Microwave Exposure from Mobile Phones and Base Stations in Sweden*

Prof. Dr. Yngve Hamnerius and Thomas Uddmar

Chalmers University of Technology, Department of Electromagnetics ,
SE 412 96 Goteborg, Sweden, yngve@elmagn.chalmers.se

Introduction

For the last 15 years, there has been a tremendous increase in the use of wireless communication. Not only businessmen and workers use mobile cellular telephones, nowadays everyone has them, even children. Conventional telephones at offices have been replaced by cordless telephony systems, everyone want's to be accessible everywhere and not bound to a fixed place. User expects faster and better wireless communication services anywhere and anytime, with these demands, an increase in the use of electromagnetic fields will continue.

The Electromagnetic Spectrum

Electromagnetic waves form the electromagnetic spectrum. The spectrum contains frequencies from 0 Hz to infinity. In figure 1 the electromagnetic spectrum is shown with frequencies from 1 to 10^{20} Hz. It is a limited nature resource where some frequency bands are more interesting than others. In most countries there is an authority who regulates the EM spectrum, in Sweden PTS (National Post and Telecom Agency) allocates frequencies from 0-116 GHz, but this is based on the international radio regulation from ITU (International Telecommunication Union).

There are many electromagnetic sources in the spectrum: power lines has a frequency of 50 Hz, FM radio has a frequency around 100 MHz, GSM 900 operate at 900 MHz. Microwave ovens have a frequency of 2450 MHz etc. Visible light has a frequency around three hundred million MHz, and X-rays have frequencies above one thousand billion MHz. In figure 2a,b measured EM spectrums for radio stations and cellular telephony is shown.

Extremely high frequencies (X-rays) have sufficient energy to break chemical bonds (ionization), therefore it is possible for X-rays to damage the genetic material of cells. At lower frequencies (radiowaves) the energy is much too low to break chemical bonds, thus radiowaves are non-ionizing.

*) Original paper

Figure 1 The electromagnetic spectrum.

