From July 2005 *High Frequency Electronics*

Electromagnetic Radiation and Human Health: A Review of Sources and Effects

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This article provides an extensive summary of the types of electromagnetic radiation and their thermal and molecular effects on the human body

Radio Frequency (RF) engineers are faced many times with the following two questions: "What are the effects of radio waves on human health?" and, more specifically, "What health risks are associated with the use of cell phones, mobile radios, microwave radios, microwave ovens, broadcast radio and television transmitters, power lines and X-rays?"

In recent times, many people have expressed an interest in learning if the use of cell phones is associated with cancer. Many have heard or read about possible links between cell phones and cancer, but conclusions are rarely definitive. This paper will attempt to answer these questions, but first, we must develop a basic understanding of electromagnetic radiation (EMR).

Electromagnetic Frequency Spectrum

Wireless communication links have been used worldwide for many years as solutions for connectivity in point-to-point and point-to-multipoint applications. The most common wireless solutions include AM and FM radio, television broadcast stations, mobile and cellular phones, radar and microwave systems.

The electromagnetic (EM) spectrum contains an array of electromagnetic waves increasing in frequency from Extremely Low Frequency and Very Low Frequency (ELF/VLF), through Radio Frequency (RF) and Microwaves, to Infrared (IR) light, Visible Light, Ultraviolet (UV) light, X-rays, and Gamma rays.

Figure 1 is a graphical representation of the spectrum of electromagnetic energy or radiation in ascending frequency (decreasing wavelength). The general nature of the effects is noted for different ranges.

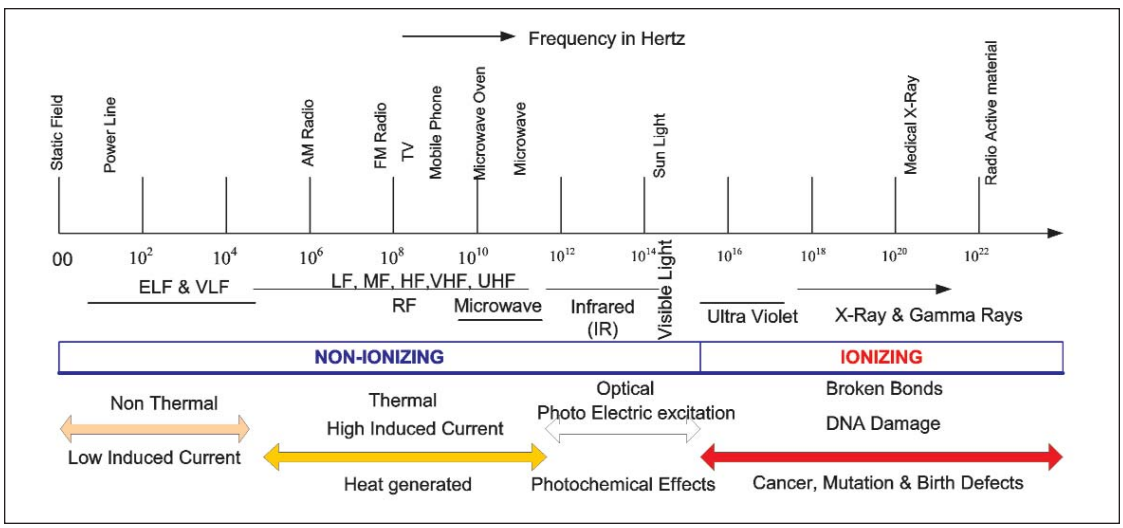

Figure 1 · Electromagnetic spectrum.

Ionizing Radiation

Ionizing radiation contains sufficient electromagnetic energy to strip atoms and molecules from the tissue and alter chemical reactions in the body (converting molecules totally or partly into ions). X-Rays and Gamma rays are two forms of ionizing radiation. These rays are known to cause damage, which is why a lead vest must be worn when X-rays are taken of our bodies, and heavy shielding surrounds nuclear power plants.

