

Calibration of Implantable Electric Field Probes for Mobile Phone Dosimetry

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Introduction

Widespread use of mobile phones raises important health issues which are of concern to the general public. To guarantee good performance the mobile handset needs to radiate few hundred milliwatts in order to establish a reliable communication link with the base station some distance away. But with a radiation source just few millimetres away from human head it is not surprising that researchers have discovered that over 40% of the RF power transmitted may be absorbed by the mobile phone user [1,2,3]. For this reason the monitoring of radiated power and the power absorbed by the user is important. The quantity of interest is usually the Specific Absorption Rate (SAR), the power deposited in a given mass of body tissue, expressed in $W\ kg^{-1}$. It has been found, however, that one of the best practical methods for estimating SAR is by the use of miniature isotropic 'implantable' RF electric field ('E-field') probes. A number of these E-field probes are available on the market. The probes are generally used to measure RF fields in tissue-equivalent phantoms. In the case of mobile phone safety testing the phantoms consist of artificial heads and hands exhibiting various degrees of geometrical approximation to their biological counterparts, but having dielectric properties close to those of the body tissues. The phantom heads generally contain brain-shaped cavities which can be filled with a liquid which simulates the dielectric properties of brain tissue. The probes can be inserted and scanned in this cavity to measure the radiation dosage from cell phones.

This paper is concerned with the calibration and characterisation of these implantable probes, the main difficulty being that they must be calibrated for measurement of field strength in the same dielectric liquid as is used in the phantoms. The reason for this is that the radiation wavelength and impedance-match change with the permittivity of the medium and so the calibration factor of the probes is significantly affected by the transmission medium. Two frequency ranges have been of concern - close to 900 MHz and close to 1.8 GHz - but requirements to expand to frequencies close to 410 MHz and above 2 GHz are already clear as cell phone technology continues to expand. In order to provide such measurements with reliable traceability, NPL has been engaging in research covering all factors governing probe performance including permittivity and E-field measurement, cell-phone communication protocols, locating the phase centre of the probe antennas and proximity effects. The work reported here covers the first NPL prototype system which operates at frequencies near 1.8 GHz.

The 1.8 GHz system uses IEC R-22 (British WG-8) waveguide as the calibration cell, see Figure 1. This is large enough to allow access for typical probes via a slot in the centre of the broad face of the waveguide whilst avoiding excessive probe/cell interaction effects, though these cannot be entirely avoided - see below. Typical probes are 5 - 12 mm in diameter and are connected to their detection system via high impedance leads in tubular polymer sheaths. The waveguide cell can be used for probe calibration both in air, for which calibrations are also available from the UK National Standards facility, and also in brain simulation liquid. The health and safety applications of these probes require that all three components of field strength be measured and this is usually realized by using three mutually orthogonal dipoles as detectors. This requires that determination of antenna pattern and isotropy must be undertaken for comprehensive characterization. Preliminary calibration results at 1.8 GHz are reported in this paper and a preliminary uncertainty budget has been drawn up. The advantages and shortcomings of this prototype method are discussed and further options for calibration are considered.

Design and Use of the Prototype IEC R-22 (WG-8) Waveguide Cell.

The probe calibration cell has been constructed in IEC R-22 waveguide (British WG-8). Its design is based on the work published by Douglas A Hill [4]. The waveguide has nominal internal cross-sectional dimensions of 109.22 x 54.61 mm, and a working frequency band 1720 MHz to 2610 MHz.

