

Electromagnetic fields at home

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19.1 Introduction

Exposure to low frequency electromagnetic fields has increased considerably over the last decades due to the extended use of electricity in everyday life. Exposure comes from various sources, like power lines outside houses, transformers near or inside houses, electric cables as permanent installations in houses, electrical heating in various forms, appliances, and transportation.

Naturally occurring fields - Outdoors, the natural environmental static electric field is about 100-130 V/m, which is due to charges in the upper atmosphere. During thunderstorms, this field may increase to several thousand volts per metre. Natural occurring ELF (extreme low frequencies, 3-3000 Hz) electric fields are mainly due to thunderstorms. Frequencies from zero up to a few kHz are present, but decreases with frequency. At about 8, 14, 20, 26 and 32 Hz, the field is somewhat larger than at other nearby frequencies. These peaks are the so-called Schumann-resonances, corresponding to standing waves around the Earth, created by lightning. At 50 or 60 Hz, the natural occurring field is only about 10^{-4} V/m (Hitchcock & Patterson, 1995).

The natural environmental static magnetic field is the magnetic field from the Earth. This is about 30 μ T and horizontally directed near the equator, and about 70 μ T and almost vertical near the magnetic poles. There are fluctuations in the environmental magnetic field. These are mainly due to solar activity and flux of charged particles from the sun entering the atmosphere. During high solar activity, the natural (near static) magnetic field may change up to 10 to 30 nT (0.01 μ T to 0.03 μ T) several times a day, but at 50 or 60 Hz, the magnetic field variation is only a fraction of a nanotesla.

It is striking that at power line frequencies, the man-made fields are very much larger than naturally occurring fields. At ground level, a 50 Hz electric field of 10 kV/m under a high tension power line may be experienced, compared to the natural field of about 10^{-4} V/m. The ratio is about 10^8 . Similarly, near a melting oven, workers may experience a 50 Hz magnetic field up to 3000 μ T, while the natural 50 Hz magnetic field may be around 0.3 nT. The ratio becomes 10^7 . These numbers are in sharp contrast to what is found for ionizing radiation, where the naturally radiation often leads to doses comparable to doses from man-made sources. The difference may not be quite so dramatic if the complete ELF frequency band is included simultaneously. However, since the exact action mechanisms for weak fields are unknown, it is not possible to do so at present.

19.2 Power lines

Power lines are often a dominant source for power frequency magnetic fields in houses near by. For large transmission lines that carry a large current, the «near by region» extend to about 60 to 80 m on each side of the line, while for smaller power lines the region extend only to about 10 m on each side. The field decreases continuously with increasing distance; the numbers given refer to the distance where the field is reduced to $0.2 \mu\text{T}$. Figure 19-1 shows magnetic field for various distances from two different power lines and one underground cable system. Details regarding the geometry are given in the figure legend. The resulting field is, as pointed out in Chapter 10:

- proportional with the electric current,
- inversely proportional to the *square* of the distance from the power line,
- proportional with the internal distance between the cables.

The last two relations are valid only at positions at least two to three times the inter-phase distance, away from the closest wire in a set.

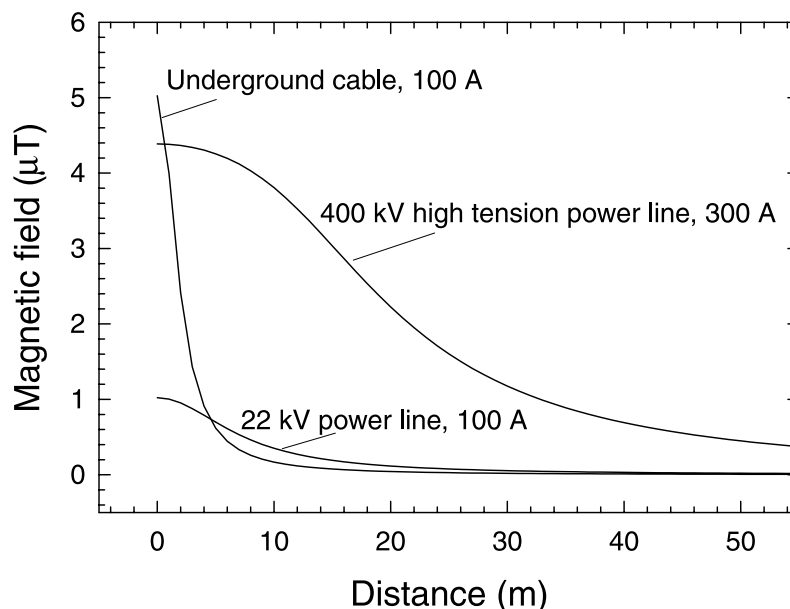


Figure 19-1: Magnetic field from a 400 kV high tension power line, a 22 kV power line, and a set of three separate underground cables. The inter-phase distance is 11 m, 1.5 m and 0.5 m, respectively, and it is assumed that all three phases are placed in the same horizontal plane. The wires are placed at 14 m and 8 m above ground level for the 400 kV and 22 kV line, respectively, and 0.8 m below ground level for the underground cables. The currents are 300 A, 100 A, and 100 A, respectively. All magnetic field values refer to 1 m above ground level, in a horizontal line perpendicular to the wires, with the zero point directly below or above the middle phase. The field from the 400 kV line may be two to three times the values given when the power consumption is maximum, while the fields given for the 22 kV line and the underground cables, are about the maximum values you will find.

Let us give an example. If the current is increased by a factor two, the field is also increased by the same factor. At a distance of e.g. 30 m away from a power line, the field is four times higher than at a distance of 60 m. And finally, at a distance of e.g. 30 m, the field from an 400 kV transmission line with phase separation of 11 m, is about 22 times greater than the field from an underground set of cables with a phase separation of 0.5 m (assumed the same current in both systems).

As a curiosity we note from figure 19-1 that the magnetic field at 1 m about ground level, the magnetic field from an underground wire may be higher than from a large overhead power line. The reason is the smaller overall distance to the underground current carrying cables, compared to the distance to the overhead wires. On the other hand, the region with high field is much narrower for underground cables than for large, overhead transmission power lines. Unfortunately, underground cables are often buried under sidewalks, so people may walk just along the region where the field from the cables is the highest. Fortunately, for transmission of moderate to low power through underground cables, it becomes more and more common to use one single cable with the three phases packed very closely together. Then the magnetic field is relatively marginal at surface level.

Most building materials have a rather negligible effect on power frequency magnetic field. Thus, the values indicated in figure 19-1 are valid both inside and outside houses. In addition come fields from other sources, as will be discussed later.

