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SAR TESTS ON MOBILE PHONES USED WITH AND WITHOUT PERSONAL HANDS-FREE KITS

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Report prepared for DTI.

Indemnity

TABLE OF CONTENTS

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SUMMARY

In April 2000, an article published by the Consumers' Association in Which? Magazine reported that the use of personal hands-free (PHF) kits had been found 'triple the radiation penetrating the skull' compared to the normal use of the phones against the ear. Following the publication of the Which? Report, Sartest was commissioned to investigate how the use of personal hands-free kits influenced SAR exposure levels using the same phones tested for Which? The separate tests reported here were commissioned by the DTI and have tested PHF kits with a wider range of phones. These include phones with stub antennas and some new-model phones with internal antennas.

The results show that, for phones with external antennas (as tested for Which? with the cable hanging vertically downwards), PHF kits do not increase SAR but reduce the SAR levels compared with the normal use of the phone.

For some newer model phones with internal antennas as opposed to the "traditional" phone with external antennas, low SAR values in the head can be achieved for the normal use of the phone as the field values close to the phone are lower on the keypad side. With these antennas, there is a specific situation (routing the earpiece cable over the phone's antenna with the cable in contact with the cheek) when SAR levels with PHF kits can be of similar levels to those due to the normal use of the phone. However, SAR levels in the hand are more significant with internal antennas and comparisons need to consider absorption by other parts of the body other besides the head.

To understand the factors affecting body exposure in the hand and elsewhere, specific tests were conducted to determine the RF field distribution along PHF earpiece cables and to determine how the potential SAR exposure at one end of the cable depends on absorptive conditions at the other.

The conclusion from this study is that, in what would be considered their normal mode of use, PHF kits offer very substantial reductions in SAR compared to the normal use of the phone against the head.

However, some specific configurations have been found, which give rise to measurable SAR levels in the head with PHF kits. These configurations still give only low SAR levels and in the cheek rather than in the ear/brain. Such conditions are considered to be extremely unlikely and should not be encountered in normal use.

It has been found that even lower levels of exposure could be achieved if ferrite suppressers were attached to the cables of PHF kits.

If phones are used against the body with a PHF kit (e.g. in a pocket) placing them keypad towards the body reduces the absorption by the user.

The recently-published Stewart Report recommends that procedures for assessing PHF kits and phone shields should be developed. The specific testing performed in this study shows complex dependencies of configuration on the results obtained. This suggests that assessment procedures for mobile phone accessories such as PHF kits need to be formulated with such dependencies in mind.

Based upon our findings, we suggest some requirements of a test methodology for assessing mobile phone accessories, which have the expectation of reducing personal dose from RF exposure.

INTRODUCTION

Prior to this study, Sartest Ltd had been commissioned by Vodafone Ltd to perform SAR tests on the same types of mobile phones and personal hands-free kits tested by Which? Magazine (Ref 1). The results of these tests (Ref 2) did not confirm the findings reported by Which? Magazine. The use of the personal hands-free kits were found to be associated with large reductions in the energy absorbed by the phantom head in scanning SAR tests. The test results are available (with Vodafone's permission) on the web at http://www.sartest.com.

For the present investigation, phones of different models to those tested above have been included. Phones with internal antennas have been included as listed below:

Table 1
Phones tested and associated PHF kits

Phones with external antennas	PHF kit
Ericsson A1018s (dual band)	Digital Images 'talkman' with Kondor adaptor
Nokia 7110 (dual band)	Type HDC - 9P Made in China
Maxon 3204 (GSM 900 band)	Vodafone Accessory MA32-PCH

Phones with internal antennas	PHF kit
Nokia 3210 (dual band)	1) Carphone Warehouse NOK3210PHFCPW-BLA 2) Orange for Nokia 3210e ORA ONKN1526
Nokia 8210 (dual band)	1) Carphone Warehouse NOK3210PHFCPW-BLA 2) Orange for Nokia 3210e ORA ONKN1526

EXPERIMENTAL TESTS

CONTROLLING THE PHONES

The tests used the Sartest SAR testing system and used a GSM test set to control the phones to transmit at a constant level at maximum power. A Test SIM card to GSM 11.10 Phase 2 was used. Tests were made using a GSM test set from Rohde and Schwarz (CTS50/55). With the test set, calls were established using maximum mobile transmit powers as below:

900 MHz Band	Control level 5 (max. power) (2W maximum)	RF Channel No. 60
1800 MHz Band	Control level 0 (max. power) (1W maximum)	RF Channel No. 600

MEASUREMENT OF THE E-FIELD DISTRIBUTION ALONG AN EARPIECE CABLE

To measure the RF field, which is associated with the earpiece cable when a PHF is attached to a GSM phone, the phone and PHF were laid out horizontally on expanded polystyrene supports with the antenna tip at one end and the earpiece at the other. An E-field probe (W&G Model 300 with a special, reduced-size probe element) was used to measure the E-field close to the cable at the distance of closest approach (approx. 1cm due to the dimensions of the probe sensor casing). Measurements were made along the cable at 1cm intervals. A typical E-field scan at 900MHz is shown in Figure 1. Figure 2 at 1800MHz shows similar behaviour but reflecting the shorter wavelength of the higher frequency signal. At each frequency, a ferrite suppresser was also applied at the phone-end of the cable and the results indicate that the radiated RF emissions have been reduced. Note that the cable is shortened by looping it once-through the clip-on suppresser.

