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Levels of Radiofrequency Radiation from GSM Mobile Telephone Base Stations¹

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Key Words: radiofrequency, radiation, measurements, mobile telephone, base station, broadcast, communications, safety, public exposure, GSM

ABSTRACT

There has been a proliferation of base station towers in recent years due to an expansion of mobile telephone networks. This has been accompanied by an increase in the level of community concern about possible health effects from the radio frequency (RF) radiation emissions from antennae mounted on the base station towers. This report presents field survey measurements data and provides information on the levels of RF radiation to which members of the public may be exposed from these base stations. The measured RF electromagnetic energy (EME) levels are compared with the maximum permitted limit for non-occupational exposure with respect to the Radiocommunications (Electromagnetic Radiation Human Exposure) Standard 1999 which specifies a maximum non-occupational exposure limit of 2 W/m² (equivalent to 200 μW/cm²) at relevant base station frequencies. Although the focus of the survey was on measuring the RF EME emission levels from the digital Global System for Mobile communication (GSM), the environmental RF EME measurement component of the project involved investigating the EME levels from other sources, including the analog Advance Mobile Phone Systems (AMPS), VHF TV, UHF TV, AM radio, FM radio and Paging. The results clearly demonstrate that the RF EME emissions from GSM base stations are several orders of magnitude below the maximum permitted limit. A worst case RF EME power flux density prediction, based on our measurements from GSM base stations, is 0.178 μW/cm² (the 200 μW/cm² limit of power flux density is at least 1,000 times this predicted value). However, the average RF exposure level from GSM base stations is considerably less, at 0.0016 μW/cm² (the 200 μW/cm² limit of power flux density is at least 100,000 times this average value). Measurements of the fixed site environmental RF EME power flux density levels indicate that, relative to the maximum exposure limit permitted in the standard, after adjusting the exposure limit with respect to the frequency of the signal, the highest environmental RF exposure was FM radio (0.0259 μW/cm²), with the 200 μW/cm² limit of power flux density at least 7,000 times this value.

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INTRODUCTION

In recent years there has been a proliferation of base station towers designed to meet increased demands placed on mobile telephone networks by the growing number of mobile phone users. In parallel with the construction of these base station towers there has been an increase in community concern about possible health effects from the radio frequency (RF) radiation emissions from the towers. The Australian Government Committee on Electromagnetic Energy (EME) Public Health Issues (CEMEPHI), as part of the public information component of its RF EME program, considers it important that the general public be informed about the RF EME levels to which they may be exposed. Accordingly, the CEMEPHI requested the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) to carry out a survey of the RF EME levels in the vicinity of mobile telephone base stations. This report provides information on the levels of RF radiation from RF transmitter towers (base stations) to which members of the public may be exposed. Reviews on the potential health risks of RF radiation are available elsewhere (e.g., UNEP/WHO/IRPA, 1993; Barnett, 1994; McKinlay et al., 1996; ICNIRP, 1998; Repacholi, 1998; Byrus et al., 1999).

A survey on RF EME in and around five Vancouver schools by Thansandote et al. (1999), both at indoor and outdoor sites, yielded power density measurements well within Canada's safety code limits (Safety Code 6, 1990). Signal sources investigated in the Thansandote et al survey included base station frequency bands for analog cellular phones and personal communication services (PCS – the new generation of digital cellular phone), as well as AM radio, FM radio and TV broadcasts. A US study by Petersen and Testagrossa (1992) characterized RF EME fields in the vicinity of several frequency modulated (FM) cellular radio antennae towers, at heights varying from 46 to 82 metres. They reported maximum power densities considered representative of public exposure levels to be less than 0.0001 W/m^2 per transmitter. Hence, in a worst-case scenario of 96 transmitters operating at an effective radiated power (ERP) of 100 watts per transmitter, the aggregate maximum power density was estimated by Petersen and Testagrossa to be below 0.01 W/m^2 . In Poland, where the maximum permissible power density value is 0.1 W/m^2 at relevant base station frequencies, measurements of electromagnetic fields (EMF) in the surrounds of 20 GSM base stations showed that 'admissible EMF intensities at the level of people's presence, in existing buildings, in surroundings of base stations and inside buildings with antennas, were not exceeded' (Aniolczyk, 1999, p.57).

The purpose of the work reported here is to provide data on RF EME levels at independently nominated sites, over the range of the digital Global System for Mobile communication (GSM) mobile telephone base stations frequency band (935 – 960 MHz), and to make comparisons with the limit for non-occupational exposure specified in the relevant Australian exposure standard. The Radiocommunications (Electromagnetic Radiation Human Exposure) Standard 1999 adopted by the Australian Communications Authority (ACA) requires mobile phones and mobile phone base stations to comply with the exposure limits in the interim Australian and New Zealand Standard 2772.1(Int):1998 which has now been withdrawn by Standards Australia. The ACA standard is subsequently abbreviated as ACAS in this publication. The non-occupational exposure limit specified in the ACAS, expressed in terms of power flux density, is 2 W/m^2 (equivalent to $200 \mu\text{W/cm}^2$) for frequencies between 10 MHz and 300 GHz, averaged over a 6 minute period. It should be noted that the exposure limits in the ACAS were 'developed on the basis of there being a threshold of 4 W/kg whole body specific absorption rate (SAR) before any adverse health consequences are likely to

appear' (ibid., p.13). However, because the SAR (units W/kg) is difficult and often impractical to measure, the ACAS provides derived levels of electric (E) and magnetic (H) field strengths, as well as the equivalent plane wave power flux densities (S), which are more readily measured.

Although the primary focus of the ARPANSA study was to measure the RF EME emission levels from GSM base stations, fixed site environmental measurements from other RF EME sources were also recorded, including the analog mobile phone system (AMPS), VHF TV, UHF TV, AM radio, FM radio and Paging.

METHOD

MEASUREMENT LOCATIONS

Measurements were performed at fourteen different locations throughout Australia. Two localities were chosen from each state, and the Northern Territory. In most instances the sites were chosen by local governments, who were asked to nominate two mobile telephone base stations sites in major population centers that were of concern to local communities. Security of monitoring equipment for the 24 hour data logging component was taken into account in the final selection of the measurement sites. Table 1 lists the RF measurement survey sites. Individual reports from each of these survey sites are available (see Appendix).

LOCATION	STATE	CARRIER
Bulleen	VIC	Telstra
South Melbourne	VIC	Telstra
Jolimont	WA	Telstra
Carey Park, Bunbury	WA	Vodafone
Repatriation Hospital, Daw Park	SA	Optus
Fulham Gardens	SA	Vodafone
Rapid Creek	NT	Telstra
Palmerston	NT	Optus
Nerang	QLD	Optus/Vodafone
Kenmore	QLD	Optus/Vodafone
West Riverside, Launceston	TAS	Optus
Glenorchy, Hobart	TAS	Telstra
Engadine	NSW	Telstra
Leichhardt	NSW	not specified

TABLE 1: LIST OF RF MEASUREMENT SURVEY SITES

At Nerang and Kenmore Optus and Vodafone shared the same tower. In the Leichhardt area concern was expressed for overall base station RF EME levels and not for a particular base station. Hence, with respect to Leichhardt the base station is listed in Table 1 as not specified. Environmental RF EME levels were the only measurements from base stations made at Leichhardt.

The RF EME levels of GSM mobile telephone base stations attributable to the major carriers (Telstra, Optus and Vodafone) were investigated, although not all were present at each

location. Only Telstra operate AMPS base stations in Australia, and these systems are currently being phased out. The base station antennae were positioned on towers between 20 to 40 metres in height, with the typical tower height being 25 metres. Most commonly, directional panel antennae were used. Such antennae divide the area around the base station into three sectors, with each sector usually covering a 120 degree arc in azimuth. Hence, three sets of antennae are normally in use at a typical base station. Omni-directional antennae were found to be employed at the Palmerston and Launceston sites surveyed. An omni-directional antenna provides 360° coverage of the area serviced by the base station.

