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Error assessment for probe / interface proximity effects for an upright phantom geometry

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Introduction
This document describes experimental tests undertaken to decide whether an additional uncertainty allowance should be made due to errors that might be introduced in the readings of an immersed SAR probe in an upright phantom geometry as the probe approaches the surface of the liquid volume.

In twin-head, bath phantoms with the ear located under the benchtop, benefits used to be claimed of the upright probe remaining approximately normal to the phantom shell in the vicinity of the source. Presumably, this geometry arose from expediency as a vertically-oriented probe can be controlled in a simple X,Y,Z manner in much the same way as a pen plotter. Latterly, it has been appreciated that this geometry is less than ideal in a half-head when the probe is exploring the regions close to the face or the back of the head. If the probe orientation is more variable with respect to the source field direction, then more account has to be taken for the full spherical isotropy of the SAR probe rather than just allowing for the smaller, axial isotropy.

With the upright phantom head geometry employed in the SARA2 system, uncertainty allowance is, in any case, made for the full range of variability of probe response in all directions between probe and field. However, the shaft of the probe itself will introduce a distortion of the E-field within a tissue-simulant liquid and experiments have been conducted to determine if such effects are of any increased significance for the upright head geometry.

Experimental tests
The registration of the SARA2 interchangeable phantoms is based upon their positioning on a rotation turntable-base. When placed on the fixed mount, the combination of the head and base mount forms a large-diameter ball bearing offering precise repeatability of positioning. The phantom can be rotated to any angle, but pins are used for accurate angular registration at the principal cardinal points. The hole machined in the top of each headshell phantom is cut whilst rotating the head on a bearing base and is, therefore, centred about the rotation axis of the head.

The angle of probe presentation within the head is constrained by the existence of this small penetration hole. The experimental aim of this study has been to compare the SAR probe readings at specific positions of the probe tip within the phantom when the probe was oriented at different angles. For this purpose, a cube-shaped phantom has been used in place of an upright head so that the probe presentation angle can be varied. The set-up is shown in Figure 1.

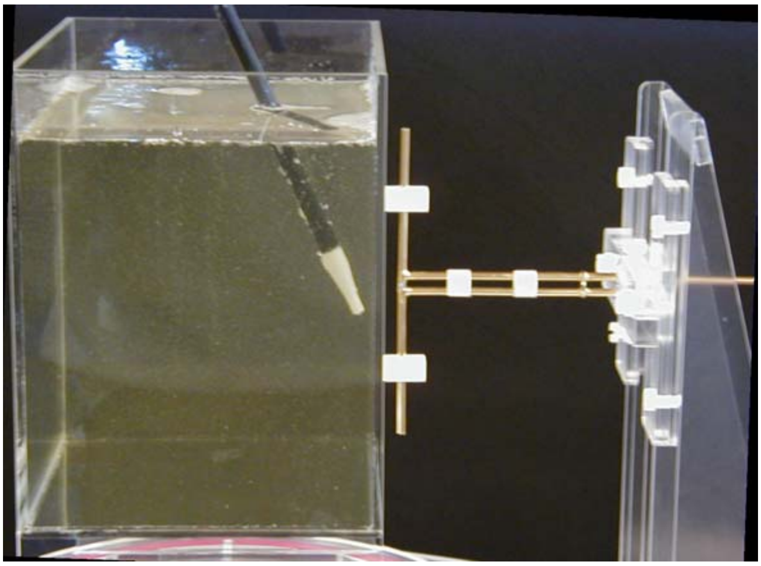

Figure 1: Showing an open-topped box phantom mounted in place of the head and with a balanced dipole placed against the side of the box.

The SARA2 software manages the process of probe placement at arbitrary positions within a phantom by constraining the presentation angle of the probe shaft to pass through a pivot point. This is normally at the centre of the opening in the top of the head. However, for the tests reported here, the location of this point has been varied. If the pivot point is far distant in the vertical direction, the probe shaft is essentially upright at all probe-tip positions. As the pivot point is lowered, the angle between the probe shaft and the vertical is increased for any tip position not underneath the pivot point. Wherever the pivot point is located, the SARA2 software still places the probe sensors at the demanded location, but at a different presentation angle.

For these tests, a scan of 200 measurements at 0.1mm intervals with increasing depth into the liquid were taken first with the probe upright and then with the probe at varying inclination to the vertical. At the closest approach to the wall, the upright probe shaft was nearly in contact with the box wall (see Figure 2). The dipole was oriented vertically as well, as this was thought to be the configuration likely to give maximum error.

