ENGINEERING TEST REPORT

SAR Probe Calibration
Model No.: ET20

In Accordance With

SAR (Specific Absorption Rate) Requirements
using guidelines established in IEEE C95.1-1992,
FCC OET Bulletin 65 (Supplement C) and
Industry Canada RSS-102(Issue 2)

This Test report is Issued under the Authority of Tri M. Luu, Professional Engineer, Vice President of Engineering UltraTech Group of Labs Date: January 22, 2009	
Report Prepared by: JaeWook Choi Revised Date: January 19, 2009	Calibrated by: Steven Lu Calibrated Dates: Jun 12, 2008

UltraTech

3000 Bristol Circle, Oakville, Ontario, Canada, L6H 6G4
Telephone (905) 829-1570 Facsimile (905) 829-8050
Website: www.ultratech-labs.com Email: vic@ultratech-labs.com

ANSI	FC	VCI	Industry Canada	NVLAP	BSMI	Korea MIC-RRL
0685	31040/SIT	C-1376	46390-2049	200093-0	SL2-IN-E-1119R	2005-82 & 83

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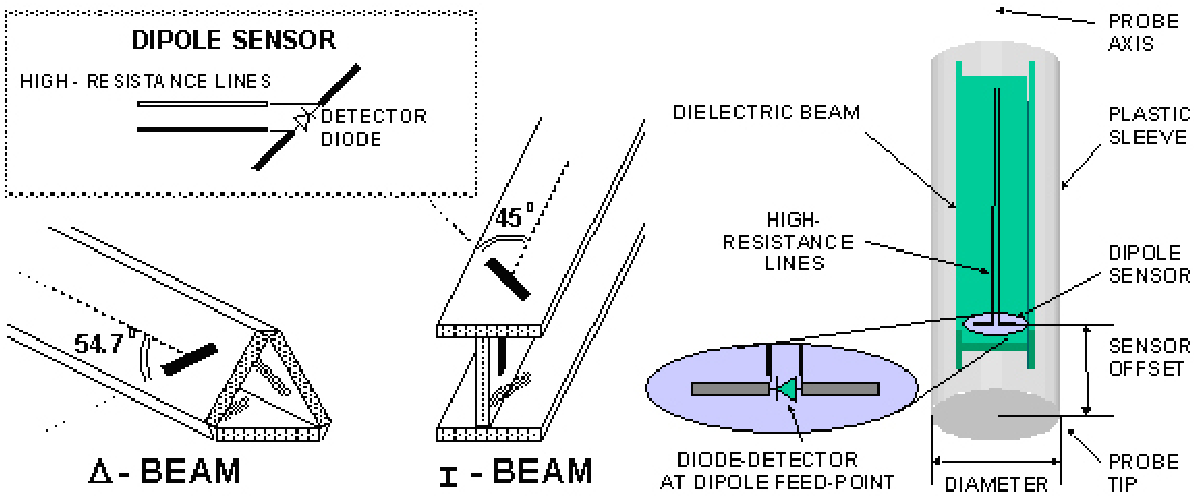
EXHIBIT 1. SAR SYSTEM CONFIGURATION

1.1. GENERIC MEASUREMENT SYSTEM SPECIFICATIONS

Positioning Equipment	**Probe**
Type : 3D Near Field Scanner Location Repeatability : 0.1 [mm] Speed 180 [^{o}/sec] AC motors	Sensor : E-Field Spatial Resolution : 1 [mm^3] Isotropic Response : ±0.25 [dB] Dynamic Range : 0.01 to 100 [W/Kg]
Computer	**Phantom**
Type : Pentium III 500MHz Memory : 256 MB RAM Operating System : Windows 2000 Pro Monitor : 19" SVGA	Tissue : Simulated Tissue with electrical characteristics similar to those of the human at normal body temperature. Left/Right Head: IEEE P1528 Compliant SAM manufactured by Aprel Body/Frontal Head: IEEE Flat Phantom 2 $_{[mm]}$ Base

1.1.1. E-field Probe Information

Sensor Type	E-field triangular beam
Manufacturer	EMF Safety
Model Number	ET20
Serial Number	03-MAR-0019
Sensor Diameter, [mm]	4.0
Sensor Offset, [mm]	2.1
Number of Channel	3
Sensor Factor, h_{Pd}	10.8
Sensor Factor, h_{E2}	0.002864721
j_1	54.7
j_2	54.7
j_3	54.7


DIPOLE SENSOR
HIGH- RESISTANCE LINES
DETECTOR DIODE
54.7°
45°
Δ- BEAM
I - BEAM
DIELECTRIC BEAM
HIGH-RESISTANCE LINES
DIODE-DETECTOR AT DIPOLE FEED-POINT
PROBE AXIS
PLASTIC SLEEVE
DIPOLE SENSOR
SENSOR OFFSET
PROBE TIP
DIAMETER

1.2. SYSTEM CALIBRATION

The SAR measurement system has two main components:

a) the probe, which is connected to the inputs of
b) the instrumentation amplifier whose outputs are connected through the optical transmission line to
c) the computer.

The system is calibrated as one unit not as individual components due to the nature of the system design limitation. If any components is modified or replaced, the system must be re-calibrated.

The system calibration is performed by two steps:

1) determination of the sensitivity of the probe in the air by introducing it into the well-defined RF field, and
2) correlation of the measured E-field in the dielectric medium to the temperature rise in a dielectric medium.

1.2.1. Probe linearity

Detector diodes at the dipole feed-point are used to rectify the sensor voltage output. The rectified signal is transmitted through resistive (RF-transparent) lines to the sensor amplifier. At low field strength levels the output voltage is proportional to the square of the amplitude of the incident field; at higher signal levels, the output voltage is not linearly proportional to $|E|^2$, but becomes proportional to E. The compensation for diode compression is carried out for the each detector diode using the 3-rd order polynomial least-square fit algorithm before any further evaluation.

$$U_{L,i} = U_{O,i} + \frac{(U_{O,i})^2}{DCP_i}$$

Where,

$U_{L,i}$: Linearized probe output voltage at channel i , Unitless voltage quantity

$U_{O,i}$: Raw probe output voltage at channel i, Unitless voltage quantity

DCP_i : Diode compensation potential at channel i

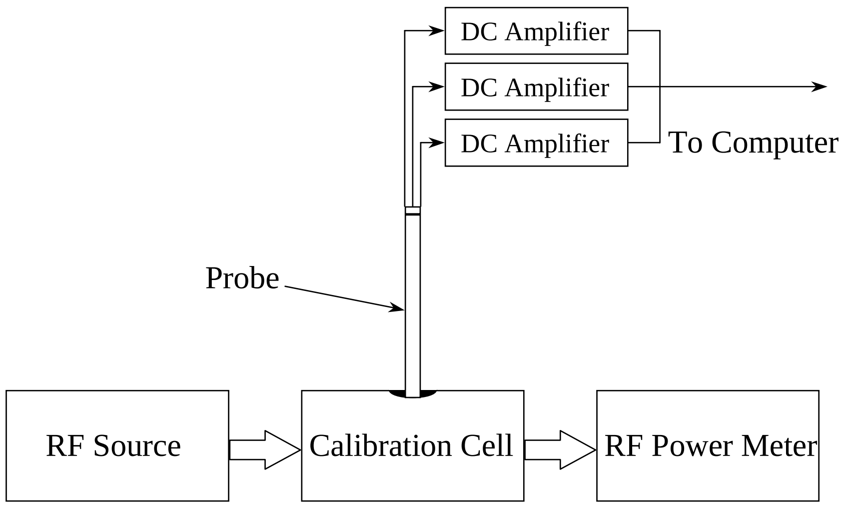
$$DCP_i = \frac{C_{1,i}}{C_{2,i}}$$

Where,

$C_{1,i}$: First order coefficient of second degree polynomial fit at channel i

$C_{2,i}$: Second order coefficient of second degree polynomial fit at channel i

1.2.1.1. Calibration Setup



1.2.1.2. Measurement procedure

Linearity calibration of E-field probes can be performed using a TEM cell manufactured by IFI (Instrumentation for Industry, Farmingdale, NY 11735) with operating frequency at or below 1 GHz. Above 1 GHz, waveguides are used to calibrate the probes in free space.

1. Connect the equipments as shown in the calibration setup above;
2. Adjust the RF generator output so that the power density at the calibration point inside the TEM cell is well-defined. (For the IFI model CC-110 cell, the uniform power density of 1.0 [mW/cm^2] requires the power level of 271.0 [mW]);
3. Mount the probe of the system to calibrate in the support fixture. Insert the probe through the aperture of the TEM cell. The probe handle should be at the geometric center of the aperture, i.e. midway

between the septum and the upper surface, and orthogonal to the side of the cell. The sensing portion of the probe should be located at a point halfway across the depth of the cell (volumetric center).

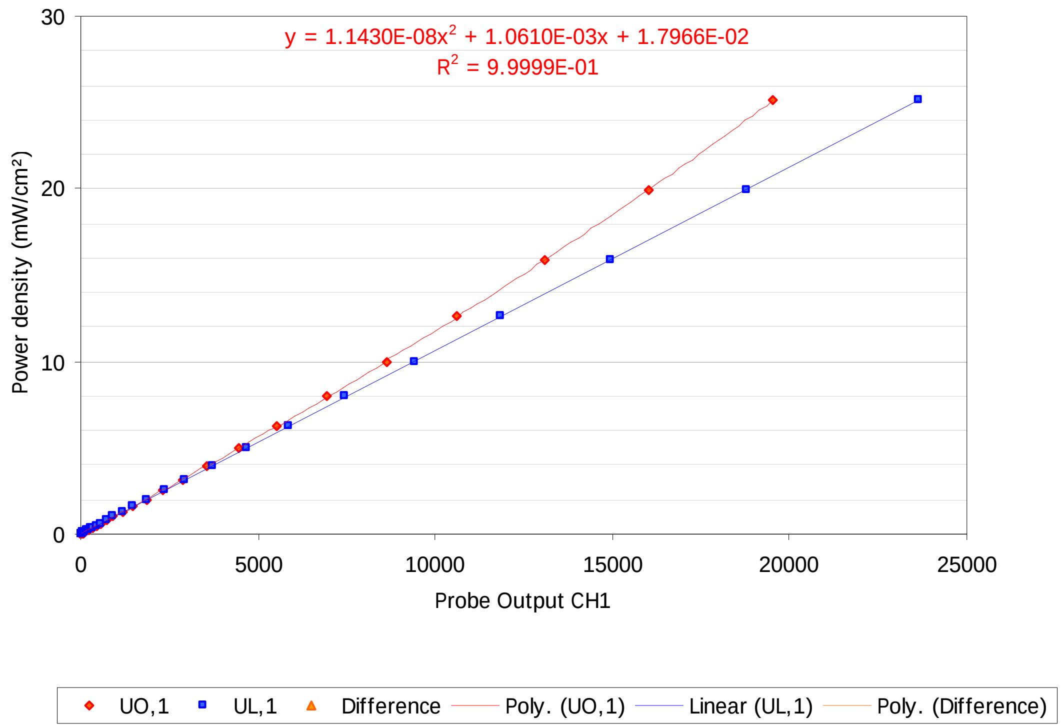
4. Verify that the RF power level remains constant throughout the measurement. While the probe is being rotated through 360 degrees, software indicators will show the maximum measured on each channel.
5. Rotate probe to position in which it yields the maximum reading at channel 1.
6. Record probe outputs while decreasing RF generator output power by 1 dB until it reaches at zero reading.
7. Adjust the RF generator output power to the level which was chosen at step 2 above.
8. Record probe outputs while increasing RF generator output power by 1 dB until it reaches at saturated reading. Disregards the last saturated probe output recorded.
9. Repeat step 5 to step 8 for channel 2 and channel 3.

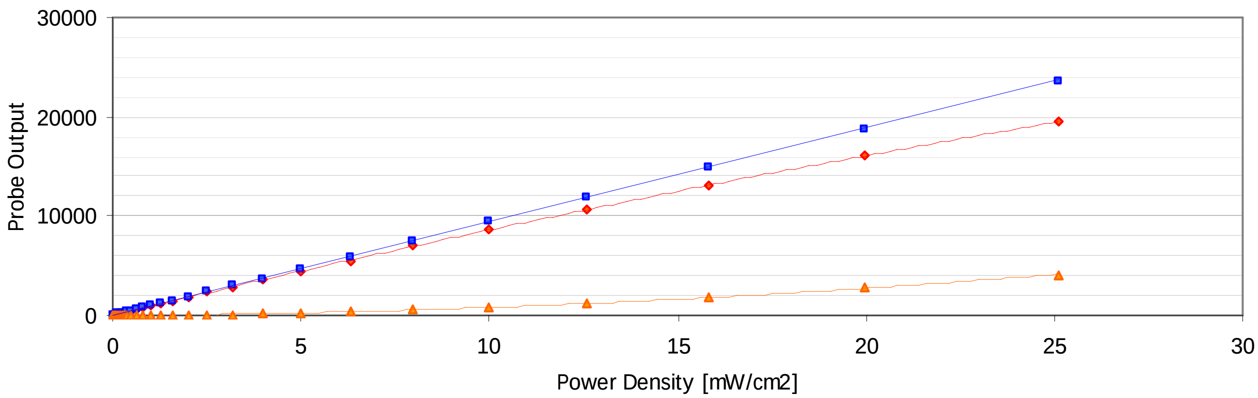
1.2.1.3. Calibration Result

Channel 1	
C_2	1.1430E-08
C_1	1.0610E-03
Channel 2	
C_2	1.4903E-08
C_1	1.4437E-03
Channel 3	
C_2	1.5500E-08
C_1	1.3425E-03
DCP_1	**92825**
DCP_2	**96871**
DCP_3	**86612**