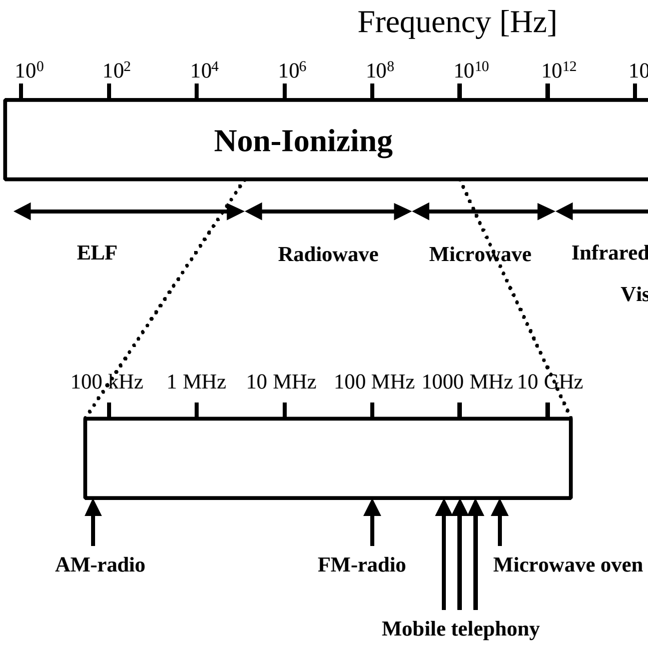


Figure 2a EM spectrum of radio stations

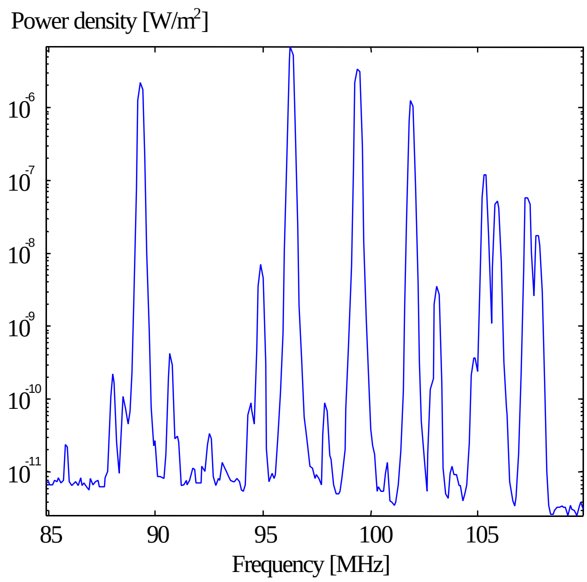
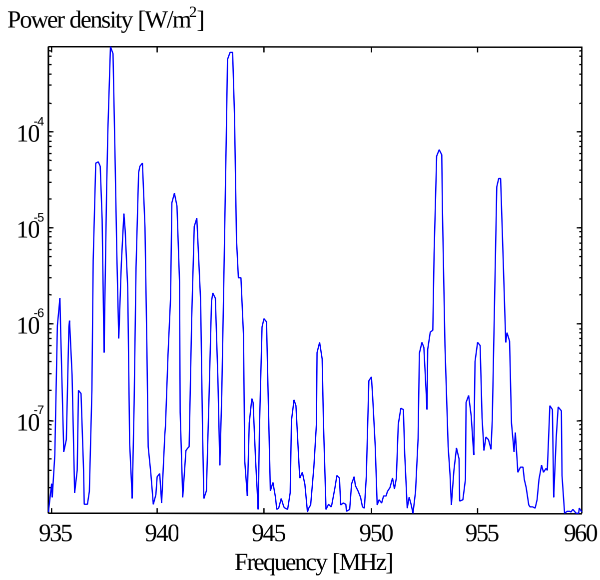


Figure 2b EM spectrum of cellular telephony



Wireless Communication Systems

The first European cellular mobile telephony started in October 1981, when the analogue NMT 450 (Nordic Mobile Telephone – 450 MHz) began in the Nordic countries. Simultaneously in the United States, the AT&T developed a comparable system called AMPS (Advanced Mobile Phone Service) which was a commercial service in Chicago in October 1983. In the mid eighties several analogue cellular mobile systems started in Western Europe and in the USA.

NMT 450 got its successor in 1986 when the NMT 900 system began. The size of the mobile station had been reduced, so it was possible to put it in one's pocket. To increase the capacity in the systems, GSM 900 (Global Service for Mobile Communications – 900 MHz) a digital cellular mobile telephony started in 1992 in several Western European countries. The development of the digital technology had by that time made it possible to compress speech. This made it possible to use a new efficient technique when transmitting the information.

In Scandinavia today, four cellular mobile telephony systems are used: the analogue radio systems NMT 450 and NMT 900 and the digital radio systems GSM 900 and DCS 1800 (Digital Cellular System – 1800 MHz). In addition, two cordless telephony systems for local use, are operating, the analogue radio system CT1 (Cordless Telephone - 1) and the digital radio standard DECT (Digital Enhanced Cordless Telecommunication system).

The technical details for these systems are summarised in table 1.

Table 1 Basic technical properties of six wireless systems.

System	NMT 450	NMT 900	GSM 900	DCS 1800	CT1	DECT
Type	Analogue mobile telephony	Analogue mobile telephony	Digital mobile telephony	Digital mobile telephony	Analogue cordless telephony	Digital cordless telephony
Data structure	FDMA	FDMA	TDMA	TDMA	FDMA	TDMA
Duplex method	FDD	FDD	FDD	FDD	FDD	TDD
Time slot repetition rate	-	-	217 Hz	217 Hz	-	100 Hz
Frame duration	-	-	4.615 ms	4.615 ms	-	10 ms
Frequency uplink	453.0-457.5 MHz	890-914 MHz [1]	890-914 MHz	1.710-1.785 GHz	914-915 MHz	1.88-1.9 GHz
Frequency downlink	463.0-467.5 MHz	935-959 MHz [1]	935-959 MHz	1.805-1.880 GHz	959-960 MHz	1.88-1.9 GHz
Channel separation	25 kHz	12.5 kHz	200 kHz	200 kHz	25 kHz	1.728 MHz
Modulation	FM	FM	0.3 GMSK	0.3 GMSK	FM	0.5 GFSK
Peak power mobile station [2]	15 W	1 W	2 W	1 W	10 mW	250 mW
Mean power mobile stations	1.5-15 W[2]	0.1-1 W[2]	0.4-250 mW[2]	0.1-125 mW[2]	10 mW	10 mW
Peak power base station	13 W[3]	10 W[3]	10 W[3]	5 W[3]	10 mW	250 mW
Number of channels	180	1999	124	374	40	120
Discontinuostrans-mitting	No	No	Yes	Yes	No	No
Cell radius	2-50 km	0.2-50 km	0.1-35 km	0.1-35 km	500 m	300 m

[1] Nowadays NMT 900 uses only 890-892 MHz respectively 935-937 MHz.

