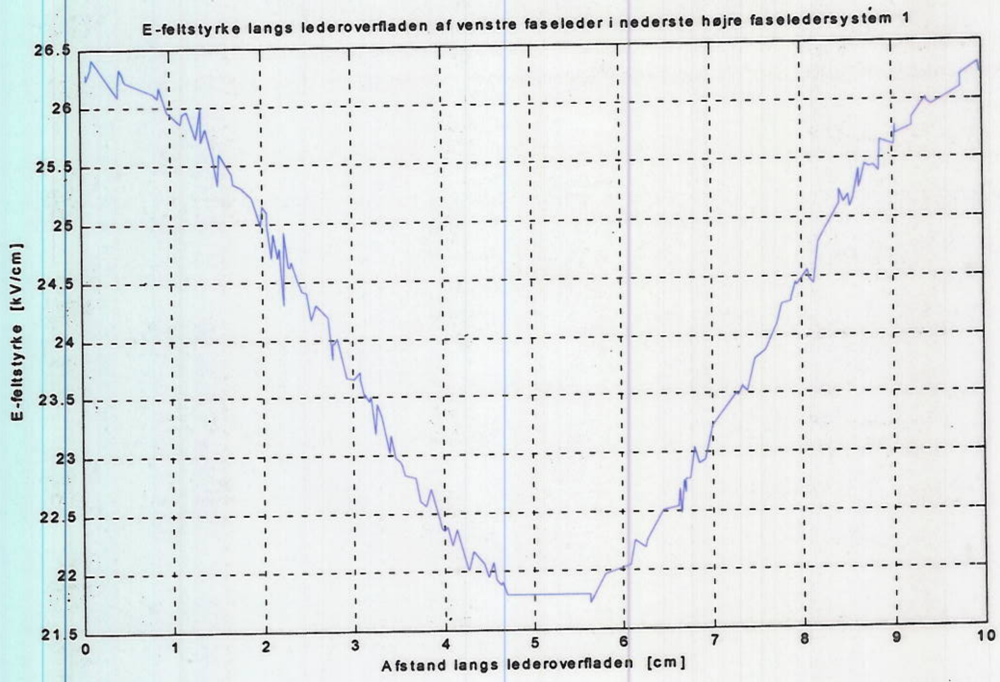




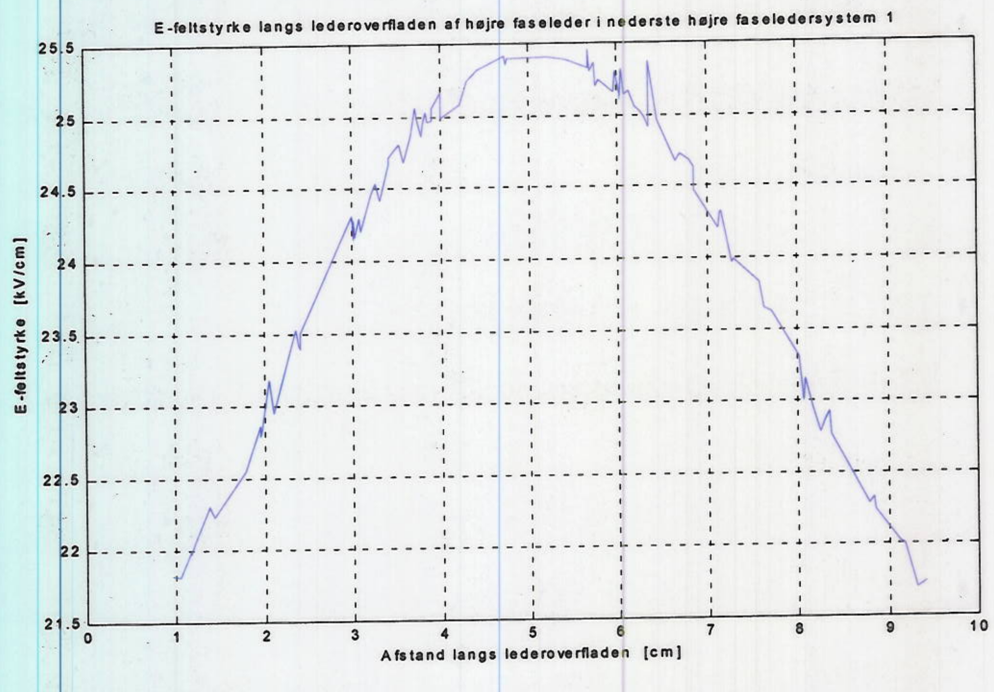
Figur 2 E-feltstyrkens afhængighed af stedkoordinaten nær fasælederoverfladen



