Electromagnetic Fields and Human Health

John G Mc Auley
MSc MIEI
Compliance Engineering Ireland Ltd

1.   Introduction

In Ireland in recent years electromagnetic fields and their possible effects on human health has been a subject of considerable controversy. At times it could be said that the debate has reached fever pitch.

This paper examines the electromagnetic spectrum, its effects on the human body, and compares typical exposure levels with international guidelines.

Compliance Engineering Ireland Ltd provides a measurement service to industry and local authorities to ensure the safety of installations both from an employee and public perspectives. This paper is based on experience from providing that service.

2.   What are Electromagnetic Fields

The electromagnetic spectrum covers a frequency range from zero hertz through radio frequencies, optical radiation and up to ionising radiation. This paper deals with frequencies up to the top end of the radio frequency range at 300 GHz.

At the high frequency end of the electromagnetic spectrum the fields are known as ionising radiation since the wave contains sufficient energy to cause ionisation. This can sometimes be damaging to living material.

At frequencies below 300 GHz the electromagnetic wave does not contain sufficient energy to cause ionisation and this part of the spectrum is called non-ionising radiation.

The sources of electromagnetic fields change with frequency as does the nature of the wave and it's effects. For example, the static magnetic field used in MRI (Magnetic Resonance Imaging) is generated by a powerful electromagnet. The earth is also a source of a static magnetic field which varies in strength between 10 and 100µT (micro Tesla).

As we move up through the frequency range to 50 Hz, power lines generate magnetic fields which are proportional to the current carried on the line and electric fields which are proportional to the line voltage.

Radio frequency fields are generated via an antenna which launches the wave in to free space. The antenna acts as a transducer between the amplifier and free space. Moving electron charges on the surface of the antenna cause similar electron movement in the air which is then propagated. Radio frequencies have the characteristic that they propagate through free space. For practical purposes this is normally considered to be at frequencies greater than 3 kHz.

The fields caused by power lines at 50 Hz do not propagate like radio frequencies and as a result the energy is largely concentrated between the

line and the ground. Therefore, it is something of a misnomer to call the fields emanating from power lines radiation.

Time varying signals such as electromagnetic fields have a wavelength which is obtained by dividing the speed of the waves (3×10^8 m/s) by the particular frequency. The free space wavelength of some key frequencies is shown below.

Table 1
Variation of Wavelength with Frequency

Frequency	Wavelength
50 Hz	6000 km
150 kHz	2000 m
100 MHz	3 m
1 GHz	30 cm
2.45 GHz	12 cm

The wavelength is important as it has implications for the effect of the wave on the human body.

Microwaves are so called because they are frequencies where the wavelength of the field is very short. The frequency at which microwaves begin is not well defined and can be considered as either 300 MHz where the wavelength falls to below one metre or at frequencies above 1 GHz. Figure 1 shows the electromagnetic spectrum and applications in the non ionising radiation region.
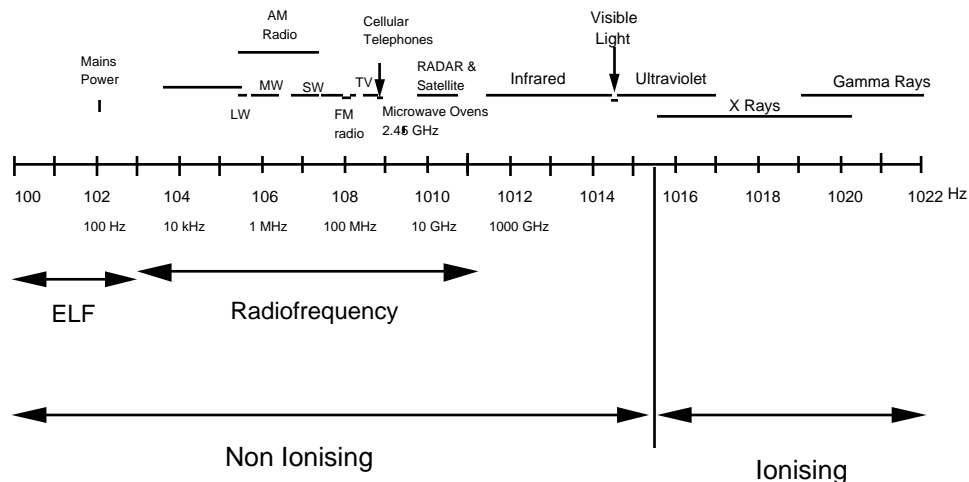
THE ELECTROMAGNETIC SPECTRUM
Figure 1

ELF is extra low frequency

## 2.1   Calculation of Power Density

The power density of RF (radio frequency) fields is expressed in watts per square metre (W/m^2). The power density is related to the product of the electric field and magnetic field components by the relationship:

Power Density (W/m^2) = Electric Field x Magnetic Field

Power Density in Watts per square metre (W/m^2)
Electric Field in Volts per metre (V/m)
Magnetic Field in Amps per metre (A/m)
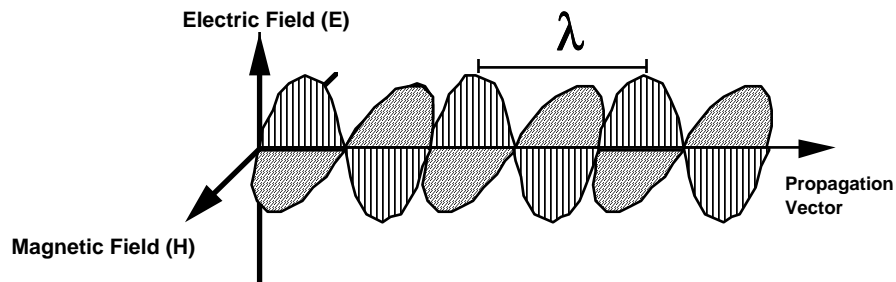
Far Field Electromagnetic Wave
Figure 2

The power density for a particular transmitter may also may be calculated from the formula:

Power Density = PG/4pd^2 (W/m^2)

where
P = the maximum output power
G = the antenna gain
d = the distance from the antenna

As can be seen the power density falls off with the square of the distance from the transmitter. For this reason the field strength close to a small transmitter can be much larger than the field strength at a greater distance from a large transmitter.

