

Appendix B - DAE & Probe Calibration Certificate

Calibration Laboratory of
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Engineering AG
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Client **SGS-TW (Auden)**

Certificate No: **DAE4-877_Mar19**

CALIBRATION CERTIFICATE

Object **DAE4 - SD 000 D04 BM - SN: 877**

Calibration procedure(s) **QA CAL-06.v29
Calibration procedure for the data acquisition electronics (DAE)**

Calibration date: **March 22, 2019**

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 $(22 \pm 3)^{\circ}\text{C}$ and humidity $< 70\%$.

Calibration Equipment used (M&TE critical for calibration)

Primary Standards	ID #	Cal Date (Certificate No.)	Scheduled Calibration
Kathley Multimeter Type 2001	SN: 0810278	03-Sep-18 (No:23488)	Sep-19
Secondary Standards	ID #	Check Date (in house)	Scheduled Check
Auto DAE Calibration Unit	SE UWS 053 AA 1001	07-Jan-19 (in house check)	In house check: Jan-20
Calibrator Box V2.1	SE UMS 006 AA 1002	07-Jan-19 (in house check)	In house check: Jan-20

Calibrated by:	Name Dominique Steffen	Function Laboratory Technician	Signature
Approved by:	Sven Kühn	Deputy Manager	

Issued: March 22, 2019

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Accreditation No.: SCS 0108

Glossary

DAE data acquisition electronics
Connector angle information used in DASY system to align probe sensor X to the robot coordinate system.

Methods Applied and Interpretation of Parameters

- **DC Voltage Measurement:** Calibration Factor assessed for use in DASY system by comparison with a calibrated instrument traceable to national standards. The figure given corresponds to the full scale range of the voltmeter in the respective range.
- **Connector angle:** The angle of the connector is assessed measuring the angle mechanically by a tool inserted. Uncertainty is not required.
- The following parameters as documented in the Appendix contain technical information as a result from the performance test and require no uncertainty.
 - **DC Voltage Measurement Linearity:** Verification of the Linearity at +10% and -10% of the nominal calibration voltage. Influence of offset voltage is included in this measurement.
 - **Common mode sensitivity:** Influence of a positive or negative common mode voltage on the differential measurement.
 - **Channel separation:** Influence of a voltage on the neighbor channels not subject to an input voltage.
 - **AD Converter Values with inputs shorted:** Values on the internal AD converter corresponding to zero input voltage
 - **Input Offset Measurement:** Output voltage and statistical results over a large number of zero voltage measurements.
 - **Input Offset Current:** Typical value for information; Maximum channel input offset current, not considering the input resistance.
 - **Input resistance:** Typical value for information: DAE input resistance at the connector, during internal auto-zeroing and during measurement.
 - **Low Battery Alarm Voltage:** Typical value for information. Below this voltage, a battery alarm signal is generated.
 - **Power consumption:** Typical value for information. Supply currents in various operating modes.

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DC Voltage Measurement

A/D - Converter Resolution nominal

High Range: 1LSB = 8.1 μ V, full range = -100...+300 mV

Low Range: 1LSB = 61nV, full range = -1...+3mV

DASY measurement parameters: Auto Zero Time: 3 sec; Measuring time: 3 sec

Calibration Factors	X	Y	Z
High Range	405.009 $\pm$ 0.02% (k=2)	404.575 $\pm$ 0.02% (k=2)	404.999 $\pm$ 0.02% (k=2)
Low Range	3.98156 $\pm$ 1.50% (k=2)	3.98173 $\pm$ 1.50% (k=2)	3.97143 $\pm$ 1.50% (k=2)

Connector Angle

Connector Angle to be used in DASY system	324.0 $^{\circ}$ $\pm$ 1 $^{\circ}$
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Appendix (Additional assessments outside the scope of SCS0108)

1. DC Voltage Linearity

High Range	Reading (μV)	Difference (μV)	Error (%)
Channel X + Input	200032.98	-1.14	-0.00
Channel X + Input	20007.92	2.70	0.01
Channel X - Input	-20004.25	1.79	-0.01
Channel Y + Input	200036.80	2.70	0.00
Channel Y + Input	20007.07	1.87	0.01
Channel Y - Input	-20005.67	0.46	-0.00
Channel Z + Input	200029.76	-4.15	-0.00
Channel Z + Input	20005.98	1.01	0.01
Channel Z - Input	-20005.75	0.42	-0.00

