RF Absorber Studies Using Transmission Lines

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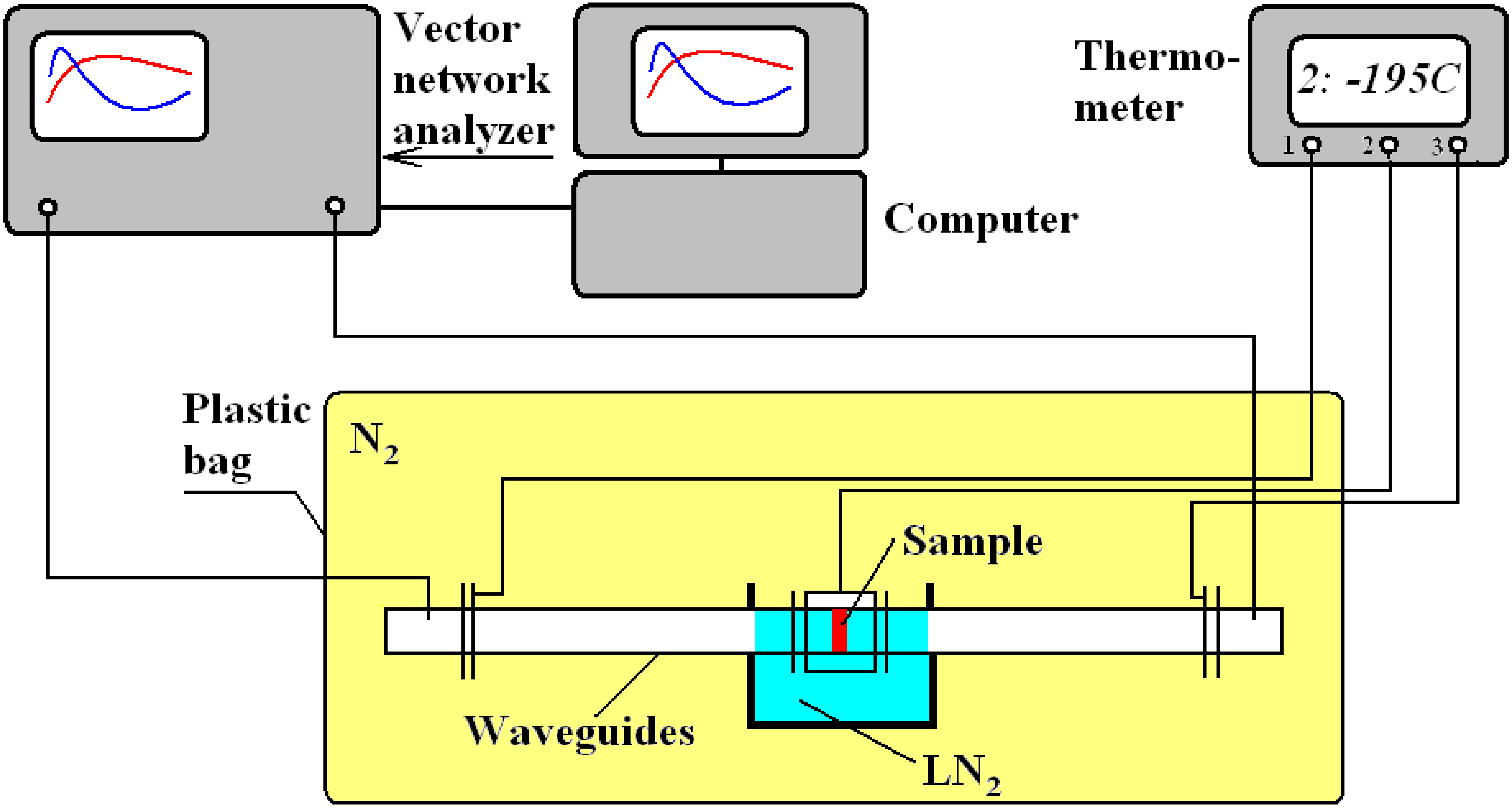
Transmission lines and samples for 4 frequency ranges: from 1 to 40 GHz

Schematic of measurements



From S11 and S21 to ε and μ

- All these values are complex, so from 4 numbers for S11 and S21 you can analytically find 4 numbers: $\varepsilon = \varepsilon' - \varepsilon''$ and

  $\mu = \mu' - \mu''$.

