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Resonances in Tapered Double-Port TEM Waveguides

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Contents

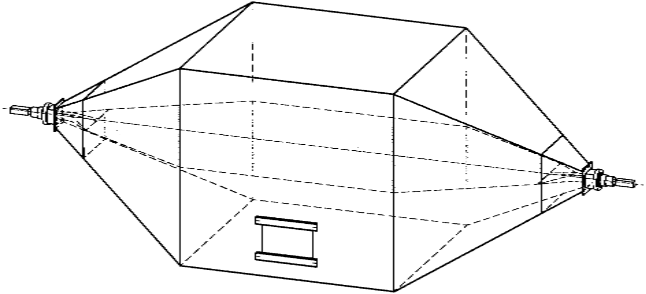
Introduction

- What are we talking about?
- What did we calculate?
- Why could this be interesting for you?

Small tapered double-port TEM waveguides

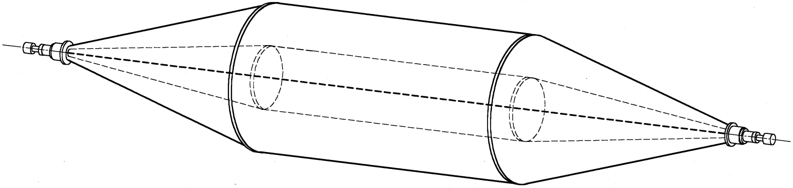
- μTEM cell, PTB, German $\vec{E}$-field standard
- μC^3 cell, proposed Circular Coaxial Calibration cell

Mechanical construction, Crawford TEM cell



- Rectangular cross section
- Flat inner conductor (Septum)

Mechanical construction, μC^3 cell



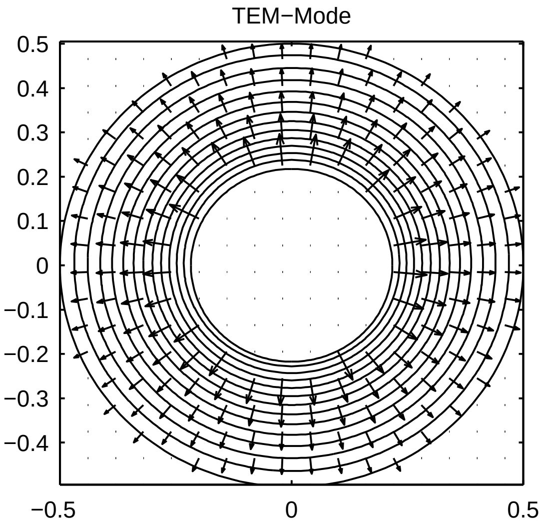
- Circular cross section
- Round inner conductor (Septum)

