In Collaboration with
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CALIBRATION LABORATORY
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## Glossary:

| | |
|---|---|
| TSL | tissue simulating liquid |
| NORMx,y,z | sensitivity in free space |
| ConvF | sensitivity in TSL / NORMx,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 θ=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:

a) 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

b) IEC 62209-1, "Measurement procedure for the assessment of Specific Absorption Rate (SAR) from hand-held and body-mounted devices used next to the ear (frequency range of 300 MHz to 6 GHz)", July 2016

c) 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

d) KDB 865664, "SAR Measurement Requirements for 100 MHz to 6 GHz"

## Methods Applied and Interpretation of Parameters:

- *NORMx,y,z:* Assessed for E-field polarization θ=0 (f≤900MHz in TEM-cell; f>1800MHz: waveguide). NORMx,y,z are only intermediate values, i.e., the uncertainties of NORMx,y,z does not effect the $E^2$-field uncertainty inside TSL (see below ConvF).
- *NORM(f)x,y,z = NORMx,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.
- *DCPx,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.
- *Ax,y,z; Bx,y,z; Cx,y,z;VRx,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≤800MHz) and inside waveguide using analytical field distributions based on power measurements for f >800MHz. 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 NORMx,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±50MHz to±100MHz.
- *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 *NORMx* (no uncertainty required).

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# DASY/EASY – Parameters of Probe: ES3DV3 – SN:3279

## Basic Calibration Parameters

| | Sensor X | Sensor Y | Sensor Z | Unc (*k*=2) |
|---|---|---|---|---|
| Norm(μV/(V/m)²)[A] | 1.32 | 1.39 | 1.31 | ±10.0% |
| DCP(mV)[B] | 104.2 | 106.6 | 106.1 | |

## Modulation Calibration Parameters

| UID | Communication System Name | | A dB | B dB√μV | C | D dB | VR mV | Unc[E] (*k*=2) |
|---|---|---|---|---|---|---|---|---|
| 0 | CW | X | 0.0 | 0.0 | 1.0 | 0.00 | 264.4 | ±2.2% |
| | | Y | 0.0 | 0.0 | 1.0 | | 276.5 | |
| | | Z | 0.0 | 0.0 | 1.0 | | 268.2 | |

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 $E^2$-field uncertainty inside TSL (see Page 4).
[B] Numerical linearization parameter: uncertainty not required.
[E] Uncertainly is determined using the max. deviation from linear response applying rectangular distribution and is expressed for the square of the field value.

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# DASY/EASY – Parameters of Probe: ES3DV3 – SN:3279

## 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 | 6.44 | 6.44 | 6.44 | 0.40 | 1.40 | ±12.1% |
| 835 | 41.5 | 0.90 | 6.25 | 6.25 | 6.25 | 0.43 | 1.48 | ±12.1% |
| 1750 | 40.1 | 1.37 | 5.40 | 5.40 | 5.40 | 0.75 | 1.19 | ±12.1% |
| 1900 | 40.0 | 1.40 | 5.16 | 5.16 | 5.16 | 0.69 | 1.25 | ±12.1% |
| 2000 | 40.0 | 1.40 | 5.13 | 5.13 | 5.13 | 0.63 | 1.31 | ±12.1% |
| 2300 | 39.5 | 1.67 | 4.92 | 4.92 | 4.92 | 0.90 | 1.10 | ±12.1% |
| 2450 | 39.2 | 1.80 | 4.71 | 4.71 | 4.71 | 0.90 | 1.16 | ±12.1% |
| 2600 | 39.0 | 1.96 | 4.54 | 4.54 | 4.54 | 0.90 | 1.15 | ±12.1% |