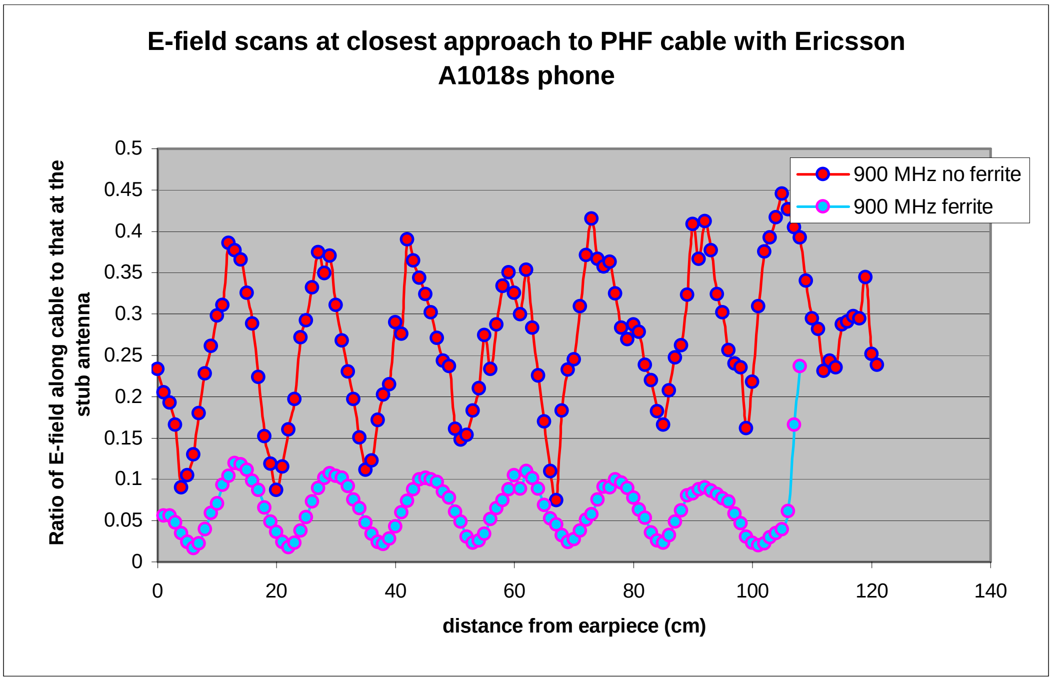


Figure 1. E-field distribution along an earpiece cable with a GSM phone at 900MHz. The position 0cm is at the earpiece and the readings extend up to the connector at the base of the phone. The E-field readings have been normalised by dividing them by the E-field reading attained with the probe against the stub antenna. For the measurement marked 'ferrite' the cable at the phone end was looped once round a ferrite clip-on suppresser.