[2] Normally used power class.

[3] Typical power level into the antenna.

Abreviations: FDMA (Frequency Division Multiple Access), TDMA (Time Division Multiple Access), FDD (Frequency Duplex Division), TDD (Time Division Duplex), FM (Frequency Modulation, GMSK (Gaussian Frequency Shift Keying)

Base Stations

To communicate with the hand units the operators use base stations. One of a systems most crucial part, is the antenna on the base station. The location of the antenna is often in a high position, it can be mounted on tall buildings or towers. However, it can also be mounted on building walls or indoors and will then often have less output power. In order to gain output power density, the antenna is often directed both horizontal and vertical, and it will therefore radiate straightforward in a sector. This is done because there is no reason to transmit power straight up in the air or in directions where no receivers are. The gain in one direction can be up to 30 times, compared to an isotropic antenna (same power distribution in all directions). Just below a directed antenna the field level is generally very low. Horizontal and vertical radiation pattern for a directive antenna is shown in figures 3a, b. Most of the antennas in a GSM and DCS system are directed, but in an NMT system, the majorities are omnidirectional (same power distribution in all horizontal directions).

Figure 3 a A typical radiation pattern for a directive antenna with a horizontal half-power beam width of 65°.

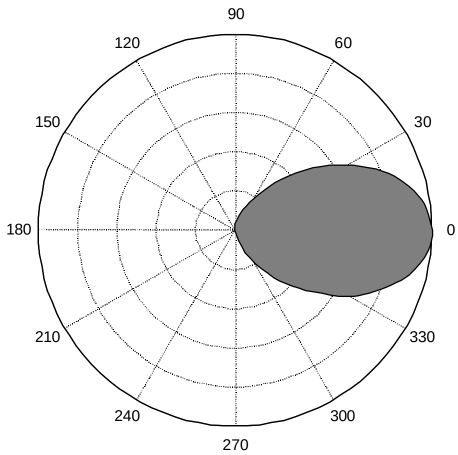
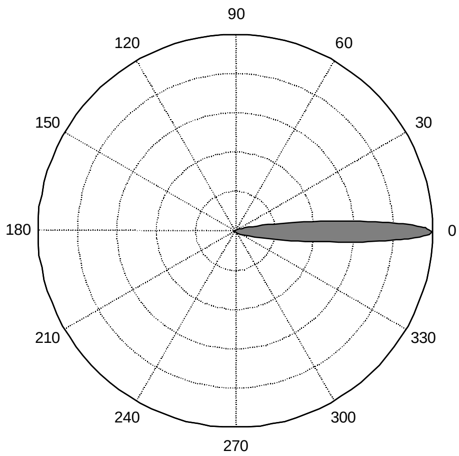


Figure 3 b Radiation pattern for a directive antenna with a vertical beam width of 9°.



Measurements of Radio Frequency Exposure

We have measured the radio frequency exposure in the band 30 MHz to 2000 MHz, at different sites in city, town and rural areas.

Measurement Procedure

The physical properties, which have been measured, are field strength [V/m] together with frequency [MHz]. In order to measure field strength a calibrated antenna and a spectrum analyser is required. The hardware used in this measurement set-up was a portable Hewlett Packard E4402B spectrum analyser and two electric field antennas. Since the frequency range is very large, it was not possible to accomplish measurements with only one antenna. In the frequency range of 30-200 MHz an ARAP01 "disc" antenna from York EMC was used and in 200-2000 MHz a PBA10200 biconical antenna from Austrian Research Centres was used. Since most of the measurements were done in field environments, where no 220 V power sources were available, a 12 V battery was connected to the analyser. The battery supported the system with electric power for about 2.5 hours. To minimise EMF reflections the antenna was mounted 1.5 m over ground on a non-conducting tripod.

To get the total electric field strength, it is necessary to measure all three polarisations (an electric field can be divided in three components x,y and z-directions), by rotating the antenna and measuring the field strength in each position, and summate all three polarisations to the total electric field strength (1). For each polarisation, a measurement in 50 seconds was done, with the analyser in the peak hold mode.

$$E_{tot} = \sqrt{E_x^2 + E_y^2 + E_z^2} \qquad (1)$$

If the electromagnetic wave is plane, the power density can be calculated from the electric field strength, this relationship is shown in (2).

$$S_{W/m^2} = \frac{E_{V/m}^2}{377} \qquad (2)$$

Results from Measurement at Different Sites

Measurements were performed at 26 different sites. These sites are divided into four environments:

City area, all these measurements were made in Göteborg.
Town area, three measurements in Kungälv and Karlskrona.
Rural area, different locations in western and southern Sweden.
Indoor, from several locations in western and southern Sweden.

