Mobile Telecommunications and Health Research Programme

SAR Testing of Hands-free Mobile Telephones

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Executive Summary

The aims of this study were to estimate the likely differences in exposure between using a GSM mobile telephone in normal mode and when used in conjunction with a hands-free kit (HFK) and to identify the system components that influence these levels.

The various ways in which a HFK can be used and its wide variation in layout relative to the mobile telephone mean that estimating the maximum exposure from a HFK is a significantly more complex process than that from a mobile telephone on its own. Yet, if we are to specify the exposure due to use of a HFK, we need to have confidence that we are measuring the maximum exposure possible in any configuration, if it is possible that such a configuration may be achieved in use.

Thus, in order to measure the maximum exposure from a HFK, the HFK layout relative to the mobile telephone needs to be optimised to induce the maximum power onto the HFK and, additionally, the HFK needs to be oriented with respect to the simulated human to give the highest deposition of power into the head where it can be measured. This was the overall strategy adopted in this study.

A set of probes was designed, fabricated and calibrated that would measure the power induced on a HFK by the mobile telephone. These probes were initially used to optimise the HFK layout relative to the mobile telephone so as to induce maximum power onto the HFK - a layout which is specific to each type of HFK / telephone. They were then used to investigate the layout of the HFK / mobile telephone with respect to a human subject so as to deliver maximum power to the region of the head.

The power absorbed in the body is quantified in terms of the specific energy absorption rate (SAR) in the unit of watt per kilogram (W/kg). The International Commission on Non-Ionizing Radiation Protection (ICNIRP) in its guidance on limiting human exposure to radio frequency electromagnetic fields advises restrictions based upon avoidance of adverse effects resulting from whole-body or partial body heating. It recommends that for public exposure the SAR should not exceed 2 W/kg in any 10 g of the head.

Given a knowledge of the HFK / telephone / body layouts defined above, measurements were made on an exposure system of the SAR due to the mobile telephones alone and when the telephones were used with their associated HFK. Additional work was carried out using numerical modelling to further understand the mechanisms leading to power deposition in the head from a HFK and thus to further validate the measured data.

The level of SAR within the head, associated with the use of a HFK with GSM mobile telephone was established. For all the combinations tested, use of a HFK resulted in a lower maximum 10g SAR value. The size of the reduction observed here is sufficiently large to give confidence that this conclusion will carry over to other HFK's.

The principal factors associated with the observed levels of SAR were identified.

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Strong factors are: layout of the HFK with respect to the phone, which has a very significant effect on the coupling; proximity of other parts of the body to the HFK as it runs towards the head – a phantom torso is not necessary when considering the maximum exposure to the head.

A moderate factor was the proximity of the HFK to the head. At higher frequency the proximity to the head becomes more important, as might be expected when considering the shortening of wavelength, and it is necessary to run the HFK close to the head to give maximum SAR.

Weak factors are: the specific type of HFK, although the type can have a significant effect on where the peak occurs, varying from down near the jaw to up around the ear; 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 the coupling between the phone and HFK.

It should be noted that the phone-HFK geometries were deliberately chosen to enhance the induced power 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

Aims and Objectives

The aims of this project were to:

1) Establish the level of SAR within the head, associated with the use of Hand's Free Kit's (HFK's) with GSM mobile telephones;

2) Identify the principal factors determining the observed levels of SAR.

Following from these aims, a number of objectives were identified:

I. To measure the differences in exposure between a hand-held mobile telephone and a mobile telephone with HFK;

II. To measure the effects on the measured SAR within the head of incorporating a representative body phantom in exposure measurements of hand-held mobile telephones with HFK's;

III. To measure the induced currents on the cabling of the HFK's with and without the presence of a representative phantom body and verify the validity of the phantom body using measurements on a human subject;

IV. To predict the SAR within the phantom head and induced currents on the cabling of the HFK's with and without the presence of a representative phantom body.

Participants

The participants involved in the work reported here were Dr Stuart J Porter, Dr Myles H Capstick, Ms Francesca Faraci, Dr Ian D Flintoft and Prof Andrew C Marvin, all of the Physical Layer Group, Department of Electronics, University of York, UK.

Achievements

The following points give an overview of the work and relate to the subsequent subsections.

1. Acquisition of mobile telephones and hand's free kits: A number of mobile telephones ("phones") and associated Hand's Free Kit's

(HFK's) were purchased. Throughout the work, the phones were operated at 888 MHz in the lower GSM band and 1750 MHz in the upper GSM band.

2. Development of a probe for measuring the induced currents on the HFK's: In order to measure the induced currents on the HFK cables, two current probes were developed, one for each operating frequency. It was considered important that the probes should involve a minimum of conducting material in order to minimise distortions of the HFK current when the probes were placed in close proximity to the cables.

3. Measurement of the induced current on the HFK's: When assessing the maximum exposure caused by HFK's it is necessary to first optimise the relative geometry of the HFK and phone in order to maximise the coupling and hence induced current on the HFK. Secondly, it is necessary to establish the relative geometry of the HFK to the human body that is likely to give the highest induced current and hence exposure.

4. Comparison of the phone SAR with the highest SAR due to the HFK's: Making use of the high-induced-current geometries derived from the current measurements, comparison can be made of the SAR due to use of a HFK and SAR due to a phone alone. To measure the SAR due to a phone alone, standard SAR practices were followed using an exposure system with a homogeneous head phantom. To measure the SAR due to use of a HFK, the same exposure system was used. The HFK/phone combination was arranged so as to lie in the same geometry as the high-induced current geometry previously discovered. Measurements of the induced current were 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 HFK cabling.

