Calibration Laboratory of
Schmid & Partner
Engineering AG
Zeughausstrasse 43, 8004 Zurich, Switzerland

Client **SGS-TW (Auden)**

Certificate No: 5G-Veri60-1018_Nov18

CALIBRATION CERTIFICATE

Object	5G Verification Source 60 GHz - SN: 1018
Calibration procedure(s)	QA CAL-45.v2 Calibration procedure for sources in air above 6 GHz
Calibration date:	November 16, 2018

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
Reference Probe EUmmWV3	SN: 9374	23-Mar-18 (No. EUmmWV3-9374_Mar18)	Mar-19
DAE4	SN: 1215	26-Feb-18 (No. DAE4-1215_Feb18)	Feb-19

Secondary Standards	ID #	Check Date (in house)	Scheduled Check

	Name	Function	Signature
Calibrated by:	Leif Klysner	Laboratory Technician	
Approved by:	Katja Pokovic	Technical Manager	

Issued: November 20, 2018

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Glossary

CW Continuous wave

Calibration is Performed According to the Following Standards

- Internal procedure QA CAL-45-5Gsources
- IEC TR 63170 ED1, "Measurement procedure for the evaluation of power density related to human exposure to radio frequency fields from wireless communication devices operating between 6 GHz and 100 GHz", January 2018
- S. Pfeifer et al. Total Field Reconstruction in the Near Field Using Pseudo-Vector E-Field Measurements, *IEEE Transactions on Electromagnetic Compatibility*, TEMC.2018.2837897

Methods Applied and Interpretation of Parameters

- *Coordinate System:* z-axis in the waveguide horn boresight, x-axis is in the direction of the E-field, y-axis normal to the others in the field scanning plane parallel to the horn flare and horn flange.
- *Measurement Conditions: (1) 10 GHz:* The forward power to the horn antenna is measured prior and after the measurement with a power sensor. During the measurements, the horn is directly connected to the cable considering the 0.2dB horn loss. (2) 30, 60 and 90 GHz: The verification sources are switched on for at least 30 minutes. Absorbers are used around the probe cup and at the ceiling to minimize reflections.
- *Horn Positioning:* The waveguide horn is mounted vertically on the flange of the waveguide source to allow vertical positioning of the EUmmW probe during the scan. The plane is parallel to the phantom surface. Probe distance is verified using mechanical gauges positioned on the flare of the horn.
- *E- field distribution:* E field is measured in two x-y-plane (10mm, 10mm + $\lambda/4$) with a vectorial E-field probe. The E-field value stated as calibration value represents the E-field-maxima.
- *Power Density:* The power density values averaged over 1cm^2 and 4cm^2 at 10mm in front of the horn are reconstructed from the E-field according to TEMC.2018.2837897.
- *Field polarization:* Above the open horn, linear polarization of the field is expected. This is verified graphically in the field representation.

Calibrated Quantity

- Local peak E-field (V/m) and peak values of the total and normal component of the poynting vector |Re{S}| and n.Re{S} averaged over the surface area of 1 cm^2 ($pS_{tot}avg1cm^2$ and $pS_n avg1cm^2$) and 4cm^2 ($pS_{tot}avg4cm^2$ and $pS_n avg4cm^2$) at the nominal operational frequency of the verification source.

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%.

Measurement Conditions

DASY system configuration, as far as not given on page 1.

DASY Version	cDASY6 Module mmWave	V1.4
Phantom	5G Phantom	
Distance Horn Aperture - plane	10 mm	
XY Scan Resolution	dx, dy = 1.25 mm	
Number of measured planes	2 (10mm, 10mm + λ/4)	
Frequency	60 GHz ± 10 MHz	

Calibration Parameters, 60 GHz

Distance Horn Aperture to Measured Plane	P_{rad}[1] (mW)	**Max E-field (V/m)**	Uncertainty ($k = 2$)	Avg Power Density n.Re{S}, |Re{S}| (W/m²)		Uncertainty ($k = 2$)
				1 cm²	**4 cm²**	
10 mm	163.3	**531**	1.27 dB	**495, 497**	**313, 315**	1.28 dB