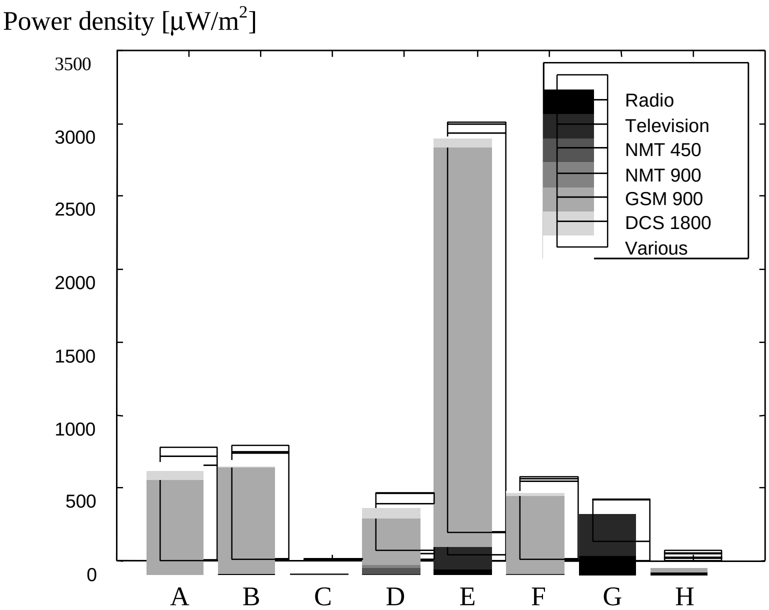
These sites have been chosen in order to reflect public exposure in different environments. On each site, the measurement position has been chosen randomly, no pre-measurements were done. The measurement results will not reflect an average from these locations, each measurement is only a sample (time and location).
The frequency range of 30 MHz to 2000 MHz has been divided into seven different frequency bands, these are:

- Radio — 87.5-108 MHz
- Television — 47-68 MHz, 174-230 MHz and 470-854 MHz
- NMT 450 — 463-467.5 MHz
- NMT 900 — 935-937 MHz
- GSM 900 — 937-959 MHz
- DCS 1800 — 1805-1880 MHz
- Various — All other frequencies within the frequency range

The first six frequency bands, contain sources that are transmitting electromagnetic fields continuos mostly twenty-four hours all days; such as base stations for mobile telephony, radio and television transmitter. The frequency band Various, contains electromagnetic sources that are only transmitting power sporadic; such as mobile stations (handsets), police and company networks.
At every site, several sources were detected and sorted into their frequency band, then each source were summed into a total power density of each band.

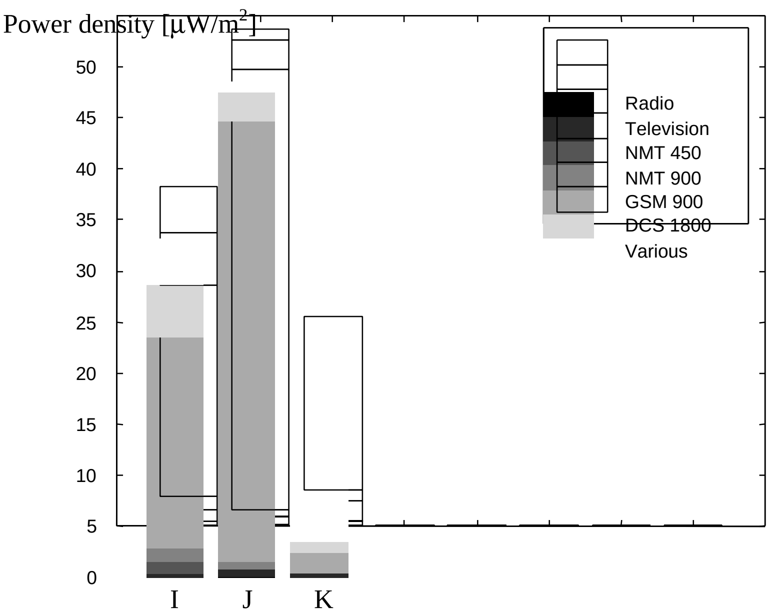
In city area (outdoors), eight measurements were done, site A, B, E and F are bus and tram stops, where many people are staying. The mean power density for these locations was 0.8 mW/m² and the median value was 0.5 mW/m². The largest contribution was from GSM 900 with a mean value of 61 % in all sites. These values are shown in figure 4.