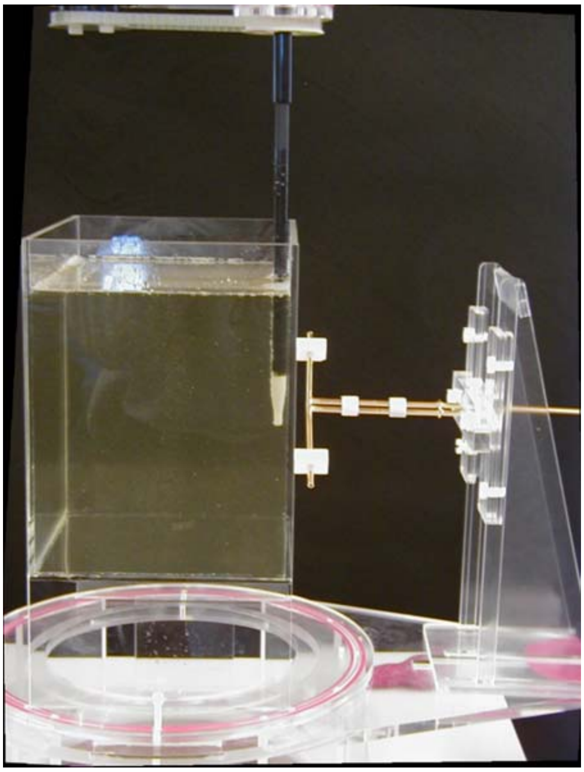

Figure 2: Showing the extreme positioning of the probe against the side of the box for the test with the probe vertical

A 900MHz brain liquid, formulated for use at 835-935MHz was employed for the tests. The feed power of 0.25 W at 900MHz CW was maintained constant for all tests.

In a further comparative test, full 3D SAR scans were made both with the dipole presented at the side of the box and also with the dipole presented underneath the box. This latter configuration is the same as that used for system validation. The same feed conditions were used for both tests, but different spacers were used for the side of the box (which is 4mm thick) and below the box (bottom of box is 2mm thick) to ensure the same spacing of the dipole arms from the liquid surface. The spacers are accurately machined from a low-density material with a relative permittivity of 1.05. For the tests at the side of the box, the usual head scanning procedures were employed – i.e. a 2D scan to locate the maximum followed by an automated 3D scan centred on the maximum. The results are shown in Table 1.

Results

Spot SAR measurements were taken at intervals of 0.1mm from 8mm below the surface to 28mm below the surface. These show a close correspondence between the test with the probe upright and the subsequent test with the probe angled (constrained to pass through the pivot point where the top of the head would be for a SAM phantom test). The results are shown in Figure 3. It was not possible to extend the comparison much closer to the phantom wall because of the thickness of the probe shaft against the side of the box (Fig. 2).

The ‘error’ between the two E-field readings at each of 200 sampling points from Figure 3 is shown in dB in Figure 4.

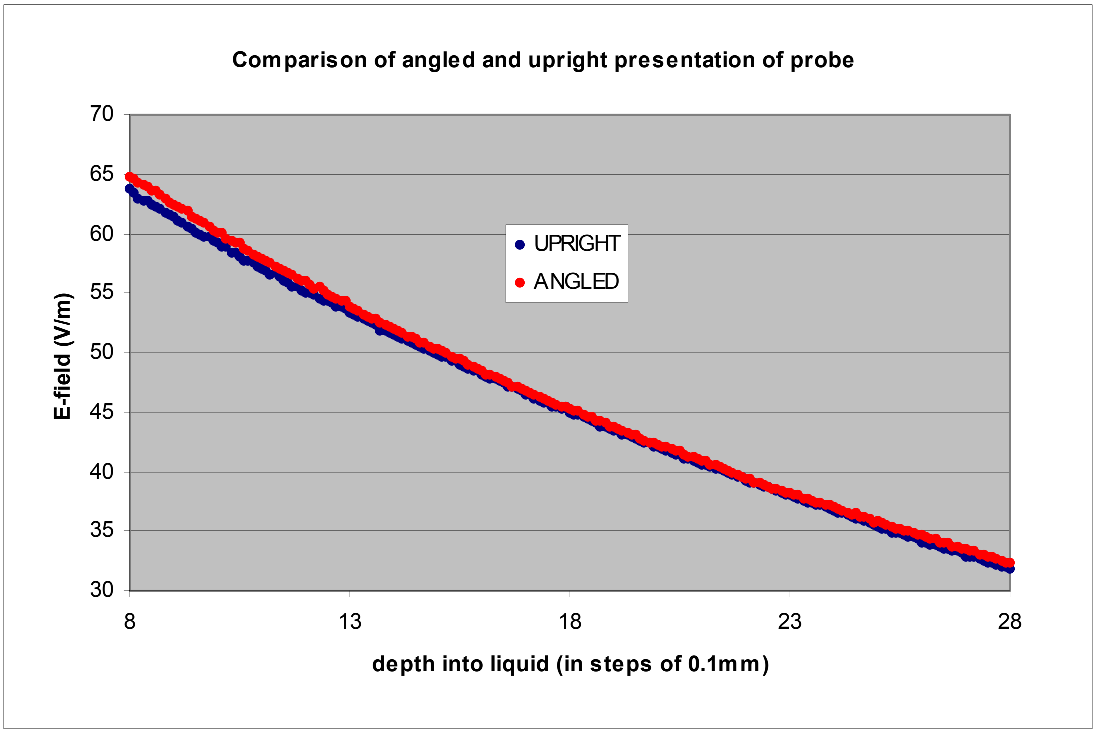

Figure 3: Comparison of the SAR scan results with the probe upright and angled (200 SAR measurements for each depth profile)