Low Range	Reading (μV)	Difference (μV)	Error (%)
Channel X + Input	2000.31	-0.51	-0.03
Channel X + Input	200.71	-0.18	-0.09
Channel X - Input	-198.89	0.16	-0.08
Channel Y + Input	2000.66	-0.14	-0.01
Channel Y + Input	199.70	-1.15	-0.57
Channel Y - Input	-199.73	-0.70	0.35
Channel Z + Input	2000.33	-0.39	-0.02
Channel Z + Input	199.36	-1.50	-0.75
Channel Z - Input	-201.36	-2.21	1.11

2. Common mode sensitivity

DASY measurement parameters: Auto Zero Time: 3 sec; Measuring time: 3 sec

	Common mode Input Voltage (mV)	High Range Average Reading (μV)	Low Range Average Reading (μV)
Channel X	200	15.42	13.43
	-200	-11.67	-13.84
Channel Y	200	-18.90	-19.48
	-200	18.01	18.21
Channel Z	200	20.03	19.90
	-200	-23.15	-23.35

3. Channel separation

DASY measurement parameters: Auto Zero Time: 3 sec; Measuring time: 3 sec

	Input Voltage (mV)	Channel X (μV)	Channel Y (μV)	Channel Z (μV)
Channel X	200	-	0.30	-3.40
Channel Y	200	7.13	-	1.49
Channel Z	200	8.92	4.35	-

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4. AD-Converter Values with inputs shorted

DASY measurement parameters: Auto Zero Time: 3 sec; Measuring time: 3 sec

	High Range (LSB)	Low Range (LSB)
Channel X	16001	16135
Channel Y	15878	16754
Channel Z	15739	17168

5. Input Offset Measurement

DASY measurement parameters: Auto Zero Time: 3 sec; Measuring time: 3 sec

Input 10M Ω

	Average (μ V)	min. Offset (μ V)	max. Offset (μ V)	Std. Deviation (μ V)
Channel X	0.70	-0.90	2.31	0.60
Channel Y	0.66	-0.90	2.30	0.71
Channel Z	0.60	-1.31	2.66	0.79

6. Input Offset Current

Nominal input circuitry offset current on all channels: <25fA

7. Input Resistance (Typical values for information)

	Zeroing (k Ω m)	Measuring (M Ω m)
Channel X	200	200
Channel Y	200	200
Channel Z	200	200

8. Low Battery Alarm Voltage (Typical values for information)

Typical values	Alarm Level (VDC)
Supply (+ Vcc)	+7.9
Supply (- Vcc)	-7.6

9. Power Consumption (Typical values for information)

Typical values	Switched off (mA)	Stand by (mA)	Transmitting (mA)
Supply (+ Vcc)	+0.01	+6	+14
Supply (- Vcc)	-0.01	-8	-9

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Client **SGS (Auden)**

Certificate No: **EX3-7509_Mar19**

CALIBRATION CERTIFICATE

Object **EX3DV4 - SN:7509**

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: **March 25, 2019**

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	04-Apr-18 (No. 217-02672/02673)	Apr-19
Power sensor NRP-Z91	SN: 103244	04-Apr-18 (No. 217-02672)	Apr-19
Power sensor NRP-Z91	SN: 103245	04-Apr-18 (No. 217-02673)	Apr-19
Reference 20 dB Attenuator	SN: S5277 (20x)	04-Apr-18 (No. 217-02682)	Apr-19
DAE4	SN: 660	19-Dec-18 (No. DAE4-660_Dec18)	Dec-19
Reference Probe ES3DV2	SN: 3013	31-Dec-18 (No. ES3-3013_Dec18)	Dec-19
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: US41090477	31-Mar-14 (in house check Oct-18)	In house check: Oct-19

Calibrated by:	Name Claudio Leubler	Function Laboratory Technician	Signature
Approved by:	Name Katja Pokovic	Function Technical Manager	Signature
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Certificate No: EX3-7509_Mar19

