SAR ASSOCIATED WITH THE USE OF HANDS-FREE MOBILE TELEPHONES

S.J. Porter, M.H. Capstick, F. Faraci, I.D. Flintoft and A.C. Marvin
Department of Electronics, University of York
Heslington, York, YO10 5DD, UK

Abstract: The material presented here outlines a study to determine the level of Specific Absorption Rate (SAR) associated with the use of Hands Free Kit's (HFK's) with GSM mobile telephones and to identify the factors that influence these levels. A novel current probe was designed to measure the current profile along the HFK cables. Measurements of the HFK current were made on human subjects in an anechoic chamber and in the presence of a phantom head used for SAR measurements – good agreement was found. The SAR level was measured for both the phones and phones with HFK's and the comparative data is presented. The factors that influence the observed level of SAR when using a HFK have been identified and their relative importance determined.

I. INTRODUCTION

This paper reports on work to:

1) Establish the level of SAR within the head, associated with the use of HFK's with GSM mobile telephones;
2) Identify the principal factors determining the observed levels of SAR in order to better understand the observed levels.

The work was funded as part of the UK government's Mobile Telecommunications and Health Research Programme in response to public concerns on the use of HFK's.

I.1 Measurement Strategy

A number of mobile telephones (referred to as "phones") and associated HFK's were purchased. Throughout the work reported here, the phones were operated at 888 MHz in the lower GSM band and 1750 MHz in the upper GSM band.

The overall strategy was to: firstly determine the specific relative geometry of each HFK-phone-human subject combination that gave rise to the highest current on the HFK cable near the head when the HFK-phone was used by a human subject; secondly to measure the SAR associated with this HFK-phone-subject geometry using a compliant SAR exposure system.

In order to measure the induced currents on the HFK cables, and thus to both understand the observed levels of SAR and ensure confidence that the quoted maximum levels of SAR were actually the maximum achievable, two current probes were developed, one for each operating frequency. It was considered important that the probes should involve a minimum of conducting material so as to minimise distortions of the current on the HFK cable when the probes were placed in close proximity to the cables.

As indicated, when assessing the maximum exposure caused by HFK-phone combinations it is necessary to: optimise the relative geometry of the HFK and phone in order to maximise the coupling and hence induced current on the HFK; establish the relative geometry of the HFK to the human body that is likely to give the highest induced current in the vicinity of the earpiece (and hence exposure). Thus, measurement of the induced current in a number of configurations was performed using human subjects in an anechoic chamber.

Making use of the high-induced-current geometries derived from the current measurements, comparison can be made of the SAR due to use of an HFK-phone combination and that due to a hand-held phone alone. To measure the SAR due to a phone alone, standard SAR practices were followed using an exposure system with homogeneous head phantom at York. To measure the SAR due to a HFK-phone combination, the same exposure system was used, with the HFK-phone combination being arranged so as to lie in the same geometry relative to the phantom head as the highest-induced current geometry previously discovered. Measurement of the induced current on the HFK cabling was made so as to be confident that the substitution of a phantom head for a human head did not significantly alter the current on the cabling.

The induced current measurements indicated that maximum current on the HFK cabling in the region of the head could be found when the HFK cables were run well away from the human torso (and thus in a mode of use similar to that which might occur when a phone is placed on a table top in front of a user). To confirm that this variation in current also translated to a variation in SAR, a homogeneous phantom torso was placed below the head phantom in the exposure system and the consequent induced current and SAR measured.

The variation of induced current on the HFK cables near/far from the human torso was established using realistic bodies - real humans. The variation of SAR when the HFK cable was near/far from the human torso was established using homogeneous phantoms. Hence simulations were performed to confirm the observed pattern of the SAR with/without a torso using both inhomogeneous and homogeneous phantoms (data will be reported elsewhere).

II. CURRENT PROBE CALIBRATION

A schematic representation of the current probe is shown in Figure 1 whilst an image of the probe is shown in Figure 2. For each current probe (one for each GSM band) a two-stage calibration process was used. A stripline measurement was performed to give a relative calibration over the dynamic range of each probe and a free-space measurement was used to give an absolute calibration at a single point within the dynamic range.

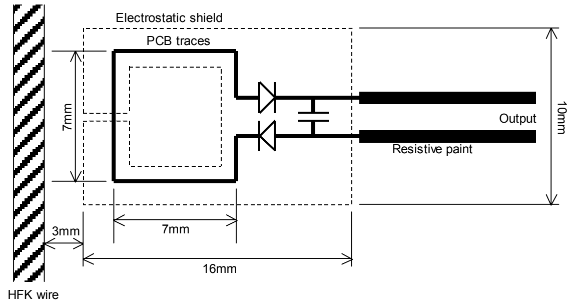

Figure 1: Schematic representation of the current probe.

