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**Accreditation No.: SCS 108**

**Client** **(sample certificate)**

**Certificate No: OCP-DAK3.5-xxxx_MMYY**

# CALIBRATION CERTIFICATE

Object: DAK-3.5 - SN: xxxx

Calibration procedure(s): QA CAL-33.v2
Calibration of dielectric parameter probes

Calibration date: month dd, year

This calibration certificate documents the traceability to national standards, which realize the physical units of measurements (SI).
The measurements and the uncertainties with confidence probability are given on the following pages and are part of the certificate.

All calibrations have been conducted in the closed laboratory facility: environment temperature (22 ± 3)°C and humidity < 70%.

Calibration Equipment used (M&TE critical for calibration)

| Primary Standards | ID # | Cal Date (Certificate No.) | Scheduled Calibration |
|---|---|---|---|
| OCP DAK-3.5 (weighted) | SN: 1084 | 9-Oct-13 (OCP-DAK3.5-1084_Oct13) | Oct-14 |
| **Secondary Standards** | **ID #** | **Check Date (in house)** | **Scheduled Check** |
| Rohde & Schwarz ZVA50 | T0170 | 4-Jun-12 (in house check May-13) | May-14 |
| Digital Thermometer DTM3000 | 2148 | 28-Mar-13 (in house check Mar-13) | Mar-14 |
| Methanol 99.9% Type 34860 | SZBC143SV | 4-Mar-13 (batch opened) | Apr-14 |
| Head Liquid, HSL U12 | 121204-1 | 25-Apr-13 (in house check Apr-13) | Apr-14 |
| 0.1 mol/L NaCl solution Type 35275 | SZBA2560 | 25-Apr-13 (in house check Apr-13) | Apr-14 |
| 0.05 mol/L NaCl solution | 120427-1 | 25-Apr-13 (in house check Apr-13) | Apr-14 |
| Head Gel, SL AGH U07 AA | 120423 | 1-May-13 (sample opened) | Apr-14 |
| Solid Substrate | AK9 | 1-May-13 (in house check) | Apr-14 |

| | Name | Function | Signature |
|---|---|---|---|
| Calibrated by: | Ferenc Muranyi | External Expert | |
| Approved by: | Katja Pokovic | Technical Manager | |

Issued: January 22, 2014

## References

[1] IEEE Std 1528-2013, "IEEE Recommended Practice for Determining the Peak Spatial-Averaged Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques", June 2013
[2] IEC 62209 – 1, "Specific Absorption Rate (SAR) in the frequency range of 300 MHz to 3 GHz – Measurement Procedure, Part 1: Hand-held mobile wireless communication devices", February 2005
[3] IEC 62209-2 Ed.1, "Human Exposure to Radio Frequency Fields from Handheld and Body-Mounted Wireless Communication Devices – Human models, Instrumentation, and Procedures Part 2: Procedure to determine the specific absorption rate (SAR) for mobile wireless communication devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz)", March 2010
[4] A. P. Gregory and R. N. Clarke, "NPL Report MAT 23", January 2012
Tables of the Complex Permittivity of Dielectric Reference Liquids at Frequencies up to 5 GHz
[5] Agilent 85070E Dielectric Probe Kit, Technical Overview, document 5989-0222EN, October 2006
[6] A. Toropainen et al, "Method for accurate measurement of complex permittivity of tissue equivalent liquids", Electronics Letters 36 (1) 2000 pp32-34
[7] J. Hilland, "Simple sensor system for measuring the dielectric properties of saline solutions", Meas. Sci. Technol. 8 pp901–910 (1997)
[8] K. Nörtemann, J. Hilland and U. Kaatze, "Dielectric Properties of Aqueous NaCl Solutions at Microwave Frequencies", J. Phys. Chem. A 101 pp6864-6869 (1997)
[9] R. Buchner, G. T. Hefter and Peter M. May, "Dielectric Relaxation of Aqueous NaCl Solutions", J. Phys. Chem. A 103 (1) (1999)

## Description of the dielectric probe

Dielectric probes are used to measure the dielectric parameters of tissue simulating media in a wide frequency range. The complex permittivity $\varepsilon_r^* = (\varepsilon'/\varepsilon_0) - j(\varepsilon''/\varepsilon_0)$ is determined from the S parameters measured with a vector network analyzer (VNA) with software specific to the probe type. The parameters of interest e.g. in standards [1, 2, 3] and for other applications are presented are calculated as follows:
(Relative) permittivity $\varepsilon'$ (real part of $\varepsilon_r^* = (\varepsilon'/\varepsilon_0) - j(\varepsilon''/\varepsilon_0)$ where $\varepsilon_0 = 8.854$ pF/m is the permittivity in free space)
Conductivity $\sigma = 2\pi f \varepsilon'' \varepsilon_0$,
Loss Tangent = $(\varepsilon''/\varepsilon')$

The **OCP** (open ended coaxial) is a cut off section of 50 Ohm transmission line, similar to the system described in [1, 2, 3, 5], used for contact measurement The material is measured either by touching the probe to the surface of a solid/gelly or by immersing it into a liquid media. The electromagnetic fields at the probe end fringe into the material to be measured, and its parameters are determined from the change of the $S_{11}$ parameters. With larger diameter of the dielectrics, the probe can be used down to lower frequencies.
The flange surrounding the active area shapes the near field similar to a semi-infinite geometry and is inserted fully into the measured lossy liquid.
The probe is connected with a phase and amplitude stable cable to a VNA which is then calibrated with Open, Short and a Liquid with well-known parameters.

All parts in the setup influencing the amplitude and phase of the signal are important and shall remain stable.

**Handling of the item**

Before usage, the active probe area has to be cleaned from any material residuals potentially contaminating the reference standards. The metal and dielectric surface must be protected to keep the precision of the critical mechanical dimensions. The connector and cable quality are critical; any movements between calibration and measurement shall be avoided.
The temperature must be stable and must not differ from the material temperature.

