ATTACHMENT R – PROBE CALIBRATION DATA

CALIBRATION OF PROBE

Description : E-field Probe

Model Type : ET20

Manufacturer : EMF Safety Inc.

Serial No : 03MAY-0026

Manufactured : MAY 20, 2003

Calibrated : March 7, 2005

Calibrated by : Lee, Seung-Bae LeeSeungbae

Approved by : Gimm, Youn-Myoung Younmyoung

1. Introduction

The measurement equipment is comprised of the probe, amplifiers and the measurement device. Current probes are based on Schottky diode detectors. The measured signal, the output of the probe, is a voltage proportional to E^2 depending on the level of RF exposure.

Most isotropic probes consist of three small sensors with orthogonal directivity patterns and detector diodes in the sensor gap. The total electrical can then be evaluated as the root sum square of the three E-field components. In the square-law region of the diode characteristic, the sensor output voltage is proportional to the mean square of the corresponding field component. Beyond that range the output voltage is compressed and therefore requires linearization of the dynamic range. Manufacturing tolerances between the sensors and diodes will produce different sensitivities for each sensor.

The total field shall be evaluated according to:

$$|E|^2 = \sum_{i=1}^{3} |E_i|^2 = \sum_{i=1}^{3} \frac{V_i}{\gamma_i}$$

where γ_i is the absolute sensitivity of the dipole sensors in the media.

2. Assessment of the sensitivity of the dipole sensors

The sensitivity factors can be determined by applying “two step” procedures for ESSAY 3 system.

2.1 Two step procedures

The total field shall be evaluated according to :

$$|E|^2 = \sum_{i=1}^{3} |E_i|^2 = \sum_{i=1}^{3} \frac{f_i(V_i)}{\eta_i \psi_i} \qquad (2\text{-}1)$$

where $f_i(V_i)$ is the linearization function of the rectified sensor signal V_i, η_i is absolute sensitivities of the dipole sensor $[\mu V/(V/m)^2]$ in free space and ψ_i the ratio of the sensitivity of the probe sensors in media to their sensitivity in free space (Sometime referred to as the conversion factor).

The separation of the probe sensitivity in two factors (η_i and ψ_i) allows partial use of the standardized procedures and provides additional validation of the probe performance and calibration set-up

3. Calibration conditions

3.1 Environment

- Ambient temperature of the laboratory : 23 °C ± 2 °C
- Temperature of the tissue : 21 °C ± 2 °C
- Reference

IEEE Std 1528-200X DRAFT Recommended Practice for Determining The Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head from Wireless Communications

Devices : Experimental Techniques

3.2 List of used equipments

Description	Manufacturer	Model / Serial No.	Date of Cal.	Calibration lab./ Certificate No.
Signal Generator	HP	68347B / 534006	2004/07/02	HCT / C-2004-14074
Power Meter	HP	436A / 1803A04211	2004/07/01	HCT / C-2004-14069
Power Meter	HP	436A / 2709A26102	2004/07/01	HCT / C-2004-14071
Power Sensor	HP	8481A / 2702A52736	2004/06/29	HCT / C2004-14070
Power Sensor	HP	8482A / 2235A07171	2004/06/29	HCT / C-2004-14072
Dual Directional Coupler	HP	778D / 13472	2004/07/01	HCT / C-2004-14073
Network Analyzer	HP	8753C / 2901A00795	2004/07/01	HCT / C-2004-14068

3.3 Mechanical description

Body

- Body material : Dielectric constant 2.5 measured at 10 GHz
  Loss tangent 0.0004 measured at 10 GHz
- Diameter : 30.0 cm length, body diameter 9.5 mm
- Sensors : Gold plated short dipole antenna (2.0 mm)
- Connector : Gold plated miniature 7 pins

Model name : ET20-03MAR-0026

- Probe type : ET20
- Serial no. : 03MAR-0026
- Tip diameter : 4.8 mm
- Dipole sensor length : 2.0 mm
- Sensor offset (from probe tip to sensor center) : 2.25 mm

* All the sensors are designed for use in free space measurements or in a lossy liquid medium.