Human beings are constantly exposed to low levels of ionizing radiation from natural sources. This type of radiation is referred to as natural background radiation, and its main sources are:

- Visible light, ultraviolet light and infrared light (sunlight)
- Radioactive materials on the earth's surface (contained in coal, granite, etc.)
- Radioactive gases leaking from the earth (radon)
- Cosmic rays from outer space entering the earth's atmosphere through the ionosphere
- Natural radioactivity in the human body

Non-Ionizing Radiation

The lower part of the frequency spectrum is considered *non-ionizing* Electromagnetic Radiation (EMR), with energy levels below that required for effects at the atomic level. Examples of non-ionizing radiations are:

- Static electromagnetic fields from direct current (0 Hz)
- Low-frequency waves from electric power (50-60 Hz)
- Extremely Low Frequency (ELF) and Very Low Frequency (VLF) fields (up to 30 kHz)
- Radio Frequencies (RF), including Low Frequency (LF), Medium Frequency (MF) High Frequency (HF), Very High Frequency (VHF), Ultra High Frequency (UHF) and Microwave (MW) and Millimeterwave (30 kHz to 300 GHz)
- Infrared (IR) light, Visible light and Ultraviolet (UV) light (above 300 GHz)
- [*Editor's note: the frequencies between the highest microwave bands and infrared light are rarely used, but are being studied for future applications*]

Some heating effect is generated by all of these waves. Insufficient energy is available from most common sources to produce any type of damage to human tissue, although it is probable that higher power densities, such as those densities very near high-voltage power lines or high-power (megawatt) broadcast transmitters, could have long-term health effects.

The power density of any source of EMR is not only related to the power level at the source, but increases rapidly as the distance from the source decreases. A common concern today, since more and more people are using cell phones than ever before, is that cell phone antennas radiate near a person's head. Cell phones, however, radiate very little power. So, even while close to the head, they are not considered a danger.

Some studies suggest that potential health hazards could be linked to excessive exposure to high-power densities of non-ionizing radiation. These health hazards include:

- Cancer
- Tumors
- Headaches
- Fatigue
- Alzheimer's Disease
- Parkinson's Disease

Researchers, however, are unsure of specific long-term effects resulting from prolonged exposure to non-ionizing radiation.

ELF and VLF EM Radiation

EMR in the ELF and VLF range is both naturally occurring and man-made. Natural EMR includes a background electromagnetic field created by the earth as well as additional EMR created by thunderstorms, as well as solar and cosmic activity. The strength of an electromagnetic field depends both on the power at the source and the distance from the source.

Exposure to man-made ELF/VLF occurs primarily due to the generation, transmission and use of electrical energy. Electromagnetic fields are created whenever electricity passes through a conductor. Actually, two interdependant fields are created: an electric field and a magnetic field. The strength of the electric field depends on the voltage being carried, while the magnetic field strength depends on the amount of current being carried (amperage). Thus, electromagnetic fields are created by a variety of electrical household appliances such as motors in refrigerators, vacuum cleaners, hair dryers, irons, electric blankets, microwaves, televisions, stereo receivers, and computers. In fact, because of the individual's proximity to household appliances, the level of electromagnetic fields is often far greater than those levels produced by transmission lines strung on high towers. However, the appliances only create electromagnetic fields while in use, whereas the transmission line electromagnetic fields are continuous. While these man-made ELF/VLF electromagnetic fields may cause biological effects, the adverse effects on human health are highly controversial.

Electrical Power Line Effects

The concern over electromagnetic fields emitted by power lines (Figure 2) has long been a topic of conversation in the real estate and power industries. New studies and conflicting reports are published every year. While it is easy to shield a house against the electric field generated by nearby power lines, it is much more difficult to shield against the magnetic fields they generate. The magnetic

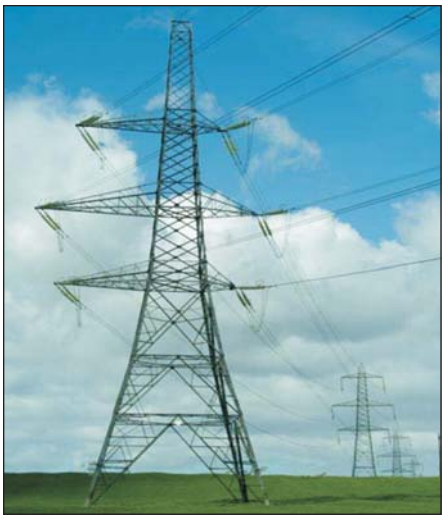

Figure 2 · Electric power line.