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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.e., $\theta = 0$ 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, "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
- 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 $\theta = 0$ ($f \leq 900$ MHz in TEM-cell; $f > 1800$ MHz: R22 waveguide). NORM_{x,y,z} are only intermediate values, i.e., the uncertainties of NORM_{x,y,z} does not affect 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 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.
- A_{x,y,z}; B_{x,y,z}; C_{x,y,z}; D_{x,y,z}; VR_{x,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.
- ConvF and Boundary Effect Parameters**: Assessed in flat phantom using E-field (or Temperature Transfer Standard for $f \leq 800$ MHz) and inside waveguide using analytical field distributions based on power measurements for $f > 800$ MHz. The same setups are used for assessment of the parameters applied for boundary compensation (alpha, depth) of which typical uncertainty values 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 ± 50 MHz to ± 100 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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EX3DV4 – SN:7509

March 25, 2019

DASY/EASY - Parameters of Probe: EX3DV4 - SN:7509**Basic Calibration Parameters**

	Sensor X	Sensor Y	Sensor Z	Unc (k=2)
Norm ($\mu\text{V}/(\text{V}/\text{m})^2$) ^A	0.47	0.49	0.47	$\pm 10.1\%$
DCP (mV) ^B	99.6	98.6	102.3	

Calibration Results for Modulation Response

UID	Communication System Name		A dB	B dB $\sqrt{\mu\text{V}}$	C	D dB	VR mV	Max dev	Unc ^E (k=2)
0	CW	X	0.0	0.0	1.0	0.00	176.8	$\pm 3.3\%$	$\pm 4.7\%$
		Y	0.0	0.0	1.0		186.0		
		Y	0.0	0.0	1.0		183.5		

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 Pages 5 and 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.

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EX3DV4- SN:7509

March 25, 2019

DASY/EASY - Parameters of Probe: EX3DV4 - SN:7509

Other Probe Parameters

Sensor Arrangement	Triangular
Connector Angle (°)	-47.6
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

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EX3DV4- SN:7509

March 25, 2019

DASY/EASY - Parameters of Probe: EX3DV4 - SN:7509**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 ^h (mm)	Unc (k=2)
750	41.9	0.89	10.41	10.41	10.41	0.51	0.80	± 12.0 %
835	41.5	0.90	10.13	10.13	10.13	0.48	0.85	± 12.0 %
900	41.5	0.97	9.89	9.89	9.89	0.44	0.84	± 12.0 %
1750	40.1	1.37	8.84	8.84	8.84	0.28	0.98	± 12.0 %
1900	40.0	1.40	8.50	8.50	8.50	0.30	0.85	± 12.0 %
2000	40.0	1.40	8.39	8.39	8.39	0.35	0.85	± 12.0 %
2300	39.5	1.67	8.13	8.13	8.13	0.29	0.88	± 12.0 %
2450	39.2	1.80	7.79	7.79	7.79	0.30	0.88	± 12.0 %
2600	39.0	1.96	7.70	7.70	7.70	0.36	0.86	± 12.0 %
5200	36.0	4.66	5.46	5.46	5.46	0.40	1.80	± 13.1 %
5300	35.9	4.76	5.20	5.20	5.20	0.40	1.80	± 13.1 %
5600	35.5	5.07	4.77	4.77	4.77	0.40	1.80	± 13.1 %
5800	35.3	5.27	4.94	4.94	4.94	0.40	1.80	± 13.1 %

^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 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 frequencies between 3-6 GHz at any distance larger than half the probe tip diameter from the boundary.

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March 25, 2019

DASY/EASY - Parameters of Probe: EX3DV4 - SN:7509

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 (mm) ^g	Unc (k=2)
750	55.5	0.96	10.91	10.91	10.91	0.45	0.80	± 12.0 %
835	55.2	0.97	10.59	10.59	10.59	0.40	0.88	± 12.0 %
900	55.0	1.05	10.47	10.47	10.47	0.40	0.80	± 12.0 %
1750	53.4	1.49	8.63	8.63	8.63	0.35	0.85	± 12.0 %
1900	53.3	1.52	8.24	8.24	8.24	0.36	0.85	± 12.0 %
2000	53.3	1.52	8.19	8.19	8.19	0.22	1.16	± 12.0 %
2300	52.9	1.81	8.11	8.11	8.11	0.35	0.88	± 12.0 %
2450	52.7	1.95	8.05	8.05	8.05	0.28	0.93	± 12.0 %
2600	52.5	2.16	7.76	7.76	7.76	0.25	0.98	± 12.0 %
5200	49.0	5.30	4.81	4.81	4.81	0.50	1.90	± 13.1 %
5300	48.9	5.42	4.66	4.66	4.66	0.50	1.90	± 13.1 %
5600	48.5	5.77	4.19	4.19	4.19	0.50	1.90	± 13.1 %
5800	48.2	6.00	4.20	4.20	4.20	0.50	1.90	± 13.1 %

^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 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 frequencies between 3-6 GHz at any distance larger than half the probe tip diameter from the boundary.