* To use in the lossy liquid medium, the distance from phantom shell inner surface to probe tip end is 2.75 mm to avoid the boundary effect of the probe.

4. Calibration result

4.1 Sensitivity in air

4.1.1 Diode compression point *

- Channel 1 : 110 [mV]
- Channel 2 : 110 [mV]
- Channel 3 : 110 [mV]

4.1.2 Sensor sensitivity in air at 835 MHz in TEM cell and 1900 MHz in waveguide

- Sensor sensitivity 1 : 0.768 [$\mu V/(V/m)^2$]
- Sensor sensitivity 2 : 0.756 [$\mu V/(V/m)^2$]
- Sensor sensitivity 3 : 0.745 [$\mu V/(V/m)^2$]

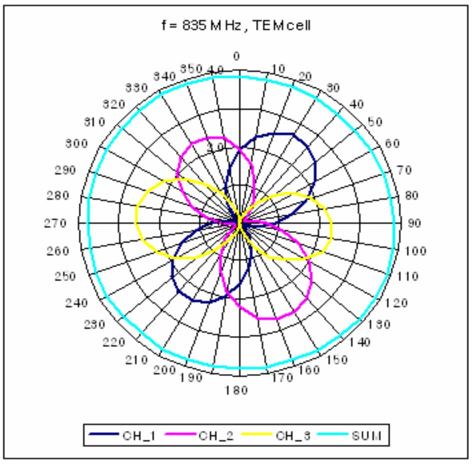
4.2 Conversion factor in tissue simulating liquid

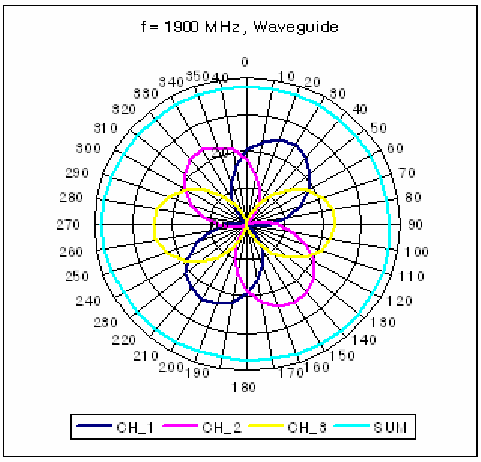
Frequency [MHz]	Tissue type	Permittivity*	Conductivity* [S/m]	Conversion Factor
835	Head	41.5 ± 5%	0.90 ± 5%	5.63 ± 10%
835	Body	55.2 ± 5%	0.97 ± 5%	4.80 ± 10%
1900	Head	40.0 ± 5%	1.40 ± 5%	4.40 ± 10%
1900	Body	53.3 ± 5%	1.52 ± 5%	4.23 ± 10%

* Data are from <Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields> Supplement C, OET Bulletin 65, June 2001.