Type of mobile radio	Frequency (MHz)	Average radiated power
Cellular/PCS	824-849 MHz 1850-1990 MHz	A few hundred milliwatts
Two-way, hand-held (walkie-talkie)	30, 50, 150, 450 and 800 MHz bands	Between 2 and 5 watts
Cordless telephone	49, 915, 2450 MHz	Tens of milliwatts

Table 1 · Typical portable/mobile radio equipment.

field can best be shielded by burying power transmission lines, but at a much higher cost compared to overhead lines.

Animal experiments, laboratory studies of cells, clinical studies, computer simulations, and human population (epidemiological) studies have been conducted to determine the relationship between exposure to electromagnetic fields and a number of disorders, including depression, childhood leukemia, central nervous system disorders, cancer, melanoma, breast cancer, etc. In the past, numerous reports have presented conflicting information. Some of these reports have provided evidence of adverse health effects, and some other reports have failed to find any such correlation. Recently, the National Academy of Sciences and the National Cancer Institute have released major studies finding no evidence of a link between electromagnetic fields and cancer. These studies suggest that power transmission lines are much less likely to cause cancer than was previously suspected.

Radio Frequency Radiation

RF energy in the frequency range of LF, MF, HF VHF, UHF or Microwaves is often referred to as radio waves, RF radiation, or RF emissions. For the purpose of this discussion, the term "RF energy" is used for all frequencies between 30 kHz and 300 GHz. Some known facts about RF energy are:

- The biological effects of RF energy are proportional to the rate of energy absorption, and the level of absorption varies little with frequency.
- RF energy has the ability to heat human tissue, much like the way that microwave ovens heat food, and can be hazardous if the exposure is sufficiently intense or prolonged.
- Damage to tissue may be caused by exposure to high levels of RF energy because the body is not equipped to dissipate the excessive amounts of heat generated. Possible injuries include skin burns, deep burns, heat exhaustion and heat stroke.

Eyes are particularly vulnerable to extended exposure to RF energy; the lack of blood flow to cool the cornea can result in cataracts.

Broadcast Stations

Commercial AM/FM radio and TV broadcast stations transmit very high levels of RF energy. Some of their antennas radiate power levels of several megawatts but, fortunately, these antennas are generally placed on high towers or buildings where no humans are nearby. Even so, humans absorb more RF energy from AM/FM radios and TV broadcast station antennas than from mobile telephone and base station antennas. However, once the energy is absorbed from either source, the effects are basically the same.

An Australian group claimed to have evidence that living near television broadcast station towers causes an increase in childhood leukemia. However, follow-up studies conducted in Australia and in the UK contradicted this claim. The follow-up studies found no significant correlation between RF exposure and the rate of childhood leukemia in these cases.

Cellular Telephones, Cordless Phones and Hand-Held Radios

Most cellular/PCS and cordless telephones have either a small antenna attached or the antenna is integrated into the body of the telephone. Because the antenna of a cellular phone is close to the user's head, such telephones create greater RF exposure than other types of RF systems. Home cordless telephones and other two-way hand-held radios have a similar effect. However, cordless telephones have very low RF power output and two-way hand-held radios are generally used in the push-to-talk mode, therefore, transmission is not continuous. Table 1 illustrates the frequency bands and average radiated power for cellular, PCS, hand-held radios and cordless telephones in the United States.

Vehicular Mobile Telephones and Radios

Vehicular mobile telephones (not cellular) and radios have an antenna mounted outside a vehicle, usually on the roof, window, trunk or fender. The metal surface of a vehicle provides a shield between the mobile telephone or radio user and the RF energy radi-

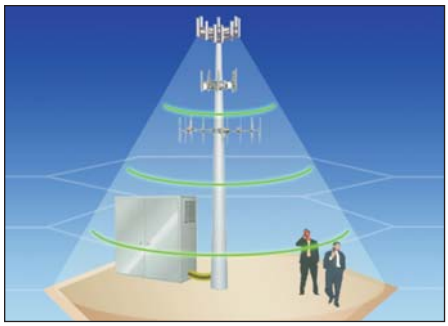

Figure 3 · Exposure of humans to RF energy from radio sites.

