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Lightning Side Flash from the Tree: Some Physical Models

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- **SIDE FLASH IS ONE OF THE MOST IMPORTANT PROBLEMS OF HUMAN DAMAGES BY LIGHTNING. THOUGH SEVERAL GUIDELINES STATE THAT YOU SHOULD NOT BE NEAR A TREE WHEN THUNDERSTORM ACTIVITY IS HIGH, LITTLE IS KNOWN ABOUT THE NECESSARY CLEARANCE QUANTITATIVELY. THERE ARE DIFFERENT STATEMENTS OF SAFE DISTANCE NEEDED TO AVOID SIDE FLASH, e.g.:**

- * "A side flash of roughly **5 m length** may occur" [*V. Rakov, M.A. Uman, "Lightning – Physics and Effects", Cambridge University Press, Cambridge, UK, 2006.*]

- **"Do not go close to or under trees – **safe distance is similar to the height**, or at least a few meters from the longest branches" [*"Lightning is threatening – what to do?" Draft of the Lightning Safety Brochure, COST P-18*]

- *** "Cone of protection' from **trees** and cliffs is an arguable concept and has no place in lightning safety education anymore. ...Instead we need to teach the 50 m leader search distance concept...If someone is within 50 m of a significantly higher object, they have a greatly reduced chance of being struck directly. You can still be struck, **especially indirectly**, but the chances are reduced. The 50 m concept works best with cliffs... **The 50 m concept does not work well for trees because the base of the tree may send out surface arcs**" [*NOLS' "Backcountry Lightning Safety Guidelines", Internet*].

NOLS' "Backcountry Lightning Safety Guidelines"

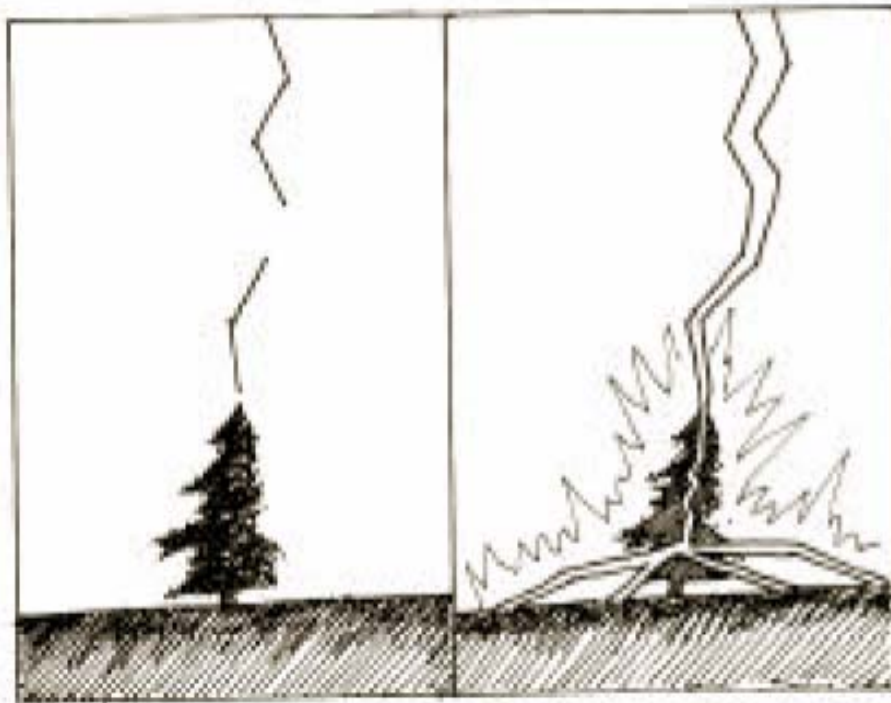


Figure 2: Left: tree with a streamer and a stepped leader.
Right: tree with return stroke, surface arcs, and electrostatic field.

