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CALIBRATION LABORATORY



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Client

UL

Certificate No: Z16-97247

CALIBRATION CERTIFICATE

Object EX3DV4 - SN:7383

Calibration Procedure(s) FD-Z11-004-01
Calibration Procedures for Dosimetric E-field Probes

Calibration date: December 27, 2016

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(Calibrated by, Certificate No.) | Scheduled Calibration |
|-------------------------|-------------|--|-----------------------|
| Power Meter NRP2 | 101919 | 27-Jun-16 (CTTL, No.J16X04777) | Jun-17 |
| Power sensor NRP-Z91 | 101547 | 27-Jun-16 (CTTL, No.J16X04777) | Jun-17 |
| Power sensor NRP-Z91 | 101548 | 27-Jun-16 (CTTL, No.J16X04777) | Jun-17 |
| Reference10dBAttenuator | 18N50W-10dB | 13-Mar-16(CTTL,No.J16X01547) | Mar-18 |
| Reference20dBAttenuator | 18N50W-20dB | 13-Mar-16(CTTL, No.J16X01548) | Mar-18 |
| Reference Probe EX3DV4 | SN 7433 | 26-Sep-16(SPEAG,No.EX3-7433_Sep16) | Sep-17 |
| DAE4 | SN 1331 | 21-Jan-16(SPEAG, No.DAE4-1331_Jan16) | Jan -17 |
| Secondary Standards | ID # | Cal Date(Calibrated by, Certificate No.) | Scheduled Calibration |
| SignalGeneratorMG3700A | 6201052605 | 27-Jun-16 (CTTL, No.J16X04776) | Jun-17 |
| Network Analyzer E5071C | MY46110673 | 26-Jan-16 (CTTL, No.J16X00894) | Jan -17 |

| | Name | Function | Signature |
|----------------|-------------|-----------------------------------|-----------|
| Calibrated by: | Zhao Jing | SAR Test Engineer | |
| Reviewed by: | Qi Dianyuan | SAR Project Leader | |
| Approved by: | Lu Bingsong | Deputy Director of the laboratory | |

Issued: December 31, 2016

This calibration certificate shall not be reproduced except in full without written approval of the laboratory.



Glossary:

| | |
|-----------------------|---|
| TSL | tissue simulating liquid |
| NORM _{x,y,z} | sensitivity in free space |
| ConvF | sensitivity in TSL / NORM _{x,y,z} |
| DCP | diode compression point |
| CF | crest factor (1/duty_cycle) of the RF signal |
| A,B,C,D | modulation dependent linearization parameters |
| Polarization Φ | Φ rotation around probe axis |
| Polarization θ | θ rotation around an axis that is in the plane normal to probe axis (at measurement center), i $\theta=0$ is normal to probe axis |

Connector Angle information used in DASY system to align probe sensor X to the robot coordinate system

Calibration is Performed According to the Following Standards:

- 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
- IEC 62209-1, "Procedure to measure the Specific Absorption Rate (SAR) for hand-held devices used in close proximity to the ear (frequency range of 300MHz to 3GHz)", February 2005
- IEC 62209-2, "Procedure to determine the Specific Absorption Rate (SAR) for wireless communication devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz)", March 2010
- KDB 865664, "SAR Measurement Requirements for 100 MHz to 6 GHz"

Methods Applied and Interpretation of Parameters:

- NORM_{x,y,z}**: Assessed for E-field polarization $\theta=0$ ($f \leq 900\text{MHz}$ in TEM-cell; $f > 1800\text{MHz}$: waveguide). NORM_{x,y,z} are only intermediate values, i.e., the uncertainties of NORM_{x,y,z} does not effect the E^2 -field uncertainty inside TSL (see below ConvF).
- NORM(f)_{x,y,z}** = NORM_{x,y,z} * frequency_response (see Frequency Response Chart). This linearization is implemented in DASY4 software versions later than 4.2. The uncertainty of the frequency response is included in the stated uncertainty of ConvF.
- DCP_{x,y,z}**: DCP are numerical linearization parameters assessed based on the data of power sweep (no uncertainty required). DCP does not depend on frequency nor media.
- PAR**: PAR is the Peak to Average Ratio that is not calibrated but determined based on the signal characteristics.
- A_{x,y,z}; B_{x,y,z}; C_{x,y,z}; VR_{x,y,z}**: A,B,C are numerical linearization parameters assessed based on the data of power sweep for specific modulation signal. The parameters do not depend on frequency nor media. VR is the maximum calibration range expressed in RMS voltage across the diode.
- ConvF and Boundary Effect Parameters**: Assessed in flat phantom using E-field (or Temperature Transfer Standard for $f \leq 800\text{MHz}$) and inside waveguide using analytical field distributions based on power measurements for $f > 800\text{MHz}$. The same setups are used for assessment of the parameters applied for boundary compensation (alpha, depth) of which typical uncertainty valued are given. These parameters are used in DASY4 software to improve probe accuracy close to the boundary. The sensitivity in TSL corresponds to NORM_{x,y,z}* ConvF whereby the uncertainty corresponds to that given for ConvF. A frequency dependent ConvF is used in DASY version 4.4 and higher which allows extending the validity from $\pm 50\text{MHz}$ to $\pm 100\text{MHz}$.
- Spherical isotropy (3D deviation from isotropy)**: in a field of low gradients realized using a flat phantom exposed by a patch antenna.
- Sensor Offset**: The sensor offset corresponds to the offset of virtual measurement center from the probe tip (on probe axis). No tolerance required.
- Connector Angle**: The angle is assessed using the information gained by determining the NORM_x (no uncertainty required).



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Probe EX3DV4

SN: 7383

Calibrated: December 27, 2016

Calibrated for DASY/EASY Systems

(Note: non-compatible with DASY2 system!)



DASY/EASY – Parameters of Probe: EX3DV4 – SN: 7383

Basic Calibration Parameters

| | Sensor X | Sensor Y | Sensor Z | Unc (k=2) |
|--|----------|----------|----------|-----------|
| Norm($\mu\text{V}/(\text{V}/\text{m})^2$) ^A | 0.39 | 0.48 | 0.51 | ±10.8% |
| DCP(mV) ^B | 97.7 | 97.3 | 101.0 | |

Modulation Calibration Parameters

| UID | Communication System Name | | A dB | B dB $\sqrt{\mu\text{V}}$ | C | D dB | VR mV | Unc ^E (k=2) |
|-----|---------------------------|---|------|---------------------------|-----|------|-------|------------------------|
| 0 | CW | X | 0.0 | 0.0 | 1.0 | 0.00 | 168.0 | ±2.5% |
| | | Y | 0.0 | 0.0 | 1.0 | | 189.9 | |
| | | Z | 0.0 | 0.0 | 1.0 | | 196.8 | |

The reported uncertainty of measurement is stated as the standard uncertainty of Measurement multiplied by the coverage factor k=2, which for a normal distribution Corresponds to a coverage probability of approximately 95%.

^A The uncertainties of Norm X, Y, Z do not affect the E²-field uncertainty inside TSL (see Page 5 and Page 6).

^B Numerical linearization parameter: uncertainty not required.

^E Uncertainty is determined using the max. deviation from linear response applying rectangular distribution and is expressed for the square of the field value.



DASY/EASY – Parameters of Probe: EX3DV4 – SN: 7383

Calibration Parameter Determined in Head Tissue Simulating Media

| f [MHz] ^C | Relative Permittivity ^F | Conductivity (S/m) ^F | ConvF X | ConvF Y | ConvF Z | Alpha ^G | Depth ^G (mm) | Unct. (k=2) |
|----------------------|------------------------------------|---------------------------------|---------|---------|---------|--------------------|-------------------------|-------------|
| 750 | 41.9 | 0.89 | 10.08 | 10.08 | 10.08 | 0.30 | 0.70 | ±12% |
| 835 | 41.5 | 0.90 | 9.69 | 9.69 | 9.69 | 0.13 | 1.45 | ±12% |
| 900 | 41.5 | 0.97 | 9.81 | 9.81 | 9.81 | 0.13 | 1.41 | ±12% |
| 1450 | 40.5 | 1.20 | 8.90 | 8.90 | 8.90 | 0.17 | 1.05 | ±12% |
| 1810 | 40.0 | 1.40 | 8.17 | 8.17 | 8.17 | 0.25 | 1.02 | ±12% |
| 1900 | 40.0 | 1.40 | 8.26 | 8.26 | 8.26 | 0.21 | 1.21 | ±12% |
| 2100 | 39.8 | 1.49 | 8.34 | 8.34 | 8.34 | 0.16 | 1.36 | ±12% |
| 2300 | 39.5 | 1.67 | 7.78 | 7.78 | 7.78 | 0.45 | 0.77 | ±12% |
| 2450 | 39.2 | 1.80 | 7.45 | 7.45 | 7.45 | 0.28 | 1.27 | ±12% |
| 2600 | 39.0 | 1.96 | 7.35 | 7.35 | 7.35 | 0.33 | 1.09 | ±12% |
| 3500 | 37.9 | 2.91 | 6.92 | 6.92 | 6.92 | 0.32 | 1.64 | ±13% |
| 3700 | 37.7 | 3.12 | 6.58 | 6.58 | 6.58 | 0.38 | 1.25 | ±13% |
| 5250 | 35.9 | 4.71 | 5.20 | 5.20 | 5.20 | 0.35 | 1.50 | ±13% |
| 5600 | 35.5 | 5.07 | 4.69 | 4.69 | 4.69 | 0.40 | 1.50 | ±13% |
| 5750 | 35.4 | 5.22 | 4.90 | 4.90 | 4.90 | 0.40 | 1.50 | ±13% |