5. Investigation of the effect of a phantom torso on the SAR due to the HFK's: The induced current measurements indicated that maximum current on the HFK could be found in the region of the head when the HFK cable was run well away from the human torso (and thus in a mode of use similar to that which might occur when a phone was 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 was placed below the head phantom in the exposure system and the consequent induced current and SAR measured.

6. Validation of the measurements of the variation of SAR with/without a phantom body: 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 examine the SAR with/without a torso using both inhomogeneous and homogeneous phantoms.

3.1 Mobile Telephones and Hands Free Kits Used

A number of phones and HFK's were purchased from a "high street" retailer. In order to anonymise their use, they are referred to by random letter/number in this report: a letter denotes each phone and a number denotes each HFK. Their general characteristics are summarised in Table 1. A "Standard" HFK type denotes a small "in-ear" earpiece, a microphone typically 100-200mm along the cable from the earpiece and a thin cable running along to the phone plug.

Mobile telephone / HFK label	Antenna type	HFK type
A7	External helical	Standard
B3	External helical	Standard
C6	Internal planar	Standard
D5	Internal planar	Standard
F11	External helical	Support for earpiece which runs 100mm of HFK cable around ear, microphone 140mm further along cable and cable wound into helix after further 140mm
G8	Internal planar	Standard
H2	Internal planar	Microphone on 70mm boom, earpiece with wire support around ear and thin cable running to phone plug

Table 1: Mobile telephone and HFK characteristics

In addition it should be noted that phone B was of a “flip-out” type where the ear speaker section swings out from the main body. The antenna is then shielded from the head by the ear speaker section.

3.2 Current Probe Design and Calibration

Two current probes were fabricated for the two frequencies under consideration: 888MHz and 1750 MHz. The design of the probes is shown schematically in Figure 1, and an image of the 888MHz probe is shown in Figure 2. Two diodes were required in order to give electrical balance. All critical dimensions were chosen so as to be less than one-tenth of a wavelength at 1750 MHz. Following simulations of the effect of placing conducting materials near current carrying cabling, the resistive feed was included to minimise interaction with the HFK current.

A two-stage calibration process was used for the current probes:

1. Stripline measurement to give a non-absolute calibration over the dynamic range of each probe;

2. Free-space measurement to give an absolute calibration at a point within the dynamic range.

For the first, 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 power in the termination to the stripline current.

For the second, a free-space measurement of the probe output voltage for particular free-space field strength was performed in an anechoic chamber using a horn antenna and signal generator as stimulus. The input was varied to give a particular probe output voltage that corresponded to that for a particular stripline current. The free-space magnetic flux density was then determined from the antenna gain and transmitted power.

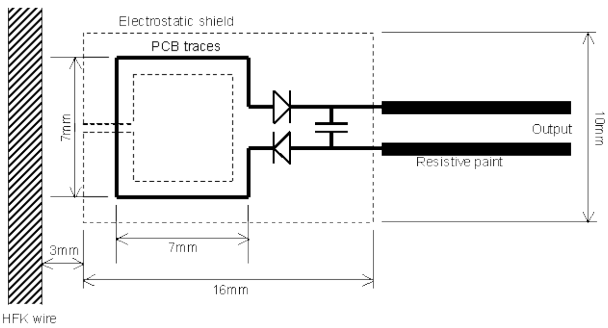


Figure 1: Schematic representation of current probe

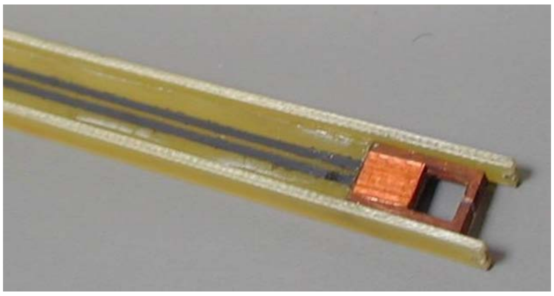


Figure 2: 888 MHz current probe

The total flux passing through the probe loop was calculated for the free-space and stripline currents, the ratio of these allowing an absolute estimate of the wire (HFK) current against probe voltage to be derived.

The final calibration for the 888 MHz probe is shown in Figure 3, giving an estimated HFK current for a particular probe output voltage. The calibration for the 1750 MHz probe is shown in Figure 4.

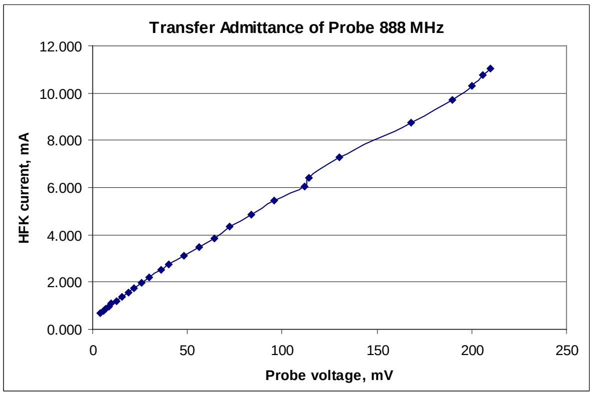


Figure 3: 888 MHz Cable (HFK) current for measured probe output voltage

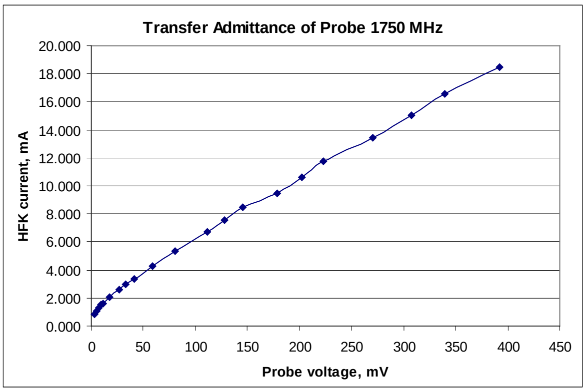


Figure 4: 1750 MHz Cable (HFK) current for measured probe output voltage.