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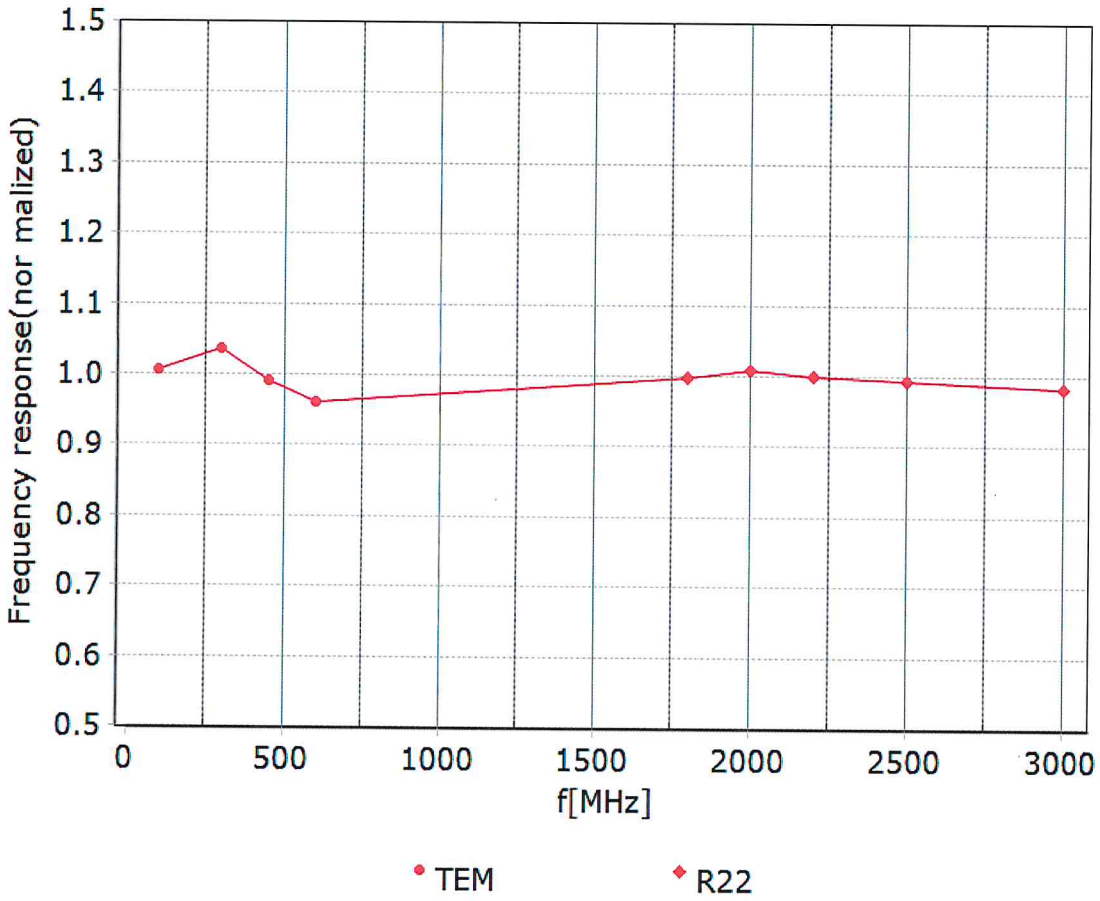
# Frequency Response of E-Field
## (TEM-Cell: ifi110 EXX, Waveguide: R22)




**Uncertainty of Frequency Response of E-field: ±7.4% (*k*=2)**

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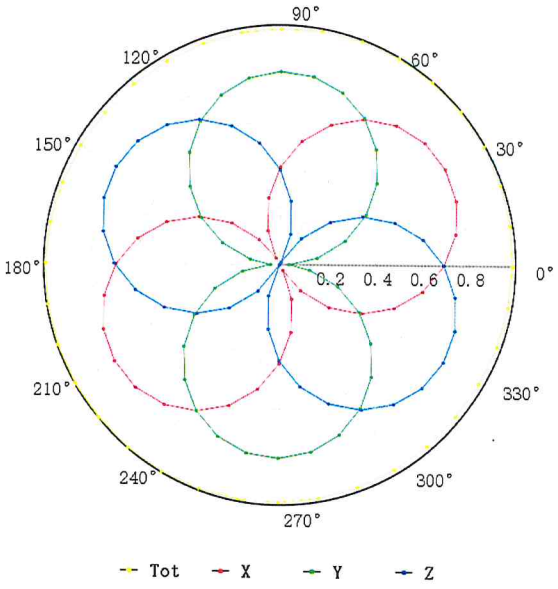
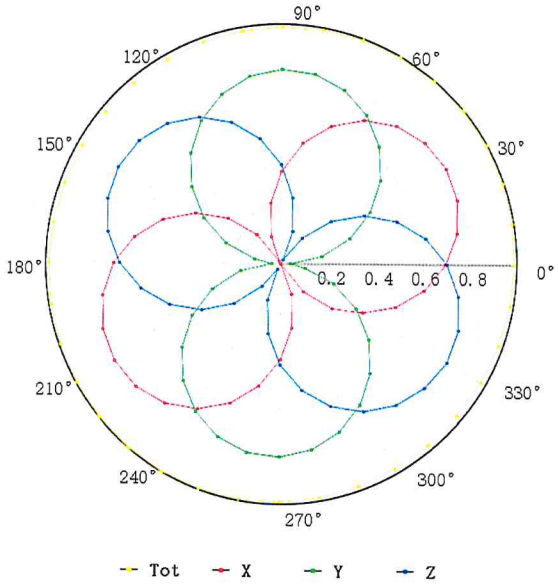
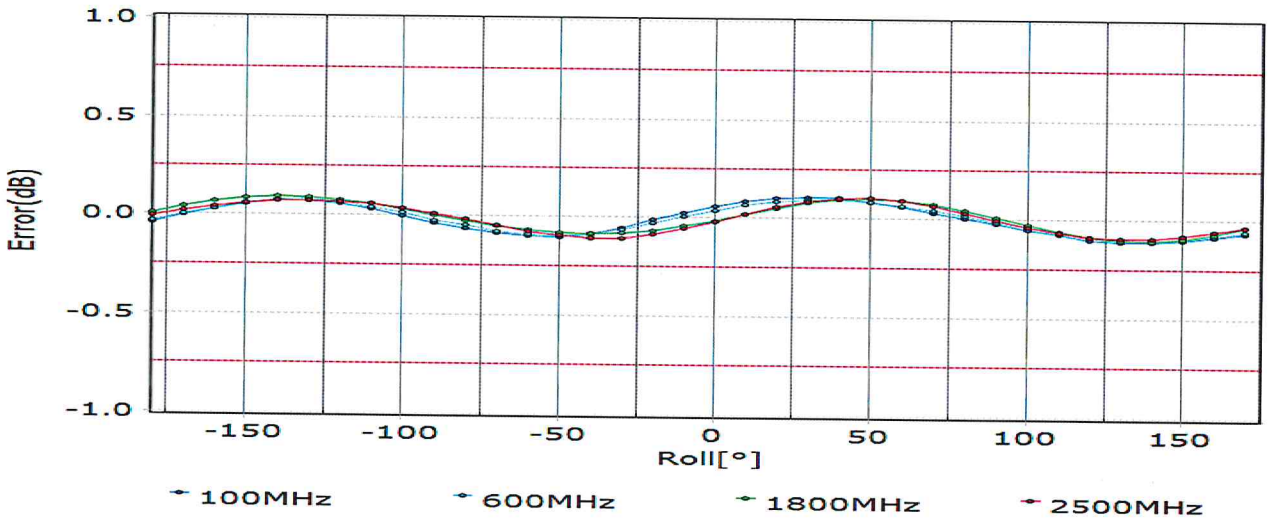
# Receiving Pattern (Φ), θ=0°