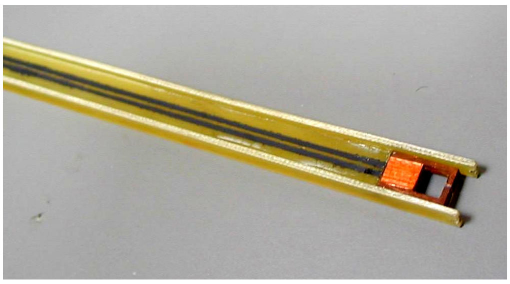

Figure 2: 888 MHz current probe.

For the relative calibration, the probe was presented to the inner conductor of the stripline. The stripline was stimulated using a signal generator and the power at the termination of the stripline measured using a power meter; a simulated GSM signal was used for the calibration. The coupler loss and mark space ratio were then used to convert the power in the termination to the stripline current. This gave a relation between the stripline current and the probe output voltage.

For the absolute calibration, a free-space measurement of the probe output voltage for a particular free-space magnetic field strength was performed in an anechoic chamber using a horn antenna and signal generator as stimulus. The input to the horn was varied so as to give a probe output voltage corresponding to one of the probe output voltages measured using the stripline. The free-space magnetic flux density was then determined from the antenna gain and the transmitted power. The total flux passing through the current probe loop was calculated for the equivalent free-space and stripline measurements and the ratio of these allowed an absolute estimate of the wire (HFK) current against probe voltage to be derived. Numerical simulations were performed to relate the flux cutting the probe to the HFK current.

III. MEASUREMENT OF INDUCED CURRENT ON THE HFK CABLING

In order to determine the HFK geometry relative to the phone that gave maximum energy induced on to the HFK cable ("maximum coupling geometry"), the orientation of each HFK with respect to the associated phone was varied whilst measuring the current at spot positions. These configurations were then used for the measurement of the induced current along the HFK cable. In general the maximum coupling occurred when the HFK cable was taped to the handset around the region of the antenna with a particular (for each phone and frequency) loop length between the tape point and the port into the phone and a particular orientation of the loop.

III.1 Induced Current Measurement Configurations

The measurements of the induced currents on the HFK cables were performed in a microwave anechoic chamber. The maximum coupling geometry was used for the layout of each HFK in the vicinity of the associated phone as determined above. Measurements were then made in four configurations for the phone-HFK system with respect to the human subject:

1) "Free space": the HFK was run straight out from the top of the telephones and distant from any other object including the human subject.
2) "Table top": the earpiece of each HFK was placed in its in-use position relative to the subjects ear and the cable was run forwards away from the subject out to a position approximating to table-top level - typical tabletop use where the phone is placed on a table in front of the subject.
3) "Body typical": the earpiece of each HFK was placed in its in-use position relative to the subjects ear and the cable was allowed to run freely downwards to the phone which was secured at the waist - approximately representative of normal "at-the-waist" use where the phone is attached to a belt or placed in a waist pocket.
4) "Body close": the earpiece of each HFK was placed in its in-use position relative to the subjects ear and the cable was then taped to the subject at a number of points in a run that travelled downwards to the phone which was secured at the waist - giving very close proximity to the subject for the major part of the cable run.

III.2 Measurement Summary

The phone-HFK combinations were measured in all four configurations in an anechoic chamber. The phone output power was set so that the maximum dynamic range of the current probe was available in each configuration and the results scaled to the maximum GSM handset power.
Summarised in Figure 3 are the peak currents across all configurations at 888MHz – the average of all combinations along with the maximum and minimum is shown for each configuration. Note that for this chart and all figures of this type presented here, the "diamond" symbols represent the average of the observed data, whilst the "error bars" represent the extremes of the observed data. Figure 4 summarises the peak currents within 10cm of the earpiece, since this is perhaps most relevant to the induced SAR.
As can be seen from the figures, there is a consistent trend of decreasing peak current on the HFK between the "Free space" to "Table top" configurations and between the "Table top" and "Body typical"/"Body close" configurations. There is no significant change between the "Body typical" and "Body close" configurations, there being a small fall for the 10cm values and a small rise for the entire cable values.