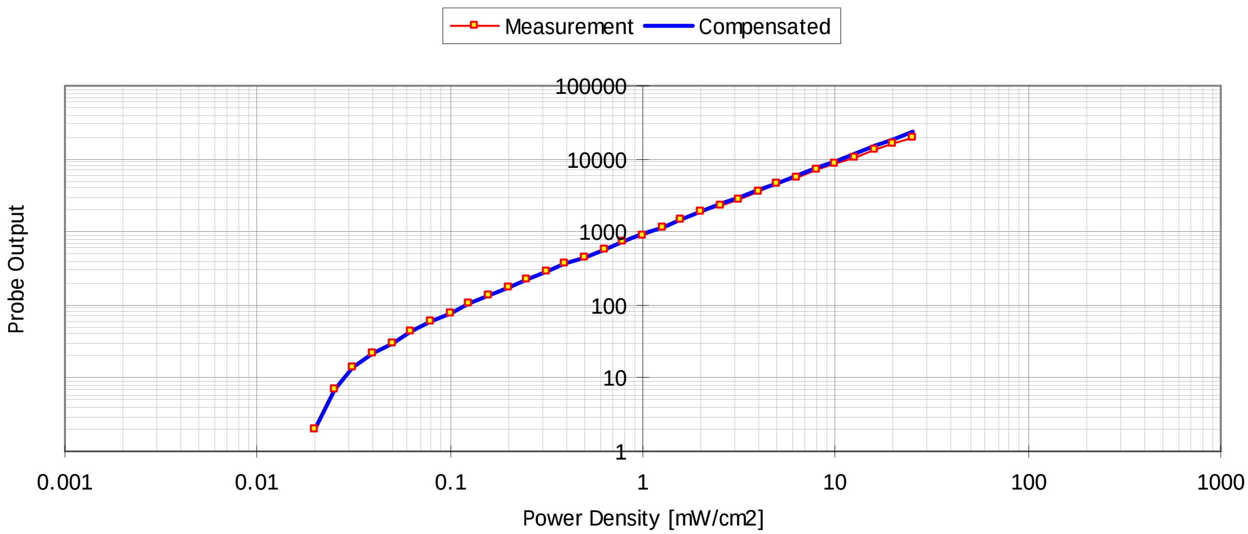
1.2.1.4. Channel 1

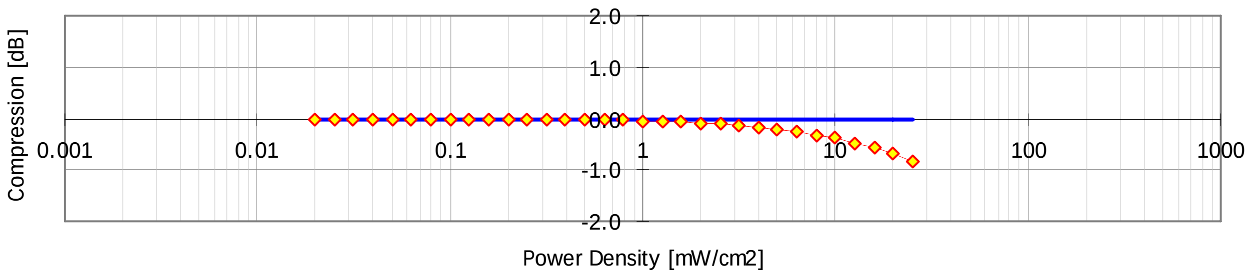
Power Density (mW/cm²)		$U_{O,1}$	$U_{L,1}$	Difference	Deviation
0.0100	-20.00 dB				
0.0126	-19.00 dB				
0.0158	-18.00 dB	0	0	0	#DIV/0!
0.0200	-17.00 dB	2	2	0	0.00 dB
0.0251	-16.00 dB	7	7	0	0.00 dB
0.0316	-15.00 dB	14	14	0	0.00 dB
0.0398	-14.00 dB	22	22	0	0.00 dB
0.0501	-13.00 dB	30	30	0	0.00 dB
0.0631	-12.00 dB	43	43	0	0.00 dB
0.0794	-11.00 dB	59	59	0	0.00 dB
0.1000	-10.00 dB	79	79	0	0.00 dB
0.1259	-9.00 dB	103	103	0	0.00 dB
0.1585	-8.00 dB	135	135	0	-0.01 dB
0.1995	-7.00 dB	173	173	0	-0.01 dB
0.2512	-6.00 dB	221	222	1	-0.01 dB
0.3162	-5.00 dB	284	285	1	-0.01 dB
0.3981	-4.00 dB	360	361	1	-0.02 dB
0.5012	-3.00 dB	458	460	2	-0.02 dB
0.6310	-2.00 dB	580	584	4	-0.03 dB
0.7943	-1.00 dB	721	727	6	-0.03 dB
1.0000	0.00 dB	918	927	9	-0.04 dB
1.2589	1.00 dB	1160	1174	14	-0.05 dB
1.5849	2.00 dB	1460	1483	23	-0.07 dB
1.9953	3.00 dB	1842	1879	37	-0.09 dB
2.5119	4.00 dB	2316	2374	58	-0.11 dB
3.1623	5.00 dB	2852	2940	88	-0.13 dB
3.9811	6.00 dB	3583	3721	138	-0.16 dB
5.0119	7.00 dB	4456	4670	214	-0.20 dB
6.3096	8.00 dB	5536	5866	330	-0.25 dB
7.9433	9.00 dB	6952	7473	521	-0.31 dB
10.0000	10.00 dB	8640	9444	804	-0.39 dB
12.5893	11.00 dB	10616	11830	1214	-0.47 dB
15.8489	12.00 dB	13120	14974	1854	-0.57 dB
19.9526	13.00 dB	16040	18812	2772	-0.69 dB
25.1189	14.00 dB	19520	23625	4105	-0.83 dB
31.6228	15.00 dB	23560	29540	5980	-0.98 dB
39.8107	16.00 dB	28272	36883	8611	-1.15 dB
50.1187	17.00 dB				
63.0957	18.00 dB				
79.4328	19.00 dB				
100.0000	20.00 dB				


y = 1.1430E-08x2 + 1.0610E-03x + 1.7966E-02
R2 = 9.9999E-01
Power density (mW/cm2)
Probe Output CH1
0
10
20
30
0
5000
10000
15000
20000
25000
UO,1
UL,1
Difference
Poly. (UO,1)
Linear (UL,1)
Poly. (Difference)


Probe Output
Power Density [mW/cm2]
0
10000
20000
30000
0
5
10
15
20
25
30

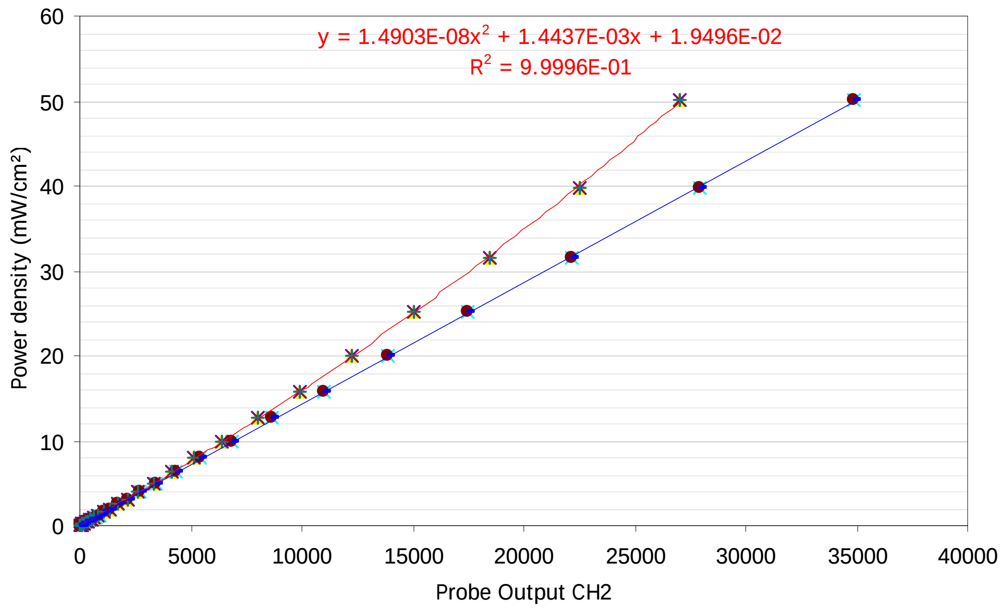
$C_{1,1}$	$C_{2,1}$	DCP_1
1.0610E-03	1.1430E-08	92825