Note: 1 MHz = 1 million hertz, 1 gigahertz (GHz) = 1 thousand million hertz
        1 mW/cm2 = 1000 microwatts per square centimetre (µW/cm2)
        = 0.1 Watts per square metre (W/m2)

3. Mechanisms of Interaction

3.1 Power Frequency Fields

The mechanisms of interaction between electromagnetic fields and the body vary with frequency.

At power frequencies the effects of the electric and magnetic components of the wave can be distinguished. The body, as a conductor, provides a path to ground to an external electric field. The surface induced charge is conducted into the body with the current densities being dependent on the size, shape and position.

Magnetic fields induce circulating currents within the body which are dependent on the loop size of the path. The currents would therefore be greater in the trunk than in the limbs.

Electric charges are induced in ungrounded conducting objects exposed to a electric field. Given a large enough object in a strong electric field a person could experience a shock hazard. This is an example of an indirect hazard.

3.2 Radio frequency Fields

As we move up through the frequency spectrum the characteristics of the electromagnetic wave change. Unlike at power frequencies where the electric and magnetic fields are independent of one another, at radio frequencies the electric and magnetic field strengths are closely related. At a distance of several wavelengths from the source the two components are related by the impedance of free space, 377 ohms. This is known as the far field region.

The effect on the body also changes with the mechanism tending away from being determined by currents flowing to ground to localised energy absorption.

The amount of coupling of an RF field into the body is dependent on the polarisation of the field with respect to the orientation of the individual and on the dimensions of the body or body part which is exposed. Maximum coupling occurs when the body is parallel to the electric field component and when the body length is similar to the wavelength of the field. When the body is electrically grounded, e.g. barefoot, it resonates at approximately 40 MHz at which frequency maximum absorption of the electromagnetic field occurs. A poorly grounded body, which is more typical as people are normally insulated from ground by their shoes, will resonate at twice this at a frequency of around 80 MHz.

RF fields absorbed by the body cause currents to flow and may also cause polar molecules to vibrate, both of which effects, if of sufficient magnitude, cause heating of the tissue. These are known as thermal effects. Other effects of RF fields on tissue have been reported which do not appear to be due to thermal heating and are known as non thermal or athermal.

Figure 3
Effect of an alternating electric field on the polar water molecule
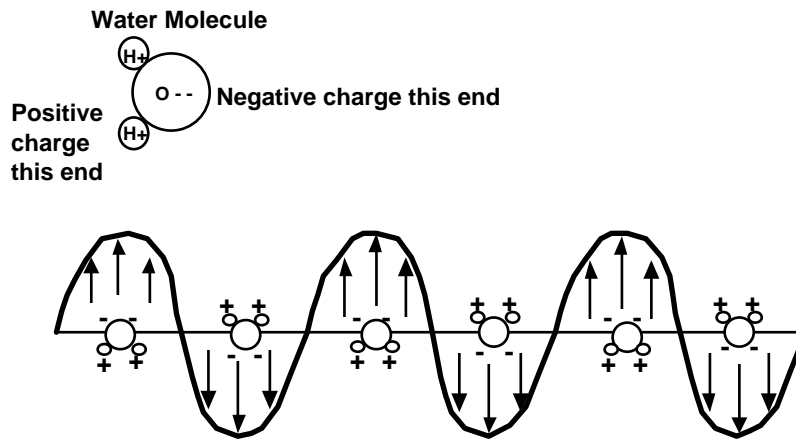
At low frequencies, where the wavelengths are long, the fields pass through the body with little absorption. With increasing frequency more of the incident energy is absorbed and at microwave frequencies the absorption is based in the surface layers of the body.

For example, in a microwave oven operating at 2.45 GHz the depth of penetration of the energy is only a few centimetres. This is evident when defrosting a loaf of bread when we find that while the surface of the loaf is hot the middle may still be frozen. To cook a large object in a microwave oven it is necessary to allow time for the conduction of heat from the surface layers to the centre.

Figure 4
Effect of Frequency on Penetration Depth
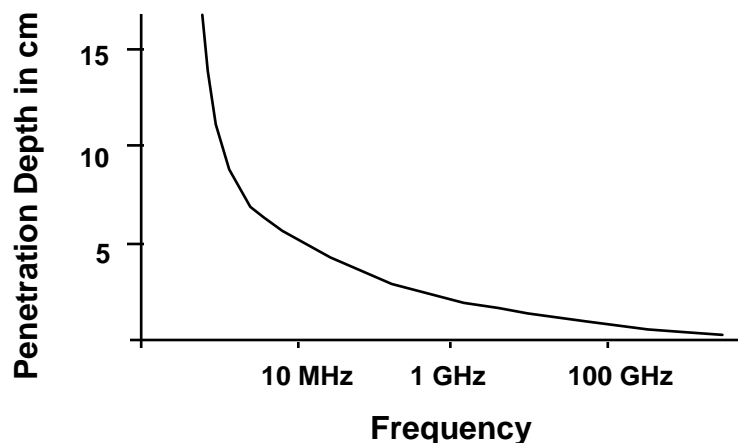
Source: NRPB

As the frequency approaches the ultra violet range the energy is deposited largely on the surface.

The frequency ranges are categorised by the ICNIRP as follows.

Table 2
Frequency Ranges

Range	Frequency	Comment
Sub resonance	less than 30 MHz	surface absorption in trunk, absorption decreases rapidly with decreasing frequency
Resonance	30 - 300 MHz 400 MHz	whole body resonance partial body resonance
Hot Spot	400 - 2000/3000 MHz	localised energy absorption caused by resonance or quasi optical focusing
Surface absorption range	greater than 3000 MHz	surface absorption

The measure of the absorption of RF fields in the body is the specific energy absorption rate (SAR) which is expressed in watts per kilogram (W/kg).

When assessing the potential hazard of a radiofrequency source it is desired to determine the SAR which defines the basic restriction. However, it is difficult to directly measure the SAR. The SAR is dependent on the field strength values which are easily measurable. Therefore, field strength limits have been derived from the SAR values and are used as the means of demonstrating compliance with the basic restrictions. Recommended limits for SAR and derived field strengths are given later.

