Measurements of high values of dielectric permittivity using transmission lines

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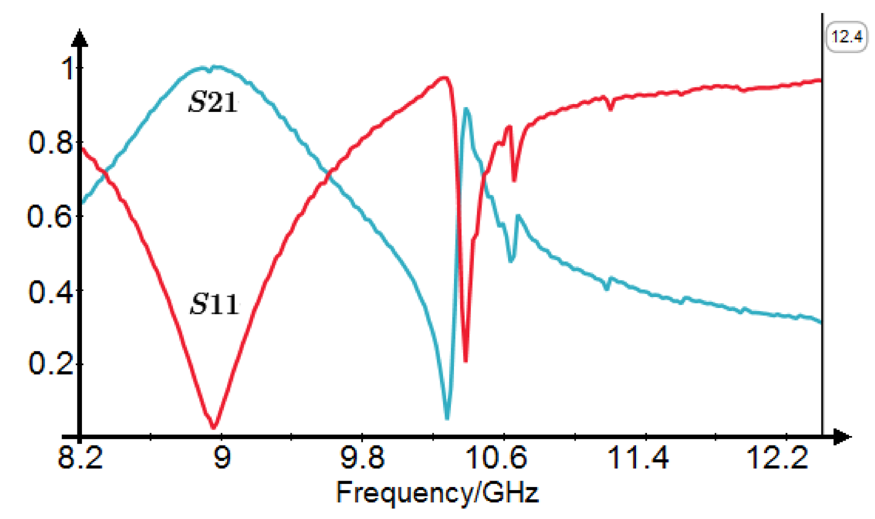
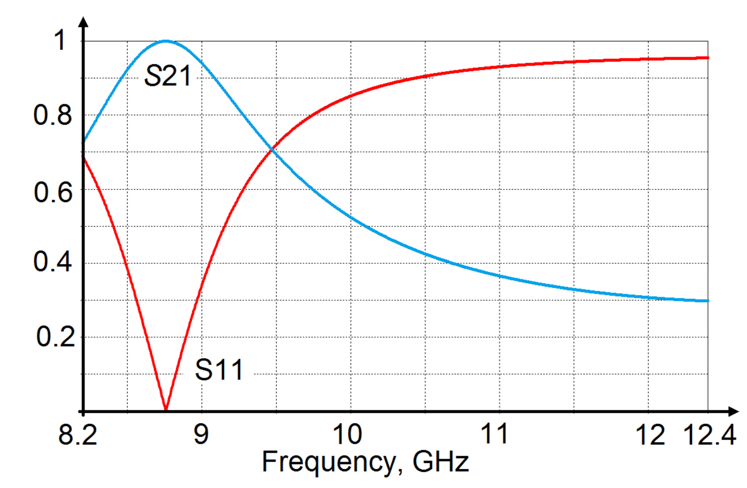
Main Statement

Usage of lossy materials is necessary for absorption of higher order modes excited in the RF cavities. Presently, measurements of lossy materials with usage of transmission lines give errors rapidly increasing with increase of the dielectric permittivity. A method is presented for measurements of high values of dielectric permittivity ε in a waveguide at high frequencies with lower errors. This method supplements the method of measurements evolved for low values of ε and is close to resonant methods, when a sample is placed into a cavity and the measurement is done at one only frequency. The new approach with use of Microwave Studio simulations makes possible to measure this value in several frequency points at one measurement.

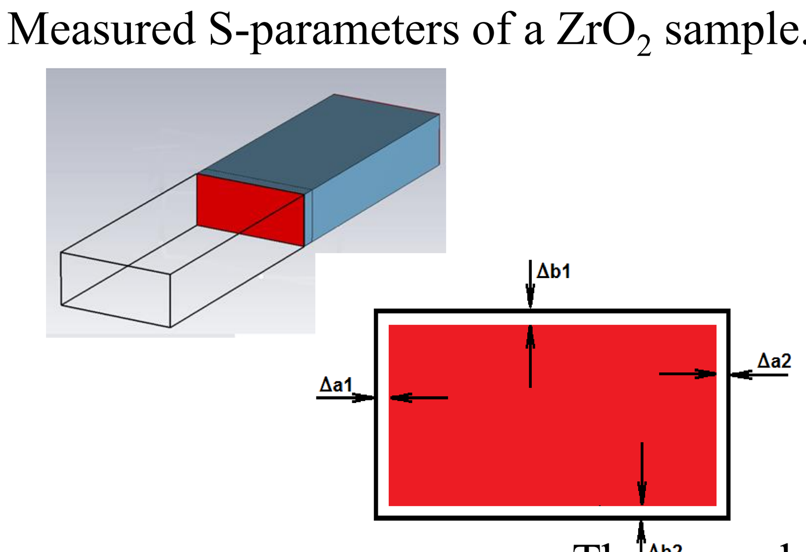
Measurement and simulation of a real dielectric sample