Electric field from power lines is more easily shielded. Most building materials reduce the external electric field considerably (with exception of glass and other materials with extremely high insulating property). Thus, inside houses, away from windows, the electric field from an external high tension power line is often reduced to a few percent of the corresponding field outside the house. In dry, wooden houses, the reduction is not as efficient, but even there the reduction is considerable. Even living trees and other vegetation may reduce the electric field from power lines. Figure 19-2 shows the electric field as a function of distance from a high tension power line. The electric field is, as pointed out in Chapter 10:

- proportional with the electric potential (voltage) of the line,
- inversely proportional with the *cube* of the distance from the power line,
- proportional with the internal distance between the cables.

Again, the last two relations are valid only at positions at least two to three times the inter-phase distance, away from the closest wire in a set. (The inverse cube distance law is in fact only valid for distances at least three to four times the *height* of the wires above ground level, and is due to induced charges at ground due to the electric field.)

There is no electric field above ground level from underground electrical cables.

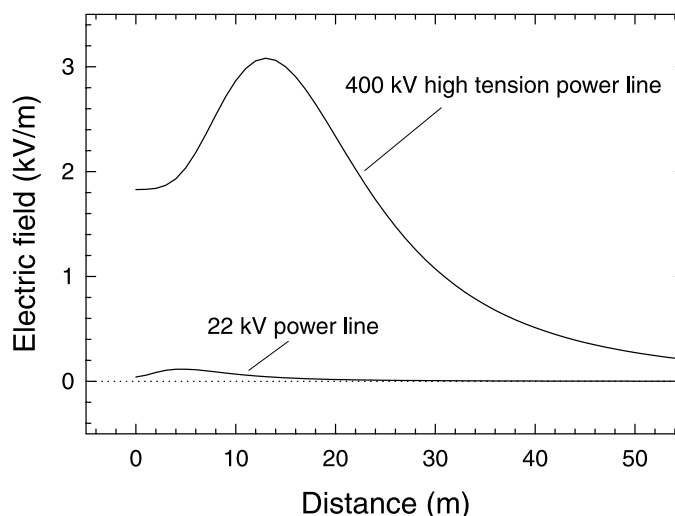


Figure 19-2: Electric field from a 400 kV high tension power line, and a 22 kV power line. The geometrical parameters are as given in the previous figure.

19.3 Transformers

High voltage is used in the transportation of electric energy over large distances, since the corresponding reduced current results in lower power loss. However, at homes and offices, one uses lower voltages for safety reasons, at an expense of higher currents. However, since the wiring is short within a house, and the current is distributed on several wires, the power loss due to resistance in the in-house cables is acceptable. It is interesting to note that a single high tension power line of 400 kV, carrying a current of 300 A (a normal situation), can supply about 40.000 homes with electric energy (even in the rich part of the world). The power line delivers after the down-transformation a total of 900.000 A locally at 230 V, or about twice as much at 110 V.

The transition between high and (relatively) low voltage systems is performed by electrical transformers. Transformation is often carried out in several steps, and the last transformer may be located near homes, or even inside apartment buildings or office buildings. These «in-house-transformers» often yield a relatively strong magnetic field. Actually, it is often not the transformer itself that produces the largest fields. The wiring on the low voltage (high current) side of the transformer is often the largest problem. With more knowledge about magnetic fields, electricians could often have reduced the fields considerably by choosing a slightly different cabling. And with more knowledge among architects, a better planning could have been achieved. Rooms adjacent and above in-house-transformers should ideally only be used for storage rooms etc. where people do not spend a large part of their day or night.

Fields from in-house-transformers are often discovered with the introduction of computers. The picture on a visual display unit of a cathode ray tube type, is often disturbed in one way or another if the external power line frequency field is of the order of 1 μT or larger. People may have lived in an apartment for years with an in-house-transformer in an adjacent room without having noticed anything unusual. But after having bought a PC or a Mac, the field may be noticed through a bad picture quality. Many people then experience a quite difficult time before they know how to handle the uncertainty of possible health effects from the fields. In principle, it is possible to reduce the magnetic field using one or several of the strategies outlined in the Fundamental chapter, but in practice it is often difficult and prohibitively expensive. The largest magnetic field I have measured in a room next to an in-house-transformer, is 140 μT (at floor level with the transformer at the basement). More typical values are between 1 and 20 μT (for 230 V systems). These numbers can be compared with the recommended maximum level of 100 μT for 50 Hz magnetic field exposure to the general public (ICNIRP guidelines, see Chapter 10).

As mentioned above, the picture on a traditional visual display unit of a computer may “vibrate”, or “float” back and forth, or get blurred, or there may be some colour distortion, if the display unit is placed in a 50 or 60 Hz magnetic field. The field may come from an “in-house” transformer, from external power lines, or from local equipment in the house. The reduced picture quality may be a health hazard in itself. People may easily get headache if they work with computers under such circumstances. If it is for practical or economic reasons impossible to reduce the magnetic field so much that the distortion disappears, one could consider to use a more modern, thin, flat-screen display unit that is not based on a cathode ray tube. Those units are very resistant for picture quality degradation due to external magnetic fields.

19.4 Electrical cabling

The usual electrical cabling in houses, apartments and offices are also sources of electromagnetic fields. The magnetic field is normally weak, since the magnetic field tend to cancel each other from the two close-lying current-carrying wires within a single cable (as discussed before). However, in cases where a «forth-current» wire do not follow closely to an «back-current» wire, larger magnetic fields may appear. A typical example is the so-called one-conductor heating cables in floors. Fields up to 30 μT are measured at floor level in day-care-centres for kids with one-conductor heating cables. For two-conductor heating cables the magnetic field is often negligible.

Several different electrical systems are used in the world. Even within a single country, several systems may be in use simultaneously. In Norway, for example, at least three different systems are in use with the following codes: IT, TN-C and TN-C-S systems. In the IT system appliances are coupled directly between two phases, while in the TN systems, the appliances are coupled between one phase and ground. We will not go into more details, but the systems differ also in the use of grounding system (use of protective earth).

The difference in electrical system implies interesting details regarding magnetic field. For the IT system no current will normally follow the ground cables (protective earth). In every part of the cables, there will be a perfect match between «forth-current» and «back-current», and the magnetic field is as low as possible. For the TN-C system, however, there will normally flow a current through the ground wire (protective earth). Since protective earth often is connected to water pipes in houses, some current will choose to follow the water pipe and ground back to the last transformer before the house. Thus, there will normally be some mismatch between the «forth-current» and «back-current» in some part of the electrical cabling in the house/apartment/office building. We call the effect for “vagabonding currents” (current on its own track).