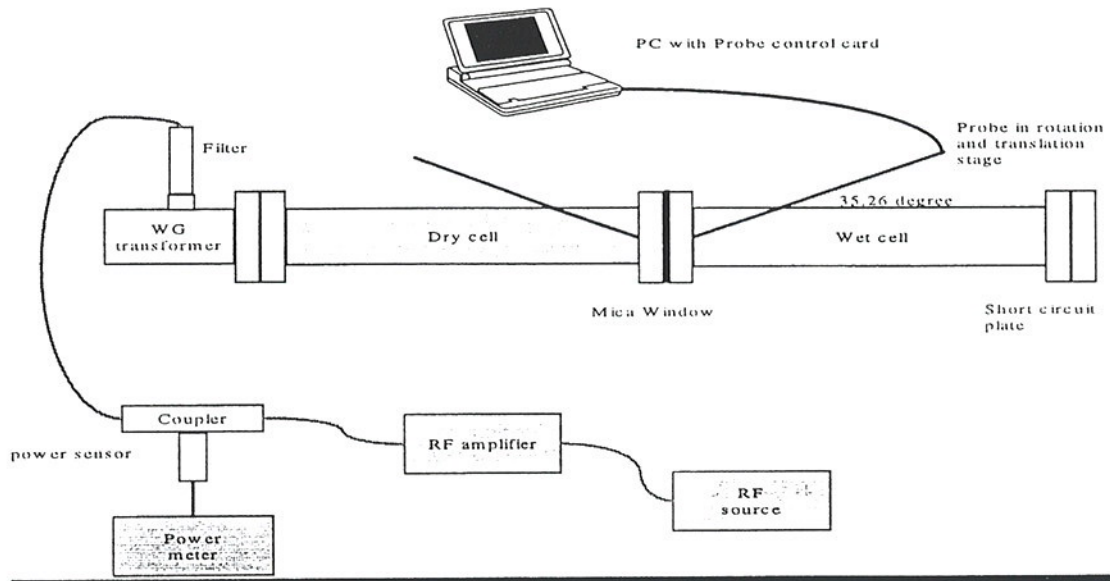


Figure 1. The IEC R-22 implantable E-field probe calibration system

The cell is designed mainly for calibrating symmetrical implantable E-field sensors, such as the Narda 8021B and the Schmid & Partner ET3DV5R probes. The philosophy of calibration is based on a performance separation principle [5]. This principle assumes that the probe calibration factor can be separated into three independent factors $f_i(V_i)$, η_i and γ_i related to the electric field components, E_i , as follows:

$$|E|^2 = \sum_{i=1}^3 |E_i|^2 = \sum_{i=1}^3 \frac{f_i(V_i)}{\eta_i \gamma_i} \quad (1)$$

where: V_i is the rectified signal from the sensor elements

$f_i(V_i)$ is the linearization function of the sensor elements to the square of the field components in air. This response linearization allows one to measure E-field over a large dynamic range. A power scan of the probe's response to the RF field will give this response function for the sensor.

η_i is the sensitivity factor between the linearized signal of a sensor element $f_i(V_i)$ and the square of the field component in the direction of the sensor, which has the physical dimension $[\mu V/(V/m)^2]$.

γ_i is the ratio of the sensitivity of a sensor element in a given dielectric medium to its sensitivity in air, i.e., $\gamma_i=1$ for air.

For an E-field probe supplied without its own software data acquisition system, all these calibration factors have to be measured independently. When an E-field probe is supplied with such an acquisition system, the owners or manufacturer will usually have measured and stored all of the calibration factors of the system themselves. In either case probe calibration can be analyzed into determination of (i) probe linearity performance, (ii) probe isotropic performance, (iii) probe sensitivity in air and (iv) probe sensitivity ratio, γ_i , in the brain simulation liquids compared against that in air.

Sections (a) to (f) below refer to a number of aspects of probe calibration which illustrate some of these steps

Probe calibration results

a. Probe linearity performance in air.

Figure 2 shows the linearity performance of a Narda 8021B E-field probe measured at field strengths between 50 V/m and 200 V/m at 900MHz and 1800 MHz. From the results it can be shown to have a linearity of better than 3.3%. giving a probe non-linearity error of ± 0.3 dB if not corrected.

From Figure 2 it can also be seen that each sensor element has a different sensitivity, differing by up to $\pm 8\%$ at the same frequency. This will give a non-isotropic performance of about ± 0.8 dB if it is not corrected. There is also a difference of approx. 20% between the two frequencies.