**Methods Applied and Interpretation of Parameters**

The calibration of the dielectric probe system is done in the steps described below for the desired frequency range and calibration package (SAR/MRI liquids, Semi-solid/solid material). Because the standard calibration in step 3 is critical for the results in steps 4 to 8, the sequence 3 to 8 is repeated 3 times. As a result, the result from these 3 sets is represented.

1. Configuration and mechanical / optical status.
2. Measurement resolution is 5 MHz from 10 to 300 MHz, 50 MHz from 300 to 6000 MHz and 250 MHz from 6 to 20 GHz.
3. Standard calibration uses Air / Short / Liquid. 1 liter liquid quantity is used to reduce the influence the reflections. The liquid type is selected depending on the lowest frequency and probe diameter:
   DAK-1.2, DAK-3.5, Agilent OCP: de-ionized water (approx. 22 °C)
   DAK-12: saline solution with static conductivity 1 S/m (approx. 22 °C)
   NPL OCP: pure ethanol (approx. 22 °C)
4. The cable used in the setup stays in a fixed position, i.e. the probe is fixed and measuring from the top in an angle of typ. 20° from the vertical axis. For DAK and Agilent probes, the refresh function (air standard) is used previous to the individual measurements in order to compensate for possible deviations from cable movements. After insertion of the probe into a liquid, the possible air bubbles are removed from the active surface.
5. Measurement of multiple shorts if not already available from the calibration in the previous step (NPL). Evaluation of the deviation from the previous calibration short with graphical representation of the complex quantities and magnitude over the frequency range. The specific probe short will be used if provided. This assessment shows ability to define a short circuit at the end of the probe for the VNA calibration in the setup which is essential at high frequencies and depends on the probe surface quality.
6. Measurement of validation liquids in a quantity of 1 liter at well defined temperature. Evaluation of the deviations from the target. The targets base on traceable data from reference sources. The deviation of the measurement is graphically presented for permittivity and conductivity (for lossy liquids) or loss tangent (for low losses at low frequencies).
7. Measurement of lossy liquids in a quantity of 1 liter at well defined temperature. Head tissue simulating liquid or saline solution with 0.5 S/m static conductivity are representative. The target data base on traceable data from reference sources or from multiple measurements with precision reference probes or different evaluations such as transmission line or slotted line methods. Evaluation of the deviation from the target and graphical representation for permittivity and conductivity over the frequency range
8. Semi-solid / solid material calibration:
   Measurements of an elastic lossy broadband semi-solid gel with parameters close to the head tissue target. Measurements of a planar very low loss solid microwave-substrate. The average of 4 measurements of the same sample at different location is shown as a single result. The deviation of the permittivity and conductivity from the reference data is evaluated.
   Measurements of a planar very low loss solid microwave-substrate. The average of 4 measurements of the same sample at different location is shown as a single result. The relative deviation of the permittivity and the absolute deviation of the loss tangent is evaluated.
   The targets base on multiple measurements (on the same material batch at identical temperature) on convex and planar surfaces with precision reference OCP.
   The measurement on semi-solid / solid materials is sensitive to the quality and planarity of the probe contact area, such as air gaps due to imperfect probes (resulting lower permittivity values).

9. Table for the probe uncertainty: The uncertainty of the probe depending on probe type, size, material parameter range and frequency is given in a table. It represents the best measurement capability of the specific probe but does not include the material (deviation from the target values).
10. Appendix with detailed results of all measurements with the uncertainties for the specific measurement. In addition to the probe uncertainty (see above), it includes the uncertainty of the reference material used for the measurement. A set of results from independent calibrations represents the capability of the setup and the lossy materials used, including the precision of the measured material and the influence of temperature deviations. Temperature and operator influence was minimized and gives a good indication of the achievable repeatability of a measurement.
11. Summary assessment of the measured deviations and detailed comments if not typical for the probe type.

**Dielectric probe identification and configuration data**

Item description

| | |
|---|---|
| Probe type | **OCP** Open-ended coaxial probe |
| Probe name | SPEAG Dielectric Assessment Kit DAK-3.5 |
| Type No | **SM DAK 040 CA** |
| Serial No | **xxxx** |
| Description | Open-ended coaxial probe with flange<br>Flange diameter: 19.0 mm<br>Dielectric diameter: 3.5 mm<br>Material: stainless steel |
| Connector 1 | PC 3.5 pos. |
| Software version | **DAK Measurement Solver 1.10.321.11**<br>Calibration Type: Air / short / water (set to measured water temp.)<br>Probe type: “DAK3.5” (software setting) |
| Further settings | VNA bandwidth setting: 50 Hz |

Accessories

| | |
|---|---|
| Cable | Huber & Suhner Sucoflex 404, SN: 1695, length 1 m,<br>PC3.5 neg. – PC3.5 neg. |
| Short | DAK-3.5 shorting block, type SM DAK 200 A<br>Contact area covered with cleaned Cu stripe |

Additional items used during measurements

| | |
|---|---|
| Adapter 1 | PC3.5 pos. – PC2.4 (VNA side) |
| Adapter 2 | PC3.5 pos. – PC3.5 neg. (probe side) |

**Notes**

- Before the calibration, the connectors of the probe and cable were inspected and cleaned.
- Probe visual inspection: according to requirements
- Short inspection: according to the requirements

**Probe Uncertainty**

The following tables provide material and frequency specific uncertainties (k=2) for the dielectric probe. The values in the tables represent the measurement capability for the probe when measuring a material in the indicated parameter range. They include all uncertainties of

- probe system
- possible systematic errors due to the design
- calibration
- temperature differences during the calibration and measurements, as described,
- VNA noise

Apart from the material used for the calibration (de-ionized water), material uncertainties of the reference materials used during the measurement in Appendix A are not included in these tables.