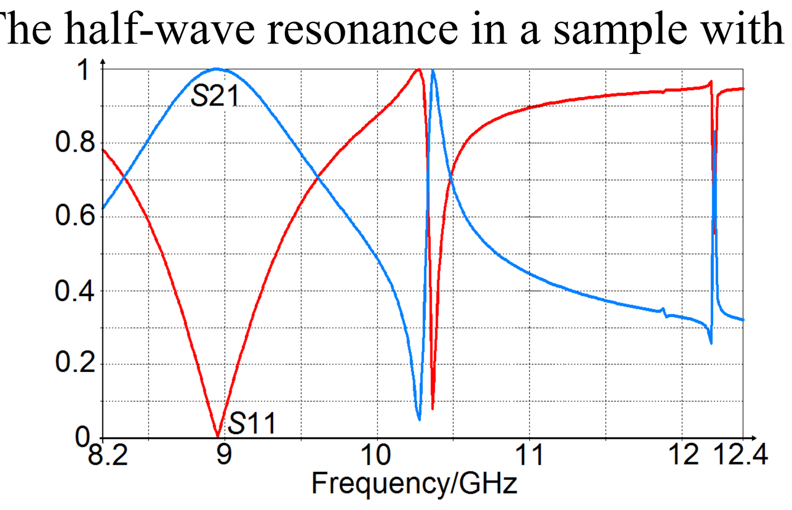
Measured S-parameters of a ZrO_2 sample.



The half-wave resonance in a sample with ε = 30.