^C Frequency validity above 300 MHz of ±100MHz only applies for DASY v4.4 and higher (Page 2), else it is restricted to ±50MHz. The uncertainty is the RSS of ConvF uncertainty at calibration frequency and the uncertainty for the indicated frequency band. Frequency validity below 300 MHz is ± 10, 25, 40, 50 and 70 MHz for ConvF assessments at 30, 64, 128, 150 and 220 MHz respectively. Above 5 GHz frequency validity can be extended to ± 110 MHz.

^F At frequency below 3 GHz, the validity of tissue parameters (ϵ and σ) can be relaxed to ±10% if liquid compensation formula is applied to measured SAR values. At frequencies above 3 GHz, the validity of tissue parameters (ϵ and σ) is restricted to ±5%. The uncertainty is the RSS of the ConvF uncertainty for indicated target tissue parameters.

^G Alpha/Depth are determined during calibration. SPEAG warrants that the remaining deviation due to the boundary effect after compensation is always less than ± 1% for frequencies below 3 GHz and below ± 2% for the frequencies between 3-6 GHz at any distance larger than half the probe tip diameter from the boundary.



DASY/EASY – Parameters of Probe: EX3DV4 – SN: 7383

Calibration Parameter Determined in Body Tissue Simulating Media

| f [MHz] ^C | Relative Permittivity ^F | Conductivity (S/m) ^F | ConvF X | ConvF Y | ConvF Z | Alpha ^G | Depth ^G (mm) | Unct. (k=2) |
|----------------------|------------------------------------|---------------------------------|---------|---------|---------|--------------------|-------------------------|-------------|
| 750 | 55.5 | 0.96 | 10.40 | 10.40 | 10.40 | 0.40 | 0.82 | ±12% |
| 835 | 55.2 | 0.97 | 10.13 | 10.13 | 10.13 | 0.15 | 1.58 | ±12% |
| 900 | 55.0 | 1.05 | 10.14 | 10.14 | 10.14 | 0.19 | 1.35 | ±12% |
| 1450 | 54.0 | 1.30 | 8.71 | 8.71 | 8.71 | 0.12 | 1.49 | ±12% |
| 1810 | 53.3 | 1.52 | 8.10 | 8.10 | 8.10 | 0.15 | 1.58 | ±12% |
| 1900 | 53.3 | 1.52 | 8.01 | 8.01 | 8.01 | 0.17 | 1.41 | ±12% |
| 2100 | 53.2 | 1.62 | 8.32 | 8.32 | 8.32 | 0.16 | 1.63 | ±12% |
| 2300 | 52.9 | 1.81 | 7.83 | 7.83 | 7.83 | 0.33 | 1.21 | ±12% |
| 2450 | 52.7 | 1.95 | 7.63 | 7.63 | 7.63 | 0.38 | 1.05 | ±12% |
| 2600 | 52.5 | 2.16 | 7.55 | 7.55 | 7.55 | 0.38 | 1.03 | ±12% |
| 3500 | 51.3 | 3.31 | 6.57 | 6.57 | 6.57 | 0.41 | 1.53 | ±13% |
| 3700 | 51.0 | 3.55 | 6.58 | 6.58 | 6.58 | 0.40 | 1.85 | ±13% |
| 5250 | 48.9 | 5.36 | 4.63 | 4.63 | 4.63 | 0.46 | 1.90 | ±13% |
| 5600 | 48.5 | 5.77 | 3.99 | 3.99 | 3.99 | 0.50 | 1.95 | ±13% |
| 5750 | 48.3 | 5.94 | 4.33 | 4.33 | 4.33 | 0.52 | 2.00 | ±13% |