NATURE AND TYPE OF MEASUREMENTS REQUIRED.

Fixed Site Environmental Measurements

Broadcast communication sources such as television, and both AM radio and FM radio, are usually transmitted at high powers from a single base facility. Such sources have very extensive areas of effective reception frequently extending to many hundreds of kilometres from a single station transmitter. Furthermore, for such sources and considering their necessary broadcast design requirements, we do not expect to encounter significant or strong variations in signal strength in relatively open areas surrounding a mobile telephone base station. Given the nature and emphasis of our study we therefore adopted a protocol of making a single set of static environmental measurements for all broadcast sources other than mobile telephone base stations. Buildings or other likely objects may significantly attenuate or scatter the RF signal. Hence, where possible, measurements were made in locations that maintained direct line-of-sight with known RF sources, at a height of ~1.7 metres above ground, in open areas in the near vicinity of the GSM base station of interest. Measurement antennae were oriented to obtain a maximum signal strength for the particular frequency band being measured. The environmental RF EME signals were measured at a location within 500 metres of the base station.

Measurement of such fixed site environmental RF EME levels involved investigating a number of different RF EME sources. These included GSM, AMPS, VHF TV, UHF TV, AM radio, FM radio and paging. All signals with power densities greater than 1% of the observed maximum for each frequency band were recorded individually. Other signals, such as emergency services (police, ambulance, etc.) and taxis, were rarely detected and are not included in this summary report. To measure the environmental RF EME levels the average RF EME levels over a six minute scanning period during the day was determined. The time taken to record all the relevant sources of environmental RF EME at each site was approximately one hour. A spectrum analyser was used and some transient signal sources, such as paging services, may have gone undetected if by chance the relevant frequency band was not swept by the spectrum analyser when the signal was transmitted.

GSM Base Station Activity Measurements

The primary aim of this study was to determine the RF EME level resulting from all signal frequencies produced by the particular GSM base stations under survey. Mobile telephone communication signals are both transient and partly random in their occurrence and distribution. In this context, we were interested in determining the RF EME levels at many locations and more particularly, we wanted to estimate both maximum and minimum levels and also the long term average value for each location and to map such levels in the area surrounding the base station. Because telephone communications are based on human activity,

a diurnal signal pattern is generally observed. Site specific GSM mobile telephone exposure levels were therefore monitored over a 24 hour period. Relevant spectrum analyser data were recorded automatically under PC control and subsequently analysed to determine both the temporal and daily average activity. Measurements were performed within a single sector, at a fixed location close to the base station, by continuously scanning the frequency bands and logging the signal level for the GSM mobile phone systems. The recorded data were used to determine the temporal activity for the GSM systems over the 24 hour period. The activity level of the data samples was determined by counting the number of simultaneous active time slots for a single carrier base station. For the majority of GSM base stations there is a possible minimum of eight and a possible maximum of thirty two time slots for any given sector. Hence, eight time slots will amount to 25% of the total activity possible from the transmitting antenna of a single carrier GSM base station.

The digital GSM base stations produce carrier frequencies between 935 to 960 MHz (analog AMPS system operates at 870 to 890 MHz). The GSM system transmits data in bursts of 0.6 μ sec with a repetition rate of 217 Hz. The temporal RF EME levels of the transmitting antennae at GSM base stations were analyzed to identify control frequencies or additional carrier frequencies. For GSM the frequency range investigated was divided up into three sub-bands, with the sampling order of each sub-band and frequency randomized to avoid bias. The system was optimized to gather as much data as possible by sampling more often when fewer frequencies were detected. Post logging data analysis was performed to determine the average activity over a six minute scanning period, yielding an activity value for every six minutes of the day. The analysis software included only the signals identified as belonging to the base station in question. Where more than one carrier (Telstra, Optus or Vodafone) shared the same tower, the combined activity from all carriers was determined. A diurnal correction factor was derived from analysis of the 24 hour activity measurements for use in mobile measurements.

Mobile GSM Base Station Area Measurements

A fixed antenna was roof mounted on a car and automated mobile measurements were made whilst driving around the streets near the GSM base station under survey. Both signal data and position information [using Global Positioning System (GPS)] were recorded. For technical reasons, we were not able to make simultaneous measurements of all frequencies at each particular mobile measurement sample location. However, for each base station sector there is always a single “control frequency” present and this frequency is produced at a constant transmitter power. The control frequency is broadcast from the same antennae as additional transient carrier frequencies. In addition, the control frequency will have similar propagation characteristics to those of any additional frequencies. Hence, to determine the RF EME area levels, only the control frequency (surrogate for all frequencies) was measured. Application of the diurnal correction factor obtained by previous activity data analysis yielded an estimate of the average RF EME over 24 hours at each measured point in the mapping area. Maps of each survey area displaying the distribution of the 24 hour average RF EME levels at each measured point are presented in the individual reports for each survey site (see Appendix).

EQUIPMENT

All RF EME measurements were recorded using a portable Tektronix Model 2712 Spectrum Analyser. This instrument is essentially a radio receiver with the capacity to measure the power distribution of a received signal as a function of frequency. Signal amplitude was usually measured in dB relative to a milliwatt (dBm). Calculation of field strength requires knowledge of the receiving antenna properties and system losses. Because the dBm measurements were all recorded in the far-field of the transmitting antennae, the measurements results could be converted to equivalent electric field strength in dB relative to microvolt per metre (dB μ V/m) using the following equation:

Field strength (dB μ V/m) = dBm measurement + 107 + receiving antenna factor + cable loss factor + spectrum analyser calibration factor

The field strength values (in dB μ V/m) were subsequently converted to power flux density. Power flux density (S) is commonly expressed in units of microwatt per square centimetre (μ W/cm²) and, in the far-field of a transmitting antenna, can be calculated from the plane wave relationship:

$$E^2 = Z * S$$

where E is the electric field strength (units V/m) and Z is the characteristic impedance of free space (≈ 377 ohms).

The spectrum analyser was interfaced to and controlled, via a communication card, by a portable lap-top computer based data logging system utilizing a portable GPS receiver. The receiver was operated in differential mode.

GSM and AMPS power density measurements were recorded from the signals radiated by the mobile telephone base stations. The signals measured by the spectrum analyser, over the frequency ranges specified below, were received using a variety of antennae. Each receiving antenna was calibrated at relevant frequencies, and the calibration factors were used in the calculations of the RF EME levels. The overall uncertainty of the measurement results is estimated to be ± 6 dB. The following receiving antennae were used:

- *Low frequency signals* (AM radio); 0.01 MHz - 30 MHz loop antenna; EMCO model 6502 active loop. This antenna was used for the stationary environmental measurements;
- *Very High Frequencies* (FM radio, VHF TV, paging); 20 MHz - 320 MHz bi-conical antenna; A.H. Systems model SAS 200/541. This antenna was used for the stationary environmental measurements;
- *Ultra High Frequency* (UHF TV, mobile telephone, paging); 300 MHz - 1000 MHz log periodic antenna; A.H. Systems model SAS 200/510. This antenna was used in the environmental and base station activity measurements; and
- *Mobile phone frequencies*; 870 MHz - 960 MHz magnetic base vehicle roof mount antenna; supplied by Telstra Shop. This antenna was used to determine 24 hour base station activity levels and mobile area survey measurements.

RESULTS

RF EME EXPOSURE AND ACTIVITY LEVELS FROM GSM BASE STATIONS

Table 2 lists the RF EME power flux density ($\mu\text{W}/\text{cm}^2$) and activity levels for the GSM base stations at the 13 relevant locations. The reference to RF EME levels always implies power flux density levels ($\mu\text{W}/\text{cm}^2$). When comparing the RF EME power flux density levels with that of the ACAS, the comparison will be given as, for example, “the limit specified in the ACAS is at least X times greater than this level.” At the bottom of Table 2 the mean and SD are given, as well as the number of sites (N) where measurements were made. No activity levels were measured from any single GSM base station in Leichhardt, and so no measurements for Leichhardt were reported in Table 2. Also, for technical reasons the activity levels at Bulleen were only recorded over a 12 hour period, between late morning and late evening.

