A.4 Simulated tissue

Simulated Tissue: Suggested in a paper by George Hartsgrove and colleagues in University of Ottawa Ref.: Bioelectromagnetics 8:29-36 (1987)

This simulated tissue is mainly composed of water, sugar and salt. At higher frequencies, in order to achieve the proper conductivity, the solution does not contain salt. Also, at these frequencies, D.I. water and alcohol is preferred.
Tissue Density : Approximately 1.25 g/cm^3

Preparation
We determine the volume needs and carefully measure all components. A clean container is used where the ingredients will be mixed. A stirring paddle and a hand drill is used to stir the mixture. First we heat the water to about 40 °C to help the ingredients to dissolve and then we pour the salt and the bactericide. We stir until all the ingredients are completely dissolved. We continue stirring slowly while adding the sugar. We avoid high RPM from the mixing device to prevent air bubbles in the mixture. Later on, we add the HEC to maintain the solution homogeneous. Mixing time is approximately 30 to 40 min.

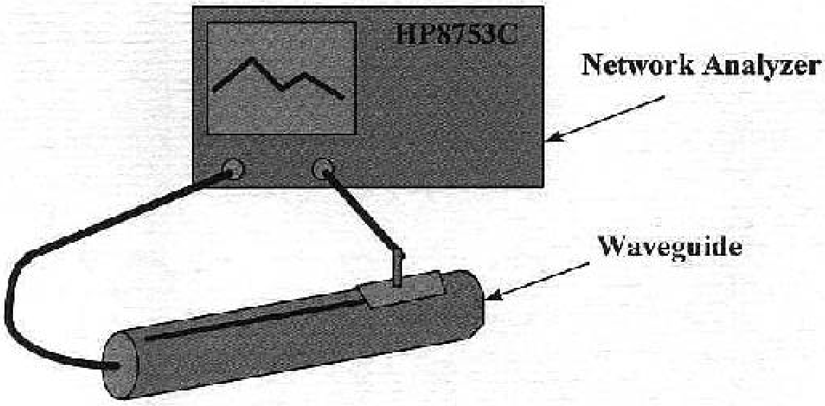
Measurement of Electrical Characteristics of Simulated Tissue

1) Network Analyzer HP8753C or others

2) Slotted Coaxial Waveguide

Description of the slotted coaxial waveguide
The cylindrical waveguide is constructed with copper tube of about 30 to 40 cm of length, generally 12.5 mm diameter, with connectors at both ends. Inside of this tube, a conductive rod about 6.3 mm is coaxial supported by the two ends connectors (radiator). A slot 3 mm wide start at the beginning of the tube to almost the two third of the tube length. The outer edge of the slotted tube is marked incentimeters. For frequency below 1GHz, 1 centimeter per step. For higher frequency above 1 GHz, 0.5 centimeter per step. A saddle piece containing the sampling probe is inserted in the slot so the tip of the probe is close but not in contact with the inner conductor (radiator).
To measure the electrical characteristics of the liquid simulated tissue, which fill the coaxial waveguide, select CW frequency and measure amplitude and phase with the Network Analyzer for every point in the slot (typically 11). An effort is made to keep the results dielectric constant and conductivity within 5 % of published data.

Electrical Characteristics Measurement Setup



$$c = 3 \cdot 10^8 \text{ m/s}$$

$$A = \frac{\Delta A}{20} \ln_{10} \frac{1}{m}$$

$$\theta = \frac{\Delta\theta \cdot 2\pi}{360}$$

$$\lambda = \frac{c}{f} \cdot \frac{100}{2.54} \text{inches}$$

$$\varepsilon_{re} = \frac{(A^2 + \theta^2) \cdot \lambda^2}{4\pi^2}$$

$$\theta' = \left| \frac{|A| \cdot \lambda}{4\pi\sqrt{\varepsilon_{re}}} \right|$$

$$S = \tan(2\theta')$$

$$\varepsilon_r = \frac{\varepsilon_{re}}{\sqrt{(1+S^2)}}$$

$$\sigma = S \cdot 2\pi \cdot f \cdot 8.854 \cdot 10^{12} \cdot \varepsilon_r \text{ (S/m)}$$

where;

