# Study of Calibration Standards for Extreme Impedances Measurement

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# Outline

- Introduction
  - Motivation and main aim
- Measurement theory
- Methodology
  - Choice of calibration standards
  - CST setting
- Simulated structures
  - Basic problems
- Conclusion

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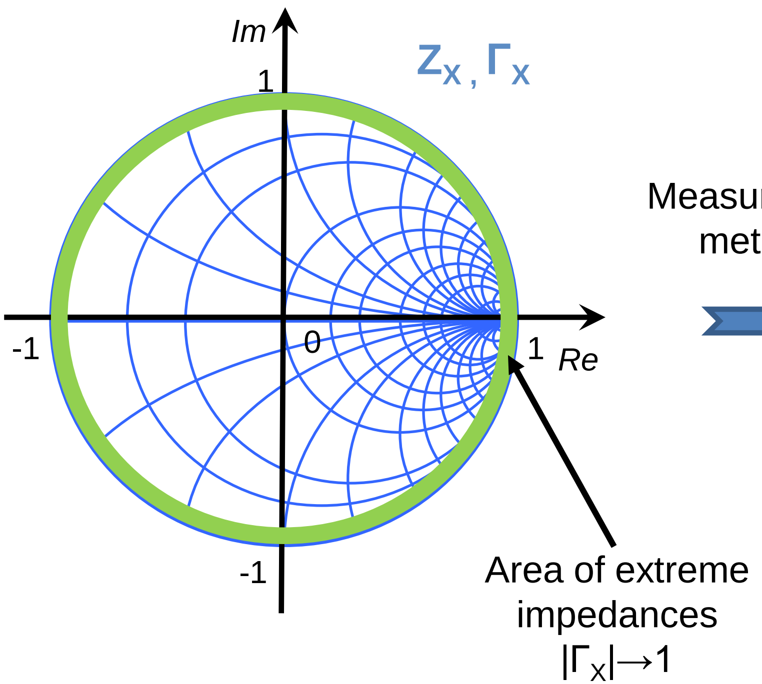
# Introduction

- Motivation
  - Devices with extreme impedances
    - Carbon nanotubes, nanowires, atto-farad varactors, very-weakly coupled resonators
  - Known method for microwave measurement of these structures
    - High sensitivity and accuracy
- Main objective of the project
  - To develop traceable calibration/verification standards for extreme impedance measurement
- Main objective of the presentation
  - To present first simulated result

# Measurement theory

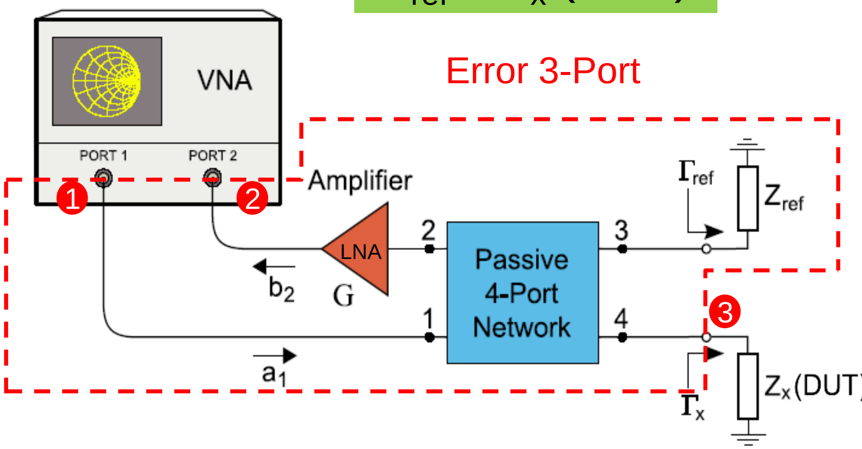



Measurement method

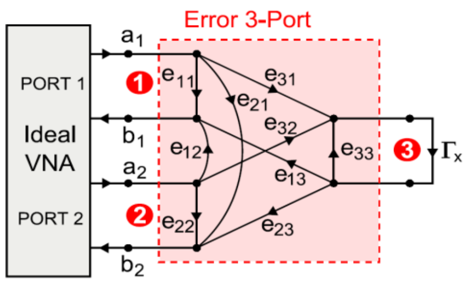
## Simple measurement method

(Suppression of VNA uncertainties)

$Z_{ref} \approx Z_x$ (DUT)