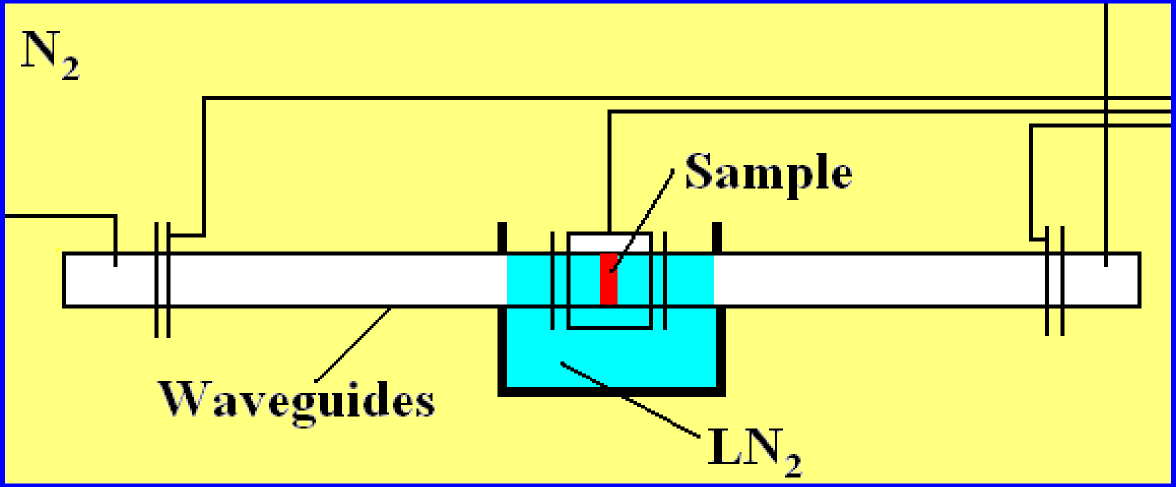
  For details see Walter Hartung, PhD Thesis, Cornell University, Ithaca, NY, 1996; http://www.lns.cornell.edu/public/SRF/1993/SRF930113-01/SRF930113-01.pdf

- Restrictions: the sample should be thin enough, the errors increase if they are thicker than wavelength. They become small, brittle and imperfections add more to the errors of measurements.

Effects of Cooling down

- Measurements at LN temperature should be done under a positive pressure in atmosphere of dry nitrogen and the waveguides should be also preliminarily "washed" with dry N to exclude ice formation because water has ε ~ 80.

- Leaks in the waveguide connections on opposite sides of the sample are not equal, so the pressure drops (about factor of 2!) not equally on the two sides of the sample and it will be moved along the w/g like a piston. To prevent this and also suction of liquid into the w/g, small holes were made in the walls near the ends of w/guides.