^C Frequency validity above 300 MHz of ±100MHz only applies for DASY v4.4 and higher (Page 2), else it is restricted to ±50MHz. The uncertainty is the RSS of ConvF uncertainty at calibration frequency and the uncertainty for the indicated frequency band. Frequency validity below 300 MHz is ± 10, 25, 40, 50 and 70 MHz for ConvF assessments at 30, 64, 128, 150 and 220 MHz respectively. Above 5 GHz frequency validity can be extended to ± 110 MHz.

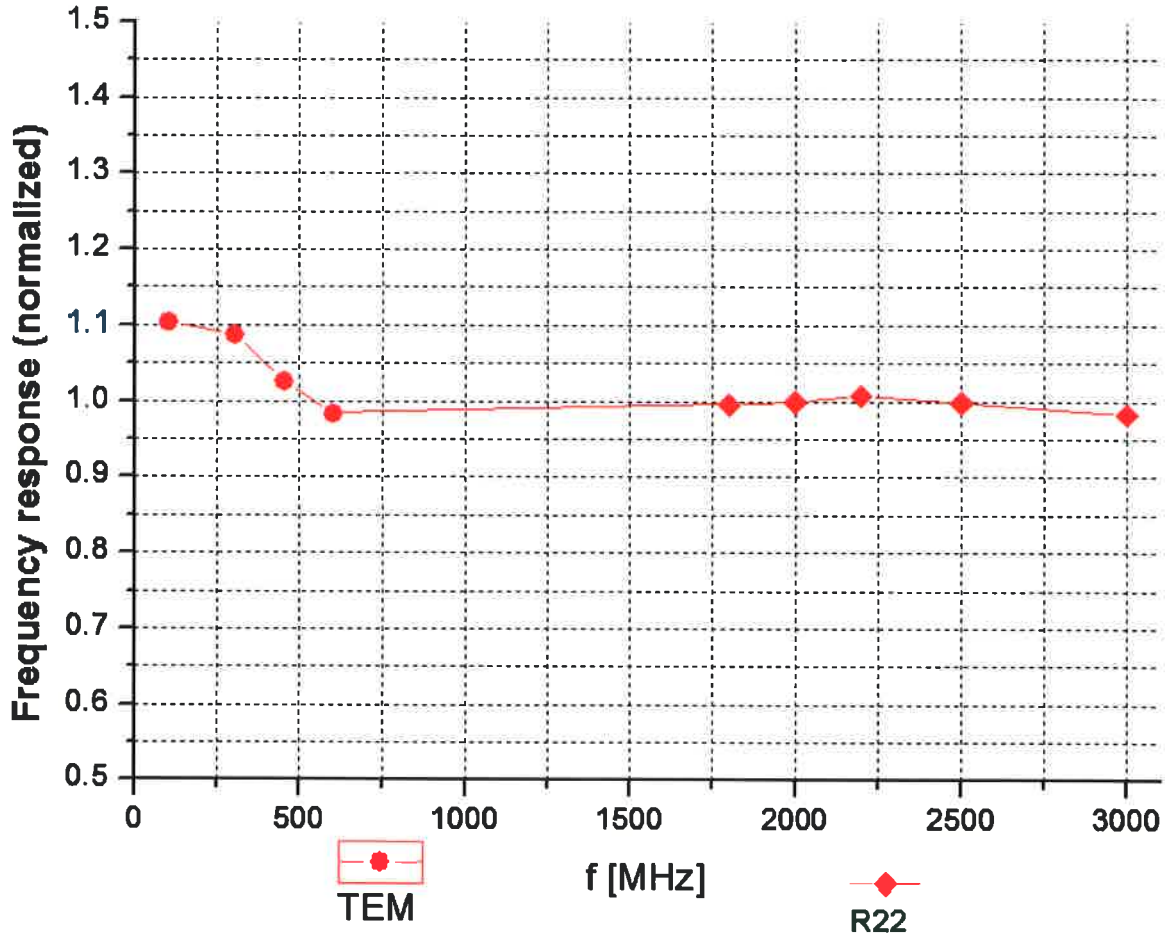
^F At frequency below 3 GHz, the validity of tissue parameters (ϵ and σ) can be relaxed to ±10% if liquid compensation formula is applied to measured SAR values. At frequencies above 3 GHz, the validity of tissue parameters (ϵ and σ) is restricted to ±5%. The uncertainty is the RSS of the ConvF uncertainty for indicated target tissue parameters.