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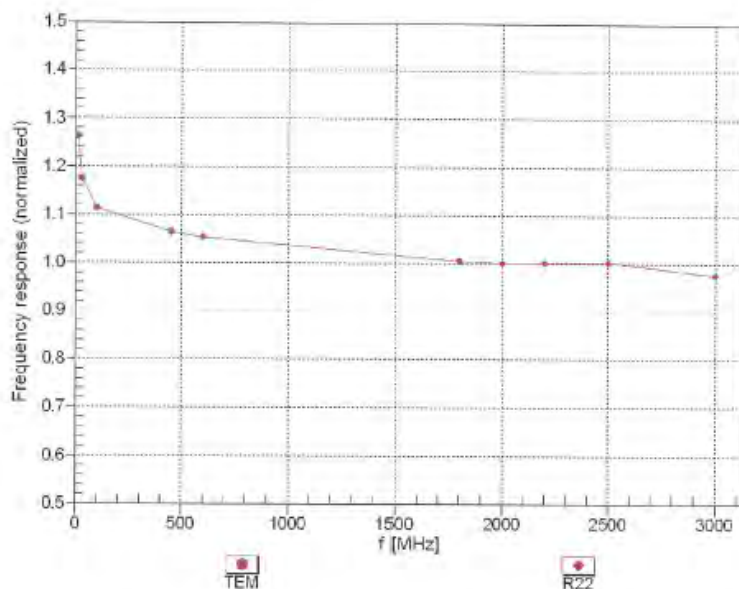
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Frequency Response of E-Field (TEM-Cell:ifi110 EXX, Waveguide: R22)



Uncertainty of Frequency Response of E-field: $\pm 6.3\%$ ($k=2$)

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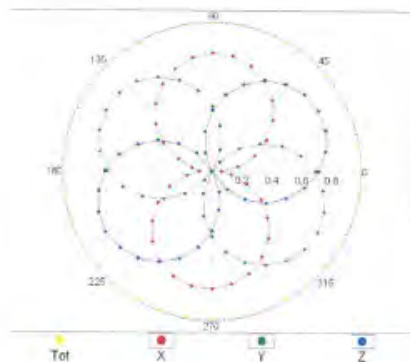
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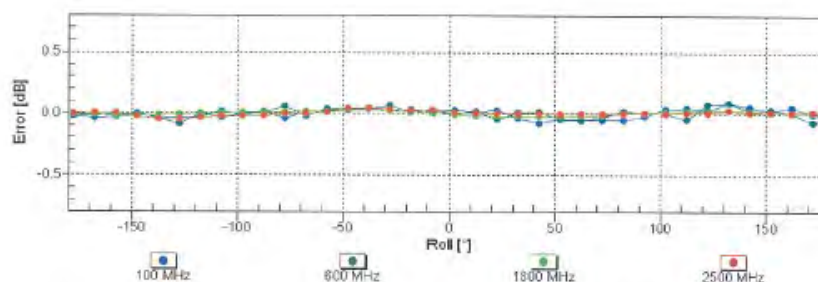
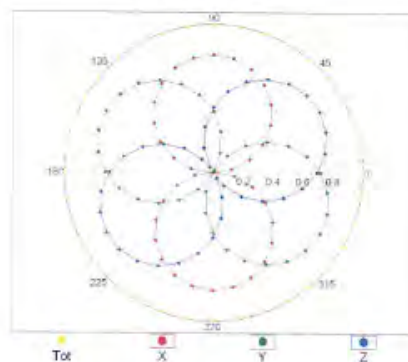
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Receiving Pattern (ϕ), $\theta = 0^\circ$

f=600 MHz,TEM



f=1800 MHz,R22



Uncertainty of Axial Isotropy Assessment: $\pm 0.5\%$ (k=2)

