Microwave multipactor and corona breakdown in inhomogeneous fields

A summary of research done by the
Chalmers-CNES-IAP collaboration
Presented by *Joel Rasch*

Outline

- Aim of collaboration
- Multipactor breakdown
- Corona breakdown
- Results
- Outlook

Aim of collaboration

- CNES, Centre National d'Études Spatiales, is a major player in space connections
  - Ariane launchers
  - Involved in ISS, Galileo, GMES, scientific and defence projects etc.
  - Research, manufacturing, services.

Aim of collaboration

- IAP, Institute of Applied Physics (Russia), has a lot of activity on plasma physics and applications. Prof. Vladimir Semenov
  - The Gyrotron was invented and developed here.
- The nonlinear electrodynamics group at Chalmers has been working with microwave breakdown and plasma physics for a long time. Profs. Dan Anderson & Mietek Lisak
  - Mainly defence applications

Aim of collaboration

- In 2001 a collaboration started to investigate the microwave (1-100 GHz) breakdown phenomena in space RF equipment.
- Microwave breakdown causes many problems to rf equipment:
  - Drastic reduction in signal reception & transmission
  - Noise, changing device impedance,heating, damage, system failure etc.

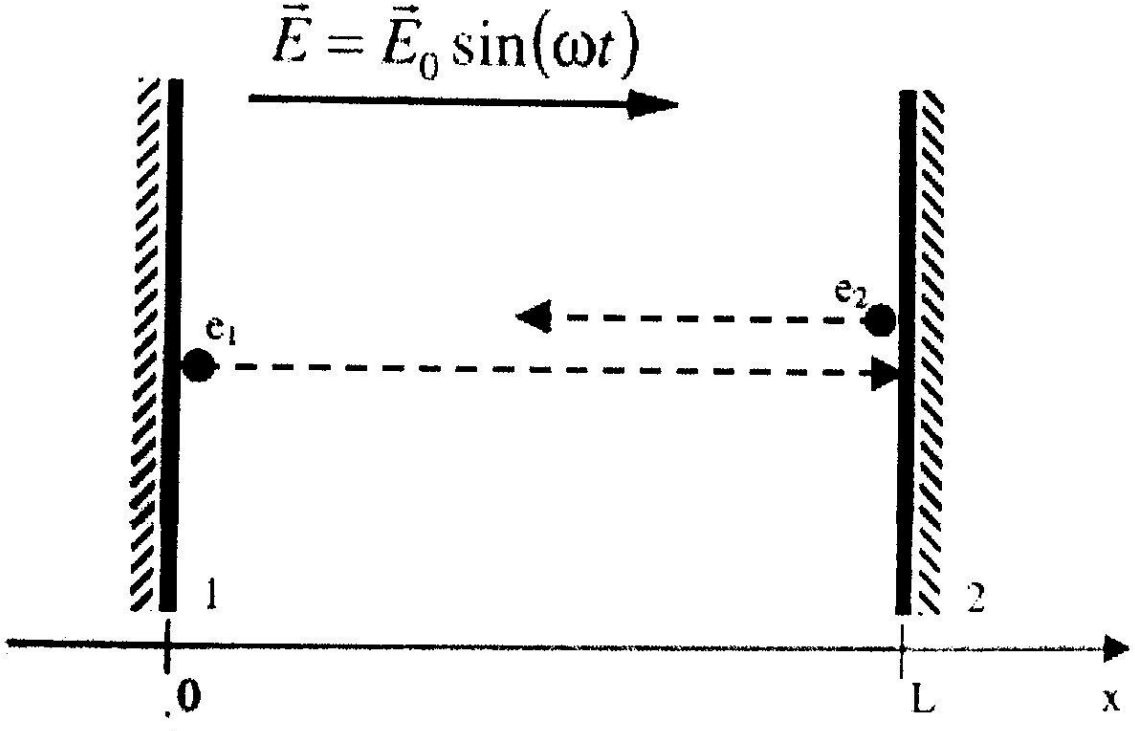
Aim of collaboration

- Two main types of microwave breakdown
  - Multipactor discharge, occurs in vacuum (orbit)
  - Corona discharge, occurs in gas (air), during testing on ground, during launch, in vacuum due to outgassing
- The aim was to further the understanding of these phenomena and develop guidelines to avoid it.