More tricks with measurements

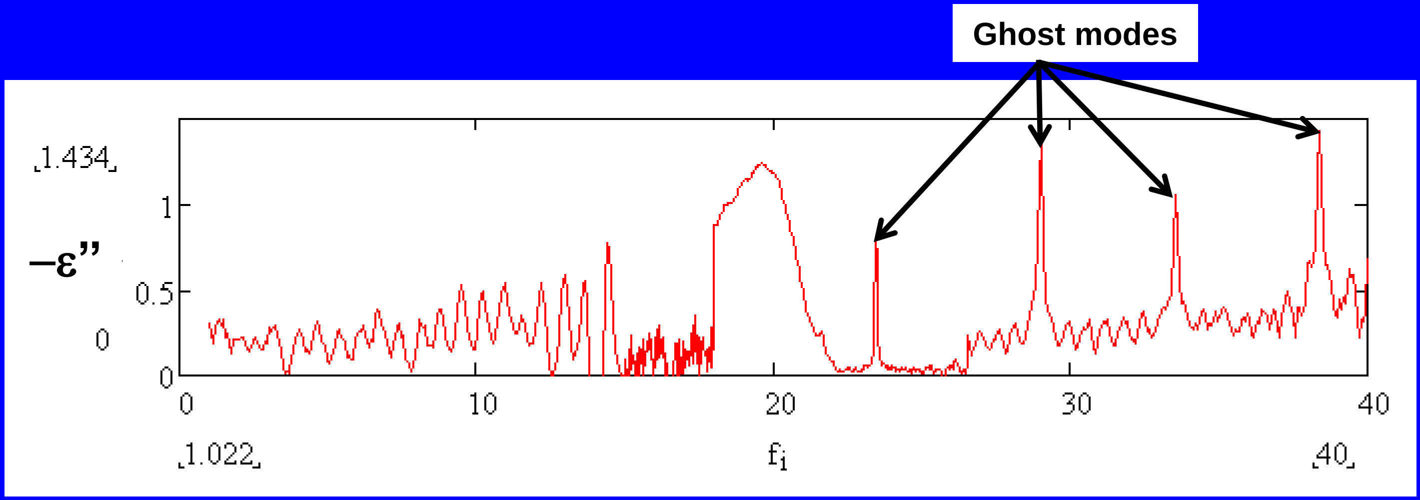
- **Position of the sample in the transmission line defines the phase of reflection. First it was measured with calipers. Having both measurements S11 and S22 makes possible to exclude mechanical measurement.**

- **Better reproducibility is obtained when using a torque wrench to consistently tighten bolts to 10 or 15 N·m.**

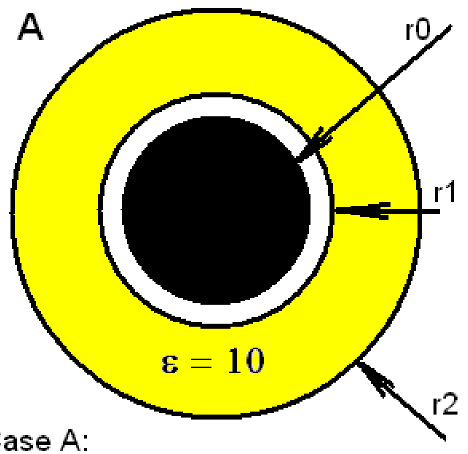
- **Cables to the waveguides should be fixed in place when w/guides are connected and disconnected in the calibration (TRL) and in measurements. Any shift of cables leads to additional errors.**

Unexpected “ghosts”

In the measurements of S-parameters, we revealed some resonant peaks that do not correspond to half-wave length of the samples: we used sufficiently short samples to avoid these resonances. Analysis has shown that these are ghost-modes described by Forrer and Jaynes in 1960. These modes are orthogonal, no coupling would be expected under ideal conditions. However, imperfections, such as slight tilt, uneven thickness can provide the modal coupling .



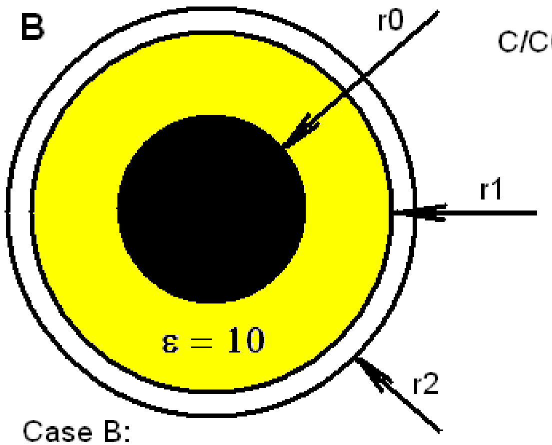
Source of errors in the measurements with a coaxial line