3.3 Measurements of Induced Current on HFK Cabling

Initially, for each phone-HFK combination, the HFK layout around the phone that gave maximum induced current on the HFK (subsequently referred to as "maximum coupling geometry") was found using measurements of the current induced on the HFK whilst the phone-HFK system was in a free space environment. Subsequently, these combinations were each tested with a human subject in three configurations to deduce the variation of HFK current across the range of common usage positions.

3.3.1 Determination of Maximum Coupling Geometries

In order to determine the maximum coupling geometries, 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 full measurements of induced current. In general the maximum coupling occurred when the HFK cable was taped to 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, as indicated in Figure 5. Exceptions to this are noted below.

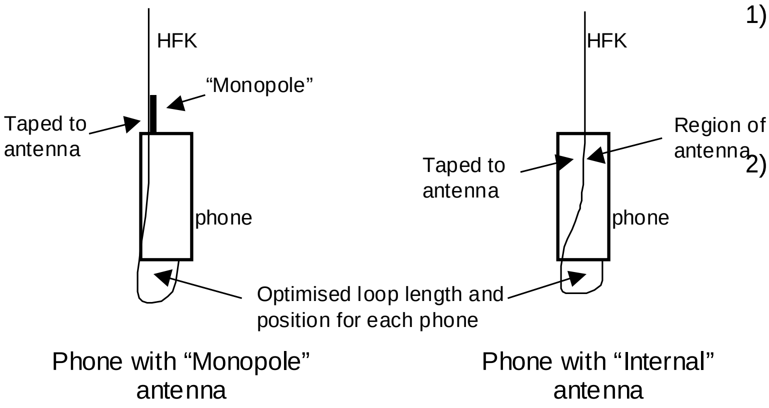


Figure 5: Common phone-HFK geometries for maximum induced current on the HFK cable

At 888 MHz, two exceptions to these geometries occurred. In the case of combinations F11 and H2, the maximum induced current was found to occur when the HFK cable was run from the port (situated at the base of the phone in both cases) directly away from the phone. At 1750 MHz, no significant exceptions to these geometries occurred. In the case of combination F11, the 6th, 7th and 8th coils of the helical part of the HFK cable were wrapped around the monopole to give maximum induced current.

In general, moving the HFK away from these geometries resulted in significant reductions in induced current.

3.3.2 Induced Current Measurement Configurations

The measurements of the induced currents on the HFK's 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 described above. Four configurations for the phone-HFK system, three with human subject, were then used for the measurements, as indicated in Figure 6-Figure 9 and discussed here:

1) Free space (Figure 6): the HFK was run straight out from the top of the telephones and distant from any other object.

2) Table top (Figure 7): the earpiece of each HFK was placed in its in-use position in/on the subjects ear and the cable was then run forwards away from the subject out to a position approximating to table level. This position was designed to be representative of tabletop use where the telephone is placed on a table in front of the subject.

3) Body typical (Figure 8): the earpiece of each HFK was placed in its in-use position in/on the subjects ear and the cable was allowed to run freely downwards to the telephone which was secured in a waist position. This position was designed to be approximately representative of normal "at-the-waist" use where the telephone is attached to a belt or placed in a waist pocket.

4) Body close (Figure 9): the earpiece of each HFK was placed in its in-use position in/on 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 telephone which was secured in a waist position. This position was designed to give very close proximity to the subject for the major part of the cable run.

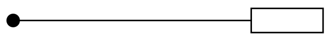


Figure 6: Phone-HFK layout for "free space" configuration

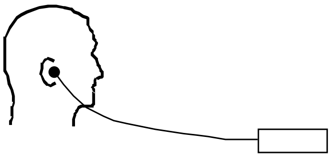


Figure 7: Phone-HFK layout in "table top" configuration

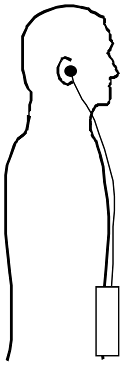


Figure 8: Phone-HFK layout for "body typical" configuration

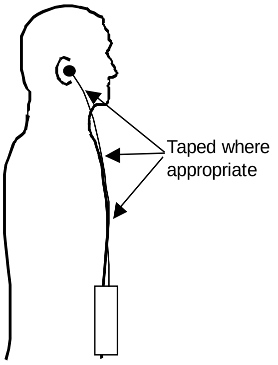


Figure 9: Phone-HFK layout for "body close" configuration

3.3.2 Summary of Results

For these measurements, 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 10 and Figure 11 are the average, maximum and minimum peak currents within 10cm of the HFK earpiece across all configurations at 888 MHz and 1750 MHz respectively. At both frequencies, there is a consistent trend of decreasing current along the HFK between the "Free space" to "Table top" configurations and between the "Table top" and "Body typical"/"Body close" configurations. There is a small decreasing trend between the "Body typical" and "Body close" configurations, but this is not significant.