ΔA is the amplitude attenuation in dB
$\Delta\theta$ is the phase change in degrees for 5 cm of wave propagation in the slotted line
f is the frequency of interest in Hz

A.5 System Description

The measurement system consists of an E-field probe, instrumentation amplifiers, RF transparent cable connecting the amplifiers to the computer, the robotics arm with its extension and proximity sensors, a phantom with simulated tissue and a radio holder to support the device under test. The E-field probe is a three channel device used to measure RF electric fields in the near vicinity of the source. The three sensors are mutually orthogonal positioned dipoles, and are constructed over a quartz substrate. Located in the center of the dipole is a Schottky diode. High impedance lines are connecting the sensor to the amplifier and then optically linked to the computer. The probe has an isotropic response and is transparent to the RF fields.

Calibration is performed by two steps:

1) Determination of free space E-field from amplified probe outputs in a test RF field. This calibration is performed in a TEM cell when the frequency is below 1 GHz and in a waveguide or some other methodologies above 1 GHz. For the free space calibration, we place the probe in the volumetric center of the cavity and at the proper orientation with the field. The probe is then rotated 360 degrees until the three channels show the maximum reading. This reading equate to $1 mW/cm^2$ if that power density is available in the correspondent cavity.

2) Correlation of the measured free space E-field, to temperature rise in a dielectric medium. E-field temperature correlation calibration is performed in a planar phantom filled with the appropriate simulated tissue.

For temperature correlation calibration, a RF transparent thermistor-based temperature probe is used in conjunction with the E-field probe. First, the location of the maximum E-field close to the phantom's inner surface is determined as a function of power into the RF source; in this case, a dipole. 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 30 seconds exposure at the same RF power levels used for the E-field measurement are recorded. The following equation relates SAR to initial temperature slope:

$$SAR = C\frac{\Delta T}{\Delta t}$$

where:

$\Delta t =$ exposure time (30 seconds),
$C =$ heat capacity of tissue (brain or muscle),
$\Delta T =$ temperature increase due to RF exposure.

The heat capacity used for brain simulated tissue is 2.7 joules/^{0}C/g and 3.0 joules/^{0}C/g for muscle.
SAR is proportional to $\Delta T / \Delta t$, the initial rate of tissue heating, before thermal diffusion takes place.
Now, it's 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:

$\sigma =$ Simulated tissue conductivity,
$p =$ Tissue density ($1.25 g/cm^3$ for simulated tissue)

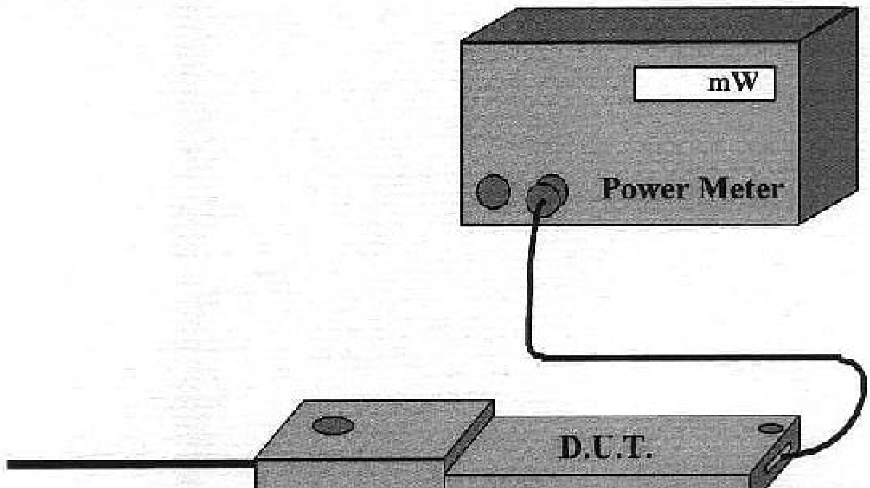
Data Extrapolation (Curve Fitting)
There is a distance from the center of the sensor (diode) to the end of the protective tube called 'probe offset'. To compensate we use an exponential curve fitting method to obtain the peak surface value from the voltages measured at the distance from the inner surface of the phantom. At the point where the highest voltage was recorded, the field is measured as close as possible to the phantom's surface and every 1mm along the ' Z ' axis for a distance of 50 mm. The appropriate exponential curve is obtained from all the points measured and used to define an exponential decay of the energy density versus depth.