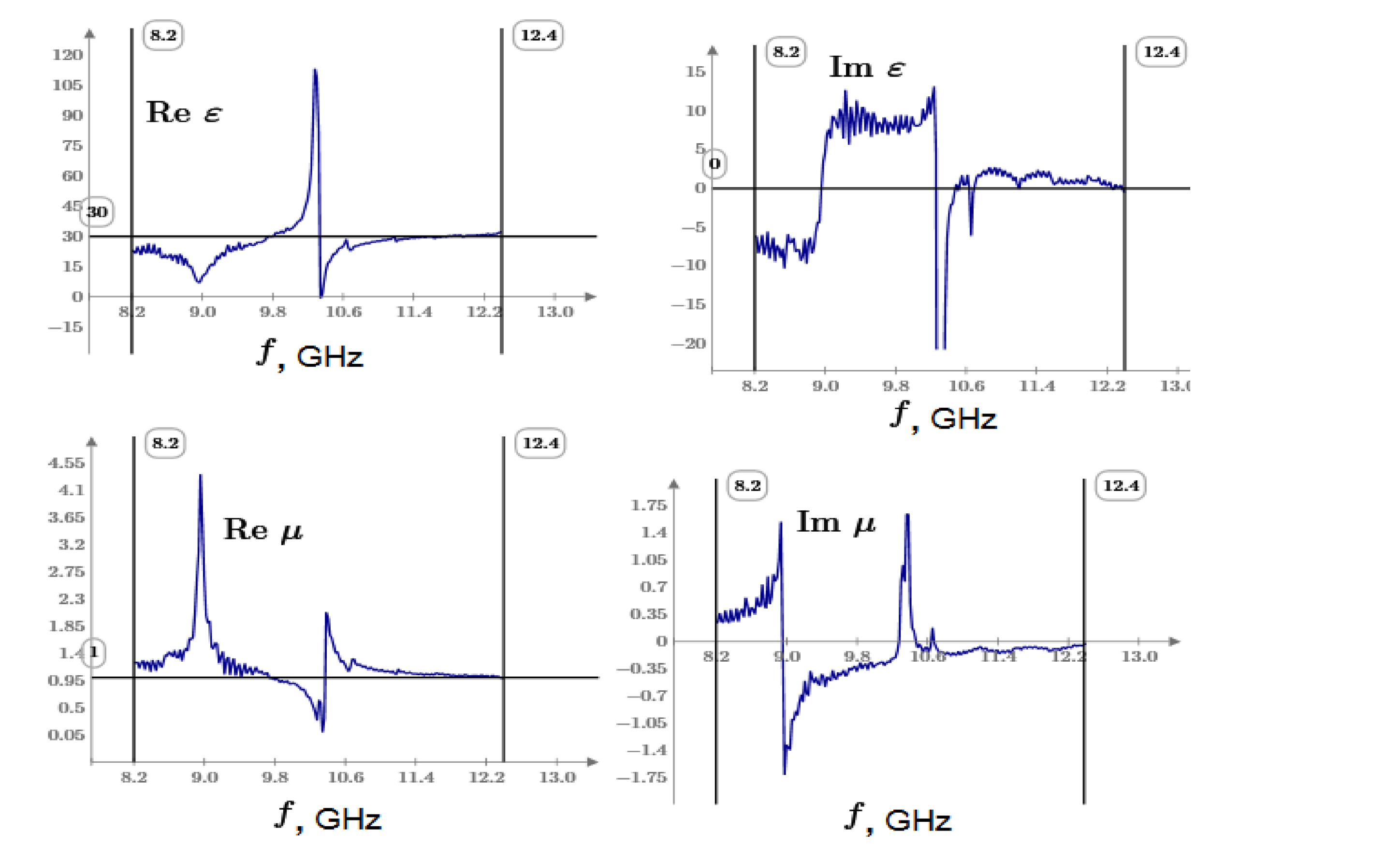


The model for simulations.



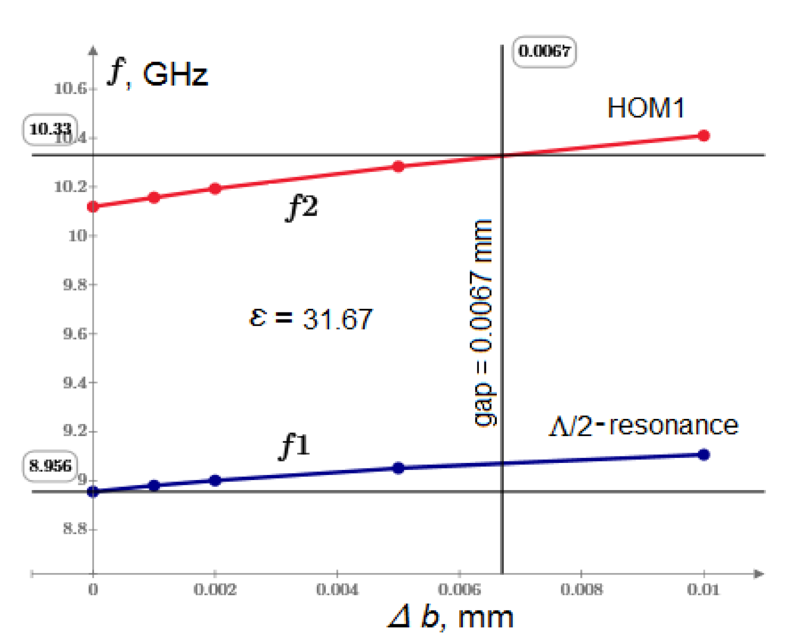
The second and other resonances appear in simulation when a gap along the long side of the sample is introduced.

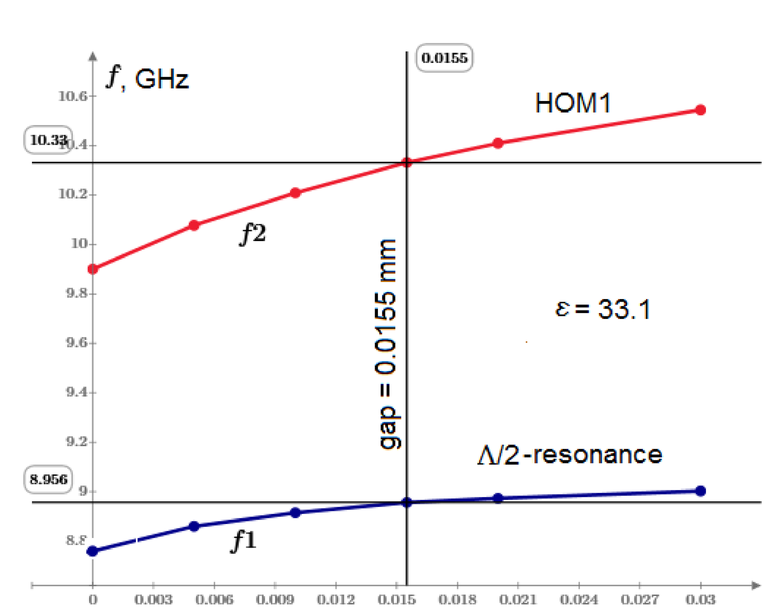
When ε is high, resonances appear, and the theory that doesn't take them into account, doesn't work



Values of ε and μ, corresponding to the measured S-parameters, calculated by formulas from [1 – 4] are presented here. We can see that the theory doesn't work in this example near the resonances, and only at the higher frequencies the values become having some physical sense, though the imaginary part of ε should be negative in this case that corresponds to losses in the material.