## 4. Effects of Electromagnetic Fields

4.1 Power Frequency Fields

An ambient power frequency electric field induces very small currents in the body[2] which are significantly lower than the body's own naturally occurring current densities. For example, the current density caused by muscle action[1] is 10 mA/m^2.

At a field strength of 10 kV/m the induced current would be in the region of 4 mA/m^2. At field strengths in excess of 10 kV/m, much in excess of the highest typical exposure levels, direct perception of the field is possible because of effects on the visual and nervous systems.

In the case of power frequency magnetic fields, large field strengths are also required to produce noticeable effects and would normally only be produced by special equipment used for research or very close to a high current carrying conductor. A 50 Hz magnetic field of 0.5 milli Tesla (mT) will cause current densities of around 1 mA/m^2 in the body given optimum conditions. At 5 mT a flickering sensation in the eyes can be produced.

Figure 5

**Effect of Electric and Magnetic Fields on Person
Standing Below a Power Line**
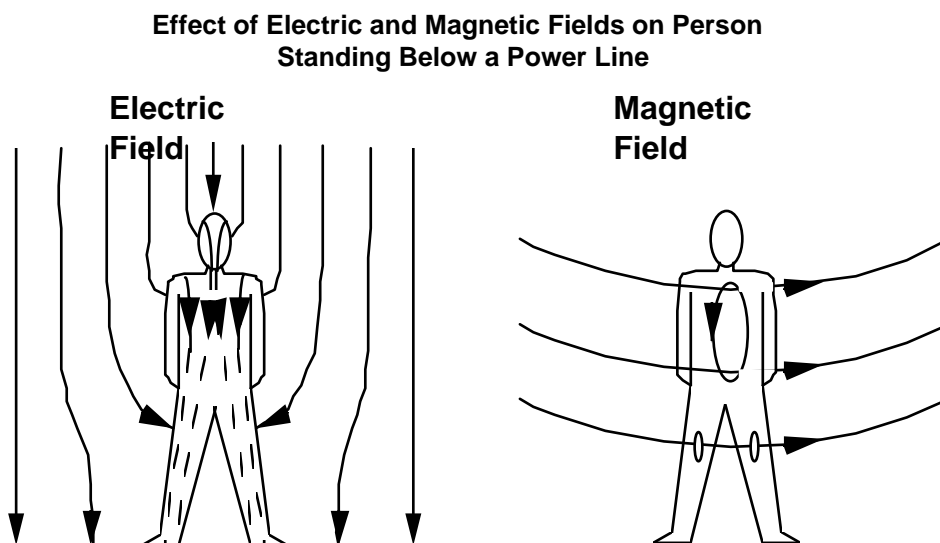
4.2 Radio Frequency Fields

The main acute effect of radio frequency fields is body heating. However, very strong fields are required to induce any significant increases in body temperature. In general, an increase of 1°C is set as an acceptable limit[3] below which no person would experience harm. In comparison, the body can sustain higher temperature rises as a result of physical exertion.

4.3   Athermal Effects

There has been much speculation concerning various illnesses and electromagnetic fields. Considering the complexities of the systems of the human body it is hardly surprising that the effects of external electromagnetic fields come into question. Add to this the apparently inconclusive nature of work to date and it would appear to be a mecca for researchers. This is evident from the conclusions of papers on the subject where it is commonly recommended that more research is needed to provide answers.

In order to identify a hazard to human health it is necessary to have correlated results from three types of study[4]- epidemiology, in vivo research and in vitro research.

Epidemiology is the study of populations on the basis of the incidence of disease and exposure to the particular agent under study. Typically this involves identifying one group of people who are exposed to electromagnetic fields and a control group not exposed to the same levels.

In vivo research involves the study of the effects of fields on laboratory animals or humans. In vitro research is literally "in glass" where cells or tissue are exposed to the fields and observed for particular changes.

For an effect to be clearly proven there must be correlation between these studies. For example, many of the accepted effects found during in vitro research have not been demonstrated during in vivo, whole body, research. This may be because the body has many complex and ongoing feedback mechanisms to counteract potentially external harmful influences.

There are many interesting theories on the effects. However, it is beyond the scope of this paper to try to discuss in detail the many effects of electromagnetic fields which have been and are currently being researched.

Tables 3 and 4 outline a synopsis of some of the effects being studied in in vivo and in vitro research. Table 3 is based on a review of a report by the Chief Technical Advisor to the Department of Energy, Dr Tom McManus titled Electromagnetic fields[4]. This report has an in depth review of the subject and the table is a précis of the same. Table 4 is taken from a report by Dr Michael Repacholi[3], chairman of the ICNIRP and a leading researcher in the field.

Overall the ICNIRP[1] does not consider that the athermal effects are of sufficient concern to justify a change in any of their guidelines. This is because they are not known to be a hazard to the health of humans and/or only occur at field strengths higher than the existing guidelines. Most of the effects detailed above are peculiar to ELF fields.

Table 3
Research on Possible Athermal Effects

Effect	Field Type	Strength	Comment
Chromosome Damage (DNA)	ELF modulated magnetic fields	greater than normal ambient	Effect now generally discounted
Cell Membrane Effect	ELF magnetic fields	low level	Study of efflux of calcium ions from cell membrane which forms part of cellular signal process.
Cyclotron[5] Resonance Hypothesis	ELF frequency window	low level	Resonance effect on ions thought to be caused by interaction between AC and DC magnetic fields
Immune Response System	ELF electric and magnetic fields	high level	Study of effect of fields on the body's natural defence mechanism. Results inconclusive
Cancer Promotion	ELF fields	-	Electromagnetic fields cannot initiate cancer but could they promote tumours?
Magnetite Theory	magnetic fields	high levels	Magnetite crystals distributed through brain and particularly in membrane may be affected by high level magnetic fields.
Excess Free Radicals	ELF	high levels	Theory that magnetic field could prevent neutralisation of naturally occurring free radicals thereby causing chromosome damage
Melatonin suppression mechanism	ELF	high levels	Theory that the fields affect the pineal gland which controls body's biological rhythm

4.4 Radio frequency Effects

In the radiofrequency range there are fewer known or speculative effects of electromagnetic fields. In general, most of the effects, with the exception of the movement of calcium ions, are caused by an increase in thermal levels and would be caused by any strong source of thermal energy .