$$E(z) = E_0 \cdot e^{-z/\delta} \text{ (mV)}$$

Interpolation and Gram Averaging
The voltage, (1 cm) above the phantoms surface (E_{tot} 1 cm), is needed to calculate the exposure over one gram of tissue. This SAR value that estimates the average over 1 gram of tissue, is obtained by taking the integral over 1 cm^2 surface of the measured field along the exponential decay curve of the energy density with depth.

$$SAR(mW/g) = \int_{s=1g} SAR(\bullet)dv = \int_{s=1cm^2} \int_0^{1cm} E(z) \cdot \frac{CF}{SensorFactor} dzds$$

Power Measurement
When ever possible, a conducted power measurement is performed. To accomplish this, we utilize a fully charged battery, a calibrated power meter and a cable adapter provided by the manufacturer. The data of the cable and related circuit losses are also provided by the manufacturer. The power measurement is then performed across the operational band and the channel with the highest output power is recorded.
Power measurement is performed before and after the SAR to verify if the battery was delivering full power for the time of test. A difference in output power would determinate a need for battery replacement and repetition the SAR test.

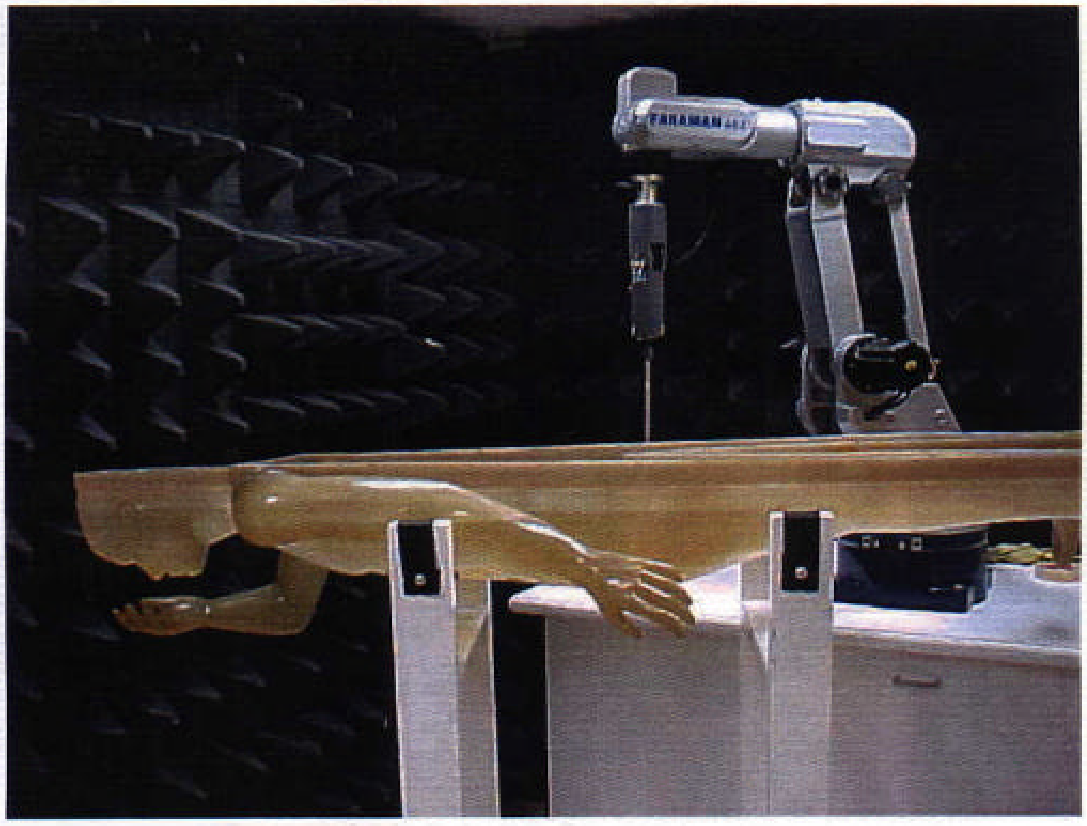


Measured Power Measured Power + Cable and Switching Mechanism Loss

Positioning of EUT

