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# TEST CELLS FOR ELECTROMAGNETIC CHARACTERIZATION OF MATERIALS

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## Goals

- Develop and build test cell for use on 4TP analyzers and a coaxial test cell for use on VNA's
- Calibration and measurement routine
- Characterize reference samples and calculate uncertainty budget
- Automation of the measurement procedure for use in industrial or R&D environment.

## Test cell design

- One test cell has been built for 4 TP analyzers
- 4TP cell can measure samples up to 10 mm in diameter and up to 5 mm thick
- Coaxial test cell built for reflection (S11) measurement
- Coaxial test cell can measure samples up to 7 mm in diameter and up to 4 mm thick
- Both cells are equipped with micrometer for quick and easy sample thickness measurement
- Prototype of coaxial test cell which will enable full 2-port measurements (S11, S21, S12 and S22) is being developed
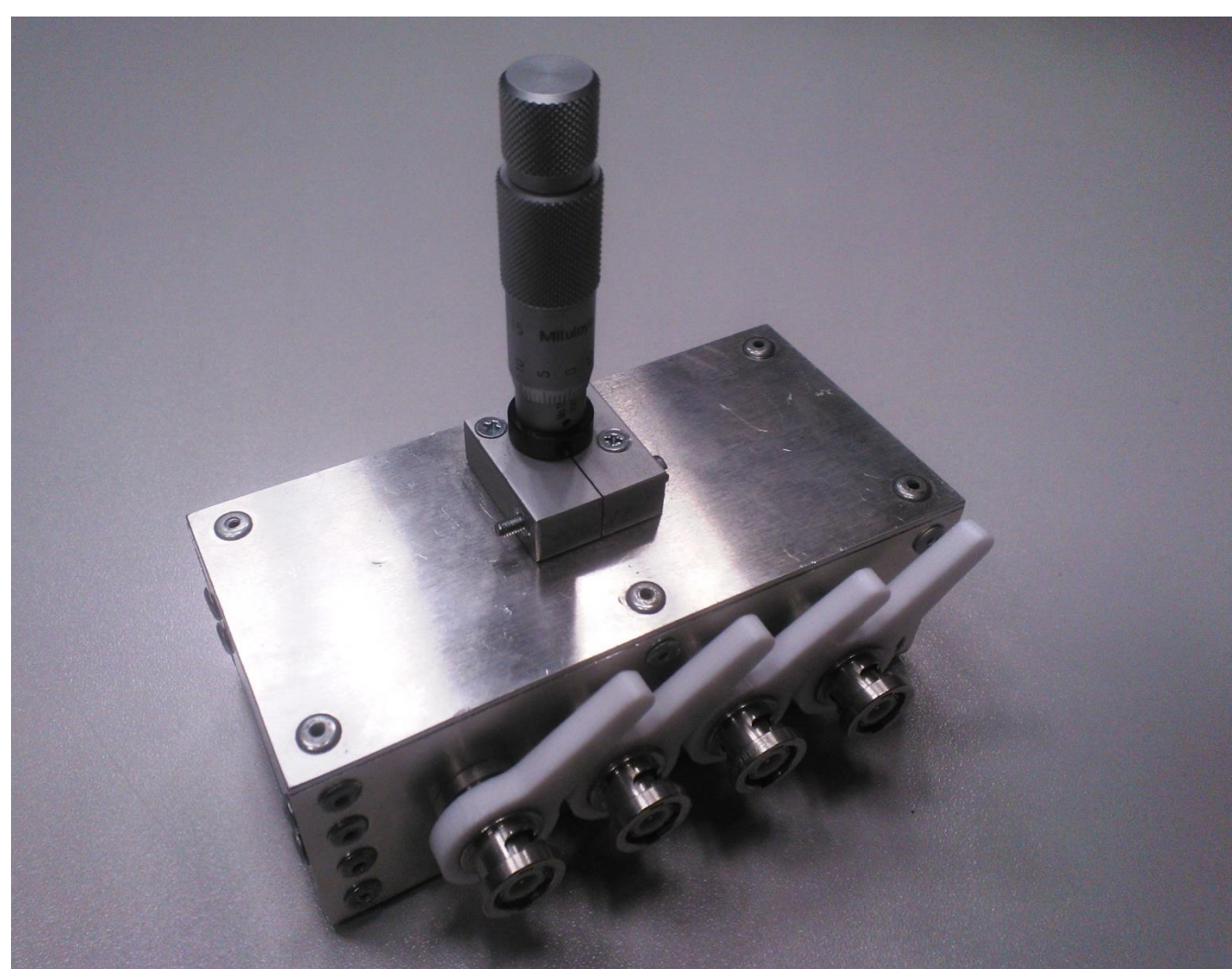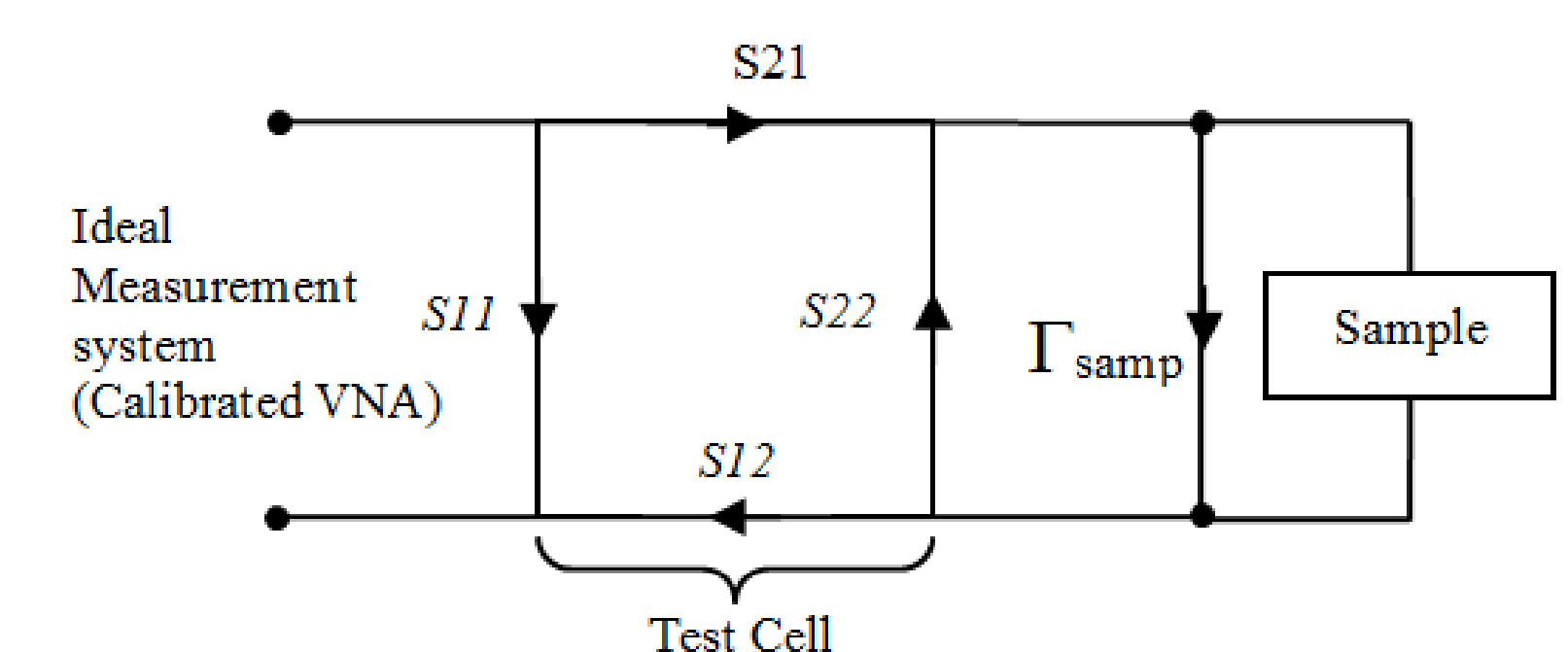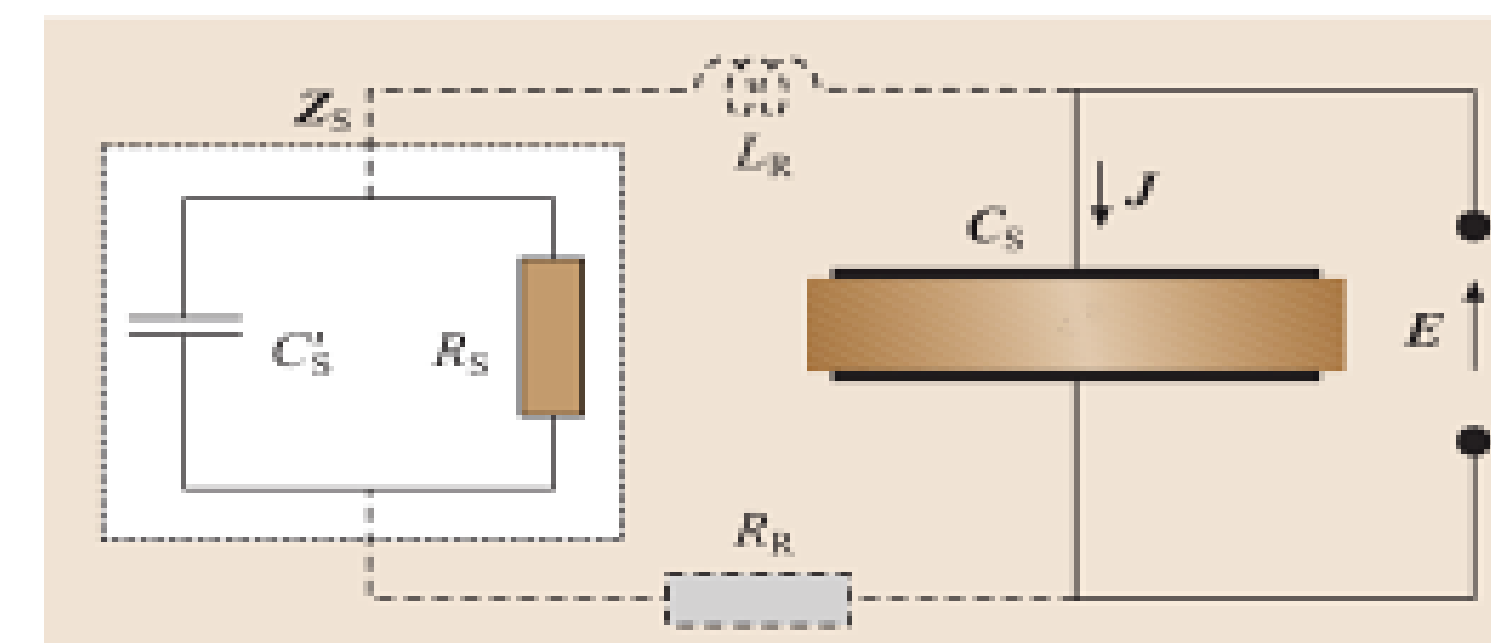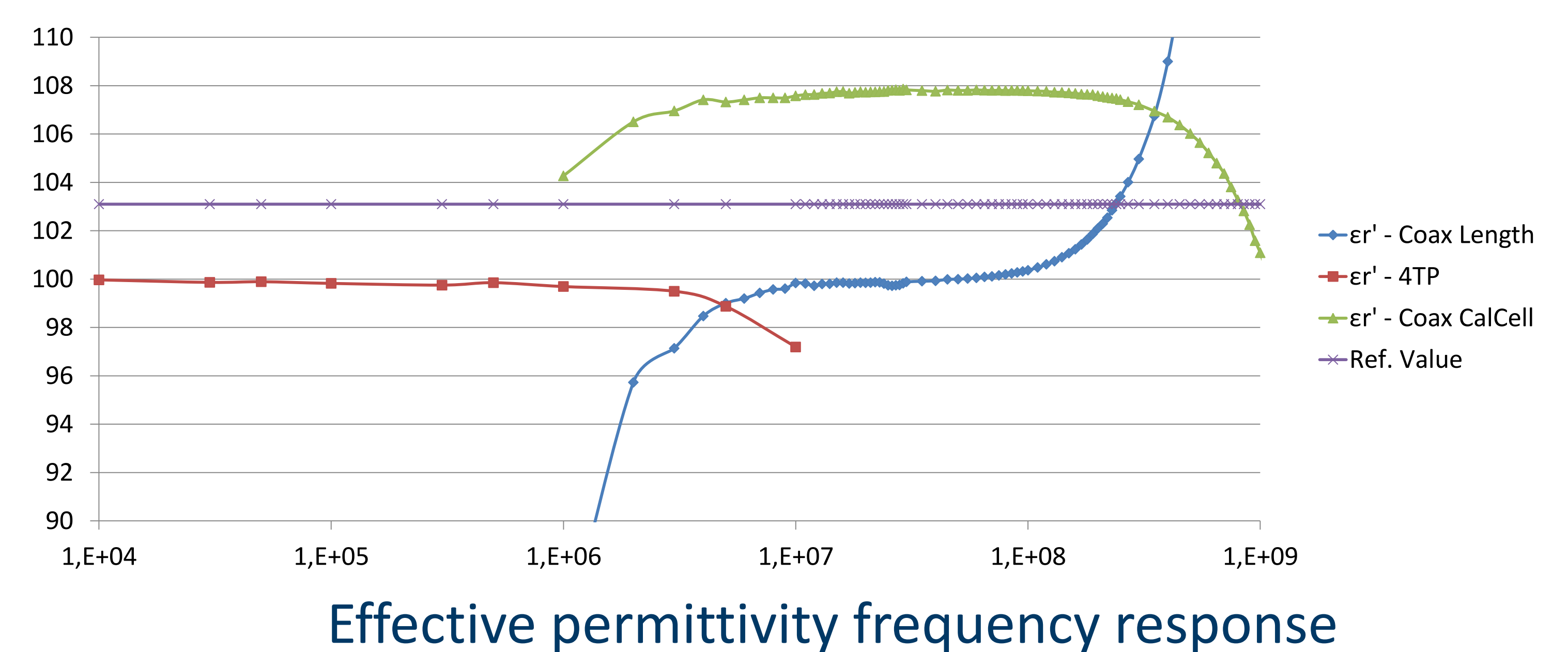