## f=600 MHz, TEM




## f=1800 MHz, R22




Uncertainty of Axial Isotropy Assessment: ±1.2% (*k*=2)

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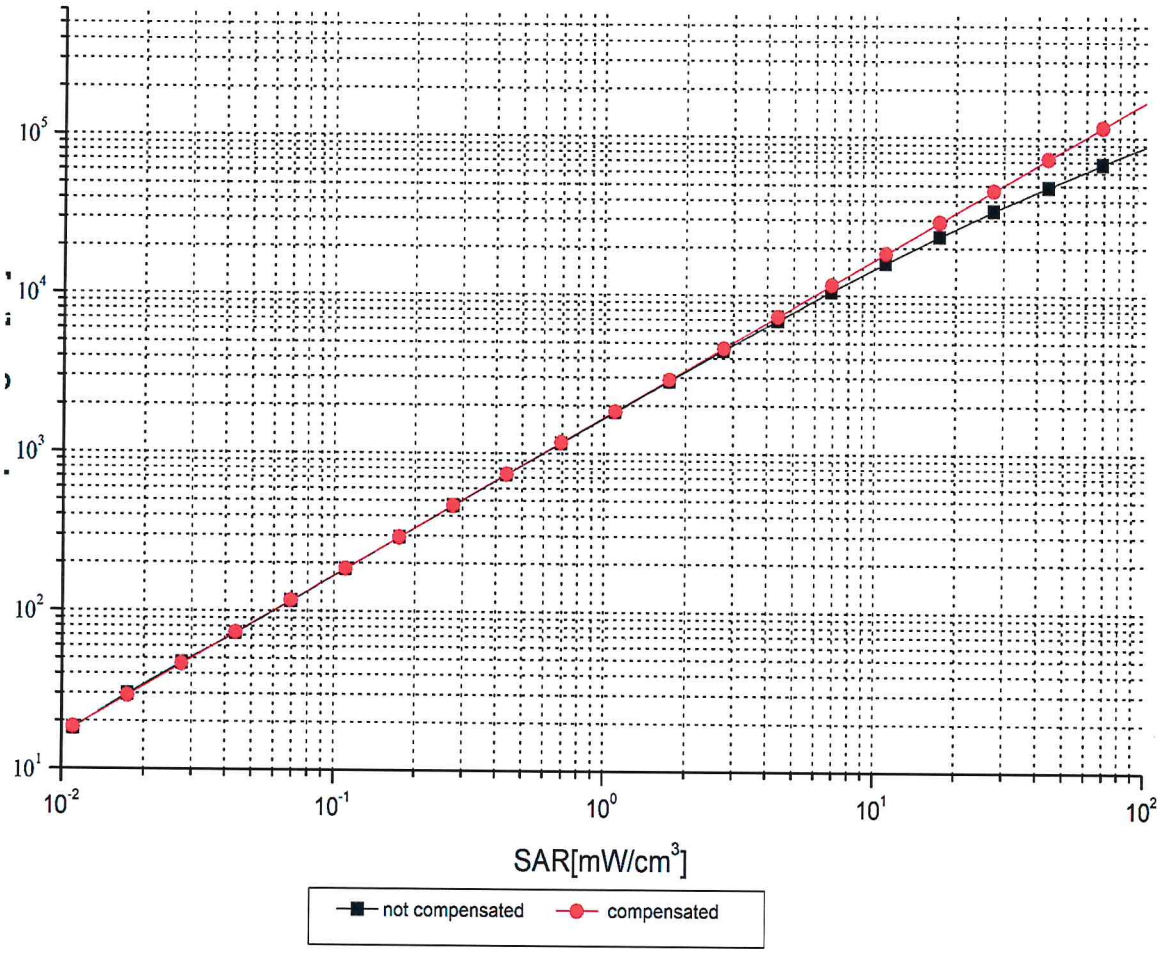
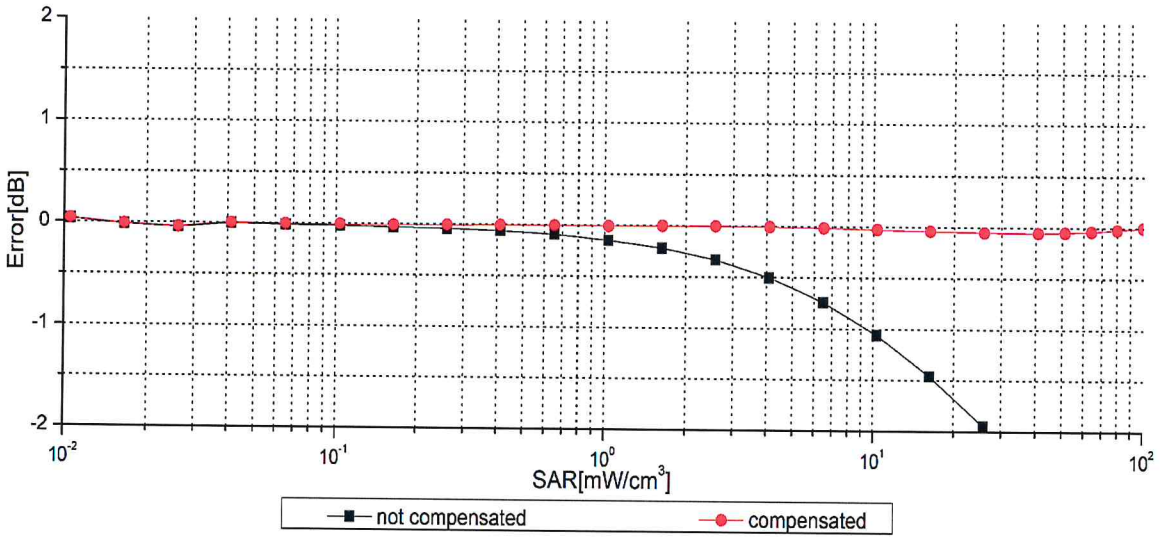