Analytical calculation

- Generalized telegraphist’s equations
- Resonance calculation

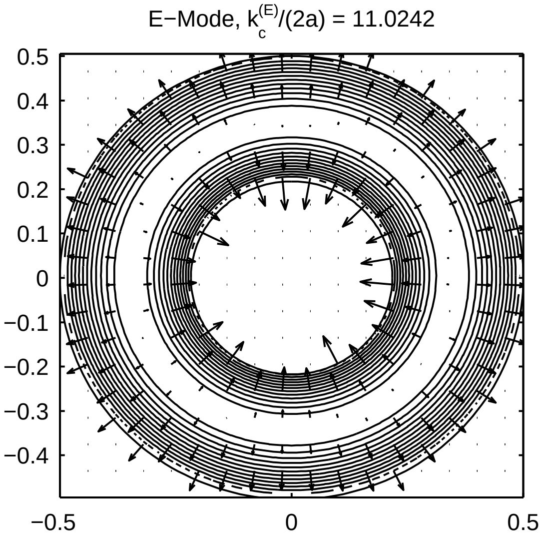
Field modes, transversal $\vec{E}$

TEM mode



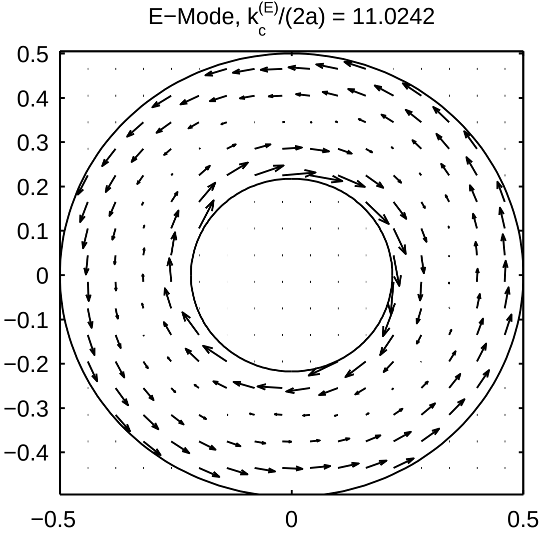
Field modes, transversal $\vec{E}$

TM_{01} mode



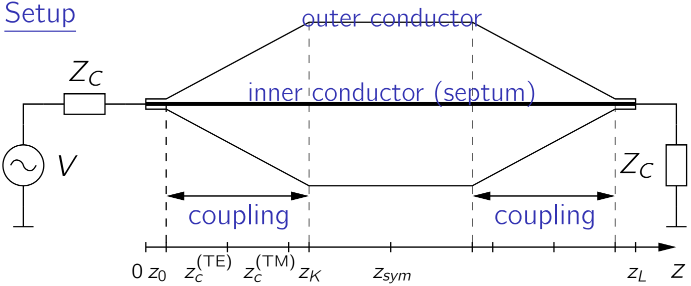
Field modes, transversal $\vec{H}$

TM$_{01}$ mode

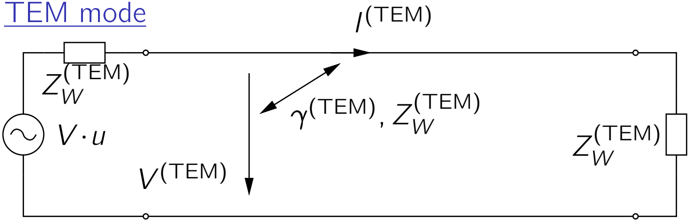


Transmission line model of a tapered TEM waveguide

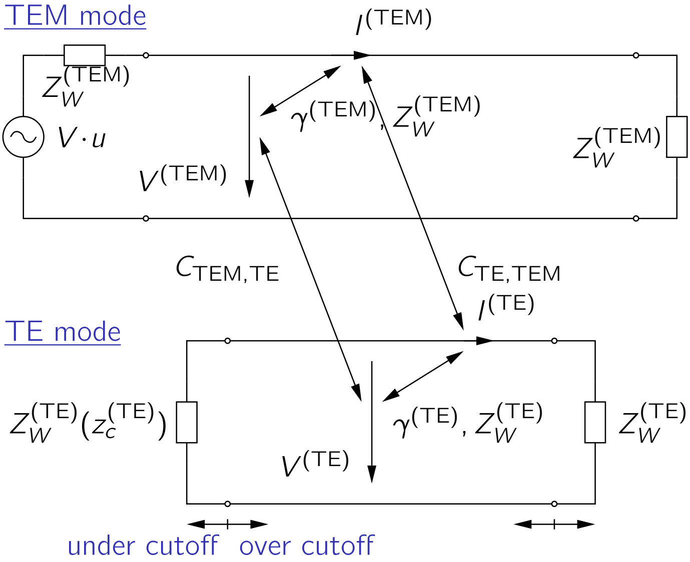
Setup



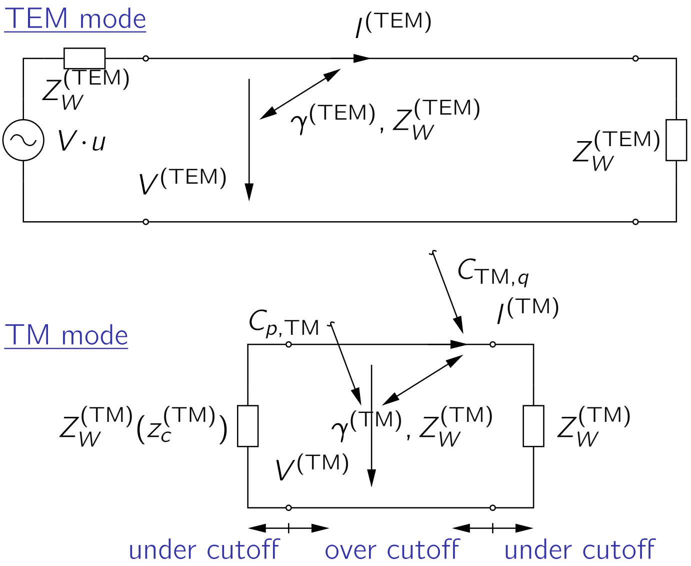
TEM mode



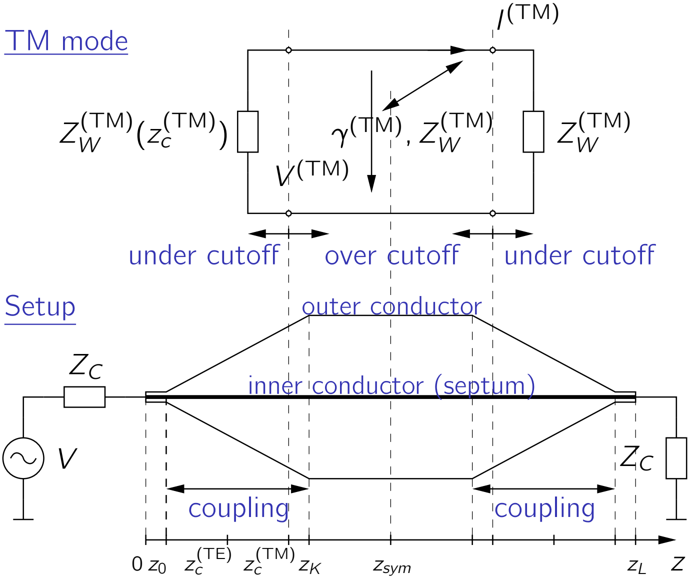
Transmission line model of a tapered TEM waveguide



Transmission line model of a tapered TEM waveguide