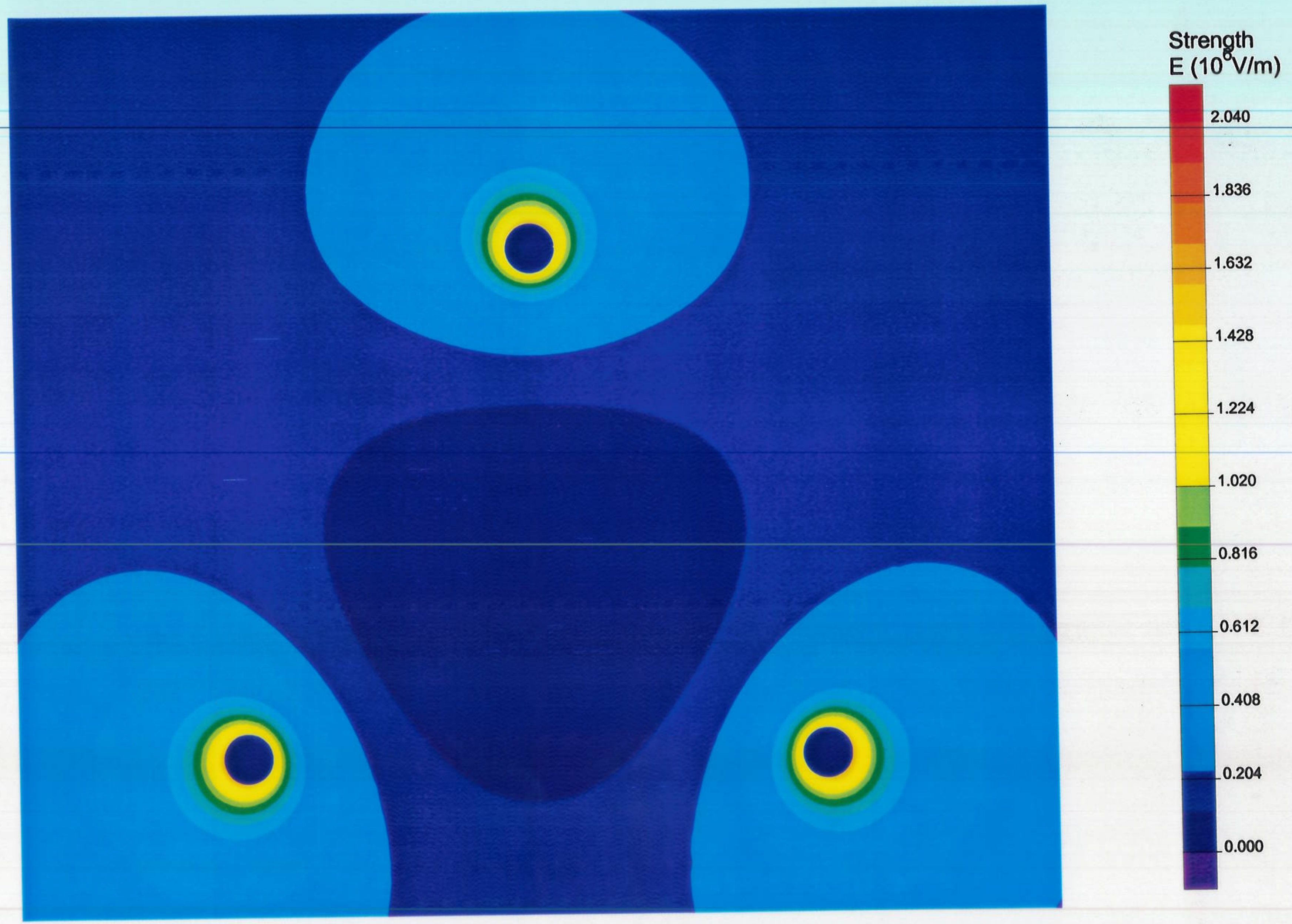
Figur 1 Duplexafstandens indflydelse på maksimalfeltstyrken for centerfaselederen for Eltra's 400 kV H-bæremast udstyret med FINCH faseledere.