The Schmid & Partner probe ET3DV5R has a computer data acquisition system for data collection. With such a system a software probe linearity and isotropic performance correction have been applied by the manufacturer. After correction, it can achieve a linearity better than ± 0.15 dB. and an isotropic performance of better than ± 0.2 dB under similar conditions.

Narda probe linearity check at both 900MHz and 1800MHz

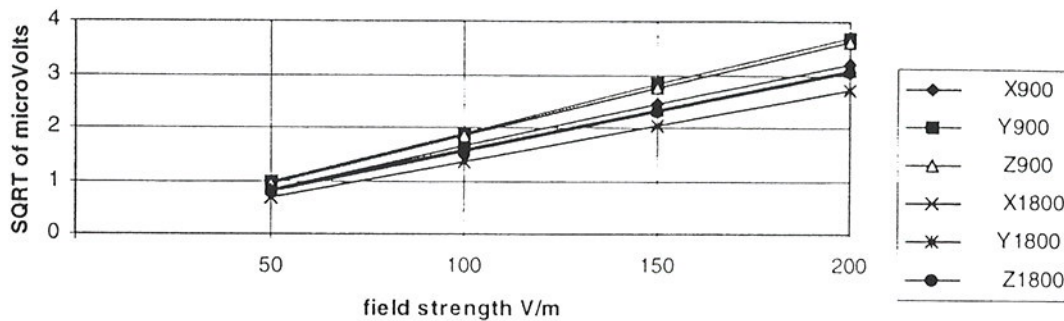


Figure 2 Linearity of the three antennas in the Narda probe at 900 and 1800 MHz.

b. Probe isotropy both in air and in brain simulation liquids.

Isotropy of probes can be measured by inserting them into the cell at an angle of 35.3° , such that one of the internal probe elements is aligned parallel to the dominant electric field in the waveguide. Then by rotating the probe around its axis each of the three orthogonal elements in turn can be so aligned. This gives rise to an antenna pattern with three-fold symmetry, as shown in Figure 3.

Schmid 1414 at 1.8 GHz Wet side

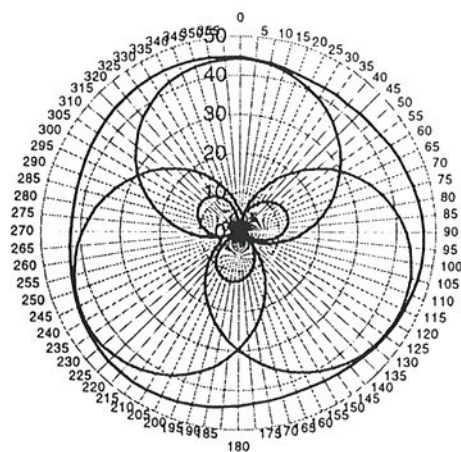


Figure 3a. Probe isotropic performance at 1.8 GHz in brain simulation liquid near the Mica window

Schmid 1414 at 1.8 GHz Dry side

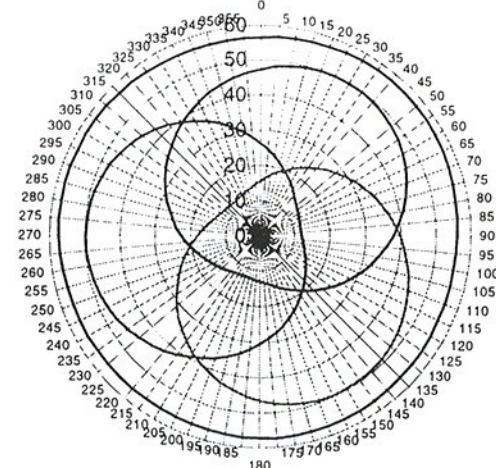


Figure 3b. Probe isotropic performance the air portion of the cell, near the Mica window

The three nearly symmetrically disposed individual traces in Figure 3a and b present the response of the individual sensor elements. The outer near-circular trace represents the total probe response to the field. The Schmid & Partner ET3DV5R probe has its own data collection software and the individual sensor sensitivity difference has been corrected in the data acquisition software, so the isotropic performance in air around the probe axis is better than ± 0.14 dB, but this degrades to ± 0.47 dB in brain simulation liquid.

c. The probe sensitivity in air.

