Evaluation of Material Characterization Systems that Utilize a Two-Wire Transmission Line

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Introduction

Two-wire transmission lines are open structures that can easily interact with the surrounding environment. This allows for *in-situ* material characterization unlike waveguide or coaxial probe methods. We assume balanced currents.

- The biggest advantage for characterization, the open structure, may also be the most problematic because the line interacts with the environment more than other techniques
- The behavior of the line is effected by the surrounding media and structures; terminations; and conductor size, spacing, and conductivity.
- Materials (solid, liquid, gas, plasma) fully surrounding the line may be characterized. Continuous, *in-situ* monitoring is possible and can be incorporated into existing structures.
- NRW extraction technique usable for 2-port measurements as line is a TEM structure.
- Investigated here is how the line is affected in characterization scenarios

Conclusion

- Fields strongest between conductors
- Permittivity most influential on line behavior
- Load and length strongly dictate radiation for electrically short lines
- Length and/or load can be adjusted to give minimum (or maximum) radiation
- Sample side length should be at least 5(D-2a), length of 10 or 20 times (D-2a)
- Structures should be at least 6(D-2a) away from center of the line

Future Work

- Material filling only the gap between wires
- Investigate higher order mode and cut-off frequencies
- Experimental investigations

References

- R. W. P. King, *Transmission-Line Theory*. New York: McGraw-Hill, 1955
- S. Ramo, J. R. Whinnery, & T. Van Duzer, *Fields and Waves in Communication Electronics*, 3rd ed. New York: Wiley, 1994
- R. Plonsey & R. E. Collin, *Principles and Applications of Electromagnetic Fields*. New York: McGraw-Hill, 1961.
- Hewlett-Packard Product Note 8510-3, "*Measuring Dielectric Constant with the HP 8510 Network Analyzer*" 1985.
- A. Temme and E Rothwell. 2014 URSI North American Radio Sci. Mtg.

Acknowledgements

Poster template from CIRTL network and H. Adam Steinberg - adam@artforscience.com

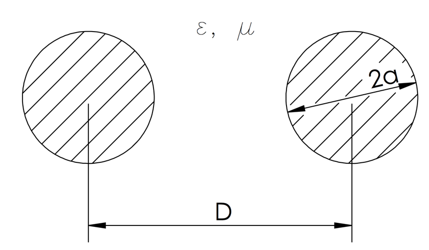
Availability

This poster and supporting files are available at github.com/temmeand and gitlab.msu.edu/temmeand in the **Temme-and-Rothwell-URSI-2015** repostiory.

Mathematical Model

$$R = \sqrt{\frac{\omega\mu_c}{2\pi^2 a^2 \sigma_c [1-(2a/D)^2]}} \qquad L = \frac{\mu}{\pi}\cosh^{-1}\left(\frac{D}{2a}\right)$$

$$G = \frac{\omega\pi\epsilon''}{\cosh^{-1}(D/2a)} \qquad C = \frac{\pi\epsilon'}{\cosh^{-1}(D/2a)}$$



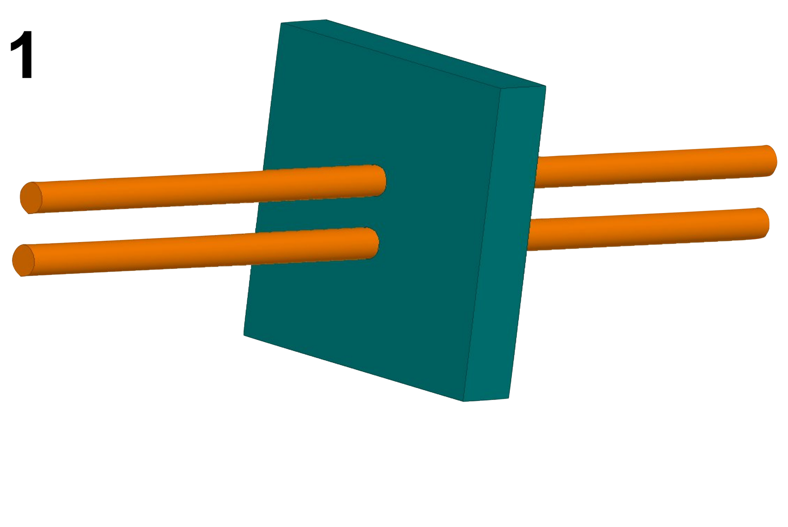
$$S_{11} = S_{22} = \frac{j\sinh(\gamma l)(Z_0/Z_{ref} - Z_{ref}/Z_0)}{2\cosh(\gamma l) + jsinh(\gamma l)(Z_0/Z_{ref} + Z_{ref}/Z_0)}$$