# Dynamic Range f($SAR_{head}$)
## (TEM cell, f = 900 MHz)




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

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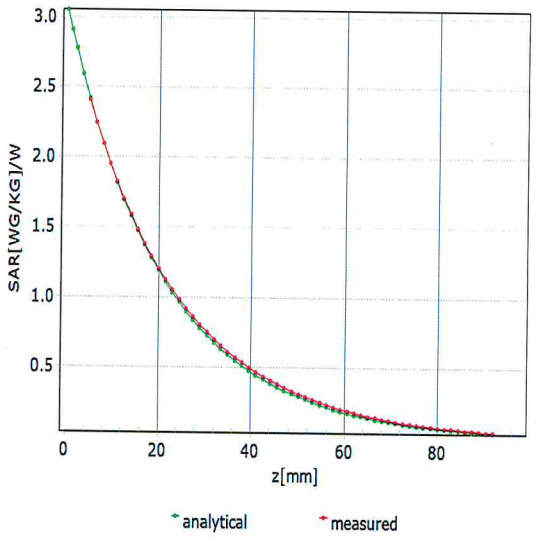
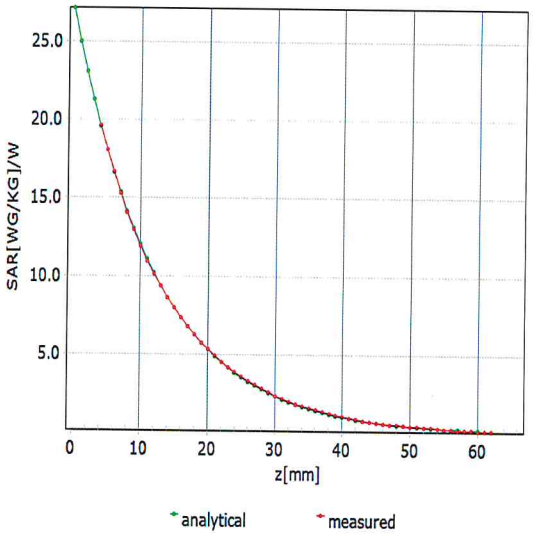
# Conversion Factor Assessment