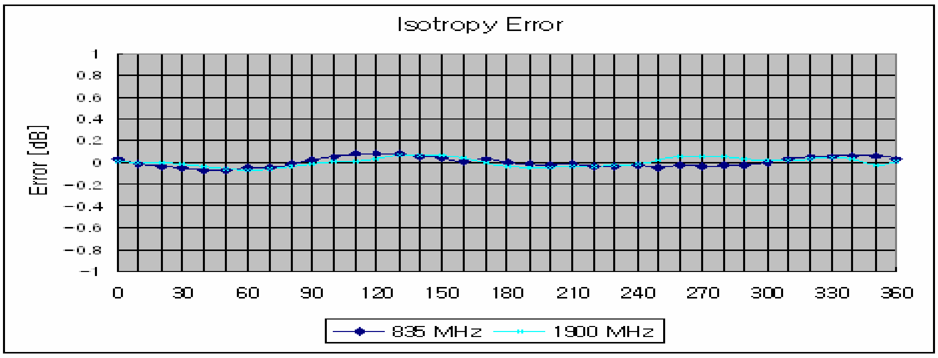
5. Data sheets

Receiving pattern in air

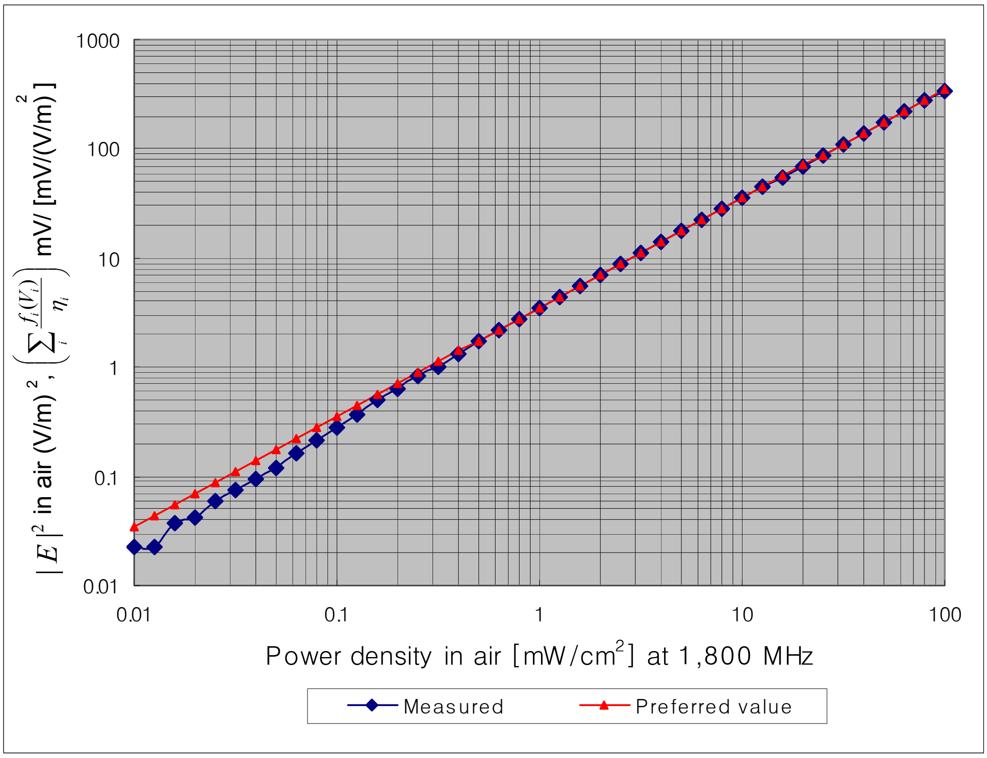




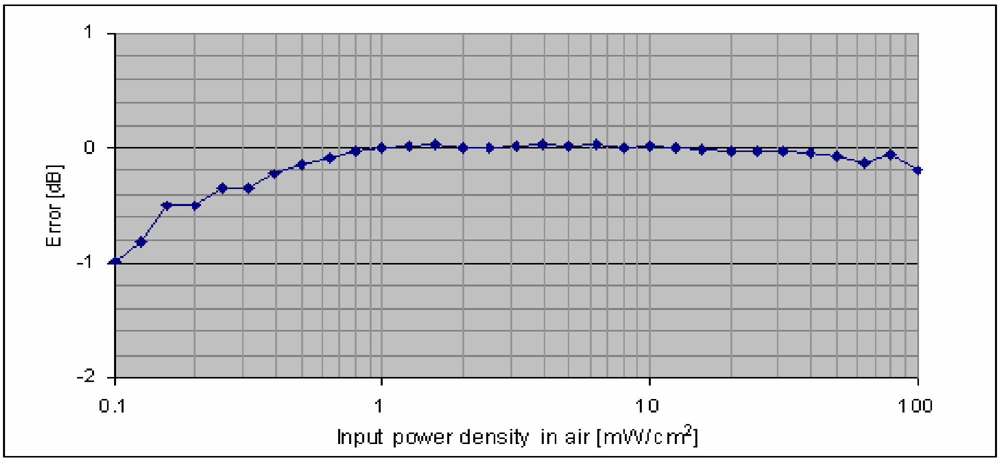
Isotropy error in air



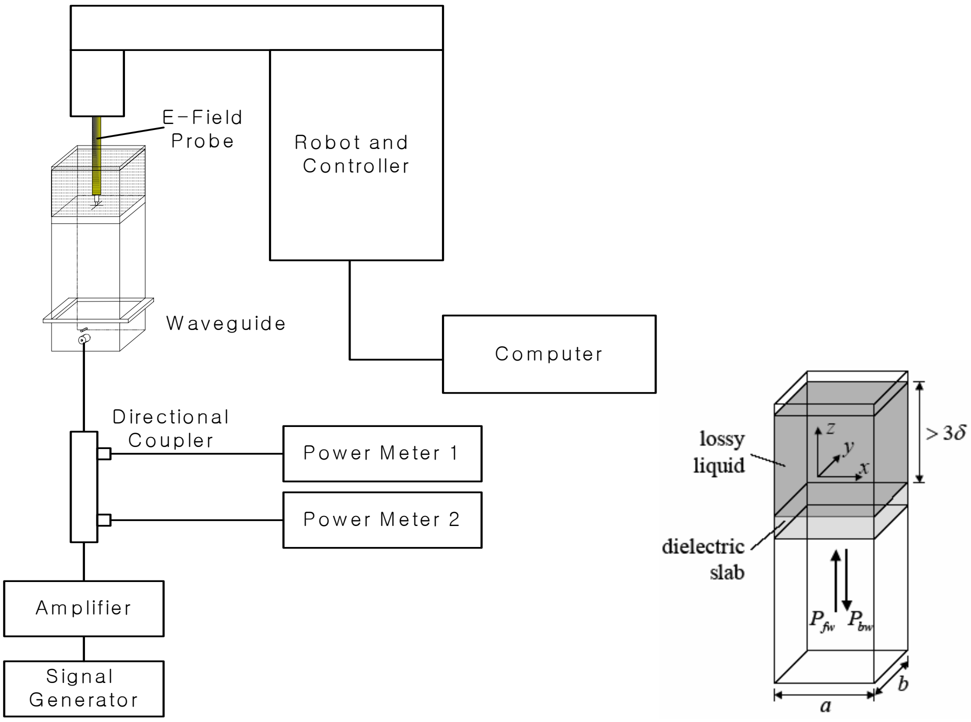
Compensated detection voltage of |E|^2 in air



Detection voltage error of a compensated probe in air at 1,800 MHz



6. Calibration with known fields in waveguides



Vertical rectangular waveguide calibration set-up

The depth of the medium (greater than three penetration depths) ensures that reflections at the upper surface of the liquid are negligible. The power absorbed in the liquid is determined by measuring the waveguide forward and reflected power. Equation (6-1) shows the relationship between the SAR at the cross-sectional center ($x = y = 0$) of the lossy waveguide and the longitudinal distance (z) from the dielectric separator

$$SAR(z) = \frac{4(P_{fw} - P_{bw})}{\rho ab\delta} e^{-2z/\delta} \qquad (6\text{-}1)$$

where the density ρ is ideally assumed to be 1000 kg/m^3, ab is the cross-sectional area of the waveguide, P_{fw} and P_{bw} are the forward and backward power inside the lossless section of the waveguide, respectively. The penetration depth δ, which is the reciprocal of the waveguide-mode attenuation coefficient α, is determined from a scan along the z-axis.

It can be assumed that conversion factors ψ_i in Equation (2-1) is isotropic in homogeneous simulant liquid. If $\psi_x = \psi_y = \psi_z = CF$ in Equation (2-1),

$$E^2 = \sum_{i=x,y,z} E_i{}^2 = \sum_{i=x,y,z} \frac{f_i(V_i)}{\eta_i CF} \qquad (6\text{-}2)$$

Inside of the simulant liquid,

$$SAR(z) = \frac{\sigma \cdot E^2(z)}{\rho} = \frac{\sigma}{\rho \cdot CF} \sum_i \frac{f_i(V_i(z))}{\eta_i} \qquad (6\text{-}3)$$