$$S_{12} = S_{21} = \frac{2}{2\cosh(\gamma l) + jsinh(\gamma l)(Z_0/Z_{ref} + Z_{ref}/Z_0)}$$

Possible Measurement Configurations

A two-wire transmisison line could be placed into various configurations for material characterization including through a sample (1), into a liquid or gel in a tank (2), into a gas flow (3), or into a plasma chamber (3).

1



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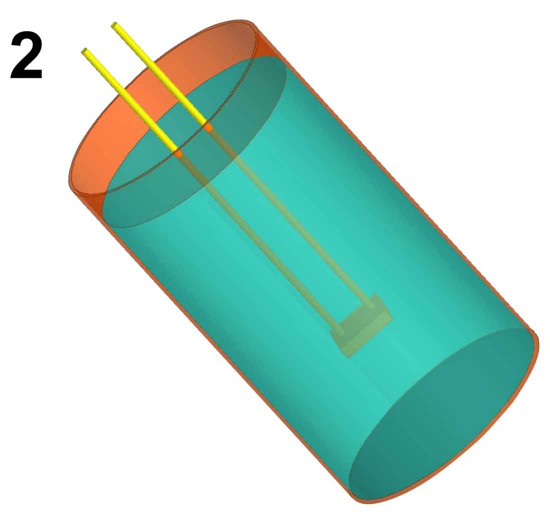

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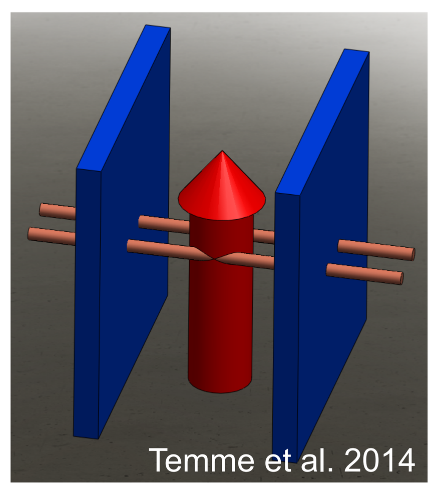

Electrostatics

The electric field is strongest between the two wires. The potential and field strength decay radial outward.

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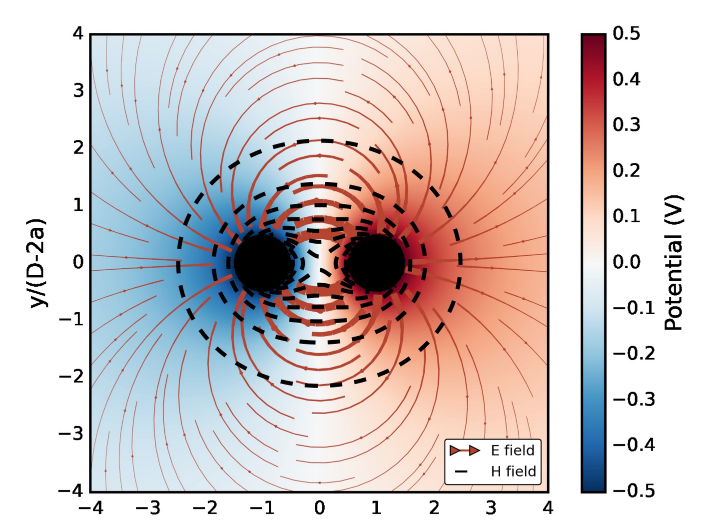

Fig. 4. The electric potential (background shading) shown behind the electric field lines (red streamlines) and magnetic field lines (black, dashed lines) of a two-wire transmission line.

