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Public exposure to radio waves near GSM microcell and picocell base stations

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Abstract
Exposures of the general public to radio waves at locations near 20 randomly selected GSM microcell and picocell base stations in the UK have been assessed in the context of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines. Compliance distances were calculated for the antennas of the base stations from their reported radiated powers. Under pessimistic assumptions that would maximise exposures, the minimum height at which the general public reference level could potentially be exceeded near any of the base station antennas was calculated to be 2.4 m above ground level. The power densities of the broadcast carriers transmitted by the base stations have been measured and scaled to include all other possible carriers. Exposures were generally in the range 0.002–2% of the ICNIRP general public reference level, and the greatest exposure quotient near any of the base stations was 8.6%. Exposures close to microcell base stations were found to be generally greater than those close to macrocell base stations.

1. Introduction

The state of research into possible health risks from mobile phones has been assessed in the UK by the Independent Expert Group on Mobile Phones (IEGMP 2000) and, subsequently, by an independent Advisory Group on Non-Ionising Radiation (AGNIR 2003). A substantial number of reviews of mobile telephony and health have also been produced by other national and international committees, expert groups and agencies (Sienkiewicz and Kowalczuk 2005). The IEGMP report noted that no independent agency had made any systematic experimental study in the UK of, for example, how the power density changes with distance from a base station. At the time of the report there had also been no systematic studies that would have allowed the IEGMP to make a useful comparison of the intensity of typical exposure levels received

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by individuals from mobile phone transmitters compared with those from other radiofrequency (RF) sources. The concerns of the IEGMP have been addressed with respect to macrocell base stations, which tend to employ visually obvious antennas mounted on free-standing masts or on the roofs of buildings (Mann *et al* 2000, Fuller *et al* 2002). However, there is a lack of information on power density around microcell base stations, which provide infill coverage and additional capacity in built-up areas, and picocell base stations, which provide indoor coverage at locations such as shopping centres, airports and railway stations. Although these base stations have lower output powers than macrocell base stations, usually a few watts, their antennas are mounted at street level and can often be approached more closely by the general public.

A study has been conducted in the UK to provide factual information about exposure of the general public to radio waves from microcell and picocell base stations, both in relation to accepted guidelines for limiting exposure and in relation to the radio waves people are exposed to from other transmitters. The principal aim of the study was to measure the power density of radio waves in the vicinity of 20 randomly selected microcell and picocell base stations (hereafter referred to generically as microcell base stations) deployed by the operators of second-generation Global System for Mobile Communications (GSM) networks. The power density measurements were made over a wide range of frequencies chosen to encompass important environmental sources in addition to the signals transmitted by the base station of interest at each site. These sources included broadcast radio and television transmitters, other mobile phone base stations and base stations for wide-area paging and terrestrial trunked radio (TETRA) networks. The measured power densities were compared with the reference level advised for exposure of the general public by the International Commission on Non-Ionizing Radiation Protection (ICNIRP 1999). The results were also compared with previously measured power densities at macrocell sites.

2. Selection and characteristics of microcell base stations

2.1. Cohort of microcell base stations

The four operators of GSM networks in the UK (O2, Orange, T-Mobile and Vodafone) each provided a list of their macrocell and microcell base stations in 2002/2003 to facilitate the study. The lists included information on each base station such as site location, number of transmitters, effective isotropic radiated power (EIRP), antenna gain and height of the antenna above ground level. This information allowed the calculation of the total radiated power of each base station. The information from the four operators was collated to produce a database containing the details of 32 837 GSM base stations.

The distribution of base stations in terms of their antenna height and radiated power is shown in figure 1. A main cluster of base stations with a peak in the distribution at an antenna height of 15 m and a total radiated power of about 50 W may be seen. The distribution also shows a distinct population of base stations with low antenna height, typically 3–6 m, and power of a few watts. Based on the distribution of data in the figure and qualitative industry definitions of microcells, a cohort was compiled of base stations considered representative of the microcell population. The cohort consisted of 3008 base stations with an antenna height no greater than 10 m and total radiated power not exceeding 5 W. There were about 2000 base stations in the distribution with low antenna height that radiated powers greater than 5 W, some transmitting several tens of watts. These were considered too powerful to be classified as microcell base stations and were not included in the cohort.

