CALIBRATING SAR PROBES IN LIQUID AT 2.45 GHZ.

B. Loader, Kevin Lees
National Physical Laboratory,
Hampton Road, Teddington, Middlesex, UK, TW11 0LW.

Abstract

This paper presents the design, testing and uncertainty analysis of a matched waveguide system for calibrating electric field probes in liquid at 2.45 GHz. This is required for measuring specific absorption rates from wireless communication devices. The system achieves a calibration uncertainty of ± 6.4% at *k* = 2.

Background

International guidelines [1] limit the maximum Specific Absorption Rate (SAR) that can result in the human body from the use of equipment emitting radio frequency radiation. SAR has units of watts per kilogram. Equipment manufacturers have a legal duty to ensure their products do not exceed these limits.

Implantable field probes are electric field probes that can be immersed in liquids. They are used to measure the field strength in tissue simulating liquids [2]. The SAR in the liquid is related to the field strength by

$$SAR = \frac{E^2 \sigma}{\rho} \qquad [1]$$

where *E* is the electric field strength, σ is the conductivity of the fluid, and ρ is its density. The sensitivity of these probes is dependent on the permittivity of the liquid in which they are placed. It is therefore necessary to calibrate the probe's sensitivity to SAR in the liquid that it will be used in. Since there are both legal and health implications if standards are exceeded, it is important probes used for SAR measurements are calibrated accurately and the calibration is traceable to National Standards.

NPL has facilities for calibrating electric field probes in liquids at 450 MHz, 900 MHz, 1800 MHz and 1900 MHz bands [3]. This work extends the calibration capability to 2.45 GHz, which is used by "Bluetooth" wireless local area network (LAN) devices.

Principle

The field inside waveguide is very well characterized, and matched waveguide systems [4] yield the lowest uncertainties for calibrating SAR probes. These systems have an air-section and a liquid-section, separated by a matching window that is designed to provide good power transfer into the liquid, as shown in Figure 1. A TE_{01} mode is launched into the system by means of a coaxial to waveguide adapter. At the center of the cross-section of the waveguide, the power absorbed per unit volume (SAR^V) in the liquid is given by

$$SAR^V = \frac{4(P_w)}{ab\delta} e^{-2Z/\delta} \qquad (2)$$

where *a* and *b* are the cross-sectional dimensions of the waveguide, δ is the skin depth for the liquid and *z* is the distance of the probe from the matching window. The value of skin depth (δ) is obtained by measuring the electric field at a number of distances from the matching window to determine the distance for the value to fall by 1/e.

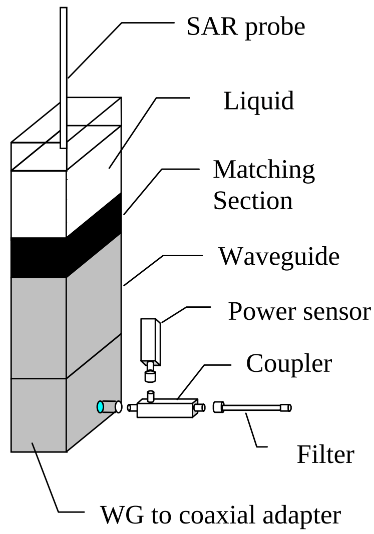

Figure 1: Waveguide system

The power delivered to the liquid (*Pw*) is determined by measuring the forward power and reflection coefficient at the input to the cell, together with the loss of the waveguide between the input port and the liquid-section. A band-pass filter is used before the coupler to reduce the effects of signal noise and harmonics on accuracy. The depth of the liquid used is at least 3 δ to prevent significant reflections occurring from the surface of the liquid.

Matching window design

The matching window is required to seal the liquid-section of waveguide from the air-section, and also to ensure efficient power transfer into the liquid. The matching window was optimised for head simulating liquid at 2.45 GHz (real permittivity 39.2, conductivity 1.8 Sm^{-1}) using an analytical model for propagation through multi-layered media.