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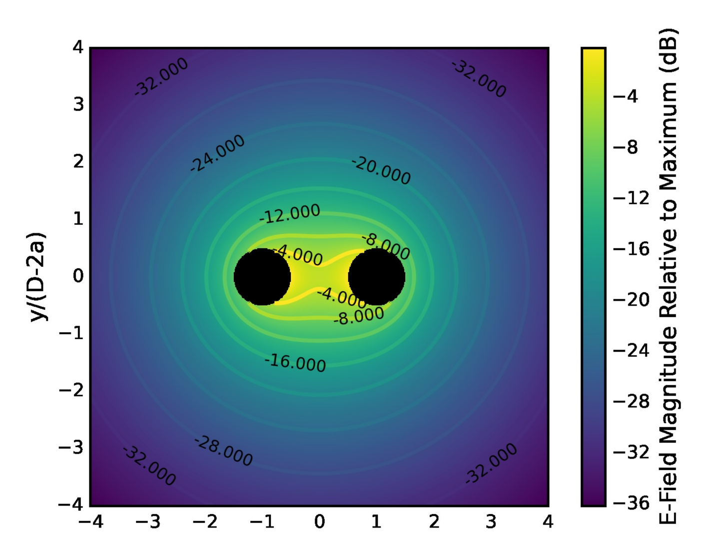
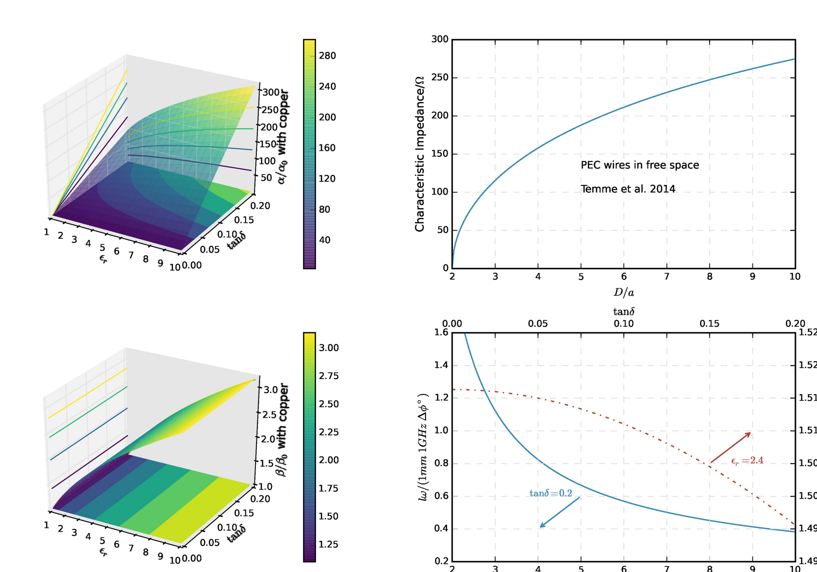


Fig. 5. The electric field strength relative to the maximum strength.

Sensitivity

Fig. 6. Attenuation **(a)** and phase **(b)** constant shown versus permittivity and loss tangent. Input impedance **(c)** shown versus size ratio. Normalized length **(d)** required for a 1 deg change in propagation.

6a b c d



Radiation

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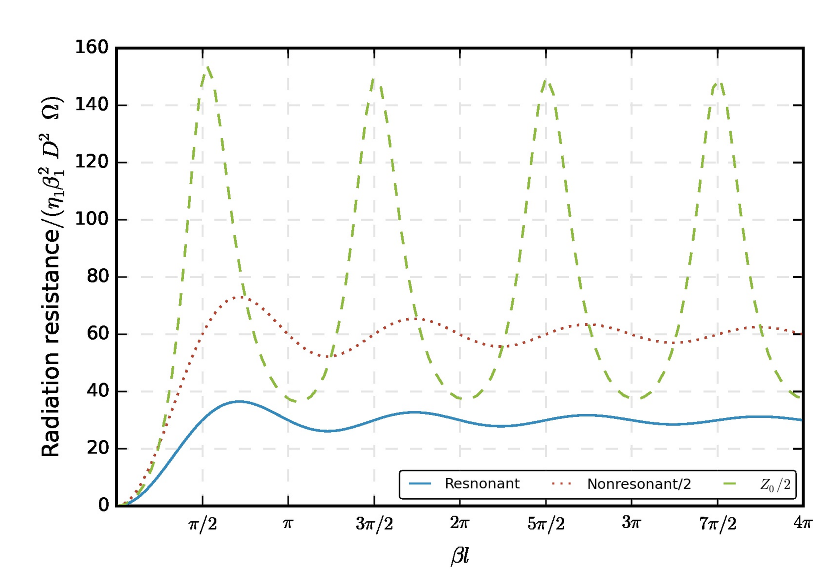