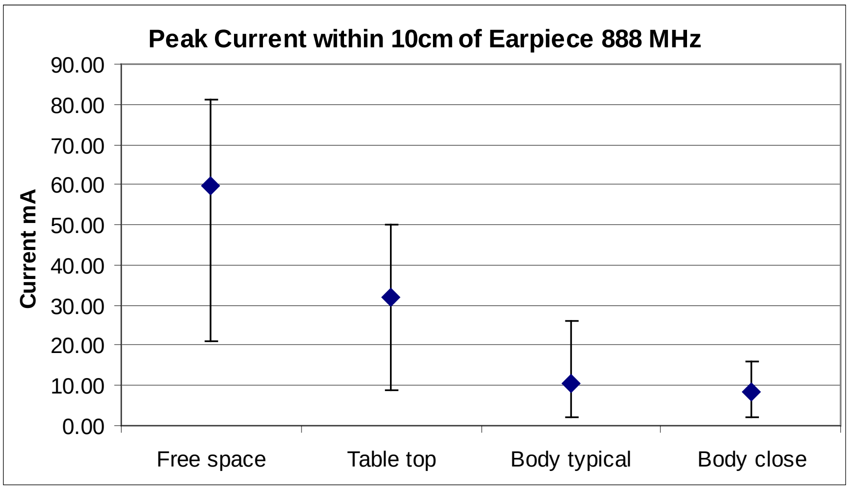


Figure 10: Peak current within 10cm of earpiece for all configurations and combinations

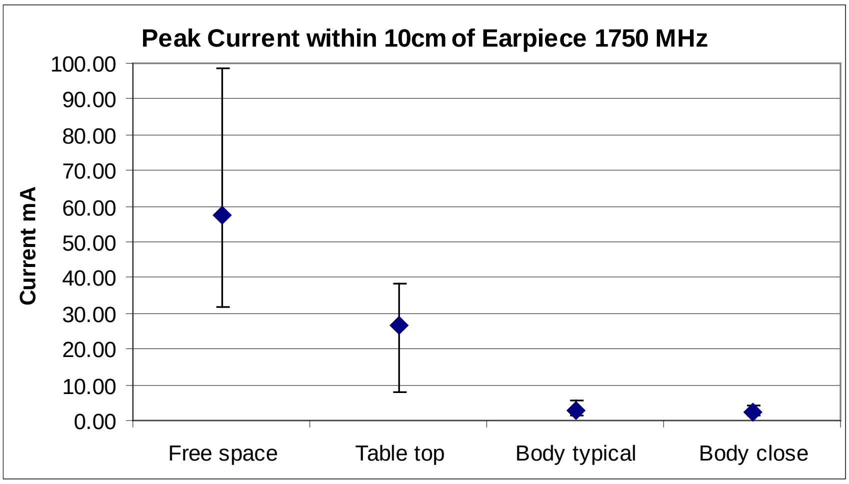


Figure 11: Peak current within 10cm of earpiece for all configurations and combinations

If a comparison is made between the two frequencies, the "Free space" and "Table top" geometries have induced currents only marginally lower at 1750 MHz than at 888 MHz, whilst the "Body typical" and "Body close" values are significantly lower at 1750 MHz. 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 generally stronger at the higher frequency, whilst there is greater attenuation caused by the body at that frequency.

SAR Measurements using a Head Phantom

Throughout the SAR measurements, the test equipment used was an IndexSAR SARA2 suite, comprising robot arm, field probe, and SAM phantom. Validation was carried out using rectangular bath measurements according to the draft standard. The system is shown in Figure 12 and Figure 13.

Figure 12: Robot arm, probe and head phantom

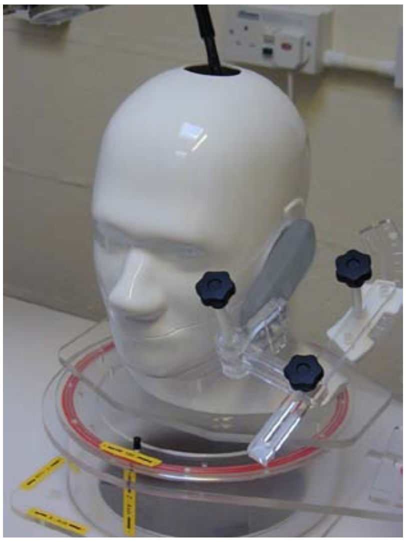


Figure 13: Close up of head phantom and phone holder

For the SAR and induced current measurements on the HFK's, the SAR laboratory was partially lined with absorber and the robot arm and controller were screened with absorber (not shown in above images) to avoid modification of the currents on the HFK's due to the environment.

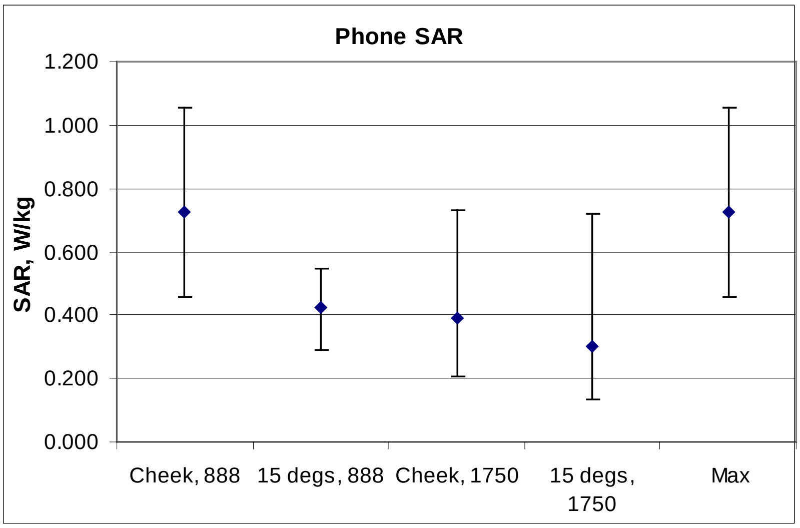
3.4.1 Mobile Telephone SAR Measurements

Seven phones were used for the phone-only measurements, comprising A, B, C, D, F, G, H. The telephones were tested in the "cheek" and "15° tilt" positions on the left side of the head as specified in [1].