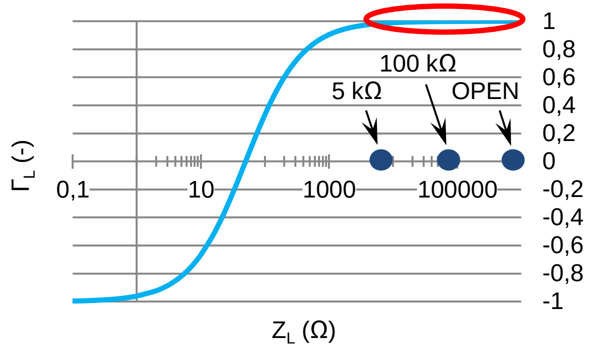



Error model




Three full known calibration standards in the area of extreme impedances

# Methodology

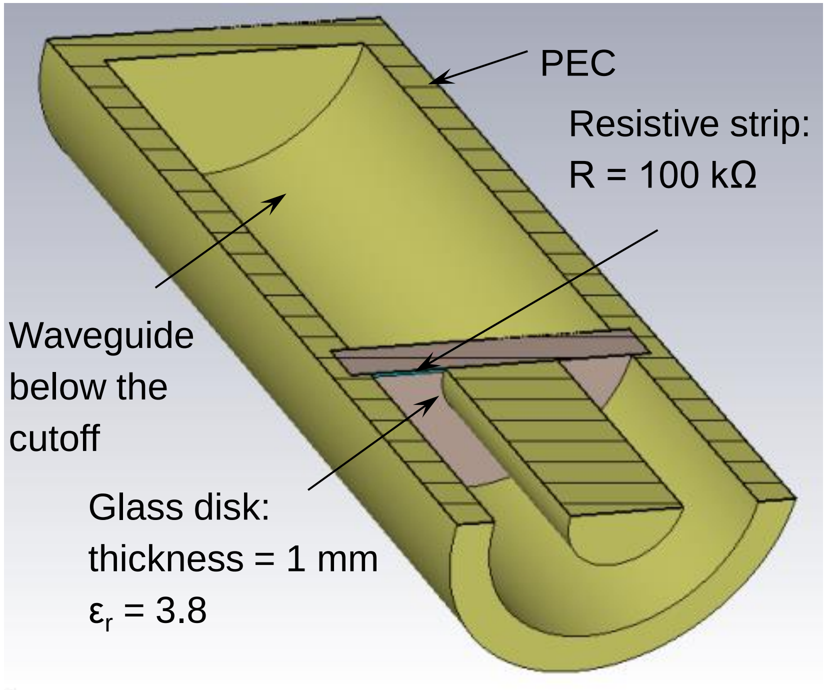



- Frequency and impedance range
  - Up to 18 GHz
    - connector APC-7 (technology, connection repeatability)
  - Extremely high impedances
    - 5 ÷ 100 kΩ (developed measurement method)
- Values of calibration/verification standards
  - 5 kΩ ÷ OPEN
- Required precision in CST
  - At least $\Delta S = 1 \cdot 10^{-4}$

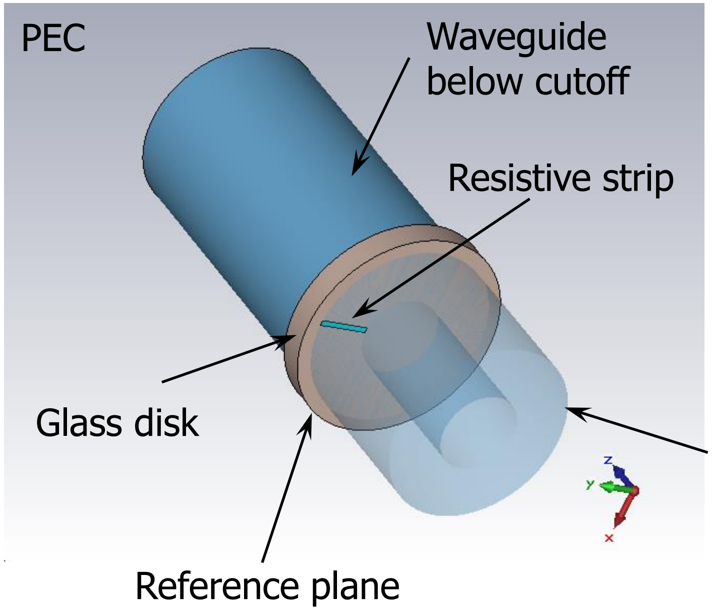
| $Z_0$ (Ω) | $Z_L$ (kΩ) | $\Gamma_L$ (-) |
|---|---|---|
| **50** | 5 | 0.980198 |
| **50** | 10 | 0.990050 |
| **50** | 25 | 0.996008 |
| **50** | 50 | 0.998002 |
| **50** | 100 | 0.999000 |
| **50** | OPEN | 0.9999.... |