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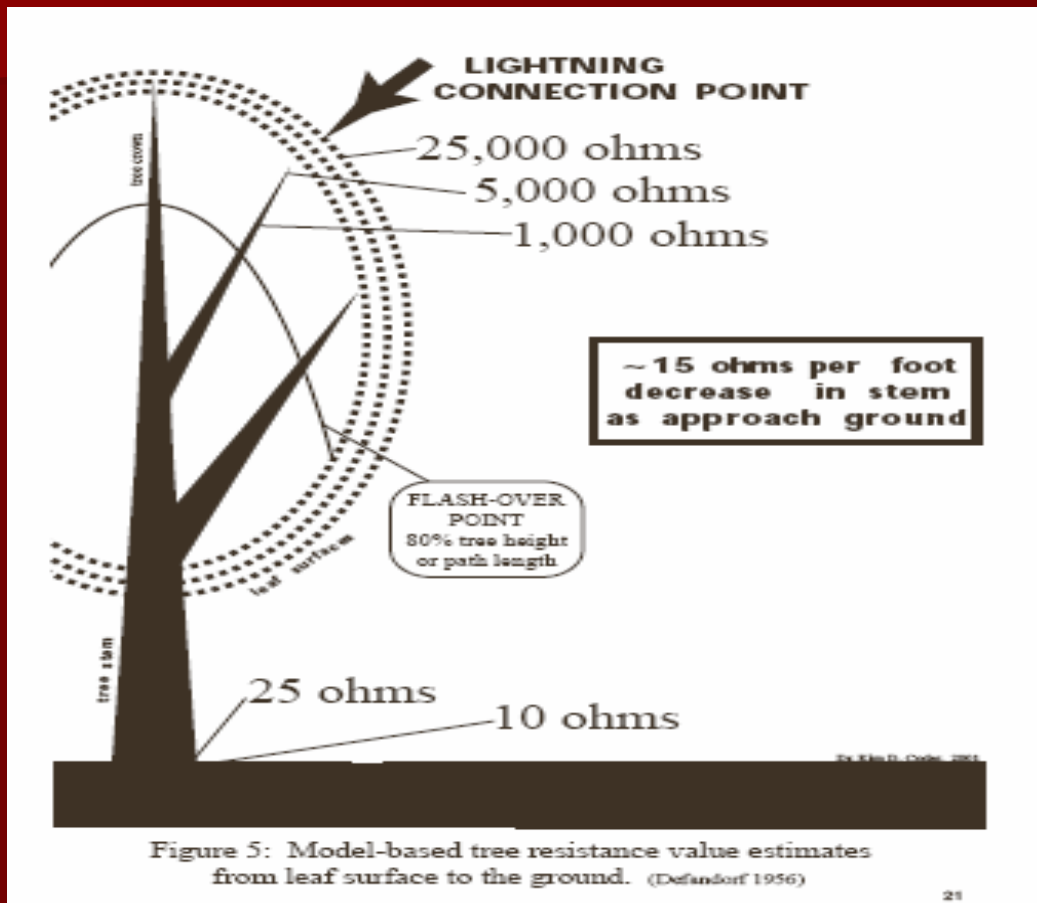
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NOLS' "Backcountry Lightning Safety Guidelines (very restrictive)

Avoid trees because they are taller than their surroundings. Tall trees are especially adept at generating streamers that attract strikes. If you need to move through a forest while seeking safer terrain, stay away from the tree trunks as you move. You should also avoid open areas that are 100 m wide or wider. Lone trees are especially dangerous: the laws of probability say you are hundreds of times safer in a forest with hundreds of trees than you are near a lone tree in an open space.

“Cone of protection” from trees and cliffs is an arguable concept and has no place in lightning safety education anymore. Lightning has been photographed striking 100 m from 200 m towers, and surface arcs have been photographed exactly where “cones of protection” inferred we were all safe. Instead we need to teach the 50 m leader search distance concept (see the first paragraph of this paper.) If someone is within 50 m of a significantly higher object, they have a greatly reduced chance of being struck directly. You can still be struck, especially indirectly, but the chances are reduced. The 50 m concept works best with cliffs and other steep terrain that provide protection without directing the strike toward you. The 50 m concept does not work well for trees because the base of the tree may send out surface arcs. (see figure 2)

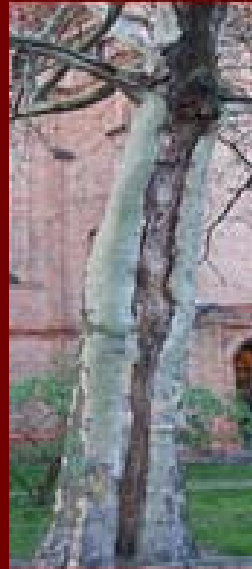
Defandorf, F.M. Electrical resistance to the earth of a live tree. Power Applications Systems, 1956:1-4



The Defandorf's parameters are right
BEFORE the lightning strike...