The clear fibreglass phantom shell have been previously marked with a highly visible line, so can easily be seen through the liquid simulated tissue. In the case of testing a cellular phone, this line is connecting the ear channel with the corner of the lips. The EUT is then placed by centering the speaker with the ear channel and the center of the radio width with the corner of the mouth. At the same time the surface of the EUT is always in contact with the phantoms shell. Three points contact; two in the ear region and one on the chin in addition to the previously describe alignment will assure repeatability of the test.
For HAND HELD devices (push-to-talk), or any other type of wireless transmitters, the EUT will be positioned as suggested by manufacturer operational manuals

PICTURE OF THE TEST SETUP



SAR Measurement System

A.6 SAR Measurement Uncertainty

This uncertainty analysis covers the 3D-EMC Laboratory test procedure for Specific Absorption Rate (SAR) associated with wireless telephones and similar devices.

Standards Covered Are:

WGMTE 96/4 - Secretary SC211/B

FCC 96-326, ET Docket No. 93-62

Industry Canada RSS 102

The laboratory test procedure, and this uncertainty analysis, may be used to cover all standards above. It is based on test equipment and procedures specified by 3D-EMC Laboratories, Inc. located in Ft. Lauderdale, Florida.

Measurement Uncertainty:

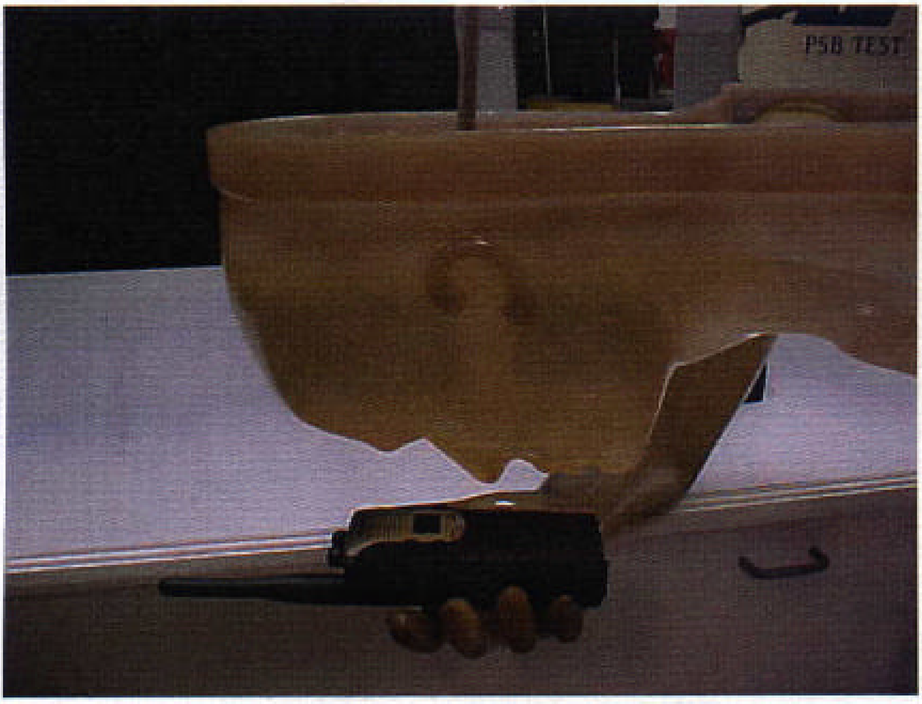
Table I. Estimated SAR Measurement Uncertainty