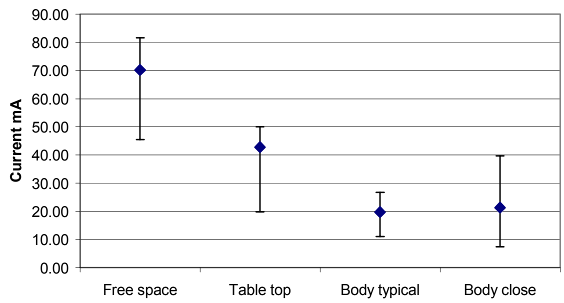

Figure 3: Peak current along entire free-cable for all configurations and combinations at 888MHz.

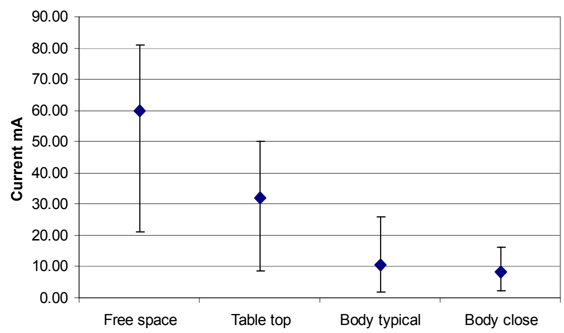

Figure 4: Peak current within 10cm of earpiece for all configurations and combinations at 888MHz.

Considering the peak currents at 1750MHz for the entire cable, Figure 5, and within 10cm of the earpiece, Figure 6, very similar trends can be discerned as at 888MHz. If comparison is made between the two frequencies the "Free space" and "Table top" geometries have induced currents only marginally lower at 1750MHz than at 888MHz, whilst the "Body typical" and "Body close" values are significantly lower at 1750MHz. It should be noted that the maximum radiated power is a factor two lower for the higher frequency GSM band. Thus, we could conclude that the coupling between the phone and HFK is typically stronger in the higher band, whilst there is greater attenuation caused by the body.

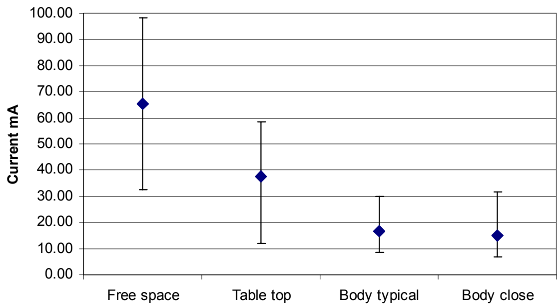

Figure 5: Peak current along entire free-cable for all configurations and combinations at 1750MHz.

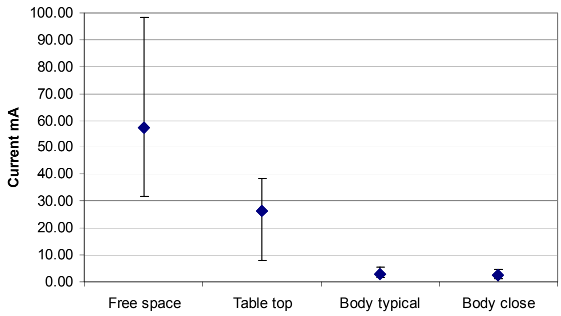

Figure 6: Peak current within 10cm of earpiece for all configurations and combinations at 1750MHz.

IV. SAR MEASUREMENTS USING A HEAD PHANTOM

For the determination of the effect of using a HFK on the induced SAR inside a head phantom at both 888MHz and 1750MHz, two configurations were used: phones alone placed against the head and HFK-phone combinations with the phone placed away from the head and the HFK terminating against the ear. Measurement of the induced current on the HFK cabling in the SAR laboratory was also made to enable comparison with the measurements made on human subjects and hence to ensure maximum current was still being induced onto the cabling. Standard test equipment and calibration procedures were used according to the draft standard.

IV.1 Phone Measurements

The phones were tested in the "cheek" and "15° tilt" positions on the left side of the head as specified in

[1]. The peak 10g average SAR values are summarised in Figure 7.

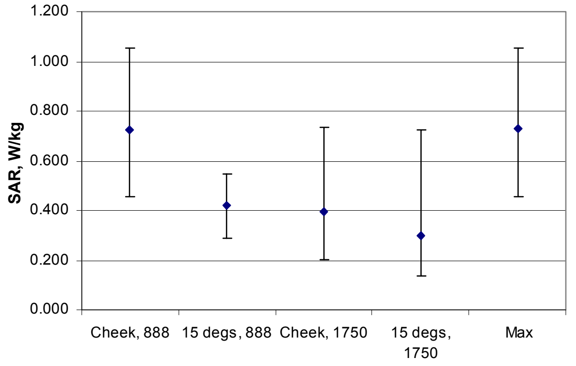

Figure 7: Peak 10 g average SAR values (W/kg) for the phones. The "Max" column is the maximum value for each phone across all positions/frequencies.