$f_i(V_i(z))$ is proportional to $e^{-2z/\delta}$ in the liquid and if we let

$$B = \sum_i \frac{f_i(V_i(0))}{\eta_i} \quad [\frac{mV}{\mu V/(V/m)^2}] = [k(V/m)^2] \qquad (6\text{-}4)$$

then $SAR(z) = \dfrac{\sigma B}{\rho \cdot CF} e^{-2z/\delta}$ (6-5)

Also $SAR(z)$ is described by forward and reflected power in Eq.(6-1) and by equating the Eq.(6-1) and (6-5), we get

$$CF = \frac{\sigma a b \delta B}{4(P_{fw} - P_{bw})} \quad \text{(in the liquid filled waveguide)} \qquad (6\text{-}6)$$

$f_i(V_i) =$ compensated signal of channel *i* (*i* = *x,y,z*) $[mV]$

η_i = sensitivity of a probe at port in air *i* ,(*i* = x,y,z) $[\mu V/(V/m)^2]$

$CF =$ probe sensitivity ratio in the simulated tissue to in air, or conversion factor

$E_i =$ electric field strength of channel *i* [*V/m*]

a, b = waveguide dimension [m] (*b* = *a* / 2)

$P_{fw} =$ forward power [W]

$P_{bw} =$ backward power [W]

δ = penetration depth [mm]

$\sigma =$ conductivity of the simulant tissue at the test frequency [S/m]

$\rho =$ mass density of the ideal (not the real) tissue simulant material [1,000 kg/m^3]

Conversion factor assessment

Analytical SAR along the centeral axis of the rectangular waveguide filled with the simulant liquid is $SAR(z) = \dfrac{4(P_{fw} - P_{bw})}{\rho ab\delta} e^{-2z/\delta}$.

Measured SAR value along the centeral axis of the rectangular waveguide filled with the simulant liquid is $SAR(z) = \dfrac{\sigma}{\rho CF} \sum_i \dfrac{f_i(V_i(z))}{\eta_i}$.

Test frequency : 835 MHz

Simulant liquid : Head

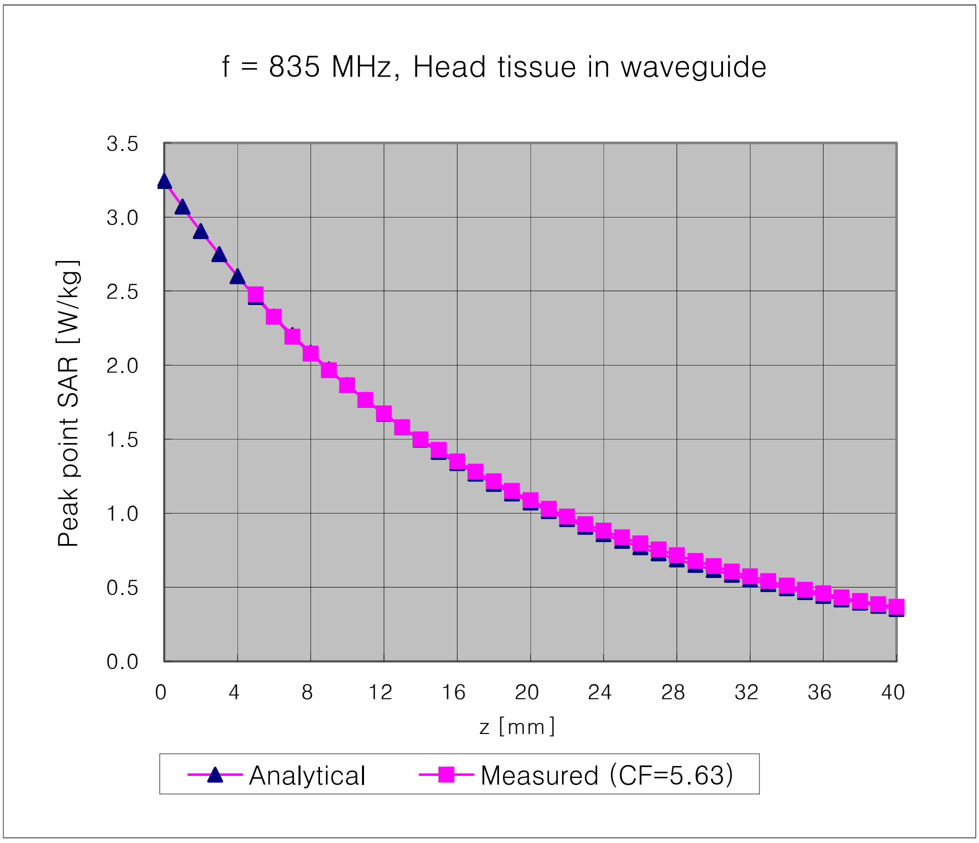
Test waveguide :