Figure 4 · Microwave communication site.

ated by the antenna. The distance between the user and the antenna also serves as protection against RF energy. Because of these two factors, users of mobile equipment have little exposure to RF energy, even though the average radiated power is significant, between 10 and 100 watts.

Base Stations and Radio Sites

Cellular/PCS and other two-way radio system base stations (radio sites) produce RF energy. Therefore, people near the base stations are exposed to this type of energy. However, the exposure is generally minimal due to the low level of power (less than 100 watts) produced and the distance between the tower-mounted antennas and any humans in the area (Figure 3).

RF Exposure Concerns

EMR from cellular/cordless and hand-held radios have billions of times less energy needed to cause ionization or damage to DNA contained in human tissue. The rapid and widespread use of this technology, however, has raised concern over possible adverse health effects, in particular brain cancer. Several studies which addressed this concern have been conducted in the United States and other countries. These studies seem to rule out, with a reasonable level of confidence, any association between EMR from these devices and cancer.

A growing number of scientific experts have shifted positions regarding the use of these types of wireless devices. Many of these experts believe that a cancer risk is associated with EMR in the higher wattage ranges.

For base stations located at radio sites, the consensus of the scientific community is that the power produced is far too low to cause health hazards so long as people are prevented from being in close proximity to the antennas.

No study, to date, has provided conclusive evidence that cell phones can cause any illnesses. However, ongoing studies are examining the issue more closely. Recent reports from Europe raised concern over possible links between cell phone use and tumors in the ear, with the risk being greater for children than adults.

It is important to note that cellular/PCS and cordless telephones are relatively new technologies, and it is impossible to prove that any product or exposure is absolutely safe in the absence of long-term research. Therefore, a good "precautionary" approach would be for adults to keep cell phone conversations short and to discourage the frequent, extended use of cell phones by children.

A notable danger involving the use of cellular phones is not radiation related, but is rather the increased risk of driving accidents while using them. The results of several studies indicate that talking on a cellular telephone while driving significantly

Figure 5 · Example of an MRI machine.

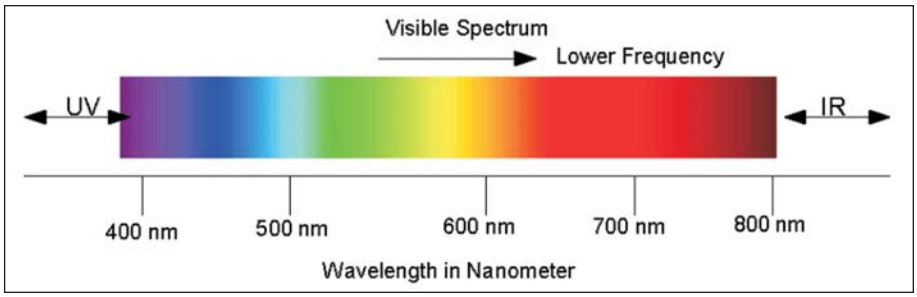

Figure 6 · Visible Light Region of the Electromagnetic Spectrum

increases the risk of having an accident, with some suggesting that it is almost as dangerous as driving while drunk.

Effect of Microwave Ovens on Human Health and Food

Concerns are often expressed regarding the effects of EMR from microwave ovens on people nearby and on the food prepared in them. Many people believe that microwave ovens may cause cancer and that food prepared by them becomes toxic.

This belief is simply not true. While forms of ionizing radiation such as X-rays usually have sufficient localized energy to cause chemical damage to the molecules in their path, non-ionizing radiation, such as microwaves, does not damage molecules. Microwaves generate purely thermal energy, creating heat in moist food or tissue placed in the oven.

Microwave ovens are designed and tested so that negligible micro-wave radiation escapes when the door is closed, making the level of the RF radiation outside the oven quite safe. However, leakage from a worn or damaged gasket around the oven's door can allow radiation leakage which can create an unsafe condition.