The presence of vagabonding currents implies higher magnetic fields. The reason is given in Chapter 10: The magnetic field from a single straight current-carrying wire is inversely proportional with the distance in *first* power, while the field from a couple of wires is inversely proportional with the *square* of the distance. A mismatch between the «forth-current» and «back-current» somewhere (due to vagabonding currents) can be regarded as a sum of a matched pair plus one single wire, completely unmatched. Due to vagabonding currents, the background level in Swedish homes (mostly TN-S systems) was found to be about 0.1 μT which is nearly twice as high as the background of about 0.05 μT in Norwegian homes (mostly IT systems).

Imbalance in an electric system due to vagabonding currents may even influence the magnetic field from distribution lines in a neighbourhood. For the large transmission lines, the imbalance is often quite negligible.

Electric field from electrical cabling is mostly moderate. The background level in homes with 230 V system, is often between 3 and 30 V/m. The level might be even lower in kitchen and bathrooms, where the electrical cables are grounded. These numbers can be compared to the electric field of 5-10 kV/m (5000-10000 V/m) 1 m above ground level beneath a high tension power line. The numbers can also be compared with the recommended maximum level of 5 kV/m for 50 Hz electric field exposure to the general public (ICNIRP guidelines, see Chapter 10).

There is an interesting difference of electric and magnetic fields from electrical cabling in buildings. The magnetic field is proportional to the current, and there is no magnetic field from a cable e.g. to a lamp if the lamp is turned off. On the other hand, the electric field is proportional to the

electric potential (voltage). Even if a lamp is turned off, the wires may have about the same voltage as if it is turned on, at least in IT systems. This comes from the fact that most switches only break the connection in one wire. To completely eliminate the electric field from electrical cables in houses when there goes no current, one have to use switches that break both wires (two-pole switches). [Someone may have noticed that fluorescent tube lamps may have a very faint light even when switched off. If two-pole switches are used for such lamps, the faint light disappear all together.]

19.5 Appliances

Appliances and every kind of equipment we connect to the mains, will produce electric and magnetic fields. In general, the higher power the equipment use, the higher magnetic field. However, this rule of thumb is so crude that it is not very useful. Another rule of thumb is that an appliance working at 110 V often produce higher magnetic field than similar equipment working at 230 V, due to higher electric current at 110 V in order to keep the power on the same level. A third rule of thumb is that appliances with a motor often produce more magnetic field than equipment without a motor. And finally, and not very well documented, cheap equipment for use only connected to the mains seems to produce more magnetic fields than more expensive equipment, and equipment supposed to be used also on batteries.

Electric razors have been popular as an example of equipment that produces high magnetic fields. In the literature we often can see listed «1500 μT at 6 cm distance». Where this number originally came from I do not know, but it has proved to be very persistent. The highest value I have ever measured on a 230 V electric razor was less than 100 μT at 6 cm distance, and the electric razor I now use, give only about 1 μT at this distance (at a slightly higher frequency than power frequencies).

These examples of field values indicates two important aspects of field exposure:

- A large variety exists in how much electromagnetic fields a given kind of appliance produces. Equipment from one manufacturer may give off far lower magnetic field than equipment from another manufacturer, but there may be large variation even from one type to another from the same manufacturer.
- Since the magnetic field decreases with distance from an appliance, one have to specify at which distance a given field value refers to.

Let us discuss the last point first, with an example from an old electric razor of mine. Figure 19-3 shows the 50 Hz magnetic field as a function of distance from the razing knife, with the razor oriented as during normal use. The magnetic field was measured along a vertical line, and the distance is given relative to an adult human body. We can see that this razor gave a field of about 60 μT at about 3 cm distance from the razing knife (as close as one could get with the probe used). We see also that the field value decreased to about 0.03 μT at a distance corresponding to my toes. This means that the magnetic field varied by a factor of more than one thousand from one part of the body to another. Which number should one then give as a «typical value» for the exposure? We do not know the answer on that question, but the answer is closely connected to the question on how to define a «dose» of low frequency field exposure in general. We will return to that problem later in this chapter.

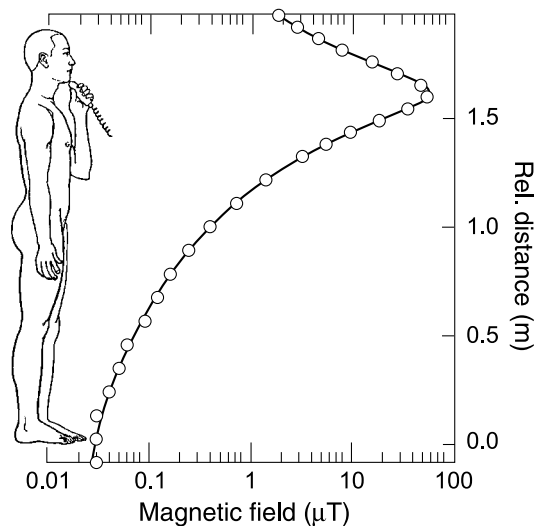


Figure 19-3: Magnetic field from an old 230 V 50 Hz electric razor, measured along a vertical line at different distances from the razing knife.

In a kitchen the heating elements in a stove is often the most important source of magnetic fields. Figure 19-4 show some numbers for the 50 Hz magnetic field measured at different positions close to one particular 1000 W (230 V) heating element when it was turned on at full power. The maximum field of 32 μT was found just above the centre of the heating element disk. But at 0.5 m distance from this spot, the field dropped down to 0.09 and 0.04 μT for displacements in the vertical and horizontal directions, respectively. The electric fields from the stove were negligible due to the grounding required in kitchens.

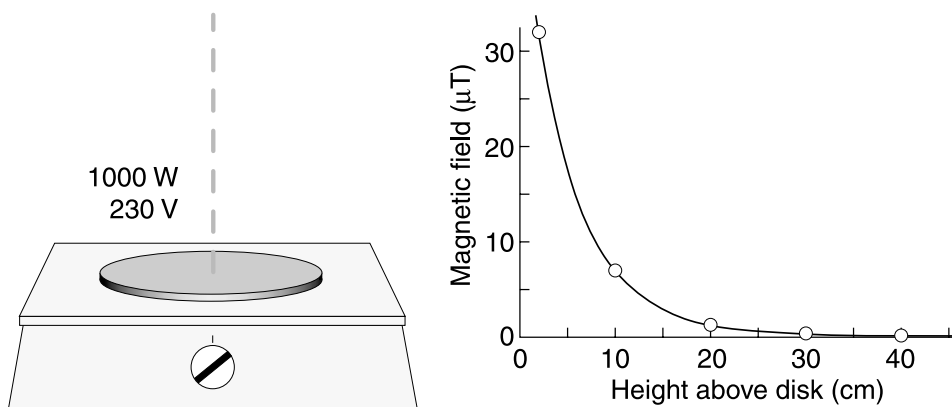


Figure 19-4: Magnetic field at different positions close to a 1000 W (230V) heating element of an electrical stove.