# CST Microwave Studio

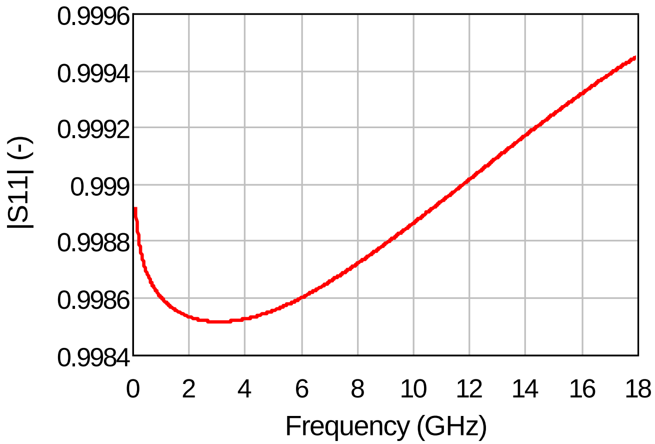
- Frequency solver
- Adaptive tetrahedral mesh refinement
  - Criterion $\Delta S = 1\cdot10^{-4}$ – reasonable trade-off
- Lossless structures
  - Better understanding
- Resistive strips
  - CrNi (supposed 10 kΩ/□)
- Glass substrate
  - Fused silica ($\varepsilon_r = 3.8$)