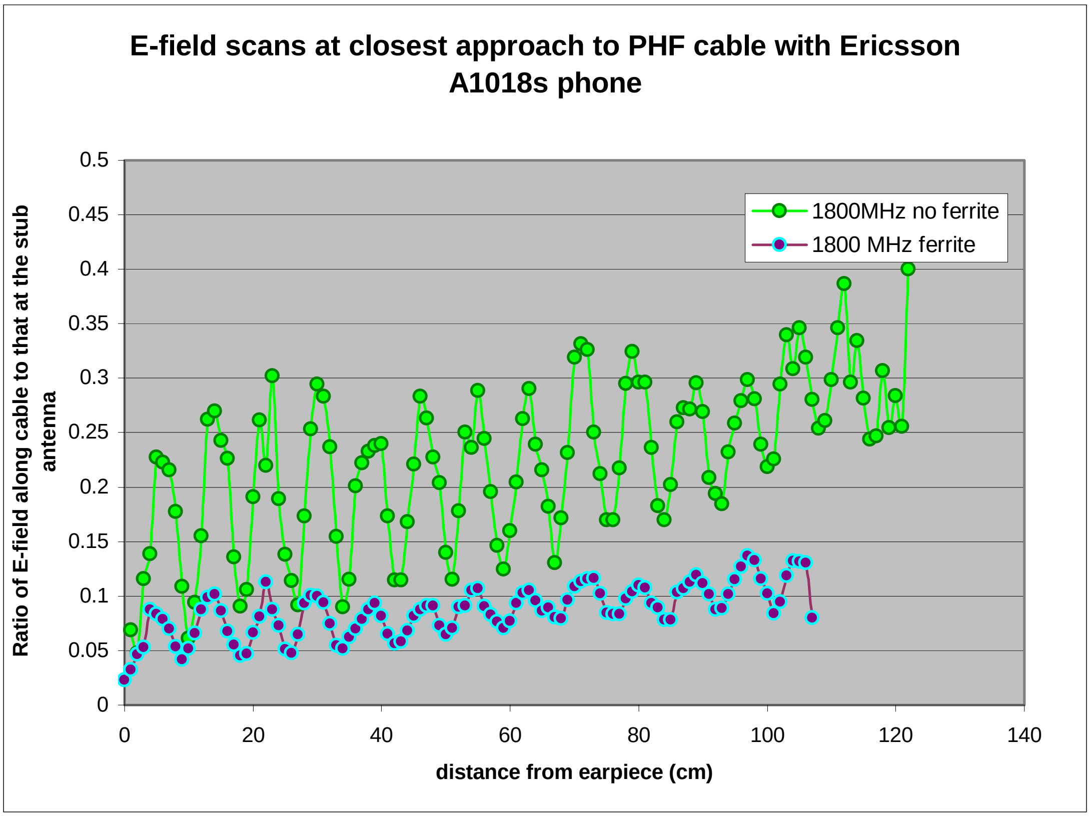


Figure 2. E-field distribution along an earpiece cable with a GSM phone at 1800MHz. The position 0cm is at the earpiece and the readings extend up to the connector at the base of the phone. The E-field readings have been normalised by dividing them by the E-field reading attained with the probe against the stub antenna. For the measurement marked 'ferrite' the cable at the phone end was looped once round a ferrite clip-on suppresser.

INVESTIGATING THE INFLUENCE OF ABSORBING MATERIAL CLOSE TO THE EARPIECE AND THE PHONE

To examine the influence of absorbing material close to the combined phone and PHF assembly, the Sartest robot was used to perform linear scans inside a Perspex box against which the phone could be placed or the earpiece assembly could be attached. Initially, a measurement such as that in Fig. 1 was done by taping the end of the earpiece cable horizontally to the empty Perspex 'phantom' and using the E-field probe to scan along a 180mm length in 2mm steps. The flat Perspex side of the box was 4mm in thickness and the centre of the probe was a further 6mm inside the box. The Nokia 3210 phone was used and 'air' scans of the earpiece end were conducted at 900 MHz. A second box-shaped phantom could be deployed close to the phone so that the influence of absorbing material adjacent to the phone on the field at the earpiece end could be examined. For this purpose, a 200mm cube-shaped box phantom was filled with 900MHz simulated brain liquid to a depth of 100mm. Figure 4 shows E-field scans in air at the earpiece end with the phone away from absorbing material and with the phone placed against the absorber. The phone was placed against the absorber in two configurations - keypad towards phantom and back of phone towards phantom. Figure 4 shows how the field at the earpiece end is affected when absorbing material is close to the phone. This is relevant to the situation where the phone is gripped by the hand or placed against the body.

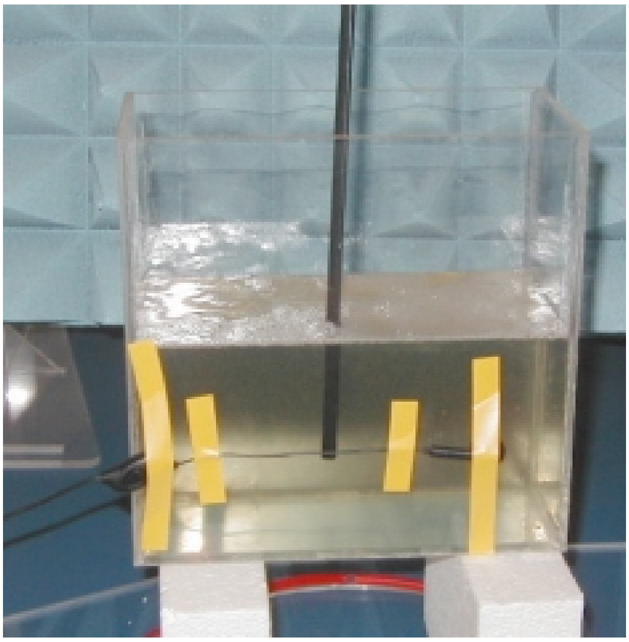


Figure 3: Showing the earpiece cable taped horizontally to a box-shaped phantom with the probe articulated within the box.

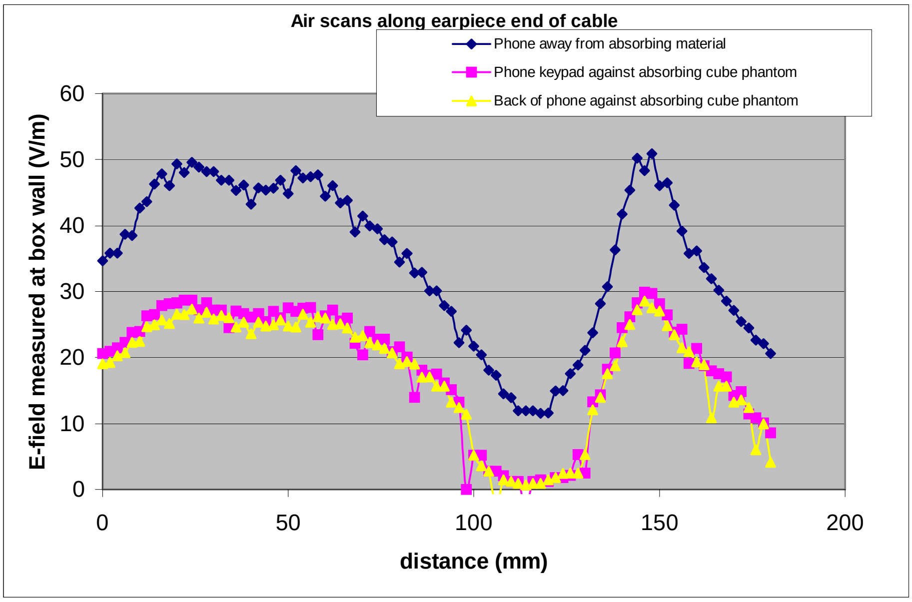


Figure 4: Air scans along the earpiece end of the PHF cable of the Nokia 3210 phone. The phone is at left and the earpiece is at distance point labelled 150mm. The E-field is reduced when the phone (at the other end of the cable) is placed against an absorber (liquid-filled box phantom).