Figure 4 Site A - H, power density in city area locations, the highest value was measured in site E with an power density of 3010 ?W/m².



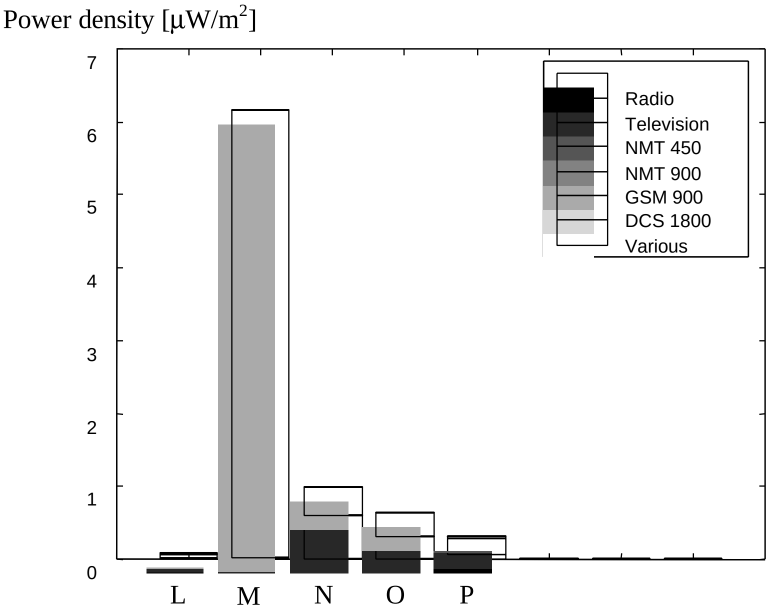
Three measurements were carried out outdoors in a town area, the mean value of these locations was 0.03 mW/m² and the median value was 0.03 mW/m². The result for this area is presented in figure 5.

Figure 5 Site I, J and K, power density in town area locations, the highest value was measured in site J with an power de



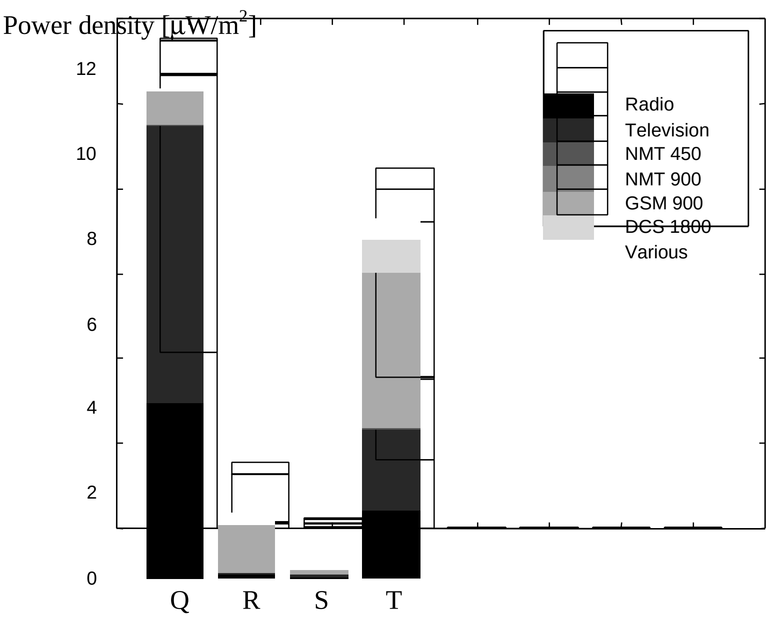
In the rural area five measurements were done outdoors, in site M a GSM base station was located about 300 meters from the measurement set-up. Because of very low background from other sources the contribution from GSM 900 was 100 %. A mean value of 2 µW/m² and a median of 0.6 µW/m² has been calculated for these positions. The power density from each site is shown in figure 6.

Figure 6 Site L, M, N, O and P, power density in rural area locations, the highest value was measured in site M with an power density of 6µW/m².