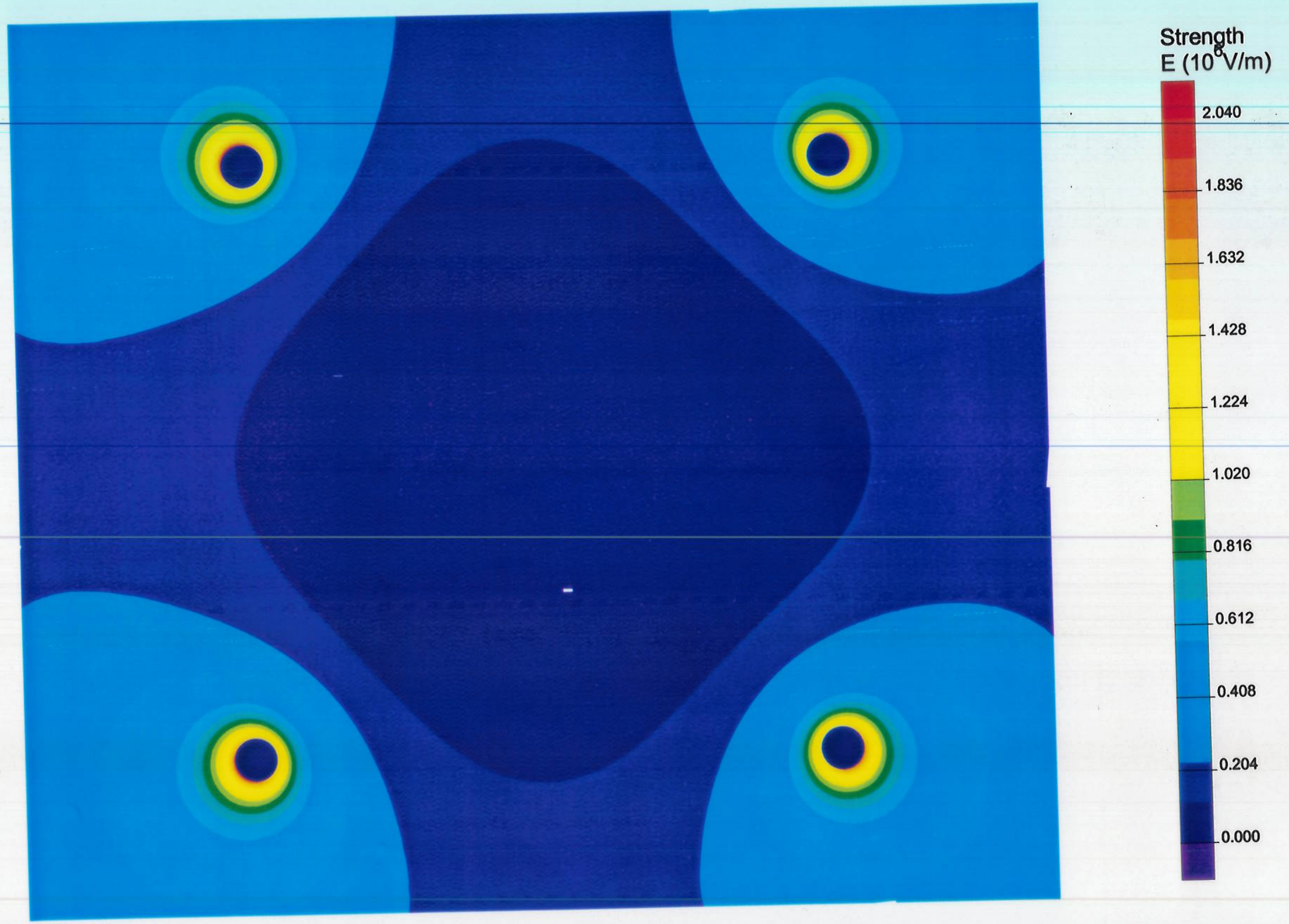


Figur 3 E-feltstyrke for donaumast med FINCH duplex faseledere, leder 2



Figur 4 E-feltstyrke for donaumast med FINCH duplex faseledere, leder 1


Strength
E (10^6 V/m)
2.040
1.836
1.632
1.428
1.224
1.020
0.816
0.612
0.408
0.204
0.000