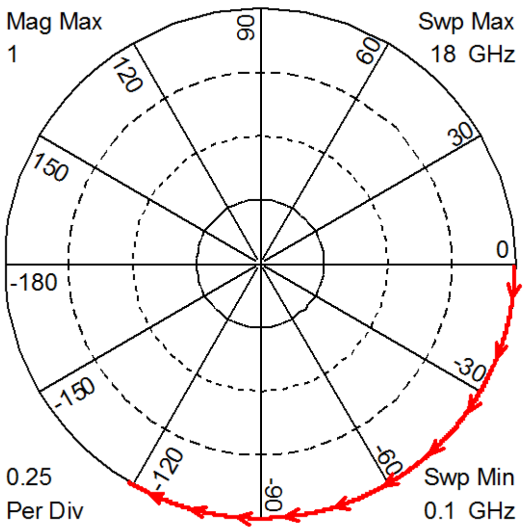


# Resistor on glass disk




S-parameter $S_{11}$ at the reference plane

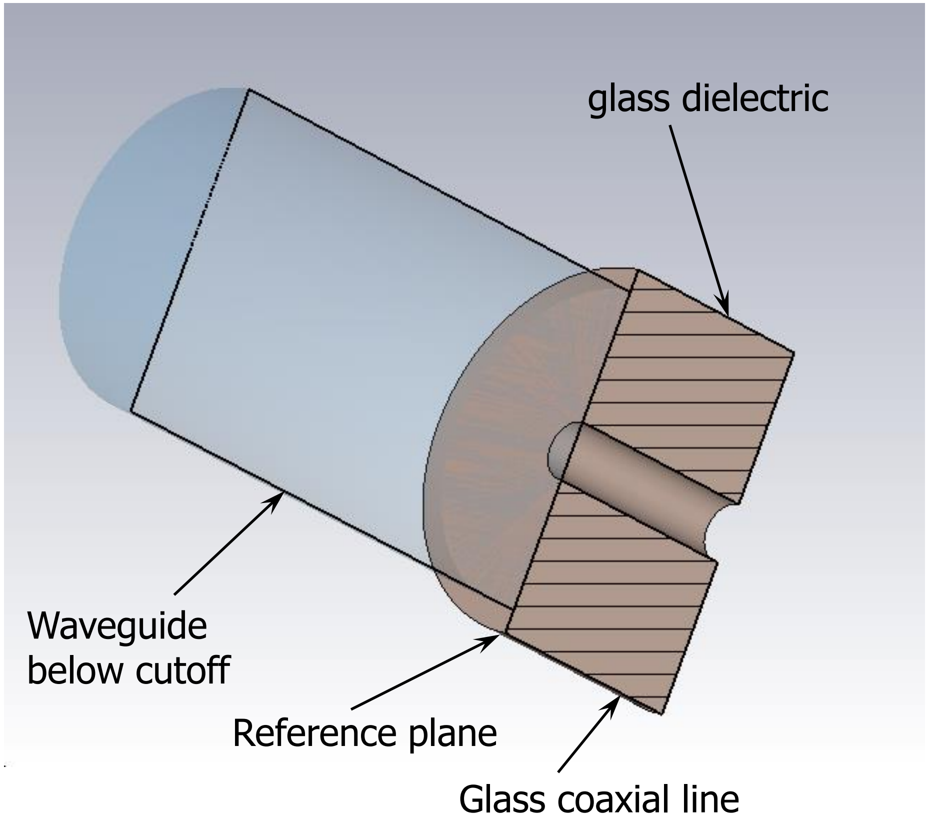


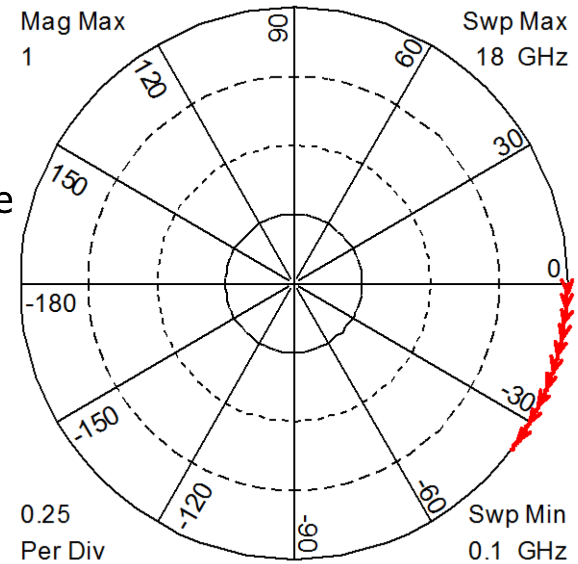

- High fringing capacity

- Parallel combination R-C
  - Short circuit at high frequencies

# Glass coaxial line

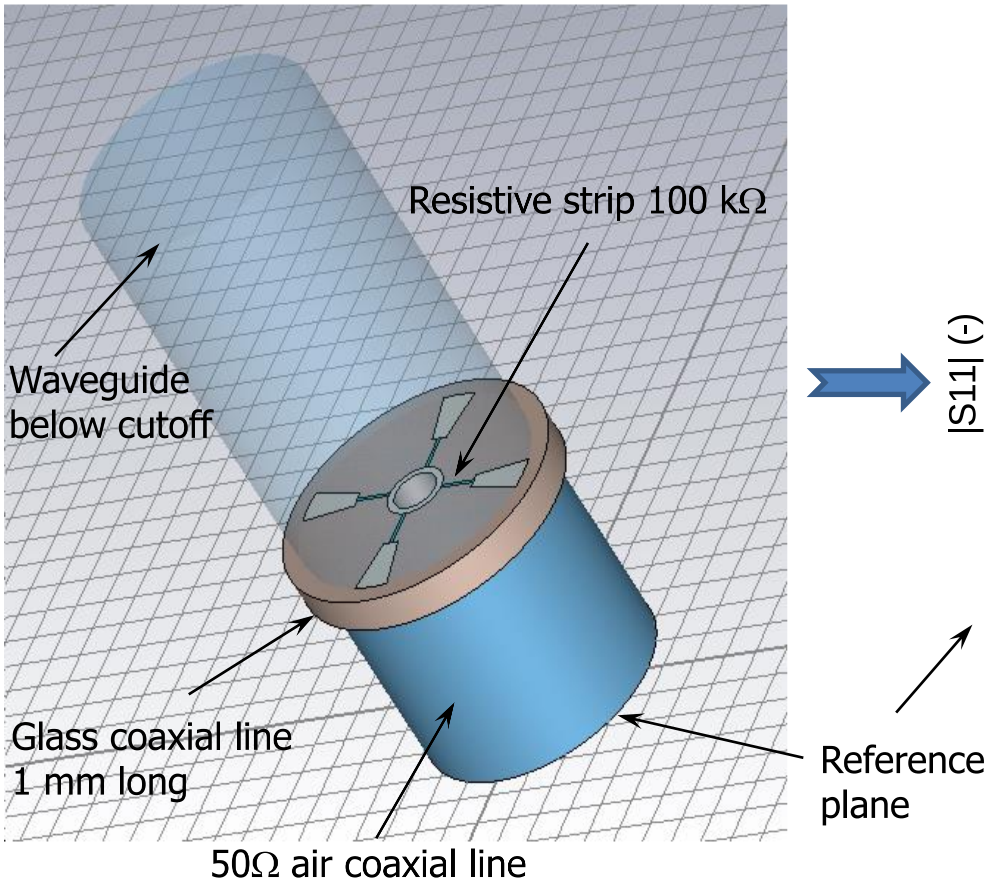