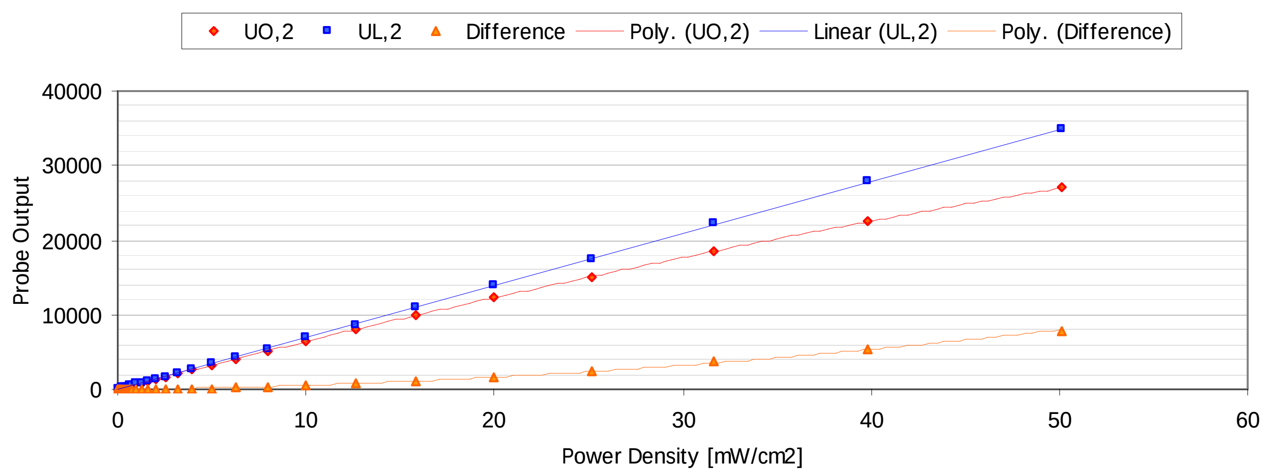




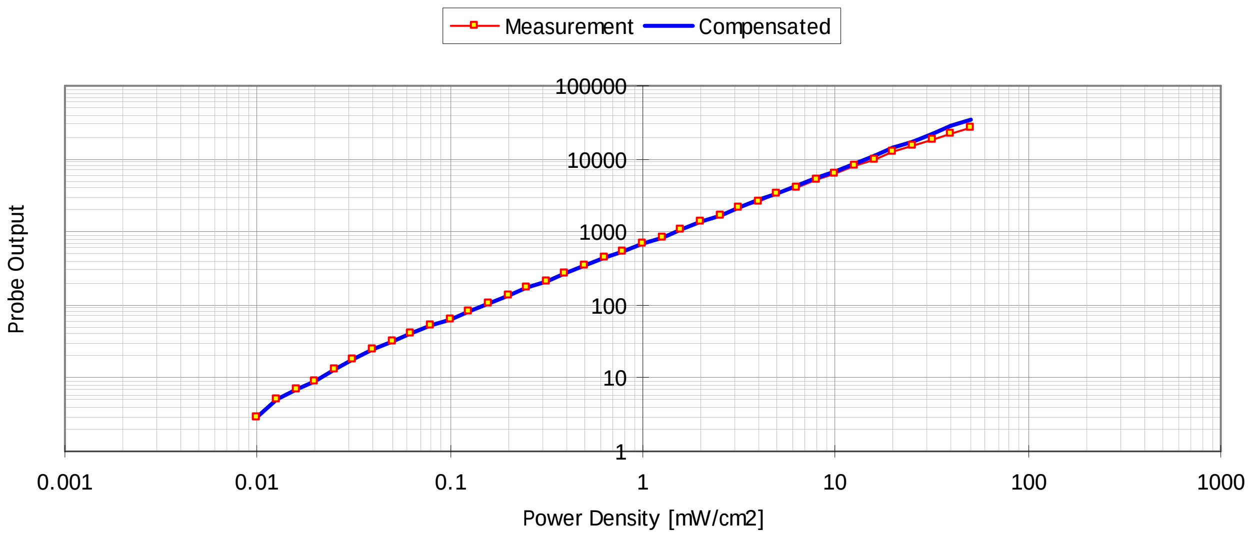
1.2.1.5. Channel 2

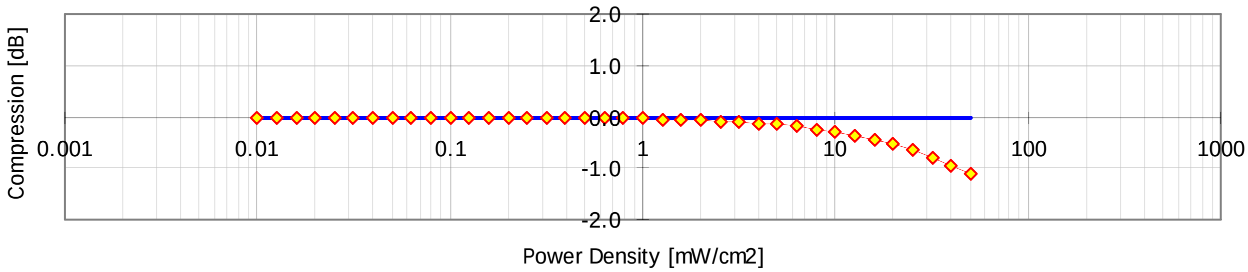
Power Density (mW/cm²)		$U_{O,2}$	$U_{L,2}$	Difference	Deviation
0.0100	-20.00 dB	3	3	0	0.00 dB
0.0126	-19.00 dB	5	5	0	0.00 dB
0.0158	-18.00 dB	7	7	0	0.00 dB
0.0200	-17.00 dB	9	9	0	0.00 dB
0.0251	-16.00 dB	13	13	0	0.00 dB
0.0316	-15.00 dB	18	18	0	0.00 dB
0.0398	-14.00 dB	24	24	0	0.00 dB
0.0501	-13.00 dB	31	31	0	0.00 dB
0.0631	-12.00 dB	40	40	0	0.00 dB
0.0794	-11.00 dB	52	52	0	0.00 dB
0.1000	-10.00 dB	65	65	0	0.00 dB
0.1259	-9.00 dB	84	84	0	0.00 dB
0.1585	-8.00 dB	106	106	0	0.00 dB
0.1995	-7.00 dB	134	134	0	-0.01 dB
0.2512	-6.00 dB	171	171	0	-0.01 dB
0.3162	-5.00 dB	216	217	1	-0.01 dB
0.3981	-4.00 dB	273	274	1	-0.01 dB
0.5012	-3.00 dB	345	346	1	-0.02 dB
0.6310	-2.00 dB	437	439	2	-0.02 dB
0.7943	-1.00 dB	551	554	3	-0.03 dB
1.0000	0.00 dB	675	680	5	-0.03 dB
1.2589	1.00 dB	850	858	8	-0.04 dB
1.5849	2.00 dB	1069	1081	12	-0.05 dB
1.9953	3.00 dB	1346	1366	20	-0.06 dB
2.5119	4.00 dB	1695	1726	31	-0.08 dB
3.1623	5.00 dB	2123	2172	49	-0.10 dB
3.9811	6.00 dB	2639	2714	75	-0.12 dB
5.0119	7.00 dB	3305	3423	118	-0.15 dB
6.3096	8.00 dB	4120	4303	183	-0.19 dB
7.9433	9.00 dB	5152	5438	286	-0.23 dB
10.0000	10.00 dB	6424	6869	445	-0.29 dB
12.5893	11.00 dB	7992	8680	688	-0.36 dB
15.8489	12.00 dB	9920	10980	1060	-0.44 dB
19.9526	13.00 dB	12280	13905	1625	-0.54 dB
25.1189	14.00 dB	15040	17477	2437	-0.65 dB
31.6228	15.00 dB	18480	22159	3679	-0.79 dB
39.8107	16.00 dB	22512	27972	5460	-0.94 dB
50.1187	17.00 dB	27008	34866	7858	-1.11 dB
63.0957	18.00 dB				
79.4328	19.00 dB				
100.0000	20.00 dB				


y = 1.4903E-08x2 + 1.4437E-03x + 1.9496E-02
R2 = 9.9996E-01
Power density (mW/cm²)
Probe Output CH2
0
10
20
30
40
50
60
0
5000
10000
15000
20000
25000
30000
35000
40000


UO,2
UL,2
Difference
Poly. (UO,2)
Linear (UL,2)
Poly. (Difference)
Probe Output
Power Density [mW/cm2]
0
10000
20000
30000
40000
0
10
20
30
40
50
60

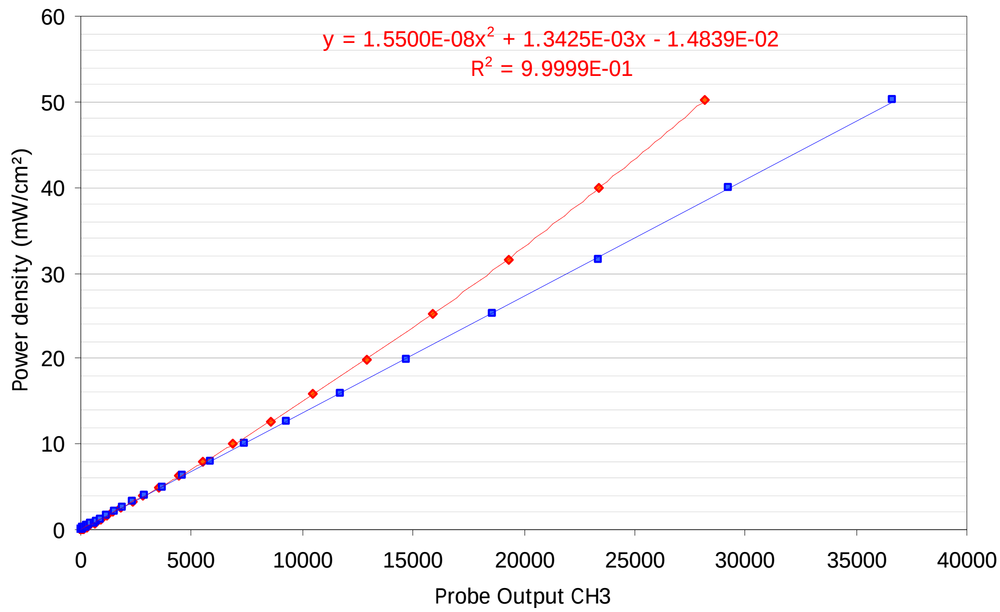
$C_{1,2}$	$C_{2,2}$	DCP_2
1.4437E-03	1.4903E-08	96871

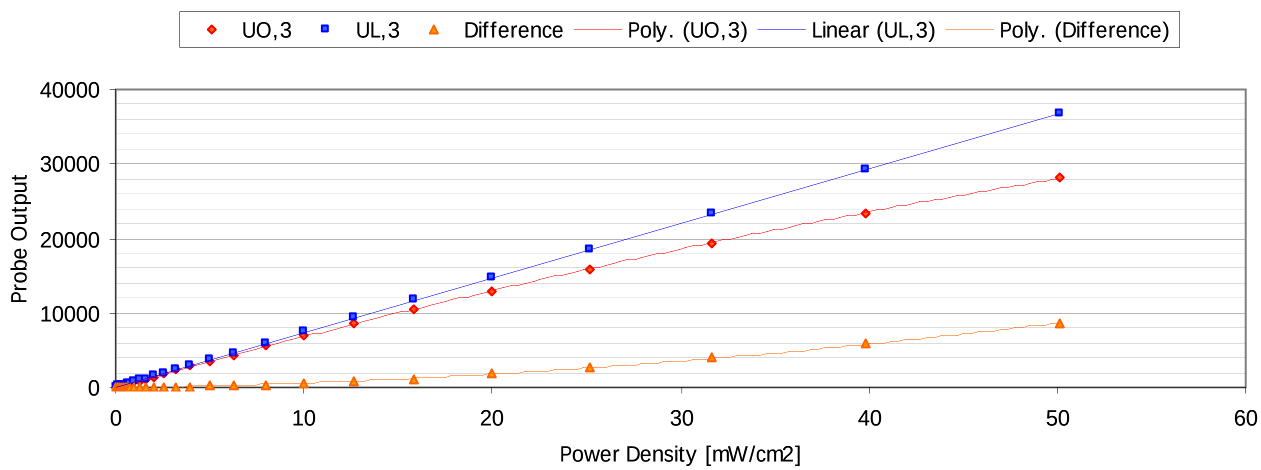




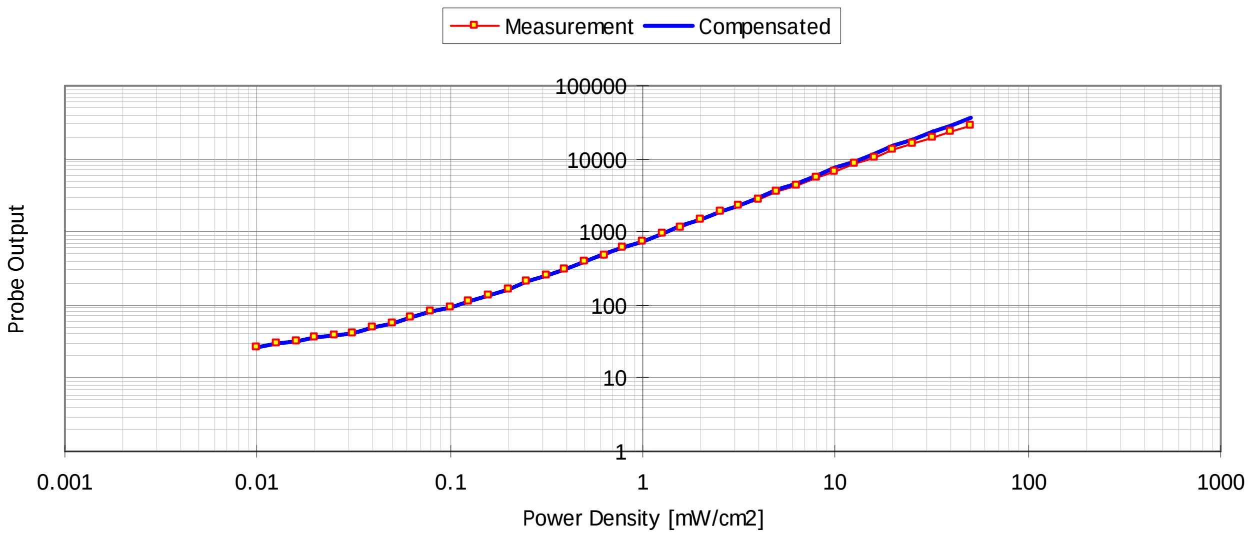
1.2.1.6. Channel 3

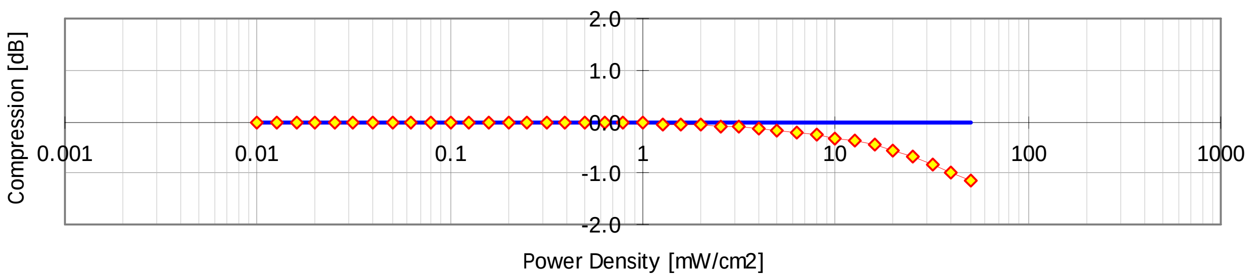
Power Density (mW/cm²)		$U_{O,3}$	$U_{L,3}$	Difference	Deviation
0.0100	-20.00 dB	27	27	0	0.00 dB
0.0126	-19.00 dB	30	30	0	0.00 dB
0.0158	-18.00 dB	32	32	0	0.00 dB
0.0200	-17.00 dB	35	35	0	0.00 dB
0.0251	-16.00 dB	38	38	0	0.00 dB
0.0316	-15.00 dB	42	42	0	0.00 dB
0.0398	-14.00 dB	50	50	0	0.00 dB
0.0501	-13.00 dB	56	56	0	0.00 dB
0.0631	-12.00 dB	66	66	0	0.00 dB
0.0794	-11.00 dB	81	81	0	0.00 dB
0.1000	-10.00 dB	95	95	0	0.00 dB
0.1259	-9.00 dB	112	112	0	-0.01 dB
0.1585	-8.00 dB	137	137	0	-0.01 dB
0.1995	-7.00 dB	168	168	0	-0.01 dB
0.2512	-6.00 dB	206	206	0	-0.01 dB
0.3162	-5.00 dB	252	253	1	-0.01 dB
0.3981	-4.00 dB	314	315	1	-0.01 dB
0.5012	-3.00 dB	391	393	2	-0.02 dB
0.6310	-2.00 dB	489	492	3	-0.02 dB
0.7943	-1.00 dB	608	612	4	-0.03 dB
1.0000	0.00 dB	750	756	6	-0.03 dB
1.2589	1.00 dB	938	947	9	-0.04 dB
1.5849	2.00 dB	1175	1190	15	-0.05 dB
1.9953	3.00 dB	1469	1492	23	-0.07 dB
2.5119	4.00 dB	1842	1879	37	-0.09 dB
3.1623	5.00 dB	2303	2360	57	-0.11 dB
3.9811	6.00 dB	2839	2926	87	-0.13 dB
5.0119	7.00 dB	3552	3688	136	-0.16 dB
6.3096	8.00 dB	4416	4626	210	-0.20 dB
7.9433	9.00 dB	5520	5848	328	-0.25 dB
10.0000	10.00 dB	6888	7399	511	-0.31 dB
12.5893	11.00 dB	8536	9321	785	-0.38 dB
15.8489	12.00 dB	10512	11702	1190	-0.47 dB
19.9526	13.00 dB	12952	14759	1807	-0.57 dB
25.1189	14.00 dB	15872	18586	2714	-0.69 dB
31.6228	15.00 dB	19320	23341	4021	-0.82 dB
39.8107	16.00 dB	23400	29299	5899	-0.98 dB
50.1187	17.00 dB				
63.0957	18.00 dB				
79.4328	19.00 dB				
100.0000	20.00 dB				


y = 1.5500E-08x2 + 1.3425E-03x - 1.4839E-02
R2 = 9.9999E-01
Power density (mW/cm²)
Probe Output CH3
0
10
20
30
40
50
60
0
5000
10000
15000
20000
25000
30000
35000
40000


UO,3
UL,3
Difference
Poly. (UO,3)
Linear (UL,3)
Poly. (Difference)
Probe Output
Power Density [mW/cm2]
0
10000
20000
30000
40000
0
10
20
30
40
50
60

$C_{1,3}$	$C_{2,3}$	DCP_3
1.3425E-03	1.5500E-08	86612





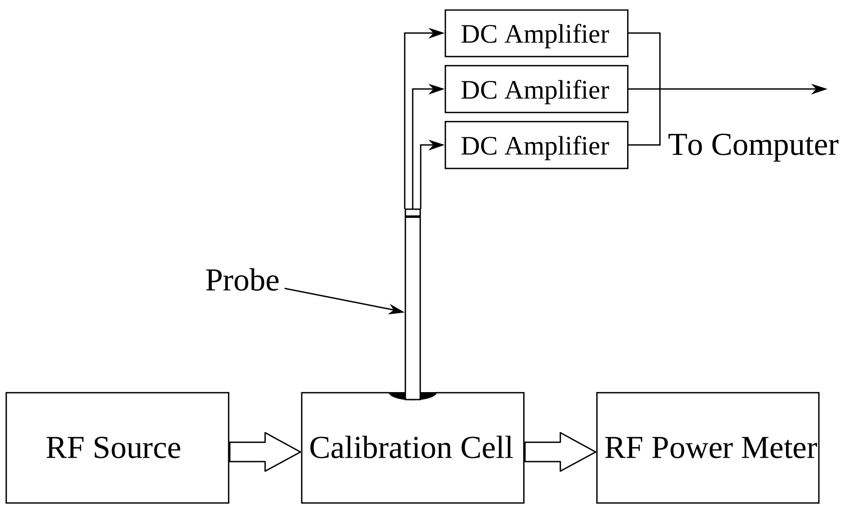
1.2.2. Isotropy Calibration

- RF Signal Generator - frequency range to at least 6 GHz,
- RF Amplifier – if needed to generate the required power density in the test cell,
- Test Cell - TEM (Crawford) cell, waveguide, or other device capable of maintaining a uniform field,
- RF Power Meter - capable of measuring at least 4 Watts (current calibration is mandatory!) if possible traceable to the National Institute of Standards and Technology (NIST).
- E-Field Probe (under calibration)
- Probe Support Fixture
- Instrumentation Amplifier
- Transmission Line
- Computer Program with the Automated Calibration System Program

1.2.3. Method

Due to impedance variations in the diodes and the transmission line, and slight differences in gain among the channels of the instrumentation amplifier, a normalization method had been designed. The calibration method actually used is to determine the factors necessary adjust each channel of the system so it's indicated output can then be equated to the well-defined RF field. These factors are referred to as "Amplifier Settings".