Strength
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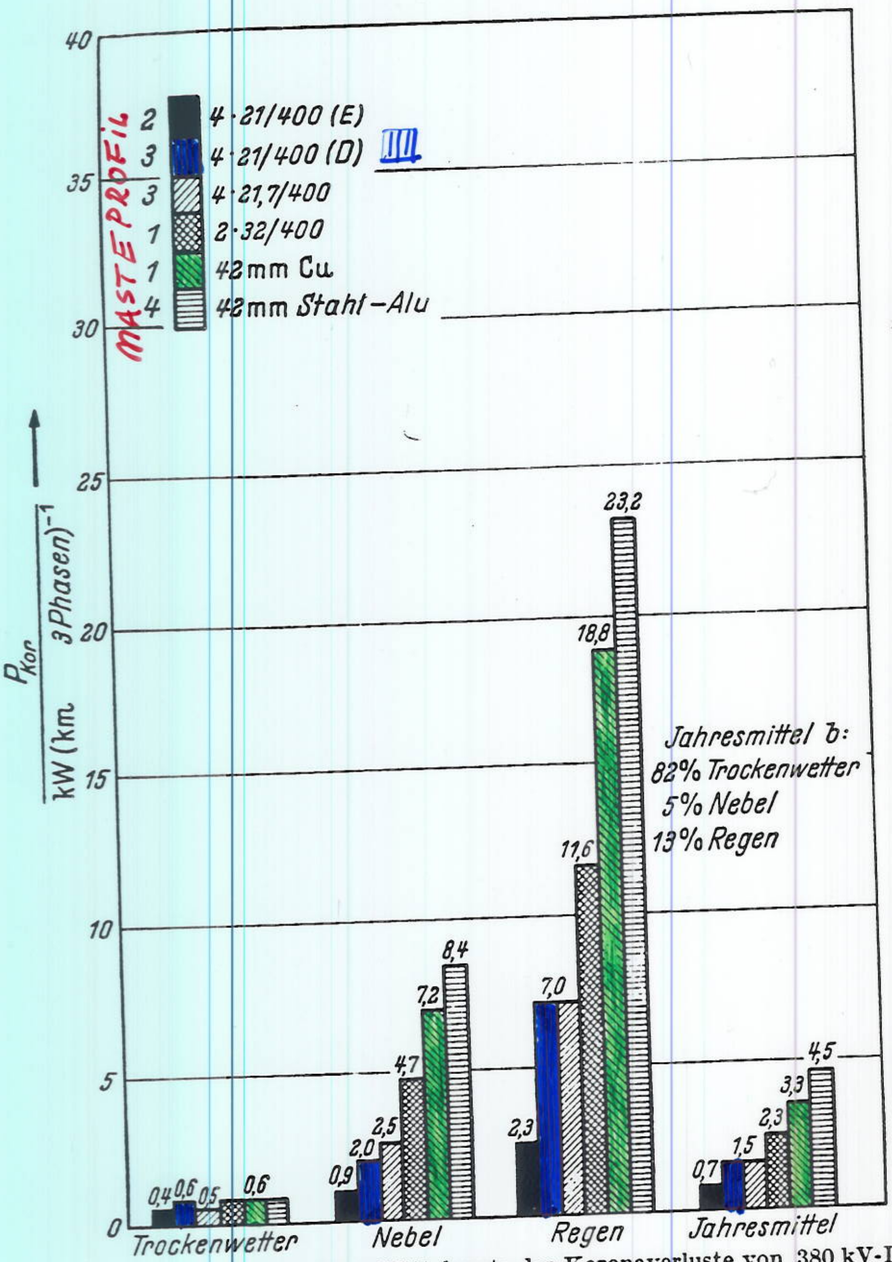