A summary of the peak 10g average SAR values (W/kg) is shown in Figure 14. The individual data sets are the: SAR at 888 MHz with phone in the cheek position ("Cheek, 888"); SAR at 888 MHz with phone in the 15° tilt position ("15 degs, 888"); SAR at 1750 MHz with phone in the cheek position ("Cheek, 1750"); SAR at 1750 MHz with phone in the 15° tilt position ("15 degs, 1750"); maximum SAR over all angles and frequencies ("Max"). The vertical lines indicate the maximum and minimum values for each position / frequency. The "Max" values indicate the values that would be quoted were a full compliance test to be carried out.

All phones show a maximum SAR when measured in the "cheek" position at 888 MHz with the exception of phone A where the maximum SAR occurs in the "15 degs" position at 1750 MHz and is 1.3% higher than the "cheek" position at 888 MHz.

In general, there is a significant reduction in the SAR at 1750 MHz compared with 888 MHz. The average SAR for 888 MHz is 0.726 W/kg, whilst that for 1750 MHz is 0.398 W/kg. There is a factor two 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, differing current distributions on the antennas, differing field distributions and differing material properties in the head phantom.



14: Peak 10 g average SAR values (W/kg) for the phones.

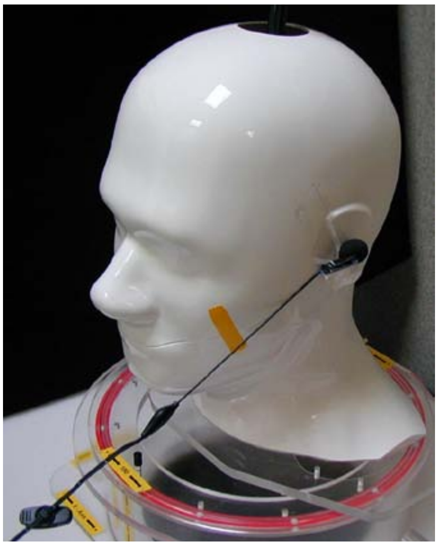


Figure 15: "Free" HFK configuration - the right edge of the yellow tape marks the extent the HFK will be taped down (see figure on right)

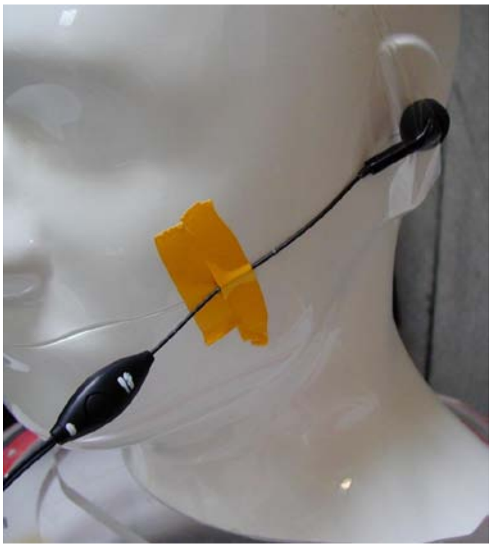


Figure 16: "Taped" HFK configuration - showing extra tape to secure HFK to marker tape

3.4.2 HFK SAR Measurements

Seven configurations of phone and HFK were used for the measurements, comprising the combinations A7, B3, C6, D5, F11, G8, H2. The phone / HFK combinations were tested in two positions:

Earpiece in "normal" position over the ear with the cable running approximately directly forwards (for example, see Figure 15) - referred to as "Free".

Earpiece in "normal" position over the ear with the cable fixed against the cheek for 8cm and then running approximately directly forwards (for example, see Figure 16) - referred to as "Taped".

A summary of the peak 10g average SAR values (W/kg) is shown in Figure 17. The individual data sets are the: SAR at 888 MHz with HFK in the free position ("Free, 888"); SAR at 888 MHz with HFK in the taped position ("Taped, 888"); SAR at 1750 MHz with HFK in the free position ("Free, 1750"); SAR at 1750 MHz with HFK in the taped position ("Taped, 1750");

maximum SAR over all angles and frequencies ("Max"). The vertical lines indicate the maximum and minimum values for each position/frequency. There is no procedure currently approved for a full compliance test but the "Max" values are indicative of the value that would be quoted were the same procedure adopted as for a phone where the maximum across all positions and frequencies is quoted.