1.2.3.1. Calibration Setup




1.2.3.2. Measurement procedure

Isotropy Calibration of E-field probes can be performed using a TEM cell manufactured by IFI (Instrumentation for Industry, Farmingdale, NY 11735) with operating frequency at or below 1 GHz. Above 1 GHz, waveguides are used to calibrate the probes in free space.

10. Connect the equipments as shown in the calibration setup above;
11. Adjust the RF generator output so that the power density at the calibration point inside the TEM cell is well-defined. (For the IFI model CC-110 cell, the uniform power density of 1.0 [mW/cm^2] requires the power level of 271.0 [mW]);
12. Mount the probe of the system to calibrate in the support fixture. Insert the probe through the aperture of the TEM cell. The probe handle should be at the geometric center of the aperture, i.e. midway between the septum and the upper surface, and orthogonal to the side of the cell. The sensing portion of the probe should be located at a point halfway across the depth of the cell (volumetric center).
13. Once the prescribed position is obtained, it must be maintained during the rest of the measurement. The only movement of the probe allowed is rotation on its axis to position the dipole in the plane of the E-field and, for channel 3 only, parallel to the vertical uniform field (max./min. output).
14. Verify that the RF power level remains constant throughout the measurement. While the probe is being rotated through 360 degrees, software indicators will show the maximum measured on each channel.

1.2.3.3. Definition of Amplifier Settings

The initial sequence of probe calibrations steps performed with SAR determinations produces the factors used in scaling probe output voltage to RF power density. For historical reasons all probes factors are compared to a factor 10.8 [mV] per [mW/cm^2] that was typical of a prototype probe, but is in fact an arbitrary number used as an intermediately constant. The factor of 10.8 [mV/(mW/cm^2)] is known as the sensor factor to the uniform power density (η_{pd}), but does not change. Also we can derive 10.8/3,770 [mV/(V/m)^2] of the sensor factor to the |E|^2 (η_{E2}), providing 377 [Ω] as free space impedance.

$$\eta_{Pd} = 10.8[mV/(mW/cm^2)] \equiv \eta_{E2} = \frac{10.8}{3770}[mV/(V/m)^2]$$

$$Pd[mW/cm^2] = \frac{PO_{tot}}{\eta_{Pd}} \text{ and } |E|^2[(V/m)^2] = \frac{PO_{tot}}{\eta_{E2}}\text{, thus } SAR = \frac{\sigma \times \left(\frac{PO_{tot}}{\eta_{E2}}\right)}{\rho}$$

Probe output voltage can calculated as shown below. **Be aware that probe output voltage is not scaled precisely to realistic voltage quantity but is scaled to historical number of 10.8 [mV], which typical prototype probe yielded even though it is noted using unit of [mV] hereafter. This is why the system can not be calibrated as individual components but only as one unit (due to system design deficiency).**

$$PO_1[mV] = U_{L,1} \times AS_1 \equiv |E_1|^2 \times \eta_{E2}$$

$$PO_2[mV] = U_{L,2} \times AS_2 \equiv |E_2|^2 \times \eta_{E2}$$

$$PO_3[mV] = U_{L,3} \times AS_3 \equiv |E_3|^2 \times \eta_{E2}$$

$$PO_{tot}[mV] \equiv |E|^2 \times \eta_{E2} = \left(|E_1|^2 + |E_2|^2 + |E_3|^2\right) \times \eta_{E2} = |E_1|^2 \times \eta_{E2} + |E_2|^2 \times \eta_{E2} + |E_3|^2 \times \eta_{E2} \equiv PO_1 + PO_2 + PO_3$$

$$|E|^2[(V/m)^2] \equiv \frac{PO_{tot}}{\eta_{E2}} = \frac{PO_1 + PO_2 + PO_3}{\eta_{E2}} = \frac{(U_{L,1} \times AS_1) + (U_{L,2} \times AS_2) + (U_{L,3} \times AS_3)}{\eta_{E2}}$$

To calibrate a probe, each channel is assigned an amplifier setting. This factor is obtained from the maximum probe output voltage measured during probe calibration. This probe output voltage is corrected for any DC offset of the instrumentation amplifier, usually a very small amount then corrected again with Diode Compensation Potential for each channels.

During calibration, the sensitivity for the E-field tangential to the dipole axis caused by the geometry of the probe construction is carefully considered to obtain the correct amplifier setting for each channel. Thus, the amplifier settings for each channel are as follows:

$$AS_i = \frac{\eta_{Pd}}{Norm_{i,peak}} \times \cos^2(\varphi - \theta_i) \times P_d$$

Where,

AS_i	Amplifier setting for channel i
η_{Pd}	Sensor factor to the uniform power density, **an arbitrary value 10.8** [mV/(mW/cm^2)]
η_{E2}	Sensor Factor to the $|E|^2$, **an arbitrary value** 10.8/3,770 [mV/(V/m)^2]
φ	Smaller angle between the probe axis and the direction of the E-field (90° providing the probe axis is parallel to the plane of the septum inside TEM cell)
θ_i	Smaller angle between the probe axis and the dipole sensor axis of the channel i ($\theta_1 = \theta_2 = 45°$, $\theta_3 = 90°$ for I-beam probe, and $\theta_1 = \theta_2 = \theta_3 = 54.7°$ for triangular-beam probe)
P_d	Well-defined power density [mW/cm^2] at the calibration point in a test cell

$Norm_{i,peak}$ Normalization factor to peak at channel i

$$Norm_{i,peak} = \frac{\sum_{\delta=0}^{360} U_{L,i}(\delta)}{Num_{pk2pk} + Corr_i} = \frac{\sum_{\delta=0}^{360} \left(U_{O,i}(\delta) + \frac{(U_{O,i}(\delta))^2}{DCP_i} \right)}{Num_{pk2pk} + Corr_i}$$

Where,

Num_{pk2pk} Number of measurement points during one peak to peak. 12 when it is measured for every 15°.

$Corr_i$ Manually chosen correction factor to refine isotropic output

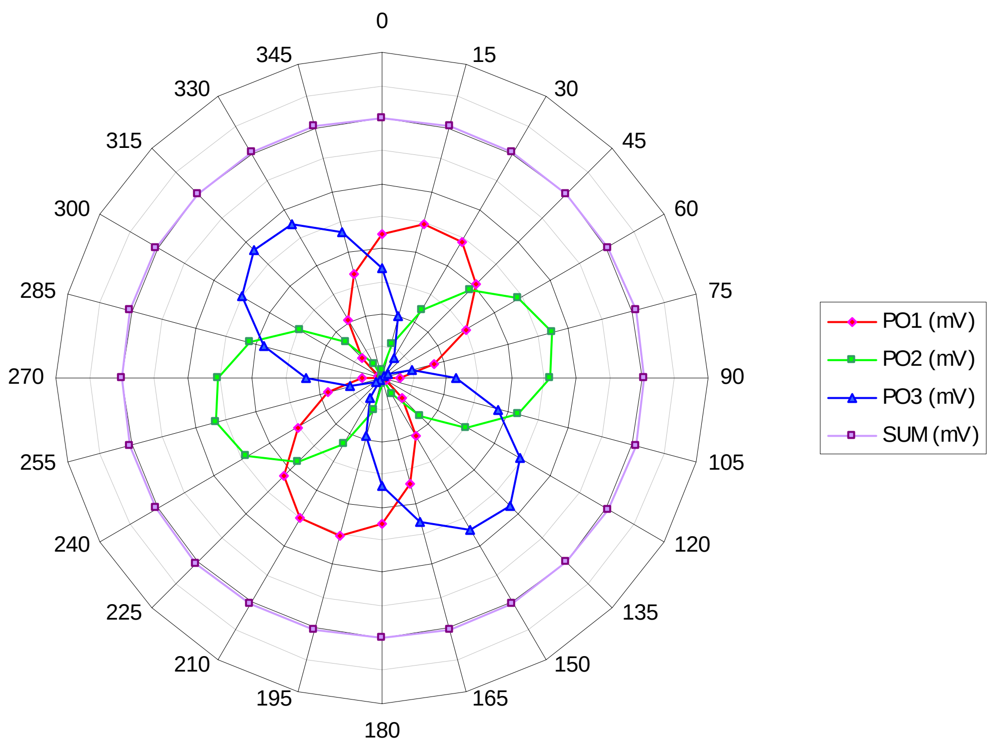
$U_{L,i}$ Linearized probe output voltage at channel i , **Unitless voltage quantity**

$U_{O,i}$ Raw probe output voltage at channel i, **Unitless voltage quantity**

DCP_i Diode compensation potential at channel i

1.2.3.4. Calibration Result

P_d, [mW/cm^2]	2.00
SUM($U_{L,1}$(0), ..., $U_{L,1}$(360))	23117
SUM($U_{L,2}$(0), ..., $U_{L,2}$(360))	21634
SUM($U_{L,3}$(0), ..., $U_{L,3}$(360))	23627
$Norm_{1,peak}$	1910
$Norm_{2,peak}$	1795
$Norm_{3,peak}$	1772
$Corr_1$	0.10
$Corr_2$	0.05
$Corr_3$	1.33
AS_1	**0.0075307056**
AS_2	**0.0080137981**
AS_3	**0.0081171369**
Isotropy Error, [dB]	**0.01**



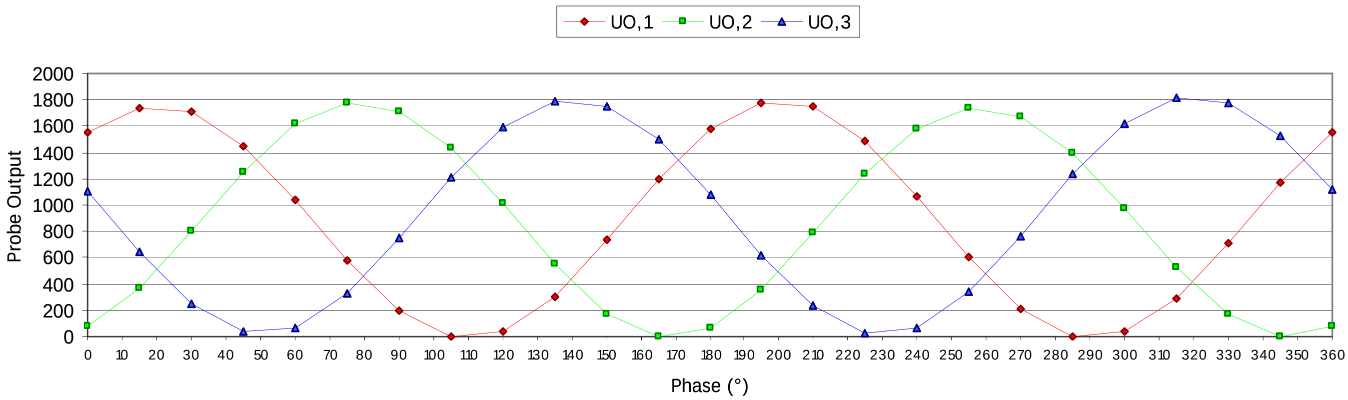
1.2.3.5. Calibration Data

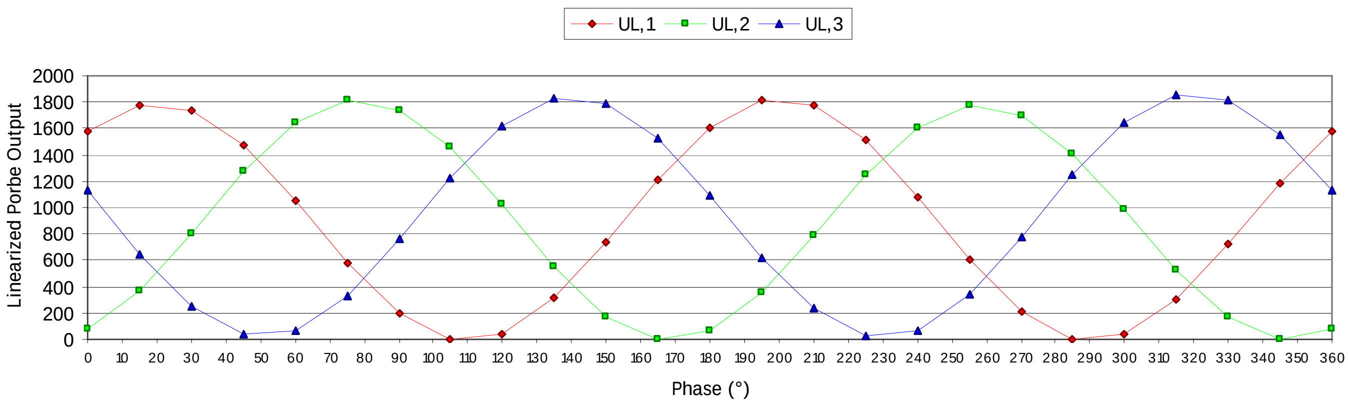
Probe Information	
Type	E-field (Triangular beam)
Model Number	ET20
Serial Number	03-MAR-0019
Sensor Diameter, [mm]	4.0
Sensor Offset, [mm]	2.1
Sensor Factor, h_{Pd}	10.8
Sensor Factor, h_{E2}	0.002864721
DCP_1	92825
DCP_2	96871
DCP_3	86612
f	90
j_1	54.7
j_2	54.7
j_3	54.7

