PERSONAL DOSIMETRY OF RF RADIATION

Laboratory and Volunteer Trials of an RF Personal Dosimeter

Final Report

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Personal Dosimetry of RF Radiation:

Laboratory and Volunteer Trials of an RF Personal Dosimeter

1 Executive Summary

Laboratory tests and volunteer trials were carried out to evaluate a personal exposure meter (PEM) that has been developed to measure exposure of the general public to radiofrequency (RF) radiation, as from telecommunications base stations, broadcast transmitters, and from the personal use of mobile phones. The PEM is designed to measure the electric field strengths of radio signals in several different frequency bands where there are known to be transmitters that contribute significantly to public exposure.

The laboratory tests showed the PEM had performance broadly in line with that required for its intended purpose, however there were several issues requiring further attention. These include that the PEM does not sum together properly the fields of multiple signals in the same band and that there appears to be a battery charging reliability problem.

The PEM has a 50 mV m^{-1} detection threshold and data from the volunteer trials suggest that this may limit the ability to construct an exposure gradient over the range of likely public exposures within a study. Nevertheless, the PEM does seem able to discriminate between the relatively high exposures of people who live near to mobile phone base station and television broadcast transmitters from those of people living elsewhere.

Currently, it cannot measure signals from TETRA base stations, wireless computer networks (WLANs) and digital cordless phones (DECT), but these capabilities could be added.

Recommendations have been made that should improve the usefulness of the PEM for validating exposure modelling techniques and as a monitor to assess RF exposure.

2 Aims and Objectives

This project aimed to evaluate a newly developed personal exposure meter (PEM), the Antennessa DSP090, that is designed to be carried by people, sometimes worn on the body, and to log exposures to RF signals over time as they move around. The project comprised laboratory investigations and a volunteer trial to assess the technical performance of the instrument and the practical aspects of its use in studies.

The PEM records electric field strength in the nine frequency bands shown in Table 1 and it contains three orthogonal sensors in order to give an isotropic response. The dynamic range is from 50 mV m^{-1} to 5 V m^{-1} with a precision of 10 mV m^{-1}. It should be noted that the PEM gives a reading of 0.05 V m^{-1} when there is no field applied. The user specifies the recording interval and the total recording time when programming the PEM with PC software in advance of a measurement.

Band name	Active sources in the UK	Range MHz
FM	VHF broadcast radio	88-108
TV3	Digital audio broadcasting	174-223
TV4&5	UHF broadcast television	470-830
GSMtx	GSM mobile phones (900 MHz)	890-915
GSMrx	GSM base stations (900 MHz)	935-960
DCStx	GSM mobile phones (1800MHz)	1710-1785
DCSrx	GSM base stations (1800 MHz)	1805-1880
UMTStx	3G mobile phones	1920-1980
UMTSrx	3G base stations	2110-2170

Table 1 Measurement frequency bands specified for the PEM

3 Participants

The project was carried out by staff from the Electromagnetic Field Dosimetry Group at the Health Protection Agency's Centre for Radiation, Chemical and Environmental Hazards in Chilton, Oxfordshire.

4 Achievements

4.1 Laboratory Testing

4.1.1 Methods

A sequence of tests was designed to examine electrical aspects of the PEM performance, such as band selectivity, response to modulated and unmodulated signals, linearity and isotropy. Tests were also carried out to examine the performance of the instrument in multi-signal RF environments. Finally, testing was carried out to determine immunity of the PEM from commonly encountered electromagnetic fields in bands other than those it was designed to measure, including 50 Hz electric and magnetic fields, and domestic TV and PC monitor fields.

The RF fields used in the testing were produced in an EMCO 5311 GTEM cell using a Mini-circuits ZHL42 amplifier driven from an Agilent E4483C Vector Signal Generator. The field strength in the cell was set by positioning a fibre-optically connected Holaday HI-6005 3-axis electric field probe at the position that would be occupied by the PEM and then controlling the power into the cell to establish the required field strength prior to testing the PEM. This system was able to produce fields of precisely known frequency, strength, modulation and polarisation.

Specially shaped blocks of a low dielectric constant material (Eccostock SH2, Emerson and Cuming) were made to hold the PEM at the correct position and orientation in the GTEM cell, as shown in Figure 1. X, Y and Z orientations were defined for which a given sensor inside the PEM was directly aligned with the vertically directed electric field.

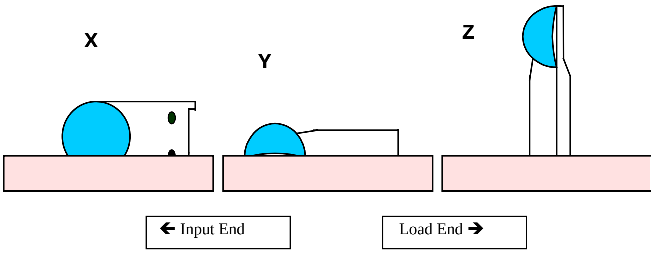

Figure 1 Orientations of the PEM inside the GTEM cell

A jig was prepared which allowed rotation of the PEM inside the GTEM cell in order to investigate its response in four different planes. These planes are shown in Figure 2.