Multipactor breakdown

- The exponential growth of the number of free electrons in a vacuum RF system until saturation by space charge effects (or other non-linear effects).
- Caused by secondary emission of electrons from metal surfaces by the impact of electrons moving in the field.

Multipactor breakdown

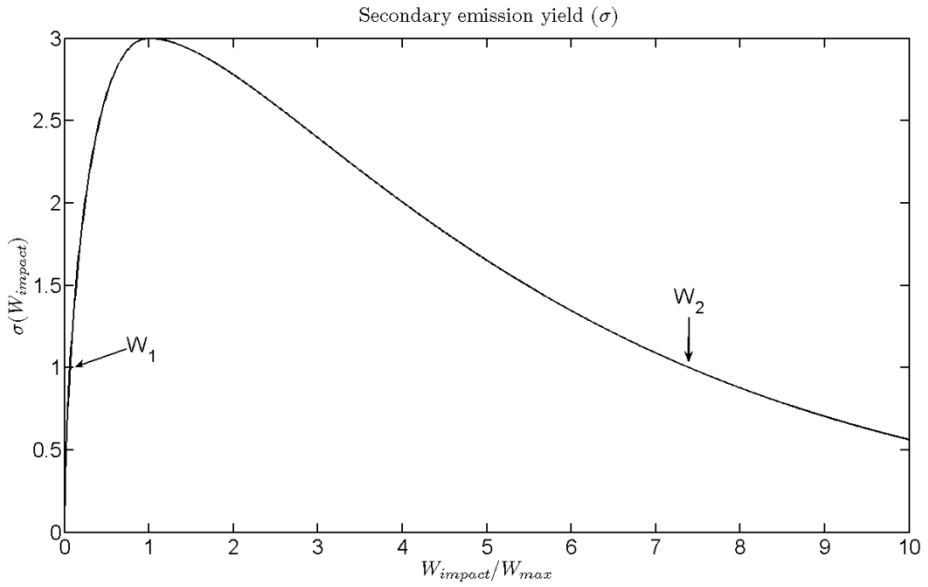


Multipactor breakdown

- Necessary criterions
  - Critical field strength for a given frequency

$$W_1 < W_{impact} < W_2$$

$$W_{impact} \approx \frac{e^2 E^2}{m\omega^2} \propto \frac{E^2}{\omega^2}$$



Multipactor breakdown

- Some typical values:

$$W_{1,Gold} = 150\ eV$$

$$W_{1,Silver} = 30\ eV$$

$$W_{1,Al} = 30\ eV$$

$$W_{1,Alodine} = 41\ eV$$

$$W_{1,Alodine} = 25\ eV$$

For Silver at 2.45 GHz:

$$E \approx 2000\ \ V/cm$$

Multipactor breakdown

- In ”small” systems, resonant electron motion is also necessary
- Typical presentation of results; Hatch-Williamson chart