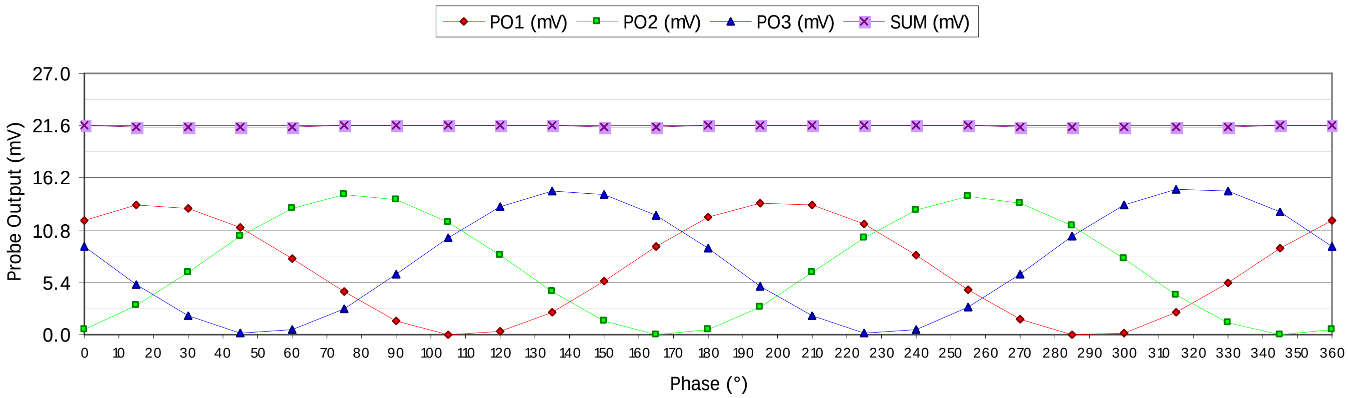
Uniform Field Generation	
	TEM cell
Model Number	APOLLO, 13492
Serial Number	12463-2
Test Frequency, [MHz]	450
Wavelength, [m]	0.6662
P_{net}[mW]/P_d[mW/cm^2]	271.0

Input Power		
PM [dBm]	OFF [dB]	P_{net} [mW]
7.34	20.00	542.00

Phase (°)	$U_{O,1}$	$U_{O,2}$	$U_{O,3}$	$U_{L,1}$	$U_{L,2}$	$U_{L,3}$	PO_1 (mV)	PO_2 (mV)	PO_3 (mV)	SUM (mV)	Dev. (dB)
0	1547	76	1111	1573	76	1125	11.84	0.61	9.13	21.59	0.00
15	1738	367	639	1771	368	644	13.33	2.95	5.23	21.51	-0.01
30	1706	799	244	1737	806	245	13.08	6.46	1.99	21.53	-0.01
45	1447	1256	33	1470	1272	33	11.07	10.20	0.27	21.53	-0.01
60	1035	1613	63	1047	1640	63	7.88	13.14	0.51	21.53	-0.01
75	581	1780	333	585	1813	334	4.40	14.53	2.71	21.64	0.01
90	197	1713	756	197	1743	763	1.49	13.97	6.19	21.65	0.02
105	0	1433	1213	0	1454	1230	0.00	11.65	9.98	21.64	0.01
120	39	1011	1594	39	1022	1623	0.29	8.19	13.18	21.66	0.02
135	309	551	1790	310	554	1827	2.33	4.44	14.83	21.61	0.01
150	735	177	1752	741	177	1787	5.58	1.42	14.51	21.51	-0.01
165	1200	3	1497	1216	3	1523	9.15	0.02	12.36	21.54	-0.01
180	1580	68	1083	1607	68	1097	12.10	0.55	8.90	21.55	0.00
195	1780	356	617	1814	357	621	13.66	2.86	5.04	21.57	0.00
210	1748	786	234	1781	792	235	13.41	6.35	1.90	21.67	0.02
225	1492	1233	31	1516	1249	31	11.42	10.01	0.25	21.67	0.02
240	1069	1581	69	1081	1607	69	8.14	12.88	0.56	21.58	0.00
255	604	1743	341	608	1774	342	4.58	14.22	2.78	21.58	0.00
270	211	1671	767	211	1700	774	1.59	13.62	6.28	21.50	-0.01
285	0	1391	1236	0	1411	1254	0.00	11.31	10.18	21.48	-0.02
300	34	971	1619	34	981	1649	0.26	7.86	13.39	21.50	-0.01
315	296	521	1817	297	524	1855	2.24	4.20	15.06	21.49	-0.02
330	715	165	1782	721	165	1819	5.43	1.32	14.76	21.51	-0.01
345	1175	2	1529	1190	2	1556	8.96	0.02	12.63	21.61	0.01
360	1547	75	1114	1573	75	1128	11.84	0.60	9.16	21.60	0.01
									Avg.	21.57	0.01
									stdev	0.06	
									avedev	0.05	


UO,1
UO,2
UO,3
Probe Output
Phase (°)


UL,1
UL,2
UL,3
Linearized Porbe Output
Phase (°)


PO1 (mV)
PO2 (mV)
PO3 (mV)
SUM (mV)
Probe Output (mV)
Phase (°)

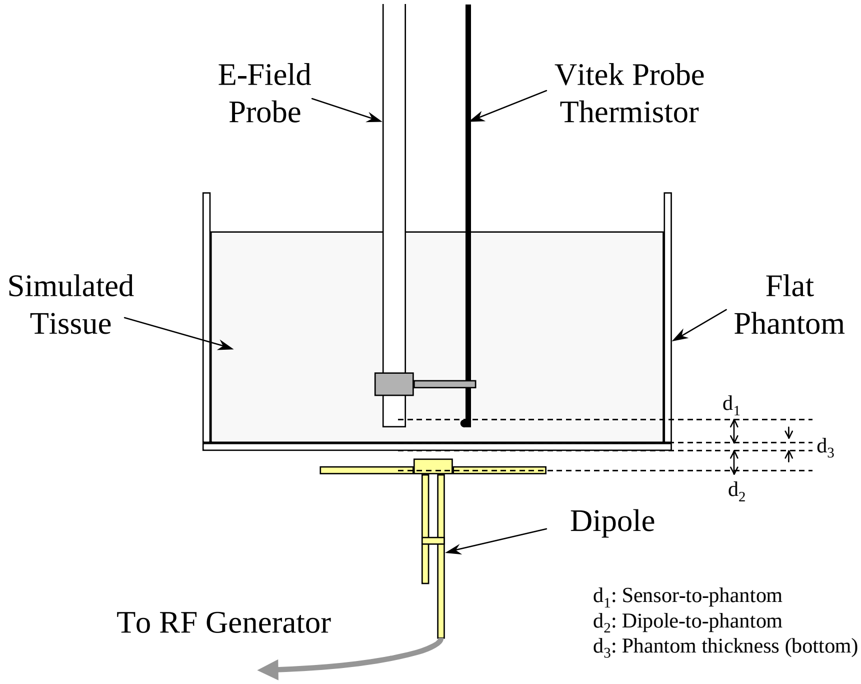
1.2.4. Thermal Transfer Calibration

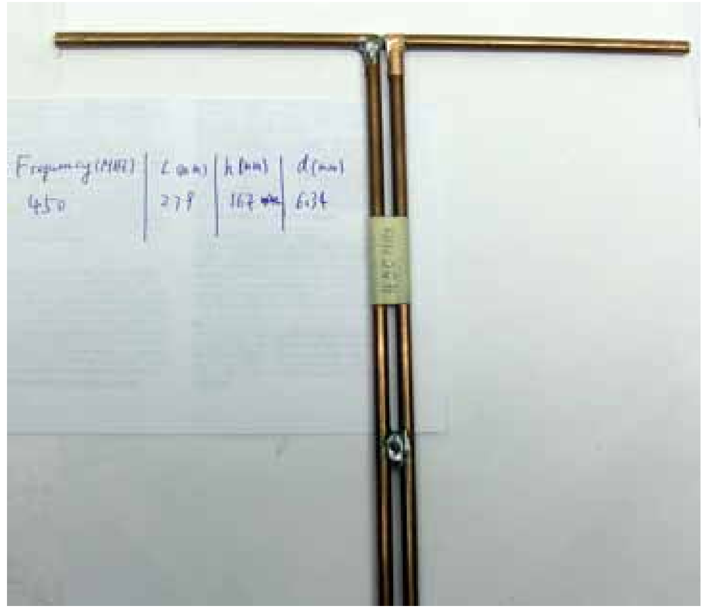
1.2.4.1. Measurement procedure

An RF transparent thermistor-based temperature probe and a isotropic E-field probe are placed side-by-side in a planar phantom while both are exposed to RF energy from a half wave dipole antenna located below the phantom The E-field probe and amplifiers were previously calibrated.

First, the location of the maximum E-field close to the phantom's bottom is determined as a function of power into the dipole, and then the E-field probe is moved sideways so that the temperature probe, while affixed to the E-field probe is placed at the previous location of the E-field probe.

Finally, temperature changes for a certain amount of time (generally 10 to 30 seconds) exposures at the same RF power levels used for the E-field are recorded. Care is taken to allow cooling down to the original temperature and temperature stabilization between tests.





The following simple thermal equation relates SAR to the initial temperature slope:

$$SAR_t = \frac{c \cdot \Delta T}{\Delta t}$$

In the above equation, Δt is the exposure time [sec], c is the specific heat capacity of the simulated tissue [J/Kg/ ^{o}C] and ΔT is the temperature increase [^{o}C] due to the RF exposure. SAR is proportional to $\Delta T/\Delta t$, the initial rate of tissue heating, before thermal diffusion takes place.

It is possible to quantify the electric field in the simulated tissue by equating the thermally-derived SAR to the E-field:

$$SAR = \frac{|E|^2 \cdot \sigma}{\rho}$$

Where σ is the conductivity [S/m] and ρ mass density [Kg/m^3] of the simulated tissue; the actual mass density of the simulated tissue is required during the thermal transfer calibration, while mass density of 1,000 [Kg/m^3] is conventionally chosen during the SAR measurements.

1.2.4.2. *Determination of Conversion Factor (γ) in the simulated tissue*

The sensitivity of the probe in the dielectric media compared to its sensitivity in the air is different. Conversion Factor (γ) is defined to determine the degree of the enhancement of sensitivity in the different dielectric media and relate it to its sensitivity in the air.

$$PO_{tot\_tissue} \equiv PO_{tot\_air} \times \gamma$$

$$\left|E_{tissue}\right|^2 = \frac{PO_{tot\_tissue}}{\eta_{E2}} \times \frac{1}{\gamma} \text{ , therefore } SAR_{tissue} = \frac{\sigma \times \left|E_{tissue}\right|^2}{\rho} = \frac{\sigma \times \left(\frac{PO_{tot\_tissue}}{\eta_{E2}} \times \frac{1}{\gamma}\right)}{\rho}$$

Where,

$\left\|E_{tissue}\right\|^2$	RMS E-field level [(V/m)^2] induced within the exposed tissue
PO_{tot_tissue}	Probe voltage output measured in the simulated tissue [mV]
PO_{tot_air}	Probe voltage output measured in the free space [mV]
η_{E2}	Sensor Factor to the |E|^2, an arbitrary value 10.8/3,770 [mV/(V/m)^2]
γ	Conversion factor; ratio of sensor response in air to response in the dielectric media

The conversion factor γ can be used to scale the E-field in terms of the thermally-derived SAR. It is the quotient of SAR_t, the SAR determined from temperature measurements in the flat phantom, and PO_{tot_tissue}, the E-field prove output voltage obtained at the same location in the phantom

$$SAR_t = SAR_{tissue}$$

$$SAR_t = \frac{c \cdot \Delta T}{\Delta t} = \frac{\sigma_{@cal} \times \left|E_{tissue}\right|^2}{\rho} = \frac{\sigma_{@cal} \times \left(\frac{PO_{tot\_tissue}}{\eta_{E2}} \times \frac{1}{\gamma}\right)}{\rho}$$

$$\gamma = \frac{\sigma_{@cal} \times \left(\frac{PO_{tot\_tissue}}{\eta_{E2}}\right)}{\rho} \times \frac{1}{SAR_t} = \frac{\sigma_{@cal} \times \left(\frac{PO_{tot\_tissue}}{\eta_{E2}}\right)}{\rho} \times \frac{1}{\left(\frac{c \cdot \Delta T}{\Delta t}\right)} = \frac{\sigma_{@cal}}{\rho \times \eta_{E2} \times c} \times \frac{PO_{tot\_tissue}}{\Delta T / \Delta t}$$

where,

SAR_t	Thermally-derived SAR [W/Kg]
c	Specific heat capacity of the simulated tissue [J/Kg/ ^{o}C]

$\sigma_{@\,cal}$	Conductivity of the simulated tissue during the calibration procedure [S/m]
ρ	Actual mass density of the simulated tissue [Kg/m^3]
$\Delta T/\Delta t$	Initial rate of tissue heating, before thermal diffusion takes place [^{o}C /sec]