[1] derived from far-field data

DASY Report

Measurement Report for 5G Verification Source 60 GHz, UID 0 -, Channel 60000 (60000.0MHz)

Device under Test Properties

Name, Manufacturer	Dimensions [mm]	IMEI	DUT Type
5G Verification Source 60 GHz	100.0 x 100.0 x 100.0	SN: 1018	-

Exposure Conditions

Phantom Section	Position, Test Distance [mm]	Band	Group,	Frequency [MHz], Channel Number	Conversion Factor
5G -	5.55 mm	Validation band	CW	60000.0, 60000	1.0

Hardware Setup

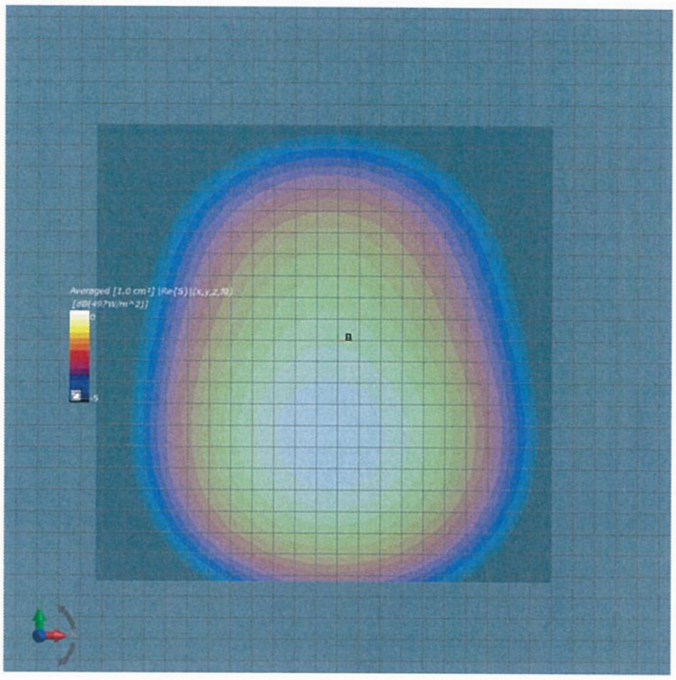
Phantom	Medium	Probe, Calibration Date	DAE, Calibration Date
5G Phantom	Air	EUmmWV3 - SN9374, 2018-03-23	DAE4 Sn1215, 2018-02-26

Scan Setup

	5G Scan
Grid Extents [mm]	32.5 x 32.5
Grid Steps [lambda]	0.25 x 0.25
Sensor Surface [mm]	5.55
MAIA	MAIA not used

Measurement Results

	5G Scan
Date	2018-11-16, 11:18
Avg. Area [cm²]	1.00
pS_{tot} avg [W/m²]	497
pS_n avg [W/m²]	495
E_{peak} [V/m]	531
Power Drift [dB]	-0.03



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IMPORTANT NOTICE

USAGE OF THE DAE 4

The DAE unit is a delicate, high precision instrument and requires careful treatment by the user. There are no serviceable parts inside the DAE. Special attention shall be given to the following points:

Battery Exchange: The battery cover of the DAE4 unit is closed using a screw, over tightening the screw may cause the threads inside the DAE to wear out.

Shipping of the DAE: Before shipping the DAE to SPEAG for calibration, remove the batteries and pack the DAE in an antistatic bag. This antistatic bag shall then be packed into a larger box or container which protects the DAE from impacts during transportation. The package shall be marked to indicate that a fragile instrument is inside.

E-Stop Failures: Touch detection may be malfunctioning due to broken magnets in the E-stop. Rough handling of the E-stop may lead to damage of these magnets. Touch and collision errors are often caused by dust and dirt accumulated in the E-stop. To prevent E-stop failure, the customer shall always mount the probe to the DAE carefully and keep the DAE unit in a non-dusty environment if not used for measurements.

Repair: Minor repairs are performed at no extra cost during the annual calibration. However, SPEAG reserves the right to charge for any repair especially if rough unprofessional handling caused the defect.