Gap along the longer side of the sample



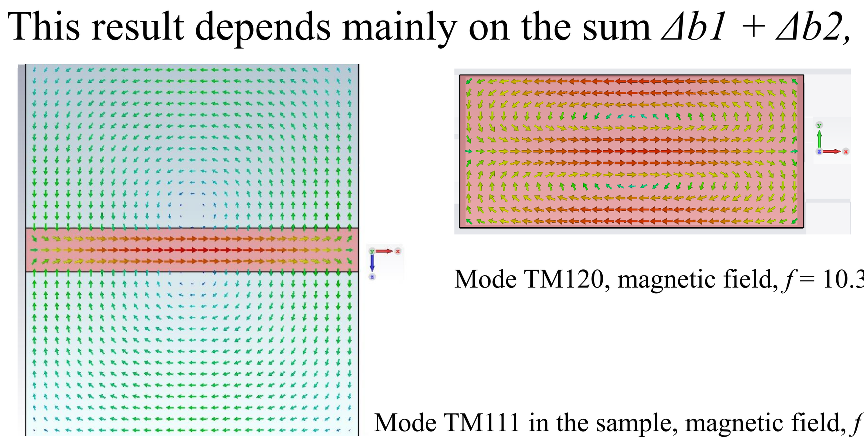


For a halfwave resonance without gaps $\varepsilon = \frac{\lambda}{4}\left(\frac{1}{a^2}+\frac{4}{\Lambda^2}\right) = \frac{c}{4f}\left(\frac{1}{a^2}+\frac{1}{d^2}\right)$, so $\varepsilon = 31.67$.

The second measured resonance $f2 = 10.33$ GHz appears in simulations if the gap is 0.0067 mm.

But the gap is the same! Fitting values of ε and the width of the gap, with ε = 33.1 we have measured both ε and Δb = 15.5 μm.

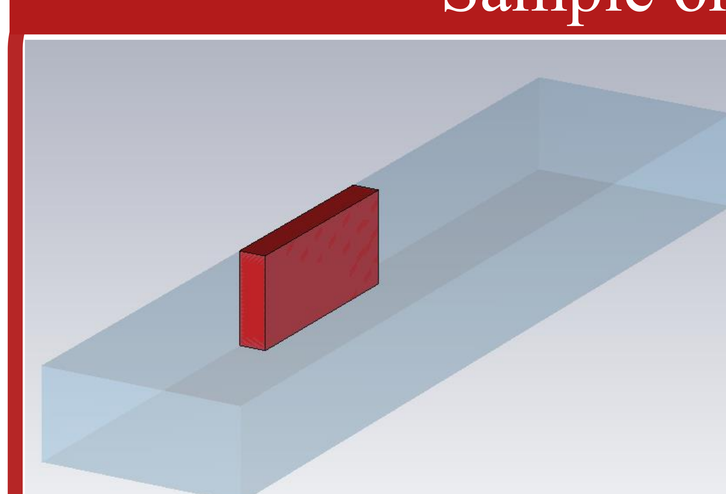
This result depends mainly on the sum $\Delta b1 + \Delta b2$, and weakly depend on $\Delta a1$ and $\Delta a2$.

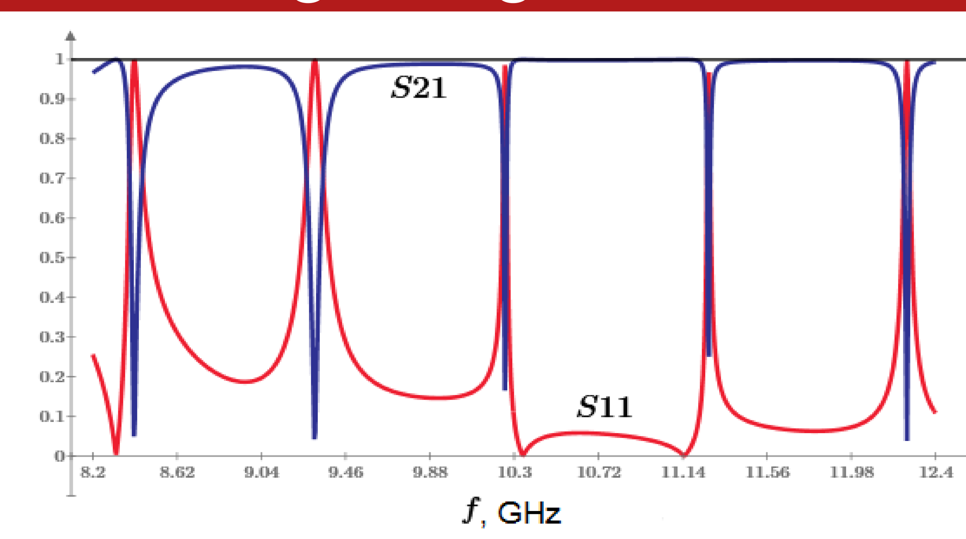


Mode TM120, magnetic field, f = 10.33 GHz.