Radiation occurs because of the opposite directed currents being slightly separated. The load effects the standing waves and radiated fields.

Critical Dimensions

Fields are effected by sample size and nearby tructures.

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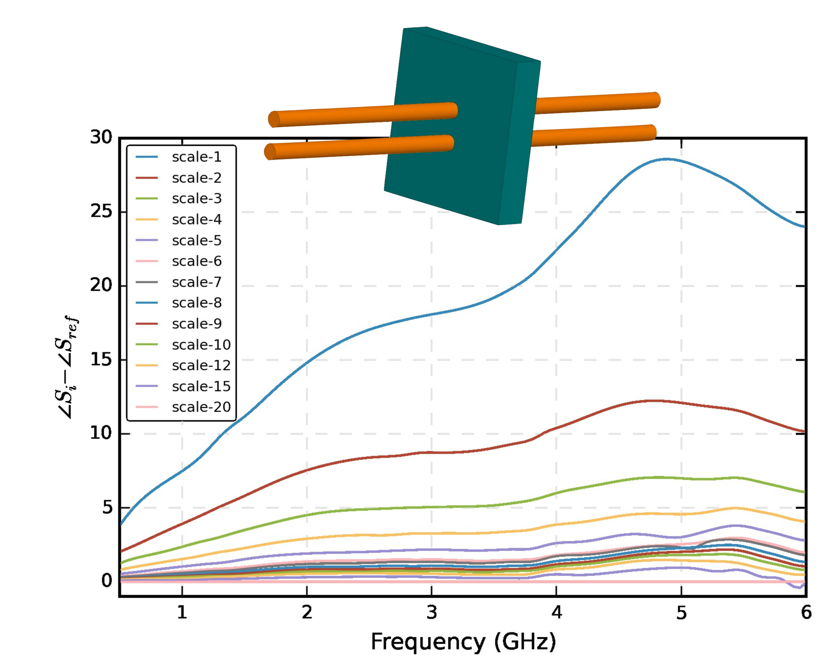

Fig. 8 The difference between phases of various side lengths and the longest side length shows how sample size affects transmission parameters.

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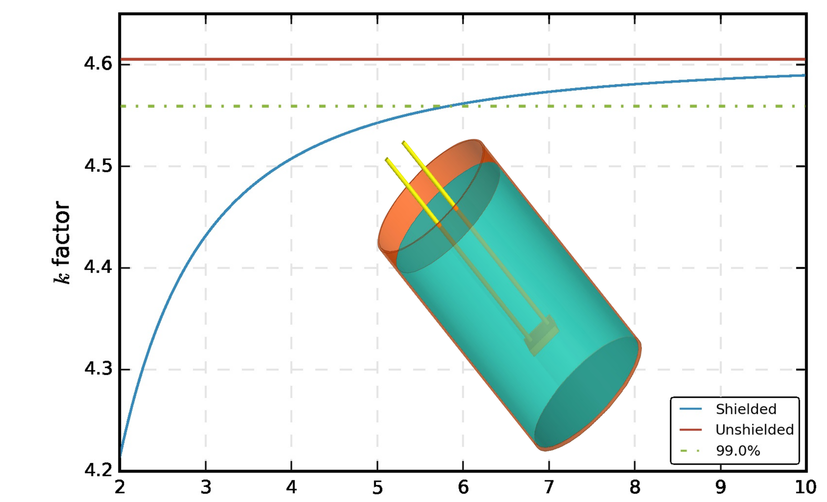

Fig. 9 Structure walls closer than approx 6 times the line gap have effects on two-wire transmission line parameters.

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