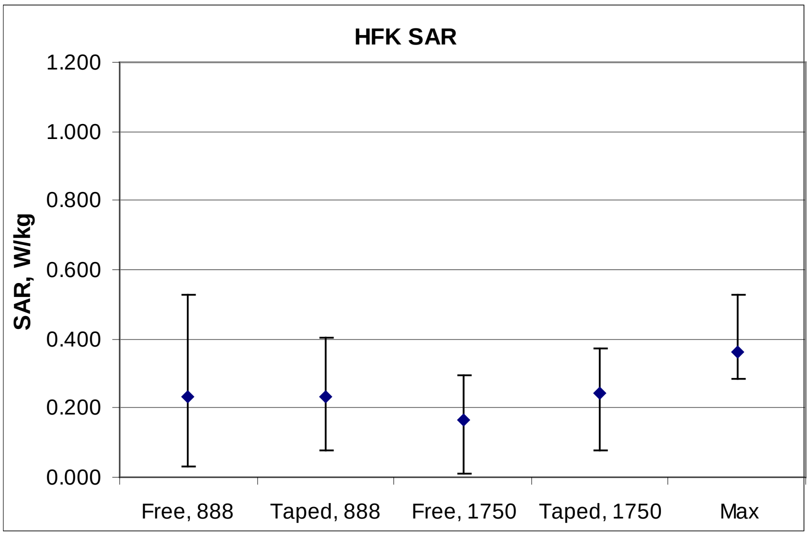


Figure 17: Peak 10 g average SAR values for the mobile telephones with HFK's.

There is a general trend for the maximum SAR to occur in the "Taped" position with the exception of combinations C6 and D5 at 888 MHz and combination C6 at 1750 MHz. There is no general trend with frequency with four maxima occurring at 888 MHz and three at 750 MHz. Considering the averages of the maximum at each frequency, at 888 MHz the average is 0.281 W/kg, whilst that for 1750 MHz is 0.251 W/kg. These similarities with frequency are in line with those noted from the induced current measurements made in the anechoic chamber.

3.4.3 Comparison of SAR for mobile telephones with and without HFK's

The combined peak 10g average SAR values (W/kg) for each frequency band and overall across all phone / HFK combinations are shown in Figure 18. Whilst there are no approved standards for measuring the SAR from HFK's, taking the highest possible value for a particular phone/HFK would be in closest alignment to the procedures for phones, as noted earlier. In this case, the maximum possible SAR from the HFK's ("HFK, comb") can be compared with the SAR observed from phones themselves ("Phone, comb").

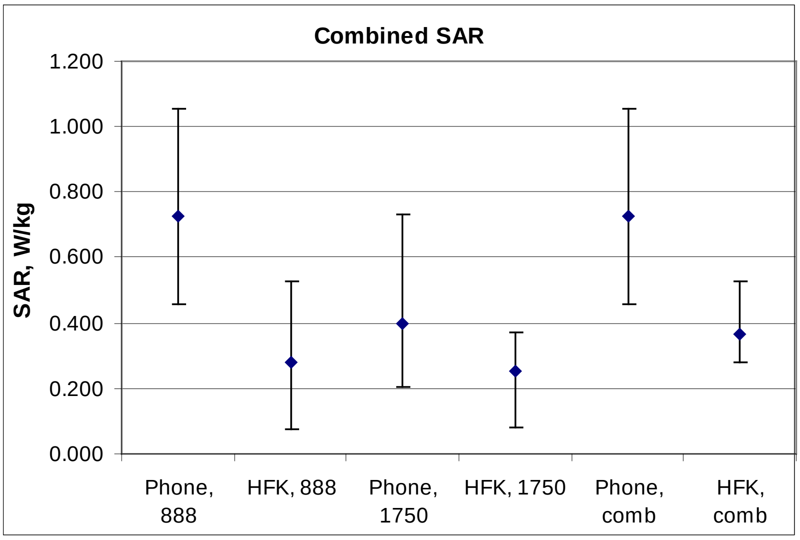


Figure 18: Combined SAR data for telephones and HFK's.

So, the data set, "HFK, comb", thus represents the maximum SAR observed from the HFK's. If a comparison is made between individual phones and their associated HFK's, all ratios are less than one. In general, all single-band ratios are less than one except for the combinations G8 and H2 at 1750 MHz where the phone SAR values represent two out of the three lowest phone SAR values observed. It can be seen that the highest SAR is generally obtained from a phone held next to the head at 888 MHz.

The position of the maximum of the 10g SAR for each phone and phone/HFK combination is indicated in Figure 19 and Figure 20 for 888 MHz and 1750 MHz respectively. The reference on the ear is at a position of (-25mm, -125mm).

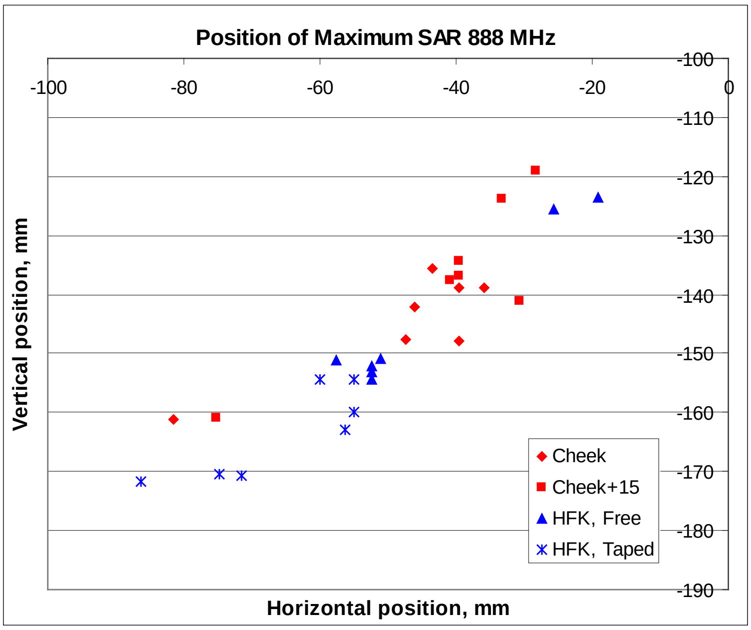


Figure 19: Position of the maximum 10g SAR for both phones and phone/HFK combinations at 888 MHz.