The RF EME measurements at each locality were each adjusted to represent the mean RF EME level for the 24 hour recording period at each particular measurement position. Column 2 in Table 2 gives the ‘highest average’ RF EME levels (i.e., the highest of all the 24 hour mean RF EME readings in the surveyed area), whilst Column 3 lists the ‘area average’ RF EME levels (i.e., the average of all the 24 hour mean RF EME readings in the surveyed area). The surveyed area at each site was restricted to a radius of a few kilometres from the GSM base station. For illustrations of the spatial variation in the 24 hour mean RF EME measurements at a particular site refer to the survey map of the report for that locality.

Column 4, Column 5 and Column 6 in Table 2 lists the minimum, maximum and average activity levels respectively over a 24 hour period. These activity levels were obtained by recording the telephone activity of the GSM base station over a 24 hour period from one position. Figure 1 illustrates the overall changes in activity at each measurement locality. The three symbols in the graph correspond to the minimum activity, average activity and maximum activity over the 24 hour period. The full names for the locality abbreviations given in Figure 1 are as follows: Bulleen (Bul), Bunbury (Bun), South Melbourne (SME), Repatriation Hospital (Rep), Rapid Creek (Rap), Palmerston (Pal), Nerang (Ner), Launceston (Lau), Kenmore (Ken), Jolimont (Jol), Hobart (Hob), Fulham (Ful) and Engadine (Eng). For graphs displaying the temporal variation in activity over the 24 hour period at each individual site refer to the specific report for that locality.

Across all GSM base stations the average of the 24 hour variation in telephone activity was 32% of the total available capacity (a factor of 1.27 compared with the minimum operational capacity of 25%), with the maximum base station activity averaging 48% of the total available capacity. The largest change possible is an increase by a factor of four, which occurs when four transmitters are operating at full power. Bulleen, Vic. had the largest measured variation in activity. For this site there was a change in activity of 40% with respect to the total available capacity (a factor of 2.6 compared with the minimum operational capacity of 25%). The smallest variation in activity was at Bunbury and Fulham, where no change in activity over the 24 hour period was recorded (i.e., it remained at 25% capacity[§]).

[§]At the time of measurement the Bunbury and Fulham Gardens sites were being established. These sites had only one transmitter frequency available in each sector and this restricted the activity to a constant level of eight operational time slots.

Location	Highest average ($\mu\text{W}/\text{cm}^2$)	Area average ($\mu\text{W}/\text{cm}^2$)	Min activity (%)	Max activity (%)	Average activity (%)	Max RF EME ($\mu\text{W}/\text{cm}^2$)	100 % Capacity ($\mu\text{W}/\text{cm}^2$)
Bulleen	0.024	0.0029	25	65	40	0.039	0.060
Bunbury	0.0070	0.00031	25	25	25	0.0070	0.028
Sth Melbourne	0.042	0.0033	25	54	34	0.067	0.124
Repat Hospital	0.0055	0.00049	25	51	31	0.0090	0.018
Rapid Creek	0.0005	0.000008	25	31	27	0.00057	0.0019
Palmerston	0.072	0.00051	25	60	37	0.012	0.020
Nerang	0.048	0.0020	25	41	27	0.073	0.178
Launceston	0.017	0.0004	25	45.4	28	0.028	0.061
Kenmore	0.052	0.0051	25	56.9	36	0.082	0.144
Jolimont	0.028	0.0026	25	49	29	0.047	0.097
Hobart	0.023	0.0033	25	58	35	0.038	0.066
Fulham	0.0009	0.00013	25	25	25	0.0009	0.0036
Engadine	0.0013	0.00007	25	64	40	0.0021	0.0033
Mean	0.020	0.0016	25	48.1	31.8	0.031	0.062
SD	0.018	0.0017	0	13.9	5.4	0.029	0.058
N	13	13	13	13	13	13	13

TABLE 2: RF EME EXPOSURE AND ACTIVITY LEVELS FROM GSM BASE STATIONS.

The Table lists the RF EME power flux density ($\mu\text{W}/\text{cm}^2$) and activity levels for the GSM base stations at the 13 locations of measurements. No activity levels were measured from any single GSM base station in Leichhardt. At the bottom of each column the mean and standard deviation (SD) are given, as well as the number of sites (N) where measurements were made.

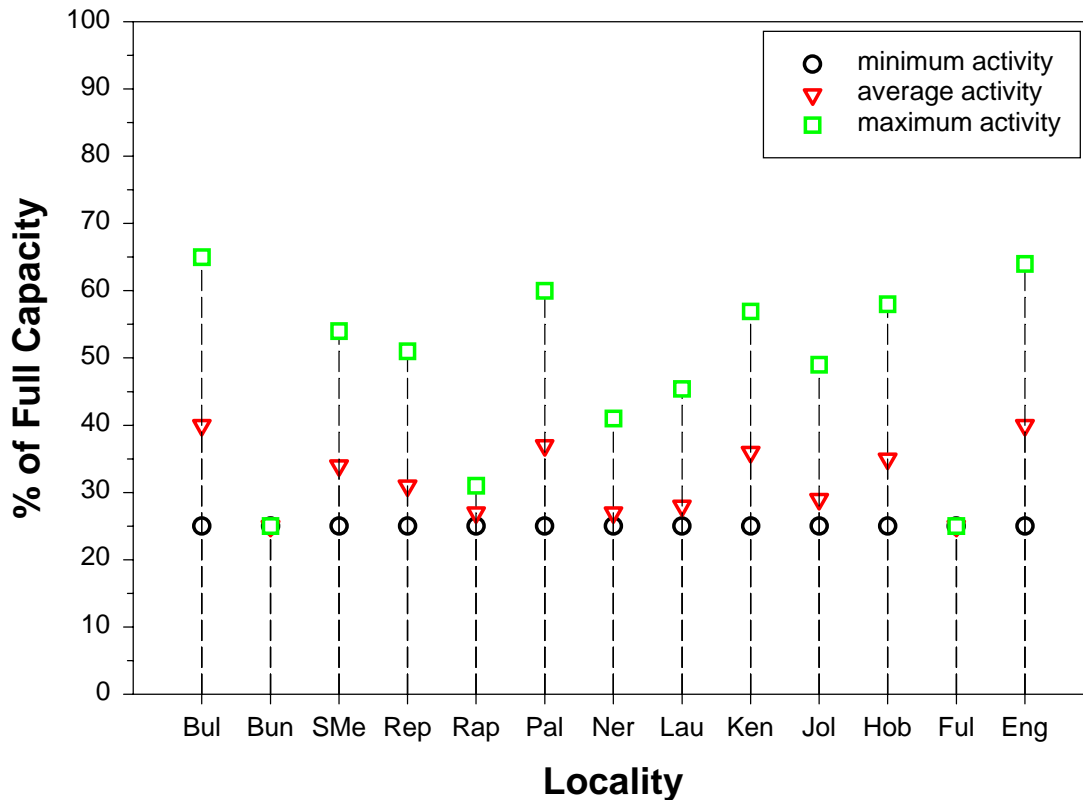


FIGURE 1: ACTIVITY LEVELS OF GSM BASE STATIONS.

The changes in activity of GSM base stations over a 24 hour period are illustrated. The full names for the locality abbreviations are given in the text.