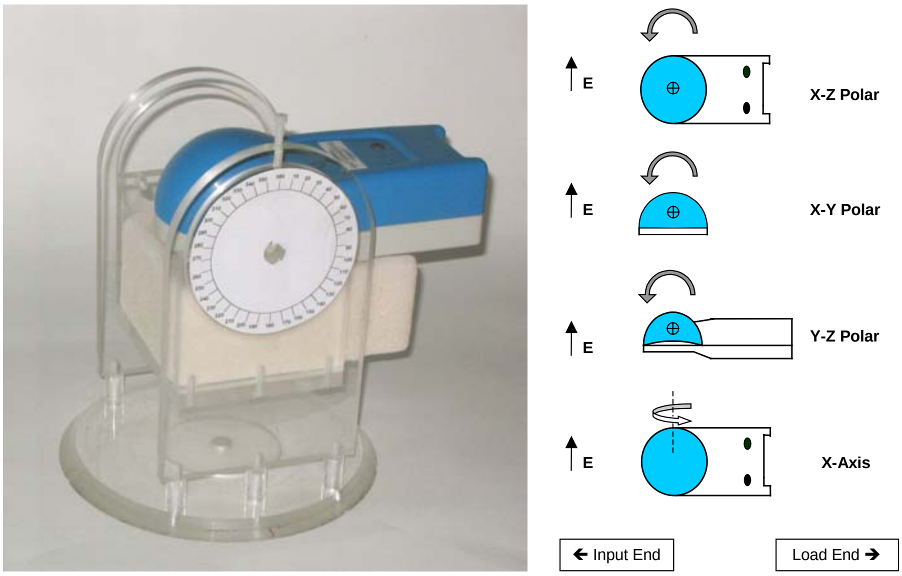

Figure 2 Jig and rotations used to examine isotropy of the PEM response

4.1.2 Unmodulated Signals

The PEM has nine response bands, as previously detailed in Table 1. In addition to the in-band performance, it was necessary to evaluate the out-of-band performance. Consequently, a large number of test frequencies were used. In addition to three frequencies per response band (lower, mid and upper), a number of out-of-band frequencies were also selected.

Each of the eight PEMs was exposed for 1 minute (with a 5 second recording interval) in three orthogonal orientations to each of the above frequencies. For each frequency and orientation, the mean recorded field value was derived, taking values of 0.05 V m^{-1} as zero field. Figure 3 shows a typical set of response data for one axis of one instrument.

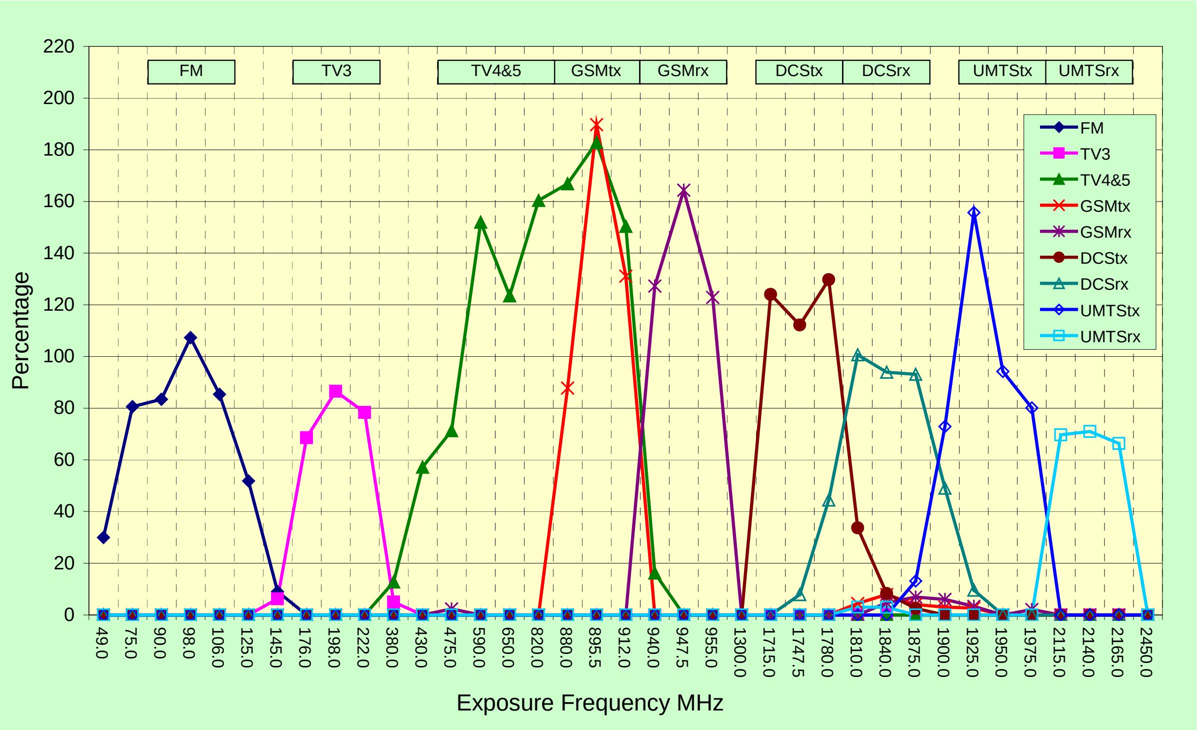

Figure 3 Relative response of a single axis of one PEM to an unmodulated field of 2.5 V m^{-1}

The results of pooling the response data from the in-band tests are shown in Table 2. The mean recorded field is shown with the standard error (n=72, i.e. 8 PEMs, 3 orientations and 3 frequencies in each band) and as the difference from the actual field value in dB. The uncertainty in the right hand column of the table is the sum of the uncertainty in the exposure field and the manufacturer's figure for isotropicity.