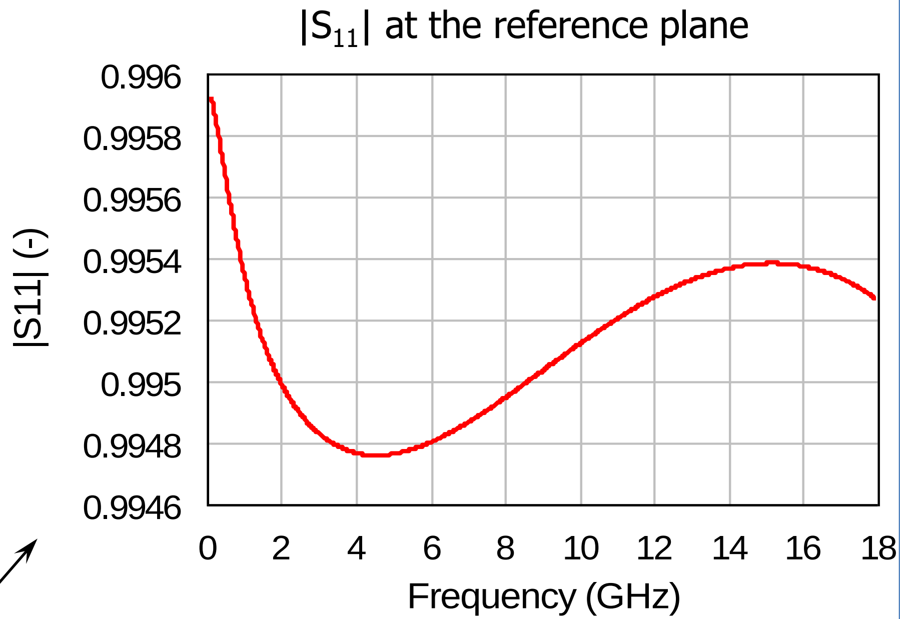

S-parameter $S_{11}$ at the reference plane




- Low fringing capacity
    - Greater differences between calibration standards

# Resistor at the end of glass coaxial line

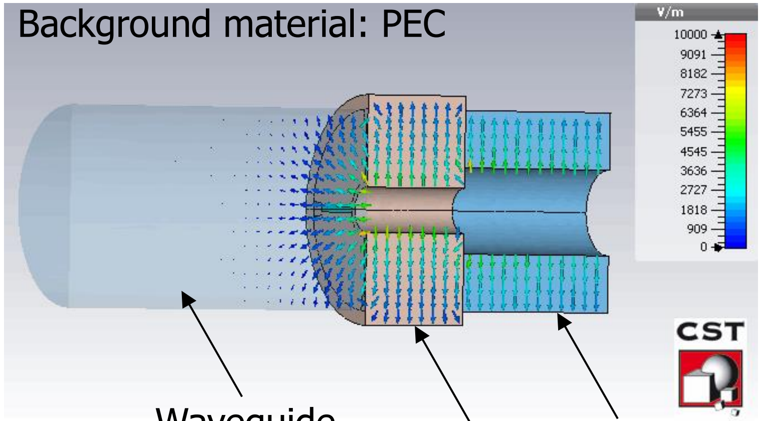


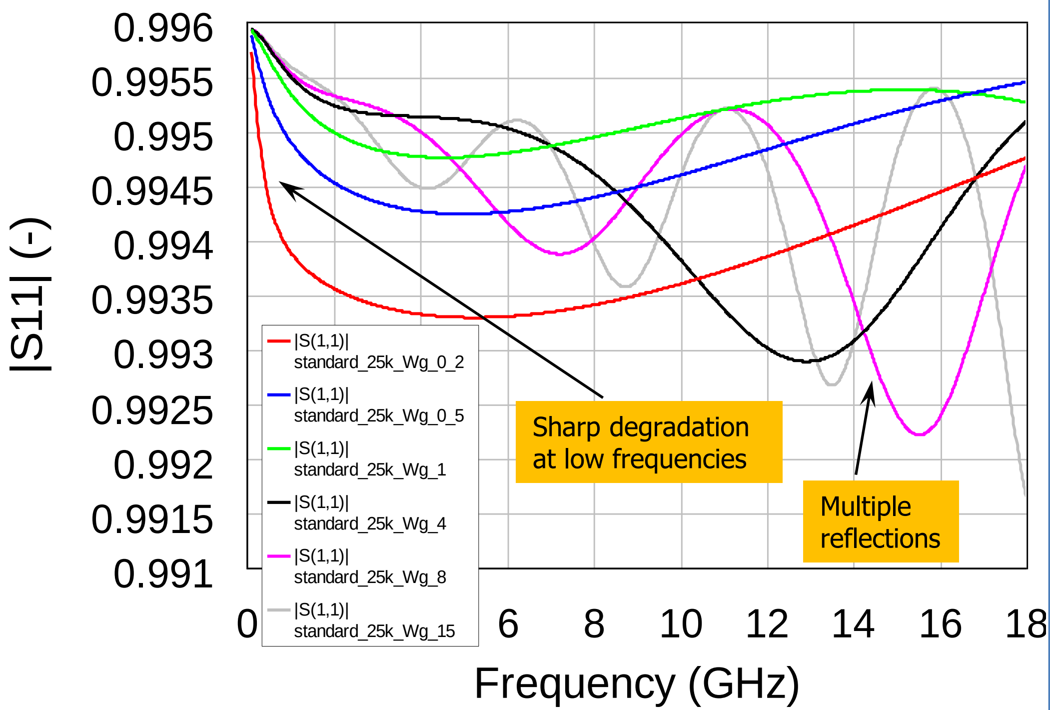




- Strong frequency dependence of reflection coefficient

Why?