The temperature E-field correlation is illustrated below (for simulated brain tissue) for an example in which the thermal quantities were,

RF power input = 0.5 [W]
$\sigma_{@\,cal}$ = 0.97 [S/m]
ρ. = 1,200 [Kg/m^3]
c = 2,700 [J/Kg/^{o}C]
ΔT = 0.0163 [^{o}C] (from thermistor-base temperature probe)
Δt = 30 [sec]

The resulting SAR$_t$ was

$$SAR_t = 2700 \times \frac{0.0163}{30} = 1.467[W/Kg]$$

Assuming that the output of the E-field probe was measured as shown below when it was introduced at the same position where the thermistor was positioned to measure thermal quantities,

$$PO_{tot\_tissue} = 28.5[mV]$$

The calculation of conversion factor γ is as shown below,

$$\gamma = \frac{\sigma_{@\,cal}}{\rho \times \eta_{E2} \times c} \times \frac{PO_{tot\_tissue}}{\Delta T/\Delta t} = \frac{0.97}{1200 \times \frac{10.8}{3770} \times 2700} \times \frac{28.5}{\frac{0.0163}{30}} = 5.482$$

One problem is that thermistor-based temperature probe is not sensitive when it is introduced into low field strength level while E-Filed probe suffers from compression of detector diode in high field strength level. Since PO_{tot_tissue} and $\Delta T/\Delta t$ are functions of input power P, we can consider partial differential equation by taking partial derivative of PO_{tot_tissue} and $\Delta T/\Delta t$ with respect to input power P, and which settles down issue between two calibration probes as well as reduces the calibration measurement uncertainty.

$$\gamma = \frac{\sigma_{@cal}}{\rho \times \eta_{E2} \times c} \times \frac{\frac{\delta}{\delta P} PO_{tot\_tissue}}{\frac{\delta}{\delta P} \frac{\Delta T}{\Delta t}}$$

Where,

$\frac{\delta}{\delta P} PO_{tot\_tissue}$ Partial derivative of PO_{tot_tissue} with respect to input power P

$\frac{\delta}{\delta P} \frac{\Delta T}{\Delta t}$ Partial derivative of $\Delta T / \Delta t$ with respect to input power P

1.2.4.3. Determining the Heat Capacity of Simulated Tissue

1.2.4.3.1. Instruments and Materials

- Calibrated thermometer
- Calorimeter
- DC Power Supply
- Hot and cold tap water
- Solution under test

1.2.4.3.2. Method

Heat can be propagated by conduction, convection and radiation. In the case of liquids heated, gravity convection is the main and predominant heating mechanism of the fluid mass.

Obtain two containers that can be rapidly heated. Fill one container with 250 ml of water, the other with the same mass of simulated tissue. The initial temperature of the water should be the same as that of the simulated tissue ($\pm$1°C). Turn on the heat source and record the initial temperature of the water and monitor the temperature increase.

After 30 seconds of heating, the water temperature should have increased by at least 5 °C. Record the time and temperature. Turn off the heat source and stir the liquid thoroughly and record the steady state temperature 1-2 minutes after stirring.

Repeat the above procedure using the container of simulated tissue. Ensure that the container is placed on the same area of the hot plate, is heated for the identical length of time, and the steady state temperature is recorded after the identical time interval.

Since the heat capacity of water is C_w = 1,000 [cal/Kg/°C] or 4,189 [J/Kg/°C] with excellent approximation (~1%) in the temperature range of interest, the heat capacity C_s of the solution is given by

$$C_s = C_w \cdot \frac{\Delta T_w}{\Delta T_s}$$

Where

ΔT_w the temperature increase of water

ΔT_s the temperature increase of the solution

The ratio of the increase values $\Delta T_w / \Delta T_s$ should be the same (within the sensitivity of the thermometer) at the end of the heating and stirring. This ensures that the liquids have been uniformly heated.

1.2.4.3.3. Rationale

$$C \cdot \Delta T = Heat\_Flow \cdot Time = Total\_Heating\_Energy$$

Assuming that the heat flow, sample mass and absorption (i.e. heat transfer) are the same for both liquids, then

$$C_w \cdot \Delta T_w = C_s \cdot \Delta T_s$$

The heat flow and total heating are kept constant by using the same source for the same amount of time. If the heat transfer mechanisms for two liquids are about the same, with insignificant differences in convective and conductive characteristics, then any differences in temperature increase are a direct measure of the specific heat capacity C.

1.2.4.4. Calibration Results

1.2.4.4.1. Conversion Factor for brain simulated tissue at 450 MHz

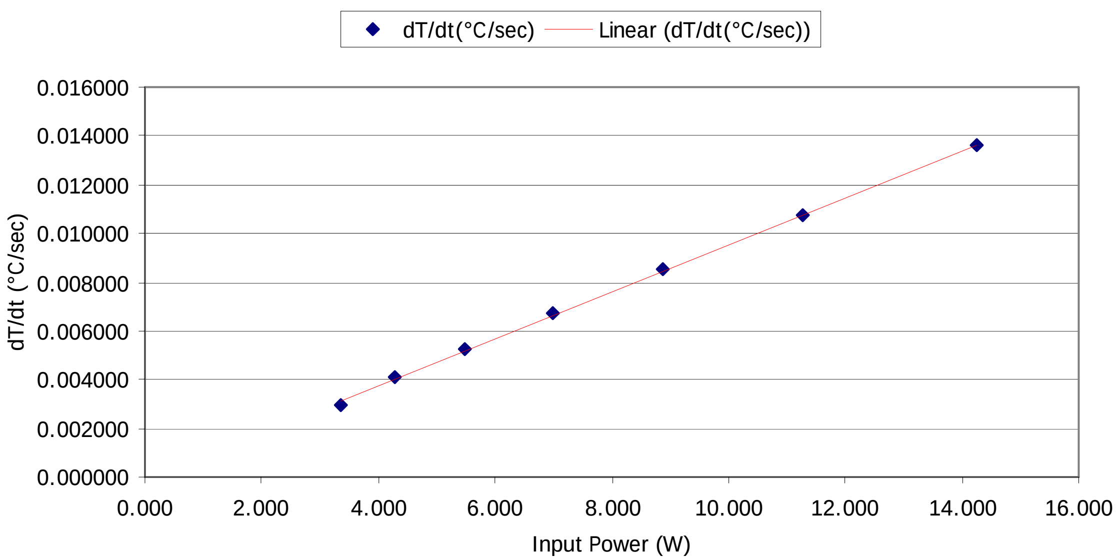
Simulated Tissue Information	
Tissue Calibration Frequency [MHz]	450
Conductivity, σ' [S/m]	0.88
Dielectric Constant, ε	43.3
Penetration Depth, δ' [m]	0.0425
Mass Density, ρ [kgS/m^3]	1318.4
Specific Heat Capacity, C [J/°C/kg]	2967.4

Calibration Result	
$dPO_{SUM,L}/dP$	**6.836156E+01**
d(dT/dt)/dP	**9.529688E-04**
Conversion Factor, γ	**5.633**
Sensitivity, ζ $_{[W/Kg/mV]}$	**5.454E-02**

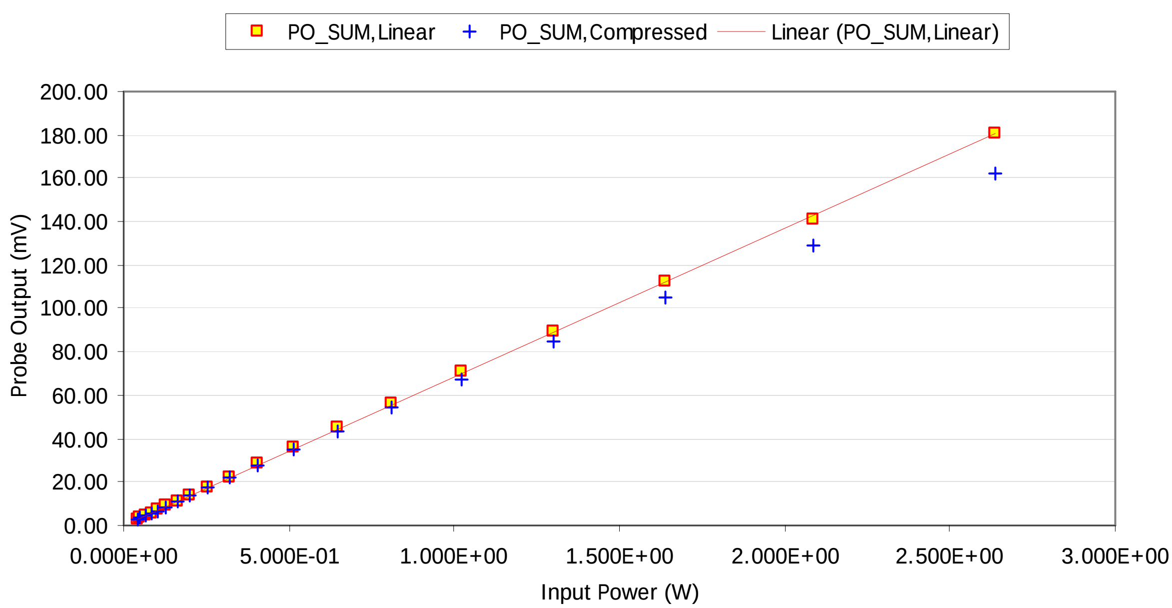
Frequency [MHz]	Meas. After 5min			DI Water at 20°C			Init. Meas.		
	ε'	ε''	σ [S/m]	ε'	ε''	σ [S/m]	ε'	ε''	σ [S/m]
425.000	43.9387	36.1769	0.86	79.1105	1.4118	0.03	43.9413	36.6622	0.87
450.000	43.3442	35.0933	0.88	79.0493	1.5660	0.04	43.3913	35.5186	0.89
475.000	42.9237	34.2336	0.90	79.2337	1.8746	0.05	42.9682	34.3428	0.91

#	$PM_{fw\ (dBm)}$	$PM_{rf\ (dBm)}$	$P_{in\ (W)}$	$dT/dt_{(°C/sec)}$
1	3.07	-50.00	14.256	0.013613
2	2.05	-50.00	11.272	0.010714
3	1.01	-50.00	8.871	0.008496
4	-0.03	-50.00	6.982	0.006708
5	-1.07	-50.00	5.495	0.005245
6	-2.15	-50.00	4.285	0.004116
7	-3.19	-50.00	3.373	0.002915

d(dT/dt)/dP	9.529688E-04



#	PM_{fw} (dBm)	PM_{rf} (dBm)	P_{in} (W)	$U_{O,1}$	$U_{O,2}$	$U_{O,3}$	$U_{L,1}$	$U_{L,2}$	$U_{L,3}$	PO_1	PO_2	PO_3	PO_{SUM} (mV)
1	-2.41	-50.00	4.1E-02	182	0	157	182	0	157	1.37	0.00	1.28	2.65
2	-1.45	-50.00	5.1E-02	234	0	195	235	0	195	1.77	0.00	1.59	3.35
3	-0.43	-50.00	6.5E-02	302	0	245	303	0	246	2.28	0.00	1.99	4.28
4	0.61	-50.00	8.2E-02	390	0	309	392	0	310	2.95	0.00	2.52	5.47
5	1.59	-50.00	1.0E-01	498	0	389	501	0	391	3.77	0.00	3.17	6.94
6	2.61	-50.00	1.3E-01	634	3	486	638	3	489	4.81	0.02	3.97	8.80
7	3.61	-50.00	1.6E-01	804	7	612	811	7	616	6.11	0.06	5.00	11.17
8	4.53	-50.00	2.0E-01	999	12	756	1010	12	763	7.60	0.10	6.19	13.89
9	5.55	-28.40	2.6E-01	1261	19	949	1278	19	959	9.63	0.15	7.79	17.57
10	6.57	-24.55	3.2E-01	1601	29	1199	1629	29	1216	12.26	0.23	9.87	22.36
11	7.57	-22.19	4.1E-01	2012	39	1503	2056	39	1529	15.48	0.31	12.41	28.20
12	8.59	-20.35	5.1E-01	2537	52	1892	2606	52	1933	19.63	0.42	15.69	35.74
13	9.59	-18.82	6.5E-01	3176	70	2368	3285	70	2433	24.74	0.56	19.75	45.04
14	10.55	-17.45	8.1E-01	3904	91	2934	4068	91	3033	30.64	0.73	24.62	55.99
15	11.57	-16.05	1.0E+00	4888	119	3670	5145	119	3826	38.75	0.95	31.05	70.76
16	12.61	-14.85	1.3E+00	6112	155	4568	6514	155	4809	49.06	1.24	39.03	89.34
17	13.63	-13.69	1.6E+00	7600	197	5704	8222	197	6080	61.92	1.58	49.35	112.85
18	14.67	-12.50	2.1E+00	9224	255	7112	10141	256	7696	76.37	2.05	62.47	140.88
19	15.69	-11.42	2.6E+00	11648	330	8864	13110	331	9771	98.72	2.65	79.31	180.69
	$dPO_{SUM,L}/dP$		6.836E+01										