4TP Test cell                    Coaxial test cell
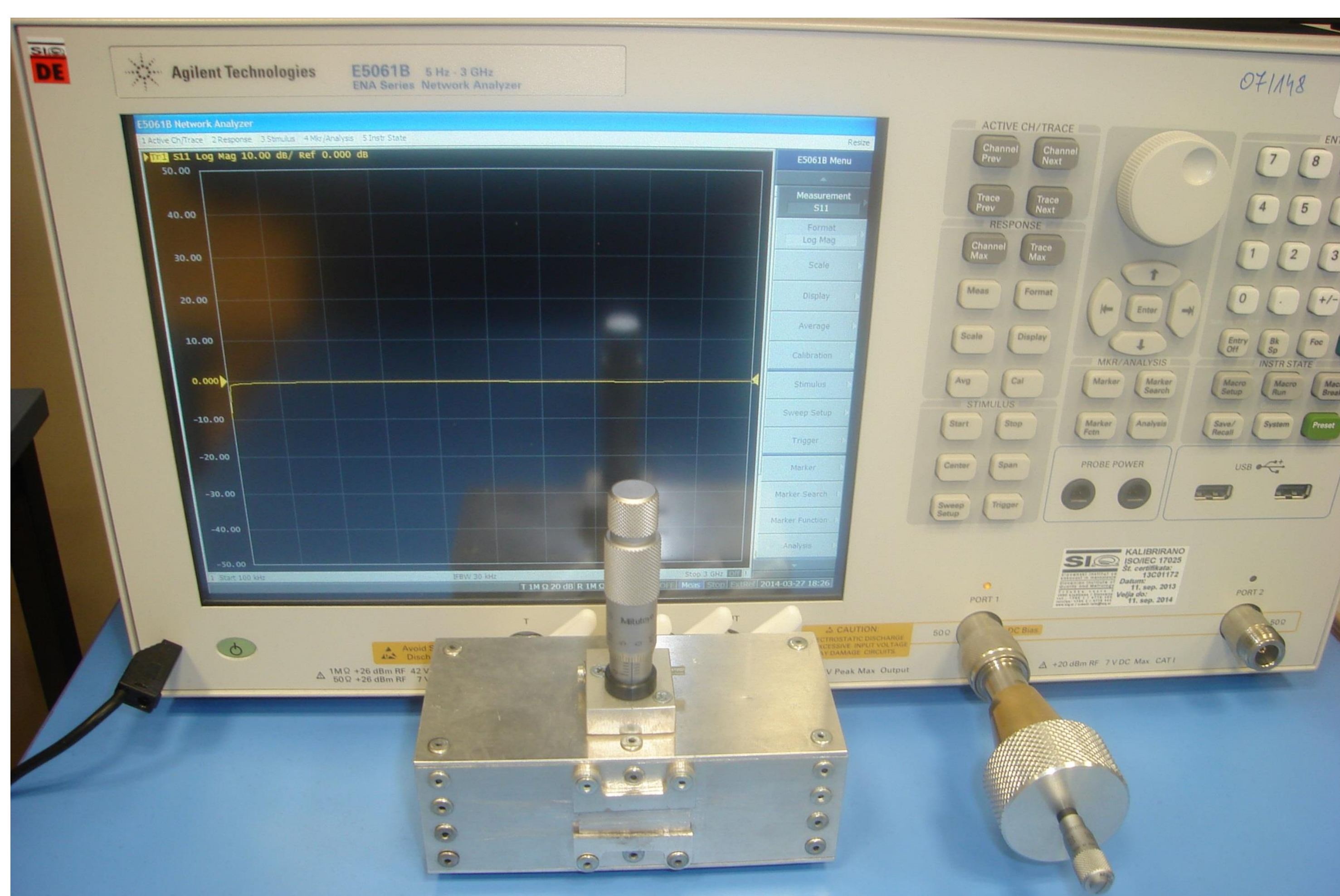