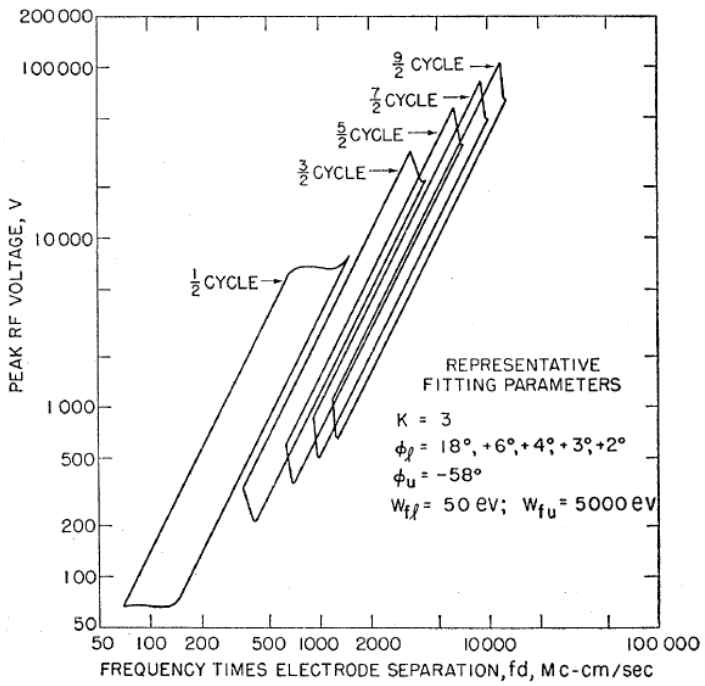


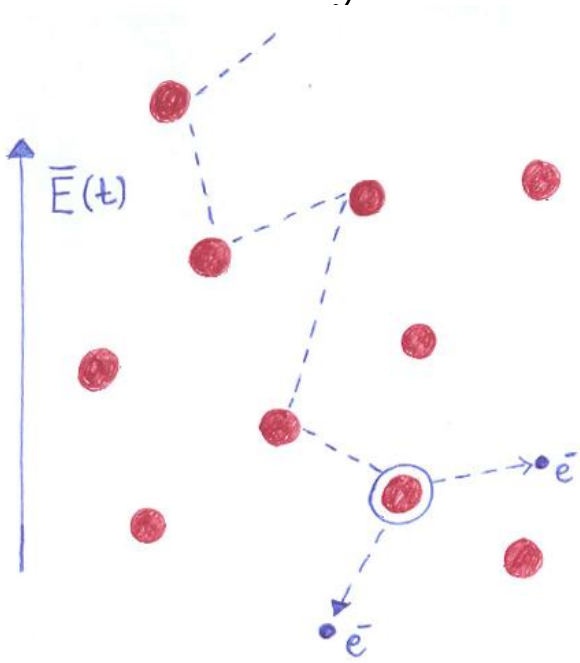
FIG. 1. Multiple mode multipacting theory, ½- through 9/2-cycle modes, $n = 1, 2, 3, 4, 5$.

Multipactor breakdown

- When geometries are nontrivial:
  - Inhomogeneous electric field
  - Complicated electron trajectories
  - Statistical effects
- Any system needs to be analyzed carefully before guidelines can be set

Corona breakdown

- The electrical breakdown of a gas in a microwave electric field
- Caused by ionization of gas molecules by electron impact ionization, and the subsequent exponential growth of the free electron number



Corona breakdown

- In Air we have N_2 and O_2, and other stuff

$$W_{i,N_2} = 15.6\,eV$$

$$W_{i,O_2} = 12.1\,eV$$

$$< W_e > \approx \frac{e^2 E^2}{\delta m(\omega^2 + \nu_c{}^2)} \propto \frac{E^2}{\omega^2 + \nu_c{}^2}$$

- For high pressures $< W_e > \propto \frac{E^2}{\nu_c{}^2} \propto \frac{E^2}{p^2}$