1.2.4.4.2. Conversion Factor for muscle simulated tissue at 450 MHz

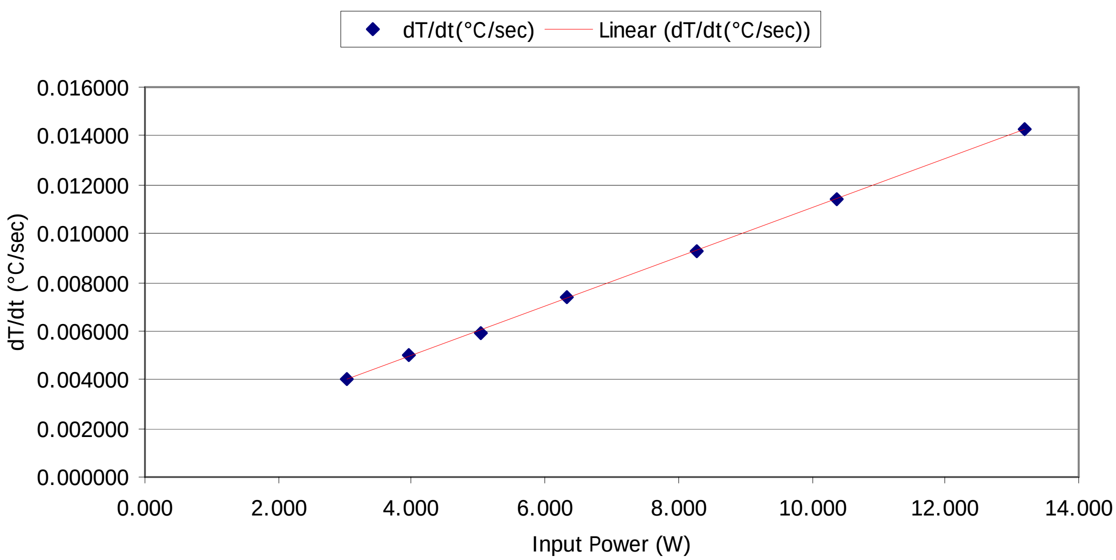
Simulated Tissue Information	
Tissue Calibration Frequency [MHz]	450
Conductivity, σ' [S/m]	0.94
Dielectric Constant, ε	56.8
Penetration Depth, δ' [m]	0.0446
Mass Density, ρ [kgS/m^3]	1251.0
Specific Heat Capacity, C [J/°C/kg]	3079.1

Calibration Result	
$dPO_{SUM,L}/dP$	**7.640716E+01**
d(dT/dt)/dP	**1.117823E-03**
Conversion Factor, γ	**5.823**
Sensitivity, $\zeta_{[W/Kg/mV]}$	**5.635E-02**

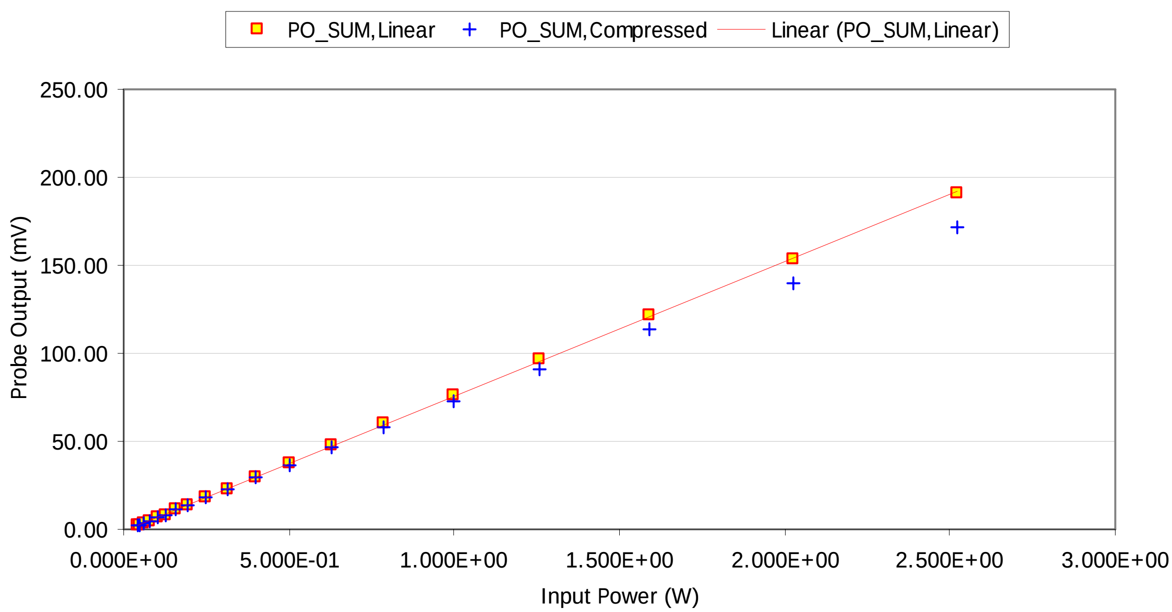
Frequency [MHz]	Meas. After 5min			DI Water at 20°C			Init. Meas.		
	ε'	ε''	σ [S/m]	ε'	ε''	σ [S/m]	ε'	ε''	σ [S/m]
425.000	57.2485	38.9365	0.92	79.1105	1.4118	0.03	57.2474	39.0882	0.92
450.000	56.8072	37.6621	0.94	79.0493	1.5660	0.04	56.8777	37.8205	0.95
475.000	56.6441	36.6467	0.97	79.2337	1.8746	0.05	56.6347	36.6029	0.97

#	PM_{fw} (dBm)	PM_{rf} (dBm)	P_{in} (W)	dT/dt(°C/sec)
1	2.73	-50.00	13.182	0.014286
2	1.69	-50.00	10.375	0.011381
3	0.71	-50.00	8.279	0.009305
4	-0.45	-50.00	6.339	0.007407
5	-1.45	-50.00	5.035	0.005942
6	-2.51	-50.00	3.945	0.004999
7	-3.65	-50.00	3.034	0.003990

d(dT/dt)/dP	1.117823E-03



#	PM_{fw} (dBm)	PM_{rf} (dBm)	P_{in} (W)	$U_{O,1}$	$U_{O,2}$	$U_{O,3}$	$U_{L,1}$	$U_{L,2}$	$U_{L,3}$	PO_1	PO_2	PO_3	PO_{SUM} (mV)
1	-2.57	-50.00	3.9E-02	185	61	0	185	61	0	1.40	0.49	0.00	1.89
2	-1.59	-50.00	4.9E-02	253	80	0	254	80	0	1.91	0.64	0.00	2.55
3	-0.57	-50.00	6.3E-02	340	104	5	341	104	5	2.57	0.83	0.04	3.44
4	0.47	-50.00	7.9E-02	452	134	31	454	134	31	3.42	1.08	0.25	4.75
5	1.47	-27.84	1.0E-01	589	172	63	593	172	63	4.46	1.38	0.51	6.36
6	2.47	-24.74	1.3E-01	763	221	105	769	222	105	5.79	1.78	0.85	8.42
7	3.49	-22.57	1.6E-01	981	282	156	991	283	156	7.47	2.27	1.27	11.00
8	4.41	-20.98	2.0E-01	1230	351	216	1246	352	217	9.39	2.82	1.76	13.97
9	5.43	-15.42	2.5E-01	1564	447	296	1590	449	297	11.98	3.60	2.41	17.99
10	6.45	-18.04	3.1E-01	1998	571	403	2041	574	405	15.37	4.60	3.29	23.26
11	7.47	-16.70	4.0E-01	2522	724	532	2591	729	535	19.51	5.85	4.34	29.70
12	8.49	-15.52	5.0E-01	3178	916	696	3287	925	702	24.75	7.41	5.69	37.86
13	9.49	-14.34	6.3E-01	3960	1155	901	4129	1169	910	31.09	9.37	7.39	47.85
14	10.45	-13.29	7.9E-01	4912	1439	1139	5172	1460	1154	38.95	11.70	9.37	60.02
15	11.47	-12.20	1.0E+00	6128	1811	1457	6533	1845	1482	49.19	14.78	12.03	76.00
16	12.49	-11.11	1.3E+00	7632	2287	1866	8259	2341	1906	62.20	18.76	15.47	96.43
17	13.51	-10.02	1.6E+00	9424	2870	2367	10381	2955	2432	78.17	23.68	19.74	121.59
18	14.55	-8.95	2.0E+00	11576	3594	2985	13020	3727	3088	98.05	29.87	25.06	152.98
19	15.51	-7.92	2.5E+00	14128	4456	3656	16278	4661	3810	122.59	37.35	30.93	190.87
	$dPO_{SUM,L}/dP$		**7.641E+01**										



1.3. SYSTEM VERIFICATION

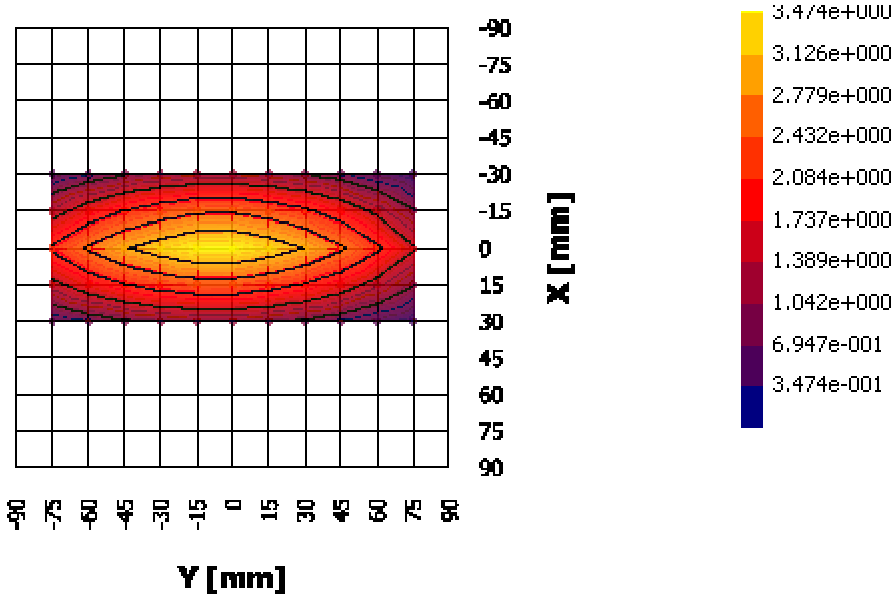
1.3.1. Reference SAR values for simulated brain tissue at 450 MHz*

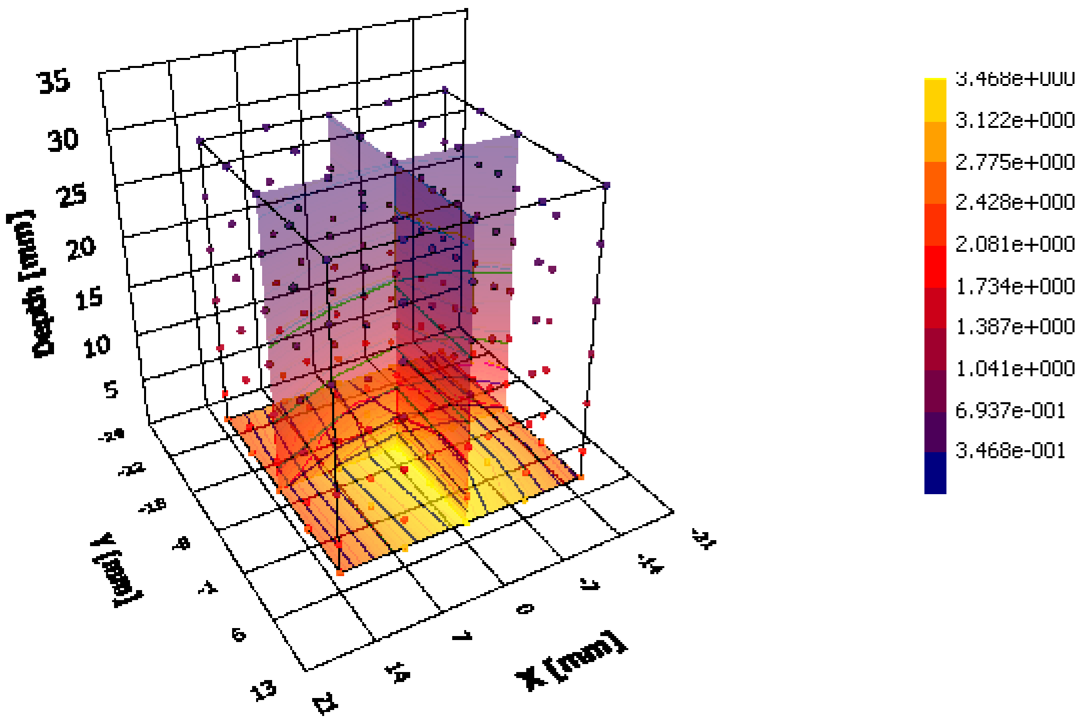
Reference SAR_{1g} [W/Kg]	4.9
Reference SAR_s [W/Kg]	7.2
Measured SAR_{1g} [W/Kg]	4.9
Measured SAR_s [W/Kg]	8.5