Other equipment in the kitchen may also give relatively high magnetic fields, e.g. food processors and other equipment that contain an electrical motor. The levels may be comparable to the one given for the stove heating element mentioned above, but most often, the levels are lower. A particular toaster tested gave e.g. a magnetic field of 4.6 μT immediately above the toaster, but the level had dropped to 0.7 μT at 0.2 m distance, and 0.1 μT at 0.5 m distance. A refrigerator has a motor (the compressor) and should be a candidate for relative strong magnetic fields. However, the motor is placed at the back of the fridge, and the fields in the front are therefore minor. For one particular fridge the field varied from 0.1 to 0.6 μT immediately in the front of the door, and

had dropped down to below $0.1 \mu\text{T}$ at a distance of 0.5 m from the door. The background level in most homes are somewhere between 0.01 and $0.1 \mu\text{T}$. The numbers could also be compared with the recommended maximum level of $100 \mu\text{T}$ for 50 Hz magnetic field exposure to the general public (ICNIRP guidelines, see Chapter 10).

In order to give a reasonably correct information regarding the field a specific appliance produces, it might be useful to make a graphical representation that shows both the equipment and normal working distance to the equipment. Figure 19-5 is an example of this. Here several common sources of low frequency electromagnetic fields are presented along with a grey-scale code indicating different levels of magnetic fields. Such illustrations may be far more informative than a simple list of field levels at one or two distances. However, illustrations like this (including the measurements behind) are quite time-consuming to produce!

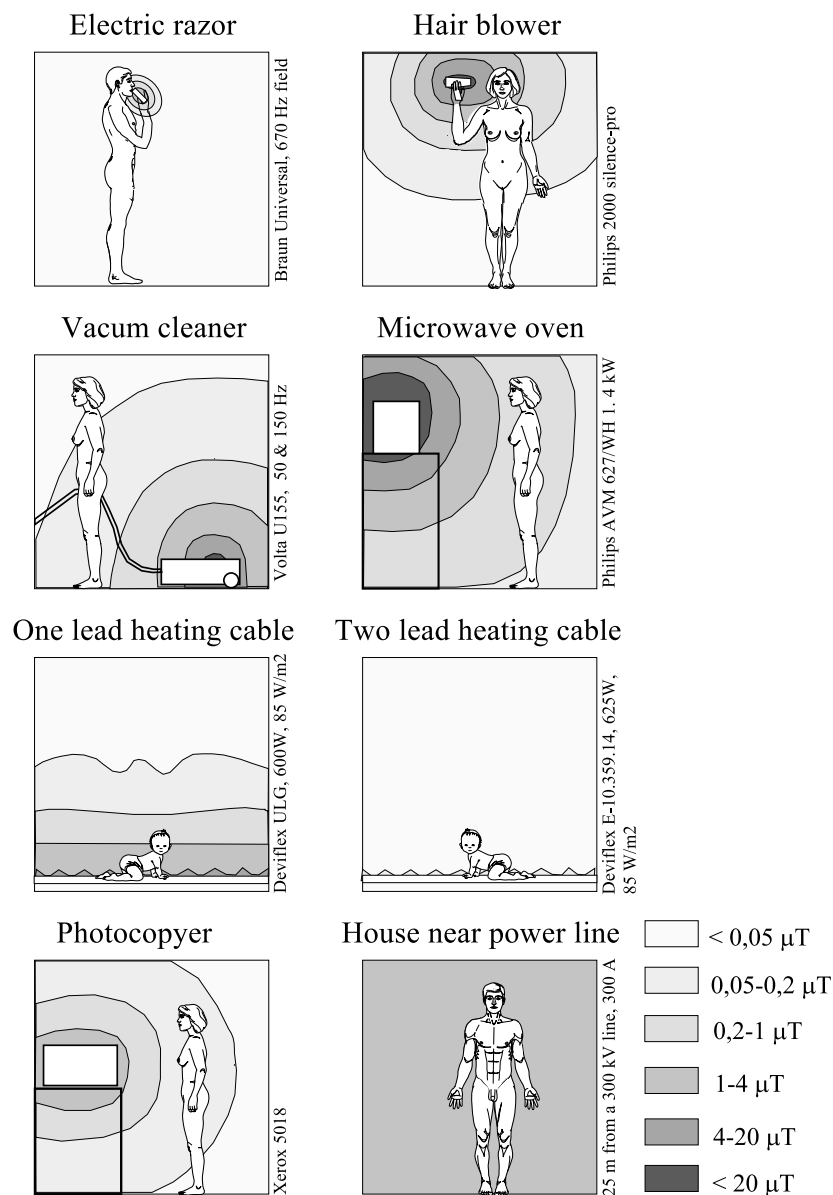


Figure 19-5: Low frequency magnetic field from various sources (230 V). The field varies with the distance from the sources. In the case the source is a power line, the variation within the size of a man is so small that it appears as constant in this plot.

Note the relatively high field value from the microwave oven in figure 19-5. This result is not due to the field from the microwaves itself. The shielding of the high frequency fields in the microwaves was quite efficient. Only immediately outside the slit between the door and the rest of the microwave oven, the level of microwaves was at a comparative level as a few centimetres away from a mobile telephone. Thus, the high level of *power frequency* magnetic field seems to be an example of bad (electrical) design rather than a necessity of the equipment itself.

Another examples of bad electrical design are found among cheap clock radios, where the power frequency magnetic field close to the surface may be up to about 100 μT (more typically 10-20 μT), even if the power consumption is quite negligible. People that like to place such a clock radio very close to the pillow at their sleeping room, may have a magnetic field exposure at the head region of their body, exceeding the exposure one can have in houses near large power lines.

Electrical lights may also be a source of both electric and magnetic fields. Fluorescent lamps produce often a higher magnetic field than incandescent lamps. A 2 x 40 W (230 V) fluorescent lamp we tested, had a magnetic field of 2.7 μT immediately close to the fluorescent tubes in the middle of the lamp. At a distance of 0.5 m the field had dropped to 0.18 μT . On the other hand, a 75 W (230 V) incandescent lamp produced a magnetic field of only 0.12 μT at about 0.02 m distance (as close as we could get the active part of the probe.) Modern halogen lights that operate at 12 V, often produce considerably higher magnetic fields than incandescent lamps operated at 230 (or 110) V. On halogen lamps there also has to be some kind of transformer, and the transformer itself may also be a considerable source for magnetic fields. Thus, it is devisable to keep the body at some distance (of the order 0.5 m) away from such lamps / transformers if one wish to minimise exposure.