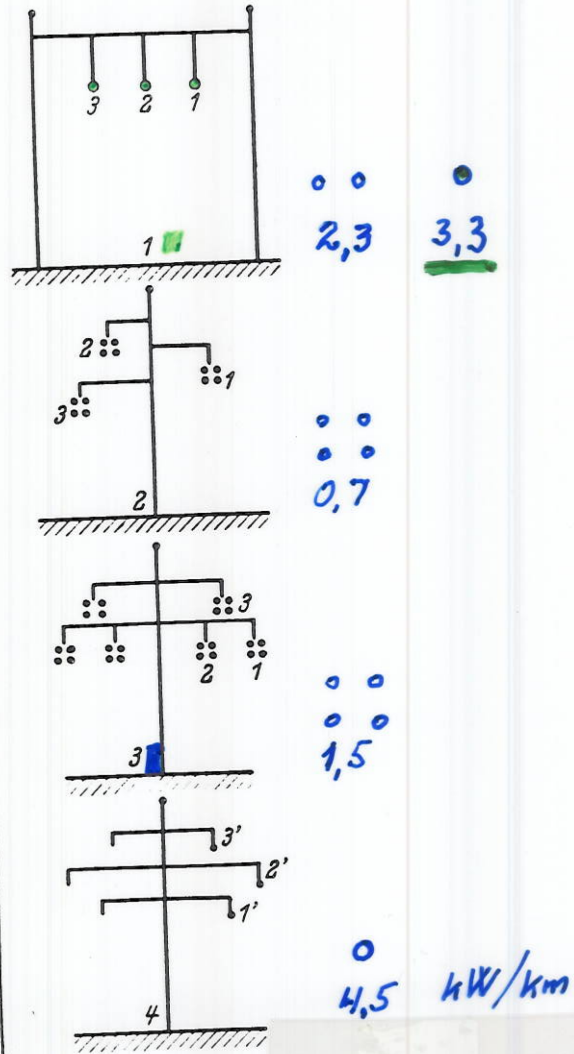

Abb. 7.44. Mittelwerte der Koronaverluste von 380 kV-Leitungen (nach Veröff. Nr. 2 der 400 kV-Forschungsgemeinschaft Heidelberg)

1. Einfachseile

a) Cu-Hohlseil 42 mm ⌀ Einfachseile zu 1

$E_1 = 17{,}3$ kV$_{eff}$/cm, max. Randfeldstärke der Phase (R)

$E_2 = 18{,}3$ kV$_{eff}$/cm, max. Randfeldstärke der Phase (S)

$E_3 = 17{,}25$ kV$_{eff}$/cm, max. Randfeldstärke der Phase (T)

$\overline{E} = 17{,}6$ kV$_{eff}$/cm, max. Randfeldstärke der Phase ($\overline{RST}$)

b) Stahl-Aluminiumseil 42 mm ⌀ Einfachseil zu 4

$E'_2 = 18{,}23$ kV$_{eff}$/cm (R)

$E'_1 = 17{,}02$ kV$_{eff}$/cm (S)

$E'_3 = 16{,}08$ kV$_{eff}$/cm (T)

$\overline{E} = 17{,}06$ kV$_{eff}$/cm ($\overline{RST}$)

2. Zweierbündel

a) 2×32/400 Stahl-Aluminiumseile zu 1

$E_1 = 15{,}6$ kV$_{eff}$/cm (R)

$E_2 = 17{,}3$ kV$_{eff}$/cm (S)

$E_3 = 15{,}8$ kV$_{eff}$/cm (T)

$\overline{E} = 16{,}2$ kV$_{eff}$/ cm($\overline{RST}$)

3. Viererbündel

a) 4×21/400 (E) Stahl-Aluminiumseile (Einsystem) zu 2

$E_1 = 12{,}59$ kV$_{eff}$/cm (R)

$E_2 = 13{,}20$ kV$_{eff}$/cm (S)

$E_3 = 13{,}62$ kV$_{eff}$/cm (T)

$\overline{E} = 13{,}12$ kV$_{eff}$/cm ($\overline{RST}$)

b) 4×21/400 (D) Stahl-Aluminiumseile (Doppels.) zu 3

$E_1 = 15{,}31$ kV$_{eff}$/cm (R)

$E_2 = 15{,}86$ kV$_{eff}$/cm (S)

$E_3 = 13.56$ kV$_{eff}$/cm (T)

$\overline{E} = 14{,}88$ kV$_{eff}$/cm ($\overline{RST}$)

c) 4×21,7/400 Stahl-Aluminiumseile zu 3

$E_1 = 14{,}86$ kV$_{eff}$/cm (R)

$E_2 = 15{,}40$ kV$_{eff}$/cm (S)

$E_3 = 13{,}16$ kV$_{eff}$/cm (T)

$\overline{E} = 14{,}45$ kV$_{eff}$/cm ($\overline{RST}$)