Mean recorded field, V m^{-1}	dB relative to 2.5 V m^{-1}	Uncertainty, dB
1.94 ±0.05	-2.20	1.50
2.43 ±0.08	-0.24	2.00
2.56 ±0.09	+0.19	2.60
2.90 ±0.12	+1.29	3.10
3.33 ±0.07	+2.49	3.10
2.66 ±0.06	+0.53	3.70
2.55 ±0.03	+0.17	3.70
2.55 ±0.08	+0.18	3.70
2.10 ±0.04	-1.51	3.70

Table 2 Pooled response data from all eight PEMs

All of the responses, except for that of the FM band, are within the expected uncertainty and the standard errors show a fair degree of consistency between responses.

In-band linearity tests were performed on two instruments. For each of the nine response bands, a field of 2.5 V m^{-1} was established in the test position in the GTEM cell using the appropriate mid-band test frequency. The cell line voltage was then reduced by a factor of two to generate a field of 1.25 V m^{-1} and this process repeated a further three times, resulting in a final field of about 0.156 V m^{-1}. No significant non-linearity was seen.

A more detailed investigation of the linearity at low fields in the FM and TV4&5 bands was carried out using one instrument. This used a similar method to the earlier linearity tests, but used fields of 2.5, 0.25, 0.125, 0.10, 0.08, 0.06 and 0.05 V m^{-1}. There were difficulties in carrying out this measurement using fields close to the instrument's lower response limit. Taking account of this, no significant non-linearity was found.

4.1.3 Modulated Signals

An extensive series of tests was conducted to determine the response of the PEM to modulated signals. In general, these were conducted with one or two instruments at field strengths of 1.0 and 2.5 V m^{-1}, using both modulated and unmodulated signals for each of the X, Y and Z orientations. Confirmation of the consistency of the RMS field between modulated and unmodulated states was obtained by the use of a thermal power meter (Rohde & Schwarz model NRS).

Responses to FM radio (98 MHz), synthetic DAB radio (198 MHz), analogue TV (CH36, with video and audio carriers at 591.25 and 597.25 MHz respectively) and synthetic digital TV (CH37) signals were essentially identical to the responses to unmodulated signals of the same frequency.

An Agilent E4438C signal source was used to produce GSM/DCS, DECT and UMTS signals for testing. The GSM/DCS uplink signals were simulated with one out of eight timeslots active and the results confirmed the operation of the pulsed vs continuous signal discrimination functions in improving the selectivity of the bands, since the GSMtx signals were not measured in the TV4&5 band. The field recorded by the PEM represented that during the active part of the signal.

The GSM/DCS downlink signals were simulated with two carriers in the relevant band. The first carrier had between 1 and 8 active slots and was intended to represent a traffic channel (TCH) and the second was from a CW signal source and intended to simulate the Broadcast Control Channel (BCCH). If this BCCH surrogate was omitted, transmissions with up to 7 active slots were not recorded. The mean field strength recorded with the BCCH surrogate carrier alone was very slightly higher than that recorded when both carriers were present, irrespective of the number of active slots. This implied that the instrument response for multiple signals may be in error and it was investigated subsequently.

The results for UMTS uplink signals were essentially identical to the responses to unmodulated signals of the same frequency. With UMTS downlink signals, the PEM reading was around 6 dB lower when the modulation was applied.

No responses were seen with a DECT signal at 1890 MHz having one out of 12 timeslots active. An ATC radar signal was simulated at a frequency of 1300 MHz, with several pulse widths and repetition rates and with a peak field strength of 2.5 V m^{-1}. No responses were seen.

4.1.4 Multiple Signals

A number of tests were conducted to investigate the response of the PEM to multiple signals occurring in the same or in different bands. Outputs from the signal sources were combined using an appropriate power combiner and the resultant signal fed to the amplifier and then into the GTEM cell. The fields of each individual component and of the combined signal were checked with the HI-6005 probe. In each case, the RMS sum of the individual components corresponded closely with the field of the combined signal. Finally, a spectrum analyser was used to confirm that no unwanted spurious mixing products were present.

The majority of combinations of signals in different bands showed no significant change between single-signal and simultaneous signal results. However, there was one important exception. Recorded field strength of signals in the TV4&5 band were significantly reduced, by about one third, in the presence of a GSM 900 (Base station, CW equivalent to the BCCH transmission) signal.

Tests with signals in the same band were carried out in several of the bands. Two or three signal sources were combined using an appropriate power combiner and the resultant signal was fed to the amplifier. The fields of each individual component and the combined signal were checked with the HI-6005 probe. In each case, the RMS sum of the individual components corresponded closely with field resulting from the combined signal.

The PEM did not respond correctly to multiple in-band signals, the response being significantly less than the RMS sum. Thus the instrument will under-read in situations where there is more than one simultaneous transmitter in a band. This is a situation that will occur in practice, particularly with broadcast (FM, TV4&5) signals, and with multi-operator cellular sites.