A number of epidemiological studies have taken place on radiofrequency exposure involving occupationally exposed groups such as naval and military personnel or workers occupationally exposed to high levels.

Table 4 compares some of the studies with the basis for international standards[3].

Table 4
RF Effects/Relation to Standards

SAR (W/kg)	Effect	Comment
0.00016	None	Typical Background level
Approx. 0.01	Movement of Calcium ions using modulated fields	No known consequences
0.08	**No health effect**	**Guideline safety level (general public)**
0.15 - 0.4	Total cancer incidence unaffected in animals	Lifetime study of mice
1 – 4	Transient changes in animal behaviour	Basis for standards
4 (for 20 min)	Human body temperature increases 0.5°C	No health consequence
2 – 8	Increased tumours in mice treated with chemical carcinogen	Temperature related - unconfirmed report
4.4	Transformation of cells treated with cancer promoter	Abnormal chromosome cell line - unconfirmed report
>15	Thermal effects in offspring	
>100	Eye cataracts in humans and animals	

5.   Recommendations on Limiting Exposure to RF Fields

There are no legal limits in Ireland at present to protect workers or members of the public from exposure to electromagnetic fields. The most commonly used guidelines are those published by International Commission on Non-Ionising Radiation Protection (ICNIRP)[1].

These guidelines were developed in co-operation with the World Health Organisation (WHO) as part of the WHO Environmental Health Criteria Programme funded by the United Nations. The work was also supported by the International Labour Office and the European Commission.

The European Commission has published a Recommendation (1999/519/EC) requesting Member States to put in place national legislation setting down maximum limits of non-ionising electromagnetic fields. This Recommendation[6] has largely adopted the ICNIRP 1998 guidelines.

The European Commission has also proposed the introduction of a Directive[7] (93/C77/102) to ensure the protection of workers from a number of physical agents including electromagnetic fields. The aim of the Directive is to protect workers and will not specify levels for the public. The proposal has passed through the European Parliament and a proposed amended version has been published (94/C230/03).

CENELEC, the European Committee for Electrotechnical Standardisation, has published a number of standards which provide protection for both workers and members of the public. The standards, covering low and high frequency ranges, have been approved by Technical Committee TC106X which comprises the EU and European Free Trade Association member countries. The standards are based on basic restrictions as published by the ICNIRP and the EU EMF Recommendation.

6.   IRPA Guidelines

6.1   Power Frequency Fields 50/60 Hz

The power frequency guideline limits are based on limiting current densities to less than about 10 mA/m^2. Limits for continuous exposure to electric and magnetic fields were determined using this criterion.

The ICNIRP guideline limits are reproduced in Table 5.

Table 5
Limits of Exposure to 50/60 Hz Electric and Magnetic Fields

Exposure Characteristics	Electric field strength kV/m (rms)	Magnetic flux density mT (rms)
Occupational		
Whole working day	10	0.5
Short term	30[a]	5[b]
For limbs	-	25
General public		
Up to 24 h per day [c]	5	0.1
Few hours per day[d]	10	1

1mT = 1000μT

[a]   The duration of exposure to fields between 10 and 30 kV/m may be calculated from the formula t = 80/E, where t is the duration in hours per work day and E is the electric field strength in kV/m.

[b]   Maximum exposure duration is 2h per work day.

[c]   This restriction applies to open spaces in which members of the general public might reasonably be expected to spend a substantial part of the day, such as recreational areas, meeting grounds, and the like.

[d]   These values can be exceeded for a few minutes per day provided precautions are taken to prevent indirect coupling effects.

6.2   Radiofrequency Fields, 100 kHz to 300 GHz

The ICNIRP guidelines[1] are stated in the form of basic restrictions from which field strength values are derived. The basic restrictions are expressed in terms of limits on induced electric current and specific absorption rates.

The appropriate restrictions on exposure recommended by the IRPA are summarised below.

> The average specific energy absorption rate in the body over any 6 minute period should not exceed 0.4 W/kg for workers or 0.08 W/kg for members of the public at frequencies above 10 MHz.
>
> When taken in conjunction with the above restriction, the maximum value of the specific energy absorption rate in any 0.1 kg of tissue, other than in the hands, wrists, feet and ankles, should not exceed 10 W/kg for workers.
>
> The maximum value of the specific energy absorption rate in any 0.1 kg of tissue in the hands, wrists, feet and ankles should not exceed 20 W/kg for workers.
>
> If a current of 50mA from point contact with an object in the field is exceeded there is a risk of producing rf burns.
>
> In addition to the time averaged limits in the case of pulsed fields the equivalent plane wave power density averaged over a pulse width should not exceed 1000 times the Peq limits or the field strength should not exceed 32 times the field strength limits.

Limits for pulsed fields are suggested by the IRPA although they state that very little information is available on the relation of biological effects with the peak values of these fields. The justification given for the pulsed limit is to avoid prolonged or frequent exposures to the auditory effect produced by the instantaneous expansion of the skull that occurs for short pulses. Although there is no evidence that the auditory effect is harmful, some degree of caution is recommended in view of the underlying cause.

From the above basic restrictions field strength levels are derived as shown below. The basic restrictions are stated in terms of body current or SAR which are not easily measured quantities. Therefore, field strengths, which are easily measured, have been derived.

The restrictions at the lower frequencies, typically below 10 MHz, are based on preventing a shock hazard from ungrounded metal objects. At higher frequencies the restrictions are based on limiting the specific absorption rate.