Corona breakdown

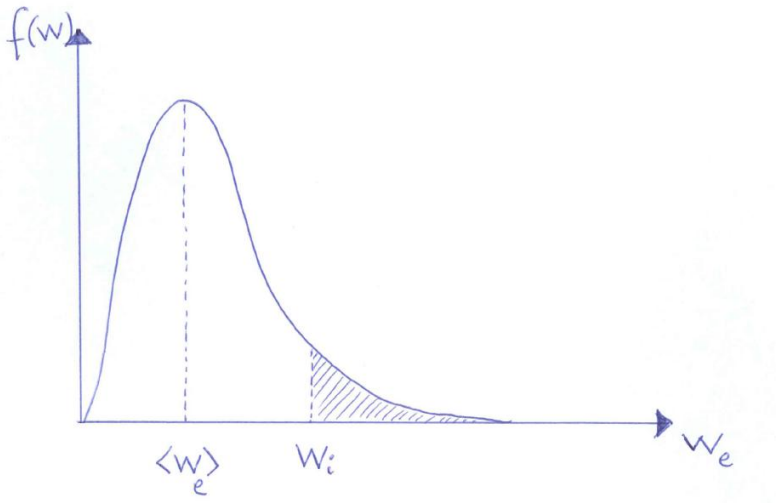
- For Oxygen, this would imply

$$\frac{E}{p} \approx 45\, V/cm \cdot Torr$$

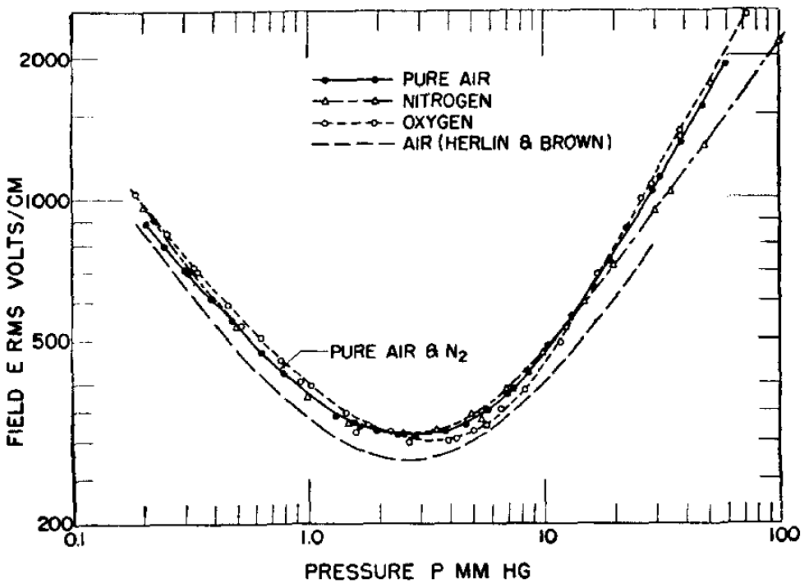
- But the Maxwellian has a high energy tail, making

$$\frac{E}{p} \approx 30\, V/cm \cdot Torr$$

a better estimate



Corona breakdown



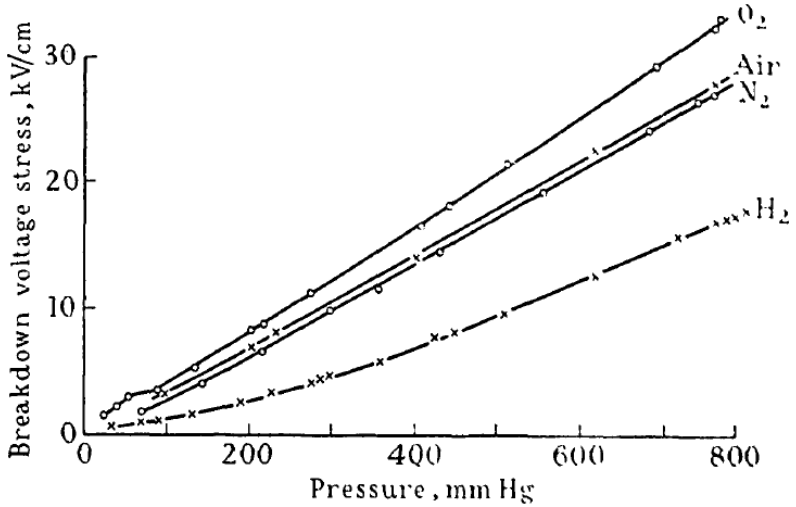


Fig. 6.—Observed breakdown voltage stresses—polyatomic gases.
Based on 28 kV/cm for air at 760 mm Hg.