All phones show a peak 10g average SAR across all positions/frequencies when measured in the "cheek" position at 888MHz with the exception of one phone where the maximum SAR occurs in the "15 degs" position at 1750MHz and is 1.3% higher than the value for that phone in the "cheek" position at 888MHz.

In general, there is a significant reduction in the peak 10g average SAR at 1750MHz compared with 888MHz. The average of the peak 10g average SARs for 888MHz is 0.726W/kg, whilst that for 1750MHz is 0.398W/kg. There is a 3dB reduction in maximum radiated power moving from the lower to the higher GSM band. However, this does not translate to an exact halving in the measured SAR due to the effects of, for example, different current distributions on the antennas, different field distributions and different material properties in the head phantom.

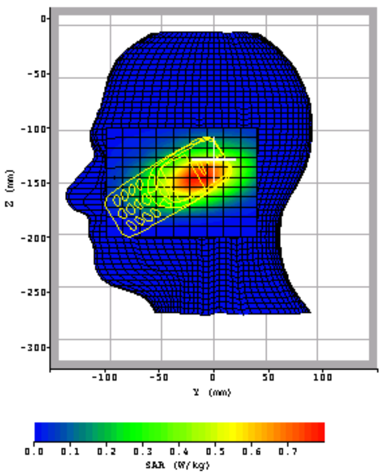

Figure 8: Surface profile of point SAR at 888MHz for a typical phone.

A typical distribution of the SAR nearest the surface of the phantom is shown in Figure 8 whilst Figure 9 shows the main exception for a flip-open phone.

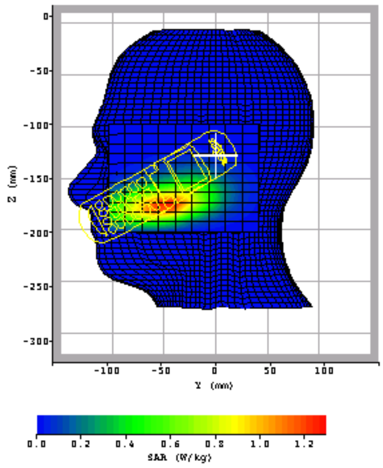

Figure 9: Surface profile of point SAR at 888MHz for flip-open phone.

IV.2 HFK SAR Measurements

The HFK-phone combinations were tested in two positions, both with the earpiece in a "normal" position over the ear: with the cable running approximately forwards (referred to as "Free"); with the cable fixed against the cheek for 8cm and then running approximately forwards (referred to as "Taped").

The peak 10g average SAR values are summarised in Figure 10. There is a general trend for the peak 10g average SAR to occur in the "Taped" position with the exception of two combinations at 888MHz and one combination at 1750MHz.

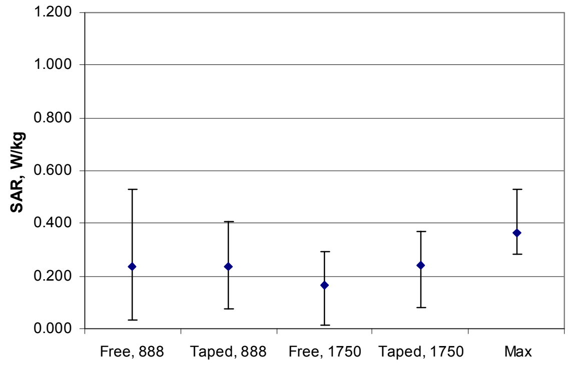

Figure 10: Peak 10 g average SAR values for the mobile telephones with HFK's. The "Max" column is the maximum value for each HFK-phone combination across all positions/frequencies.

There is no general trend with frequency with four maxima occurring at 888MHz and three at 1750MHz. Considering the averages of the peak 10g average SAR at each frequency, at 888MHz the average is 0.281W/kg, whilst that for 1750MHz is 0.251W/kg. These similarities with frequency are in line with those noted from the induced current measurements made in the anechoic chamber.