4.1.5 Isotropy

The equipment shown in Figure 2 was used to execute the rotations also shown in the figure in order to examine the isotropy of the PEM response. The experimental method was similar to that of the previous tests, with a nominal 2.5 V m^{-1} field. Rotational increments of 10° were used with a recording duration of 1 minute for each position.

The results showed that there are deep nulls in the polar response of the PEM for certain frequencies and directions. This is to be expected given the overall size of the PEM in relation to the wavelength and that its battery boxes and circuitry cards would have passed between its sensor and the incidence direction of the exposure field for the X-Y rotation.

4.1.6 Electromagnetic Immunity

A parallel plate exposure system was used to establish a typical maximum environmental 50 Hz electric field strength of 5 kV m^{-1} and then a helmholtz coil system was used to establish a typical maximum 50Hz magnetic flux density of 100 μT. With both systems, the PEM was placed in the field with each of its sensors aligned in turn with the field for 1 minute, and then the logged data were downloaded. No responses were seen.

The PEM response to HF fields at frequencies of 1.8 and 27.12 MHz was examined by exposing the instrument in a TEM cell exposure system. The method was similar to that employed for the CW tests in the GTEM cell system and a field of 5.0 V m^{-1} was used. Whilst there was no response to the 1.8 MHz field, for the 27.12 MHz exposures the mean field was recorded as being 0.59 V m^{-1} in the FM band.

In order to evaluate the possibility of interference from TV receiver and PC monitor fields, PEMs were placed close to a number of PC monitors and domestic TV receivers. No responses were seen.

4.2 Volunteer Trial

4.2.1 Methods

Ten members of staff from HPA's Centre for Radiation, Chemical and Environmental Hazards (CRCE) volunteered to use a PEM for a period of one week and to provide feedback on their experiences and perceptions. Each PEM was programmed to record every 2 minutes over the trial week – a total of 5040 measurements – and the volunteer was also asked to keep a written diary indicating where they were at a given time so this could be correlated with the recorded data.

In advance of receiving the PEM, each volunteer identified four locations where they generally expected to spend most of their time over the trial week. Typically, these locations included their office at work, and their kitchen, bedroom and living room at home. Spot measurements of signal frequencies and field strengths over the RF spectrum from 80 MHz to 2.5 GHz were made at the locations on the day of deployment and on the day of collection of the PEM. These narrowband spot measurements were made with an antenna on a tripod close to the centre of each location and the equipment is described in more detail below.

Initially, the data from these narrowband spot measurements were examined to determine whether there were any signals contributing significantly to exposure with frequencies outside the bands covered by the PEM. Then, the signal strengths were summed to evaluate the total RMS electric field strength present in each of the PEM bands, and compared with the data recorded by the volunteer's PEM when their diary showed them to have been present at the same location.

After returning the PEM, the volunteers completed a short questionnaire reporting back on their experiences and perceptions of the instrument. The questionnaire was divided into four sections, the first of which considered how much of the time the PEM had been worn and where it had been placed when not worn. The next section asked about perceptions on the design aspects of the instrument and the practicality of wearing it in various situations. The volunteers were asked to suggest any improvements for the design of the PEM and whether they felt using it had modified their behaviour in any way. The third section asked about experiences such as whether the volunteers had felt self-conscious with the instrument or whether it had attracted any attentions/comment. Finally, the volunteers were asked how long they would be prepared to use the instrument if asked to do so again, with or without a diary. Similarly, they were asked how long they felt it would be reasonable to ask a member of the public to use the PEM.

The equipment used for the narrowband spot measurements consisted of an ARCS miniature biconical antenna connected to an Agilent E4407B spectrum analyser controlled from a laptop computer so that all of its settings were applied automatically. The measurement was made in

13 sub-bands, each with appropriate bandwidths, frequency resolutions and dwell times, as shown in Table 3, in order to measure the RMS field strength at each of 14788 fixed frequencies. The measurements were made in three orthogonal polarisations and at heights of 1.1, 1.5 and 1.7 m, and this took around an hour to perform.

Band	Frequency, MHz		Number of points	Resolution bandwidth	Sweep time, seconds	Notes
	Start	Stop				
1	80	154.95	1500	30 kHz	4.5	Includes FM Radio
2	155	389.9	2350	100 kHz	12	
3	390	394.998	1667	10 kHz	15	TETRA base stations
4	395	469.9	750	100 kHz	7.5	
5	470	854	1537	1 MHz	40	UHF Television
6	855	923.5	138	1 MHz	4.1	
7	924	961	1481	100 kHz	45	GSM base stations
8	961.5	1803.5	843	3 MHz	25	
9	1804	1880	3041	100 kHz	90	GSM base stations
10	1880.25	1901	416	100 kHz	13	DECT
11	1901.5	2108.5	208	3 MHz	6.2	
12	2110	2170	201	3 MHz	6	UMTS base stations
13	2172.5	2500	656	3 MHz	20	Includes WLAN

Table 3 Spectrum analyser settings for narrowband spot measurements

The resultant RMS electric field strength at each frequency was then calculated and spatially averaged over all three heights to reduce the sensitivity of the measurement to spatial fading. Then, a peak search algorithm was used to form tables of signal frequencies and field strengths, and experimentally derived correction factors were applied in order to account for losses due to the restricted spectrum analyser bandwidths. Finally, the signal strengths were accumulated to evaluate the total RMS electric field strength present in each the PEM bands, as defined in Table 1, and other bands of interest.