Television sets produce very much the same kind of electric and magnetic fields as a traditional computer terminal, before the “low radiation” certification started (see next few paragraphs). However, most people watch a television set at a larger distance than people watch a visual display unit of a computer. Therefore, the exposure during television watching is usually negligible. Children that sometimes watch a television set at much closer distance, may have an exposure that exceed that of a computer operator, by a factor of five or more.

19.6 Computer displays

It has been a considerable interest in the electromagnetic fields from computer terminals, or in particular, from visual display units (VDUs) of the traditional cathode ray tube (CRT) type (modern plasma display panels or similar will be shortly treated below).

The traditional VDUs are the most complicated source of low frequency electromagnetic fields that I know of. The equipment use power from the mains, which implies that it also will produce power frequency (50 or 60 Hz) both electric and magnetic field. The picture is drawn on the display unit by directing a tiny beam of electrons to various parts along the inside of the front glass surface, which is covered with phosphorus dots or lines that emit light when hit by the electrons. The electron beam is directed to each dot or line by means of magnetic fields inside the CRT. Some of the directing field is also leaking out into the surroundings, both magnetic field and electric field.

The picture is composed by drawing one horizontal line after another, from the top of the unit to the bottom, and then starting over again (see figure 19-6). The unit uses about 10-30 microseconds on each line, depending on the resolution of the unit. This corresponds to a primary frequency («line frequency») of 30-100 kHz. The unit uses about 6-20 milliseconds in order to draw one complete picture, from top to bottom. The corresponding primary frequency («picture frequency» or «refresh rate») is 50-160 Hz. The fields vary far from harmonically («sinusoidal») with time, which implies that a frequency analysis reveals a number of higher harmonics to each primary frequency (see figure 19-7). In addition to all these different frequency components of both electric and magnetic fields, one has a static electric field coming from the high voltage used to accelerate the electron inside the CRT. In old VDUs, the front glass could have an apparent surface potential of several thousand volts.

Electromagnetic fields from VDUs have several frequencies:

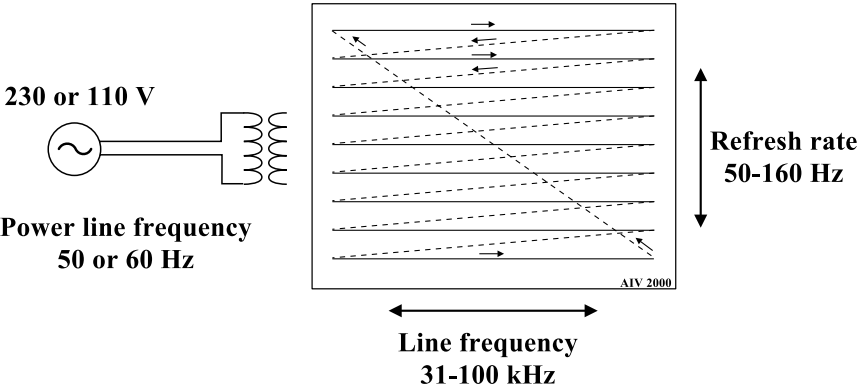


Figure 19-6. The principle of drawing a picture on an traditional VDU for computer use. See the text for more details.

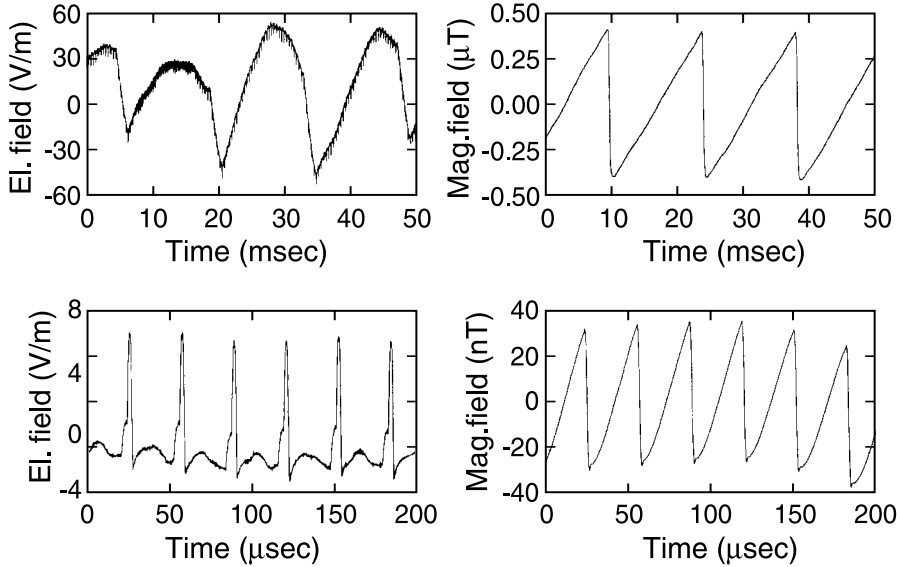


Figure 19-7: Example of the time variation of the electric and magnetic field produced by a VDU. Note the different time scales on the diagrams that shows the combined power frequency and refresh rate frequency fields (at the top) and the diagrams that shows the line frequency fields (at the bottom).

To make the field picture even more complicated, the various field components have their maximum at different orientations relative to the VDU, and the field direction itself (remember that fields are vectorial quantities!) are different for the different main categories of frequencies. It takes hours to characterise the fields from one single VDU if one should do it properly!

A Swedish testing organisation (MPR, later taken over by TCO) has developed a testing protocol on how to standardise measurements of VDUs. They compared a lot of different VDUs, and found that some produced much less fields than others. In order to influence the manufacturers so that they should try to produce VDUs with as low leakage fields as possible, MPR established in 1987 a «low radiation» standard based on available practical measurements. VDUs that had less leakage fields to the surroundings than specified by the standard, could be classified as «low radiation VDUs». This standardisation had an important impact on the manufacturing of VDUs, and today most serious computer companies only sell «low radiation» display units.

The field values from various “low-radiation” VDUs can be given indirectly by referring to some details in the certification criteria from TCO (per 1997):

- Static electric field: The front of the VDU should have an apparent surface potential less than 500 V.
- Power frequency and refresh rate frequency (combined) magnetic field should be less than 0.25 μT at 50 cm around the VDU.
- The corresponding electric field should be less than 25 V/m at 50 cm in front of the VDU.
- The line frequency magnetic field should be less than 0.02 μT at 50 cm around the VDU.
- The corresponding electric field should be less than 2.5 V/m at 50 cm around the VDU.

Today it is less focus on possible health hazards in working in front of VDUs than it was in the late 1980-ies and in the first half of the 1990-ies. The reason is less alarming results from the latest epidemiological and model studies, combined with the reduced field values due to the introduction of «low-radiation» units.