Transmission line model of a tapered TEM waveguide



Generalised telegraphist's equations for mode p

Using propagation constant $\gamma^{(p)}$ and wave impedance $Z_W^{(p)}$:

$$\frac{\mathrm{d}V^{(p)}}{\mathrm{d}z} = -\gamma^{(p)}(z) Z_W^{(p)}(z) I^{(p)}(z) + \sum_{q=1}^{\infty} C_{pq}(z) V^{(q)}(z)$$

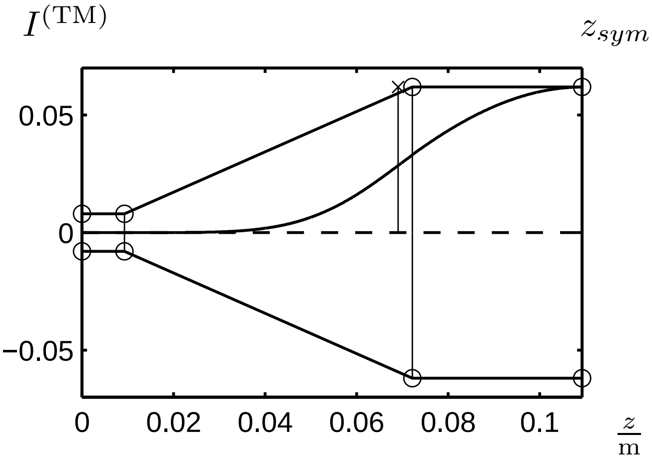
$$\frac{\mathrm{d}I^{(p)}}{\mathrm{d}z} = -\frac{\gamma^{(p)}(z)}{Z_W^{(p)}(z)} V^{(p)}(z) - \sum_{q=1}^{\infty} C_{qp}(z) I^{(q)}(z)$$

Neglecting mode coupling using wavenumber $k = \omega\sqrt{\mu\varepsilon}$:

$$\frac{\mathrm{d}^2 V_k^{(\mathrm{TE})}}{\mathrm{d}z^2} = \left(k_c^{(\mathrm{TE})^2}(z) - k^2\right) V_k^{(\mathrm{TE})}(z)$$