But AFTER the lightning strike?

Resistive voltage drop along the current path...



■ T. G. ENGEL, A. L. DONALDSON, M. KRISTIANSEN

*The Pulsed Discharge Arc Resistance and its
Functional Behavior*, **IEEE TRANSACTIONS ON
PLASMA SCIENCE, VOL. 17, NO. 2, APRIL 1989**

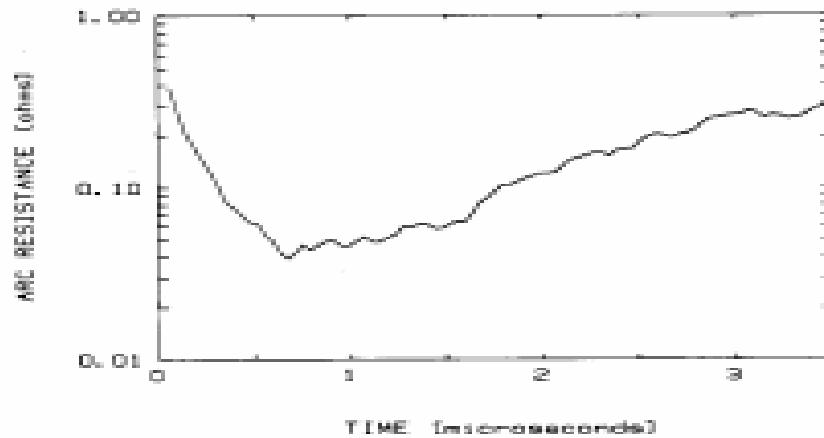


Fig. 1. The experimental arc resistance as measured by Akiyama *et al.* [1].

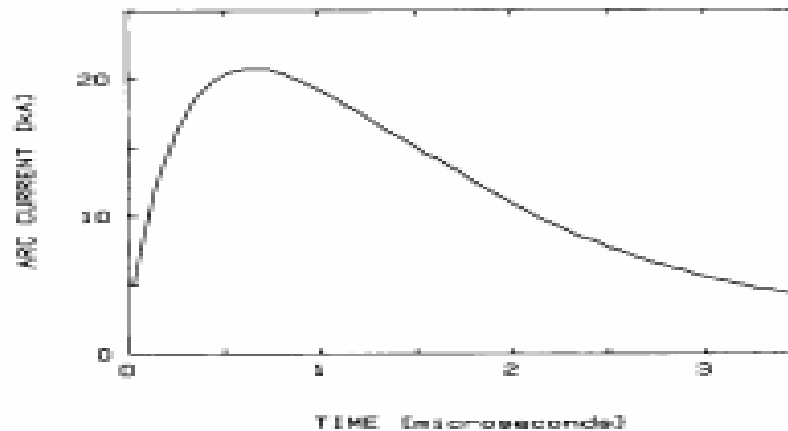


Fig. 2. Arc-current waveform used in the experimental [1] and theoretical (Figs. 3–10) evaluation of the arc resistance ($P = 0.86 \times 10^7$ Pa, $d = 0.01$ m).