Column 7 in Table 2 shows what the RF EME levels at maximum activity was at the point in the surveyed area that yielded the ‘highest average’ reading. Column 8 lists what the RF EME levels would be at the point in the surveyed area that yielded the ‘highest average’ reading if the base station operated at full (100%) capacity. Figure 2 displays graphically the GSM RF EME levels for the different activity levels at the 13 locations of measurement. As illustrated in Figure 2 the ‘area average’ RF EME levels were considerably less than the ‘highest average’ RF EME levels at most sites. The largest of the ‘highest average’ RF EME levels was at Kenmore ($0.052 \mu\text{W}/\text{cm}^2$ – the limit specified in the ACAS is at least 3,000 times greater than this level), as was the largest of the ‘area average’ RF EME levels ($0.0051 \mu\text{W}/\text{cm}^2$ – the limit specified in the ACAS is at least 30,000 times greater than this level). At maximum activity the largest RF EME occurred at Kenmore ($0.082 \mu\text{W}/\text{cm}^2$ – the limit specified in the ACAS is at least 2,000 times greater than this level), whilst at 100% activity the largest RF EME was at Nerang ($0.178 \mu\text{W}/\text{cm}^2$ – the limit specified in the ACAS is 1,000 times greater than this level). The mean of the ‘highest average’ RF EME levels over all sites was $0.020 \mu\text{W}/\text{cm}^2$ (the limit specified in the ACAS is 10,000 times greater than this level). The mean of the ‘area average’ RF EME levels over all sites was $0.0016 \mu\text{W}/\text{cm}^2$ (the limit specified in the ACAS is at least 100,000 times greater than this level). For maximum and 100% activity the means were $0.031 \mu\text{W}/\text{cm}^2$ (the limit specified in the ACAS is at least 6,000 times greater than this level) and $0.062 \mu\text{W}/\text{cm}^2$ (the limit specified in the ACAS is at least 3,000 times greater than this level) respectively.

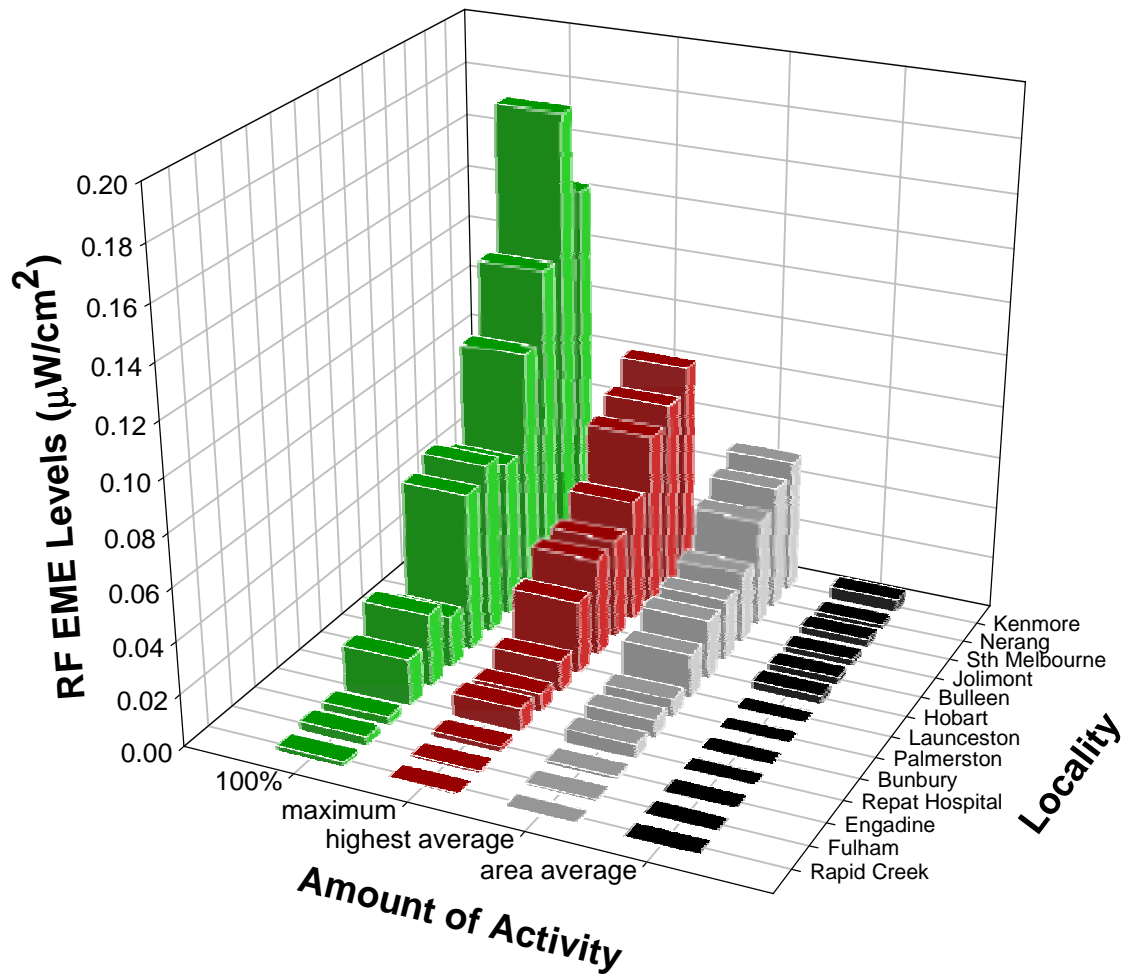


FIGURE 2: RF POWER FLUX DENSITY LEVELS ($\mu\text{W}/\text{cm}^2$) FOR GSM BASE STATIONS.

The above 3D plot is of the GSM base stations RF EME power flux density levels for the 13 different locations, at different activity levels. For explanations of the different activity levels see the text.

FIXED SITE ENVIRONMENTAL RF EME LEVELS FROM VARIOUS SIGNAL SOURCES

Table 3 lists the average fixed site environmental RF EME power flux density levels over a six minute scanning period for the different signal sources at the 14 base stations. In this report the reference to RF EME levels always implies power flux density levels ($\mu\text{W}/\text{cm}^2$). The RF EME power flux density levels in Table 3 are given to four decimal places to make it easier for comparison of signal levels. At the bottom of Table 3 the mean levels and standard deviation (SD) are given, as well as the number of sites (N) where signals were detected. It is emphasized that the environmental RF EME levels are only given as a guide. Except for GSM, the distances from the signal sources of the RF EME power flux density measurements were not known or considered. Hence, if the TV or Radio broadcasting transmitter was very distant then this may underestimate the typical population exposure to those RF sources. Likewise, if the broadcasting transmitters were very close, such as the FM transmitter at Palmerston, then this may overestimate the typical population exposure to those RF sources. Generally, transmitter TV and radio towers tend to be much higher and further away from

population areas than base stations. Also, with these other RF sources the wavelength of the RF EME radiation is longer and there is a more uniform distribution of the signal. Figure 3 is a presentation of the environmental RF EME levels of all the signal sources, at the 14 locations of measurements. Figure 4 shows the same data as in Figure 3, except that the RF EME levels for AM radio have been excluded so as to show more clearly the RF EME levels produced by high frequency sources. As is illustrated in Figure 3, AM radio signals were the dominant signal source over all the other signal sources combined in 11 of the 14 sites of measurement, and in seven of these localities AM radio contributed >95% of the total RF EME (i.e., at Bulleen, Bunbury, Fulham, Jolimont, Launceston, Repatriation Hospital, South Melbourne). At Palmerston the FM radio RF EME level was considerably greater than the AM radio RF EME level, contributing 93% of the total RF EME. At Nerang and Engadine the GSM base stations contributed 67% and 63% respectively of the total RF EME at these locations. Except for the high RF EME level in Palmerston, the RF EME levels of FM radio were generally similar in scale to that of GSM, AMPS, UHF TV and VHF TV, as illustrated in Figure 4, although the ratio of the RF EME levels from these different signal sources varied between localities.