Table 6
## Derived Power Density and Field Strength Limits
for the General Public

Whole Body Exposure

Frequency f(MHz)	Unperturbed RMS Field Strength		Equivalent Plane Wave Power Density	
	Electric E(V/m)	Magnetic H(A/m)	(W/m^2)	(mW/cm^2)
0.1 - 1	87	0.23/f$^{1/2}$	-	-
1 - 10	87//f$^{1/2}$	0.23/f$^{1/2}$	-	-
10 - 400	27.5	0.073	2	0.2
400 - 2000	1.375f$^{1/2}$	0.0037f$^{1/2}$	f/400	f/2000
2000 - 300000	61	0.16	10	1

Figure 6
Power Density

IRPA Guideline Levels for Public Environment
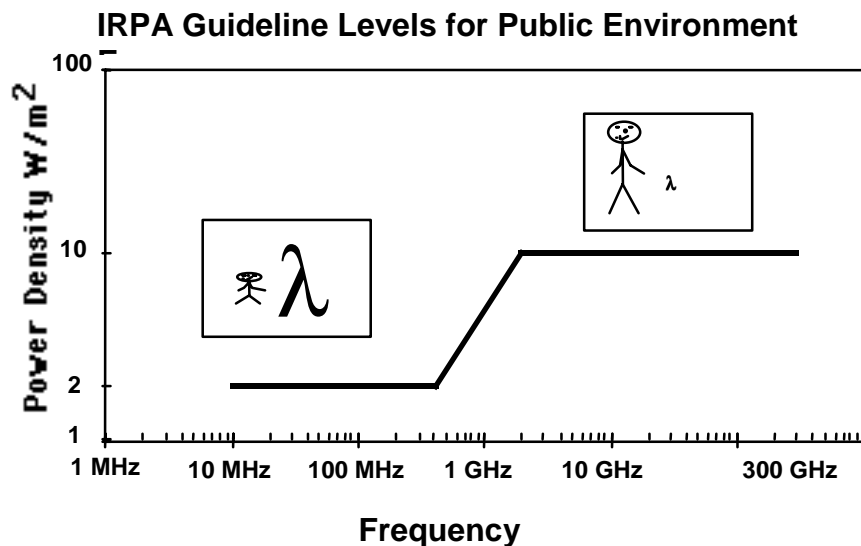
Figure 7
IRPA ELECTRIC FIELD GUIDELINE LIMITS
PUBLIC EXPOSURE
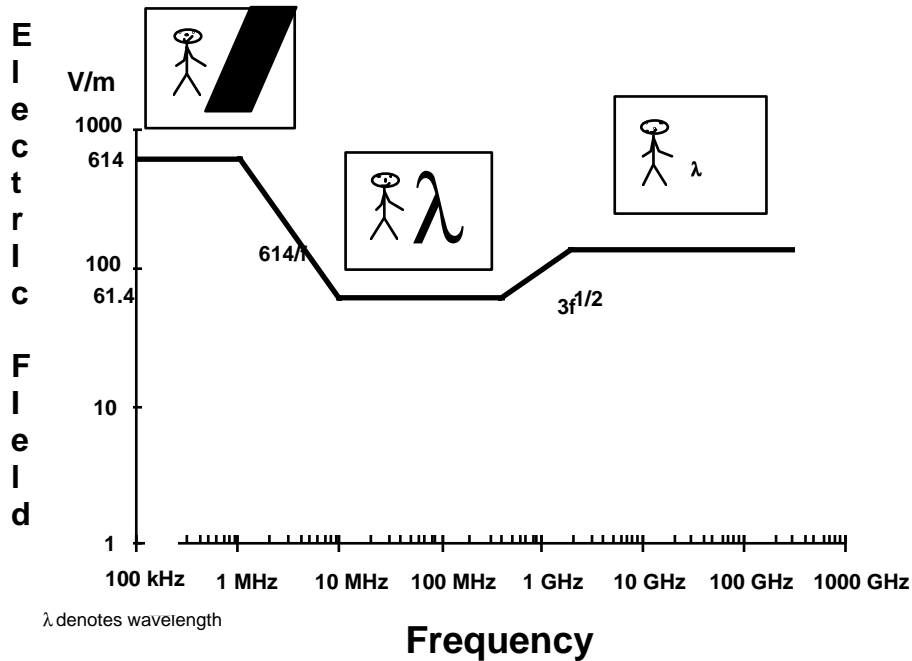
The levels in the VHF frequency range are one fifth of those in the microwave range because of the improved coupling of the field to the body at these frequencies.

These levels are based on preventing thermal effects. However, they state that protection against athermal effects was also kept in mind.

The IRPA also set a threshold power level of 7 watts below which they recommend that the transmitter does not require consideration. This is based on the view that transmitters of lower power than this are inherently incapable of causing a thermal hazard.

7.   Field Strength Levels

Some common sources of electromagnetic fields are now reviewed.

7.1   Power Lines

There has been considerable concern expressed regarding electromagnetic field emissions from power lines. More work has been carried out on this source than any other and the levels have been measured and modelled extensively. In Ireland, it would appear that exposure to power frequency fields is much lower than in some other countries with a much higher density of population. In some countries the pylons and lines were installed at

16

relatively low heights to minimise the visual impact resulting in a higher field strength under the line.

It must also be remembered that, as noted earlier, the fields from power lines are largely concentrated below the line and fall off quickly with distance from the line. Therefore, one often finds that the field strengths inside a building are dominated by the house wiring rather than the emissions from the line. For example, an electric field strength of approximately 30 V/m could be expected below a light bulb and magnetic fields of the order of several micro Tesla close to the consumer unit or some electrical appliances. In comparison the electric field from a power line would be largely conducted away by the building structure resulting in no significant contribution to the field inside the house. The magnetic field from a 220 kV line would have fallen to approximately 0.8 micro Tesla at 40 m. Table 7 shows the typical field strengths at various distances from common line types. There highest voltage lines in Ireland at present are 400 kV.

Table 7
Typical Electric and Magnetic Field Strengths

Voltage (kV)	Line Type	Electric Field (volts/m) Distance from Centreline (m)				Magnetic Field micro Tesla (µT) Distance from Centreline (m)			
		10	20	40	50	10	20	40	50
110	Single Circuit	850	250	40	-	2.7	1.0	0.3	-
110	Double Circuit	450	120	100	-	3.2	1.5	0.5	-
220	Single Circuit	2600	1200	200	-	4.2	2.0	0.6	-
220	Double Circuit	1900	400	250	-	3.8	2.2	0.8	-
400	Single Circuit	6000	3500	600	250	8.0	2.0	1.2	0.8
400	Double Circuit	6000	1400	500	400	7.0	4.5	1.8	1.2
500	Double Circuit	6000	1500	350	250	20.0	8.0	2.0	1.0
1100	Single Circuit	8500	8300	3300	1500	28.0	22.0	10.0	7.0

Source: Ref 10

The question of emissions from substation transformers is often raised. In our experience power transformers, while using strong magnetic flux densities internally, have very low emissions by virtue of the closed magnetic circuit. In practice the predominant electromagnetic field strengths around substations are caused by cabling to and from the transformer.