Case A:

$$\frac{\Delta C}{C_0} = -\frac{\varepsilon - 1}{\ln(r_2/r_0)} \cdot \frac{\Delta r}{r_0}$$

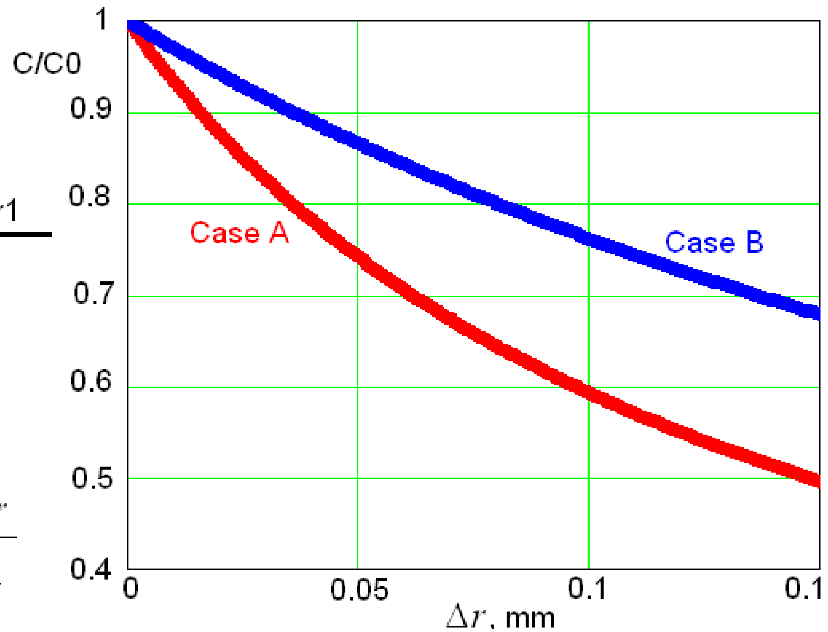
$$\Delta r = r_1 - r_0$$



Case B:

$$\frac{\Delta C}{C_0} = -\frac{\varepsilon - 1}{\ln(r_2/r_0)} \cdot \frac{\Delta r}{r_2}$$

$$\Delta r = r_2 - r_1$$



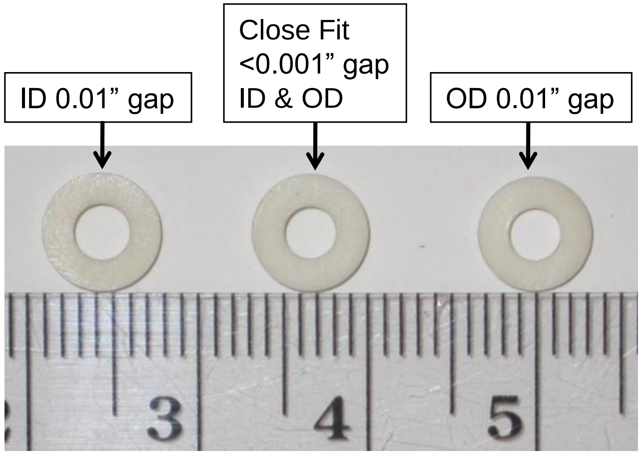
Capacitance decreases in both cases.
For 50 Ohm line and ε = 10, the multiplier in formulas before $\frac{\Delta r}{r}$ is close to 10.

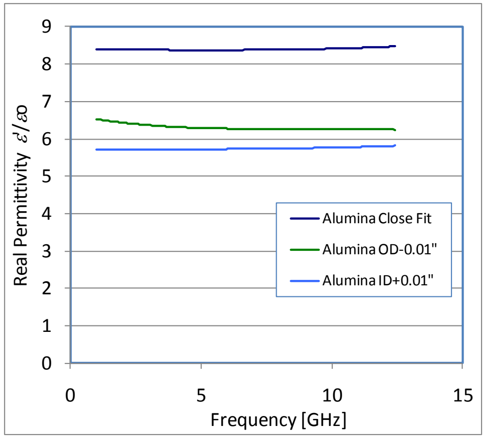
For 1 % of error in the inner conductor, r0 = 1.52 mm, the error of capacity is 10 %.
10 % of error (0.15 mm) lead to 50 % in capacity.