Modern plasma display, active matrix, liquid crystal, and similar panels, used in lap-top computers and also more and more often for stationary PCs, have usually far lower both electric and magnetic fields than the traditional VDUs. However, since these panels also use electricity, they do produce both electric and magnetic fields. «Field-free display units» are therefore only an illusion used in some marketing of such panels. The frequencies involved are different from those found in the traditional VDUs.

19.7 Problems with electrical fields

In most of the discussion on fields from appliances, there has been most focus on magnetic fields. Is not the electric field also of interest?

There are different opinions on this, but one important reason for less focus on electric field is certainly related to measuring problems. Low frequency magnetic field can be measured easily since the body and most materials do not perturb such a field. Low frequency electric field, however, is very easily disturbed. In order to do a «non-perturbing measurement» of an electric field, the operator has to be at least one to two meters away from the measuring probe! That makes electric field measurements far more challenging than measuring magnetic fields!

In the MPR/TCO low radiation standard, one chose another approach. In that case, an electric field probe was used that certainly do perturb the electric field. And the probe was grounded, so that it became rather immune against perturbations from nearby operators or other equipment. The procedure was useful in order to compare one VDU with another. However, a similar standardised procedure using a grounded probe, seems to be almost impossible to develop for a general electrical measurement situation. At least if the results of the measurements should be representative for what typically will happen in a human body when it comes close to the various sources.

Let us take a simple example in order to illustrate the difficulties involved in measuring electric fields. Assume we place a 1 x 1 m plane metal sheet horizontally 1 m above the floor in a house, with empty space between the plate and the ceiling. The plate is connected to a 12 V AC power frequency source. The true electric field is then about 10 V/m above the central part of the plate. The true field will vary very little with the distance, for distances up to about 20 cm above the centre of the plate. If one tried to measure the electric field by a grounded probe similar to the ones used in the TCO certifications, the result would be quite different. One would measure about 120 V/m if the probe was placed 10 cm above the plate, and 1200 V/m if the probe was placed only 1 cm above the plate! The field is actually changed dramatically (more than a factor of 100) by the introduction of the measuring device.

As pointed out, there exist inherent problems with measuring electric fields. Furthermore, we lack an understanding of what kind of field measurements that are most representative for what happens in the human body when exposed to such fields. These problems makes it likely that the electric field studies will have less popularity than magnetic field work also in the years to come.

19.8 Electromagnetic fields and transportation

Regardless whether we travel by a common gas engine car, an electrical car, train, subway, tram, or aeroplane, we will be exposed to low frequency magnetic fields produced locally. The frequency is normally not 50 or 60 Hz in most of these examples, but varies with a primary frequency between 0 and 400 Hz. In common gas engine cars, the magnetic fields come from the ignition system, electric fans, and all other electrical systems in the car. The field value can be of the order of a few microtesla, but such field values are often restricted to near/under the dashboard and near the engine.

Electrical cars may in principle produce large magnetic fields, but the field values will depend strongly on how the electrical wiring is carried out. Representative measurements are not readily available so far.

A tram, a subway and a train are all getting their power by a power line (contact line) on one hand and the tracks on the other. There are many different systems in use. In Norway the tram and subway use direct current (DC, zero frequency), while the train use $16 \frac{2}{3}$ Hz (one third of 50 Hz).

If direct current is used, the magnetic field that is produced, could be compared with the static magnetic field of the Earth (between 50 and 70 μT). The magnetic fields produced by a tram or subway are seldom higher than 10 to 100 μT , which is comparable to the natural static field. It

should be remembered, however, that the magnetic field from a tram or subway is only quasi-static since it varies from about zero to about the maximum value within seconds, as the driver of the tram changes the power during driving. In that respect, possible health effects might still be of interest.

For tram, subway and train most people think of the power line (contact line) as the dangerous part. The tracks seem quite innocent. The reason is that the tracks do not carry any high voltage, in fact the voltage may be close to zero. However, the tracks carry an electric current comparable to the current in the contact line (see figure 19-8). The current flows even if the train is not in the immediate neighbourhood. The current can be several hundred amperes, leading to a quite high magnetic field, at least close to the tracks. When an overhead contact line is used, the passengers are placed in between the contact line (the «forth-current») and the tracks (the «back-current» or “return current”). In this region the fields from the two «wires» add constructively, so that the field becomes larger than if only one «wire» was present. On the other hand, most trains are made from metal, and even if the metal walls only give a rather moderate shielding from low frequency magnetic fields, the reduction is easy to prove.

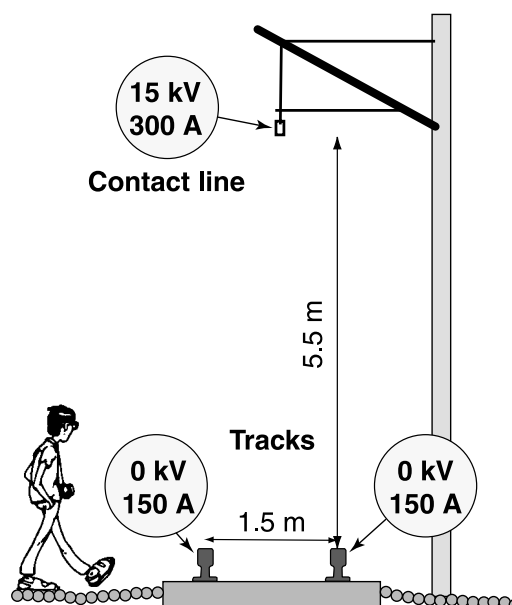


Figure 19-8: Electrical voltage and current for a typical train track.

There are several different electrical systems used in railroads in different countries. In some systems efforts are done in order to keep the return current in the tracks, in other systems current is free to leak out in the nearby ground (soil). The field in houses near the railway will depend heavily on this difference. In Norway the policy is to keep as much of the return current as possible in the tracks (as low «vagabonding currents» as possible if we use an expression from above), leading to relatively low magnetic fields in nearby houses.

The amount of currents through the ground was experimentally determined during a particular test situation. One typical railroad section was closed one night and the currents in the contact line and the tracks were kept constant for a period of hours, while we measured the field from the railway. The result is shown in figure 19-9. It is used a so-called log-log plot in order to follow the field accurately for four different magnitudes. Based on these measurements one can conclude that only about 5 percent of the return current passed through the soil. Thus, the magnetic field was reduced according to the inverse square law up to about one hundred meters away from

the tracks. After that distance, the field from the 5 % imbalance took over, and the field from thereon was reduced only according to an inverse first power law.

The first point in the graph indicates that the magnetic field 1 m above track level was about 40 μT at a current of 290 A, which is a typical peak current on this particular railway.