The other factor illustrated by Fig. 4 is that, whilst the earpiece is at a local maximum of the E-field, the E-field shows a minimum a certain distance away from the earpiece. It is at this point that maximum coupling of the field to an absorbing body would be expected. To check this, the box phantom with the earpiece taped to it was filled with simulated brain fluid and the scanning procedure was repeated to measure spot SAR inside the liquid. The results are shown in Fig.5. They show a maximum of SAR associated with the minimum of Fig. 4 and also show the same dependency on phone configuration as discussed above for the air scan.

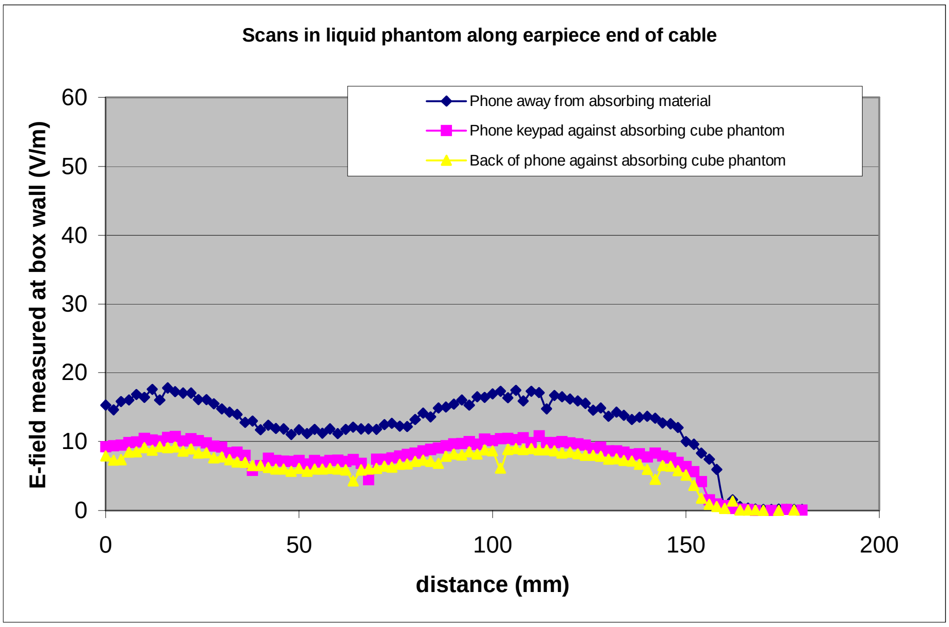


Figure 5: SAR scans inside the liquid-filled phantom along the earpiece end of the PHF cable of the Nokia 3210 phone (taped to the outside of the box). The phone is at left and the earpiece is at distance point labelled 150mm. The E-field in the liquid is reduced when the phone is placed against an absorber (another liquid-filled box phantom).

To assess the comparative SAR levels with the phone placed against the phantom used for the scans of Figs 4 and 5, the cable was turned round so that the phone was placed against the phantom containing the probe. The phone was placed both keypad towards the flat side of the box phantom and with the back of the phone against the box. In each configuration, the earpiece was either taped to the other absorbing phantom or left away from any absorber. Figure 6 indicates that the SAR levels from the phone are higher than the SAR levels associated with the earpiece (Fig.5). Figure 6 also shows that higher SARs are measured with the back of the phone against the phantom. This is expected with this phone, which has an internal antenna at the back. Placing the earpiece close to the absorber has a noticeable, but minor, effect.

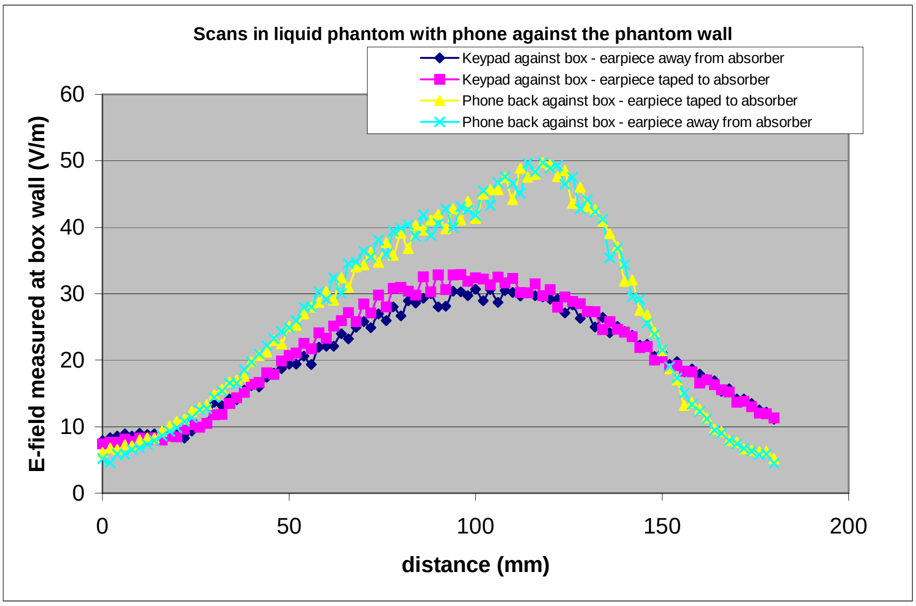


Figure 6: SAR scans inside the liquid-filled phantom along the mid-line of the Nokia 3210 phone (placed against the outside of the box). The earpiece is at left and phone is centred at the point 90mm on the distance axis.. The SAR is higher when the back of the phone is placed against the absorber and is slightly influenced by whether the earpiece is also against an absorber.