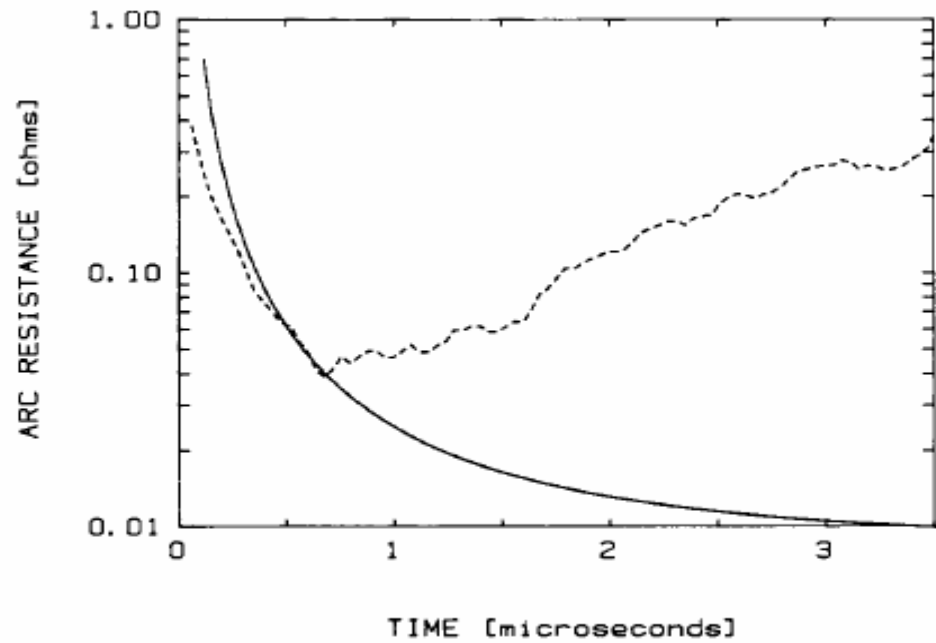


Fig. 9. Toepler's [8] calculated arc resistance (solid line) compared to the experimental arc resistance [1] (dashed line).

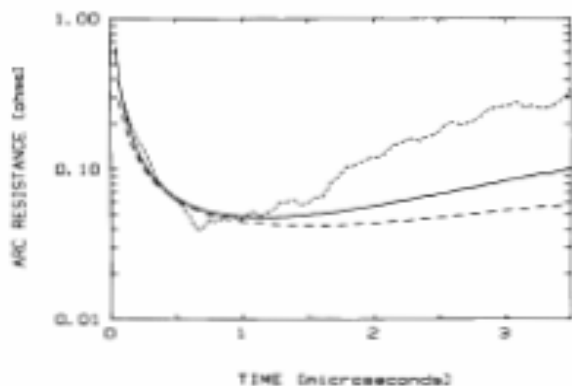


Fig. 4. The measured arc resistance [1] (finely dashed line) compared with Demetrik *et al.*'s [3] calculated arc resistance using equation (1) for the channel radius (solid line) and equation (10) for the channel radius (coarsely dashed line).

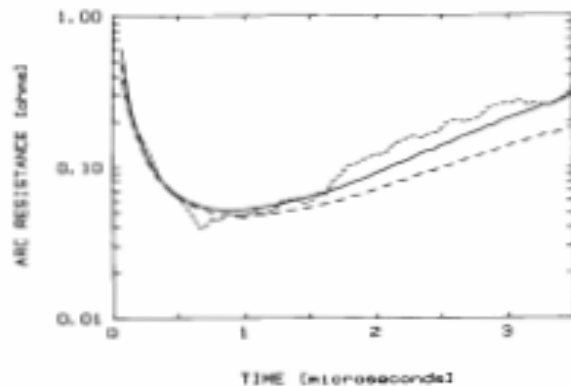


Fig. 6. The measured arc resistance [1] (finely dashed line) compared with Kaskner *et al.*'s [5] calculated arc resistance using equation (1) for the channel radius (solid line) and equation (10) for the channel radius (coarsely dashed line).

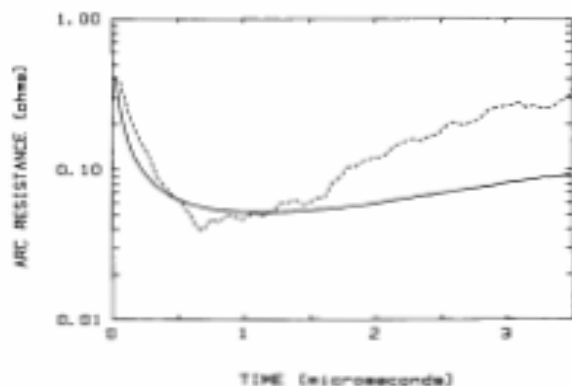


Fig. 5. Gocharenko and Romanenko's [4] calculated arc resistance (solid line) compared to the experimental arc resistance [1] (dashed line).