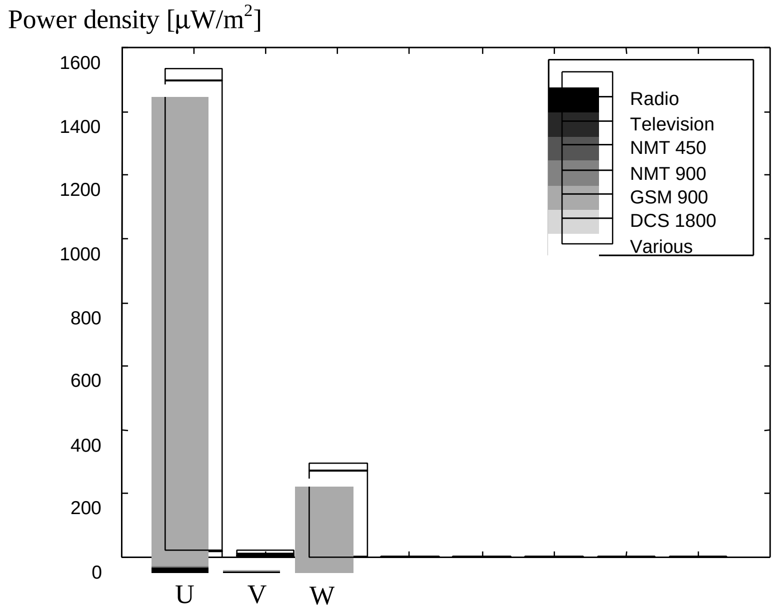
Four measurements were done indoors in residential locations, in city area, which gave a mean value of 6µW/m² and a median value of 5 µW/m². The values are shown in figure 7.

Figure 7 Site Q, R, S and T, power density in city area indoor locations, the highest value was measured in site Q [illegible] 12 µW/m²



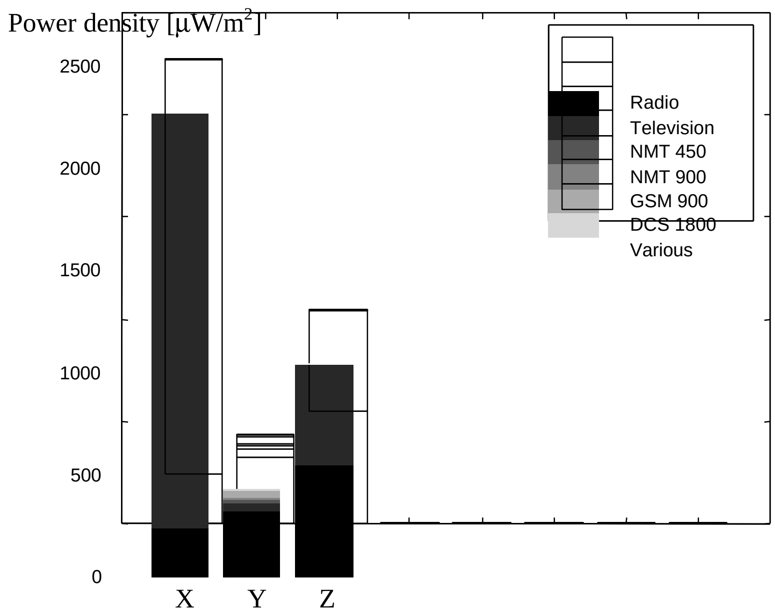
In figure 8, results from indoor measurement are shown. Site U and V are offices, in location U a GSM 900 base station was located nearby (about 100 meters) and gave a contribution of 96 % in this band. In site W (train station) a GSM 900 base station was mounted indoors and gave a power density of 0.3 mW/m^2. The mean value was determind to 0.6 mW/m^2 and median value to 0.3 mW/m^2.

Figure 8 Site U, V and W, power density at offices and in a train station wih an indoor GSM 900 antenna, the highest value was measured in site U with an power density of 1533?W/m^2.



All measurements in figure 9 were carried out near radio and television transmitters. Because of this the largest contributions are from Radio and Television bands.The calculated mean value of the three sites was 1 mW/m^2 and a median value of 0.4 mW/m^2.

Figure 9 Site X,Y and Z, power density from locations near radio and television antennas, the highest value was measure[illegible]



Results from Measurement on Cordless Telephony

Measurements where done on cordless telephony in different office environments. The power density and distance to the base station was measured. Mean power density was calculated. A reference ratio expressed in ppm, is shown and it should not exceed a value of 1 million

DECT

In an office, 16 fixed DECT base stations were located in the building. They were mostly wall mounted about 2 meters from the floor. In some places personal worked at a distance of 2-3 meters from base stations (position 4). In table 2 the results are presented and in figure 10 and 11 a DECT frame is shown for position 2 and 5.