| **DAK-3.5** | | | | |
|---|---|---|---|---|
| Permittivity range | | Frequency range | (sigma / LT range) | Unc. (k=2) |
| | 1 – 15 | 10 MHz - 20 MHz | | --- |
| | | 20 MHz - 200 MHz | | --- |
| | | 200 MHz - 3 GHz | LT < 0.1 | 2.4% |
| | | 3 GHz - 6 GHz | LT < 0.1 | 2.0% |
| | | 6 GHz - 20 GHz | LT < 0.1 | 2.1% |
| | 10 – 40 | 10 MHz - 20 MHz | | --- |
| | | 20 MHz - 200 MHz | | --- |
| | | 200 MHz - 3 GHz | sigma : 1 – 10 S/m | 1.9% |
| | | 3 GHz - 6 GHz | sigma : 1 – 10 S/m | 2.3% |
| | | 6 GHz - 20 GHz | sigma > 10 S/m | 3.5% |
| | 35 – 100 | 10 MHz - 20 MHz | | --- |
| | | 20 MHz - 200 MHz | | --- |
| | | 200 MHz - 3 GHz | sigma : 1 – 10 S/m | 1.8% |
| | | 3 GHz - 6 GHz | sigma : 1 – 10 S/m | 1.9% |
| | | 6 GHz - 20 GHz | sigma > 10 S/m | 2.4% |
| | | | | |
| Conductivity range (S/m) | | Frequency range | (epsilon / LT range) | Unc. (k=2) |
| | 1 – 10 | 10 MHz - 20 MHz | | --- |
| | | 20 MHz - 200 MHz | | --- |
| | | 200 MHz - 3 GHz | eps : 35 - 100 | 2.7% |
| | | 3 GHz - 6 GHz | eps : 35 - 100 | 3.0% |
| | | 6 GHz - 20 GHz | eps : 10 - 40 | 3.0% |
| | | | | |
| Loss tangent range | | Frequency range | (epsilon / LT range) | Unc. (k=2) |
| | < 0.1 | 10 MHz - 20 MHz | | --- |
| | | 20 MHz - 200 MHz | | --- |
| | | 200 MHz - 3 GHz | eps : 1 - 15 | 0.03 |
| | | 3 GHz - 6 GHz | eps : 1 - 15 | 0.03 |
| | | 6 GHz - 20 GHz | eps : 1 - 15 | 0.03 |

**Calibration Results**

Uncertainty limits (k=2) for the material measurements in the figures of Appendix A are represented with red dashed lines. These uncertainties contain - in addition to probe uncertainty - the uncertainty of the material target parameter determination.
The measurements show the results obtained from independent calibrations for the same material. The differences between the individual measurement curves give therefore an indication for the obtainable repeatability and shall lie within the uncertainties stated in the tables.

*Materials for DAK-3.5 calibration:*
*Appendix A with curves for Methanol, HSL, and 0.05 mol/L NaCl solution (200 MHz - 6 GHz, optional 20 GHz), HS gel and low loss solid substrate are optional.*

# Appendix A: Detailed Results

## A.1 Probe appearance and calibration sequence

### A.1.1 Appearance

The OCP appearance is fully according to the expectations:
- the flange surface is intact

### A.1.2 Calibration sequence

The following sequence was repeated 3 times in the low frequency range from 200 – 300 MHz in 5 MHz steps and in the high frequency range from 300 to 6000 MHz in 50 MHz steps, and from 6 GHz to 20 GHz in 250 MHz steps.

- Air
- Short 1 short, then immediate verification with a second short (with eventual repetition)
- Water De-ionized water, temperature measured and set in the software (for DAK-12 0.1 mol/L saline solution, temperature measured and set in the software)
- Methanol Pure methanol, temperature measured and set in the software
- Liquids Measurement of further liquids (e.g. Head tissue simulating liquid and 0.05 mol/l saline)
- Cleaning Probe washed with water and isopropanol at the end of the sequence.
- Shorts 4 additional separate short measurements to determine the deviation from the original
- Refresh Refresh with Air
- Solid 4 separate solid low loss planar substrate measurements to determine one average (optional)
- Semisolid 4 separate head gel measurements on fresh intact surface to determine one average (optional)
- Cleaning Probe washed with water and isopropanol at the end of the sequence

Evaluation of the additional shorts from the calibrated (ideal) short point at the left edge of the Smith Chart, represented as magnitude over the frequency range (fig. 2.1.x) and in polar representation (fig. 2.2.x).

Evaluation of the Liquid measurements and representation of the permittivity and conductivity deviation from their reference data at the measurement temperature. The results of each of the 3 calibrations is shown in the appendix for each material (fig. 3ff) in black, red, blue. The red dashed line shows the uncertainty of the reference material parameter determination.

Evaluation of the Semisolid measurements (optional) by representing the 3 average deviations (each resulting from the 4 separate measurements per set), equivalent to the liquid measurement. Representation of the permittivity and conductivity deviation from their reference data at the nominal temperature.

Evaluation of the Solid measurements (optional) by representing the 3 average deviations (each resulting from the 4 separate measurements per set), equivalent to the liquid measurement. Representation of the permittivity deviation from their reference data and the loss tangent at the nominal temperature.

## A.2 Short residual magnitudes

After each of the 3 calibrations with a single short (as per the DAK software), 4 additional separate, short measurements were performed after the liquid measurements and evaluated from the S11 data. The residuals in the graphs represent the deviation from the ideal short point on the polar representation on the VNA screen.

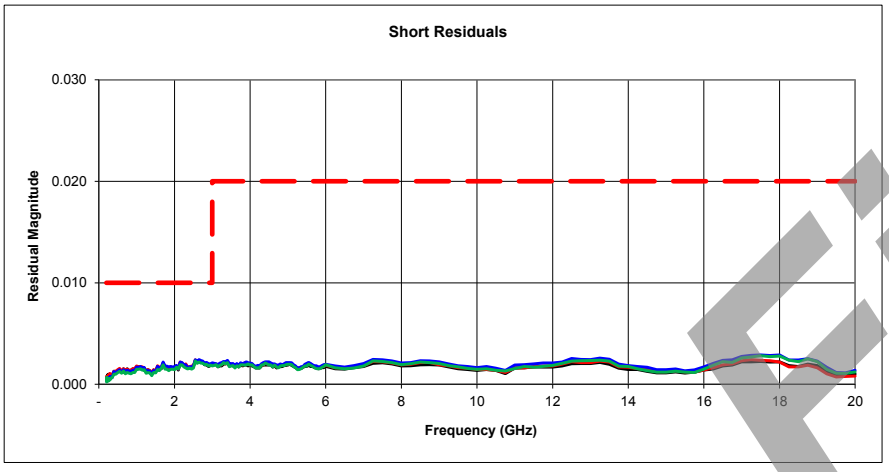


Fig. 2.1a Magnitude of the residual of the shorts, 200 MHz – 20 GHz, after calibration a)