Foods cooked in a microwave oven suffer no lasting effects. No conclusive evidence exists of any chemical changes in microwave-prepared food beyond those effects caused by heating, as in a normal oven.

Microwave Communication Links

Microwave communication links operate in frequency bands between 1 GHz and 60 GHz. As mentioned previously, heat will be generated in living tissue exposed to RF frequencies, including microwave radiation. The human eye is particularly susceptible to damage from microwave energy. In extensive, but controversial, research on the ocular effects of microwaves on animals, lens cataracts have been produced after exposure to very high frequencies.

Microwave links used for communications employ highly focused beams of energy sent through space directly between antennas usually placed high on special towers (Figure 4). This practice makes it unlikely that anyone can inadvertently come directly in the path of this type of energy.

Magnetic Resonance Imaging

MRI is based on the magnetic properties of atoms. Magnetic resonance technology is based on the absorption and emission of energy in the radio frequency from various body tissues. MRIs use a powerful magnet to produce a magnetic field approximately 10,000 times stronger than the natural background magnetic field produced by the earth, and generate a variable RF radiation in the 1 MHz to 100 MHz range. A very small percentage of hydrogen atoms within a human body will align with the static magnetic field. When focused, radio wave pulses are transmitted toward the aligned hydrogen atoms in tissues of interest, where they will reflect a weak signal. Images are creates through the reception and analysis of the reflected weak radio signals. These slight differences in the signal received from various body tissues enable the MRI to produce images of extraordinary resolution that differentiate organs, and potentially contrast benign and malignant tissue (Figure 5).

Although power deposition in the patient can be substantial, no side effects or after effects are experienced, since MRI does not utilize ionizing radiation. However, hazards of improperly applied MRI therapy do exist that can cause severe injuries or even death. These hazards are primarily the result of:

- Strong magnetic fields from MRIs causing interference with implanted electronic devices such as pacemakers.
- RF burns resulting from induced currents in conductors accidentally placed on the patient's skin surface (e.g., leads from electro-cardiographs and other monitoring devices).

Optical Effects (Ultraviolet, Visible and Infrared Light)

Sources of optical radiation exposure include:

- Sunlight
- Heat lamps
- Lasers
- Other incandescent sources

Intense optical radiation will cause electron excitation. This means that

electrons in tissue near the body's surface can absorb energy from intense optical sources, thereby causing heating and even burning. Visible light spectrum is illustrated in Figure 6.

Optical radiations are not very penetrating; therefore, the eye and the skin are the organs of greatest concern. The immediate effects can be retinal injury to the eye as well as abnormal redness and burning of the skin due to solar radiation (sunburn). Delayed effects include cataract formation, retinal degeneration, accelerated aging, and skin cancer.

Effects of Infrared (IR)

Infrared (IR) is an energy field similar to visible light but with a longer wavelength. This radiation, typically emitted by heat lamps, molten metal or glass, fireplace embers and other "hot" objects, is invisible to the human eye. The thermal effects, characteristic of the IR region, extend into the spectrum of visible light. However, while visible light energy is emitted by objects only at a high temperature, infrared energy is emitted by all objects at ordinary temperatures. Some studies have shown that infrared energy can have positive effects on human cells in that it can help to rebuild connective tissue. Infrared radiation has no correlation with ultraviolet radiation and, applied in moderation, has no damaging effect on human health.

Effects of Ultraviolet (UV)

The main effect of Ultraviolet (UV) radiation is photochemical; this effect is also the case, but to a lesser degree, with visible light. Everyone is exposed on a daily basis to the UV radiation contained in sunlight. The harmful effects of UV exposure depend on the level of exposure, the duration of exposure and differences in the susceptibility of individuals to UV light. UV radiation has both positive and negative effects. The positive effects of UV radiation include warmth, photosynthesis in plants, and vitamin D synthesis in the human body. However, overexposure to UV radiation has adverse health effects. In addition to the immediate effect of sunburn, overexposure to UV radiation can cause skin cancer, eye damage, immune system suppression, and premature aging. Children are highly susceptible to harmful UV radiation. Because of its greater biological effects, some references consider UV to be ionizing radiation.