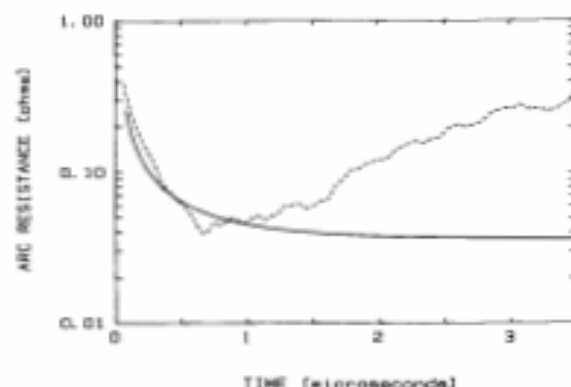


Fig. 7. Popovic *et al.*'s [6] calculated arc resistance (solid line) compared to the experimental arc resistance [1] (dashed line).

$$R(t) = \frac{k_i}{\int_0^t i(t) dt} \quad (1)$$

$$R(t) = k_k \left\{ \frac{P_0^3}{A^2 [i(t)]^6} \right\}^{\frac{1}{5}} \quad (2)$$

$$R(t) = 0.93 \cdot 10^{-3} \delta_0^{-\frac{1}{6}} i^{\frac{1}{3}} t^{\frac{1}{2}} \quad (3)$$

I – current, t – time, k_t – const, k_x – const,

p_0 – pressure,

A – cross-sectional area of the discharge,

$r(t)$ – radius of the discharge channel,

δ_0 – air density at atmospheric pressure

- Resistive voltage drop along the current path of 2 m

$$U_{R(2m)} = 200\text{ kV} \dots 400\text{ kV}$$

- Inductive voltage drop along the current path

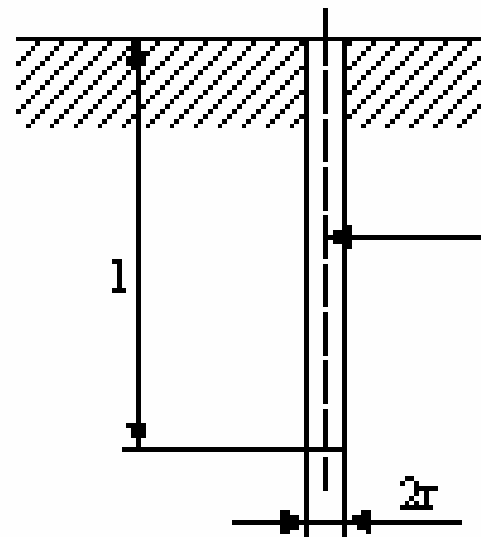
$$U_{L(2m)} = \text{up to } 400\text{ kV}$$

($L=2 \cdot 2 \cdot 10^{-6}\text{ H}$, current derivate = 10^{11} A s^{-1} , as 5% quantile)

SAFE DISTANCE: 1-2 m

Resistance of grounding?

Perpendicular



Hemispherical Perpendicular Horizontal Ring Figures Lightning parameters

Earth electrode data:

ρ [Ωm] 50
 r [mm] 25
 l [m] 1

Lightning parameters:

I [kA] 34
 di/dt [kA/ μs] 43
 W [kJ/ Ω] 60

Electrical parameters of a person

R_{human} [Ω] 1000
 d_x [m] 1

Calculated data:

R_{ground} [Ω] 34,87
 U_{touch} [kV] 1080
 W_{touch} [J] 4449

Dependencies: U [kV] U_{step} [kV] W_{human} [J] $U_{\text{spark-over}}$ [MV]



CALCULATE

Choose a diagram...

- U [kV]
- U_{step} [kV]
- W_{human} [J]
- Spark-over distance

Hemispherical Perpendicular Horizontal Ring Figures Lightning parameters

Earth electrode data:

ρ [Ωm] 50
 r [mm] 10
 l [m] 0,1

Lightning parameters:

I [kA] 34
 di/dt [kA/ μs] 43
 W [kJ/ Ω] 60

Electrical parameters of a person

R_{human} [Ω] 1000
 d_x [m] 1

Calculated data:

R_{ground} [Ω] 238,3
 U_{touch} [kV] 7966,
 W_{touch} [J] 2105

Dependencies: U [kV] U_{step} [kV] W_{human} [J] $U_{\text{spark-over}}$ [MV]