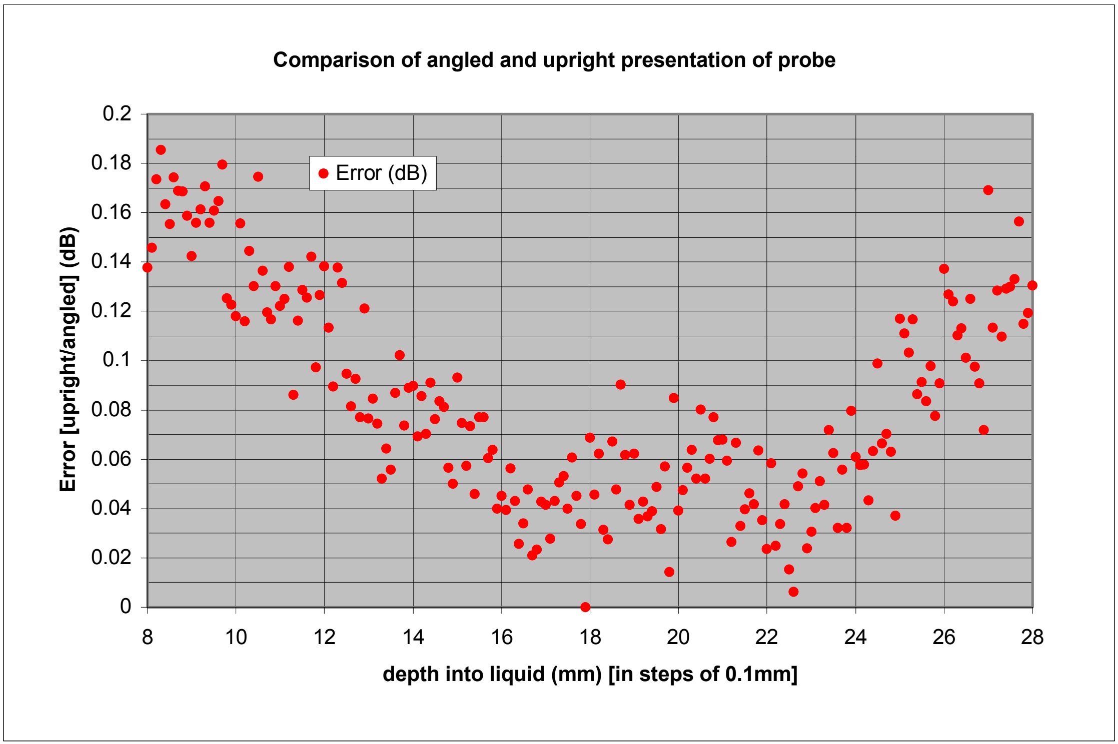

Figure 4: Error between upright and angled in dB with position

The results obtained for 3D SAR scans at the side of the box and underneath are shown in Table 1.

Table. 1 Max. 1g SAR results for the dipole both against the vertical side of the box phantom and also placed underneath the box.

Dipole at side of box		Max. 1g SAR
Test1	dipole vert	2.491
Test2	dipole vert	2.386
Test3	dipole horiz	2.458
Dipole underneath box		2.402

Implications for uncertainty assessment

The maximum errors between the probe readings for scans when the probe is upright compared to the probe readings with it angled (as in normal SARA2 use) are greatest close to the surface when the larger-diameter portion of the probe shaft will be at its closest approach to the vertically-oriented dipole source on the other side of the phantom wall.

In spite of this, the error is always less than 0.2dB, which is well within the allowance made for the spherical isotropy of the SAR probe.

Volume scans undertaken with the source at the side of the phantom and with the same source underneath the box gave 1g volume averaged SAR values (shown in Table 1) that were all within 0.2dB of each other. This is true for both vertical and horizontal orientations of the dipole at the side of the box.

The tests reported here use a canonically-shaped, box phantom rather than actual SAM headshells because upright SAM head shells only have a small area of liquid surface and the comparisons performed require an open-topped phantom. Nevertheless, the probe orientation angles studied are representative of those used when scanning upright head shells.

The uncertainty budget for the upright phantoms includes the full range of spherical isotropy (typically +/- 0.5dB) rather than the more restricted range of the axial isotropy (typically +/-0.25dB). The comparative measurements reported here indicate errors between upright and angled scanning (and between the side of a phantom and the bottom), are less than 0.2 dB which is within the additional allowance for spherical isotropy which is, of course, designed to make allowances for such changes in probe presentation angle.

Consequently, it is concluded that no additional uncertainty contribution is required for the upright-phantom scanning mode other than the additional isotropy allowance already made.