$$< W_e > \propto \frac{E^2}{\omega^2 + \nu_c^{\,2}}$$

$$\frac{E}{p} \approx 30\,V/cm \cdot Torr$$

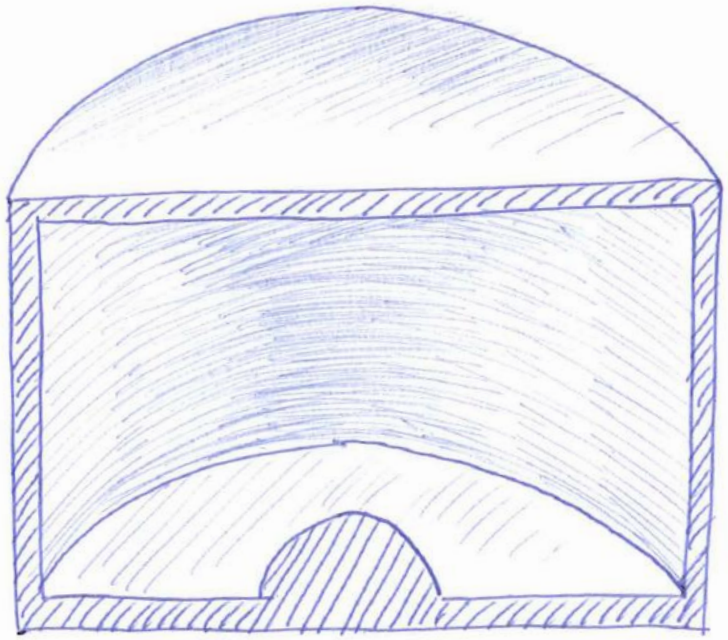
Corona breakdown

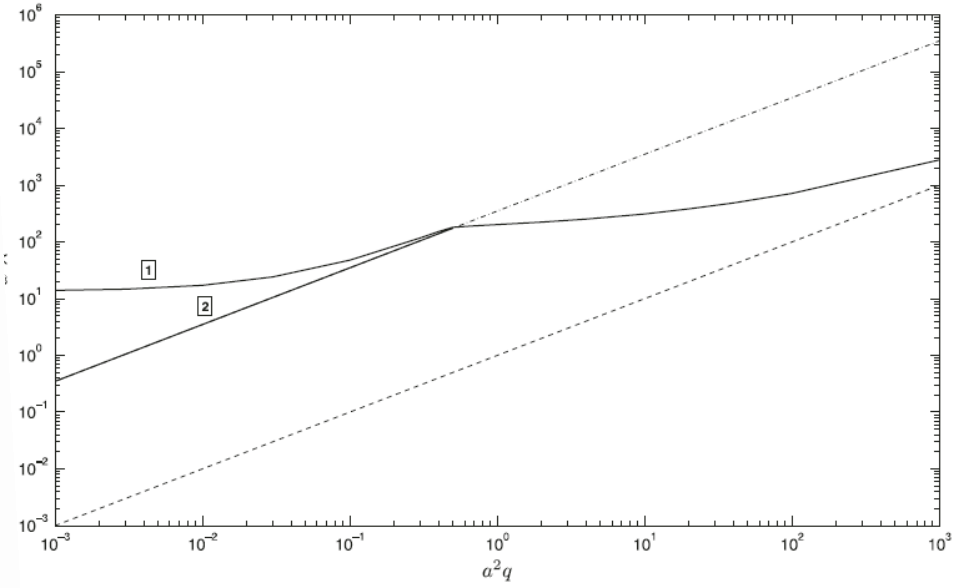
- This formula applies to attachment dominated breakdown, high pressure
- Because electron free path is smaller than any variation in the system
- If this is not true (happens alot) we need to solve some complicated equations

$$\frac{\partial n}{\partial t} = \nabla^2 (Dn) + n(\nu_i - \nu_a)$$

Corona breakdown

Corona breakdown in cylindrical cavity with hemispherical boss





Results

- 32 journal papers
  - 9 in IEEE Transactions on Plasma Science
  - 14 in Physics of Plasmas
  - 8 in Journal of Physics D: Applied Physics
  - 1 in Contributions to Plasma Physics
- Some 40 conference contributions