DASY Configuration Files: Since the exact values of the DAE input resistances, as measured during the calibration procedure of a DAE unit, are not used by the DASY software, a nominal value of 200 MOhm is given in the corresponding configuration file.

Important Note:
Warranty and calibration is void if the DAE unit is disassembled partly or fully by the Customer.

Important Note:
Never attempt to grease or oil the E-stop assembly. Cleaning and readjusting of the E-stop assembly is allowed by certified SPEAG personnel only and is part of the annual calibration procedure.

Important Note:
To prevent damage of the DAE probe connector pins, use great care when installing the probe to the DAE. Carefully connect the probe with the connector notch oriented in the mating position. Avoid any rotational movement of the probe body versus the DAE while turning the locking nut of the connector. The same care shall be used when disconnecting the probe from the DAE.

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Accreditation No.: SCS 0108

Client **SGS-TW (Auden)**

Certificate No: DAE4-1260_Nov18

CALIBRATION CERTIFICATE

Object	DAE4 - SD 000 D04 BM - SN: 1260
Calibration procedure(s)	QA CAL-06.v29 Calibration procedure for the data acquisition electronics (DAE)
Calibration date:	November 30, 2018

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
Keithley 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	04-Jan-18 (in house check)	In house check: Jan-19
Calibrator Box V2.1	SE UMS 006 AA 1002	04-Jan-18 (in house check)	In house check: Jan-19

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

Issued: November 30, 2018

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.

DC Voltage Measurement

A/D - Converter Resolution nominal

High Range: 1LSB = 6.1μV , 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	404.190 ± 0.02% (k=2)	404.604 ± 0.02% (k=2)	404.793 ± 0.02% (k=2)
Low Range	3.99161 ± 1.50% (k=2)	4.00001 ± 1.50% (k=2)	4.00892 ± 1.50% (k=2)

Connector Angle

Connector Angle to be used in DASY system	341.5 ° ± 1 °

Appendix (Additional assessments outside the scope of SCS0108)

1. DC Voltage Linearity

High Range		Reading (μV)	Difference (μV)	Error (%)
Channel X	+ Input	200033.72	-1.26	-0.00
Channel X	+ Input	20003.07	-2.10	-0.01
Channel X	- Input	-20003.16	2.78	-0.01
Channel Y	+ Input	200038.25	3.73	0.00
Channel Y	+ Input	20002.41	-2.63	-0.01
Channel Y	- Input	-20006.86	-0.69	0.00
Channel Z	+ Input	200033.80	-1.16	-0.00
Channel Z	+ Input	20001.51	-3.36	-0.02
Channel Z	- Input	-20006.68	-0.48	0.00

Low Range		Reading (μV)	Difference (μV)	Error (%)
Channel X	+ Input	2001.18	0.25	0.01
Channel X	+ Input	200.87	-0.09	-0.04
Channel X	- Input	-198.21	0.79	-0.40
Channel Y	+ Input	2001.05	0.24	0.01
Channel Y	+ Input	199.97	-0.89	-0.44
Channel Y	- Input	-199.76	-0.64	0.32
Channel Z	+ Input	2000.74	0.04	0.00
Channel Z	+ Input	199.77	-1.03	-0.51
Channel Z	- Input	-200.48	-1.28	0.64

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	-0.90	-2.92
	- 200	4.87	2.75
Channel Y	200	-5.45	-5.41
	- 200	4.55	4.20
Channel Z	200	-16.55	-16.45
	- 200	13.88	14.44

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	-	0.68	-5.24
Channel Y	200	8.97	-	1.84
Channel Z	200	10.48	5.66	-

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	16236	16097
Channel Y	15859	16057
Channel Z	16152	16351

5. Input Offset Measurement

DASY measurement parameters: Auto Zero Time: 3 sec; Measuring time: 3 sec
Input 10MΩ

	Average (μV)	min. Offset (μV)	max. Offset (μV)	Std. Deviation (μV)
Channel X	0.63	-0.78	1.69	0.43
Channel Y	0.10	-0.90	1.53	0.41
Channel Z	-1.03	-2.00	0.10	0.44