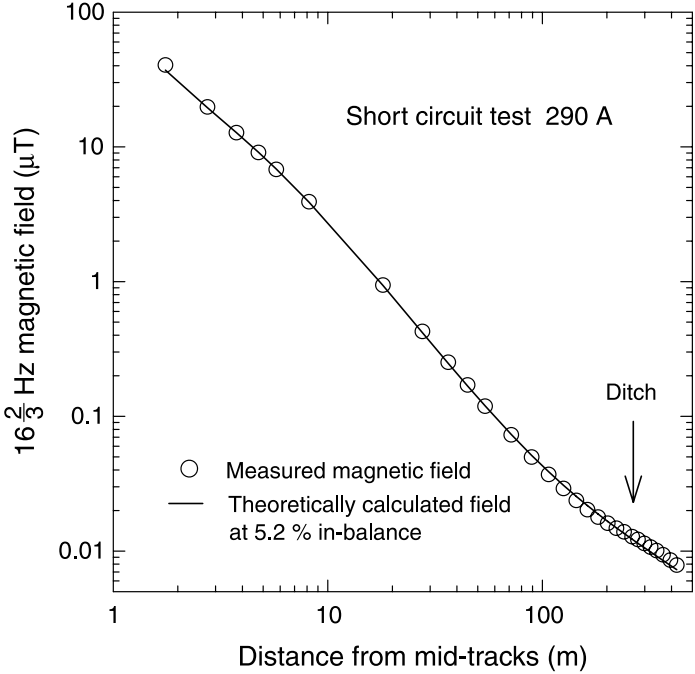


Figure 19-9: Magnetic field from a railway: measured and theoretically calculated values. The theoretical calculations were based on 5 % imbalance (electrical current through the soil). The current was kept constant during the measurements.

In normal use, the current varies very much when trains traffic a railroad. Figure 19-10 shows magnetic field recorded at a location a few meters away from a train track. The magnetic field close to a power line, especially large transmission lines, do vary much less and much more slowly than the fields from railroads. Thus, it is difficult to compare exposure from power lines and exposure from railroads.

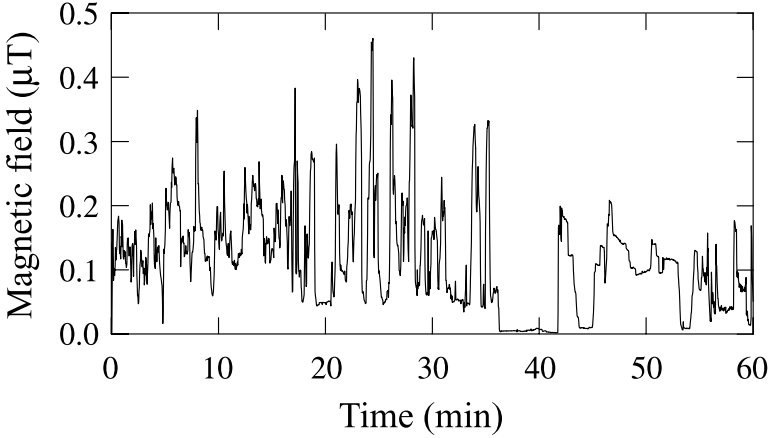


Figure 19-10: Magnetic field at a fixed position a few meters away from a railroad when the traffic went as usual.

The exposure as a passenger is somewhat different to the exposure of a neighbour to a railroad. We are not going into detail here, but it depends on segmentation of the railroad. The engine driver receives a third kind of exposure, due to the magnetic field exposure produced by the engine and local electrical system. The exposure of the engine driver is covered elsewhere in this book.

The results from a few studies indicate that there might be some health impacts on locomotive crew (engine drivers). We are not aware of any study on passengers, but there was not found any increased cancer incidence among linemen, who spend large parts of their working day along tracks of an electrical railway (compared to linemen working on non-electrified railways).

19.9 Theft alarms

In many shops alarms are installed preventing people to steal items. At the exit of the shop a special device is placed in order to detect the particular marking device (“tags”) fastened to the merchandise. Several systems are in use, but in most cases only weak radio frequency fields are involved. For some systems where the marking is not removed, the marking tags are deactivated by a strong, magnetic field pulse. One person have told us stories that indicates that the field from one particular type of tags deactivation devices might be large enough to trigger nerves at the cashier’s lower arm (so-called acute effect mentioned in Chapter 10). The field is probably quite harmless for the customer, but could be of health effect for the cashier. Systematic measurements are required in order to explore this hypothesis further.

19.10 Exploration of exposure

Exposure of low frequency magnetic field can be explored in two principally different manners. One can measure the field from various sources, at different distances from the sources, and register the movement of people and thus construct a possible typical exposure situation during minutes, hours or days. We say that this method is based on spot measurements.

In the other procedure the person of interest carry an instrument that register regularly (e.g. every fourth second) the magnetic field, stores it in a memory. After a day the data can be down-loaded into a computer and analysed further. We say that this method is based on personal dose-meters.

Both methods have their strong and weak points, and we are not going into the details here. However, we want to stress that measurements only have a limited value as long as we do not know the exact mechanism by which weak fields have an effect on the body.

Figure 19-11 shows magnetic field recordings from two different persons that carried a personal dose-meter for 24 hours (only a fraction of the total time lapse is shown). The most direct use of such diagrams, are the possibility to identify sources of the strongest field values, and to describe qualitatively the exposure. Other use of the data is more questionable. The reason is that we do not know:

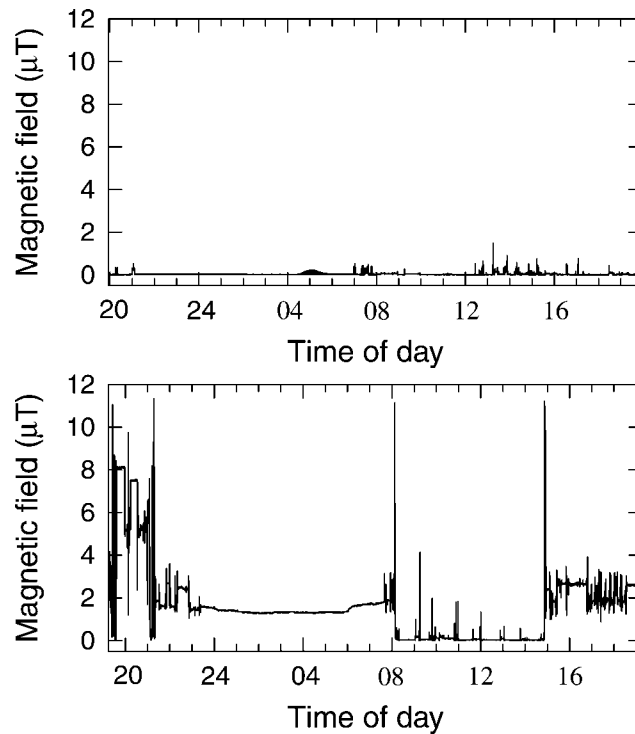


Figure 11: Magnetic field recording with a personal dose-meter, from two different children. At the top is a part of the data shown for a girl living in a house far from a power line. At the bottom the corresponding data are shown for a boy living in a house only about 10 m away from a transmission line. The boy passed under the line on his walk to the school.