Cells connected to VNA

## Calibration and measurement routine

- Calculation of needed parameters (effective permittivity, loss...)
- Taking into account the effects of the test cells (length, loss...)
- Test cells characterized for parasitic effects
- Calibration using 3 reference samples



$$\frac{1}{\overline{Z}_S} = \frac{1}{R_S} + i\omega C_S'$$

$$\varepsilon_r^*(\omega) = \varepsilon_r'(\omega) - i\varepsilon_r''(\omega) = \frac{\overline{C}_S}{C_0}$$



Effective permittivity frequency response

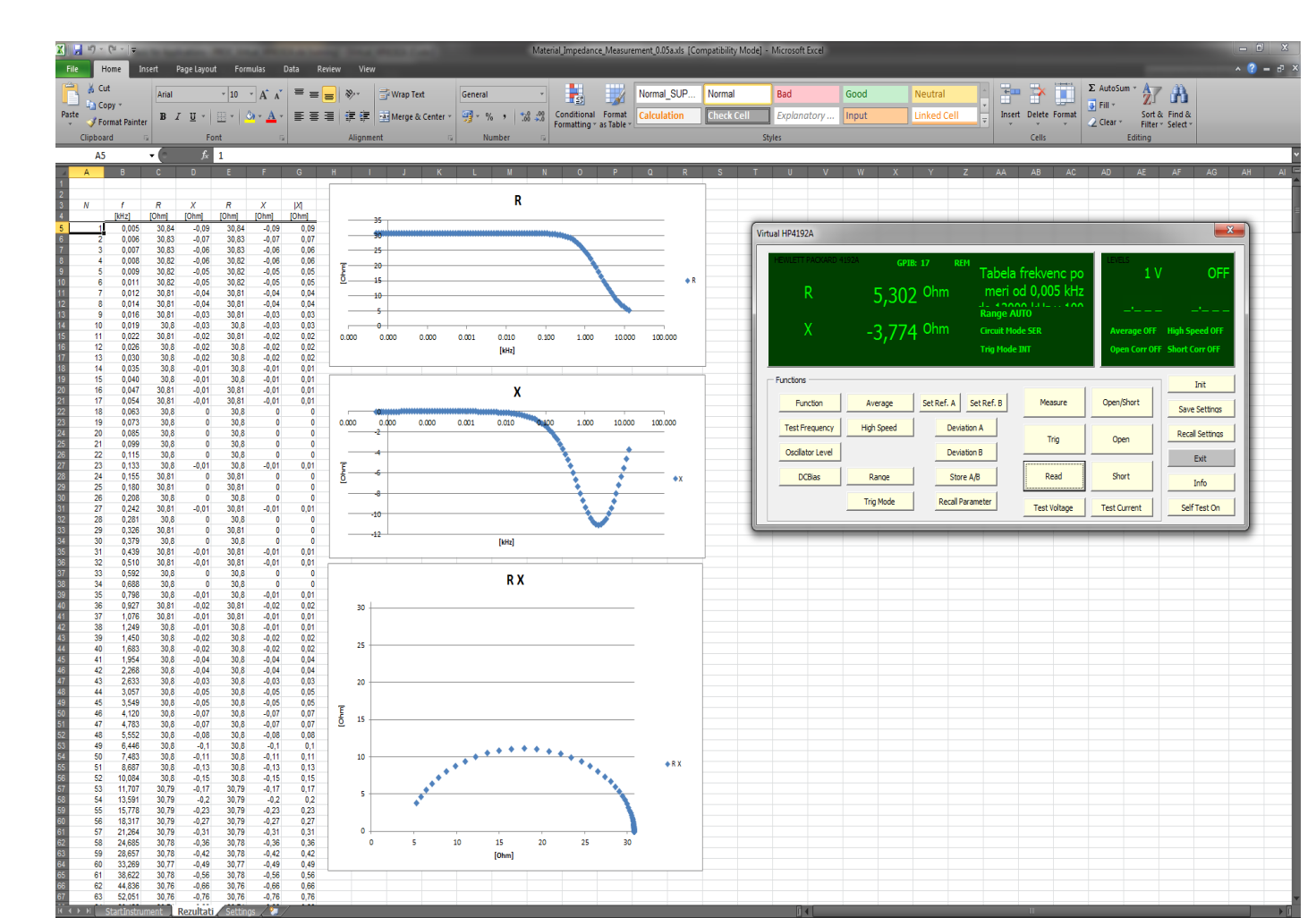## Reference samples and uncertainty sources