Table 2 Power density from DECT base stations, the first office environment.

Position	Distance	Peak Power Density	Mean Power Density	Referenve ratio
	[m]	[µW/m²]	[µW/m²]	[ppm]
1	4.0	163	8	0.7
2	1.6	3698	154	16.2
3	3 und 6	428	17	1.9
4	2 und 3	157	7	0.7
5		Several timeslots	max 0.5	0.1

Figure 10 Measured power density from a DECT frame in position 2, 2 meters distance from base station. Time slots (0-5 ms) are from handsets and the other (5-10 ms) are from the base stations.

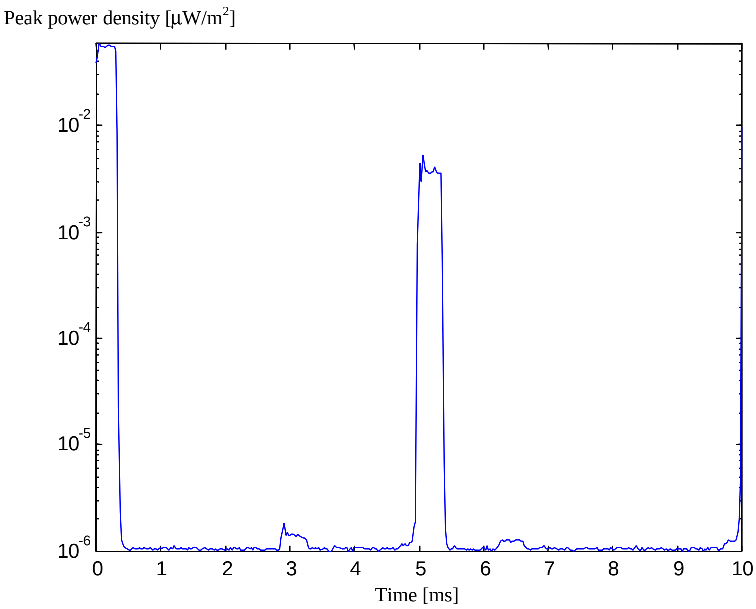
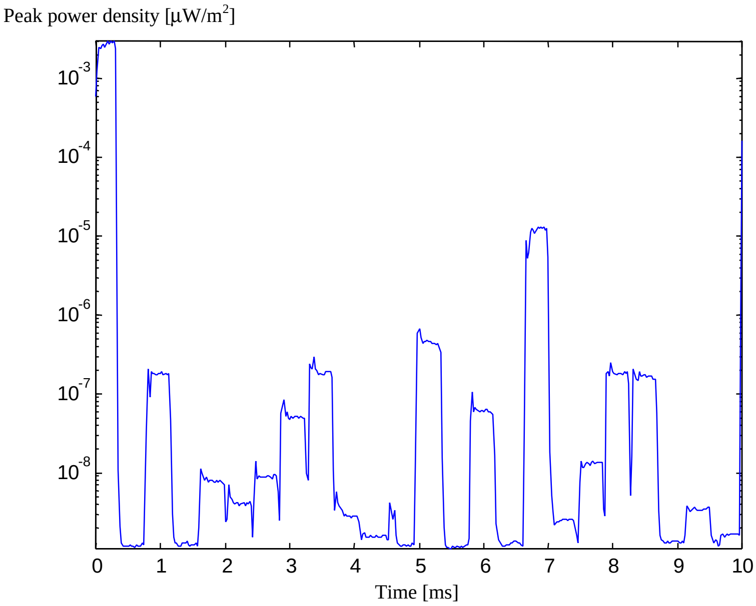


Figure 11 Measured peak power density from a DECT frame in position 5. On one frequency, several base stations can share a frame. These timeslots (from 5-10 ms) are transmitted from at least three base stations.



CT 1

This measurement was carried out on a CT1 system in two rooms, with one base and mobile station placed in the first room. In both locations measurements were done in five positions and averaged to one value for respectively stations (two values for each room). The distance from room 1 to room 2 was 10 meters and with four concrete walls between the rooms. The results are presented in table 3. The output power from both stations is 10 mW.

Table 3 CT1 measurements in two rooms.