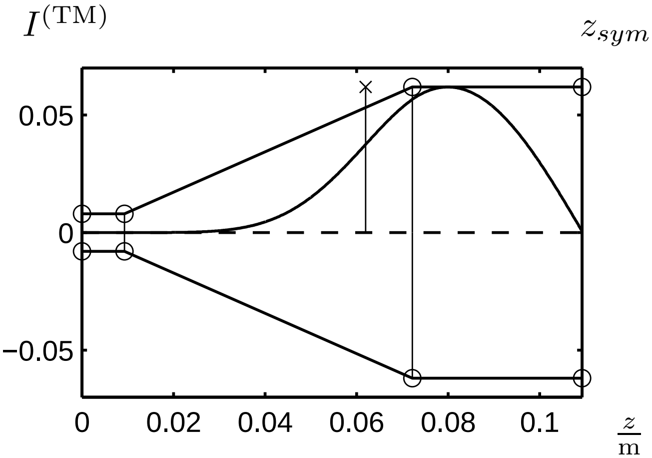
$$\frac{\mathrm{d}^2 I_k^{(\mathrm{TM})}}{\mathrm{d}z^2} = \left(k_c^{(\mathrm{TM})^2}(z) - k^2\right) I_k^{(\mathrm{TM})}(z)$$

$I^{(\mathrm{TM})}(z)$ of TM_{01} at resonance in a μC^3-cell



First resonance at $f_{res} = 4.456\mathrm{GHz}$

$I^{(\mathrm{TM})}(z)$ of TM_{01} at resonance in a μC^3-cell

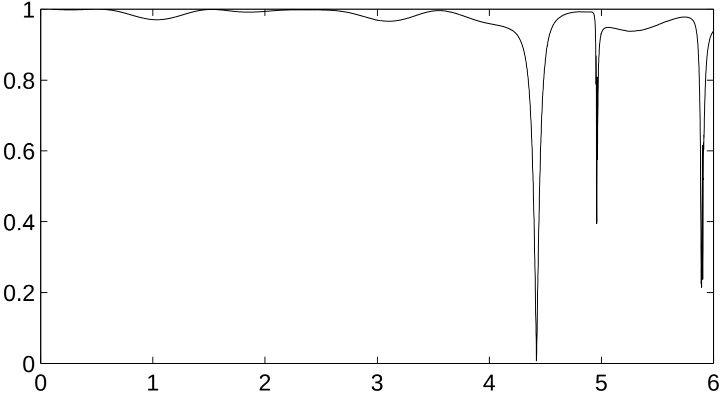


Second resonance at $f_{res} = 5.001\mathrm{GHz}$

Simulation

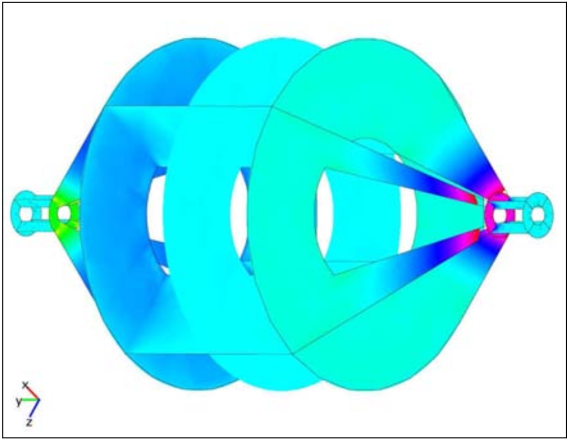
- MATLAB/NAG simulation
- FEMLAB simulation

Simulation using generalised telegraphist's equations



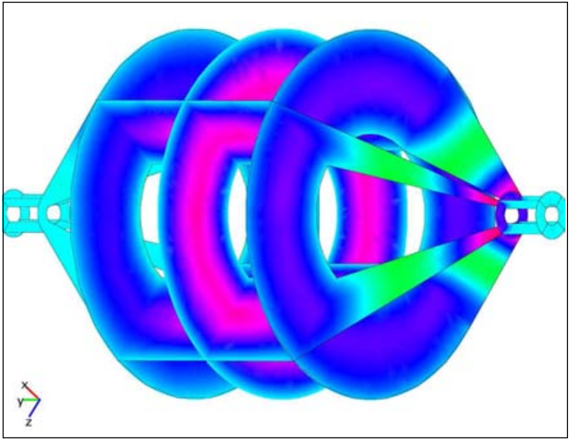
MATLAB with NAG toolbox, S_{21}, range $0 < f < 6$GHz