A typical distribution of the SAR nearest the surface of the phantom is shown in Figure 11 whilst Figure 12 shows the main exception for a HFK with an ear support, albeit one that was not electrically connected to the main HFK cable.

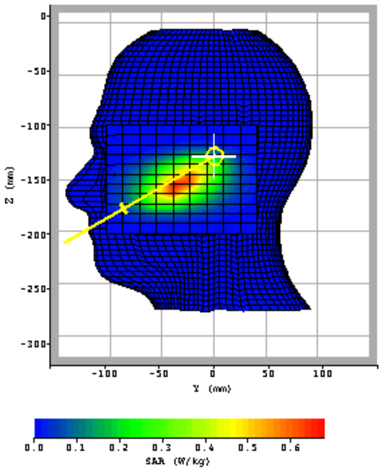

Figure 11: Surface profile of point SAR at 888MHz for a typical HFK-phone combination.

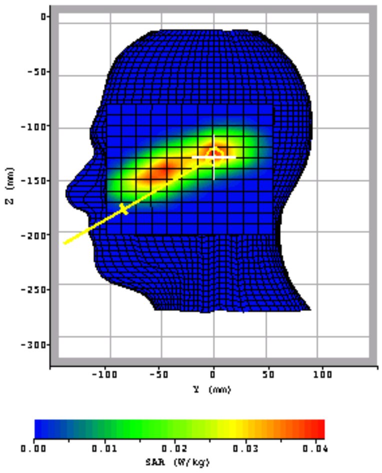

Figure 12: Surface profile of point SAR at 888MHz for the HFK-phone combination with ear support.

IV.3 Comparison of SAR for Phones with and without a HFK

The peak 10g average SAR values for each frequency band and overall for each phone/HFK-phone are shown in Figure 13. It can be seen that the highest SAR is generally obtained from a phone held next to the head at 888MHz. Whilst there are currently no standards for measuring the SAR from HFK-phones, it is suggested that taking the highest possible value for a particular HFK-phone across all positions and frequencies would be in closest alignment to the procedures for hand-held phones. Using this procedure, all of the ratios of the HFK-phone SAR to phone SAR are less than one. In general, all single-band ratios are less than one except for two combinations in the 1750MHz band where the phone SAR values represent two out of the three lowest phone SAR values observed.

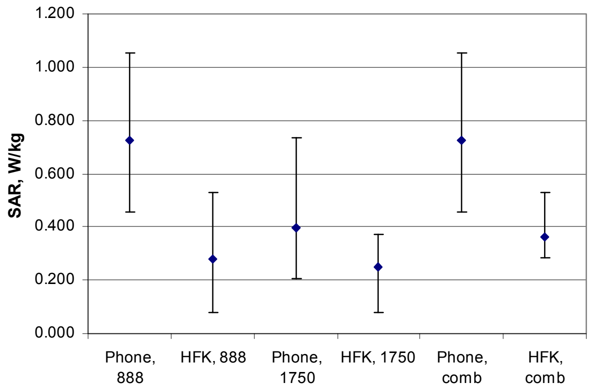

Figure 13: Peak 10g average SAR data for phones and HFK-phones. "Phone, comb" and "HFK comb" are the maximum values across all frequencies/positions.

The position of maximum SAR is also of interest. The position of the peak 10g average SAR for each phone and HFK-phone combination is indicated in Figure 14 at 888MHz and in Figure 15 at 1750MHz. It should be noted that the reference on the ear is at a position of (-25mm, -125mm). An impression of the distribution of the SAR around the peak can be gained from Figure 8, Figure 9, Figure 11 and Figure 12.

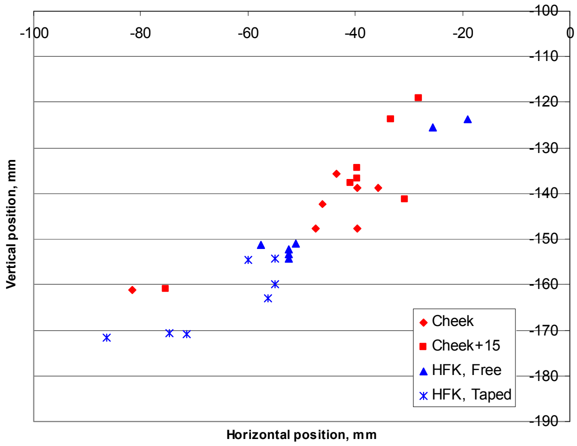

Figure 14: Position of peak 10g average SAR for both phone and HFK-phone combinations at 888MHz.