Location	Powerdensity	Reference ratio
	[µW/m²]	[ppm]
Room 1, Base	367	76
Room 1, Mobile	120	26
Room 2, Base	0.06	0.01
Room 2, Mobile	0.11	0.02

Discussion

The rapid development and implementation of new wireless communication systems, leads to a change in radio frequency emission. The aim of this study, was to estimate the radio frequency exposure, at different sites from all sources in the frequency range 30 to 2000 MHz. To our knowledge, there exist no recent broadband survey in Sweden, in the open literature. We are aware, that the mobile phone operators have made extensive measurements of base station coverage in Sweden. However, these data are not public.

In a survey from 1978 in the United States [1], a median exposure level was determined to 50 µW/m^2. Measurement data had been obtained in 373 locations from 12 large cities and represented approximately 11000 measurements of VHF and UHF sources. They used a propagating model to increase the measurements data, this could be done because there were only a few sources in each city.

A total mean value of all the 26 measured sites, in our study, was 0.5 mW/m^2, and the median value was 40 µW/m^2. The contributions from different sources are presented in table 4. The major contributor was GSM 900, with 47 %, for all sites. In city area, the mean contribution for GSM 900 was 61 %, for town area 54 %, rural area 39 % and in residential premises 41 %. Television has a mean contribution of 48 % in rural area, for residential premises 24 %, 13 % city area and 1% in town area.

Table 4 Mean contributions from different sources. The values are calculated as the mean percent part of the total ratio from the environments.

System	Total ratio [%]
Radio	15
Television	23
NMT 450	1
NMT 900	0
GSM 900	47
DCS 1800	3
Various	10

If only sites in city and town areas are included, there was a mean value of 0.6 mW/m^2 and a median value of 0.4 mW/m^2. This is approximately 10 times higher power density than the results from US cities and towns the 1978 survey. In 1978 no cellular phone systems were operating in US. There are several differences between the surveys, one is that the 1978 survey had many more measurement sites (373). Their approach with a propagating model to increase measurements data, has not been made, in our study, because of the huge number of sources and complex propagation from these.
The reference level was never exceeded in any site. Highest exposure was 0.07 % of the reference level at site X, FM/TV-tower, Brudaremossen.

The results from measurements on cordless telephony (base stations) in office environment also showed low power density levels, even at short distances from base stations (1.6 m). The reference ratio is never exceeded, in any location. The maximum reference ratio was 0.008 % of the reference level.

Another important aspect could be exposure time. Exposure time for radio, television and base station for mobile telephony is twenty-four hours all days. For instance, twenty-four hours exposure in a residential area (indoors) is 24 h · 5 $\mu W/m^2$ = 120 $\mu W/m^2 \cdot h$, this corresponds to a 1 minute exposure from a GSM 900 handset (2 W output power) at a distance of 1 meters. In an outdoor city area the twenty-four hours power density corresponds to a 2 hours exposure from GSM 900 handset at a distance of 1 meters.

Measuring the electromagnetic spectrum is very complicated, several variations makes it difficult to get fair values. When measuring the 26 sites the "worst case" approach was taken. Because of this method, the discontinuous sources such as GSM 900 and DCS 1800 will be overestimated when more than one base stations TRX are operating and only a few time slots are transmitted on these TRX's.

To get a good population exposure value it is necessary to increase the number of measurement sites. A continuous monitoring of the electromagnetic spectrum is needed. In the future, there will be more base stations for other new wireless systems. These will transmit EMF with much more complex techniques, than nowadays. Measurements are especially needed indoors, because most new base stations will be mounted there. In many homes and offices small base stations will be mounted inside, with only a few meters coverage and be connected to the mobile telephony operators network.

Conclusions

This article shows that the power density levels from wireless communication systems are very low compared to reference levels. The total mean value for all sites was 0.5 mW/m^2. Reference level has not been exceeded in any site. Highest exposure from measured at any of the 26 sites was 0.07 % of the reference level.
Major contributor in all sites was GSM 900 with 47 %, in city areas GSM 900 contributed to 61 % of the total power density. In rural areas, the major contributor was Television with 48 %.

For wireless systems at offices (CT1 and DECT) the power density levels are also low. The reference level for these systems has never been exceeded in any location. The highest reference ratio was 0.008 %

References

[1] Tell R. A. and Mantiply E. Population exposure to VHF and UHF broadcast radiation in the United States. Radio Science, 1982, vol. 17, Number 5S, pp 39S-47S.