4.2.2 Spot Measurements

An initial test of repeatability of the spot measurement procedure was performed by comparing the band-accumulated data taken on deployment of the PEM with those taken on collection of the PEM. There was no guarantee that the RF spectrum would not have changed over the trial week, but even so, the data agreed with each other to within 3.4 dB (95% confidence) across the 40 locations.

Signals were measured in the FM band at 12 locations and in the TV3 band at 2 locations, however the field strengths in these bands never exceeded 50 mV m^{-1}. Signals were measured in the TV4&5 band in the houses of all but three of the volunteers, but the field strengths were only above 50 mV m^{-1} in the house of volunteer 5, who lived closer to TV broadcast masts than the other volunteers. Signals were rarely measured in the GSMtx and DCStx bands, and the field strength was always below the PEM detection threshold, suggesting that the signals were from distant phones, and no signals were measured in the UMTStx band. Signals were measured at 34 locations in the GSMrx band and at 24 locations in the DCSrx bands; however, the fields were only above 50 mV m^{-1} at three locations, all in the house of Volunteer 1. Signals were measured in the UMTSrx band at three locations, all in the house of Volunteer 1, and the signal strengths at two of these locations were above 50 mV m^{-1}. It is notable that Volunteer 1 lived around 300 m from a mast with TETRA, GSM and UMTS cellular antennas installed, and this was significantly closer to a mast than any of the other volunteers.

The deployment data were examined further to determine the influence of certain sources with frequencies outside the defined PEM bands. The sources of primary interest were TETRA base stations (390–395 MHz), wireless local area networks (WLANs) (2.4–2.5 GHz), and DECT cordless phones (1880–1900 MHz). TETRA signals made a measurable contribution at all but 10 of the locations, and they made a dominant contribution at the three locations in the house of Volunteer 1. DECT signals were measured in the houses of five of the volunteers and gave significant contributions to the total field. Two of the volunteers (1 and 6) had home computers with IEEE 802.11b WLAN capability in their houses and the signals from these were detected when the narrowband measurements were made in the same room as the computers, but not when the measurements were made in other rooms.

Detailed examination of the signals grouped under the "other" category showed that truncation of the TV4&5 band caused TV signals between 830 and 854 MHz to be excluded from the relevant summation. Similarly, truncation of the GSMrx band caused E-GSM base station signals in the range 925–935 MHz to be excluded. These theoretical exclusions do not appear to be a problem in practice as the laboratory testing has shown that the band filters are sufficiently wide to include these parts of the spectrum.

4.2.3 Personal Measurements

The records in the personal exposure data from each volunteer were assigned tag numbers based on where the diary showed the volunteer was present at the corresponding point in time. The first four tag numbers were the spot measurement locations for each volunteer, and a small number of other tag values were assigned, e.g. travelling in a car, and time spent outdoors. This allowed the recorded data to be analysed separately for each location. The data from Volunteer 10 were lost because of a battery charging problem.

The PEM records the field strength in V m^{-1} and to two decimal places. A histogram was thus formed for each volunteer/location combination, and also for the entire data set arising from each volunteer, with each of the 495 levels from 0.05 to 5.00 V m^{-1} defined as a separate bin. The data were then further processed to form curves, similar to that in Figure 4, in which the x-axis was a field strength threshold and the y-axis was the percentage of the appropriately tagged samples above that threshold.

Figure 4 shows that the highest GSMrx exposures for Volunteer 1 occurred in the dining room, where the field strength of 96% of the records (i.e. 96% of the time) was above 50 mV m^{-1}. Very little of the time was the field strength for any of the locations above 250 mV m^{-1}. A set of graphs similar to Figure 4, but covering all volunteer/band/tag combinations was produced. Numerical methods were then used to estimate the mean electric field strengths and the results are shown in Table 4.

The numerical methods proved unreliable where very few data were above the detection threshold and so mean field strengths were not estimated where less than ten such values were recorded. Among 43934 records taken across all the volunteers, only eight were above 50 mV m^{-1} in each of the FM, TV3 and UMTStx bands, and so these bands are omitted from the table. The GSMtx and DCStx bands were omitted from the table as there were few situations giving rise to many records above 50 mV m^{-1} and these situations are discussed below.