Designation : WR-975(EIA), RG-204/U(JAN)

Dimensions : 247.6 mm × 123.8 mm

Frequency range : 750 MHz ~ 1,120 MHz for dominant TE_{10} mode

Net input power to waveguide : 902 mW



Test frequency : 835 MHz

Simulant liquid : Body

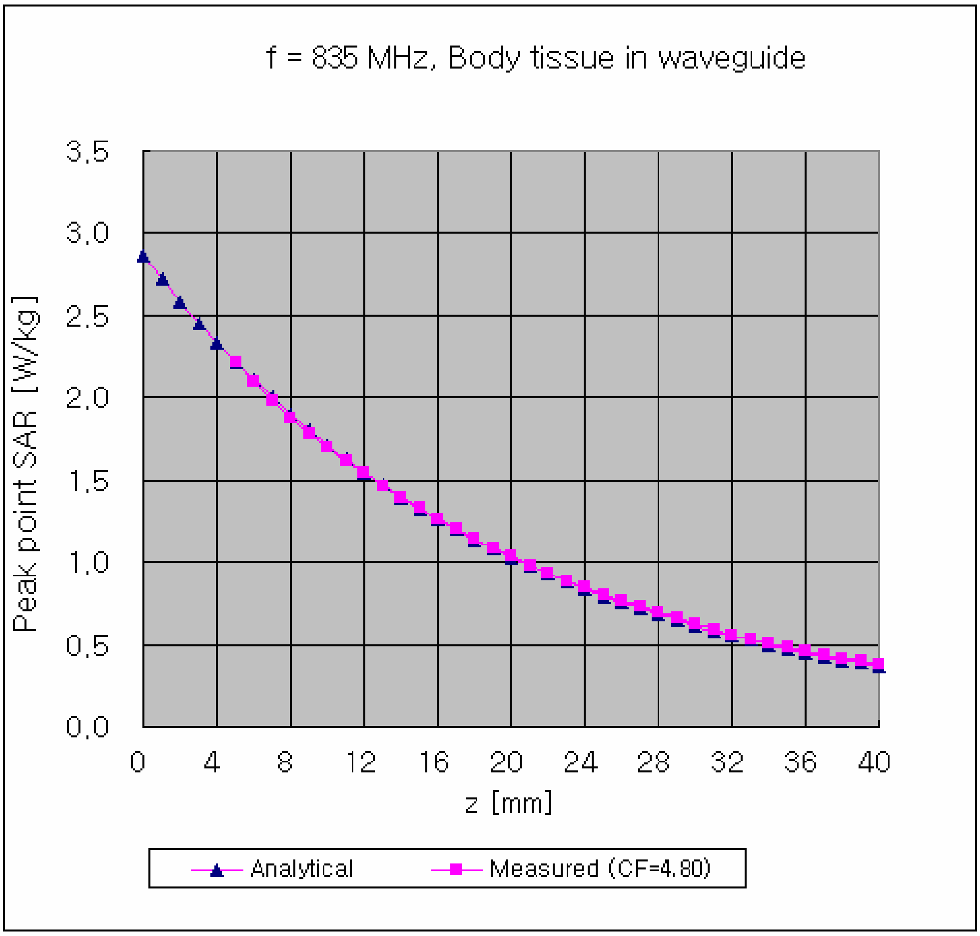
Test waveguide :

Designation : WR-975(EIA), RG-204/U(JAN)