Traceable sensitivity measurements were performed upon a Schmid & Partner ET3DV5R probe in the NPL tapered cell national standard facility, which can perform calibrations with an uncertainty of ± 1.0 dB. Field strengths of 200 V/m were used and the probe was rotated around its own axis with a step size of 10° per step for a full antenna pattern. The average field measured was 204 V/m at 900 MHz, and 199.1 V/m at 1800 MHz, with values varying between 197.6 V/m and 208.1 V/m at 900 MHz and between 194.4 V/m and 203.5 V/m at 1800 MHz. These figures correspond to probe sensitivity calibration discrepancies of +0.17 dB at 900 MHz and -0.04 dB at 1800 MHz against the national standard values in air. The isotropic performance was better than +0.17/-0.28 dB at 900 MHz and +0.19/-0.40 dB at 1800 MHz in air.

Referring to Figure 1, it can be seen that if the liquid portion of the cell is left empty (i.e. no liquid), and if it is terminated with a matched waveguide load, it becomes a slotted-line waveguide cell. Such a cell can itself be used to calibrate probes in air and could in future replace the tapered cell for this type of small probe measurement - the latter is already in continuous use for calibrations at NPL. A preliminary estimate of an achievable uncertainty (at 95% confidence level) of the field strength in air inside the waveguide lies in the range $\pm 5\%$ to $\pm 10\%$, or ± 0.45 dB to ± 0.9 dB. Work on this approach is continuing.

d. Probe sensitivity ratio in brain simulation liquid compared against that in air.

To measure the probe sensitivity ratio inside dielectric media, the preliminary approach has been to rely upon the principle of the continuity of tangential E-field across a dielectric boundary. In the cell of Figure 1, a 0.25 mm thick mica window separates the dry and wet cells. This is of virtually negligible thickness at 1.8 GHz as far as this principle is concerned. Keeping one sensor element of the probe parallel to the dominant E-field component inside the waveguide and moving it axially on both sides of the window, allows a standing wave pattern to be plotted, as shown in Figure 4. The probe sensitivity ratio can be read from the figure. A degree of extrapolation is required on each side of the window because of the finite size of the protective sheathe of the probe and the need to avoid proximity effects (multiple reflections) between probe and window. In the diagram, the medium in the liquid cell is Schmid & Partner 1800 MHz simulation liquid.