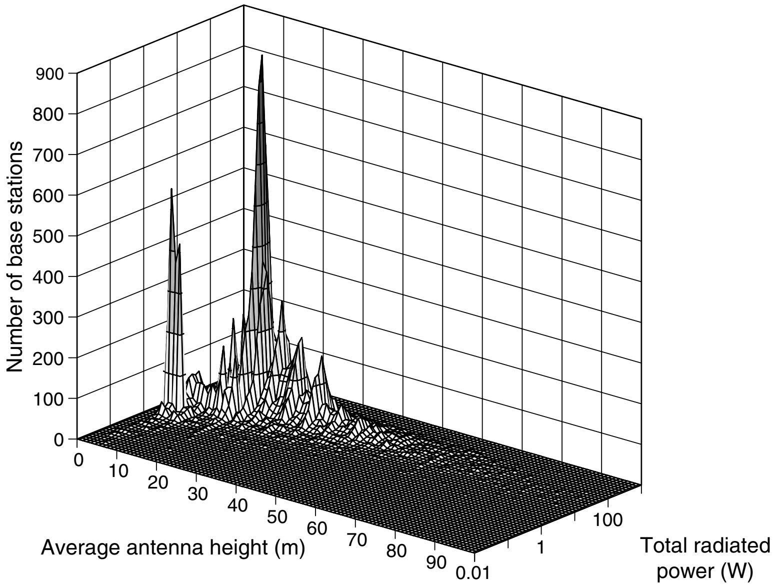

Figure 1. Distribution of GSM base stations according to antenna height and total radiated power. Antenna height is given as an average value since some base stations with multiple antennas have the antennas mounted at different heights.

2.2. Selection of base stations to be surveyed

Twenty base stations were selected at random from the cohort defined above, with the sole proviso that the number of selected base stations run by each of the network operators should be the same, i.e. five. At the time of the selection, the number of base stations known to fulfil the selection criteria numbered 2993.

Three of the 20 selected base stations were found to be sited on land or inside buildings that were owned privately. The owners or proprietors of two of the sites granted permission for measurements to be carried out; however, consent was not obtained to conduct measurements at the third site. A substitute base station belonging to the same network was selected at random and was found to have been installed at a site where no special provisions for access were required.

All 20 selected base stations employed a single antenna and between one and four transmitters. The range of antenna heights was 2.5–9 m above ground level and total radiated power ranged from 1.0 to 5.0 W. The antennas associated with 17 of the base stations were mounted on the faces of exterior walls of buildings. Two of the other base stations employed antennas mounted on street furniture and the antenna associated with the remaining base station was mounted on the underside of a suspended ceiling within a public building. Further information on the selected base stations, including antenna down-tilt and half-power beamwidth, was provided by the network operators. The characteristics of the selected base stations are published in greater detail elsewhere (Cooper *et al* 2004).

3. Theoretical compliance distances

The maximum distance from the base station antenna at which the power density could equal the reference level advised by ICNIRP (1999) for exposure of the general public was calculated

Table 1. Characteristics of the 20 selected base stations, including theoretical compliance distance and minimum height above the ground at which the ICNIRP public reference level could potentially be exceeded.

Base station	Band (MHz)	Antenna height (m)	Number of transmitters	EIRP per transmitter (dBm)	Total radiated power (W)	Maximum compliance distance (m)	Minimum height at which the reference level could be exceeded (m)
A	900	2.8	2	37.15	2.0	0.42	2.4
B	900	6	2	37.05	2.0	0.41	5.6
C	900	2.6	2	29.15	1.0	0.17	2.4
D	900	4.5	1	37.05	1.0	0.29	4.2
E	900	7	2	29.15	1.0	0.17	6.8
F	1800	2.5	2	28.9	1.0	0.12	2.4
G	1800	5	2	40.4	3.1	0.44	4.6
H	900	9	2	33.25	1.1	0.26	8.7
I	900	5	1	37.15	1.0	0.30	4.7
J	900	5	2	37.45	2.0	0.43	4.6
K	1800	5	2	40.4	3.1	0.43	4.6
L	1800	4	2	39.5	2.8	0.39	3.6
M	1800	7	4	35.6	2.1	0.35	6.6
N	1800	7	2	45.7	5.0	0.79	6.2
O	900	4.8	2	38.15	2.5	0.47	4.3
P	1800	6	1	45.8	4.2	0.57	5.4
Q	1800	3.0	1	46.6	5.0	0.62	2.4
R	1800	4.8	2	43.2	4.6	0.60	4.2
S	900	5	2	37.15	2.0	0.42	4.6
T	1800	6	1	45.2	3.6	0.53	5.5