● Equivalent scheme and voltage waveform for external partial discharges

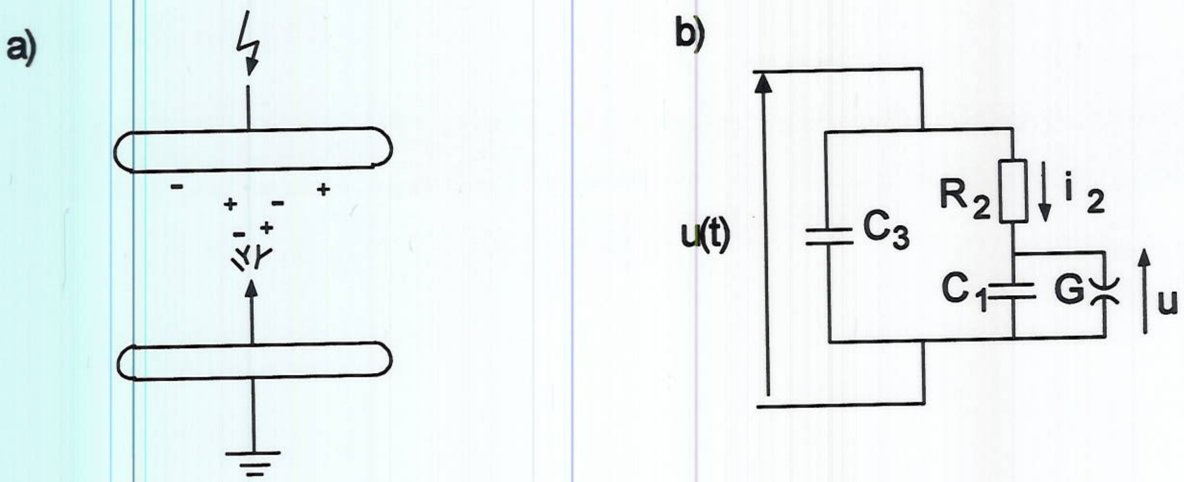

Fig. 9.7 Setup with external partial discharges
a) Point-plate electrodes b) Equivalent scheme

- C_1: Capacitance of gaseous volume (extension) which breaks down, when the applied voltage increases above the ignition voltage U_t.

- G: Sparking gap which breaks down (short circuits) when the capacitive volume C_1 breaks down.

- R_2: Active (resistive) losses caused by the conductivity of the gas.

- C_3: Normal capacitance of the electrode gap setup.

Assuming $R_2 >> 1/\omega C_1$ makes the current through R_2 equal to:

$$i_2 = \frac{u(t)}{R_2} \qquad [A]$$

Applied voltage is a sinusoidal waveform:

$$u(t) = \hat{U} \sin \omega t \qquad [V]$$

The "not broken down" voltage $U_{10}(t)$ across the discharge capacitance C_1 can be

$u_{10} = U_t = \frac{\hat{U}}{\omega C_1 R_2} \Rightarrow \hat{U} = \omega C_1 R_2 \cdot U_t$

calculated as: $u_{10}(t) = X_{C1} \bullet i_2(t)$ phase shifted 90°:

$$u_{10} = \frac{\hat{U}}{\omega\, C_1\, R_2} \sin\left(\omega t - \frac{\pi}{2}\right) \qquad [V]$$

Increasing the applied voltage $u(t) = \hat{U} \bullet \sin(\omega t)$ ie. increasing $\hat{U}$ ➜ A specific value of $\hat{U}$ makes the ignition voltage U_t so high that G breaks down.

This happens for $\hat{U}$ equal to:

$$\hat{U} = \hat{U}_{ut} = \omega\, C_1\, R_2\, U_t \qquad [V]$$

This discharges C_1 and the "not broken down" voltage u_{10} becomes zero.

Recharging C_1 will happen according to the +/- du/dt , ie. a positive du/dt makes a renewed breakdown for $+U_T$ and a negative du/dt gives a negative $-U_T$.

Increasing $\hat{U}$ further increases the number of rechargings to U_T followed by breakdown for each period. The partial breakdowns appear (are concentrated) around maximum du/dt for the voltage u_{10}, ie. they appear around the peak of the applied voltage u(t).

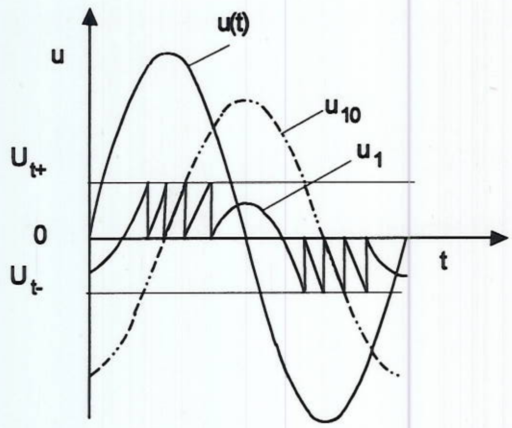

Fig. 9.8 Voltage waveform of externally partial discharges (corona) at $u_{10} = 2\,U_T$.