Location	FM Radio	AM Radio	GSM	AMPS	UHF TV	VHF TV	Paging	Total RF
Bulleen	<0.0001	0.2282	0.0001	<0.0001	<0.0001	<0.0001	ψ	0.2284
Bunbury	<0.0001	0.0010	<0.0001	ψ	ψ	ψ	<0.0001	0.0010
Sth Melbourne	<0.0001	0.0662	0.0023	0.0004	UHF+VHF=0.0002		0.0002	0.0693
Repat Hospital	ψ	0.0822	0.0012	0.0001	<0.0001	<0.0001	ψ	0.0835
Rapid Creek	0.0010	0.0058	0.0002	ψ	<0.0001	<0.0001	ψ	0.0069
Palmerston	0.0259	<0.0001	0.0003	ψ	0.0018	<0.0001	<0.0001	0.0280
Nerang	0.0002	<0.0001	0.0007	ψ	0.0001	ψ	ψ	0.0010
Leichhardt	0.0015	0.0722	0.0009	0.0011	0.0047	0.0032	0.0001	0.0837
Launceston	0.0008	0.0648	0.0001	ψ	0.0003	0.0001	ψ	0.0661
Kenmore	0.0004	0.0016	0.0001	ψ	<0.0001	0.0002	<0.0001	0.0023
Jolimont	<0.0001	0.0608	0.0004	ψ	<0.0001	<0.0001	<0.0001	0.0612
Hobart	0.0012	0.0035	0.0003	<0.0001	0.0001	0.0007	ψ	0.0058
Fulham	<0.0001	0.0634	0.0007	ψ	0.0001	<0.0001	ψ	0.0643
Engadine	0.0002	0.0008	0.0027	0.0001	0.0001	0.0003	0.0001	0.0043
Mean	0.0024	0.0464	0.0007	0.0003	0.0006	0.0004	0.0001	0.0504
SD	0.0071	0.0621	0.0008	0.0004	0.0014	0.0010	0.0001	0.0611
N	13	14	14	6	12	11	7	14

TABLE 3: ENVIRONMENTAL RF EME POWER FLUX DENSITY LEVELS ($\mu\text{W}/\text{cm}^2$).

Table 3 lists the average fixed site environmental RF EME power flux density levels over a six minute scanning period for the different signal sources at the 14 locations of measurement. At the bottom of each column the mean and standard deviation (SD) are given, as well as the number of sites (N) where signals were detected (ψsignal not detected).

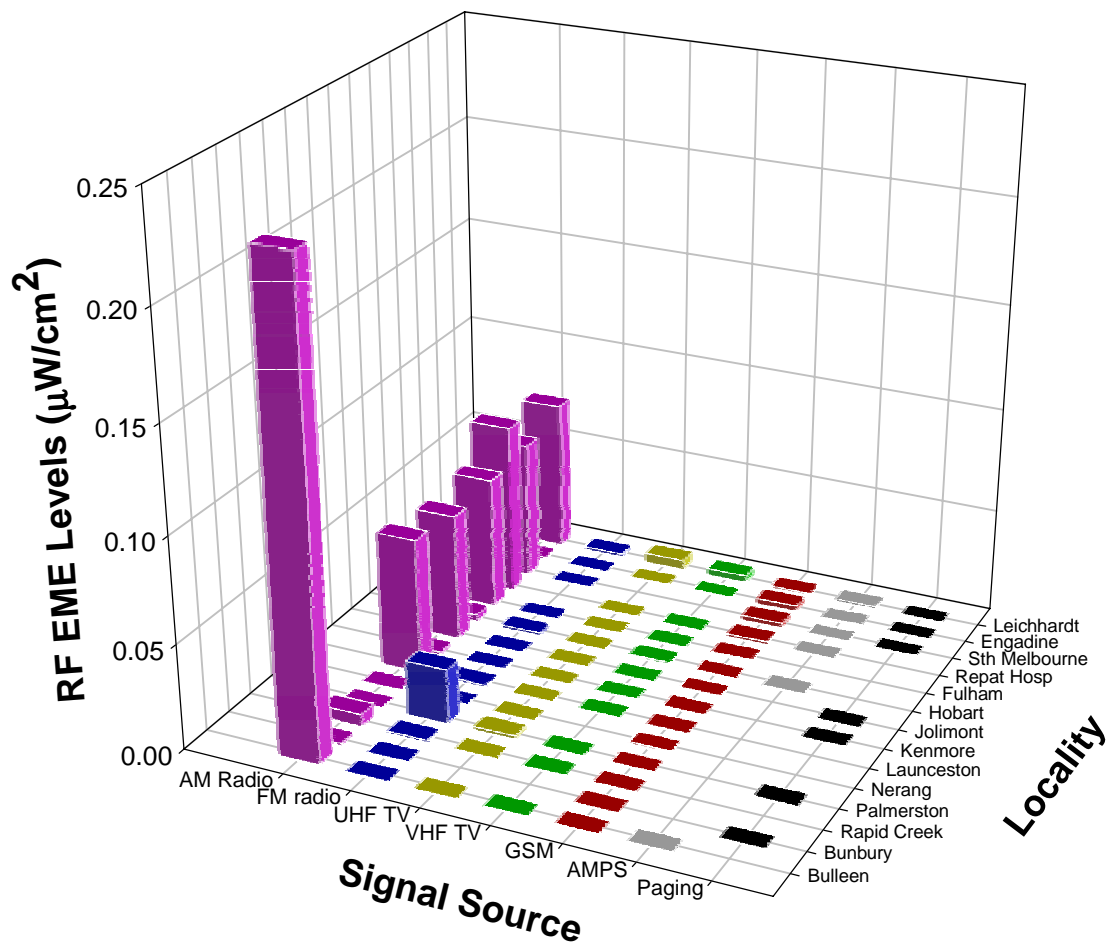


FIGURE 3: ENVIRONMENTAL RF EME POWER FLUX DENSITY LEVELS ($\mu\text{W}/\text{cm}^2$).

The above 3D plot is of the fixed site environmental RF EME power flux density levels from the 14 different locations. All significant signal sources are plotted, including AM Radio, FM Radio, UHF TV, VHF TV, GSM, AMPS and Paging.

The largest fixed site environmental RF EME levels were at: Bulleen for AM radio⁷ ($0.2282 \mu\text{W}/\text{cm}^2$ – the limit specified in the ACAS is at least 8,000 times greater than this level), Palmerston for FM radio ($0.0259 \mu\text{W}/\text{cm}^2$ – the limit specified in the ACAS is at least 7,000 times greater than this level), Engadine for GSM ($0.0027 \mu\text{W}/\text{cm}^2$ – the limit specified in the ACAS is at least 70,000 times greater than this level), Leichhardt for AMPS ($0.0011 \mu\text{W}/\text{cm}^2$ – the limit specified in the ACAS is at least 100,000 times greater than this level), Leichhardt for UHF TV ($0.0047 \mu\text{W}/\text{cm}^2$ – the limit specified in the ACAS is at least 40,000 times greater than this level), Leichhardt for VHF TV ($0.0032 \mu\text{W}/\text{cm}^2$ – the limit specified in the

⁷The ACAS exposure limit value was determined by assuming a frequency of approximately 1 MHz for AM radio. Note that the exposure limit in the ACAS for frequencies between 1 and 10 MHz is not constant, but varies according to frequency. Also, the limits in the AM radio frequency range are not given in power flux density, but in electric or magnetic field strength. To allow an approximate comparison of the measured values with the limit specified in the standard, the electric field strength limit for a frequency of 1 MHz in the standard was converted to a power flux density value, yielding an approximate exposure limit for AM radio of $2008 \mu\text{W}/\text{cm}^2$. Hence, the RF EME exposure limit for AM radio is weighted differently to that of the other higher frequency signal sources.

ACAS is at least 60,000 times greater than this level), and South Melbourne for Paging (0.0002 $\mu\text{W}/\text{cm}^2$ – the limit specified in the ACAS is 1,000,000 times greater than this level).