^G Alpha/Depth are determined during calibration. SPEAG warrants that the remaining deviation due to the boundary effect after compensation is always less than ± 1% for frequencies below 3 GHz and below ± 2% for the frequencies between 3-6 GHz at any distance larger than half the probe tip diameter from the boundary.



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Frequency Response of E-Field (TEM-Cell: ifi110 EXX, Waveguide: R22)



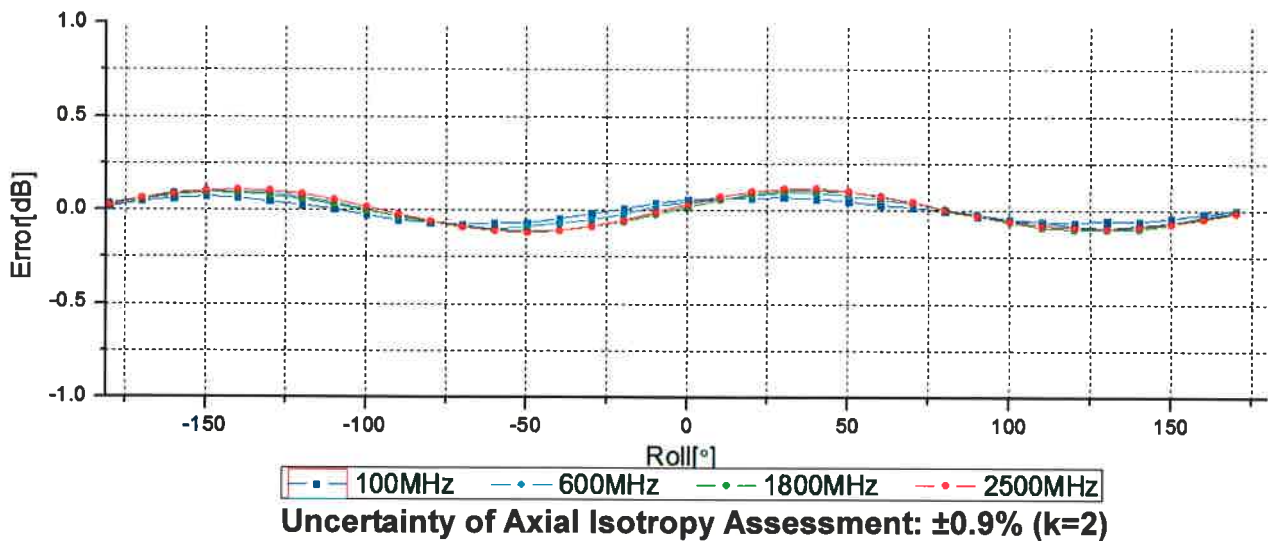
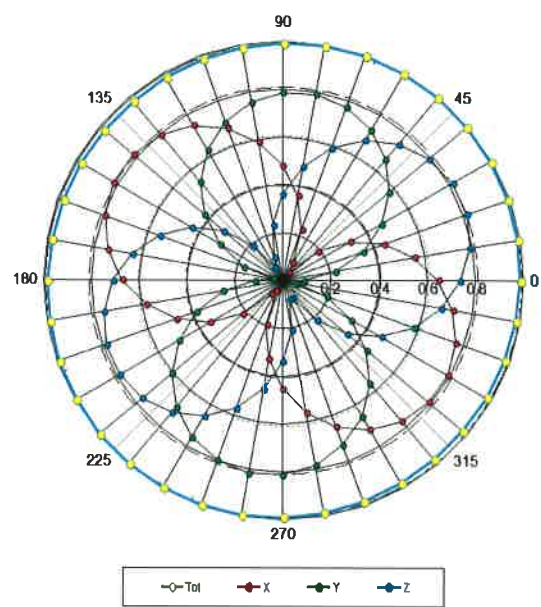
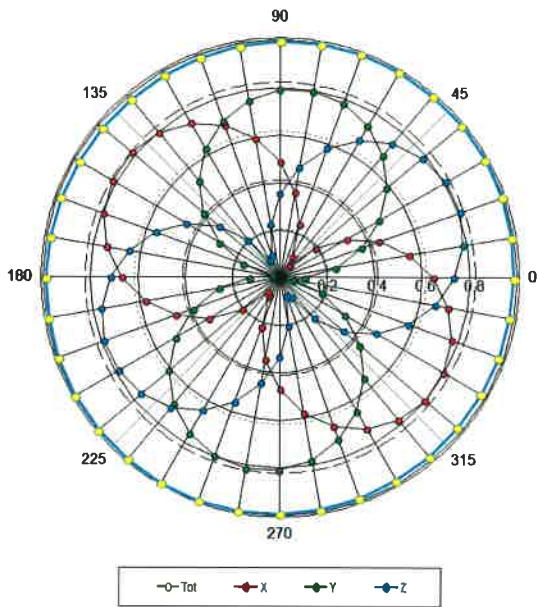
Uncertainty of Frequency Response of E-field: $\pm 7.5\%$ (k=2)