Considering the data at 888MHz, it can be seen that the peak SAR from the HFK-phones generally occurs low and left of the peak from the phones. That is, the peak SAR from the HFK-phones occurs low towards the jaw rather than near the ear. Exceptions to this are: two HFK-phone combinations where the effect of the support around the ear is to move the peak up around the region of the ear (for example, Figure 12); the "flip-open" phone where the effect of the body of the phone near the mouth is to move the peak low to the jaw (Figure 9).

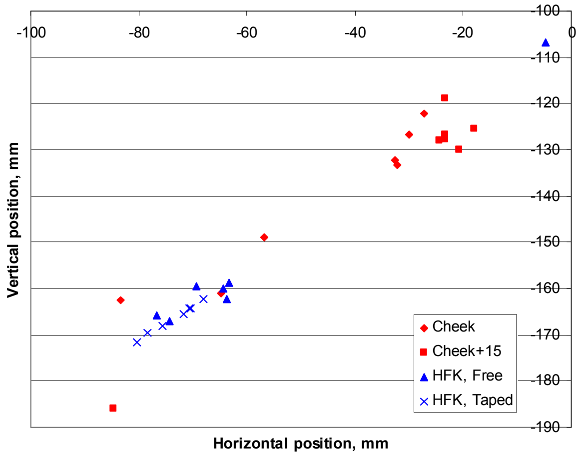

Figure 15: Position of peak 10g average SAR for both phone and HFK-phone combinations at 1750MHz.

Consideration of the data at 1750MHz shows that the peak SAR from the HFK-phones occurs even more noticeably low and left of the peak from the phones. Again, the peak SAR from the HFK-phones occurs low towards the jaw rather than near the ear. Exceptions to this include: one HFK-phone combination in a "Free" position where the effect of the support around the ear is to move the peak up around the region of the ear; the "flip-open" phone where the effect is as at 888 MHz.

IV.4 HFK Current Measurements

Measurements were made of the current along the HFK cables in the SAR Laboratory and compared with those for the anechoic room measurements in a table top configuration which might be expected to be the closest comparison to the phantom head configurations. The results show that there is a good correspondence between the two sets of measurements, the SAR Laboratory currents being significantly closer to the "Table top" anechoic chamber currents than to the "Free space" or "Body" currents.

IV.5 Use of a Phantom Torso

Measurements were also made of the SAR due to the HFK-phone combinations when attached to a phantom torso and routed up the torso to the phantom head. Significant reduction in the point and 10g average SAR was observed for all combinations. The HFK cable currents were also measured for these configurations, the currents generally being observed to fall to the level of those observed in the anechoic chamber measurements on human subjects in the "Body typical" / "Body close" configurations .

V. CONCLUSIONS

The level of SAR within the head, associated with use of hands free kits with GSM mobile telephones has been established for the samples used. For the combinations tested, use of a HFK resulted in a lower peak 10g average SAR value. Additionally, the range of peak SAR observed here across the HFK samples is relatively small, indicating that a significantly greater level of SAR for other HFK-phone combinations is unlikely.

The principal factors associated with the observed levels of SAR have been identified and are ranked here in the order in which they effect the observed SAR.

Strong factors are:

1) Layout of the HFK with respect to the phone, which has a very significant effect on the coupling – movement of the HFK away from the optimal geometries reduces the SAR greatly;
2) Proximity of other parts of the body to the HFK cable as it runs towards the head – thus a torso is not necessary when considering the maximum exposure to the head.

Moderate factors are:

1) Proximity of the HFK to the head. At higher frequencies the proximity to the head becomes more important, as might be expected when considering the shortening of wavelength.

Weak factors are:

1) The specific type of HFK, although the type can have a significant effect on where the peak occurs;
2) Changing between the two GSM bands, although this may be because the change in maximum radiated power between the bands is offset by changes in coupling efficiency between the phone and HFK.

It should be noted that the phone-HFK geometries were deliberately chosen to enhance the current and hence the SAR. Thus, the SAR values represent an approximation to the worst case – in typical use the SAR values would be expected to be significantly lower.

Use of a ferrite bead placed around the HFK lead, at a point beyond where the fields from the phone might induce strong currents in the HFK, significantly reduces the induced SAR when using a HFK. Direct coupling from the handset to the HFK near the earpiece is not found and, hence, if use of a ferrite bead is desired, it should be placed at a position beyond where the phone is expected to come into close proximity to the HFK but probably not closer than 15cm to the earpiece.

REFERENCES

[1] EN 50360:2001/50361:2001