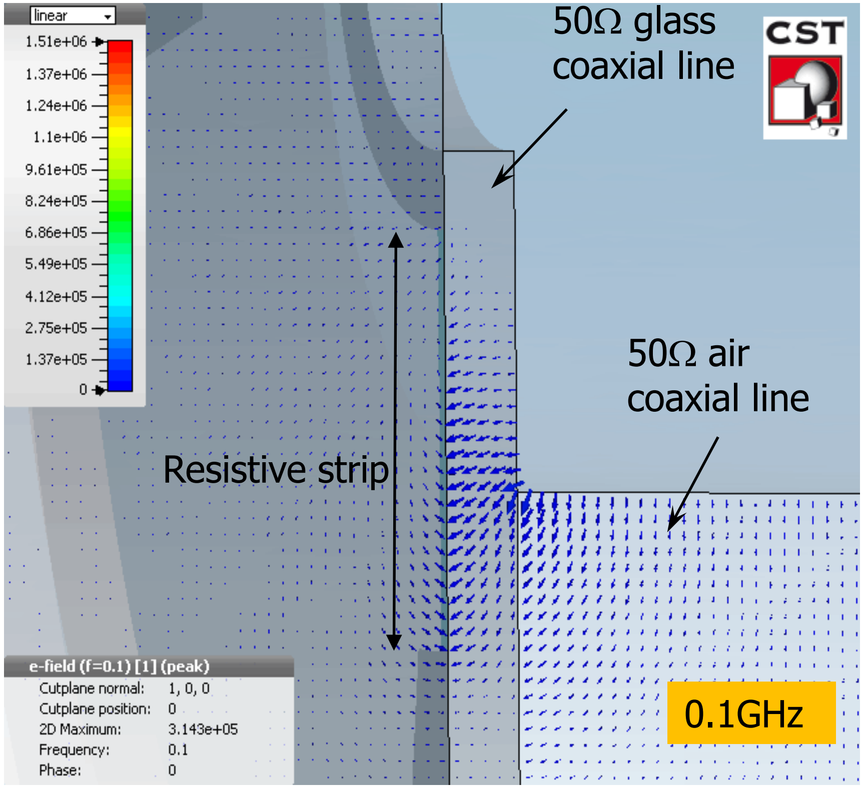
# Dependence on length of glass coaxial line

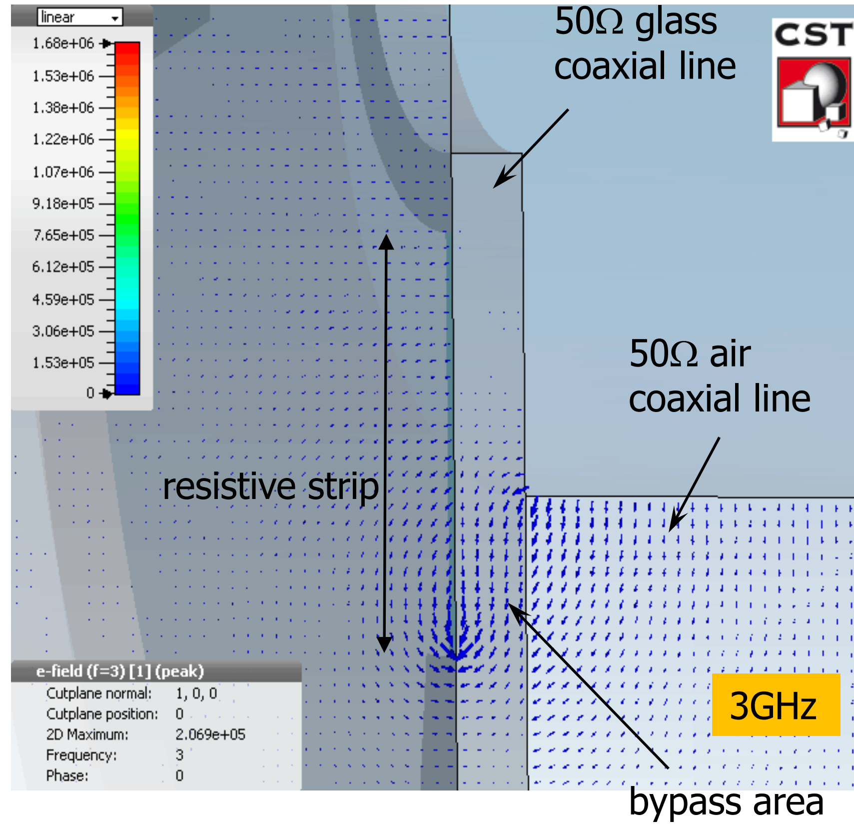



- Ripples
  - Multiple reflections at both ends of glass line - elimination by the method
- Low frequency degradation
  - Too short glass line - capacity coupling

# Low frequency degradation - 0.2 mm long glass coaxial line




- Resistor is only partially effective even on low frequencies
- Bypassed on frequencies above 3GHz