- whether it is the mean value or some peak values that determine an eventual biological effect
- whether it is the arithmetic or the geometric mean, or the median that is of most interest (these three numbers may differ considerably!)
- whether it is the mean value during a typical day, or the accumulated «dose» (calculated as mean value times time) during years that matters
- whether it is more «dangerous» to have an intermittent type of exposure, or a steady state value, provided that the mean value is the same
- whether it is only periods when the magnetic field is above a certain level that matters
- whether exposure in some part of the body is of more interest than in other parts
- whether exposure at night is more important than exposure at daytime
- whether kids and pregnant women is more vulnerable to exposure than other people
- whether there exist particular sensitive people to electromagnetic fields or not

As mentioned before, we do not know the answers to these questions, and this fact put a very serious limitation to e.g. epidemiological studies. In most of these studies exposure is given as one kind of time-weighted average. The effective “dose” for a particular biological effect, may in the future turn out to be described by a quite different measure. The association between e.g. magnetic field exposure and the particular biological effect may then turn out to be much stronger than it may seem today. However, since we do not know the answer, all this is pure speculation.

What we *do* know, is that the statistical association between health effects and exposure to moderate to weak low frequency electromagnetic fields at the present is weak. The result is that the

scientific community is divided in about two equally large groups. One group thinks that the biological effects are real and may lead to either beneficial or deleterious effects, depending on the circumstances. The other group thinks that weak fields do not have any biological effect at all. On the other hand, about everyone agrees that acute effects appear at exposure to strong fields. However, acute effects often requires field values in the order of 1000 μT or higher to occur, and as we have seen from our survey, exposure to such large fields is very rare indeed. It only happens for particular workers at very special work-places.

In order to present some of the details regarding exposure situations indicated by the points on the previous page, one may describe exposure matrices in a graphical way as indicated in figure 19-12 and 19-13. The exposures of different categories of people are given in three-coded bars, where exposure for the whole body, 24 hours a day, is the base. Exposure only for shorter times a day is the next measure of exposure, and exposure for short time and only parts of the body are the last category. In all categories the bars are chamfered, indicating the normal interval in field level found within the group of people. Two different diagrams are drawn in order to point out that exposure to static (or quasi-static) fields may have a quite different health effect than time-varying fields.

Diagrams like those in figure 19-12 and 19-13 can be drawn in many different ways, but the statistics behind the diagrams may be rather poor. In spite of this, these diagrams often remind the reader of the complexity of exposure in a better way than when simple tables are used, giving only the estimated mean values.

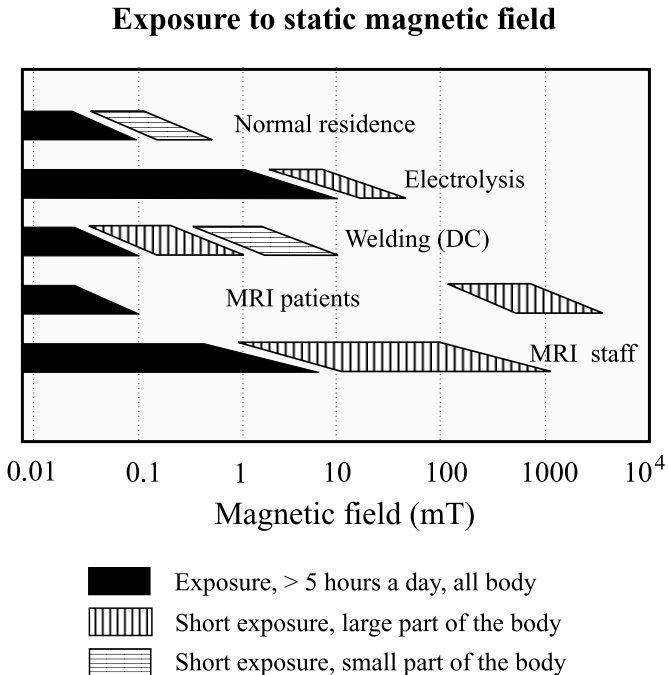


Figure 19-12: Typical exposure levels of static magnetic field for some selected groups of people.

Exposure to extremely low frequency magnetic field

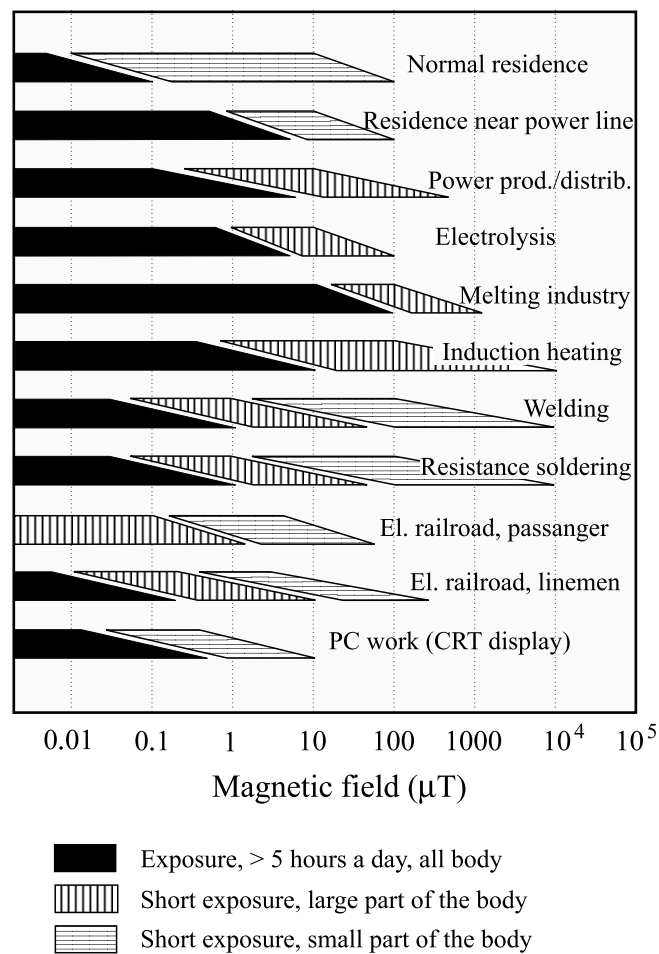


Figure 19-13: Typical exposure levels of time-varying (mostly power frequency) magnetic field for some selected groups of people. The numbers refer to Norway where the 230 V IT system is used most places.

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