Receiving Pattern (Φ), $\theta=0^\circ$

f=600 MHz, TEM

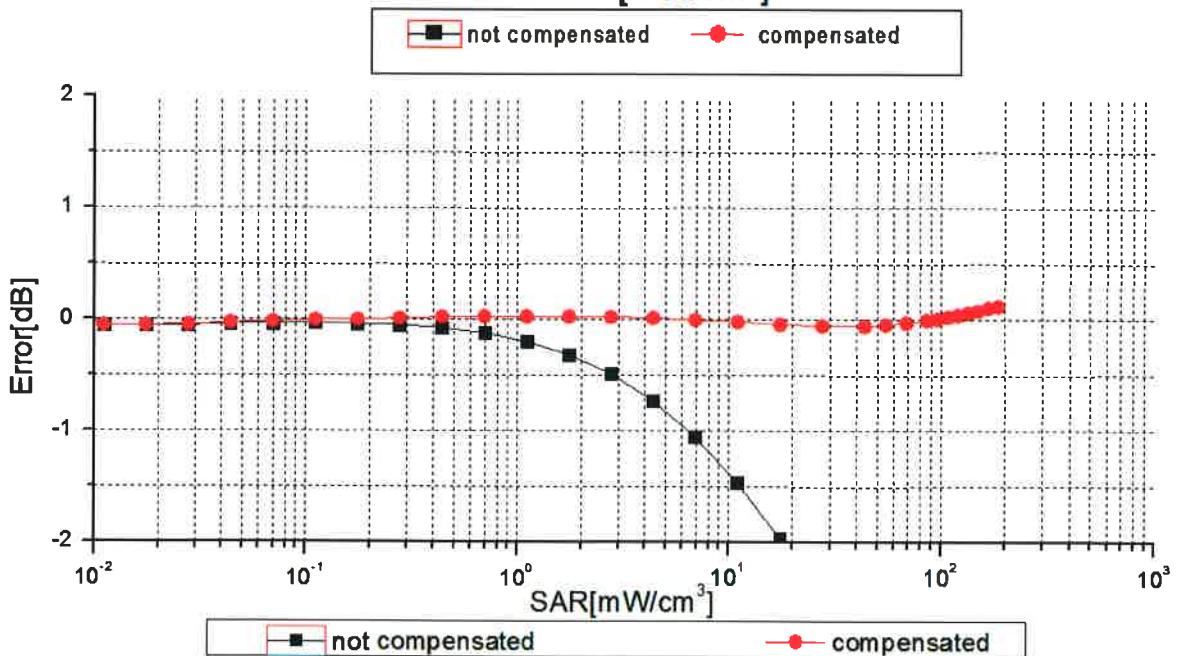
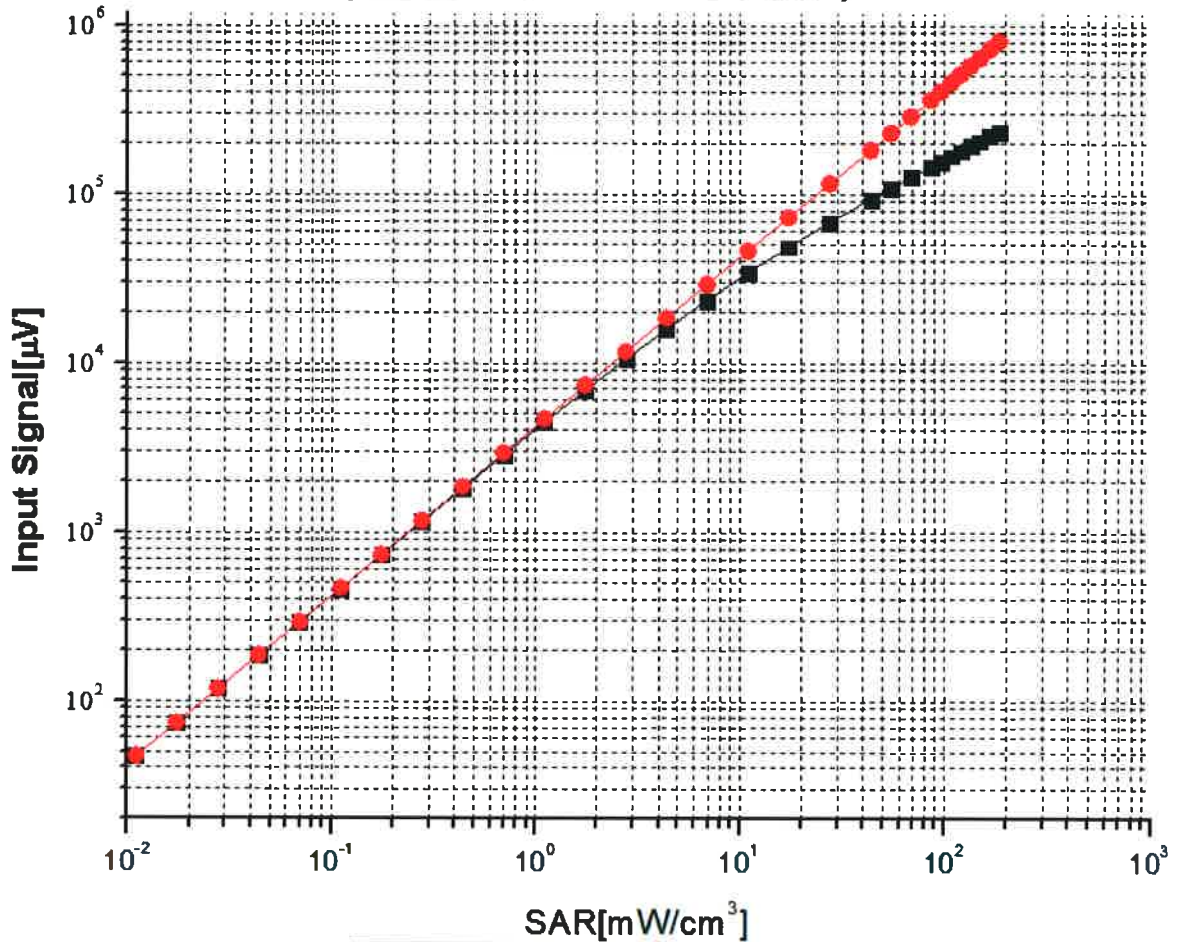
f=1800 MHz, R22