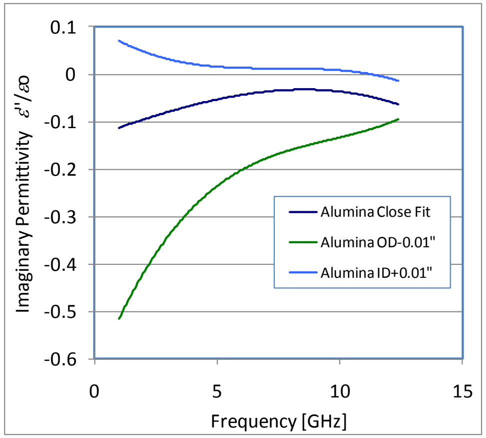
Smaller value of capacity will be interpreted as smaller value of ε. This is just what is seen in the measurements.

Test bench: Alumina has ε = 9.8

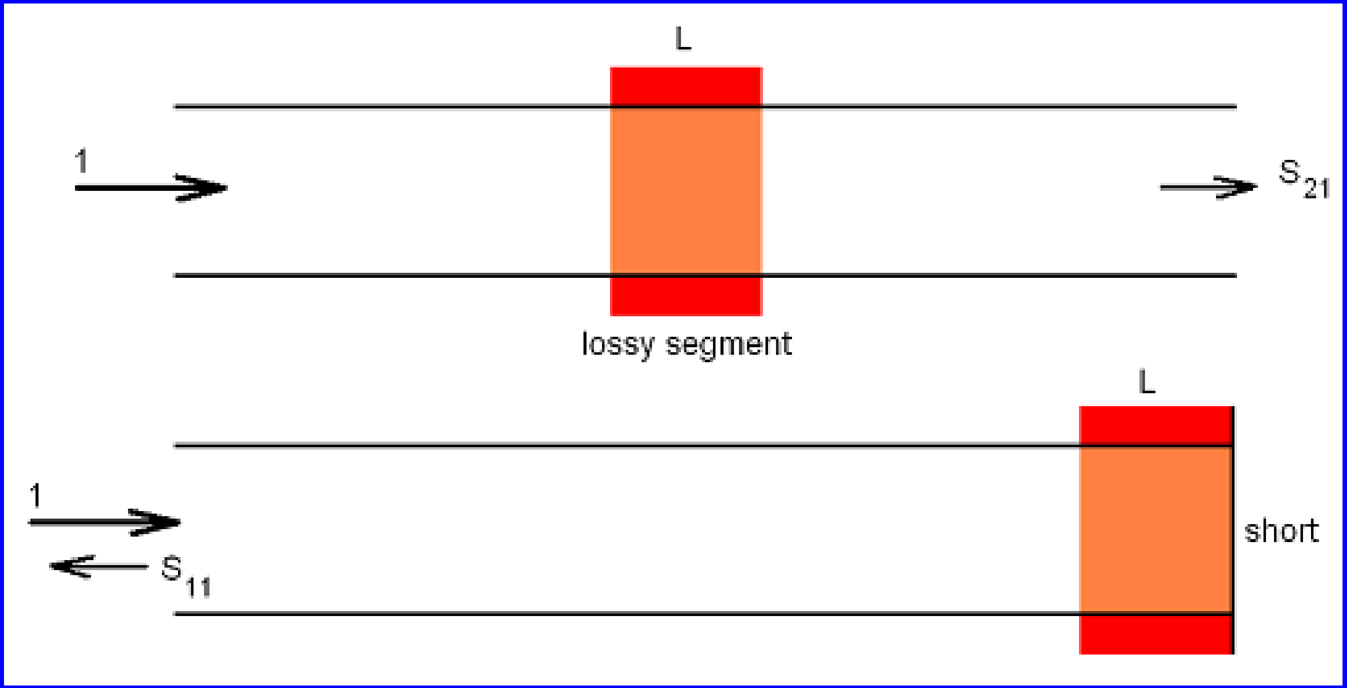
Three alumina coax samples, ~99% pure.