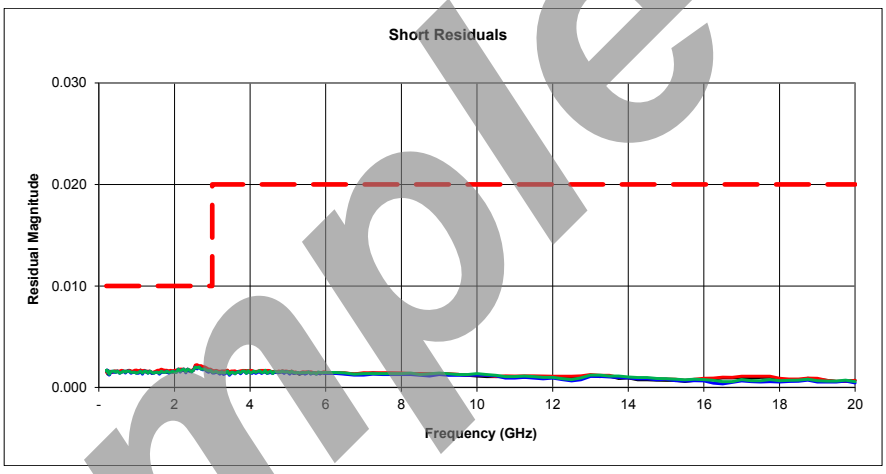


Fig. 2.1b Magnitude of the residual of the shorts, 200 MHz – 20 GHz, after calibration b)

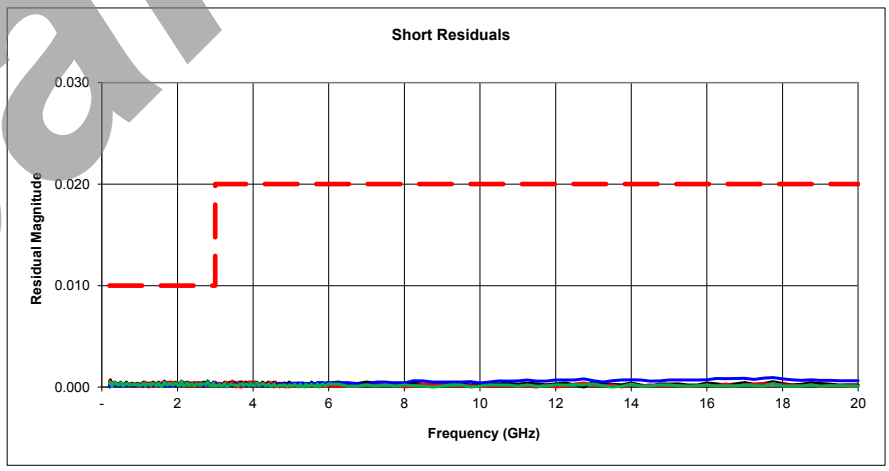


Fig. 2.1c Magnitude of the residual of the shorts, 200 MHz – 20 GHz, after calibration c)