The upper window layer is Polyetheretherketone (PEEK), as this has excellent chemical resistance, and low absorption of liquids. Emerson and Cuming HiK500, permittivity 10 is used as the high-permittivity layer in the window. HiK500 and PEEK are very low-loss materials, ensuring negligible power loss in the window. The chosen layer thickness and measured material permittivity are shown in Table 1. The upper layers were bonded together with matched-permittivity glue to prevent distortion during machining. Silicone rubber glue was used to seal the window to the waveguide.

Table 1: Thickness of window layers.

Material	Thickness (mm)	Relative Permittivity
Head Liquid	>4δ	39.2
PEEK	6.82	3.18
HiK500	6.47	9.80
Air	7.65	1
PEEK	20.60	3.18

The modelled return loss of this window is greater than 50 dB. The measured input return loss of the system with liquid is shown in Figure 2.

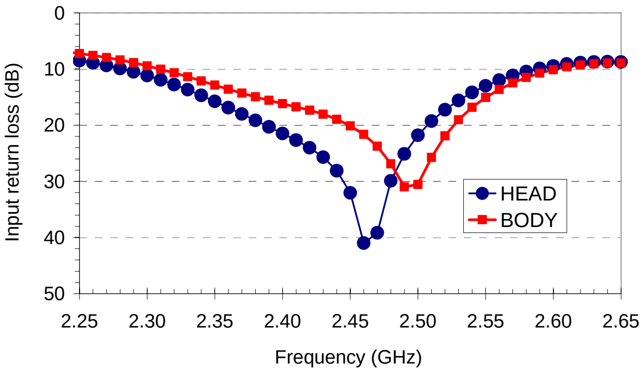

Figure 2: Measured input return loss of waveguide system with liquid.

Calibration uncertainty

The calibration uncertainties for 2.45 GHz are presented in Table 2. The field distribution in the liquid was measured with a 1 mm diameter probe to verify TE_{01} mode propagation. A significant proportion of the uncertainty is related to the liquid properties.

Measurements of the rate of rise in temperature in the liquid were used to verify the calculated SAR value corresponding to 80 W input. The estimated uncertainty for the thermal measurement of SAR is ± 7.6% at $k = 2$, and the calculated and measured values agreed to within 6%. Comparison of the results with those supplied by the probe manufacturer show agreement to within 3%.

Table 2: Measurement uncertainties for SAR probe calibration at 2.45 GHz.

Source of uncertainty	Standard Uncertainty U_i (±%)
Power delivered to the liquid	1.53
Variation from TE_{01} mode in liquid	0.87
Measurement of decay depth (δ)	1
Temperature coefficient of liquid	0.87
Difference of liquid permittivity from target values	2
Measurement of liquid conductivity	1
Waveguide dimensions	0.6
Accuracy of setting distance of probe from window	0.1
Accuracy of setting probe at the centre of the waveguide.	0.25
Combined uncertainty	3.2
Expanded uncertainty $k = 2$	**6.4**

Conclusions

A National Standard has been developed for calibrating SAR probes in liquid at 2.45 GHz. The system is based waveguide, and uses a multi-layer matching window achieving a high input return loss for the system. The calibration uncertainty has been evaluated as ± 6.4% at $k = 2$, corresponding to a confidence level of approximately 95%.

References

[1] "Guidelines of limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)", *Health Physics*, April (1998), **74**, No 4, 494-522 (1998).

[2] *IEEE Standard 1528: 2003* "IEEE Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head due to Wireless Communications Devices: Measurement Techniques", IEEE 2003, ISBN 0-7381-3716-2.

[3] W. Liang, P. West, B. Loader, K. Lees, A.P. Gregory and R.N. Clarke, "Traceable calibration of specific absorption rate (SAR) for mobile phone dosimetry", *CPEM 2000*, Sydney, pp. 496-497, May 2000.

[4] K.T Pokovic, T. Schmid and N. Kuster, "Robust set-up for Precise Calibration of E-field probes in Tissue Simulating Liquids at Mobile Phone Frequencies", *Proceedings ICECOM 1997*, Dubrovnik, Croatia, pp. 120 – 124, Oct 12-17, 1997.