Considering the data at 888 MHz, it can be seen that the peak SAR from the HFK's occur low and left of the peak from the phones. That is, the peak SAR from the HFK's occurs low towards the jaw rather than near the ear. Notable exceptions to this are: F11 and H2 where the effect of the support around the ear is to move the peak up around the region of the ear; B which is the "flip-out" phone where the effect of the body of the phone near the mouth is to move the peak low to the jaw.

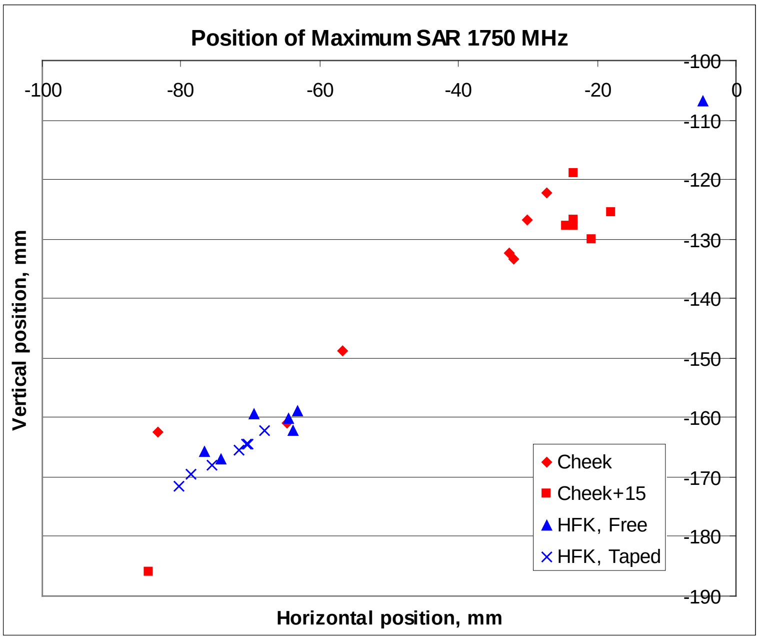


Figure 20: Position of the maximum 10g SAR for both phones and phone/HFK combinations at 1750 MHz

Considering the data at 1750 MHz, it can be seen even more clearly than at 888 MHz that the peak SAR from the HFK's occurs low and left of the peak from the phones. Again, the peak SAR from the HFK's occurs low towards the jaw rather than near the ear. Notable exceptions to this are: F11 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; B which is the "flip-out" phone whose effect is as at 888 MHz.

3.4.4 HFK Current Measurement Comparison

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 tabletop configuration, which might be expected to be the closest comparison to the phantom head configurations. 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 (as was used in the actual SAR measurements).

The results showed 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. The average difference is 25.4%. This gives a good indication that the coupling between the phones and HFK's is similar for the head phantom in the SAR laboratory and a live subject in the anechoic chamber.

A comparison was also made of the peak HFK currents vs. the measured SAR levels. It appeared that, while there is strong evidence that the induced

HFK currents measured in the SAR laboratory with a

of the currents found in the anechoic chamber with human subjects, it is difficult to accurately predict the SAR arising from a particular induced current on a HFK. In general the SAR does fall with decreasing

3.4.5 Effect of Deliberate Attenuation of HFK Current on Observed SAR

To further investigate the relation between the induced HFK current and observed SAR, a ferrite bead was placed around the HFK lead at a point beyond where the fields from the phone might induce strong currents in the HFK. With the presence of the ferrite bead, the HFK current was reduced below the noise floor of the current measurement system and the SAR was below the measurement threshold of the SAR system. Thus a ferrite bead placed as described above significantly reduces the induced SAR when using a HFK.

3.5 SAR Measurements using a Head and Torso Phantom

Measurements were made of the SAR inside a head phantom at 888 MHz due to phones placed at a “waist” position on a simulated homogeneous torso with a HFK terminating against the ear. Measurements of the induced current on the HFK’s in the SAR laboratory were also made to enable comparison with the measurements made on human subjects. For the SAR and induced current measurements on the HFK's, the SAR laboratory was partially lined with absorber and the robot arm and controller were screened with absorber to avoid modification of the currents on the HFK's due to the environment.

The phones were secured to the side of the torso at approximately "waist" height and the HFK was run up to the ear and secured in the ear position as before. The torso consisted of a plastic cylinder filled with 32 litres of fluid. The fluid consisted of 40g salt / 1 litre of water giving material properties at 888 MHz of 1.18 S/m conductivity and 18.7 relative permittivity. The fluid was chosen to give properties tending to those of muscle, with lower permittivity. It should be

homogeneous phantom are representative

current but it is likely that the geometry of the HFK in the vicinity of the phantom head also contributes strongly to the level of SAR observed.

noted that the attenuation caused by a human torso might be lower due to the greater proportion of materials with properties nearer to free space than that chosen.

All exposures with a torso showed a reduction in SAR compared with the equivalent exposure without a torso, with the reduction factor varying from 0.026 to 0.70 with an average value of 0.43. Thus the introduction of a phantom torso reduces the observed SAR in the head due to the HFK for all the combinations. The reduction varies significantly between the different phone-HFK combinations.