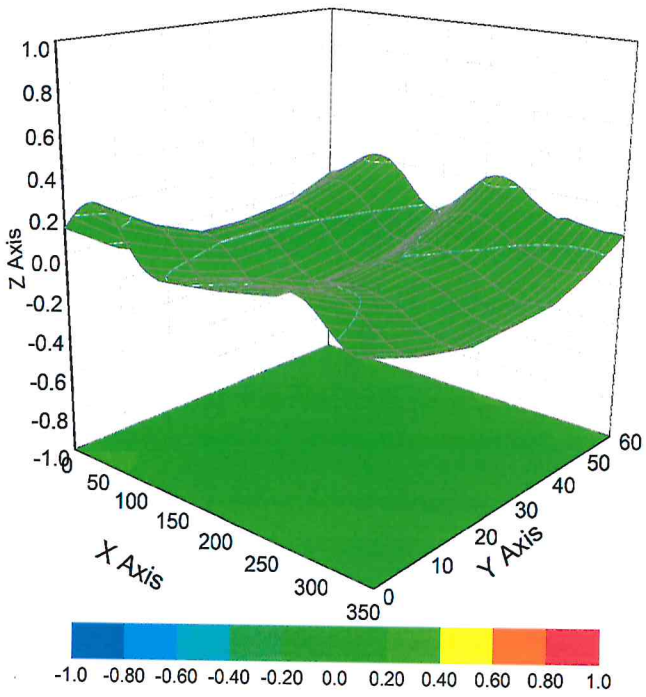
## f=750 MHz,WGLS R9(H_convF)




## f=1750 MHz,WGLS R22(H_convF)




# Deviation from Isotropy in Liquid




**Uncertainty of Spherical Isotropy Assessment: ±3.2% (*k*=2)**

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# DASY/EASY – Parameters of Probe: ES3DV3 – SN:3279

## Other Probe Parameters

| | |
|---|---|
| Sensor Arrangement | Triangular |
| Connector Angle (°) | 170.7 |
| Mechanical Surface Detection Mode | enabled |
| Optical Surface Detection Mode | disable |
| Probe Overall Length | 337mm |
| Probe Body Diameter | 10mm |
| Tip Length | 10mm |
| Tip Diameter | 4mm |
| Probe Tip to Sensor X Calibration Point | 2mm |
| Probe Tip to Sensor Y Calibration Point | 2mm |
| Probe Tip to Sensor Z Calibration Point | 2mm |
| Recommended Measurement Distance from Surface | 3mm |

**Calibration Laboratory of**
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Engineering AG
**Zeughausstrasse 43, 8004 Zurich, Switzerland**

**S** Schweizerischer Kalibrierdienst
**C** Service suisse d'étalonnage
**S** Servizio svizzero di taratura
Swiss Calibration Service

Accredited by the Swiss Accreditation Service (SAS)
**The Swiss Accreditation Service is one of the signatories to the EA Multilateral Agreement for the recognition of calibration certificates**

**Accreditation No.: SCS 0108**

**Client** Sporton

**Certificate No: EX3-7592_May20**

# CALIBRATION CERTIFICATE

Object: EX3DV4 - SN:7592

Calibration procedure(s): QA CAL-01.v9, QA CAL-14.v5, QA CAL-23.v5, QA CAL-25.v7
Calibration procedure for dosimetric E-field probes