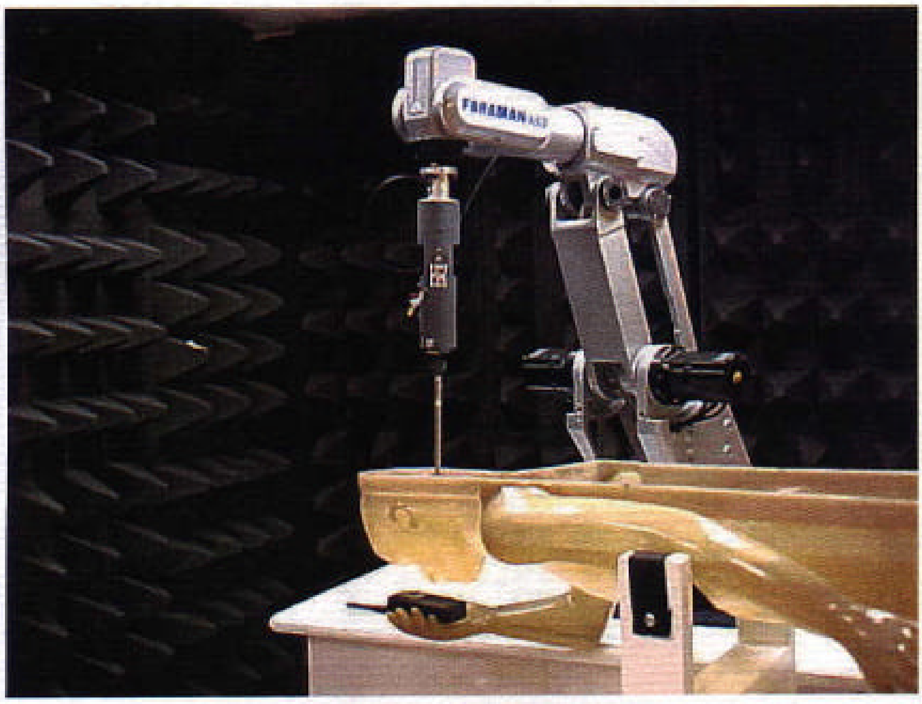
Contribution	Error (±dB)	Probability Distribution	Type Evaluation	Standard Uncertainty (±dB)
A. Field Measurement Errors:		Rectangular	Type B	
Isotropy in Phantom BTS Liquid	0.8			0.46
Frequency Response	0.2			0.12
Linearity	0.2			0.12
Probe Calibration Error (rss)	0.7			0.40
Duty Factor Variability	0.2			0.12
B. Spatial Peak SAR Errors:		Normal	Type A	
Extrapolation & Interpolation, and Position	0.2			0.20
Integration & Search Routine	0.1			0.10
Cube Shape	0.2			0.20
C. Additional Errors:		Rectangular	Type B	
Solution Variability (Worst-Case SAR)	0.21			0.12
D. Combined Standard Uncertainty, u_c:		Normal	-	0.52
E. Expanded Uncertainty, U:		Normal (k=2)	-	1.04
		95% Confidence	-	27.14%

A.7 Test Support Equipment List

Instrument	Model	S/N	Cal Date
SAR Measurement System	--	9912002	N/A
Boonton RF Power Meter	4532	52101	Dec 2000
Boonton Power Sensor	51075	30574	Dec 2000
Boonton Power Sensor	51013	20036	July 2000
Spectrum Analyzer	8564E	3846A01466	Apr 2000
Network Analyzer	8722D	US36140358	June 1999
RF Signal Generator	68347C	#04306	Dec 2000
Amplifier Research Power Amplifier	25W1000B	27226	N/A
Dual Directional Coupler	HP778D	18286	Jan 2000

Face-Hand Held SAR Test Setup Photographs [Model: RadioShack 19-903]
(Using the Open Back Full Body Phantom)





Tissue for Brain at 465MHz

Tested By: TSH **Date:** 21/2/2001

Frequency: 465 MHz

Composition					
Tap Water	DI Water	Sugar	Salt	HEC	Bactericide
22000.00 g	0.00 g	28000.00 g	1400.00 g	0.00 g	100.00 g
42.72 %	0.00 %	54.37 %	2.72 %	0.00 %	0.19 %