When considering the measurement of induced current along the HFK cables with a phantom torso, it was found that the currents along the cables are reduced by the presence of the torso. The reduction makes them significantly less similar to the anechoic "Table top" measurements and now similar to the anechoic "Body typical" measurements. The average difference between the SAR laboratory torso measurements with the anechoic chamber "Body typical" measurements was found to be 32%, the phantom torso HFK currents being, on average, higher than the human measurements.

Better agreement might be achieved by closer specification of the proximity of the HFK to the human subject or phantom torso and by refinement of the phantom torso fluid. Closer specification of the proximity of the HFK to the subject would not be useful since the geometry used should represent a "typical" in-use layout rather than an idealised one. Refinement of the phantom torso fluid would be useful: conventional SAR measurements in the head have the objective of capturing the maximum likely exposure while in this part of the work the objective was to assess the likely affect of the presence of the torso, thus requiring a better estimate of the average material properties of a torso. This was beyond the scope of the current work but within the scope of the York MTHR project [2].

3.6 Simulation of SAR using an Inhomogeneous Phantom

The objective of the simulation work was to investigate the effect that variations in the phantom models have on the SAR from HFK's. A number of scenarios were considered, each being run with and without the torso. The insertion of the torso always resulted in lower SAR being observed in the head, with an average reduction factor of 0.50 (cf. the 0.43 reduction seen in the measurements). The greatest difference was observed for homogeneous models where the material parameters used (muscle) appear to cause an overestimate of the attenuation due to the torso.

4. Analysis of Objectives Met

With regard to the initial aims of this project:

1) The level of SAR within the head, associated with the use of Hand's Free Kit's (HFK's) with GSM mobile telephones has been established across a sample of phones;

2) The principal factors determining the observed levels of SAR have been identified.

With regard to the objectives:

I. The differences in exposure between a hand-held mobile telephone and a mobile telephone with HFK were measured for a sample set of phones;

II. A representative body phantom was incorporated in exposure measurements of hand-held mobile telephones with HFK's and the effect on the measured SAR within the head was measured;

III. Induced currents on the cabling of the HFK's with and without the presence of a representative phantom body were measured and verified against measurements on a human subject;

IV. Predictions were made of the SAR within the phantom head and induced currents on the cabling of the HFK's with and without the presence of a representative phantom body.

All aims and objectives were addressed.

5 Interpretation

The level of SAR within the head, associated with the use of HFK's with GSM mobile telephones has been established for the samples used and the data can be seen in Figure 18. For the combinations tested here, use of a HFK resulted in a lower maximum 10g average SAR value. The size of the reduction is sufficiently large to give confidence that this conclusion will carry over to other HFK's.

The principal factors associated with the observed levels of SAR have been identified. Strong factors are:

- Layout of the HFK with respect to the phone, which has a very significant effect on the coupling.

- Proximity of other parts of the body to the HFK as it runs towards the head – a phantom torso is not necessary when considering the maximum exposure to the head.

Moderate factors are:

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

Weak factors are:

- The specific type of HFK, although the type can have a significant effect on where the peak occurs.

- 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 induced 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

6 Future Priorities

Referring to the overview of work (Section 3), comment can be made concerning further work that would enhance the current study.

1. Acquisition of mobile telephones and hand's free kits

2. A wider survey over more phones and HFK's would, as always, enhance the statistical reliability of the conclusions.

3. Development of probe for measuring currents on HFK's

4. Preliminary work was carried out to produce a second calibration route for the current probes and, while initial measurements were consistent with the current calibration, a firmer confirmation of this would be desirable.

5. Measurement of induced current on HFK's

6. While there is substantial isolation of the coupling between the HFK and phone from the interaction of the head with the HFK cable in the high SAR geometries, a complementary study of the variation in SAR with the localised HFK-phone geometry would confirm the isolation (such a study would be costly in time).

7. Comparison of phone SAR with highest SAR due to HFK's

8. Measurement of the SAR at the extremes of the GSM bands would enhance the coverage of the bands although the relatively small changes in wavelength may be unlikely to produce significant changes in observed SAR. The maximum coupling geometries for the phone-HFK would need to be reviewed for each target frequency.

9. Effect of incorporating a phantom torso on SAR due to HFK's

10. A fluid that better represents the typical attenuation due to the torso would be useful in more accurately estimating the SAR in the presence of the torso (although this is unlikely to produce the highest values of SAR in the head).

11. Validation of measurements of the variation of SAR with/without a phantom body

12. A wider study of the effects of using a homogeneous rather than an inhomogeneous phantom would be useful as would a detailed study of variations in position of the HFK when it runs close to a torso (again, as the previous point, the torso is unlikely to produce the highest values of SAR in the head and the study would be more useful in assessing the exposure to the torso itself).

7. Publications

The following publications have appeared:

S J Porter, M H Capstick, F Faraci, I D Flintoft and A C Marvin. **SAR and induced current measurements**

on wired hands-free mobile telephones. *IEE Technical Seminar on Antenna Measurements and SAR*, University of Loughborough, UK, pp 9-13, 25-26 May, 2004. ISBN: 086341415X.

S J Porter, M H Capstick, F Faraci, I D Flintoft, A C Marvin. **SAR associated with the use of hands-free mobile telephones**. *EMC Europe 2004*, Eindhoven, PprNo. B10, 6-10 September 2004.

A journal publication on this work is under preparation.

8 Financial Summary

Total project cost: £122,626

9 References

[1] EN 50360:2001/50361:2001

[2] Project: "Interaction of Emerging Mobile Telecommunications Systems with the Human Body", DoH/RUM4, MTHR Programme.

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