Calibration date: May 22, 2020

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 |
|---|---|---|---|
| Power meter NRP | SN: 104778 | 01-Apr-20 (No. 217-03100/03101) | Apr-21 |
| Power sensor NRP-Z91 | SN: 103244 | 01-Apr-20 (No. 217-03100) | Apr-21 |
| Power sensor NRP-Z91 | SN: 103245 | 01-Apr-20 (No. 217-03101) | Apr-21 |
| Reference 20 dB Attenuator | SN: CC2552 (20x) | 31-Mar-20 (No. 217-03106) | Apr-21 |
| DAE4 | SN: 660 | 27-Dec-19 (No. DAE4-660_Dec19) | Dec-20 |
| Reference Probe ES3DV2 | SN: 3013 | 31-Dec-19 (No. ES3-3013_Dec19) | Dec-20 |
| | | | |
| Secondary Standards | ID | Check Date (in house) | Scheduled Check |
| Power meter E4419B | SN: GB41293874 | 06-Apr-16 (in house check Jun-18) | In house check: Jun-20 |
| Power sensor E4412A | SN: MY41498087 | 06-Apr-16 (in house check Jun-18) | In house check: Jun-20 |
| Power sensor E4412A | SN: 000110210 | 06-Apr-16 (in house check Jun-18) | In house check: Jun-20 |
| RF generator HP 8648C | SN: US3642U01700 | 04-Aug-99 (in house check Jun-18) | In house check: Jun-20 |
| Network Analyzer E8358A | SN: US41080477 | 31-Mar-14 (in house check Oct-19) | In house check: Oct-20 |

| | Name | Function | Signature |
|---|---|---|---|
| Calibrated by: | Jeton Kastrati | Laboratory Technician | |
| Approved by: | Katja Pokovic | Technical Manager | |

Issued: May 27, 2020

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

## Glossary:

| | |
|---|---|
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| NORMx,y,z | sensitivity in free space |
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| 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.e., ϑ = 0 is normal to probe axis |
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- *NORM(f)x,y,z = NORMx,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*.
- *DCPx,y,z:* DCP are numerical linearization parameters assessed based on the data of power sweep with CW signal (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
- *Ax,y,z; Bx,y,z; Cx,y,z; Dx,y,z; VRx,y,z*: *A, B, C, D* 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.
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- *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 *NORMx* (no uncertainty required).

# DASY/EASY - Parameters of Probe: EX3DV4 - SN:7592

## Basic Calibration Parameters

| | Sensor X | Sensor Y | Sensor Z | Unc (k=2) |
|---|---|---|---|---|
| Norm ($\mu V/(V/m)^2$)[A] | 0.66 | 0.47 | 0.46 | ± 10.1 % |
| DCP (mV)[B] | 98.7 | 100.2 | 98.2 | |

## Calibration Results for Modulation Response

| UID | Communication System Name | | A dB | B dB√μV | C | D dB | VR mV | Max dev. | Max Unc[E] (k=2) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | CW | X | 0.00 | 0.00 | 1.00 | 0.00 | 143.0 | ± 3.3 % | ± 4.7 % |
| | | Y | 0.00 | 0.00 | 1.00 | | 137.6 | | |
| | | Z | 0.00 | 0.00 | 1.00 | | 139.6 | | |
| 10352-AAA | Pulse Waveform (200Hz, 10%) | X | 20.00 | 96.67 | 23.94 | 10.00 | 60.0 | ± 3.2 % | ± 9.6 % |
| | | Y | 20.00 | 95.48 | 23.94 | | 60.0 | | |
| | | Z | 20.00 | 95.35 | 23.55 | | 60.0 | | |
| 10353-AAA | Pulse Waveform (200Hz, 20%) | X | 20.00 | 98.13 | 23.72 | 6.99 | 80.0 | ± 1.6 % | ± 9.6 % |
| | | Y | 20.00 | 96.17 | 23.28 | | 80.0 | | |
| | | Z | 20.00 | 99.34 | 24.32 | | 80.0 | | |
| 10354-AAA | Pulse Waveform (200Hz, 40%) | X | 20.00 | 103.13 | 24.87 | 3.98 | 95.0 | ± 1.2 % | ± 9.6 % |
| | | Y | 20.00 | 100.39 | 24.05 | | 95.0 | | |
| | | Z | 20.00 | 107.03 | 26.46 | | 95.0 | | |
| 10355-AAA | Pulse Waveform (200Hz, 60%) | X | 20.00 | 109.16 | 26.39 | 2.22 | 120.0 | ± 1.2 % | ± 9.6 % |
| | | Y | 20.00 | 106.91 | 25.85 | | 120.0 | | |
| | | Z | 20.00 | 115.84 | 28.99 | | 120.0 | | |
| 10387-AAA | QPSK Waveform, 1 MHz | X | 1.66 | 64.78 | 14.38 | 1.00 | 150.0 | ± 1.5 % | ± 9.6 % |
| | | Y | 1.82 | 65.72 | 15.24 | | 150.0 | | |
| | | Z | 1.64 | 65.30 | 14.64 | | 150.0 | | |
| 10388-AAA | QPSK Waveform, 10 MHz | X | 2.15 | 66.68 | 15.00 | 0.00 | 150.0 | ± 1.0 % | ± 9.6 % |
| | | Y | 2.39 | 68.24 | 15.90 | | 150.0 | | |
| | | Z | 2.16 | 67.14 | 15.34 | | 150.0 | | |
| 10396-AAA | 64-QAM Waveform, 100 kHz | X | 2.92 | 69.89 | 18.38 | 3.01 | 150.0 | ± 0.7 % | ± 9.6 % |
| | | Y | 3.01 | 70.02 | 18.55 | | 150.0 | | |
| | | Z | 2.52 | 68.22 | 17.84 | | 150.0 | | |
| 10399-AAA | 64-QAM Waveform, 40 MHz | X | 3.50 | 66.65 | 15.46 | 0.00 | 150.0 | ± 0.7 % | ± 9.6 % |
| | | Y | 3.65 | 67.33 | 15.92 | | 150.0 | | |
| | | Z | 3.49 | 66.76 | 15.61 | | 150.0 | | |
| 10414-AAA | WLAN CCDF, 64-QAM, 40MHz | X | 4.93 | 65.49 | 15.38 | 0.00 | 150.0 | ± 1.3 % | ± 9.6 % |
| | | Y | 4.87 | 65.08 | 15.27 | | 150.0 | | |
| | | Z | 4.88 | 65.48 | 15.46 | | 150.0 | | |