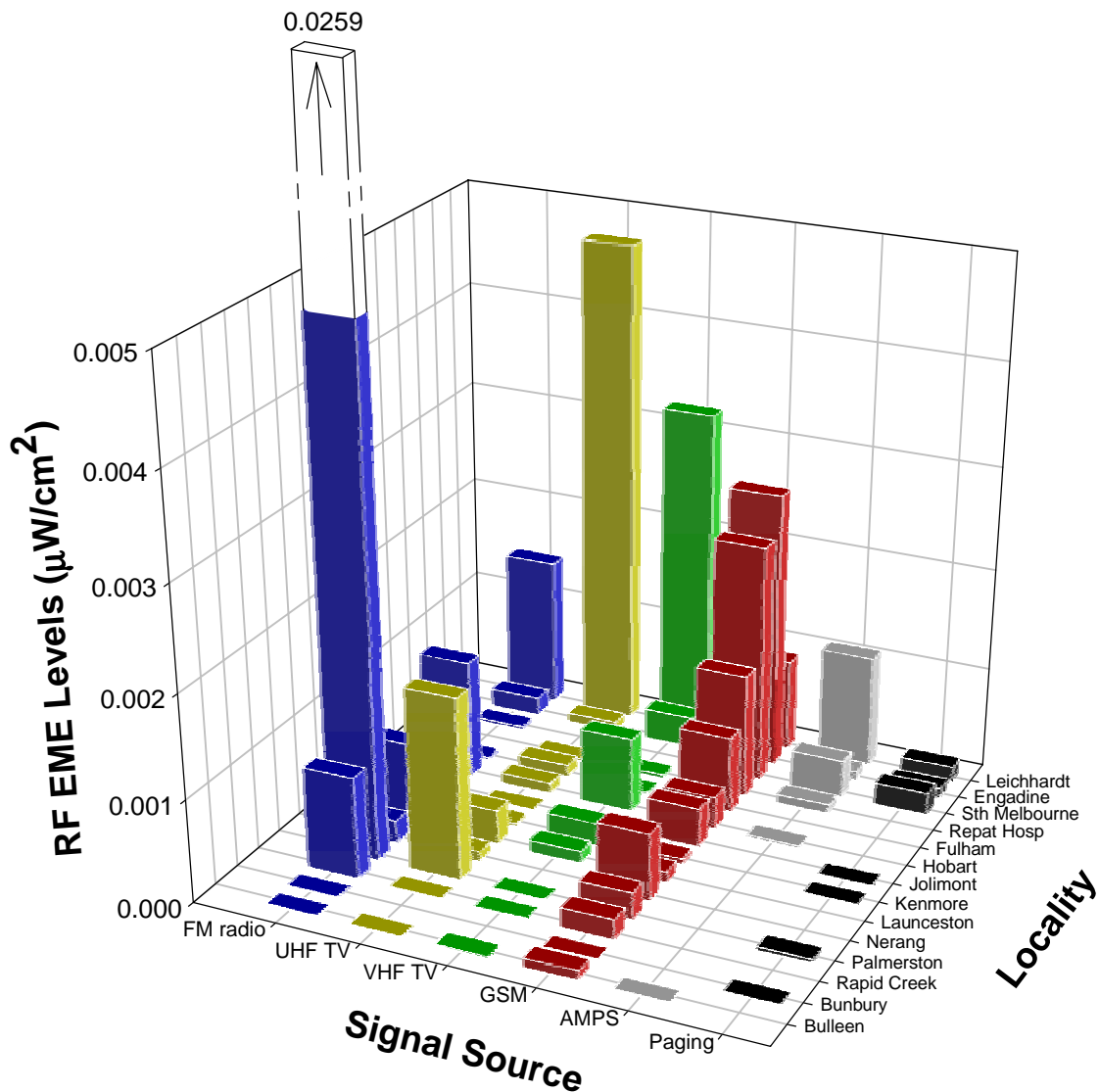


FIGURE 4: ENVIRONMENTAL RF EME POWER FLUX DENSITY LEVELS ($\mu\text{W}/\text{cm}^2$).

A plot of the data in Figure 3, with the RF EME power flux density levels for AM Radio excluded in order to show more clearly the RF EME levels produced by high frequency sources. Note that all the data fit the scale, except for FM Radio at Palmerston, which is much larger (arrow on graph indicates value).

Figure 5 displays graphical comparisons, at four different magnifications, of the mean and SD fixed site environmental RF EME levels for the different signal sources. When comparing the mean and SD RF EME levels of the various signal sources to the RF EME maximum non-occupational exposure level given in the ACAS (top left) the levels of the signal sources are not visible at the illustrated scale. However, when magnified x2000 the AM radio mean RF EME level (0.0464 $\mu\text{W}/\text{cm}^2$) becomes apparent (top right). As is clearly evident AM radio is

by far the dominant signal source. The mean AM radio RF EME level is $0.0464 \mu\text{W}/\text{cm}^2$, with the limit specified in the ACAS at least 40,000 times greater than this mean level. The levels of the other signal sources are more clearly visible in Figure 5 (bottom left) with a further magnification $\times 10$ (total $\times 20,000$ with respect to the top left graph). The mean FM radio RF EME level ($0.0024 \mu\text{W}/\text{cm}^2$) was the next strongest signal source (the limit specified in the ACAS is at least 80,000 times greater than this level). However, if the large signal from Palmerston was removed from the average the mean FM Radio RF EME level would be $0.0004 \mu\text{W}/\text{cm}^2$, comparable in scale to GSM, UHF TV, VHF TV and AMPS. To make it easier to compare these other signal sources the scale was magnified another factor of $\times 5$ (total $\times 100,000$ with respect to the top left graph). Figure 5 (bottom right) shows only small differences between the mean RF EME levels of the GSM ($0.0007 \mu\text{W}/\text{cm}^2$), UHF ($0.0006 \mu\text{W}/\text{cm}^2$), VHF ($0.0004 \mu\text{W}/\text{cm}^2$) and AMPS ($0.0003 \mu\text{W}/\text{cm}^2$) signal sources, with the Paging mean RF EME level ($0.0001 \mu\text{W}/\text{cm}^2$) being the smallest.