6. Input Offset Current

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

7. Input Resistance (Typical values for information)

	Zeroing (kOhm)	Measuring (MOhm)
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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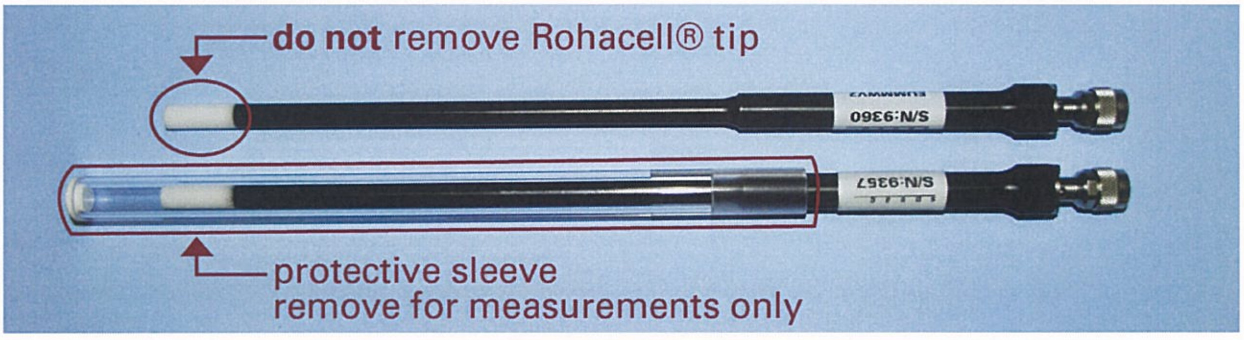
IMPORTANT NOTICE
READ INSTRUCTIONS BEFORE USE

Usage and handling of EUmmWVx PROBES

CAUTION!
Never remove protective Rohacell® tip - it is part of the probe design and removal will cause permanent probe damage!

- Each EUmmWVx probe consists of a black PEEK probe body and a white Rohacell® tip.
- The white tip is part of the probe design and extremely fragile; **make sure to handle the probe with utmost care**; in particular, never flex or bend the probe tip.
- The probe is protected with a transparent sleeve; the sleeve must be removed before each measurement; **after using the probe, carefully re-attach the sleeve**.
- **Probe usage is limited to free-space measurements**; water, sugar-water solutions, nutrient solutions and glycol solutions will permanently damage the probe.
- When returning the probe to SPEAG, it must be sent with (1) the protective sleeve mounted to the probe and (2) inside the original packing; take extra care that the shipping box is sent with sufficient paddings.



For support please contact us at: support@speag.swiss

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Accreditation No.: SCS 0108

Client **SGS-TW (Auden)**

Certificate No: EUmmWV3-9399_Nov18

CALIBRATION CERTIFICATE

Object	EUmmWV3 - SN:9399
Calibration procedure(s)	QA CAL-02.v8, QA CAL-25.v6, QA CAL-42.v2 Calibration procedure for E-field probes optimized for close near field evaluations in air
Calibration date:	November 16, 2018

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
Reference Probe ER3DV6	SN: 2328	09-Oct-18 (No. ER3-2328_Oct18)	Oct-19
DAE4	SN: 789	07-Aug-18 (No. DAE4-789_Aug18)	Aug-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 HP 8753E	SN: US37390585	18-Oct-01 (in house check Oct-18)	In house check: Oct-19

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

Issued: November 20, 2018

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Accreditation No.: SCS 0108

Glossary:

NORMx,y,z	sensitivity in free space
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., ϑ = 0 is normal to probe axis
Connector Angle	information used in DASY system to align probe sensor X to the robot coordinate system
Sensor Angles	sensor deviation from the probe axis, used to calculate the field orientation and polarization
k	is the wave propagation direction

Calibration is Performed According to the Following Standards:

a) IEEE Std 1309-2005, “IEEE Standard for calibration of electromagnetic field sensors and probes, excluding antennas, from 9 kHz to 40 GHz”, December 2005

Methods Applied and Interpretation of Parameters:

- *NORMx,y,z:* Assessed for E-field polarization ϑ = 0 for XY sensors and ϑ = 90 for Z sensor (f ≤ 900 MHz in TEM-cell; f > 1800 MHz: R22 waveguide). For frequencies > 6 GHz, the far field in front of waveguide horn antennas is measured for a set of frequencies in various waveguide bands up to 110 GHz.
- *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
- The frequency sensor model parameters are determined prior to calibration based on a frequency sweep (sensor model involving resistors R, R_p, inductance L and capacitors C, C_p).
- *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.
- *Sensor Offset*: The sensor offset corresponds to the mechanical 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).
- *Equivalent Sensor Angle*: The two probe sensors are mounted in the same plane at different angles. The angles are assessed using the information gained by determining the *NORMx* (no uncertainty required).
- *Spherical isotropy (3D deviation from isotropy)*: in a locally homogeneous field realized using an open waveguide / horn setup.

DASY - Parameters of Probe: EUmmWV3 - SN:9399

Basic Calibration Parameters

	Sensor X	Sensor Y	Unc (k=2)
Norm (μV/(V/m)^2)	0.01851	0.02027	± 10.1 %
DCP (mV)[B]	120.0	103.0	
Equivalent Sensor Angle	-54.7	31.2	

Calibration results for Frequency Response (25 – 110 GHz)

Frequency GHz	Target E-Field V/m	Deviation Sensor X dB	Deviation Sensor Y dB	Unc (k=2) dB
26.6	96.89	0.26	0.35	± 0.98 dB
30	92.55	0.33	0.38	± 0.98 dB
35	93.71	-0.05	0.18	± 0.98 dB
40	91.46	0.03	-0.18	± 0.98 dB
50	19.62	0.50	0.44	± 0.98 dB
55	22.38	0.79	0.52	± 0.98 dB
60	23.03	0.22	0.10	± 0.98 dB
65	27.40	-0.01	-0.12	± 0.98 dB
70	23.95	-0.17	-0.32	± 0.98 dB
75	19.61	-0.53	-0.51	± 0.98 dB
75	14.11	-0.30	-0.23	± 0.98 dB
80	21.51	-0.28	-0.14	± 0.98 dB
85	22.75	-0.02	0.07	± 0.98 dB
90	23.84	0.18	0.25	± 0.98 dB
92	23.93	0.11	0.10	± 0.98 dB
95	20.55	0.11	0.07	± 0.98 dB
97	24.41	0.19	0.11	± 0.98 dB
100	22.61	0.12	0.07	± 0.98 dB
105	22.75	-0.11	-0.07	± 0.98 dB
110	18.85	-0.45	-0.41	± 0.98 dB

Calibration Results for Modulation Response

UID	Communication System Name		A dB	B dB√μV	C	D dB	VR mV	Max dev.	Unc[E] (k=2)
0	CW	X	0.0	0.0	1.0	0.00	115.0	+ 3.5 %	± 4.7 %
		Y	0.0	0.0	1.0		56.6		

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%.

[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 - Parameters of Probe: EUmmWV3 - SN:9399