for each installation, assuming free-space propagation of radio waves. The calculation gives a theoretical upper limit for the 'compliance distance', r_c, in metres through application of the inverse-square law, given by the relation

$$r_c = \sqrt{\frac{N_{Tx} 10^{EIRP/10}}{4\pi S_{ref}}} \qquad (1)$$

where N_{Tx} is the number of base station transmitters, S_{ref} is the ICNIRP power density reference level in watts per square metre and EIRP is quantified logarithmically, in decibels relative to 1 W (dBW). The results are given in table 1 in which each base station is identified by a single alphabetical letter. The lowest heights above the ground at which the reference level could potentially be exceeded are also given in the table. These heights were evaluated simply by subtracting the compliance distance from the antenna height and are lower than would occur in practice since antennas do not radiate isotropically.

The theoretical compliance distances calculated using equation (1) ranged from 0.12 to 0.79 m. In considering these values, it should be noted that the ICNIRP reference levels are not intended as limits in themselves. They are values of external field strengths below which basic restrictions on the specific absorption rate (SAR) of energy in the body tissues cannot be exceeded. The reference levels are derived under assumptions of maximal coupling between the body and the field, such as with a uniform field strength over the body. Exposure within the first few metres of a microcell base station will be non-uniform over the body and so the coupling will be weaker. Hence, lesser compliance distances would be expected if the SAR in the human body was to be assessed and compared with the basic restrictions advised by ICNIRP. The minimum height at which the reference level could potentially be exceeded at any of the base stations was 2.4 m above ground level.

4. Measurement equipment and surveying procedures

Two types of instrumentation were used for the measurements of power density carried out during the study, broadband equipment and narrowband equipment. The broadband equipment consisted of a HI-4417 portable survey system, manufactured by Holaday Industries. The meter was supplied with an isotropic probe that incorporated diode detectors. The sensor head was removed from the handle and mounted on a wooden tripod, and was connected to the display unit by fibre-optic leads.

The narrowband equipment consisted of an Anritsu MS2711B handheld spectrum analyser connected to a PCD 8250 precision conical dipole, manufactured by ARC Seibersdorf Research GmbH. The equipment was lightweight and portable, allowing measurements at locations of general public access, such as busy town and city centres where many microcell base stations are sited. The small antenna was mounted on a wooden tripod and kept at least 1 m from pedestrians, vehicles and structures such as walls, fences and street furniture that offered the potential for mutual coupling. The coaxial cable that was used to connect the antenna to the spectrum analyser was 5 m long and beaded with ferrite to choke any RF currents on the cable and decouple it from the antenna.

Two measurement procedures were implemented, one for determining the power density due to the base station of interest, the other for evaluating the total exposure due to RF sources transmitting across a wider spectrum (Mann *et al* 2000, Apollonio *et al* 2001). When assessing simultaneous exposure to multiple radio signals with different frequencies, exposures due to individual signals should be combined since their effects are additive. Total exposure can be expressed in terms of a quotient based on the measured power density S of each detected signal and the ICNIRP reference level corresponding to the frequency of the signal, thus

$$\text{exposure quotient} = \sum_{i=1}^{N_t} \frac{S_i}{S_{\text{ref},i}} \qquad (2)$$

where N_t is the total number of signals producing the exposure. An exposure quotient not exceeding unity indicates compliance with the ICNIRP guidelines.