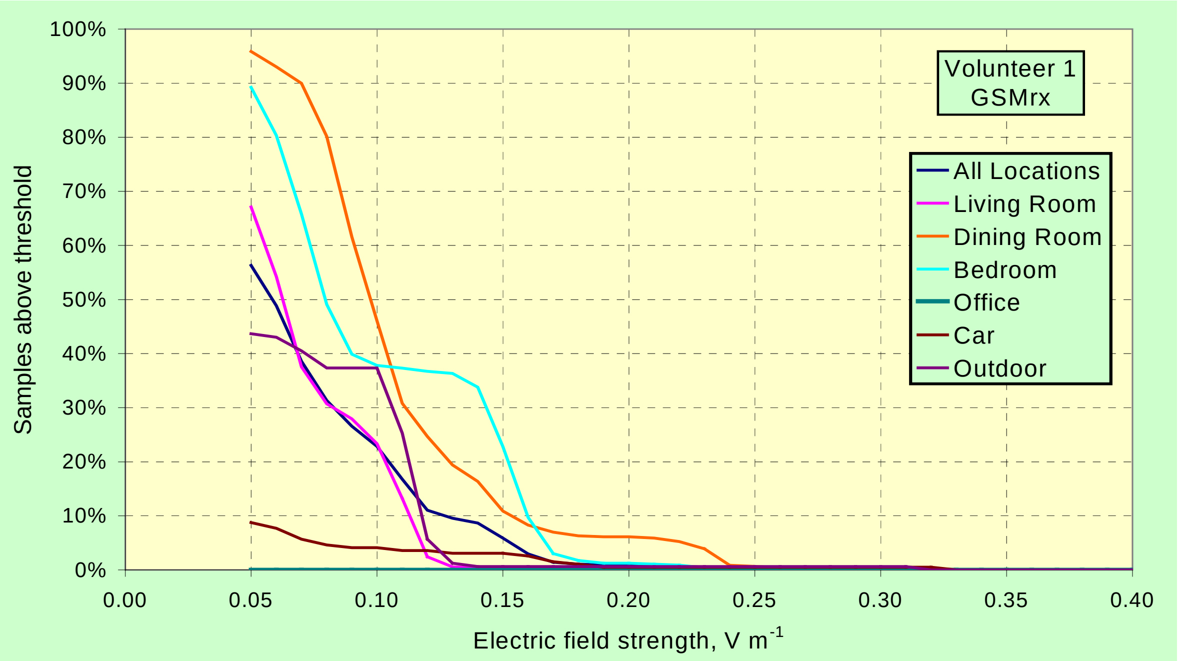

Figure 4 Example of processed personal exposure record results for the exposure of one volunteer in the GSMrx band

A range of exposures was evident in the TV4&5 bands across the volunteers and locations, although 94% of samples taken across all volunteers were below the detection threshold. 69% of the samples above the threshold were acquired from Volunteer 5, who, as noted in analysing the spot measurement data, lived nearer to VHF/UHF broadcast radio masts than the other volunteers.

The data from the GSMtx, DCStx and UMTStx bands indicated that the volunteers made little use of personal mobile phones. Data above 50 mV m^{-1} were recorded in certain situations, for example 43% of the time when Volunteer 5 travelled on a commuter train. Another notable occasion was when a volunteer placed a PEM next to a DECT base station by their bedside. Continual recording of data just above 50 mV m^{-1} throughout the night indicated that the DECT signals were being measured in the GSMtx band.

In analysing the spot measurement data, it was noted that Volunteer 1 lived closer to a TETRA/GSM/DCS/UMTS mast (around 300 m) than any of the other volunteers. The personal measurements reflect this situation in that the mean field strength estimates for this volunteer are appreciably higher than with the other volunteers. The readings from the other volunteers exceeded the detection threshold for much smaller amounts of time, typically less than 10%, and mean estimates could not be constructed for many of the situations. The greatest fields seemed to be recorded when the volunteers were outdoors or in their cars, rather than inside their homes. Few records were above the detection threshold in the UMTSrx band.

The only situations where data were available both from spot measurements and personal exposures were with the TV4&5 band in the house of Volunteer 5 and with the GSMrx and DCSrx bands in the house of Volunteer 1. In this limited set of cases, the data were within 6 dB of each other, suggesting that the spot measurements gave a fair representation of subsequent personal exposures at the locations.

Volunteer number	Location number	Frequency band

			TV4&5		GSMrx		DCSrx		UMTSrx	
1	All		33	(30-35)	73	(64-84)	53	(47-61)		
	1	Living room	41	(38-45)	77	(67-88)	56	(49-64)		
	2	Dining room	42	(39-45)	104	(77-144)	68	(59-78)		
	3	Bedroom			115	(100-132)	131	(97-181)		
	4	Office (Work)								
	5	Car			38	(33-43)	25	(19-35)		
	6	Outdoor								
2	All									
	1	Living room								
	2	Dining room								
	3	Bedroom								
	4	Office (Work)								
	5	Car	14	(12-16)						
	6	Outdoor								
3	All		15	(11-21)			15	(11-21)		
	1	Living room								
	2	Kitchen								
	3	Bedroom								
	4	Office (Work)								
	5	Car	53	(39-73)	39	(29-53)	46	(34-64)	25	(22-29)
	6	Outdoor	67	(58-77)	50	(32-84)				
4	All		9.0	(6.7-12)	12	(9.2-17)	9.8	(9.1-11)		
	1	Living room								
	2	Kitchen								
	3	Bedroom								
	4	Office (Work)								
	5	Car	26	(23-30)	29	(21-40)	21	(18-24)		
	6	Outdoor	9.1	(8.0-11)	19	(18-21)	16	(15-17)		
	7	Bathroom (Home)	51	(47-55)						
5	All		52	(48-56)	11	(7.9-15)	18	(14-25)	8.1	(7.1-9.3)
	1	Living room	55	(51-59)						
	2	Kitchen	53	(49-57)	13	(10-19)				
	3	Bedroom	68	(63-74)						
	4	Office (Work)								
	5	Car	26	(24-31)	49	(36-68)	40	(30-56)	27	(23-31)
	6	Outdoor	29	(27-32)	26	(24-28)	54	(40-75)		
	7	Train	530	(330-820)	63	(47-89)	47	(36-67)		
	8	Study (Home)	98	(85-110)						
6	All									
	1	Living Room								
	2	Kitchen								
	3	Bedroom								
	4	Office (Work)								
	5	Car								
	6	Outdoor	19	(16-22)	7.6	(5.6-10)	10	(7.6-14)		
7	All		4.3	(3.8-5.0)	6.3	(4.7-8.8)				
	1	Living Room								
	2	Kitchen								
	3	Bedroom								
	4	Office (Work)								
	5	Car	39	(34-45)	19	(16-21)	19	(17-22)		
	6	Outdoor	15	(14-17)	30	(22-41)	27	(23-31)	25	(22-29)
	7	Train								
8	All		7.1	(5.2-9.8)	8.8	(7.7-10)	8.1	(6.0-11)		
	1	Living Room								
	2	Kitchen								
	3	Bedroom								
	4	Office								
	5	Car	30	(22-41)	36	(26-49)	36	(27-50)	19	(17-22)
	6	Outdoor	40	(38-44)						
	7	Dining Room	16	(14-18)						
9	All		13	(9.3-17)	13	(9.9-18)	17	(13-24)	9.8	(7.3-14)
	1	Living Room	15	(14-16)						
	2	Kitchen								
	3	Bedroom								
	4	Office								
	5	Music Room	100	(95-110)			56	(51-60)		
	6	Outdoor	24	(18-34)	36	(23-60)	46	(29-77)		