The results obtained in the tests described above (Figures 4 - 6) were used to plan certain elements of the subsequent SAR testing. Firstly, certain tests of the earpiece were performed with the cable taped against the cheek of the phantom so that the region of maximum coupling would be represented in the area scanned. Secondly, the importance of the influence of the absorber close to the phone was covered in the SAR tests by using a phantom hand, which could, optionally, hold the phone for selected tests.

The findings on the effects of the phone orientation against the absorber on SAR are not relevant for assessing SAR in the head, but are relevant to assessing the body dose to the hand. If the phone is used (with PHF) in a shirt pocket, say, the SAR level to the chest will depend on whether the phone is placed keypad towards the body or the other way round.

PROCEDURE USED FOR COMPARATIVE SAR TESTING

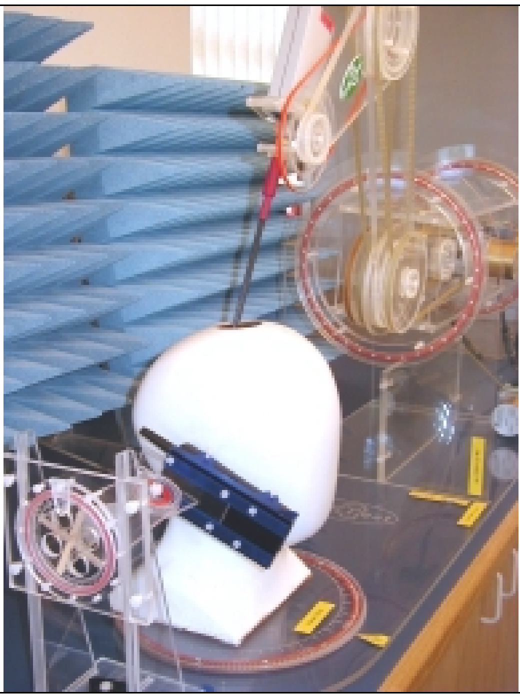
The experimental arrangement used for SAR tests is shown below. The upright head-shell used is a specific shape produced by SARTest, which has the same shape and dimensions as the 'generic twin' phantom, which is usually used in the form of a horizontal bath. The upright version was produced from the published digital dataset of the horizontal phantom.

The ears are not specifically modelled in the generic twin phantom and a 3.6mm spacer (20mm diameter) is used to distance the phone from the ear. When combined with the thickness of the shell (2.4mm) this ensures that the phone remains 6mm away from the inside surface of the phantom in the ear region. It is filled with simulated brain liquids specially formulated for use at either 900 MHz or 1800MHz.

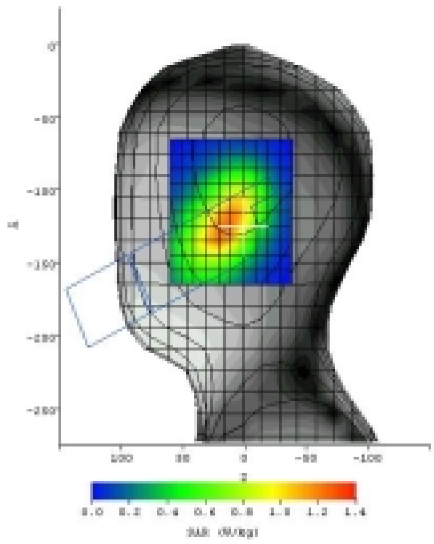
The phantom can be positioned to perform tests at either the LH or RH ear. An E-field probe, calibrated in the simulant liquid by a thermal substitution method, is used to determine the SAR level in the liquid-filled head. The E-field probe is supported from a non-metallic robot arm for performing volume scans within the head shell.

The software first scans close to the wall of the phantom and subsequently scans a volume encompassing the region of maximum SAR. The maximum 1g and 10g SAR values are obtained by volume averaging the interpolated 3D scan measurements.

Further details of SARtest procedures can be found at the web site http://www.sartest.com .



Test set-up used for measuring SAR with upright phantom shell based on the published shape of the 'generic twin' phantom. A test at the RH ear is shown.



The position of typical data points scanned in the SAR testing at the LH ear shown in relation to a representation of the head shape. The ear channel position and the position of device being tested are also shown.

Figure 7. Test set-up used for measuring SAR .

COMPARATIVE TEST SEQUENCE AND RESULTS

1) Test conditions used for SAR tests of the hands-free kits

To find the worst-case exposure conditions when using the personal hands-free kits, the robot was used to position the probe close to the ear inside the phantom. Each phone was then set on transmit using the test set and the earpiece was taped against the head in the recess of the ear.