4.1. Base station power density

The first measurement procedure governed the measurement of the time-averaged power density due to the carrier of the broadcast control channel (BCCH) transmitted by the base station of interest. This allowed the estimation of the maximum power density from the base station by multiplying the measured value by the number of transmitters installed. Most of the measurements were carried out using the narrowband equipment described above; however, measurements at a few sites transmitting in the 900 MHz band were conducted using the broadband equipment since this allowed more measurements to be performed in a given time. The broadband equipment was used only at locations within 20 m of microcell antennas where the exposure was dominated by the emissions from the base station of interest (this was confirmed by narrowband measurements).

At most base station sites, the probe or receiving antenna was mounted with its electrical centre 1.5 m above ground level, following convention (Anglesio *et al* 2001, CEPT 2002); however, additional measurements were made at other heights at a few sites. When using the narrowband equipment, the PCD 8250 antenna was positioned in three orthogonal orientations at each measurement location. The spectrum analyser was deployed with its ‘average’ detection method selected and data were collected over a period of about 15 s for each orientation of the antenna. Time-averaging was applied because the power density varied continuously due to a

Table 2. Frequency bands examined for the assessment of total exposure.

Band	Frequency range (MHz)	Resolution bandwidth (kHz)
1	80–170	30
2	170–470	30
3	470–870	1000
4	915–960	100
5	960–1710	100
6	1805–1880	100
7	1880–2500	100

number of effects including fluctuations in temperature and humidity, electrical noise, vibration and fading resulting from the varying amplitudes and phases of the radio waves in the various propagation paths between the microcell antenna and the receiving antenna. The 400 captured data points were combined on a root-mean-square (rms) basis to yield the rms voltage received for each antenna orientation at any given measurement location.

The power density at each measurement location was calculated using the formula

$$S = K_{\mathrm{GSM}} \frac{(V_x^2 + V_y^2 + V_z^2)}{Z_0} (F_{\mathrm{A}} L_{\mathrm{C}})^2 \tag{3}$$

where V_i is the rms signal voltage with the antenna oriented parallel to direction i, F_{A} is the antenna factor, L_{C} is the linear cable loss and Z_0 is the intrinsic impedance of free space, i.e. 377 Ω. The dimensionless constant K_{GSM} is a correction factor to compensate for the response of the spectrum analyser to GSM signals when a narrow intermediate-frequency filter is used. The value of the correction factor was derived empirically from the results of laboratory tests comparing the response of the analyser to unmodulated continuous-wave (cw) signals and GMSK-modulated signals (Cooper *et al* 2004).

4.2. Total exposure

The second measurement procedure was devised to permit the calculation of the total exposure quotient due to sources transmitting over a range of frequencies in the very high frequency (VHF), 30–300 MHz, and ultra high frequency (UHF), 300–3000 MHz, bands. The narrowband instrumentation was used for all the measurements and was located in areas where the environmental clutter was least dense at each site. The receiving antenna was mounted with its electrical centre 1.5 m above ground level.

The frequency range over which the receiving antennas had been calibrated (80–2500 MHz) was divided into seven bands, listed in table 2, and each band was examined in turn for radio signals. For any given band, the spectrum analyser was used to sweep through the spectrum for 1 min with each orientation of the antenna; this process resulted in a measurement time of about 30 min per location. The bands did not encompass the frequencies used by GSM handsets since the peak power densities from handsets would generally be far greater than, and therefore unrepresentative of, the time-averaged power densities at any given location. The positive peak detection method was selected and the maximum hold facility of the analyser was employed, as recommended by the Electronic Communications Committee (ECC) within the European Conference of Postal and Telecommunications Administrations (CEPT 2002). The resolution bandwidth was selected to reflect the typical bandwidth of the signals detected in each band and the values chosen are also given in table 2.