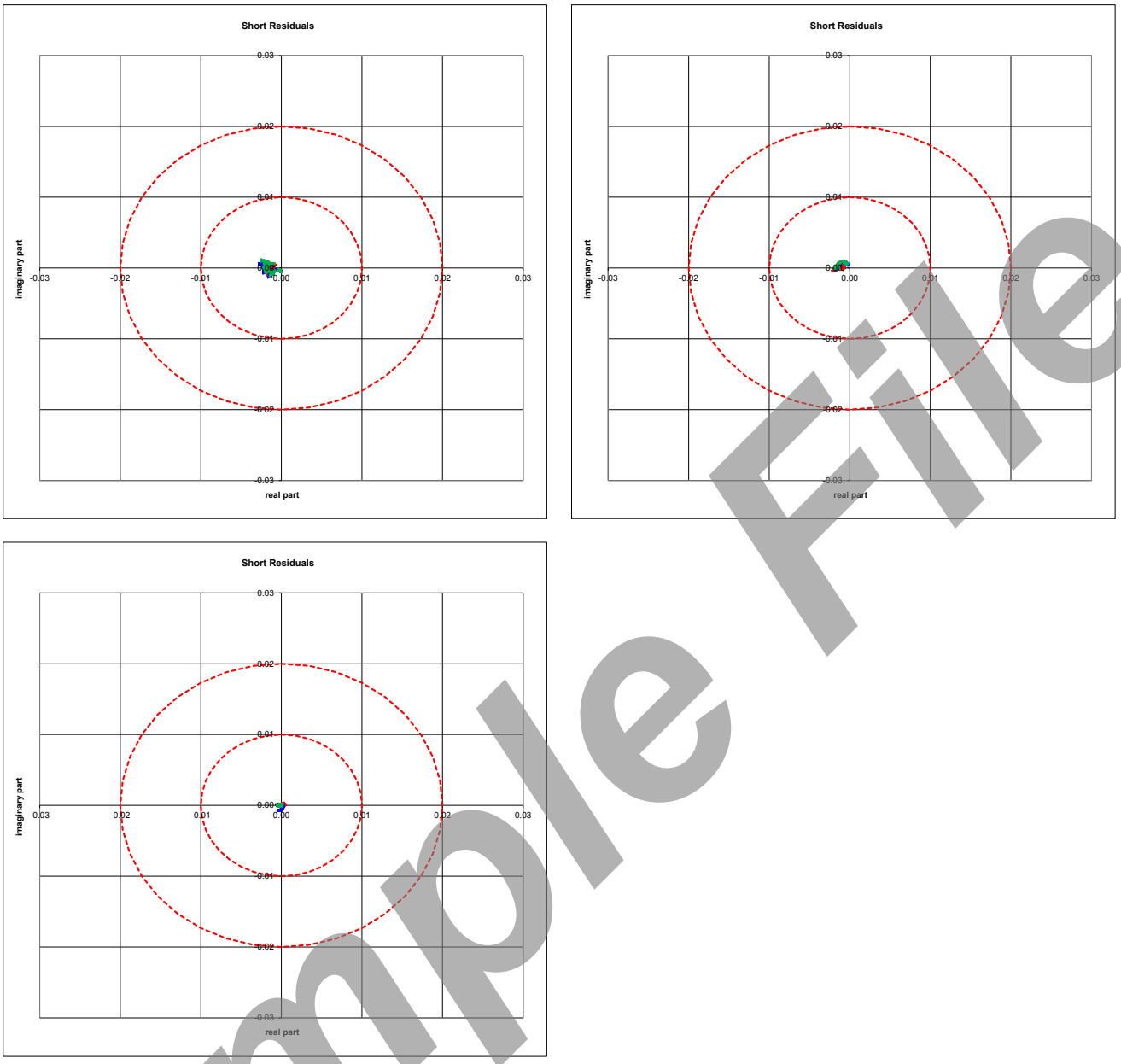


Fig. 2.2a-c Complex representation of the residuals of the shorts, 200 MHz - 20 GHz, after calibrations a)-b) in the top and c) in the bottom

All shorts have good quality. Some minor deviations might be visible from contact quality (left - right).

## A.3 Methanol

Methanol (99.9% pure) was measured at a temperature of 22 +/- 2 °C. The liquid temperature was stabilized within 0.05 °C of the desired temperature. Deviations are presented relative to the nominal material parameters at this temperature, calculated from NPL data for this temperature.

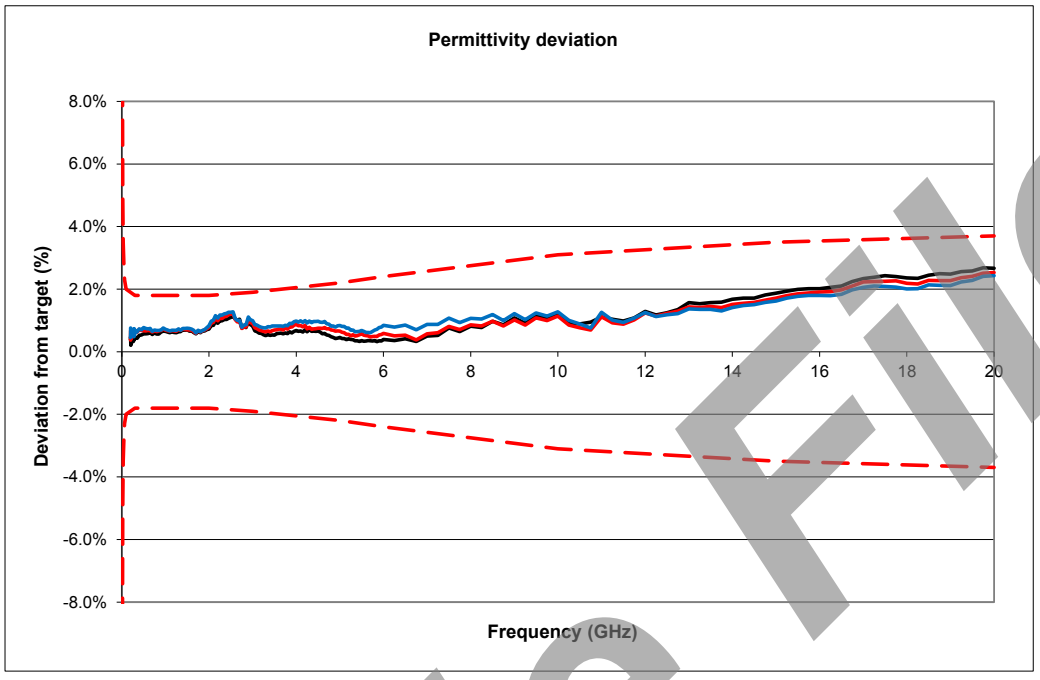


Fig. 3.1 Methanol permittivity deviation from target, 200 MHz – 20 GHz

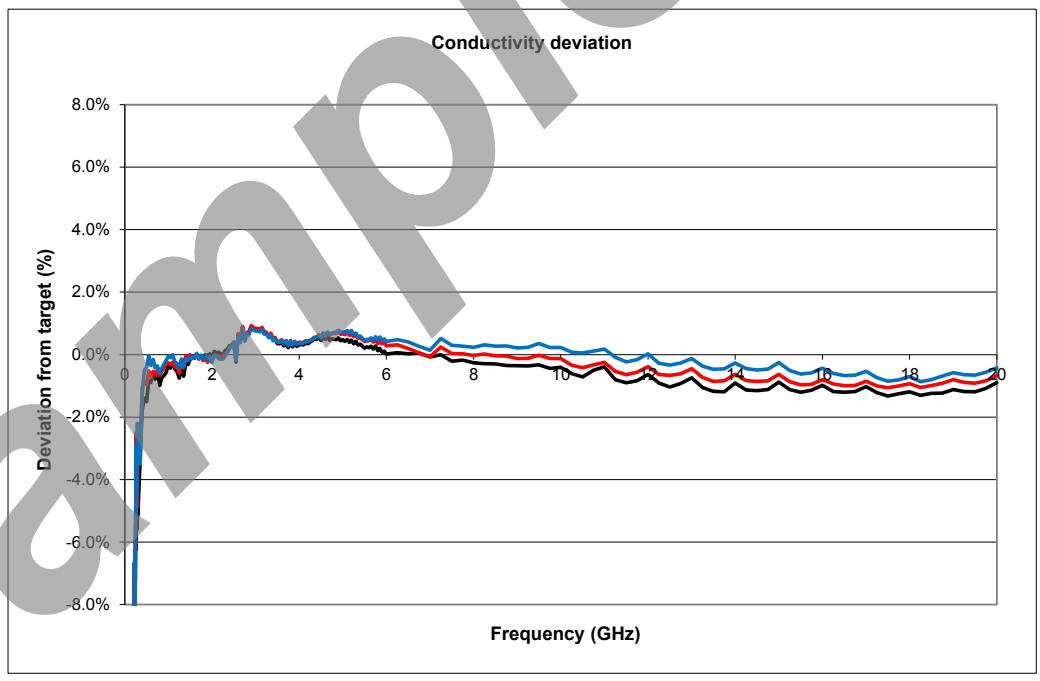


Fig. 3.2 Methanol conductivity deviation from target, 200 MHz – 20 GHz

Conductivity error can be high at low frequencies due to the low absolute conductivity values.