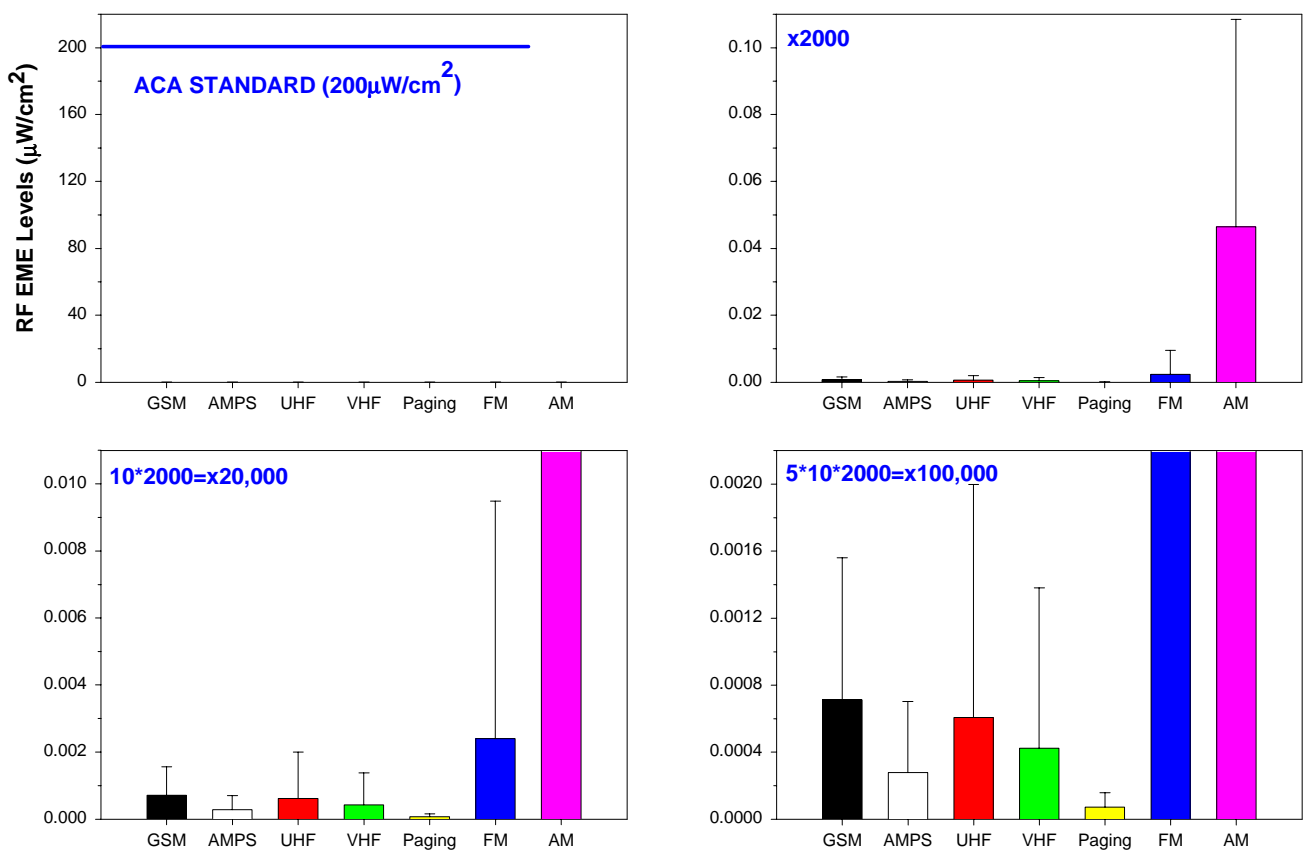


FIGURE 5: MEAN ENVIRONMENTAL RF POWER FLUX DENSITY LEVELS ($\mu\text{W}/\text{cm}^2$).

Illustrated is the mean and standard deviation fixed site environmental RF EME power flux density levels for the various signal sources, as follows: compared with the ACA Standard (ACAS) for frequencies between 10 MHz and 300 GHz (top left); and magnified with respect to the ACAS graph (top left): $\times 2000$ (top right), $\times 20,000$ (bottom left), $\times 100,000$ (bottom right).

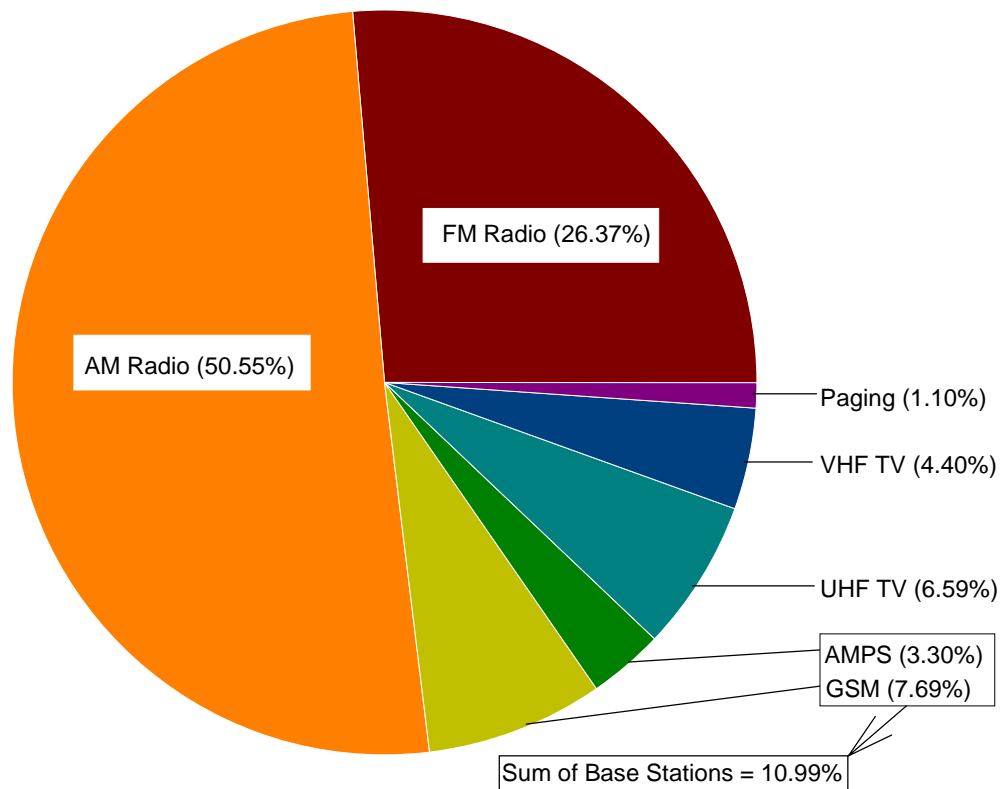
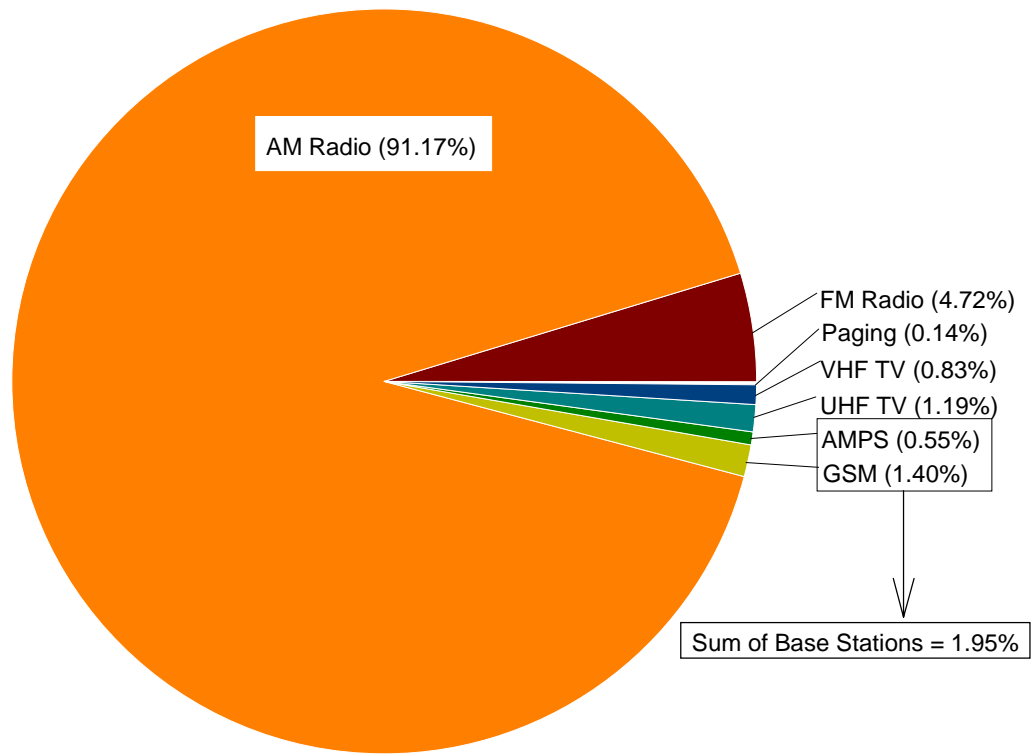


FIGURE 6: RATIO OF MEAN ENVIRONMENTAL RF POWER FLUX DENSITY LEVELS.

The top pie chart illustrates the ratio of the mean fixed site environmental RF EME power flux density levels ($\mu\text{W}/\text{cm}^2$) between the various signal sources. The bottom pie chart illustrates the same comparison, except that the signals have been weighted for frequency.

When all the mean fixed site environmental RF EME power flux density levels from the seven different signal sources were summed together the RF radiation from the base stations (AMPS and GSM combined) contributed 2.0% of the total mean RF EME, with the GSM base stations proportion being 1.4%. FM and AM radio contributed 4.7% and 91% of the total mean RF EME levels, respectively. However, a more meaningful comparison is obtained when the signals have been weighted for frequency (see footnote on page 12 for explanation). When this is done the RF radiation from the base stations (AMPS and GSM combined) contributed 11% of the total mean RF EME, with the GSM base stations proportion being 7.7%. FM and AM radio contributed 26% and 51% of the total mean RF EME levels, respectively. A pie chart comparison of the ratio (in percentage) of the mean RF EME levels between the significant fixed site environmental signal sources is shown in Figure 6.