The data obtained from the measurements were combined to give the vector-summed resultant voltage at each frequency in the sweep across the entire spectrum of interest. The

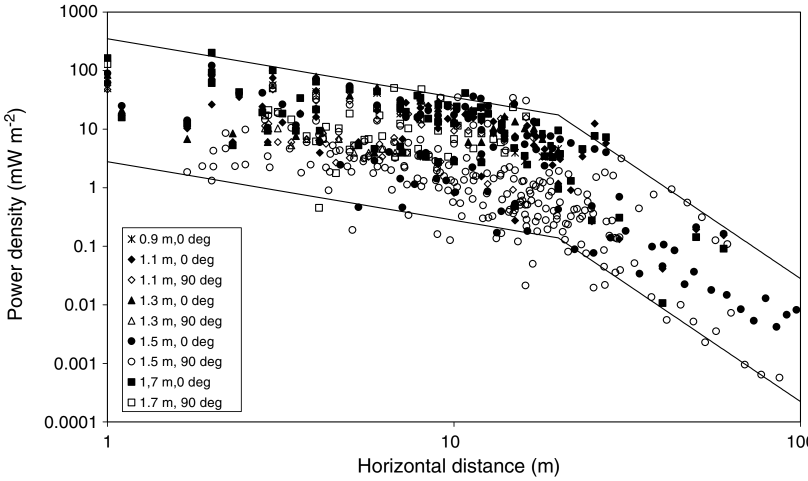

Figure 2. Power density of the BCCH carrier as a function of horizontal distance from the microcell antenna at 10 sites. The key shows the measurement height and azimuth angle with respect to the antenna beam. The solid lines represent an empirical fit to the data.

frequencies and amplitudes of all the radio signals that were clearly above the noise floor were recorded and the power density of each signal was calculated.

5. Results of exposure assessments

5.1. Base station power density

The power density of the BCCH carrier transmitted by the microcell base station of interest was measured in the vicinities of 10 of the 20 selected base stations to examine the variation as a function of distance from the antenna. Such measurements were not considered appropriate near the 10 remaining base stations, usually because the environments were cluttered due, for example, to narrow pavements, parked vehicles or high densities of pedestrians.

The results of the power density measurements are combined in figure 2. Measurements were made at a total of 610 unique locations distributed over the 10 sites. Most of the measurement locations were outdoors and accessible to the general public. Different symbols in the figure denote different heights above ground level, ranging from 0.9 to 1.7 m, and also indicate whether the measurements were made in the boresight direction with respect to the microcell antenna or at another angle (usually 90° with respect to boresight, except at base station A where measurements were made along horizontal axes of 45° with respect to boresight).

An empirical fit to the power density measurements was made by defining two 'tramlines' bounding 95% of the data points, as shown in figure 2. The values of the gradients of the tramlines, the distance at which the gradient changes and the intersections with the y-axis were assigned visually in order to minimise the separation between the tramlines. The tramlines are separated by 21 dB and the upper one intercepts the y-axis at 350 mW m^{-2}. The tramlines have a gradient of -10 dB per decade up to a distance of 20 m and a gradient of -40 dB per decade thereafter. A gradient of -40 dB is predicted at large distances from radio antennas by theoretical line-of-sight propagation models such as the two-ray ground reflection model (see, e.g., Bacon 1996, Rappaport 2002) and the formulation of the International Telecommunication

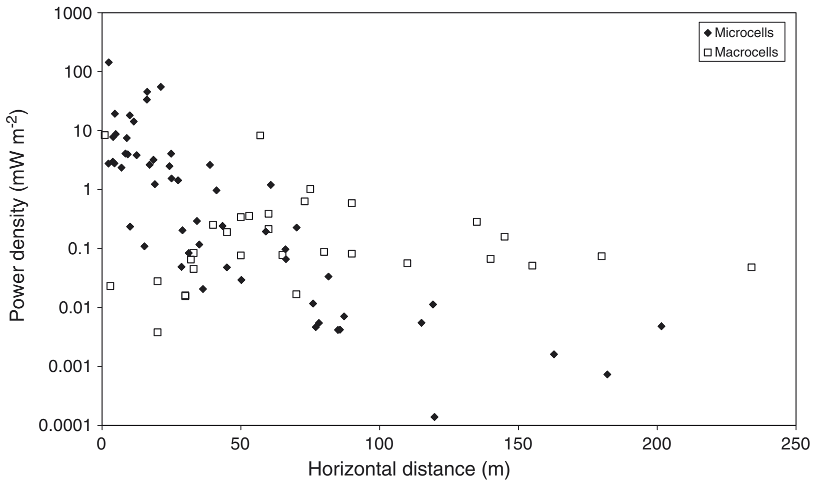

Figure 3. Total power density due to signals transmitted by the base station of interest as a function of horizontal distance from the base station antenna.