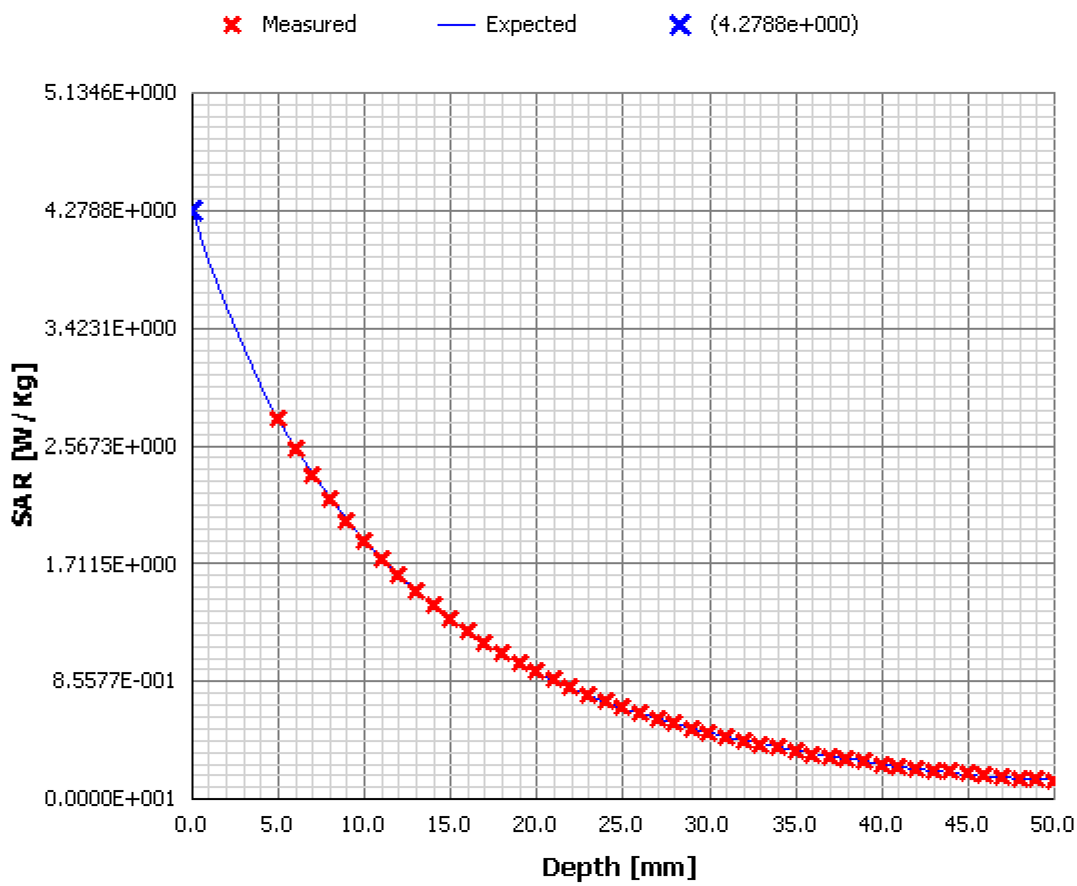
1.3.2. Verification result at 450 MHz

Test date [MM/DD/YYYY]	06/12/2008
Test by	Steven Lu
Room temperature [°C]	21
Room humidity [%]	40
Simulated tissue temperature [°C]	21
Test frequency [MHz]	450
E-field Probe	M/N: ET20, S/N: 03MAR-0019, Sensor Offset: 2.1 mm
Sensor Factor (η_{Pd}) [mV/(mW/cm^2)]	10.8
Amplifier Settings (AS_1, AS_2, AS_3)	0.0075307056, 0.0080137981, 0.0081171369
Tissue Type	Brain
Measured conductivity [S/m]	0.88 (+1.0 %)
Measured dielectric constant	43.3 (-0.4 %)
Conversion Factor (γ)	5.633
Sensitivity (ζ) [W/Kg/mV]	5.453E-02
Power [mW]	500
Measurement Volume Specification (X × Y × Z)	5 pts × 5 pts × 7 pts, 28 mm × 28 mm × 30 mm; Resolution: 7 mm × 7 mm × 5 mm
SAR_{1g} [W/Kg]	2.48
SAR_s [W/Kg]	4.27

* All SAR values are normalized to a forward power of 1 W.


-90
-75
-60
-45
-30
-15
0
15
30
45
60
75
90
X [mm]
Y [mm]
3.474e+000
3.126e+000
2.779e+000
2.432e+000
2.084e+000
1.737e+000
1.389e+000
1.042e+000
6.947e-001
3.474e-001


35
30
25
20
15
10
5
Depth [mm]
Y [mm]
X [mm]
3.468e+000
3.122e+000
2.775e+000
2.428e+000
2.081e+000
1.734e+000
1.387e+000
1.041e+000
6.937e-001
3.468e-001


Measured
Expected
(4.2788e+000)
5.1346E+000
4.2788E+000
3.4231E+000
2.5673E+000
1.7115E+000
8.5577E-001
0.0000E+001
SAR [W / Kg]
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
Depth [mm]

1.4. TEST EQUIPMENT LIST

Test Instruments	Manufacturer	Model No.	Serial No.	Operating Range
Attenuator	Weinschel	46-20-34	BM1347	DC - 18 GHz
Attenuator	Weinschel	46-30-34	BM5354	DC - 18 GHz
Beakers	CORNING			500 mL, 1000 mL
Bi-directional Coaxial Coupler	Narda	3020A	35482	50 MHz ~ 1000 MHz
DC Power Supply	TENMA	72-6153	1526	0 - 18 V, 0 - 10 A
Dielectric Probe Kit	Agilent	85070C	US99360174	
Double-walled Calorimeter		MS-J07051		
Network Analyzer	Hewlett Packard	8353-D	3410J02042	30 kHz - 6 GHz
Power Meter	Hewlett Packard	436A	2016A07747	
Power Meter	Hewlett Packard	436A	2347A17246	
Power Meter	Hewlett Packard	438A	35BU4639	
Power Sensor	Hewlett Packard	8481A	1550A15143	DC - 18 GHz
Power Sensor	Hewlett Packard	8481A	US37295684	DC - 18 GHz
Power Sensor	Hewlett Packard	8481A	2702A68983	DC - 18 GHz
Precision Weight Scale	OHAUS	GT8000	3989	0 g - 8000 g
Spectrum Analyzer	Advantest	R3271	15050203	100 Hz - 26.5 GHz
Stirrer / Hot Plate	CORNING	PC-320	3006584	
Synthesized RF Signal Generator	Gigatronic	6061A	5130408	10 kHz - 1050 MHz
TEM Cell	IFI	CC-110	162	
Wideband RF Amplifier	KALMUS Engineering	720FC	062293-5	400 - 1000 MHz

1.5. SAR MEASUREMENT UNCERTAINTY

1.5.1. Measurement Uncertainty

1.5.1.1. Measurement Uncertainty evaluation

a	*c*	*d*	*e = f(d,k)*	*F*	*h = c x f / e*	*k*
Uncertainty Component	**Tol. (%)**	**Prob. Dist.**	**Div.**	**c_i (1-g)**	**1-g u_i (%)**	**v_i**
Measurement System						
Probe Calibration	3.0	N	1	1	3.0	
Axial Isotropy	5.0	R	3	0.7	2.0	
Hemispherical Isotropy	8.0	R	3	1	4.6	
Boundary Effect	10.0	R	3	1	5.8	
Linearity	4.2	R	3	1	2.4	
System Detection Limits	2.0	R	3	1	1.2	
Readout Electronics	1.0	N	1	1	1.0	
Response Time	1.5	R	3	1	0.9	
Integration Time	2.0	R	3	1	1.2	
RF Ambient Conditions	3.0	R	3	1	1.7	
Probe Positioner Mechanical Tolerance	1.0	R	3	1	0.6	
Probe Positioning with respect to Phantom Shell	3.0	R	3	1	1.7	
Extrapolation, interpolation and Integration Algorithms for Max. SAR Evaluation	3.5	R	3	1	2.0	
Test sample Related						
Test Sample Positioning	7.5	N	1	1	7.5	*11*
Device Holder Uncertainty	6.5	N	1	1	6.5	*8*
Output Power Variation - SAR drift measurement	5.0	R	3	1	2.9	
Phantom and Tissue Parameters						
Phantom Uncertainty (shape and thickness tolerances)	4.0	R	3	1	2.3	
Liquid Conductivity Target - tolerance	5.0	R	3	0.7	2.0	
Liquid Conductivity - measurement uncertainty	4.0	R	3	0.7	1.6	
Liquid Permittivity Target tolerance	5.0	R	3	0.6	1.7	
Liquid Permittivity - measurement uncertainty	4.0	R	3	0.6	1.4	
Combined Standard Uncertainty		RSS			14.3	
Expanded Uncertainty (95% confidence interval)	(Coverage Factor of k = 2)				**±28.5 %**	

EXHIBIT 2. SAR CALCULATION SUMMARY

$U_{O,i}$	Raw probe output voltage at channel i, Unitless voltage quantity
$U_{L,i}$	Linearized probe output voltage at channel i , Unitless voltage quantity
DCP_i	Diode compensation potential at channel i
AS_i	Amplifier Setting for channel i (i = 1, 2, 3)
P_d	Power density at the measurement point [mW/cm^2]
PO_{tot_air}	Probe Output in the air [mV]
PO_{tot_tissue}	Probe Output in the simulated tissue [mV]
η_{Pd}	Sensor Factor to the uniform power density, **an arbitrary value** 10.8 [mV/(mW/cm^2)]
η_{E2}	Sensor Factor to the $\lvert E\rvert^2$, **an arbitrary value** 10.8/3,770 [mV/(V/m)^2]
γ	Conversion factor; ratio of sensor response in air to response in the dielectric media
ζ	Sensitivity of the probe in the simulated tissue [W/Kg/mV]
c	Specific heat capacity of the simulated tissue [J/Kg/ ^{o}C]
$\sigma_{@cal}$	Conductivity of the simulated tissue during the thermal transfer calibration [S/m]
$\sigma_{@meas}$	Conductivity of the simulated tissue during the SAR measurement [S/m]
ρ	Mass density of the simulated tissue [Kg/m^3]
$\Delta T/\Delta t$	Initial rate of tissue heating, before thermal diffusion takes place [^{o}C /sec]

2.1.1. Sensor factor(η_{Pd} and η_{E2}) in the free sapce

$$\eta_{Pd} = 10.8[mV/(mW/cm)^2] \equiv \eta_{E2} = \frac{10.8}{3{,}770}[mV/(V/m)^2]$$

$$Pd[mW/cm^2] = \frac{PO_{tot}}{\eta_{Pd}} \quad , \quad |E|^2[(V/m)^2] = \frac{PO_{tot}}{\eta_{E2}} \quad \text{and} \quad SAR[W/Kg] = \frac{\sigma \times \left(\frac{PO_{tot}}{\eta_{E2}}\right)}{\rho}$$

2.1.2. Diode Compression Potential

$$U_{L,i} = U_{O,i} + \frac{(U_{O,i})^2}{DCP_i}$$

2.1.3. Amplifier settings(AS_i)

$$AS_i = \frac{\eta_{Pd}}{Norm_{i,peak}} \times \cos^2(\varphi - \theta_i) \times P_d$$

$$Norm_{i,peak} = \frac{\sum_{\delta=0}^{360} U_{L,i}(\delta)}{Num_{pk2pk} + Corr_i} = \frac{\sum_{\delta=0}^{360}\left(U_{O,i}(\delta) + \frac{(U_{O,i}(\delta))^2}{DCP_i}\right)}{Num_{pk2pk} + Corr_i}$$

2.1.4. Probe output in the free space

$$PO_1[mV] = U_{L,1} \times AS_1 \equiv |E_1|^2 \times \eta_{E2}$$

$$PO_2[mV] = U_{L,2} \times AS_2 \equiv |E_2|^2 \times \eta_{E2}$$

$$PO_3[mV] = U_{L,3} \times AS_3 \equiv |E_3|^2 \times \eta_{E2}$$

$$PO_{tot}[mV] \equiv |E|^2 \times \eta_{E2} = \left(|E_1|^2 + |E_2|^2 + |E_3|^2\right) \times \eta_{E2} = |E_1|^2 \times \eta_{E2} + |E_2|^2 \times \eta_{E2} + |E_3|^2 \times \eta_{E2}$$
$$\equiv PO_1 + PO_2 + PO_3$$

$$|E|^2[(V/m)^2] \equiv \frac{PO_{tot}}{\eta_{E2}} = \frac{PO_1 + PO_2 + PO_3}{\eta_{E2}}$$
$$= \frac{(U_{L,1} \times AS_1) + (U_{L,2} \times AS_2) + (U_{L,3} \times AS_3)}{\eta_{E2}}$$

2.1.5. Conversion factor (γ) in the simulated tissue

$$PO_{tot\_tissue} \equiv PO_{tot\_air} \times \gamma$$

$$|E_{tissue}|^2 = \frac{PO_{tot\_tissue}}{\eta_{E2}} \times \frac{1}{\gamma}, \quad SAR_{tissue} = \frac{\sigma \times |E_{tissue}|^2}{\rho} = \frac{\sigma \times \left(\frac{PO_{tot\_tissue}}{\eta_{E2}} \times \frac{1}{\gamma}\right)}{\rho}$$

2.1.6. Conversion factor (γ) Calculation

$$\frac{\delta}{\delta P} SAR_t = \frac{\delta}{\delta P} SAR_{tissue}$$

$$\frac{\delta}{\delta P}\left(c \times \frac{\Delta T}{\Delta t}\right) = \frac{\delta}{\delta P}\left(\frac{\sigma_{@cal} \times \left|E_{tissue}\right|^2}{\rho}\right) = \frac{\delta}{\delta P}\left(\frac{\sigma_{@cal} \times \left(\frac{PO_{tot\_tissue}}{\eta_{E2}} \times \frac{1}{\gamma}\right)}{\rho}\right)$$

$$\gamma = \frac{\frac{\delta}{\delta P} SAR_{PO_{tot\_tissue}}}{\frac{\delta}{\delta P} SAR_t} = \frac{\frac{\sigma_{@cal} \times \frac{\frac{\delta}{\delta P} PO_{tot\_tissue}}{\eta_{E2}}}{\rho}}{c \times \frac{\delta}{\delta P}\frac{\Delta T}{\Delta t}} = \frac{\sigma_{@cal}}{\rho \times \eta_{E2} \times c} \times \frac{\frac{\delta}{\delta P} PO_{tot\_tissue}}{\frac{\delta}{\delta P}\frac{\Delta T}{\Delta t}}$$

2.1.7. Sensitivity Factor (ζ) in the simulated tissue

$$SAR_{tissue} = \frac{\sigma_{@meas} \times \left(\frac{PO_{tot\_tissue}}{\eta_{E2}} \times \frac{1}{\gamma}\right)}{\rho_{@meas}} = \frac{\sigma_{@meas} \times \left(\frac{1}{\eta_{E2}} \times \frac{1}{\gamma}\right)}{1000} \times PO_{tot\_tissue} = \left(\frac{\sigma_{@meas}}{1000 \times \eta_{E2} \times \gamma}\right) \times PO_{tot\_tissue}$$

$$\zeta[W/Kg/mV] = \frac{\sigma_{@meas}}{1{,}000[Kg/m^3] \times \eta_{E2} \times \gamma}$$

2.1.8. SAR calculation

$$SAR[W/Kg] = \zeta[W/Kg/mV] \times PO_{tot\_tissue}[mV]$$