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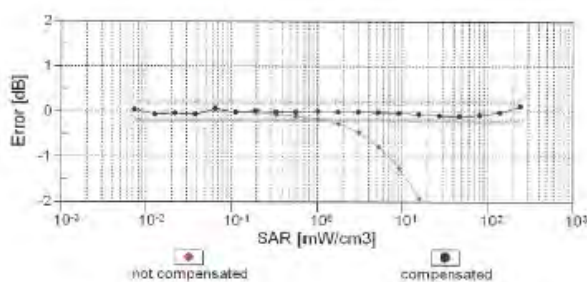
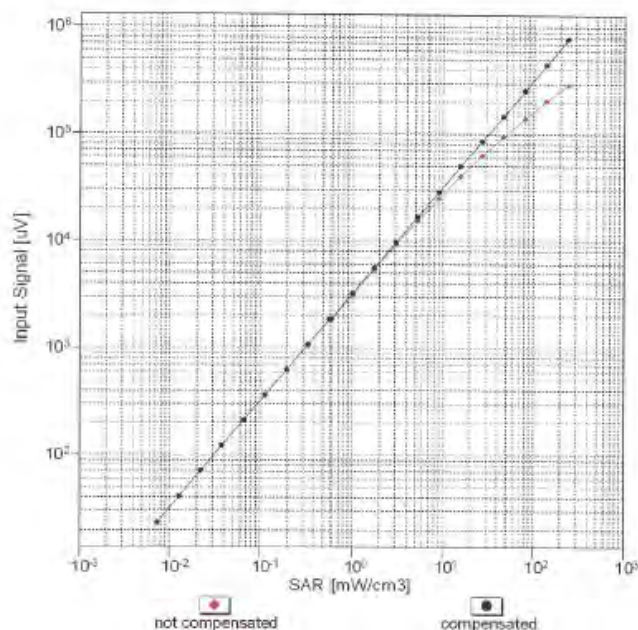
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Dynamic Range f(SAR_{head}) (TEM cell, f_{eval}= 1900 MHz)



Uncertainty of Linearity Assessment: $\pm 0.6\%$ (k=2)

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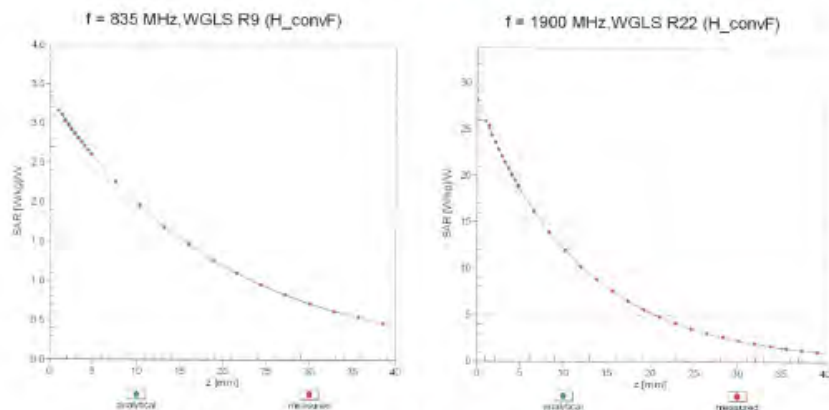
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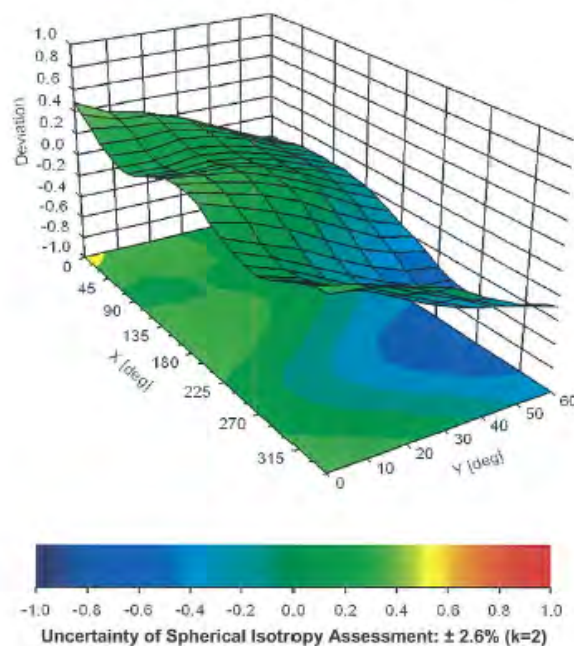
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Conversion Factor Assessment



Deviation from Isotropy in Liquid

Error (ϕ , θ), $f = 900$ MHz



Uncertainty of Spherical Isotropy Assessment: $\pm 2.6\%$ ($k=2$)

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- End of report -

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