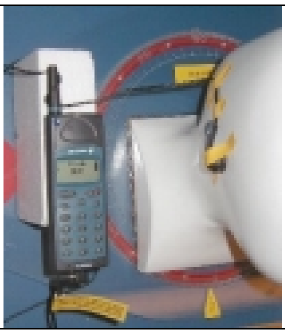
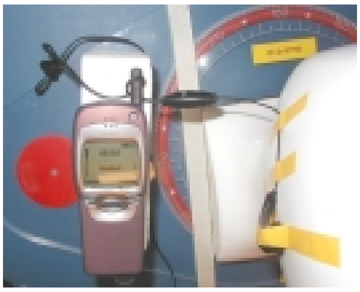
The lead to the earpiece and the phone were placed in a range of different positions and, using software which charts the instantaneous SAR reading from the probe, the position giving the greatest SAR indication was noted. On the basis of the results with the flat phantom test, a laboratory test configuration was defined with the earpiece cable taped to the cheek of the phantom and with the microphone towards the mouth. The findings were used to define the configurations listed below. Conditions used to represent the 'worst-case' test conditions are set out in Tables 1a and 1b.

Normal use position
For this configuration, the earpiece was taped to the ear and the cable was allowed to hand naturally in the manner expected for normal use. Additionally, the phone was placed in a phantom hand placed at least 200mm from the head.

Earpiece cable close to phone's antenna
For this configuration representing a worst-case configuration, the cable to the earpiece was wrapped round the antenna (external antenna phones) or laid across the antenna (internal antenna phones).

Worst-case laboratory test configuration
This absolute worst case configuration combines two rather unlikely arrangements. In addition to the placing of the cable against the antenna (as above) the cable from the earpiece was taped against the cheek.

Table 1a
Configurations used to represent worst-case conditions
External antenna phones

Phone	Absolute 'worst-case' configuration tested	Illustration
Ericsson A1018s	Cable wrapped round antenna	
Nokia 7110	Cable wrapped round antenna (view from above)	

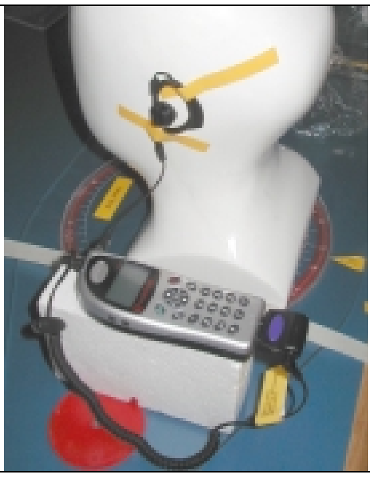
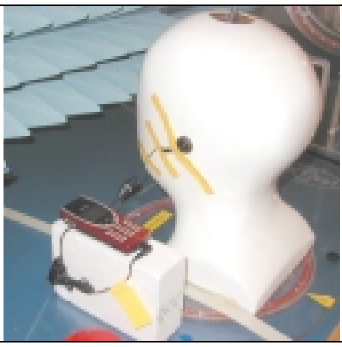
Maxon 3204	Cable wrapped round antenna	

Table 1b
Configurations used to represent worst-case conditions
Internal antenna phones

Phone	Absolute 'worst-case' configuration tested	Illustration
Nokia 3210	Cable laid over internal antenna	-
Nokia 8210	Cable laid over internal antenna	

2) Comparative SAR testing with and without the personal hands-free (PHF) kits

Table 3
10g volume averaged SAR test results at LH ear of phantom. PHF tested with earpiece taped inside spacer ring and with cable either hanging down or taped in contact with phantom along cheek in direction of mouth. Phones tested in the CENELEC intended use position (i.e. in line with mouth opening and at 80° to the line joining the ear canals.

External antenna phones

Phone	CENELEC intended use position (see Note 1)	Normal use of PHF kit	With PHF kit in 'worst-case' configuration with cable hanging down	With PHF kit in laboratory test configuration with cable taped to cheek
Ericsson A1018s 900MHz 1800MHz	 0.33 0.29	 0.01	 0.07 0.02	 0.26 0.05
Nokia 7110 900MHz 1800 MHz	 0.22 0.35	 0.01	 0.02 0.06	 0.29 0.21
Maxon 3204 900 MHz	 0.44	 0.03	 0.10 (See Note 2)	 0.10 (See Note 2)

Internal antenna phones

Phone	CENELEC intended use position (see Note 1)	Normal use of PHF kit (phone in phantom hand)	With PHF kit in 'worst-case' configuration with cable hanging down	With PHF kit in laboratory test configuration with cable taped to cheek	PHF kit used
Nokia 3210 900MHz 1800 MHz	 0.56 0.13	 - 0.02	 -	 0.47 0.39 0.21	(see Note 3) 1) 2) 1)
Nokia 8210 900MHz 1800 MHz	 0.52 0.20	 0.01 0.01	 0.07 0.05	 0.34 0.52 0.14	 1) 2) 1)

Notes to Table 3:

1) These are not maximum values for the normal use as only one CENELEC position was tested at just the LH ear.

2) The earpiece cable is shaped round the ear in this design - see illustration in Table 1a - so the cable is against the shell in normal use.

3) Details of the PHF kits used are given in the Introduction section of this report.