Results

- Multipactor:
  - Between two cylinders (helix), coaxial waveguide, microstrip lines, single surface, waveguide iris, rectangular waveguide, circular waveguide, wedge-shaped waveguide
  - Polyphase, hybrid modes, non-resonant multipactor, low pressure gas, quadratur phase shift keying, different SEY properties, secondary electron velocity spread

Results

- Corona:
  - Spherical cavity, rectangular cavity, cylindrical cavity with boss, between two cylinders, in coaxial waveguide, circular waveguide, rectangular waveguide, around edges, in slots
  - Multicarrier and non-CW signals

Results

- The transition between multipactor and corona, Udiljak (2003)

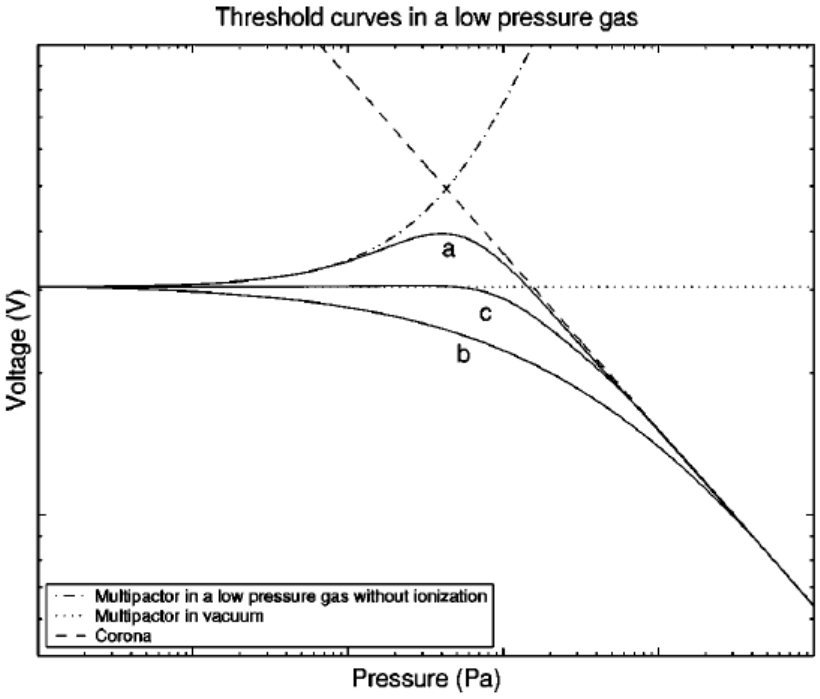


FIG. 8. Qualitative form of the dependence of breakdown threshold with pressure in the region between which multipactor and corona, respectively, dominate the breakdown process: (a) collision ionization negligible compared to secondary emission, (b) collisional ionization contributes significantly to the total number of electrons, (c) intermediate situation.