Note: For details on UID parameters see Appendix

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 $E^2$-field uncertainty inside TSL (see Page 5).
[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:7592

## Sensor Model Parameters

| | C1 fF | C2 fF | α $V^{-1}$ | T1 $ms.V^{-2}$ | T2 $ms.V^{-1}$ | T3 ms | T4 $V^{-2}$ | T5 $V^{-1}$ | T6 |
|---|---|---|---|---|---|---|---|---|---|
| X | 50.2 | 372.49 | 35.00 | 18.44 | 0.06 | 5.10 | 1.55 | 0.19 | 1.01 |
| Y | 58.2 | 434.14 | 35.52 | 23.57 | 0.33 | 5.10 | 1.00 | 0.32 | 1.01 |
| Z | 46.8 | 350.57 | 35.76 | 12.03 | 0.37 | 5.09 | 0.94 | 0.20 | 1.01 |

## Other Probe Parameters

| | |
|---|---|
| Sensor Arrangement | Triangular |
| Connector Angle (°) | 9.2 |
| Mechanical Surface Detection Mode | enabled |
| Optical Surface Detection Mode | disabled |
| Probe Overall Length | 337 mm |
| Probe Body Diameter | 10 mm |
| Tip Length | 9 mm |
| Tip Diameter | 2.5 mm |
| Probe Tip to Sensor X Calibration Point | 1 mm |
| Probe Tip to Sensor Y Calibration Point | 1 mm |
| Probe Tip to Sensor Z Calibration Point | 1 mm |
| Recommended Measurement Distance from Surface | 1.4 mm |

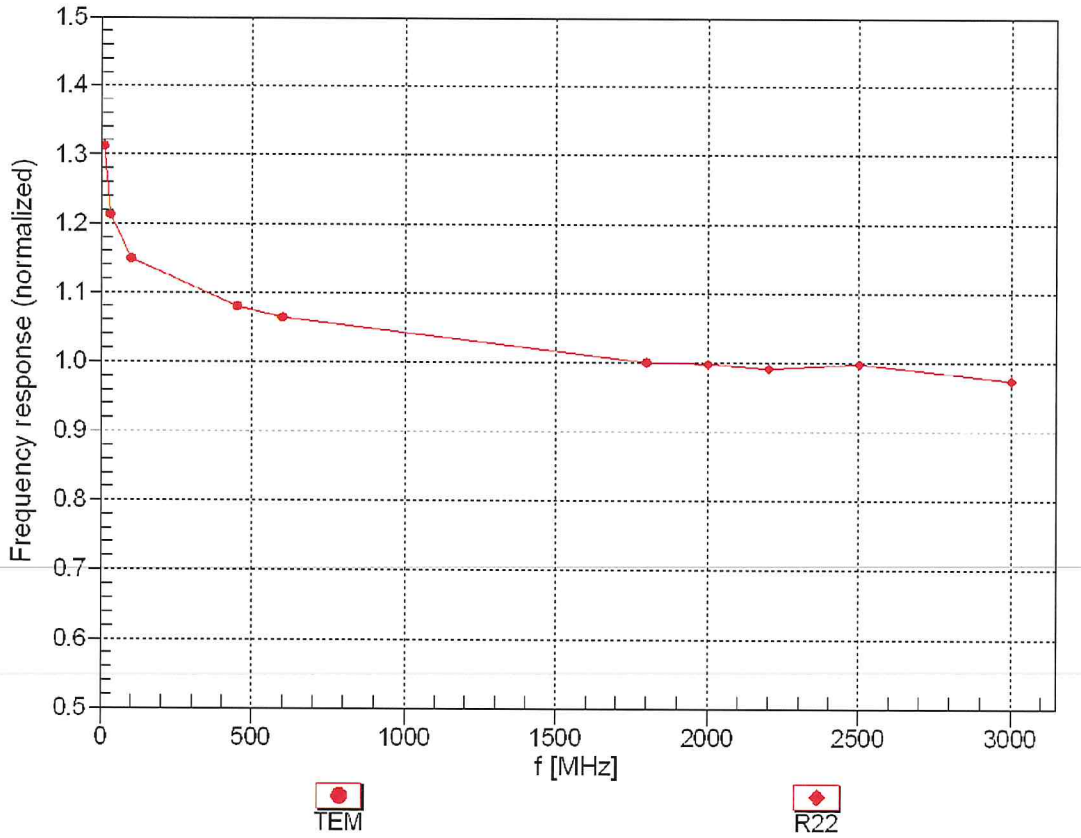
# DASY/EASY - Parameters of Probe: EX3DV4 - SN:7592