Mixture: Brain

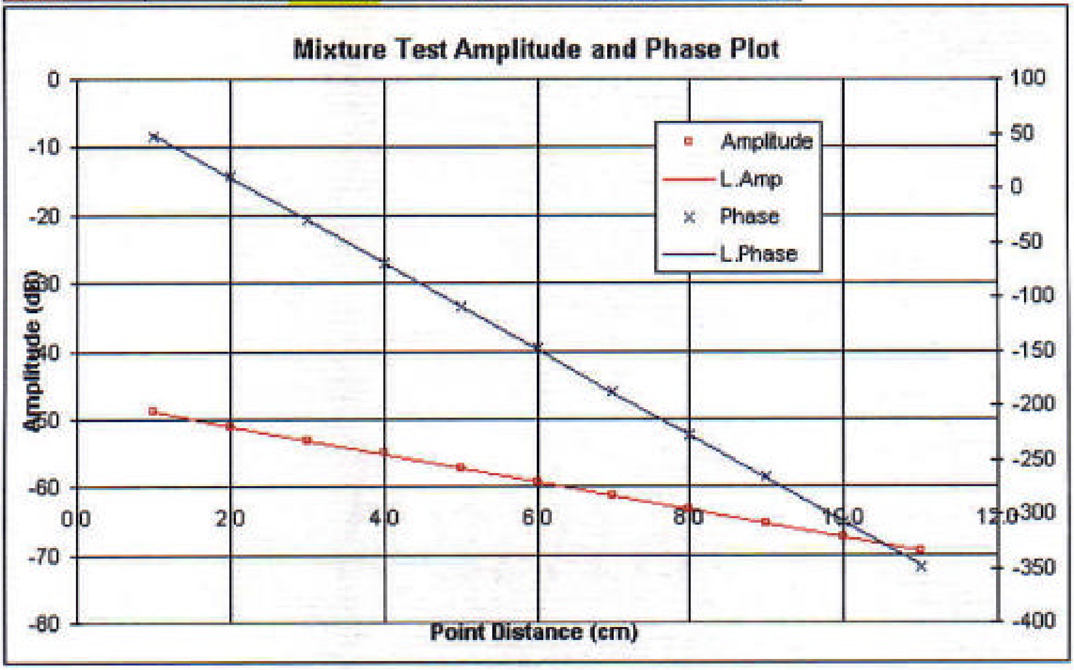
# of Points: 11 **Point Dist:** 1 cm **Temperature:** 24 °C

Point	Amplitude	Phase
1	-48.90	47.50
2	-51.10	10.20
3	-53.10	-29.80
4	-55.10	-69.50
5	-57.40	-109.10
6	-59.40	-147.90
7	-61.40	172.00
8	-63.40	132.10
9	-65.60	94.00
10	-67.60	52.50
11	-69.50	11.00

-49.9	
-51.6	-2.064545455
-53.5	-46.93090909
-55.3	-39.61454545
-56.9	88.86909091

Omega:	2921681168	rad/sec
Epsilon 0:	8.85E-14	F/m
mu:	1.26E-08	H/m
alpha avg:	-0.237689579	Np/cm
beta avg:	-0.69140425	rad/cm

Results:		Target	Low Limit	High Limit	% Off Target
D. Const:	44.4	43.5	41.32	45.675	2.01
Cond:	0.90	0.87	0.826	0.9135	2.86



ANNEX D **REFERENCES**

The methods and procedures used for the measurements contained in this report are details in the following reference standards:

Publications	Year	Title
FCC OET Bulletin 65	1997	"Evaluating Compliance with FCC Guidelines for Human Exposure to radio Frequency Fields"
IEEE Standard 1528-200X	2000	"Product Performance Standards Relative to the safe Use of Electromagnetic Energy"
ANSI/IEEE C95.3	1992	"Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields - RF and Microwave"
ANSI/IEEE C95.1	1992	"Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3kHz to 300GHz"