7.2   Interference on VDUs

An interesting problem to come to light in recent years has been the problem of interference with the steadiness of text on computer displays which can be caused by strong magnetic fields. Most common VDUs (visual display units) will have a susceptibility threshold at about 1µT at which point the effect becomes perceptible. The effect takes the form of jitter or instability in the displayed characters caused by direct modulation of the electron beam by the magnetic field.

The problem has become more noticeable in recent years because of the proliferation of personal computers. While the magnetic fields may have always been there, being caused by proximity to high current carrying cables or some lighting circuits, their existence was unknown. The effect has also been exacerbated because of the trend towards higher refresh rates which were introduced, ironically, to improve display quality. Older VDUs used a 50 Hz rate which was synchronised with the power frequency and resulted in no net effect. As refresh rates have increased to 60 and 70 Hz the display wobbles at a frequency of 10 and 20 Hz respectively which, at sufficient amplitude, can be disorientating for the user.

Fortunately the 1 µT threshold is significantly below the IRPA guideline limit of 500 µT for workers, but nonetheless observance of the effects can cause alarm among uninformed staff. It should be noted that the VDU Directive (90/270/EEC) stipulates that the image on the screen should be stable, with no flickering or other forms of instability.

7.3   Emissions from Visual Display Units

VDUs themselves are often a source of concern as an emitter of electromagnetic fields. This originally resulted from a Swedish study which claimed a higher level of miscarriages in pregnant VDU operators. Subsequent, more reliable studies were unable to demonstrate any link. Nonetheless, the harm had been done and VDUs still suffer from some common prejudice. The IRPA released a paper[9] in 1988 titled "Alleged Radiation Risks from Visual Display Units" which as the title suggests contradicts the fears. Display manufacturers have voluntarily undertaken measures to reduce the emissions from VDUs to below levels described in a Swedish voluntary standard[10] known as MPR 2. As a result, most VDUs produced in the last few years have very low level emissions.

7.4   Radio Frequency Sources

Apart from well known applications such as power distribution, radio broadcasting and communications there are many industrial and medical applications which use electromagnetic fields[11]. For example, diathermy equipment uses radio frequency fields for therapeutic purposes in physiotherapy. In this process contacts are placed across the area to be treated, e.g. across the knee, and a radio frequency current passed through to heat the affected area. The frequency of 27 MHz is often used because of the good depth of penetration at this frequency.

Another common application of strong electromagnetic fields is in plastic welding where the heating effect is used to fuse plastics together in an efficient and clean process.

7.5 Radio Transmitters

Radio transmitters have been in use for many years. In fact Ireland was the location of one of the worlds first transmitters established by Guglielmo Marconi at Clifden in Co Galway. His system used a 300 kW sparking type transmitter operating at a frequency of approximately 43 kHz. One wonders what bandwidth the output spanned.

Most of the measurement work in Ireland has concentrated on the MMDS (Multi-point Microwave Distribution System) television system and cellular telephone basestations which because of their nation-wide application which has resulted in numerous planning applications.
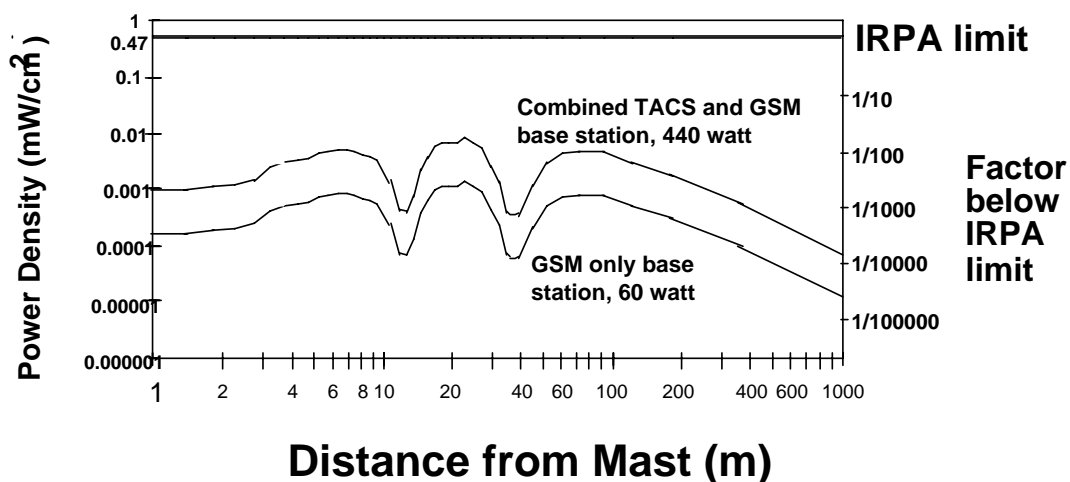
Predicted and measured field strengths from typical cellular telephone and MMDS transmitters are reviewed below. In addition, measurements of the ambient electromagnetic field strengths have been carried out to determine the typical field strengths that a Dublin resident could experience on a continuous basis. Typical exposures from occupational sources have been derived from work done by the NRPB.

7.6 Cellular Telephone Basestations

Predicted levels from a GSM cellular telephone basestation were calculated based on a system utilising three transmitter channels. This represents a maximum implementation as the system would currently be installed and would provide coverage for 23 mobile telephones in the cell and one control channel (eight channels per frequency).

Figure 8 shows the results for the system utilising three 20 watt amplifiers (effective isotropic radiated power 1728 watts) feeding into a Celwave AP901211 directional antenna. At points close to the antenna the field strengths are caused by side lobes as the main beam does not intersect with the ground for some considerable distance.