- Reference samples provide traceability
- Uncertainty of instruments
- Effects of test cells
- Temperature effect
- Uncertainty of algorithms and other calculations
- Uncertainty calculation done using Monte Carlo simulation
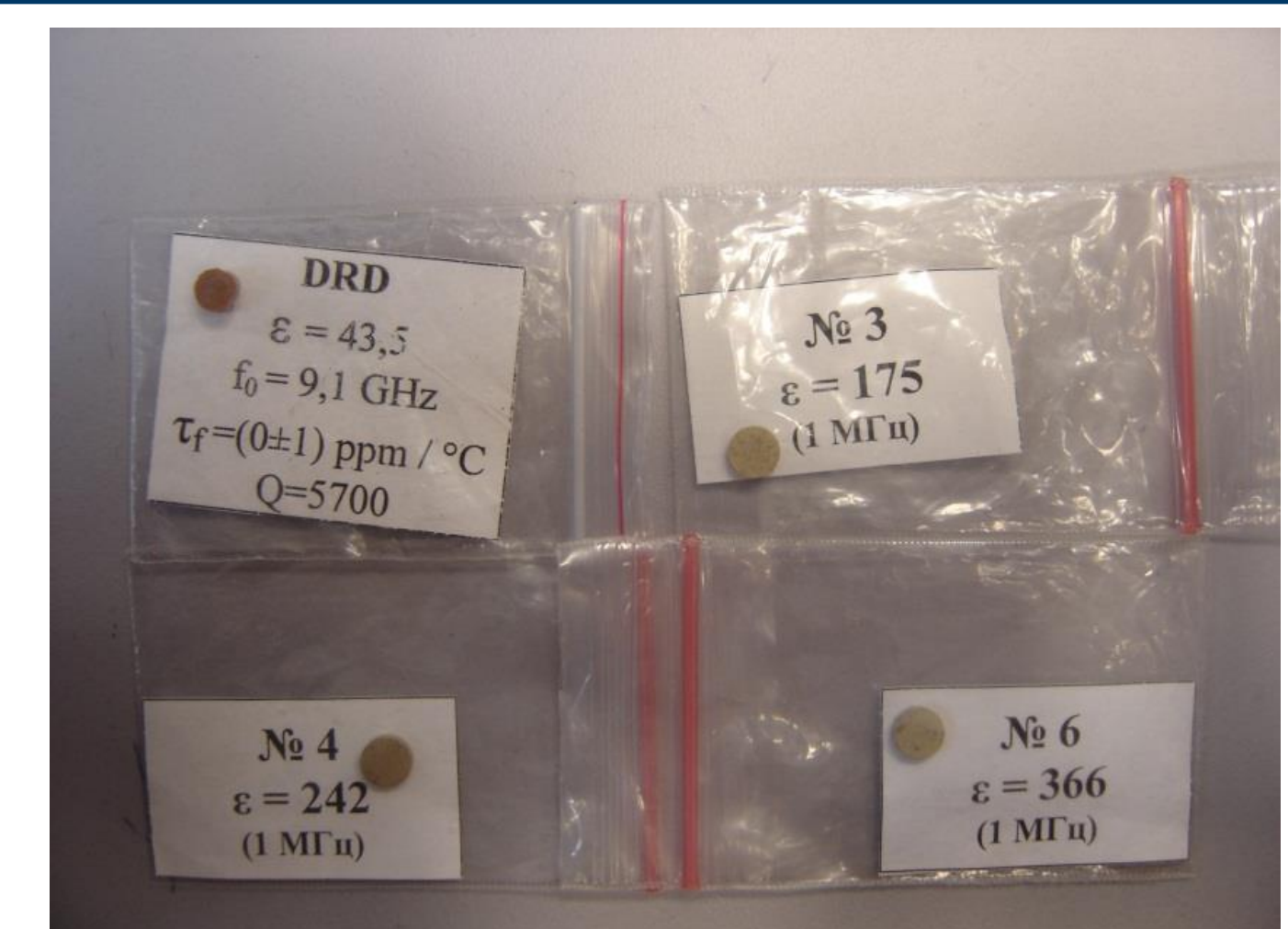


Reference samples

## Automation of measurement

- Remote control software for instruments and other equipment
- Software for sample traceability and chart generation
- Cole-Cole, Nyquist , Bode plot
- System installed at Jozef Stefan Institute for quality control and R&D for ceramic samples



Remote control software