Longitudinal component of the electric field $\vec{E}$



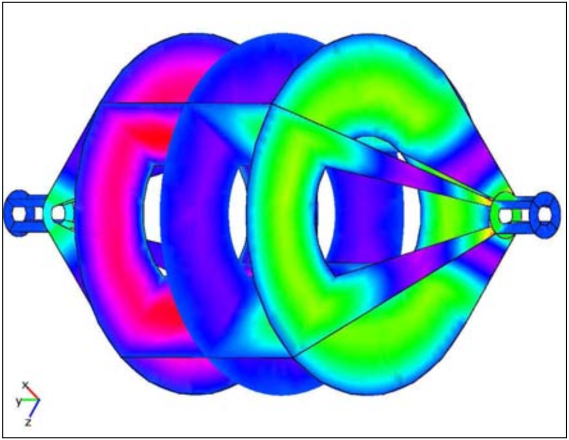
Below resonance at $f = 1\text{GHz}$

Longitudinal component of the electric field $\vec{E}$



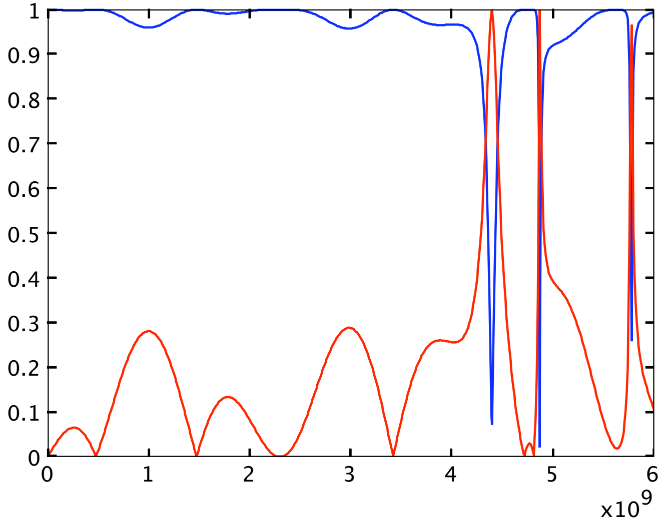
At first TM_{01} resonance $f_{\mathrm{TM}_{011}} = 4.4\mathrm{GHz}$

Longitudinal component of the electric field $\vec{E}$



At second TM_{01} resonance $f_{TM_{012}} = 4.9\text{GHz}$

Simulation using FEM model, FEMLAB with RF toolbox

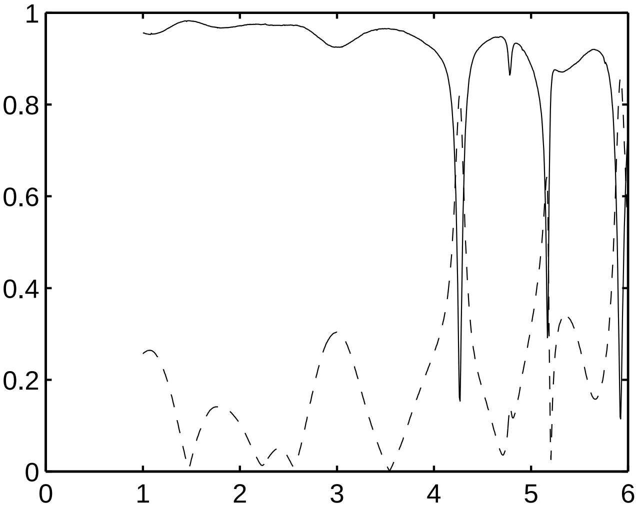


S_{11}, S_{21}, range $0 < f < 6\text{GHz}$

Measurements

- Comparison with analytical calculations
- Comparison with simulation results

Simulation using FEM model, FEMLAB with RF toolbox



S_{11}, S_{21}, range $0 < f < 6$GHz

Conclusion

Conclusion

- An analytical method for the calculation of resonant frequencies has been presented
- A comparison of results obtained using two different simulation methods
  1. Generalised telegraphist's equations (MATLAB with NAG toolbox)
  2. FEM model (FEMLAB with RF toolbox)

  and measurents shows close agreement
- Simulations can be benchmarked using this analytical method