Results

- Conformal mapping analysis of multipactor in waveguide iris

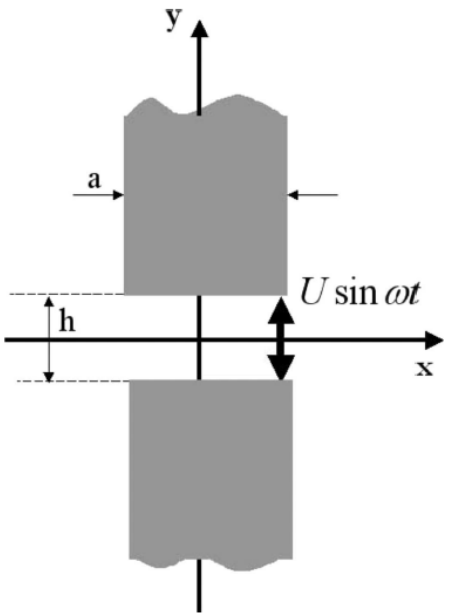
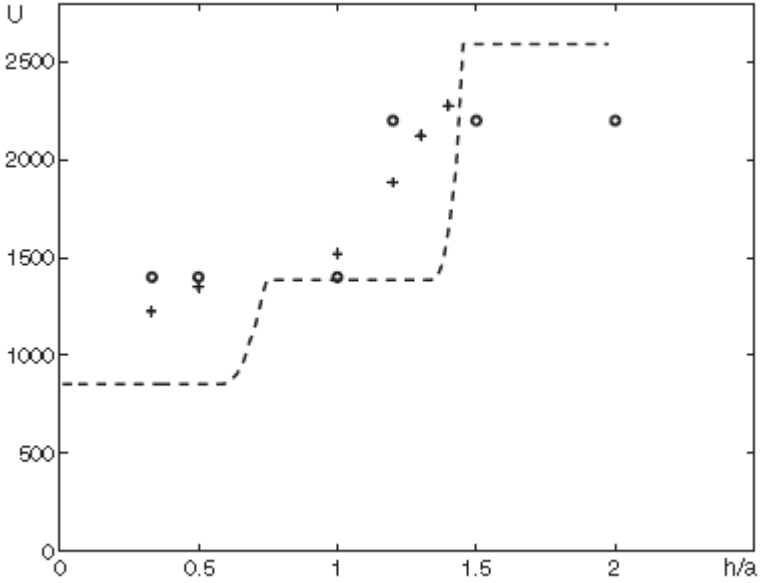
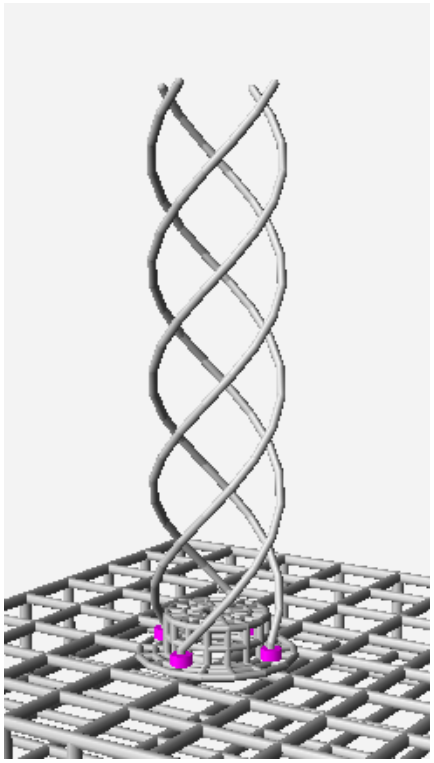