DISCUSSION

The main purpose of this study was to provide data on the RF EME levels at GSM mobile telephone base stations and make comparisons with the required limit for non-occupational exposure with respect to the Australian Communications Authority Standard (ACAS) for RF exposure [Radiocommunications (Electromagnetic Radiation Human Exposure) Standard 1999]. The results clearly demonstrated that the RF EME emissions from GSM base stations were several orders of magnitude below the limit specified in the ACAS.

At 100% activity, which requires the GSM base stations to operate four transmitters at full power, the worst case RF EME power flux density prediction, based on our measurements, is $0.178 \mu\text{W}/\text{cm}^2$, at Nerang, QLD. The RF human exposure limit of $2 \text{ W}/\text{m}^2$ (equivalent to $200 \mu\text{W}/\text{cm}^2$) represents a power flux density at least 1,000 times greater than this worst case predicted value. In practice, the largest RF EME was $0.082 \mu\text{W}/\text{cm}^2$ at Kenmore, QLD (the limit specified in the ACAS is at least 2,000 times greater than this maximum power flux density value). These worst case and maximum values were obtained by examining numerous RF EME measurements across 13 survey localities over a 24 hour period. However, the typical RF exposure levels were generally well below these worst case values, with the mean of all the RF EME measurements, across all survey locations over a 24 hour period, recorded at $0.0016 \mu\text{W}/\text{cm}^2$ (the ACAS specifies a limit for power flux density at least 100,000 times greater than this average value).

A GSM base station operates one transmitter at full power, regardless of the telephone traffic, in order to remain operational. This operation, which is at 25% of the total capacity available, occurs mostly in the off-peak time zones late at night, but at the newly commissioned Bunbury, WA and Fulham, SA base stations the telephone network operated at 25% capacity constantly. Additional transmitters, usually up to three more at most base stations, can be turned on in response to increased telephone traffic. These additional transmitters yield output power in proportion to the number of telephone calls handled (each transmitter can allow eight simultaneous telephone calls). At full capacity, with four transmitters operating at full power, the total output power of a GSM base station could be in the order of 100 watt with minimum system losses. The average of the 24 hour variation in telephone activity across all GSM base stations was 32% of the total available capacity (a factor of 1.27 compared with the minimum operational capacity of 25%), whilst the average maximum of the activity was 48% of the total available capacity. Bulleen, Vic. had the largest measured variation in activity. For

this site there was a change in activity of 40% with respect to the total available capacity. This was still less than the largest change possible, which is an increase by 75%.

Measurements of the fixed site environmental RF EME power flux density levels indicated that the most significant contributor of RF EME emissions was AM radio, with the contribution from the remaining six RF radiation sources generally being small in comparison. The largest environmental RF EME level recorded was 0.2282 $\mu\text{W}/\text{cm}^2$ for AM radio at Bulleen, VIC (if the electric field strength limit for a frequency of 1 MHz in the standard is converted to a power flux density value then the limit specified in the ACAS is at least 8,000 times greater than this level). For GSM and AMPS the largest fixed site environmental RF EME levels were recorded at Engadine, NSW (0.0027 $\mu\text{W}/\text{cm}^2$) and Leichhardt, NSW (0.0011 $\mu\text{W}/\text{cm}^2$) respectively. AM radio, GSM and AMPS contributed 91%, 1.4% and 0.55% of the total mean RF EME power flux density levels respectively across all survey locations. Hence, whilst the contribution of AM radio was quite large, the maximum RF EME level for AM radio was still well below the limit specified in the ACAS. The highest environmental RF exposure relative to the ACAS was FM radio at Palmerston, NT (0.0259 $\mu\text{W}/\text{cm}^2$), with the limit specified in the ACAS at least 7,000 times greater than this level. However, the measurements of environmental RF EME levels from the different signal sources were all made in the same position at each site, and are not clearly indicative of the maximum RF EME level in the area. This is because reflections from the ground, buildings and other objects cause the RF EME levels to vary considerably within a surveyed area.

The RF EME levels reported here were obtained from measurements at as many as 14 different sites. Measurement surveys have finite spatial resolution, and so it is possible that there are RF EME levels exceeding the recorded values. It is considered that the reported RF EME levels reported in this publication are a good representation of what might be expected at other base stations.

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APPENDIX

Listed below are the titles of all individual reports, by Michael J. Bangay, from each of the 14 survey sites. These reports will be available for download early in 2000 from within the ARPANSA Website: <http://www.arpansa.gov.au>. For further information about these reports contact the ARPANSA Information Officer (see footnote on first page for contact details).

1. MEASUREMENT AND ANALYSIS OF RF EME LEVELS FROM THE TELSTRA MOBILE TELEPHONE BASE STATION LOCATED AT BULLEEN, VICTORIA
2. MEASUREMENT AND ANALYSIS OF RF EME LEVELS FROM THE VODAFONE MOBILE TELEPHONE BASE STATION LOCATED AT CAREY PARK, BUNBURY, WESTERN AUSTRALIA
3. MEASUREMENT AND ANALYSIS OF RF EME LEVELS FROM THE TELSTRA MOBILE TELEPHONE BASE STATION LOCATED AT ENGADINE, NSW
4. MEASUREMENT AND ANALYSIS OF RF EME LEVELS FROM THE VODAFONE MOBILE TELEPHONE BASE STATION LOCATED AT FULHAM GARDENS, SOUTH AUSTRALIA
5. MEASUREMENT AND ANALYSIS OF RF EME LEVELS FROM THE TELSTRA MOBILE TELEPHONE BASE STATION LOCATED AT GLENORCHY, HOBART, TAS
6. MEASUREMENT AND ANALYSIS OF RF EME LEVELS FROM THE TELSTRA MOBILE TELEPHONE BASE STATION LOCATED AT JOLIMONT, WESTERN AUSTRALIA
7. MEASUREMENT AND ANALYSIS OF RF EME LEVELS FROM THE VODAFONE/OPTUS MOBILE TELEPHONE BASE STATIONS LOCATED AT KENMORE, QUEENSLAND
8. MEASUREMENT AND ANALYSIS OF RF EME LEVELS FROM THE OPTUS MOBILE TELEPHONE BASE STATION LOCATED AT WEST RIVERSIDE, LAUNCESTON, TAS
9. MEASUREMENT AND ANALYSIS OF RF EME LEVELS FROM MOBILE TELEPHONE BASE STATIONS LOCATED AT LEICHHARDT, NSW
10. MEASUREMENT AND ANALYSIS OF RF EME LEVELS FROM THE VODAFONE/OPTUS MOBILE TELEPHONE BASE STATIONS LOCATED AT NERANG, QUEENSLAND
11. MEASUREMENT AND ANALYSIS OF RF EME LEVELS FROM THE OPTUS MOBILE TELEPHONE BASE STATION LOCATED AT PALMERSTON, NORTHERN TERRITORY
12. MEASUREMENT AND ANALYSIS OF RF EME LEVELS FROM THE TELSTRA MOBILE TELEPHONE BASE STATION LOCATED AT RAPID CREEK, NORTHERN TERRITORY
13. MEASUREMENT AND ANALYSIS OF RF EME LEVELS FROM THE OPTUS MOBILE TELEPHONE BASE STATION LOCATED AT THE REPATRIATION HOSPITAL, DAW PARK SOUTH AUSTRALIA
14. MEASUREMENT AND ANALYSIS OF RF EME LEVELS FROM THE TELSTRA MOBILE TELEPHONE BASE STATION LOCATED AT SOUTH MELBOURNE, VICTORIA