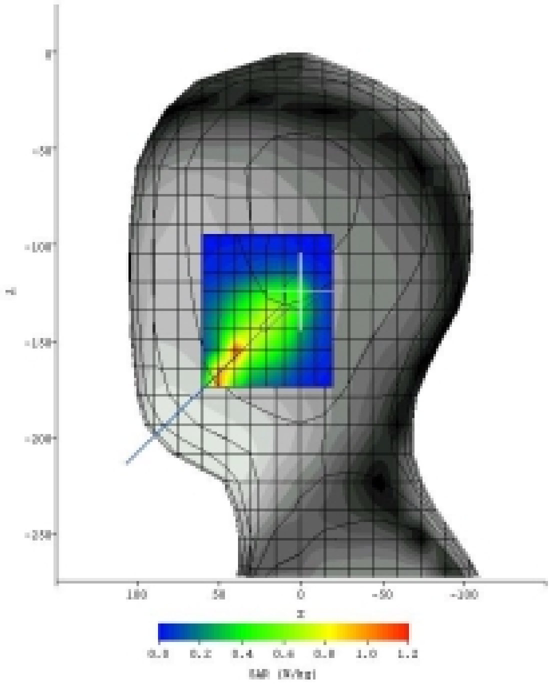


Figure 8: Spot SAR distribution measured close to the phantom wall with Carphone Warehouse PHF kit used with the Nokia 3210 phone on 900MHz band.

Figure 8 shows a typical coarse SAR scan with an earpiece cable taped to the cheek. The point of maximum SAR is approximately 60mm from the earpiece. The values shown are the 'spot' SAR values measured inside the phantom close to the surface of the shell.

UNCERTAINTY IN MEASUREMENTS

An assessment of the uncertainties in the estimation of the absolute SAR values has previously been performed making additional allowances for the upright geometry of the Sartest phantoms and for the way that the probe is articulated through the entry penetration at the top of the head. This shows that the expanded uncertainty in SAR values is 40% for absolute measurements. For comparative measurements as described in this report, many of the contributory uncertainties affect paired comparative measurements equally and uncertainties are reduced to approximately 5%.

DISCUSSION OF RESULTS

In previous tests (Ref 2) carried out by Sartest Ltd., personal hands-free (PHF) kits were tested with the cable hanging vertically down from the earpiece, when it was attached to the phantom ear. This is believed to accord with the procedure used for tests done for the Consumers' Association (Ref 1).

As a result of further exploratory tests done for the present study, it was found that exposure from PHF kits was raised when the earpiece cable is placed in contact with the cheek of the phantom. This gives generally higher SAR values for PHF kits than when the earpiece cable hangs vertically downwards although the maximum occurs in the cheek rather than at the ear/brain location. This behaviour can be explained with reference to the tests of the field distributions along the earpiece cables (Figs 4 & 5). These show a minimum of E-field close to the cable some distance from the earpiece and this is expected to be an H-field maximum and the position where the SAR coupling is expected to be highest. With the cable taped to the cheek, it is at its closest approach with no spacer component as used with a phone at the ear. The earpieces were placed at the ear position in contact with the headshell whilst the phones were distanced from the shell using a 3.6mm thick spacer.

The previous tests (Ref 2) have also been extended in this study by the inclusion of recent-model phones with internal antennas. These can show lower RF signal levels close to the phone on the keypad side, which can lead to low SAR. With a PHF, however, SAR levels are similar to those obtained with external antenna phones and there is little or no reduction in 'worst-case' SAR in the head for internal antenna phones afforded by the use of PHF kits. However, the hand probably has higher exposure than the head during the normal use of an internal antenna phone.

With a PHF kit in use, the maximum body absorption depends on where the mobile phone is placed. If it is in the hand, the situation is similar to normal use of the phone against the ear. If it is in a pocket, then the body absorption is expected to depend on which way round the phone is placed. There will be lower body dose by ensuring that the keypad of the phone is facing the body.

Even with the earpiece cable in contact with the cheek, significant SAR levels are only measured when an abnormal mode of use of the PHF kits is employed. This involves leading the earpiece cable close to or around the phone's antenna. It should be noted that the effects of such cable routing are sensitively affected by the exact configuration employed especially with external antennas and it is hard to define reproducible conditions. In this study, worst-cases were identified by trial and error. For the internal antennas, the earpiece cables were laid horizontally across the case close to the internal antennas as shown in the illustrations of Table 2b and this arrangement is easier to reproduce consistently.

The other factor affecting the results obtained is the proximity of other absorbing parts of the body to the phone when the PHF kit is in use. The hand acts as an absorber reducing the SAR in the head from the PHF. Other parts of the body will behave similarly depending upon where the phone is deployed.

All measurements with the phones and PHF kits tested were comfortably within the exposure guidelines for SAR set out by CENELEC and ICNIRP (Refs 4 & 5) although tests with the phone against the ear were only performed in one position and at the LH ear only. The performance of PHF kits can either be expressed as a ratio of the normal use value or an absolute value for SAR could be stated. There would seem to be some justification for using an absolute value rather than a ratio for PHF kits because the effect arises from the additional equipment and is not aiming to modify the transmission characteristics of the antenna in the handset.

No significant differences in performance between the various models of PHF cable tested have become apparent. Although the microphones are in different places on different cables and some contain push buttons, they don't appear to incorporate any design elements to avoid RF transmission along the cables.