Figure 8

Combined TACS and GSM base station, 440 watt

GSM only base station, 60 watt

IRPA limit

Factor below IRPA limit

Power Density (mW/cm^2)

Distance from Mast (m)

As can be seen the predicted levels are substantially lower than the IRPA guideline limit. The levels produced by a GSM only basestation are substantially lower than those from a combined analogue (TACS) and GSM basestation. The older analogue system uses one transmission frequency to service each mobile phone whereas the digital GSM system can accommodate up to eight telephones on each frequency.

When assessing the emissions from a particular transmitter it must be remembered that the cumulative level from other local transmitters must be considered to determine the overall safety margin. However, for levels as low as these it is possible to say that in a situation where other sources were producing a cumulative level close to the limit the additional contribution from this transmitter would be negligible.

Measurements carried out at a busy cellular telephone base station comprising 19 analogue channels and one GSM channel showed a maximum cumulative level of 0.000351 mW/cm^2, a factor of over 1300 times less than the IRPA public guideline limit. These levels were determined by multiplying the level of strongest channel by the total number of channels which gives a pessimistic result. In practice only a few channels would be operating at full power at any one time.

7.7   MMDS

MMDS (Multi-point Microwave Distribution System) is a terrestrial television system[12] which comprises a maximum of 11 channels operating at frequencies between 2.5 and 2.7 GHz. The system was installed to increase the number of TV channels available to rural communities not serviced by cable systems. It is provided on a cellular basis with interlacing of frequencies and different polarisations being used to prevent interference between cells.

Coverage in a cell is normally provided by a main transmitter located on a suitable hilltop. The beam from the antenna is shaped to channel the energy in a pattern which provides best coverage of the target area. Antennas which produce a flat beam with an omnidirectional or cardioid radiation pattern are normally used. As many of the most suitable locations are already occupied by transmitter installations belonging to other systems providers the MMDS systems often share these masts.

Because of the line of sight nature of transmission, areas of the cell which are obscured by a hill or other topographical feature require fill-in transmitters which are commonly known as beam benders. In fact, these do not bend the beam as the name implies but operate by receiving the signal from the main transmitter using a conventional antenna which is then fed to a booster amplifier and retransmitted to the local area. The beam benders are located on a suitable vantage point such as a dedicated mast or on an existing building.

Typically the main transmitter will have a power output of up to 550 watts. Most beam benders have a power output of around 1 watt which, considering

that they are located in an elevated position, are very small from a radiation hazards perspective.

Figure 9 shows an example of the levels of emissions that have been predicted for a main transmitter using the full 11 channels each utilising a 30 watt amplifier. The antenna was an Andrews HMD16 with 14 dBi gain and sidelobes at -5, -10 and -14 degrees.

Figure 9

Predicted Power Flux Density at Ground Level
MMDS Transmitter

Distance from Antenna, m
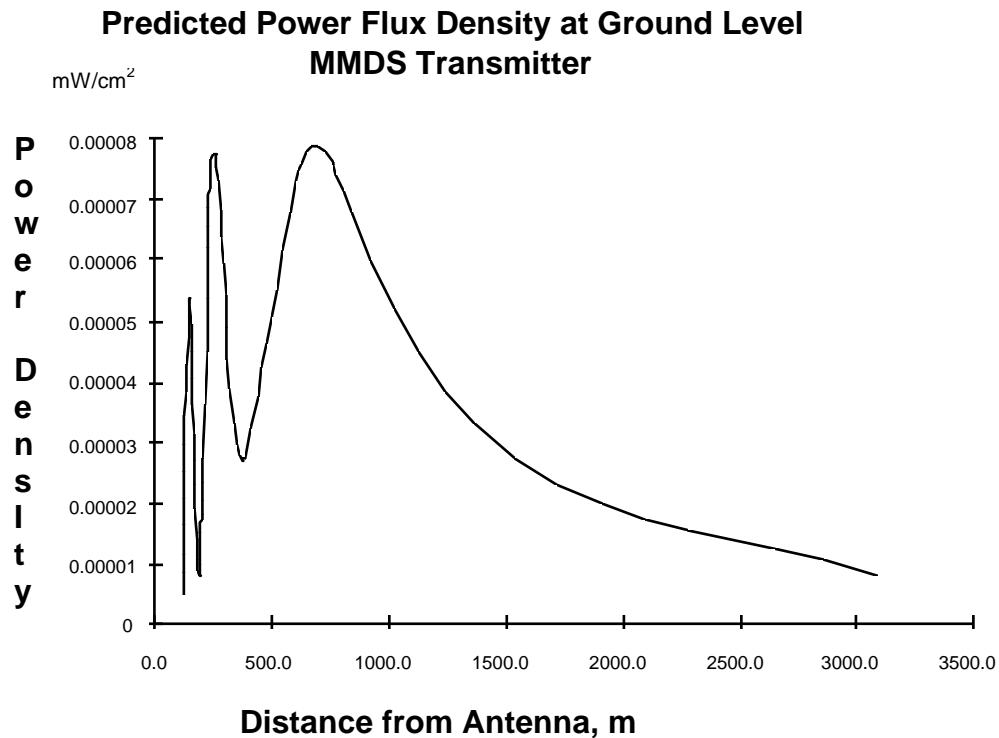
A 3m allowance was incorporated to allow for local ground variations. In carrying out the calculations it was assumed that there were no losses in the feeder system which gives a pessimistic result. In reality there are substantial losses in the path between the amplifiers and the antenna.

The maximum level predicted was 0.00008 mW/cm^2 at a distance of 250m from the antenna. This is a factor of greater than 12500 less than the IRPA public limit.

The results of measurements carried out in the area around a similar transmitter showed a maximum level, measured close to the transmitter, of 0.000058 mW/cm^2, a factor of 17000 times less than the IRPA guideline limit.

Typically the beambender systems use a one watt composite power output for eleven channel operation. Measurements on these systems have shown that the power density at one metre distance from the antenna front face was 50 times less than the IRPA public limit. These measurements were carried out by gaining access to the front of the antenna which would not normally be accessible to the public. In fact the main beam did not intersect with the

ground until some distance from the antenna. It follows that in areas of public access that the levels were substantially less than the IRPA guideline limit.