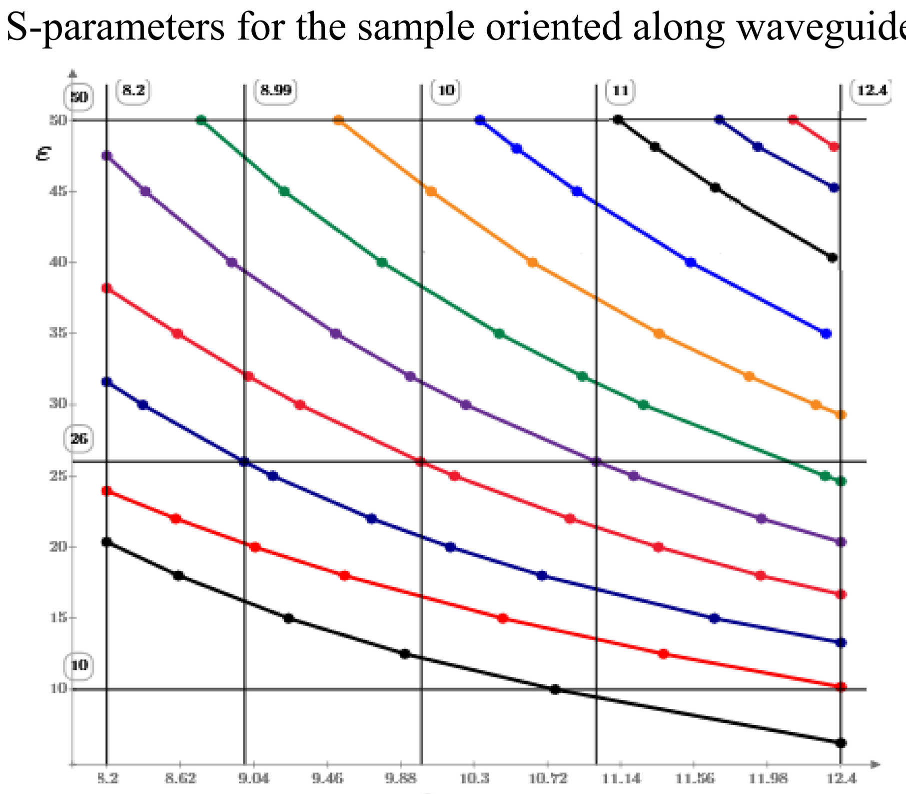
Mode TM111 in the sample, magnetic field, f = 8.956 GHz.

Sample oriented along waveguide





S-parameters for the sample oriented along waveguide, ε = 30, d = 3 mm, waveguide 22.86 × 10.16 mm.



A typical pattern of the S-parameters, when the sample is oriented along the waveguide and placed near the narrow wall is shown above. The number and positions of the peaks of S11 depend on ε and dimensions of the sample and the waveguide. For a given waveguide WR90 and the sample thickness 3 mm, the positions of the S11 peaks are presented in the figure on left. If we have a measured plot of the S-parameters, like in figure above, we have to measure the frequencies of the peaks and to use the left figure to define ε.

Conclusion and references

A method is presented for measurements of high values of dielectric permittivity ε in a waveguide at high frequencies. This method supplements the method of measurements evolved for low values of ε [1 – 4], and is close to resonant methods [5], when a sample is placed into a cavity and the measurement is done at one only frequency, but makes possible to measure this value in several frequency points at one measurement.

The special shape of the sample used for measurements in a waveguide makes possible to use well-defined positions of it and gives additional possibilities of measuring both real and imaginary part of dielectric permittivity.

Usage of CST Microwave Studio simulations gives a possibility to define both real and imaginary parts of ε, comparing the pattern of the plots.

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[4] V. Shemelin, N. Valles. Improved accuracy of measurements of complex permittivity and permeability using transmission lines. Nucl. Instr. Meth. Phys. Res. A 767 (2014) 385 – 396.
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