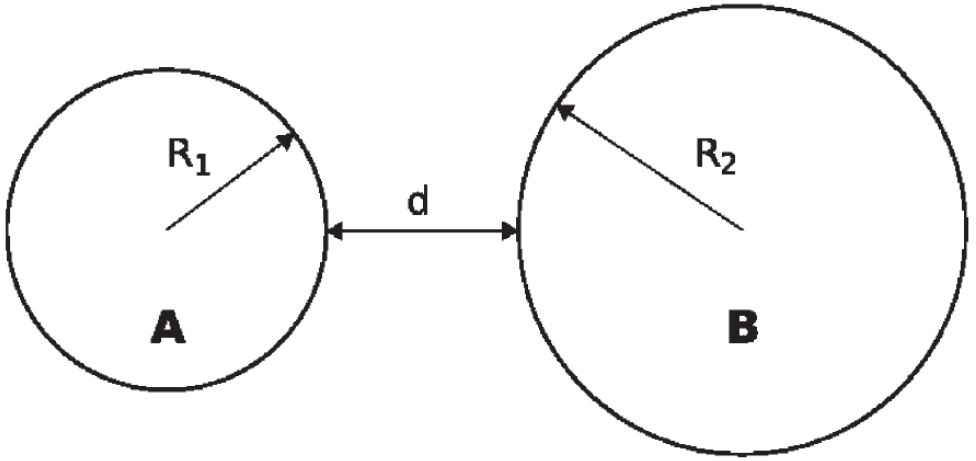
FIG. 1. The 2D model used in the conformal mapping analysis.



Results

- Multipactor in a helix antenna system





Results

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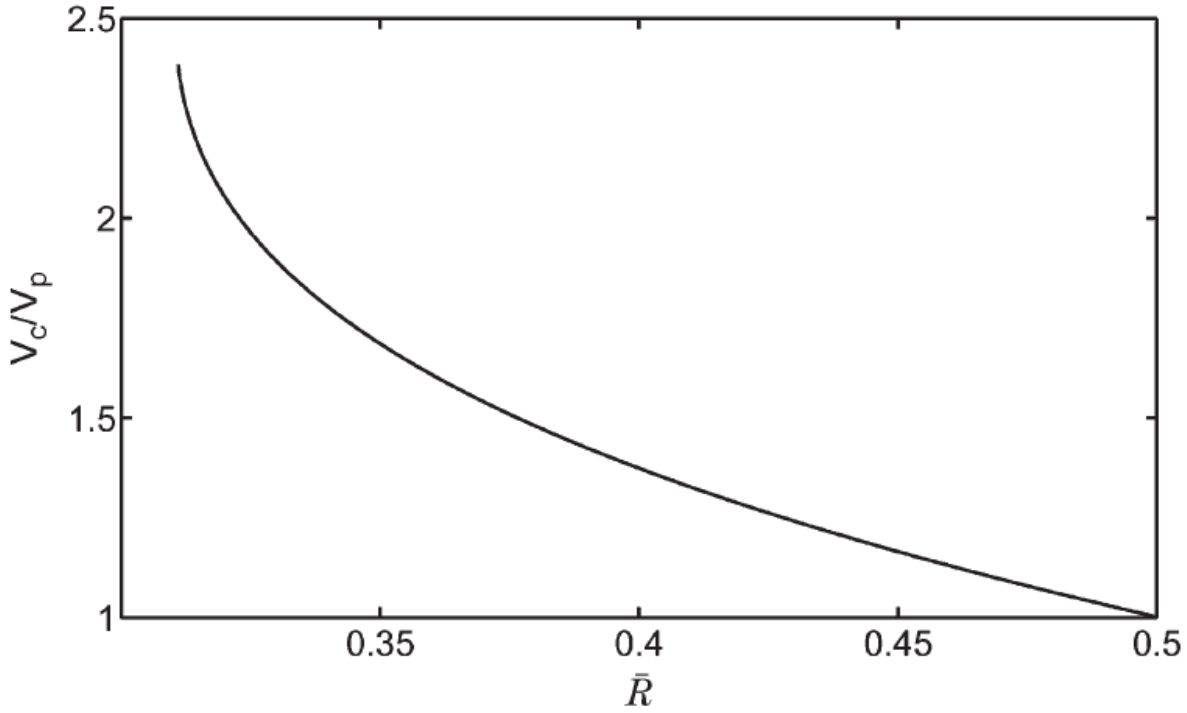

Outlook

- Prof. Dan Anderson has retired.
- One more 1.5 year contract has been signed, but after that the Chalmers group will be restructured, I will get my PhD…….