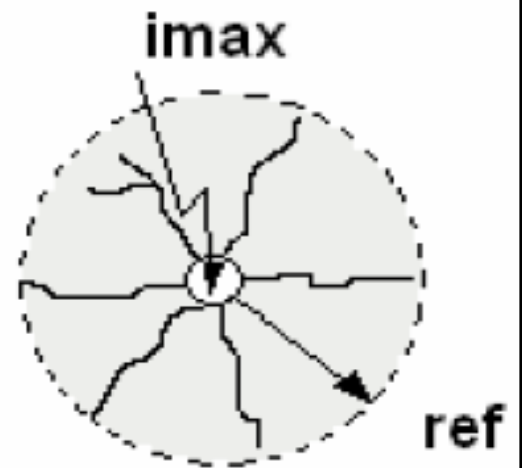
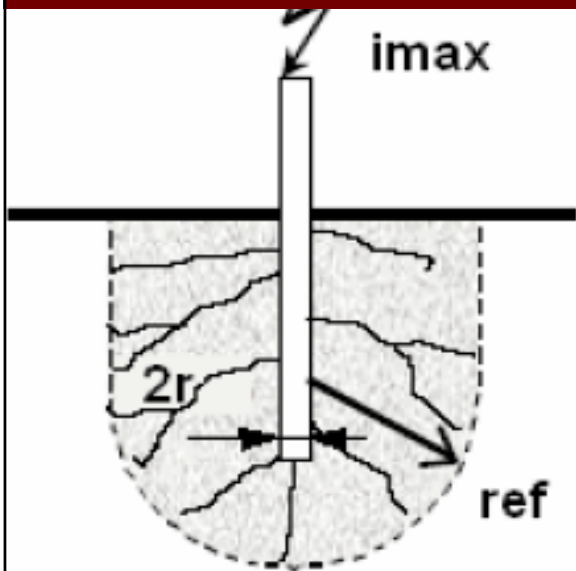


CALCULATE

Choose a diagram...

- U [kV]
- U_{step} [kV]
- W_{human} [J]
- Spark-over distance

- Streamer discharges in soil phenomena



RESISTIVITY OF SOIL	CURRENT DENSITY FOR STREAMERS IN SOIL	RADIUS OF THE STREAMERS RANGE HEMISPHERE (for I=36 kA)	RESISTANCE OF GROUNDING	SAFE DISTANCE (for I=36 kA)
ρ	j_k	r	R_g	d
$[\Omega m]$	$[Am^{-2}]$	$[m]$	$[\Omega]$	$[m]$
50	≥ 6000	0.98	8.1	0.58
100	≥ 3000	1.38	11.5	0.83
500	≥ 600	3.09	25.8	1.85
1000	≥ 300	4.37	36.4	2.62
5000	≥ 60	9.7	82.0	5.90

CONCLUSIONS

- 1. Safe distance is strictly determined by soil resistivity and DENSITY; are possible streamer discharges or not...
- 2. There is neither any quantitative formula nor general solution of the problem
- 3. The guidelines ought (must?) make allowances for kind of the terrain and soil.
- 4. The quantitative recommendations must be based on statistics of fatalities and lightning electric shock accidents.

REFERENCES

- [1] H. Akiyama *et al.*, "Current voltage characteristics of a high-current pulsed discharge in air," *IEEE Trans. Plasma Sci.*, vol. 16, pp. 312-316, Apr. 1988.
- [2] S. I. Barannik *et al.*, "Resistance and inductance of a gas arc," *Sov. Phys.-Tech. Phys.*, vol. 19, pp. 1449-1453, May 1975.
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- [5] M. J. Kushner *et al.*, "Arc resistance of laser triggered spark gaps," *J. Appl. Phys.*, vol. 58, pp. 1744-1751, Sept. 1985.
- [6] M. M. Popovic *et al.*, "Investigation of the beginning of high current discharges in pulsed arcs," in *Proc. Int. Conf. Gaseous Discharges*,
- [7] R. Rompe and W. Weizel, "Über das toeplersche funkengesetz," *Z. Phys.*, vol. 122, pp. 636-639, 1944.
- [8] M. Toepler, "Zur kenntnis der gesetz der gleitfunkenbildung," *Ann. Phys. D.*, 4 folge, bd. 21, pp. 193-222, 1906.



Thank you for your attention!