## A.4 Head Tissue

Broadband head simulating liquid was measured at a temperature of 22 +/- 2 °C. The liquid temperature was stabilized within 0.05 °C of the desired temperature. Deviations are presented relative to the reference data for this material. Those parameters have been evaluated from multiple measurements on the used bath with precision reference OCP and further methods.

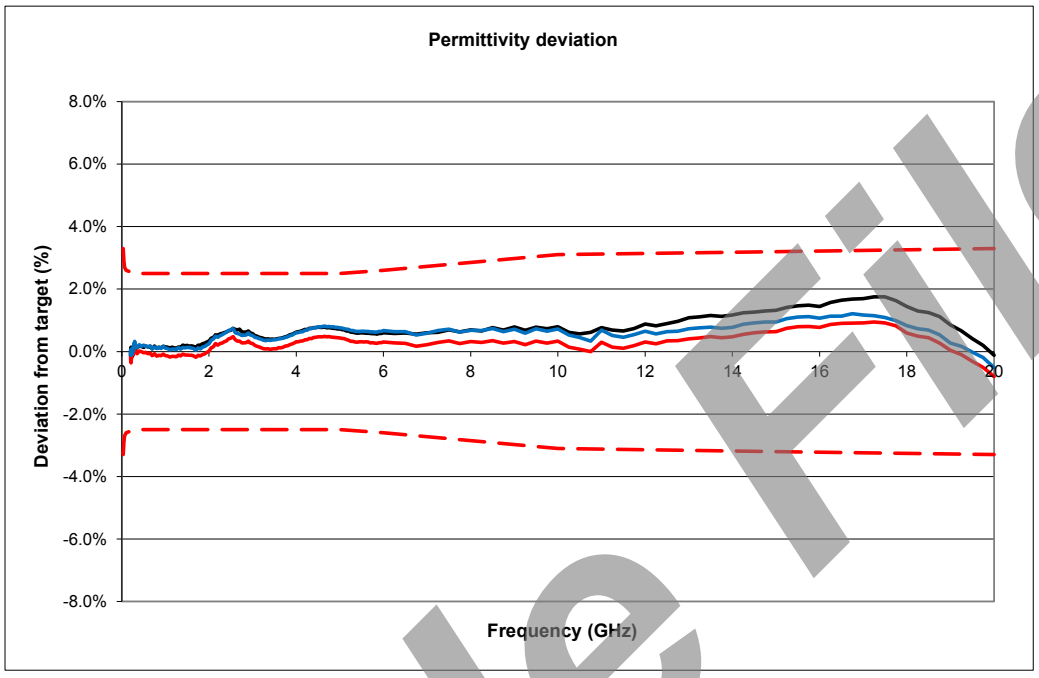


Fig. 4.1 HSL permittivity deviation from target, 200 MHz – 20 GHz

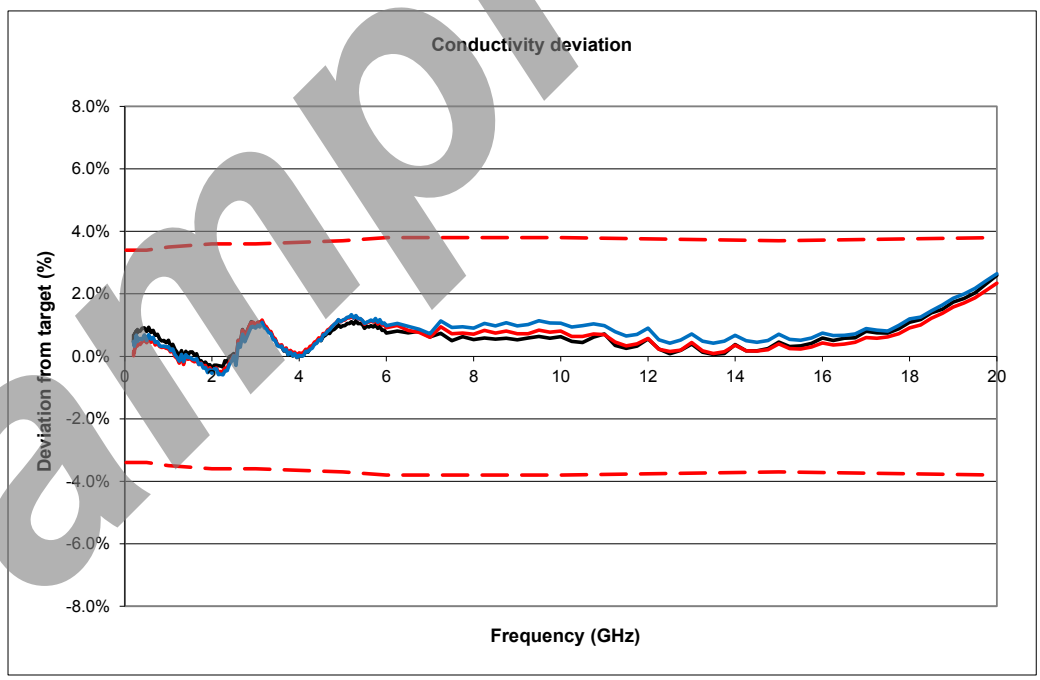


Fig. 4.2 HSL conductivity deviation from target, 200 MHz – 20 GHz

## A.5 0.05 mol/L NaCl solution

0.05 mol/L NaCl / water solution has a static conductivity of 0.5 S/m, similar to MRI HCL (High Conductivity Liquid). It was measured at a temperature of 22 +/- 2 °C. The liquid temperature was stabilized within 0.05 °C of the desired temperature. Deviations are presented relative to the reference data for this material. These parameters have been derived from the theoretical model according to [7], matched to the measurements from reference probes and other sources.
A quantity of 1 liter was used for the measurement.