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Dynamic Range f(SAR_{head}) (TEM cell, f = 900 MHz)



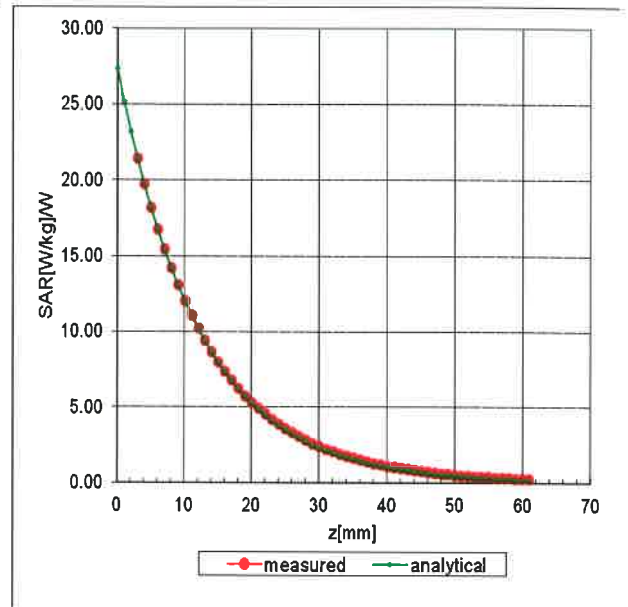
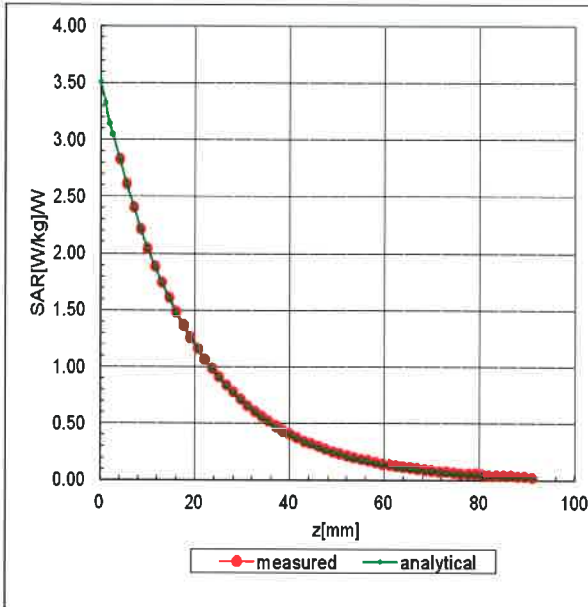
Uncertainty of Linearity Assessment: ±0.9% (k=2)