Dimensions : 247.6 mm × 123.8 mm

Frequency range : 750 MHz ~ 1,120 MHz for dominant TE_{10} mode

Net input power to waveguide : 857 mW



Test frequency : 1900 MHz

Simulant liquid : Head

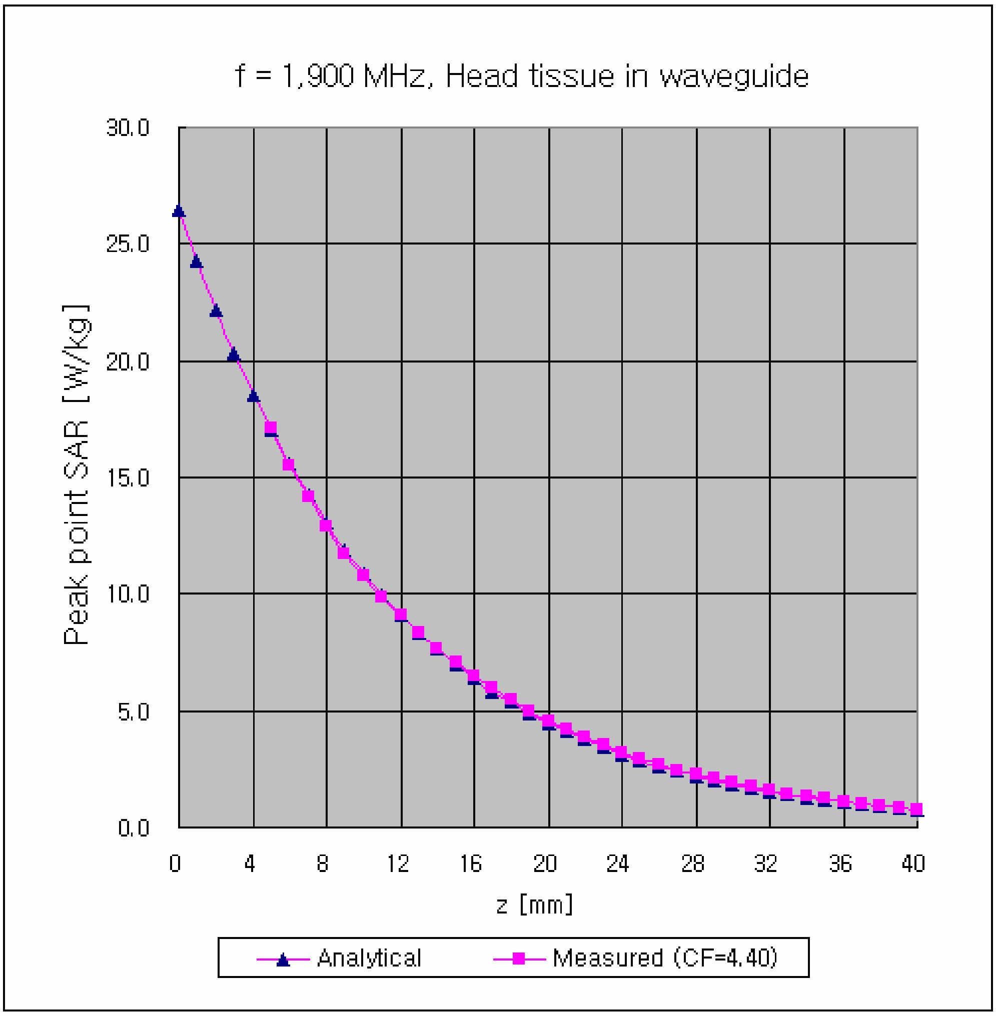
Test waveguide :

Designation : WR-430(EIA), RG-104/U(JAN)

Dimensions : 109.2 mm × 54.6 mm

Frequency range : 1,700 MHz ~ 2,600 MHz for dominant TE_{10} mode

Net input power to waveguide : 890 mW



Test frequency : 1900 MHz

Simulant liquid : Body

Test waveguide :

Designation : WR-430(EIA), RG-104/U(JAN)

Dimensions : 109.2 mm × 54.6 mm

Frequency range : 1,700 GHz ~ 2,600 GHz for dominant TE_{10} mode

Net input power to waveguide : 864 mW