Sensor Frequency Model Parameters

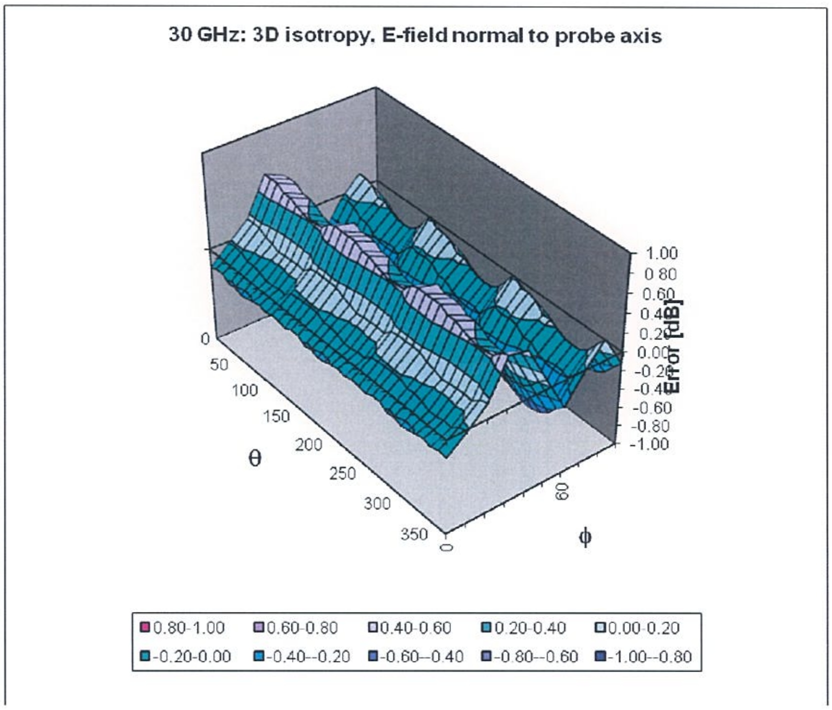
	Sensor X	Sensor Y
R (Ω)	32.25	35.82
R_p (Ω)	98.60	94.68
L (nH)	0.03423	0.03282
C (pF)	0.1783	0.2141
C_p (pF)	0.1391	0.1341

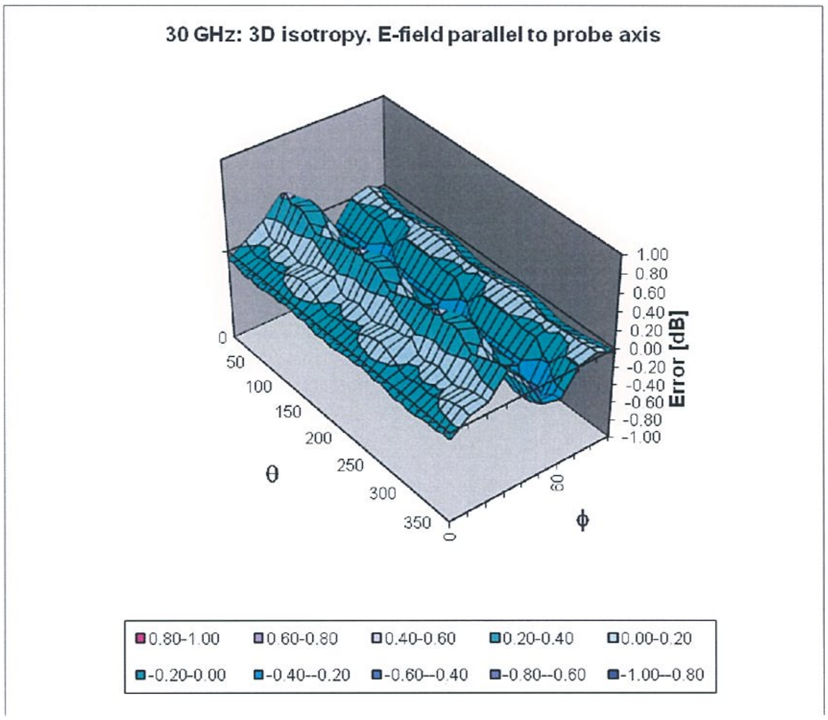
Other Probe Parameters

Sensor Arrangement	Rectangular
Connector Angle (°)	-26.7
Mechanical Surface Detection Mode	enabled
Optical Surface Detection Mode	disabled
Probe Overall Length	320 mm
Probe Body Diameter	8 mm
Tip Length	23 mm
Tip Diameter	8.0 mm
Probe Tip to Sensor X Calibration Point	1.5 mm
Probe Tip to Sensor Y Calibration Point	1.5 mm

Deviation from Isotropy in Air

f = 30 GHz





Probe isotropy for E_{tot}: probe rotated φ = 0° to 360°, tilted from field propagation direction $\bar{k}$
Parallel to the field propagation (ψ =0° - 90°): deviation within ± 0.49 dB
Normal to field orientation (ϑ =0° - 90°): deviation within ± 0.56 dB