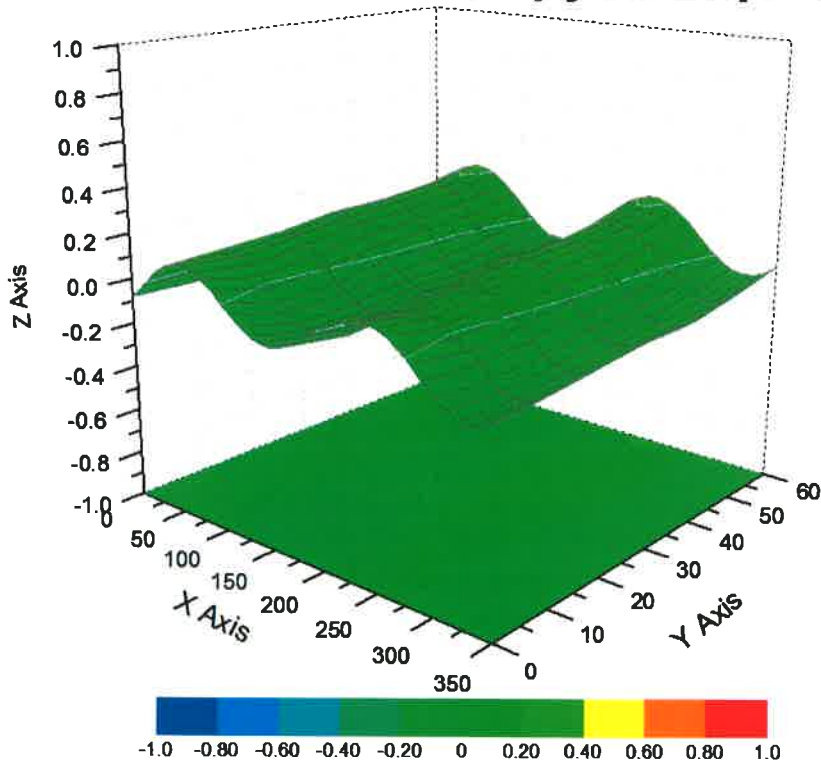
Conversion Factor Assessment

f=900 MHz, WGLS R9(H_convF)

f=1810 MHz, WGLS R22(H_convF)



Deviation from Isotropy in Liquid



Uncertainty of Spherical Isotropy Assessment: $\pm 2.8\%$ (K=2)



DASY/EASY – Parameters of Probe: EX3DV4 – SN: 7383

Other Probe Parameters

| | |
|--|-------------------|
| Sensor Arrangement | Triangular |
| Connector Angle (°) | 127.9 |
| Mechanical Surface Detection Mode | enabled |
| Optical Surface Detection Mode | disable |
| Probe Overall Length | 337mm |
| Probe Body Diameter | 10mm |
| Tip Length | 9mm |
| Tip Diameter | 2.5mm |
| Probe Tip to Sensor X Calibration Point | 1mm |
| Probe Tip to Sensor Y Calibration Point | 1mm |
| Probe Tip to Sensor Z Calibration Point | 1mm |
| Recommended Measurement Distance from Surface | 1.4mm |