## 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) | Unc (k=2) |
|---|---|---|---|---|---|---|---|---|
| 750 | 41.9 | 0.89 | 10.31 | 10.31 | 10.31 | 0.49 | 0.80 | ± 12.0 % |
| 835 | 41.5 | 0.90 | 10.05 | 10.05 | 10.05 | 0.45 | 0.85 | ± 12.0 % |
| 900 | 41.5 | 0.97 | 9.90 | 9.90 | 9.90 | 0.44 | 0.80 | ± 12.0 % |
| 1750 | 40.1 | 1.37 | 8.41 | 8.41 | 8.41 | 0.27 | 0.80 | ± 12.0 % |
| 1900 | 40.0 | 1.40 | 8.22 | 8.22 | 8.22 | 0.34 | 0.81 | ± 12.0 % |
| 2000 | 40.0 | 1.40 | 8.11 | 8.11 | 8.11 | 0.31 | 0.80 | ± 12.0 % |
| 2300 | 39.5 | 1.67 | 7.81 | 7.81 | 7.81 | 0.29 | 0.90 | ± 12.0 % |
| 2450 | 39.2 | 1.80 | 7.57 | 7.57 | 7.57 | 0.34 | 0.90 | ± 12.0 % |
| 2600 | 39.0 | 1.96 | 7.31 | 7.31 | 7.31 | 0.26 | 1.10 | ± 12.0 % |
| 3500 | 37.9 | 2.91 | 6.66 | 6.66 | 6.66 | 0.40 | 1.35 | ± 14.0 % |
| 3700 | 37.7 | 3.12 | 6.58 | 6.58 | 6.58 | 0.40 | 1.35 | ± 14.0 % |
| 3900 | 37.5 | 3.32 | 6.43 | 6.43 | 6.43 | 0.40 | 1.60 | ± 14.0 % |
| 4100 | 37.2 | 3.53 | 6.15 | 6.15 | 6.15 | 0.40 | 1.60 | ± 14.0 % |
| 4400 | 36.9 | 3.84 | 6.13 | 6.13 | 6.13 | 0.35 | 1.80 | ± 14.0 % |
| 4600 | 36.7 | 4.04 | 5.87 | 5.87 | 5.87 | 0.35 | 1.80 | ± 14.0 % |
| 4800 | 36.4 | 4.25 | 5.71 | 5.71 | 5.71 | 0.40 | 1.80 | ± 14.0 % |
| 4950 | 36.3 | 4.40 | 5.47 | 5.47 | 5.47 | 0.40 | 1.80 | ± 14.0 % |
| 5250 | 35.9 | 4.71 | 5.24 | 5.24 | 5.24 | 0.40 | 1.80 | ± 14.0 % |
| 5600 | 35.5 | 5.07 | 4.65 | 4.65 | 4.65 | 0.40 | 1.80 | ± 14.0 % |
| 5750 | 35.4 | 5.22 | 4.69 | 4.69 | 4.69 | 0.40 | 1.80 | ± 14.0 % |

[C] Frequency validity above 300 MHz of ± 100 MHz only applies for DASY v4.4 and higher (see Page 2), else it is restricted to ± 50 MHz. The uncertainty is the RSS of the 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. Validity of ConvF assessed at 6 MHz is 4-9 MHz, and ConvF assessed at 13 MHz is 9-19 MHz. Above 5 GHz frequency validity can be extended to ± 110 MHz.
[F] At frequencies up to 6 GHz, the validity of tissue parameters ($\varepsilon$ and $\sigma$) can be relaxed to ± 10% if liquid compensation formula is applied to measured SAR values. 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 frequencies between 3-6 GHz at any distance larger than half the probe tip diameter from the boundary.

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




**Uncertainty of Frequency Response of E-field: ± 6.3% (k=2)**