The measurements made with a ferrite absorber attached to the cable (Figs 1 & 2) show that there is plenty of design scope in reducing RF emissions from the cables and making PHF kits with even lower 'worst-case' SAR levels.

Simple guidance could be offered to users of PHF kits based on our findings, which would ensure that they could be used without any significant dose to the head. The guidance is, essentially, to let the phone cable hang naturally from the ear, keep the earpiece cable away from the phone's antenna and not to place the phone where the antenna is close to other parts of the body.

The findings reported here show that a complex range of factors affect the SAR levels measurable when PHF kits are used with different phones. The Stewart Report (Ref. 3) identified the need to define test procedures for the evaluation of devices sold with any expectation that they might reduce the body exposure from mobile phones. Based upon our experiences, we set out suggestions for such procedures in the Appendix to this report.

CONCLUSIONS

In their intended mode of use, personal hands free kits offer very substantial reductions in SAR compared to the normal use of a mobile phone held against the ear.

If ferrite suppressers were added to the earpiece cables, then even lower levels of exposure could be achieved.

If seeking to reduce their exposure as a precautionary measure, we recommend that users of personal hands free kits should let the earpiece cable hang down naturally from the ear, keep the cable away from the phone's antenna and should not place the phone directly against the body.

REFERENCES

1) "Which?" Magazine, April 2000. Special Report, pages 11-17.

2) "SAR tests of two mobile phones with personal hands-free kits", Sartest Report for Vodafone, April 2000 (available at http://www.sartest.com).

3) Report of the Independent Expert Group on Mobile Phones (Chairman Sir William Stewart), May 2000 (available at http://www.iegmp.org.uk).

4) CENELEC European Specification ES59005 October 1998 - "Considerations for the evaluation of human exposure to Electromagnetic Fields (EMFs) from Mobile Telecommunication Equipment (MTE) in the frequency range 30 MHz - 6 GHz."

5) ICNIRP. Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300GHz). *Health Phys.*, **74**, No. 4, 494-522 (1998).

APPENDIX

Some requirements of a methodology for testing the effectiveness of various mobile phone accessories in reducing the user's exposure to absorbed radiation.

Objectives

A number of devices are available as accessories for mobile phones, which claim to reduce exposure from electromagnetic fields. Hands free kit, which is not designed to reduce exposure, but for audio convenience, can also be used as a means to reduce exposure. The Independent Expert Group on Mobile Phones recommended measurement work should be undertaken so that the consumer could make informed choices about the effectiveness of such devices. Published information on the effectiveness of different types of SAR-reducing accessories would also be valuable to help distributors of such products to assess the claims made for them thus protecting their commercial investments.

Generic information could usefully be made available about the performance constraints of different types of devices. Such information could also counter common misconceptions about how exposure arises.

What constitutes good performance?

Arguably, there is no need to further reduce SAR from mobile phones, which already meet recognised exposure guidelines. However individuals or parents on behalf of children may choose to take a precautionary approach. Proposals are in hand to provide the public with more information e.g. at point of sale, about SAR values, how they are derived and what they mean. It follows that reliable data should also be available about devices which claim reductions in exposure.

Some products claim percentage reductions from the normal use of the phone, without defining or quantifying what is a 'good' level of reduction. Consumers may be unaware that most of the shield devices attaching to mobile phones appear to reduce the overall output from the phone uni-directionally and any directional benefit towards the head may be very minor. If effects are unidirectional, clearly 100% reduction means the phone no longer works, so products with high reduction figures may not be fit for purpose. For other devices, their effects are minor and a measured SAR value would demonstrate a corresponding small reduction.

A further approach would be to define a figure, such as the ratio of SAR reduction to reduction of useful transmitted power. This would favour devices, which reduce SAR without compromising phone performance. This is especially necessary since, over a certain power output range, phones adjust their output power to optimise the communications link to the transmitter.

For hands free kit (PHF) measurement values would indicate the reduction in exposure possible.

General principles

The test methodologies employed should be closely aligned to those being recommended for standardised dosimetry assessments for mobile phone handsets. The draft methodology TC211 should be followed where appropriate in the elements of the procedures for assessing the performance of shield devices, PHF kits, etc in relation to energy absorbed by the body.

The basis of the tests should be comparative SAR testing. However, parts of the body other than the head need to be explicitly considered.

There is a need for tests on phone accessories to be made simple and low-cost, as the devices themselves are inexpensive. The procedures should be simpler than the full product testing of a particular phone type for compliance purposes.

Specific requirements

It should be agreed which products are more suited to either a comparative or absolute approach to performance assessment. For example, PHF kits may be more suitable for absolute assessment, whilst devices attaching to a phone are more suited to comparative assessment.

Absolute measurements should be related to the maximum exposure for all parts of the body, which may absorb significant energy levels.

Comparative measurements should take care to control all the variables affecting comparisons such as device position, output power constancy, etc.

Tests must be performed on examples of the actual products sold. Tests performed on the materials from which they are made are not of relevance.

Tests should not necessarily require full scanning measurements with body phantoms, but they should measure or compare the SAR levels in phantoms made from suitable simulant materials.

If scanning measurements are not made to find the point of maximum SAR, comparative measurements are only justified if the distribution of SAR is unaffected by the configurations being compared.