Union (ITU 2003). The inverse square law would imply a gradient of −20 dB per decade within the main beam close to a microcell antenna; however, there is a tendency to leave the main beam as an antenna is approached with these measurements, because the measurement is made at a lower height than the antenna. Hence a less steep gradient than −20 dB per decade would be expected to be found and −10 dB per decade would seem plausible.

The maximum time-averaged power density that could be produced by the microcell base station at each measurement location was obtained by multiplying the measured power density from the BCCH carrier by the number of transmitters installed. Exposures due to the radio waves transmitted by the base stations were generally found to be in the range 0.002–2% (the 5th to 95th percentiles) of the reference level advised by ICNIRP for exposure of the general public. The greatest power density measured anywhere near the selected base stations was 8.6% of the reference level. This was at a height of 1.7 and 2 m horizontally in front of a base station antenna mounted on a wall at a height of 2.8 m. Exposure in the context of the ICNIRP basic restrictions would be lower than 8.6% because the power density was found to reduce over the height of a person stood at that location.

5.2. Comparison between microcells and macrocells

The power densities of all signals detected with frequencies between 80 MHz and 2.5 GHz were measured to permit calculation of the total exposure quotient for this frequency range. In addition a comparison was made of the exposure quotient due to the base station of interest with exposure quotients due to other transmitters. The measurements were conducted at 60 locations, with between one and five locations at each of the 20 selected base station sites. All but two of the locations were outdoors; the remaining two locations were inside a public building. About 50 of the measurement locations had a clear line-of-sight path to the antenna of the base station of interest. The view of the antenna was either partially obscured or completely obstructed at the other locations.

The total power density of signals transmitted by the base station of interest was calculated from the sum of the power densities of the BCCH carriers and non-BCCH carriers (where relevant) for each measurement location, and the results are shown in figure 3. The figure also shows the results of power density recorded at outdoor locations at macrocell base station sites, previously reported by Mann *et al* (2000). The two sets of data were obtained using broadly similar instrumentation and methodologies.

The data shown in figure 3 suggest that at horizontal distances of less than approximately 50 m from antennas, power densities from microcell base stations are generally greater than those from macrocell base stations. The primary reasons for this trend are likely to be the lower heights of the antennas at microcell sites and the broader beams produced by microcell antennas in the plane of elevation. These two factors combine such that the lower edge of the main beam (based on a 3 dB reduction of power) reaches the ground within 25 m of the antenna at microcell sites, based on the 20 base stations selected for the study. As the horizontal distance reduces below 25 m, the power density from microcell antennas continues to generally increase. This is because, even though the angle from the main beam is increasing, the rate at which this gives a reduction in power density is not so great as the rate at which power density increases due to reducing radial distance through the effect of the inverse square law. In contrast, at macrocell sites, the main beam is narrower and has more sharply defined edges so it does not usually reach ground level until the distance from the antenna is at least 50 m (Mann *et al* 2000). Consequently, people are likely to be well below the main beam when on the ground close to buildings or masts supporting macrocell antennas but are likely to be in or close to the main beam when in the vicinity of microcell antennas.

At horizontal distances greater than around 50 m from the base station antennas the trend observed appears to be reversed and the power density from macrocell base stations typically exceeds that from microcell base stations. This is likely to be largely due to the greater EIRP and number of transmitters found at macrocell base stations in comparison with microcell installations. Exposures of the public at either type of site are likely to be in or close to the main beam at distances of 50 m or more, providing there is an unobstructed line of sight to the relevant antenna.

5.3. Total exposure

The data from the 60 locations where complete spectra were obtained were analysed to calculate the total power density arising from all the radio signals detected, including those from the base station of interest. The results are shown in figure 4, which again includes results reported previously for outdoor locations at macrocell sites.