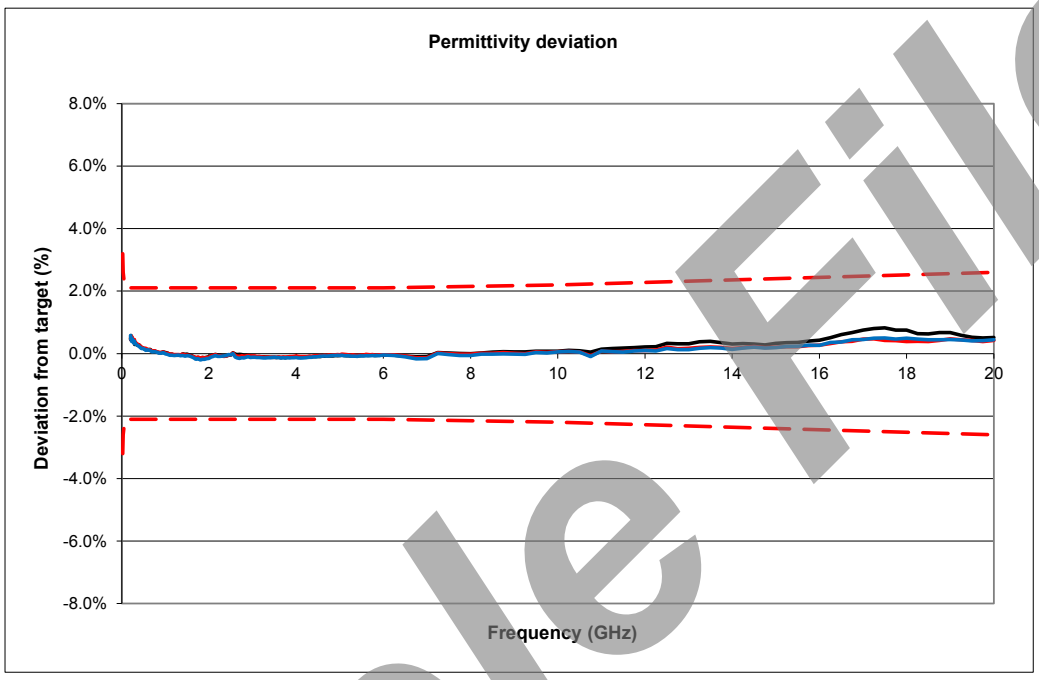


Fig. 5.1 0.05 mol/L solution permittivity deviation from target, 200 MHz – 20 GHz

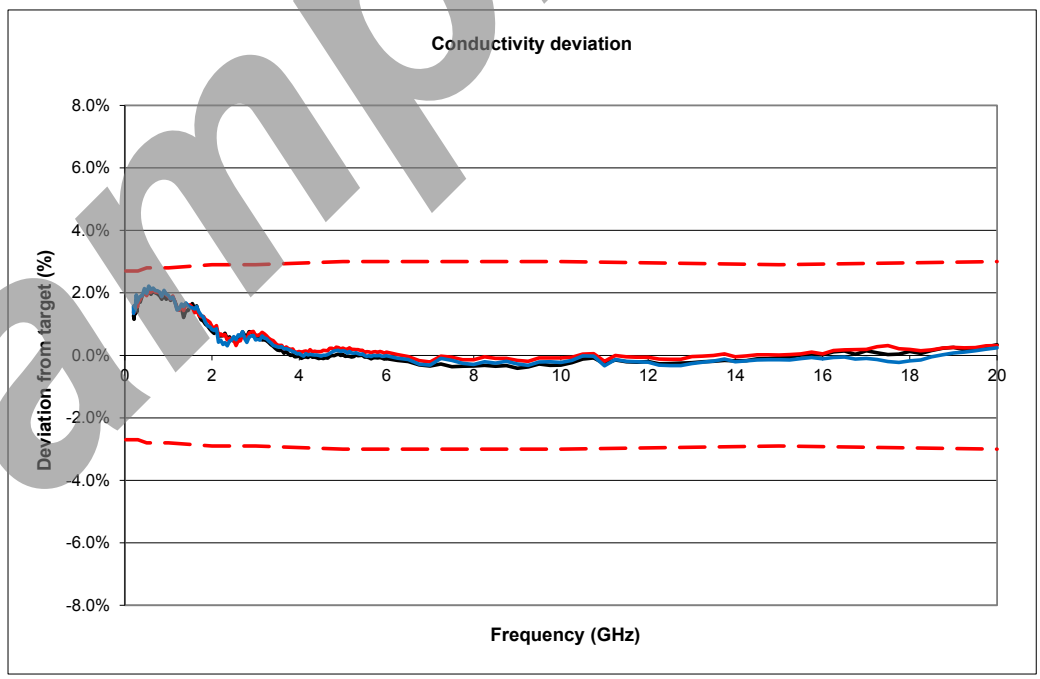


Fig. 5.2 0.05 mol/L solution conductivity deviation from target, 200 MHz – 20 GHz