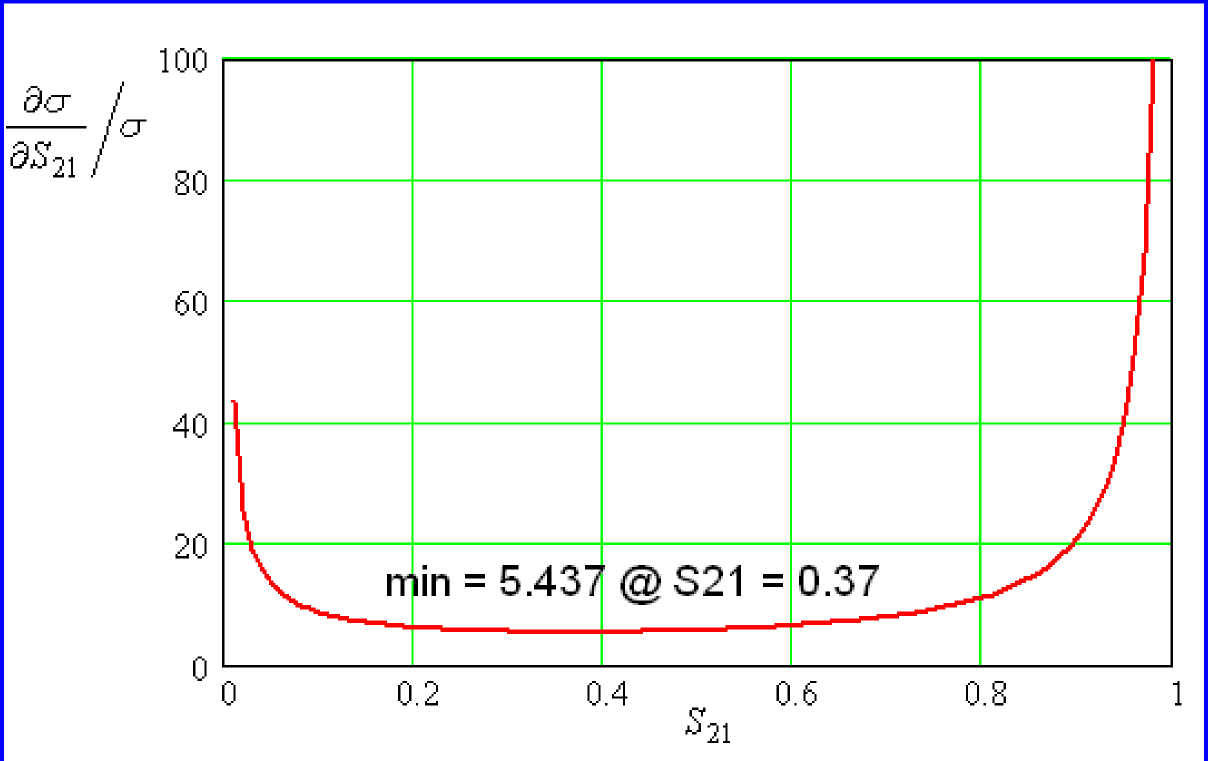


Measurement of conductivity of waveguide walls



Formulas for dependence of conductivity on the S21 or S11, length and cross-section of a lossy waveguide, and frequency are derived in: http://www.lns.cornell.edu/public/ERL/2010/ERL10-1/ERL10-1.pdf

Logarithmic derivative of conductivity with respect to S21



For accurate measurement of conductivity, the absorption in the waveguide should not be very small or too big, this can be adjusted by the length of the absorber.