Table 4 Personal exposure mean electric field strength estimates in mV m^{-1} (95% CI) for various volunteer/band/location combinations

4.2.4 Feedback Questionnaire

The volunteers were not given prescriptive instructions about how and when they were to wear the PEM on their body, but the belt clip and the method of mounting on the waist were drawn to their attention. The volunteers were encouraged to experiment with wearing the PEM in different ways to find what suited them and their clothing style. Five of the volunteers did not use any form of bag/rucksack and reported varying degrees of success in wearing the PEM using its belt clip. Particular difficulties reported with wearing the instrument on the waist included the clip pushing off the belt when the volunteer sat down and that the clip did not suit all types of clothing, e.g. dresses without belts. One volunteer wore the PEM inside a small rucksack behind their shoulders. This meant that the PEM did not interfere with movement when standing and walking, but the rucksack had to be removed when sitting down. There would be the possibility of the PEM rotating inside the rucksack to face the body, thus shielding its sensors, but this was avoided by hanging the PEM by its belt clip from a loop of tape inside the rucksack. Two volunteers used the PEM inside a bag strapped around their waist, which had the comfort advantages of using a rucksack and also allowed the bag to be rotated around the waist to a convenient position. The remaining two volunteers used shoulder bags, with which the loose shoulder straps allowed the PEM to be moved around the body to a convenient position, even when driving.

When the volunteers were not moving around, they generally removed the PEM and placed it nearby. When in their lounges, volunteers were usually sat on a sofa or chair and placed the PEM on the arm of the chair, or on a table next to the chair. The volunteers indicated that it was easy to forget to pick up the PEM when they went to the kitchen or bathroom, and that sometimes when they knew they would only be away for a few minutes, they chose to leave the PEM behind. On some occasions volunteers left the PEM in the living room overnight rather than taking it to their bedroom because they forgot to pick it up.

There was a clear consensus among the volunteers that the instrument was larger than ideal and that it should be made smaller if possible. One volunteer observed that a good target size would be similar to a large mobile phone. Conversely, two volunteers pointed out that the large size of the PEM meant that they were more likely to notice it and therefore less likely to forget to pick it up. Views on the weight of the instrument were split roughly equally, with only two volunteers strongly expressing that the PEM was too heavy when worn on the waist. Carrying the PEM in some form of shoulder bag would probably lessen concerns about its weight.

Using a body worn instrument, such as a personal exposure meter, inevitably causes some changes in the behaviour of the wearer. The important question is whether any of these changes in behaviour affect their exposure. The volunteers were asked whether there were any situations in this trial where they felt using the PEM had appreciably modified their behaviour. The main issues were associated with filling in the diary and keeping the PEM near the volunteer. One volunteer felt they had moved around less in their house due to the burden of knowing that they would have to complete a diary entry. Another highlighted forgetting to pick up the instrument on leaving a location, because they then had to retrace their movements and find where they had left it. Generally the volunteers did not feel overly self-conscious with the PEM, although it was regarded as better to wear it under clothes or in a bag so it was not on view. There were some situations where volunteers chose not to wear/use the PEM and these were in an aerobics class, in a nightclub, and at home on a day when they spent some time closely supervising a small child.

Questions were asked about how long the volunteers would be prepared to use the PEM in a future trial with and without keeping a written diary. Generally, a week was seen as the maximum time while keeping a written diary, with seven of the volunteers indicating this period. Without keeping a written diary, some of the volunteers would be prepared to wear the PEM for longer, so two to four weeks would seem practical.