The total power density tended to be dominated by the signals transmitted by the base station of interest at locations close to the base station, unless the site had multiple occupancy. Consequently, the data in figure 4 for measurement locations within 50 m of the antennas have a similar distribution to that of the corresponding data in figure 3. However, there appears to be less of a distinction between the data at microcell sites and those at macrocell sites for distances greater than 50 m when all the environmental signals are taken into account. This indicates that other sources have greater significance at these distances and that the base station of interest, particularly if it serves a microcell, may contribute only a small fraction of the overall power density.

The total exposure quotient was determined for each measurement location in terms of the ICNIRP general public reference level. Summary statistics for the exposure quotients calculated for microcell sites and outdoor locations at macrocell sites where complete spectra were obtained are given in table 3. In addition to the total exposure quotients, statistics are given for the base station of interest and all telecommunications base stations serving GSM, TETRA and third-generation Universal Mobile Telecommunications System (UMTS) networks.

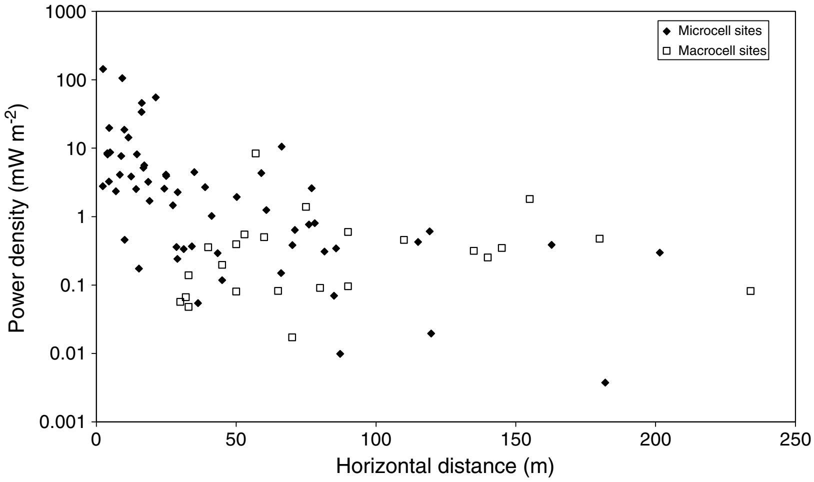

Figure 4. Total power density due to all environmental radio signals as a function of horizontal distance from the antenna of the base station of interest.

Table 3. Summary statistics for the exposure quotients derived from spectral measurements.

	Exposure quotient					
	Microcell sites			Macrocell sites		
Statistic	Base station of interest (%)	All base stations (%)	All sources (%)	Base station of interest (%)	All base stations (%)	All sources (%)
Arithmetic mean	0.12	0.17	0.17	0.010	0.011	0.013
Geometric mean	0.0051	0.021	0.027	0.0015	0.0021	0.0037
5th percentile	0.000 03	0.000 51	0.0015	0.000 23	0.000 24	0.000 61
95th percentile	0.43	0.61	0.61	0.019	0.023	0.028
Maximum	3.1	3.1	3.1	0.17	0.17	0.18

The results given in table 3 show that the exposure quotients at microcell sites were generally greater than those at macrocell sites. This was expected from the distribution of the data since two-thirds of the spectral measurements at microcell sites were conducted within 50 m of the base station antennas. Total exposure quotients at microcell sites were generally in the range 0.001–0.6% at the locations where measurements were made. The greatest exposure quotient evaluated from the data was 3.1% of the ICNIRP public reference level. This is less than the greatest exposure quotient reported in section 5.1 because the spectral measurements were not necessarily made at the locations where the base station power density was greatest. However, the results of the spectral measurements might be considered more representative of people's time-averaged exposures due to the selection of measurement locations at places where members of the public might be most likely to linger.

The percentage of the total exposure quotient that was contributed by the base station of interest was determined from the spectral data accumulated for each measurement location, and the results are shown in figure 5. Summary statistics for the percentages of total exposure due to the base stations of interest, determined for microcell sites and outdoor locations at macrocell sites, are given in table 4.