## Appendix B: Nominal parameters of reference materials used for calibration

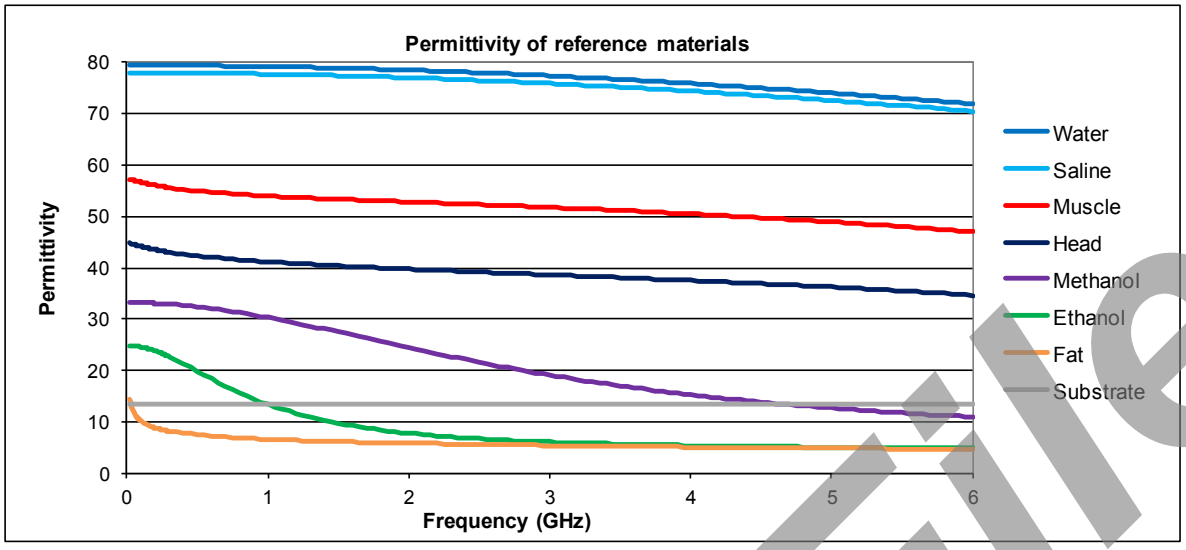


Fig. B.1 Permittivity of reference materials

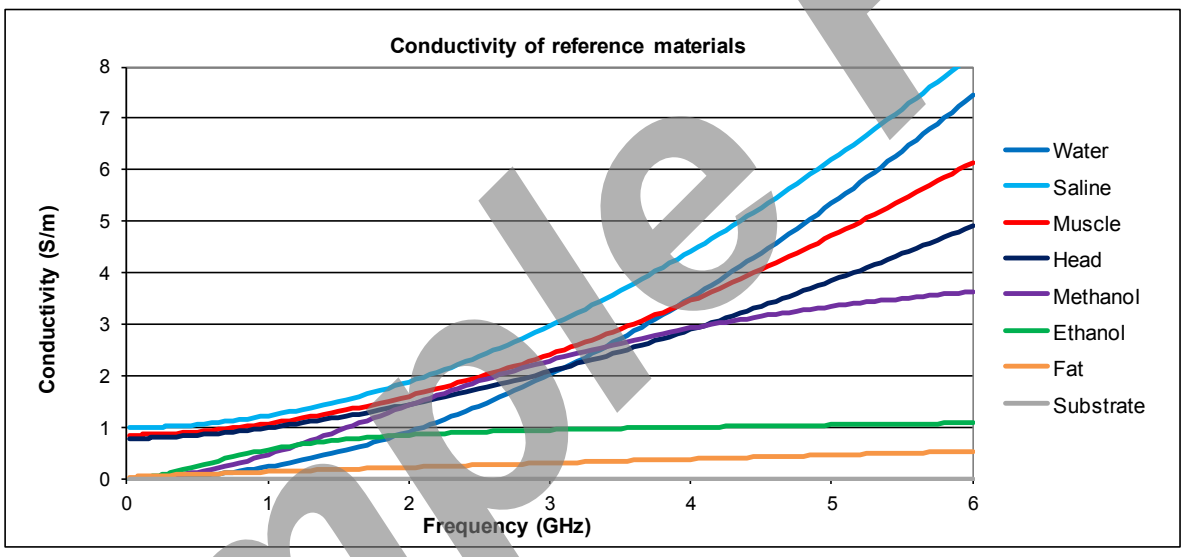


Fig. B.2 Conductivity of reference materials

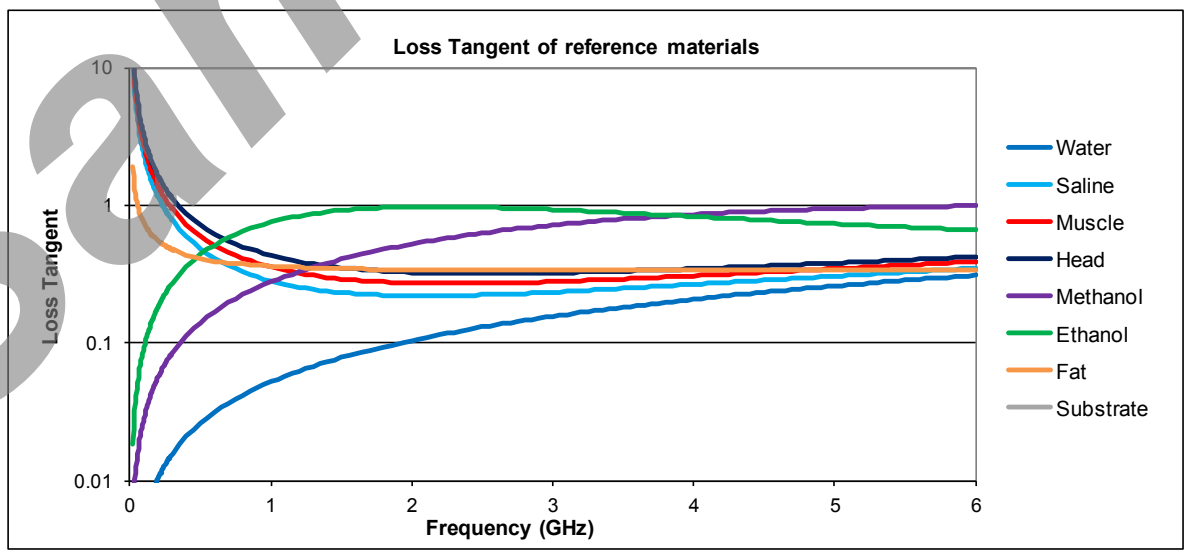


Fig. B.3 Loss tangent of reference materials (substrate << 0.01)