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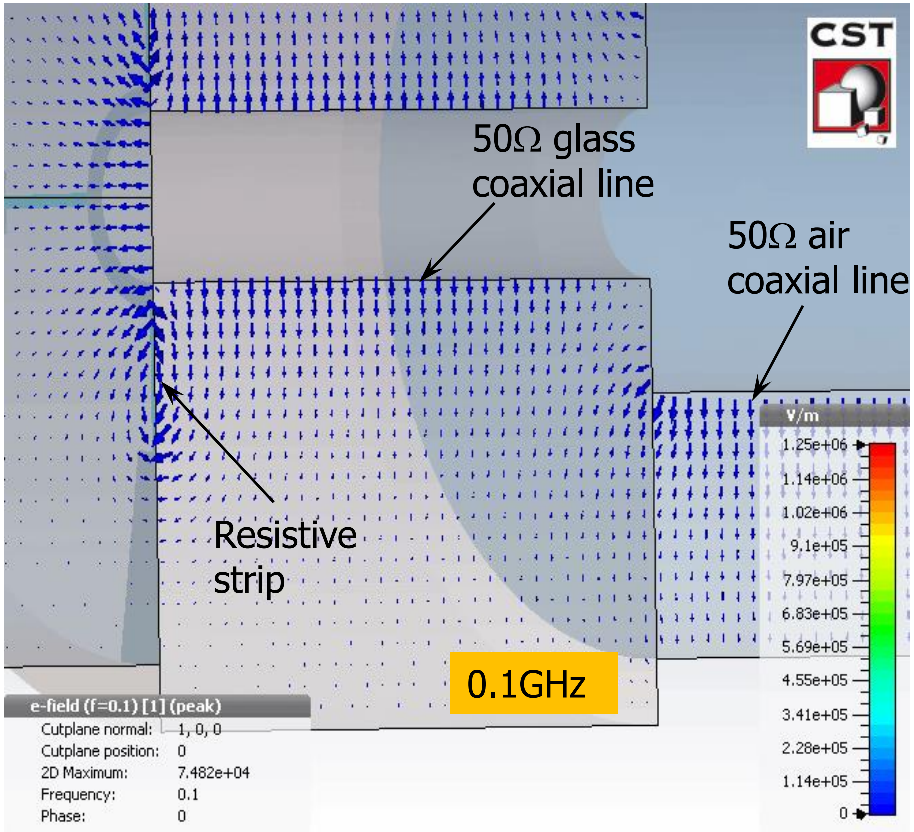
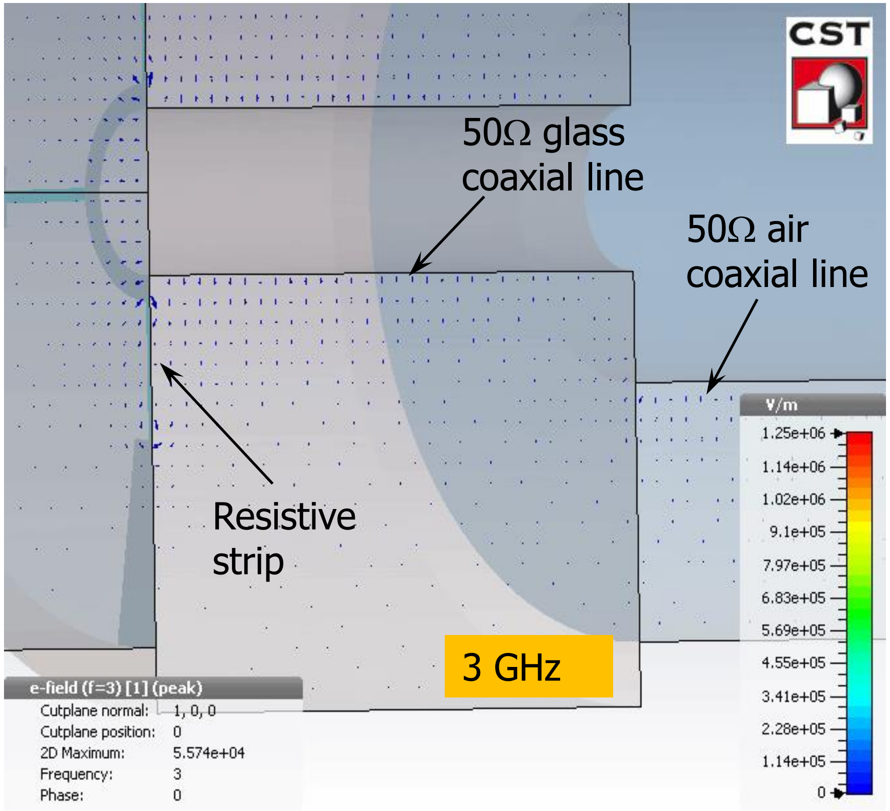
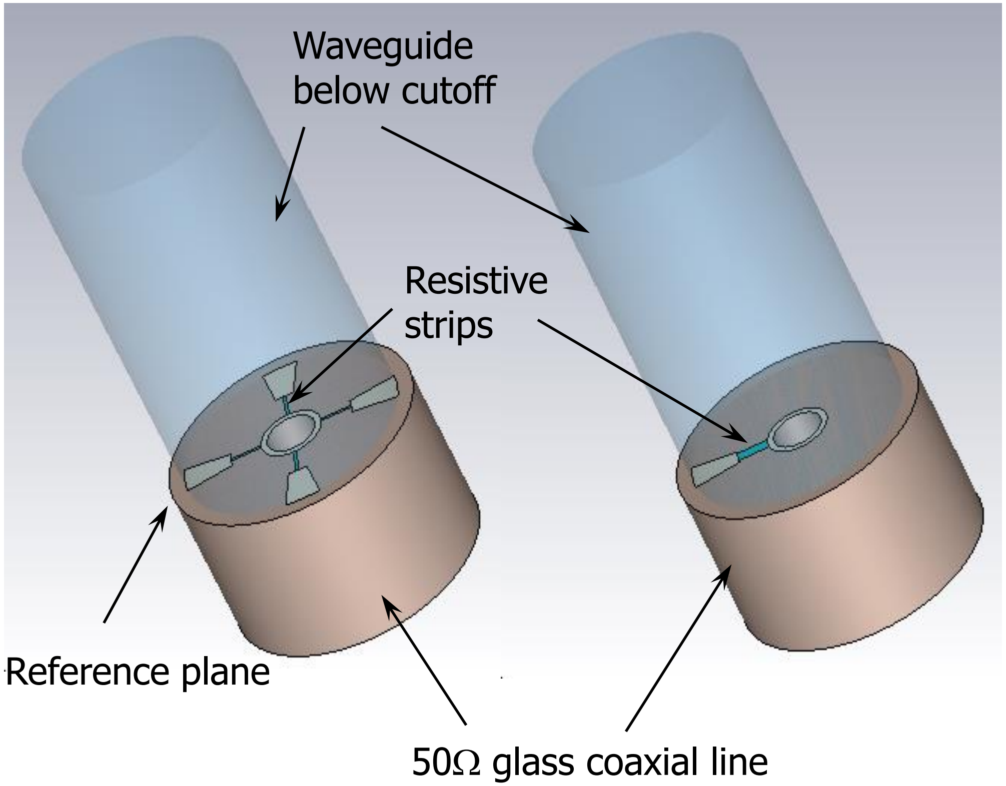
# E distribution – 5 mm long glass coaxial line