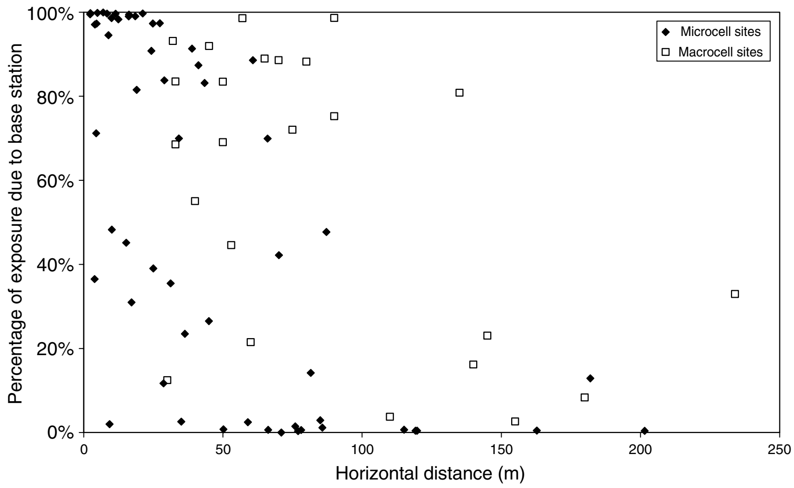

Figure 5. Percentage contribution of the base station of interest towards the total exposure quotient.

Table 4. Summary statistics for the percentages of total exposure due to the base stations of interest.

	Percentage contribution	
Statistic	Microcell sites (%)	Macrocell sites (%)
Arithmetic mean	52	58
Geometric mean	20	41
5th percentile	0.4	4
95th percentile	100	98
Maximum	100	99

The data shown in figure 5 are highly variable. The base station of interest generally contributed between 0.4% and 100% of the total exposure at microcell sites. The contribution was less than 5% at 16 of the 60 measurement locations, and more than 95% at another 16 locations. At macrocell sites, between 4% and 98% of the total exposure was generally due to the base station of interest. There was an overall trend for the percentage contribution to increase with decreasing distance to the base station antenna at both types of site.

6. Conclusions

The distribution of 32 837 base stations in terms of antenna height and radiated power has been examined from information provided by the operators of GSM networks in the UK. The distribution showed a distinct population of base stations with low antenna height, typically 3–6 m, and power of a few watts. Nine per cent of the base stations had antenna height no greater than 10 m and total radiated power not exceeding 5 W and these were considered representative of the microcell population.

Twenty microcell base stations were selected at random for detailed study. An upper limit for the compliance distances, in terms of the ICNIRP general public reference level, was calculated for each of the selected base stations. The compliance distances ranged from 0.1 to 0.8 m in front of the antennas. The calculations used in deriving these distances do not consider the non-uniform spatial distributions of field strength close to small antennas, and lesser compliance distances would be expected to result from SAR assessments. Assuming isotropic radiation patterns, the minimum height at which the reference level could theoretically be exceeded near any of the 20 base station antennas was 2.4 m above ground level. Real antennas do not have isotropic radiation patterns and so, again, lesser distances would be expected with a more detailed assessment.

Exposure quotients were derived from the power density of the BCCH carrier transmitted by the base station of interest. This was measured at 610 locations, distributed around 10 of the selected base stations. Most of the measurements were outdoors, at heights in the range 0.9–1.7 m above ground level, and were accessible to the general public. Exposure quotients were generally in the range 0.002–2%, and the greatest quotient evaluated from the data was 8.6% of the ICNIRP reference level. This was at a height of 1.7 m and 2 m horizontally in front of a base station antenna mounted on a wall at a height of 2.8 m.

The power densities of all radio signals detected with frequencies in the range 80–2500 MHz were measured at 60 locations spread around the 20 selected base stations. The spectral measurements suggested that at horizontal distances less than approximately 50 m from antennas, exposures 1.5 m above the ground near microcell base stations are generally greater than those near macrocell base stations under the same conditions. The primary reasons for this trend are the lower heights used for antennas at microcell sites and the broader beams produced by microcell antennas in the plane of elevation. At greater distances, no consistent difference between the two types of site was observed due to the influence of signals from other sources.

On the basis of the results from measurements and calculations, members of the public would not be exposed in excess of the ICNIRP guidelines whilst standing on the ground near any of the representative microcell base stations.

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