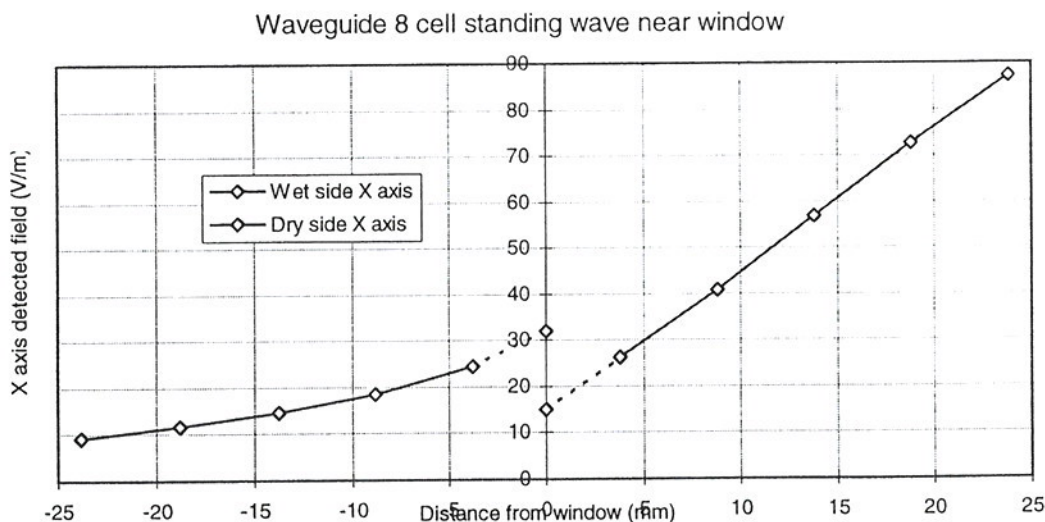


Figure 4. Measurement of the probe sensitivity ratio between air and brain simulation liquid

e. Probe/Field Interaction effects.

The difference in the probe antenna response patterns in Figure 3a and 3b is largely caused by the interaction of the electric fields with the probe which is inserted into the cell at an angle. This launches evanescent axial electric fields into the cell, a phenomenon which is most apparent in the air side of the cell. This effect has been analyzed mathematically, and it is possible to simulate probe antenna response patterns very similar to those in Figure 3. The pattern in Figure 3a is produced when the E-field direction is $+1.5^\circ$ inclined away from the Mica window. And the pattern shown in Figure 3b is obtained when the E-field is inclined 31.20° away from Mica window on the air side. It is not surprising that the disturbance on the air side is greater - the probe sheathe disturbs the fields before they reach the antennas there. It is also to be expected that there will be field discontinuities in the vicinity of the mica window, and indeed at any position where there are dielectric property boundaries. All of these phenomena have significant consequences for the use of implantable probes for measuring fields in phantoms, and this programme of work seeks to quantify the

uncertainties caused by these effects. Both analytic and Finite Difference Time Domain (FDTD) modelling are being used to achieve this.

f. Numerical simulation of the calibration cell.

Numerical simulation is being used to understand the detailed workings of the cell. Figure 5 shows the use of FDTD simulation to calculate the main component of the E-field distribution in the IEC R-22 cell, which is configured, as intended, with air in section 1, an un-matched dielectric window, as section 2, and brain simulation liquid in section 3. An E-field probe is inserted into the liquid. The probe was modelled by a dielectric tube 12 mm in diameter, filled with air. With this simulation The following four key phenomena can be seen in the figure:

- A standing wave in the air filled section
- A standing wave in the window material
- An exponentially decaying field in the liquid filled section
- A ripple near the probe position caused by probe-field interaction.

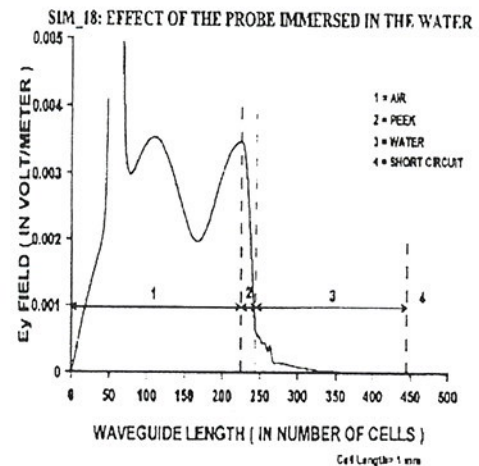


Figure 5. Numerical simulation of E-field distribution inside the WG8 cell

More detailed numerical simulation is continuing to analyse the probe-cell interaction.

g Discussion.

Calibration of implantable probes is now of significant interest for many organizations around the world including cell phone manufacturers and health and safety authorities. International standards are being set up by bodies such as the IEEE and CENELEC to ensure that this activity is performed correctly. It is intended that these NPL facilities will provide a traceable capability which can back up such standards and that ongoing research will be able to improve uncertainties in this area of metrology in future. This paper has illustrated only part of the work that is being undertaken. Ongoing work includes the setting up of calibration facilities at 900 MHz, study of probe interaction effects and the investigation of calibration factors in different tissue equivalent liquids.

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