The volunteers were then asked to consider how long they felt it would be reasonable to ask a member of the public to use the PEM in a future study. With a diary, most of the volunteers felt a week would be acceptable, but there were a number of reservations and one volunteer felt it would be unreasonable to expect a member of the public to keep a diary for any length of time. One volunteer felt that much would depend on whether the PEM could be made lighter and smaller. If a member of the public were not expected to keep a diary, again it would seem possible to use the PEM for longer, with 1-2 weeks seeming acceptable.

5 Analysis of Objectives Met

This project has achieved its aim in evaluating the RF personal dosimeter and its potential for use in future studies. The research team has also provided feedback to the manufacturer, which was taken into account to improve the instrument during the project.

The methods and results have been shared with researchers in France who are currently planning studies with the PEM. This should assist them in planning their studies and harmonising approaches to any future collaborative work.

6 Interpretation

On the basis of laboratory tests and volunteer trials, the PEM had performance broadly in line with that required for its intended purpose, however there were several issues requiring further attention. These include that the PEM does not sum together properly the fields of multiple signals in the same band and that there appears to be a battery charging reliability problem.

The PEM has a 50 mV m^{-1} detection threshold and data from the volunteer trials suggest that this may limit the ability to construct an exposure gradient over the range of likely public exposures within a study. Nevertheless, the PEM does seem able to discriminate between the relatively high exposures of people who live near to mobile phone base station and television broadcast transmitters from those of people living elsewhere.

Currently, it cannot measure signals from TETRA base stations, wireless computer networks (WLANs) and digital cordless phones (DECT), but these capabilities could be added.

7. Future Priorities

Research groups in other European countries are now considering how the PEM might be used in future studies. A feasibility study into future epidemiological studies on the health effects of mobile telephone base stations (Neubauer et al, 2005) seems likely to be influential. The next generation of the PEM will shortly become available and this is expected to have additional bands provided for DECT, WLAN and TETRA. It is understood the battery charging and data retention problems have been overcome, but the issue of incorrect summation of multiple signals may remain as a source of uncertainty.

7.1 Study of Population Exposure

A French research group is planning to use the new PEM in a pilot study to begin in late 2005 (Cardis, 2005). Volunteers are to be recruited as a representative population sample in the two study centres of Lyon and Besançon. Two hundred volunteers from each location will use a PEM for 24 hours and a further 20 from each location will use a PEM for one week. The UK should consider a similar project with a compatible protocol, if possible, so that the data can be considered together. The issue of placement of the PEM when not on the body will need addressing and suitable guidelines/training will be required for volunteers and survey workers.

A valuable addition to personal monitoring would be the use of spot measurements in homes. These data would form a further resource regarding population exposure, with the advantages over the PEM of improved sensitivity, frequency information, and accuracy.

Possible determinants of the exposure of the subjects in the population trial should be gathered through a questionnaire and geographical databases. These might include the distance at which the volunteers reside in relation to RF sources such as broadcast and telecommunications transmitters, whether they are mobile/cordless phone users, the building materials of their houses, time spent outdoors, and time spent travelling in cars or trains. The outcome would help to answer important questions for future epidemiological study design, especially whether distance of residence from a mobile phone base station can ever be used as a predictor of exposure.

7.2 Dosimetry and Related Exposure Assessment Issues

It is important that, so far as practical, the personal measurements made in the study are traceable to standards, however it is difficult to define representative calibration conditions. This is because the PEM is to be worn on the body in a position that is not fixed and because it is to be exposed in a multipath, fading environment rather than to a plane-wave.

Computer modelling of a person exposed to a plane wave with the PEM mounted on their body could be carried out to examine the relationship between the measured field with the PEM on the body and the unperturbed (body-absent) field. Such work could also be carried out experimentally in an anechoic chamber with a turntable used to vary the angle of wave incidence.

It is known that exposure will vary significantly during sampling intervals as long as 2 minutes due to temporal fading and movement of the study subject. Hence, the relationship between sparsely sampled exposures recorded with the PEM and fully time-integrated exposures should be investigated.

The development of optimal statistical techniques to estimate mean exposures when using the PEM also requires development.

8 Publications

A draft technical report was delivered to MTHR on 31st May 2005 and subsequently considered at a meeting of the PEM Working Group on 11 July 2005. Comments were fed back to the project team before the finalised report was delivered to MTHR and published on the HPA website.

> S M Mann, D S Addison, R P Blackwell, and M Khalid. Personal Dosimetry of RF Radiation: Laboratory and Volunteer Trials of an RF Personal Exposure Meter. HPA-RPD-008, Chilton, October 2005.

Portions of the results from this work were presented at a WHO meeting on "Base Stations and Wireless Networks: Exposures and Heath Consequences" held in Geneva from 15-16 June 2005, and a written paper will appear in the workshop proceedings.

9 Financial Summary

The effort required for the project was costed at £65,520 according to the usual man-hour rates for the grades of those workers expected to be carrying out the work. It was agreed that 50% of this sum, i.e. £32,760, would be provided by MTHR and that the remainder would be met from NRPB/HPA core funds. In addition, MTHR agreed to meet travel and subsistence expenses of £5000. The total project budget was therefore £70,520.

At close of the accounts, total spending on the project was £83,019 and thus there was an over-spend of £12,499, which has been met from NRPB/HPA core funds. The reasons for the over-spend were an unexpectedly high involvement in the technical work by principal grade staff and extra experimental work required due to functional problems with the PEMs.

All of the above figures are quoted exclusive of VAT.

10 References

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