X-Rays, Gamma Rays and Other Nuclear/Cosmic Rays

The adverse effects of large doses of ionizing radiation were seen shortly after the discovery of radioactivity and X-rays in the 1890s. In 1902, skin cancers were reported in scientists who were studying radioactivity. The role of radiation in causing leukemia in humans (primarily in physicians and radiologists) was first reported in 1944.

X-Ray and CT Scan

Due to the extremely high frequencies and energies of these forms of EMR, they have sufficient energy to break chemical bonds in living tissue. The well-known biological effects of X-rays are associated with the ionization of molecules. The many types of X-ray devices include:

- Radiographic systems (dental, podiatry, veterinary, medical, chiropractic)
- Fluoroscopic imaging systems; (hospitals, radiologists)
- Cancer therapy
- CT Scan (Computed Tomography)
- Mammography
- Cabinet X-ray systems for security (baggage inspection at airports)
- Industrial radiography (pipe welds, circuit board analysis)
- Bone Density Scans for detection of osteoporosis
- Other medical and research applications

A CT scan is essentially a sophisticated type of X-ray that can take cross section images of the body. These scans

provide excellent bone detail by shooting multiple X-ray beams through the body to create a computer-generated image. Whole-body scans require higher doses of the X-ray radiation to make these images. As is the case with other forms of ionizing radiation, X-rays, over the long term can the modify genetic material in cells and cause mutations leading to cancer.

It is important to realize that the amount of X-ray radiation used in most diagnostic procedures is so small that the risk is extremely low. Multiple X-Ray examinations do not appear to increase risk, and no limits have been placed on the number of medically necessary X-ray examinations a person may undergo. However, it is always safe to assume that the same kind of effects that occur at high doses of radiation could occur at low doses; therefore, it is better to try to reduce exposure as much as possible. Patients should, if possible, minimize their exposure to X-rays, especially to CT scans which should not be performed on women who may be pregnant.

Gamma Rays

Everybody is basically aware of the high degree of danger associated with atomic radiation. Gamma rays, as well as Alpha and Beta particles emitted from radioactive material and nuclear reactions, are forms of ionizing radiation; these rays and particles can cause chemical or physical damage when they deposit energy in living tissue.

Health effects resulting from exposure to radiation vary from no effect at all to death, and can cause disorders such as leukemia or bone, breast, and lung cancer. In addition, the children of pregnant women who were exposed to high doses of radiation have shown an increased risk of birth defects.

These effects have been observed in various studies of medical radiologists, uranium miners, radium workers, radiotherapy patients, and the people exposed to radiation from Chernobyl and the atomic bombs dropped on Hiroshima and Nagasaki.

Safety Guidelines

In the United States, federal, state and local authorities require that all equipment and facilities emitting electromagnetic radiation comply with their exposure guidelines. These guidelines are designed to protect both occupational workers and the general public with a very large margin of safety. These limits have been endorsed by federal health and safety agencies such as the Environmental Protection Agency, the Food and Drug Administration, etc. These standards limit exposure to levels many times below those levels generally accepted as having the potential to cause adverse health effects.

Conclusions

Electricity—Studies of workers exposed to strong electric and magnetic fields (60 Hz) from power lines provide no consistent evidence that these fields are damaging to DNA or that they are capable of causing mutations or cancer.

RF—The most apparent biological effects of RF energy to living cells are due to heating. While it is not certain that RF radiation generally poses any risks to human health, some reasons exist for being concerned about human health effects from the cellular phones themselves. These concerns exist because the antennas of these phones deliver much of their RF energy to small portions of the user's head.

No evidence exists regarding any harmful effects resulting from exposure to typical levels of RF and EMF radiation. However, everyone should be aware that exposure to such radiation may not be completely safe at certain power levels and frequencies. It is always a good idea to avoid unnecessary radiation exposure whenever possible.

EMR exposure at the highest frequencies (X-Rays, Gamma rays) is a source of serious biological damage. Health effects from exposure to this form of radiation vary from no effect at all to death, and can cause diseases such as leukemia or bone, breast, and lung cancer.

Acknowledgements

Many thanks to Robert Edmondson and Ernest Roiz for review comments and their valuable suggestions regarding ways to improve this paper.

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