7.8   Ambient Electromagnetic Field Strengths

Measurements of the maximum ambient radio frequency spectrum were carried out on the roof of a five storey building at Forbairt, Glasnevin. The elevated and unobstructed position ensured that the maximum level of each signal was measured. The aim of the exercise was to determine the cumulative power density and therefore estimate the typical exposure level experienced by a person.

Figure 10 shows the results of the survey. Only the maximum levels are shown as there were a plethora of lower level signals from low frequency foreign radio broadcast stations. A feature of this type of survey is that several dominant signals will be the main contributors to the total power density. For example, a signal of 80 dB(µV/m) has a power density of one hundredth of a signal with a field strength of 100 dB(µV/m) and would not make a significant contribution to the total power density.

Figure 10

Radiofrequency Spectrum at Glasnevin
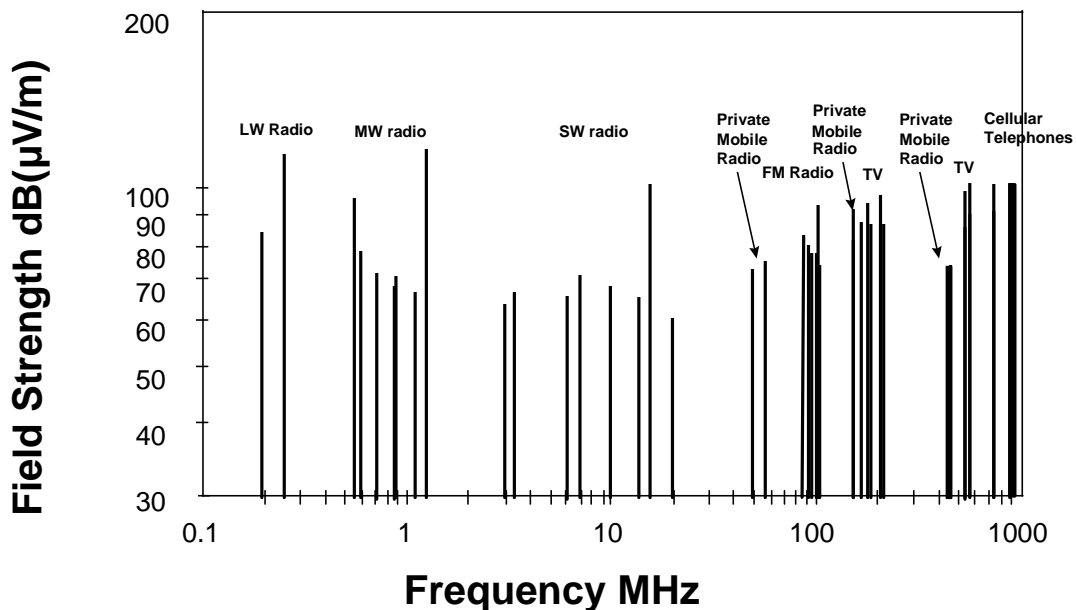
The IRPA guidelines require that in instances of simultaneous exposure to multiple sources that the sum of the exposure levels should be considered. In these cases the power density at each frequency should be expressed as a fraction of the limit at that frequency and the sum of these should not exceed unity.

The total power density of the signals shown was calculated to give 0.0002 mW/cm2, a factor of over 4000 below the IRPA public guideline.

These levels will be stronger than those experienced by most people and show that, in general, the population is exposed to very low levels of electromagnetic fields compared to the IRPA guidelines.

7.9   Mobile Transmitters

Mobile transmitters such as walkie talkies and cellular telephones probably produce the strongest field strengths that are encountered by people on a widespread basis. Although the power levels from these transmitters are low, less than 5 watts, because of the close proximity of the operator to the antenna higher field strengths can be experienced. For example the field strength from a 450 MHz walkie talkie has been measured at 100mm to be 10 V/m, 0.26 mW/cm^2.

At a few mm from a cellular telephone antenna the field strength has been measured at 30 V/m, 2.38 mW/cm^2. These exposures are on a very localised basis and would cause a specific absorption rate below the appropriate IRPA guideline limit of 10 W/kg. As the fields fall off on a square law basis the whole body exposure is at most 1 V/m, 0.0026 mW/cm^2, again considerably less than the relevant limit..

8.   Conclusions

It is evident that the levels of exposure from base station transmitters are extremely low compared to the guideline levels promulgated by the authoritative international agencies. There is a smaller margin of compliance from portable transmitters such as mobile phones and private mobile radio.

There continues to be considerable debate as to whether electromagnetic fields pose a threat to human health.

In this context, it should be remembered that the inconclusive nature of epidemiological studies shows that if a risk does exist, then it is small.

References

1.	Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz) - International Commission on Non-Ionizing Radiation Protection, Health Physics April 1998, Volume 74, Number 4:494-522

2.	Electric Power Transmission and the Environment: Fields, Noise and Interference, CIGRE Working Group 36.01 Report, 1993

3.	Cellular Telephone Base Stations and Health - Dr Michael H Repacholi, 1994.

4.	Electromagnetic Fields; a Review of Recent Developments in Research and Public Attitudes, and the Response of Authorities to these Developments, Government Publication Sales Office, Dr T McManus, Chief Technical Advisor, Department of Energy.

5.	The Cyclotron Resonance Hypothesis, Electric Power Research Institute, EN.3014.3.90

6.	Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz) (1999/519/EC)

7.	Proposal for a Council Directive on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (93/C77/02), Official Journal of the European Communities No C77/12, March 1993. Updated by 94/C230/03

8.	Electromagnetic Fields from High Voltage Transmission Lines, Government Publication Sales Office, Dr T McManus, Chief Technical Advisor, Department of Energy.

9.	Alleged radiation risks from visual display units. A statement by the International Non-Ionizing Radiation Committee of the International Radiation Protection Association. Health Physics Vol. 54, No. 2 pp. 231-232, 1988

10.	Test Methods for Visual Display Units 1990:10, Swedish Board for Technical Accreditation.

11.	Review of Occupational Exposure to Optical Radiation and Electric and Magnetic Fields with Regard to the Proposed CEC Physical Agents Directive, S G Allen et al, NRPB-R265

12.	Technical conditions relating to the establishment of a programme retransmission system (MMDS) in the band 2500 to 2686 MHz