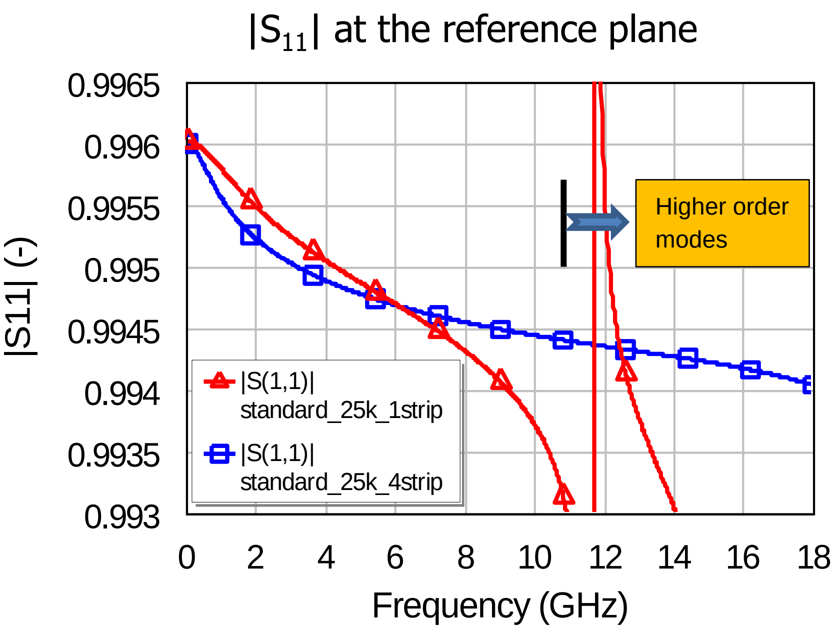



- E distribution around the resistor nearly independent

# Possible configurations




- Higher order modes limit frequency band
- Still small frequency dependence of resistive strips at low frequencies - unclear

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# Conclusion

- More possible configurations of calibration standards were studied
- Calibration standards for extreme impedance measurements based on the coaxial connector APC-7 are achievable
- Resistive strip(s) placed at the end of glass coaxial line are reasonable solution
- Future tasks
    - Technology dimension optimization
    - Uncertainties determination (mounting repeatability, HFSS simulations)
    - Fabrication of calibration/verification standards
    - Experimental verification

Thank you for your attention