Electrical Tech Note — 229

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Electromagnetic Field Basics (EMF)

Energy can be transmitted in nature in the form of electromagnetic radiation, sometimes referred to as electromagnetic fields (EMF). It is transmitted from one point to another in the form of waves. The waves can be close together or stretched out over a long distance. This is called the frequency. Frequency is the number of waves that occur in a unit time of one second. Frequency is waves or cycles per second which is called Hertz. Some electromagnetic frequencies will pass right through a material and other frequencies will be blocked by that same material. Electromagnetic waves will travel through a vacuum, and in a vacuum they travel at a speed of approximately 186,000 miles per second (3×10^8 m/s). Light is electromagnetic radiation. Obviously light is transmitting energy, because we feel heat when we stand in the sun which is an intense beam of electromagnetic radiation. An object absorbs the light of the sun, gets hot and then radiates the heat. Heat radiating from an object is also an electromagnetic wave (infrared radiation), but infrared radiation is at a lower frequency than light.

Electric and Magnetic Waves: Electromagnetic radiation is made up of two components; an electric wave and a magnetic wave, both with the same frequency. At high frequencies the electric and magnetic waves are coupled together and act as a single electromagnetic wave. ***Extremely low frequency fields*** *(**ELF**) are defined as frequencies between 3 and 3000 Hertz.* The electrical power system in North America operates at 60 Hertz which is in the ELF frequency range. For extremely low frequency electromagnetic fields, the magnetic wave and the electric wave can act independent of each other in that the amplitude of one can be increased without increasing the amplitude of the other. Any electrical conductor carrying electrical current will produce an electric field and a magnetic field in the space near the conductor as illustrated in *Figure 229.1.*

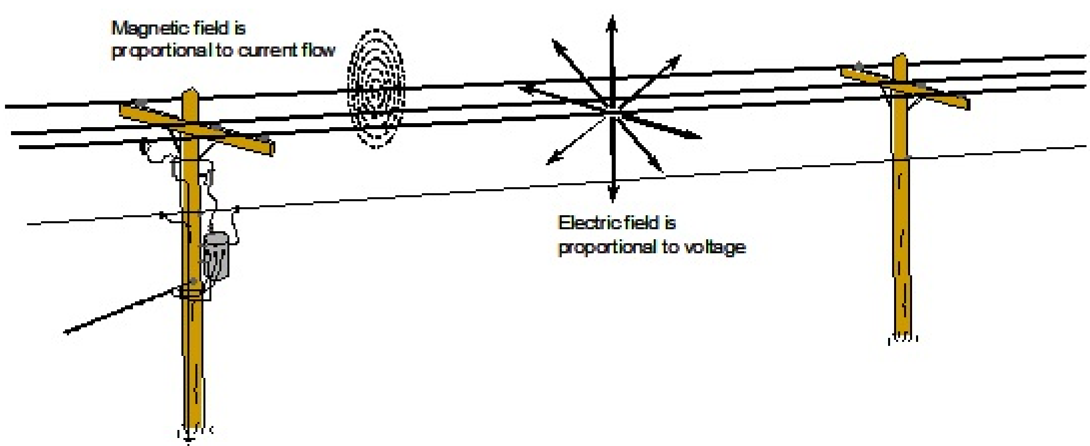

Figure 229.1 *An energized wire with a voltage, but no current will produce an electrical field. A wire carrying current with little voltage will produce a magnetic field. A wire with high voltage and high current will produce a strong magnetic field and a strong electric field.*

Induced Current In Plants, Animals, and Humans: High frequency electromagnetic waves transfer more energy than do low frequency magnetic waves. Microwaves are at a frequency of several billion Hertz and their fields will cause heating in conducting materials. X-rays are at an extremely high frequency and they can cause ionization of chemicals that result in the breaking apart of molecules. Electromagnetic fields caused by electrical wires, appliances, and power lines are considered to be extremely low frequency *(ELF) and cannot cause ionization or heating of materials, but they can cause very weak electrical currents to flow in conducting objects, even plants, animals, and humans*. In plants, humans and animals, this current is too weak to penetrate cell membranes and when present flows mostly in the spaces between cells. There are natural currents that flow in the body of humans and animals as a result of brain and heart activity. *Current "induced" by power wires are usually weaker than the natural body currents*, although the currents are different. The electric power induced currents, even though weak, alternate at 60 Hertz. Natural body currents do not have the same form as electric power induced body currents. People and animals are exposed to EMF 24 hours per day with the level varying throughout the day depending upon location and equipment in use. Exposure to EMF in patterns such as shown in *Figure 229.2* are not uncommon. The graph represents EMF from low frequency, ac sources of all kinds including wiring and appliances in the home, exposure to power lines, and wiring and equipment in the work environment. The high peaks in the graph could be a person in close proximity to a power line or being near home appliances, office equipment, power tools, or electrical powered machinery.

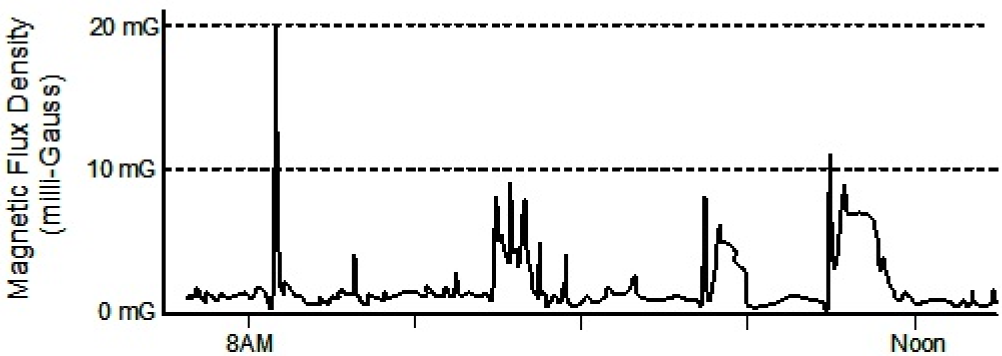

***Figure 229.2** A graph of EMF exposure of a human during a four hour period from home to work. Location and exposure to various equipment or wiring was not documented.*

Magnetic Fields: Whenever an electrical current flows through a conductor there will be a magnetic field built up around the conductor. *The strength of this magnetic field is proportional to the level of current*. Voltage causes current to flow in a conductor, but there can be a high level of current in a conductor at a very low voltage. High voltage does not necessarily mean there is high current. Direct current (dc) flows only in one direction through a conductor, and as a result, the magnetic field around that conductor will build up and remain static. Static means it does not move. One unit of measure of magnetic field strength is the milli-Gauss (mG). There is a static geomagnetic field which at the earth's surface ranges in magnitude from 250 mG to 600 mG depending upon the locations on the earth with respect to the poles. This geomagnetic field is strongest at the poles and weakest at the equator.

In the case of alternating current (ac), the current flows back and forth through the conductor at a regular time interval. This regular time interval is called the frequency. For electrical power systems in North America, the current alternates back and forth in the conductor 60 times each second (60 Hz). An important fundamental of electricity is that when a conductor moves with respect to magnetic field a current will be caused to flow (induced) in the conductor. Since the magnetic field around a conductor carrying 60 Hertz current is in constant motion, it will “induce” a current to flow in adjacent electrical conducting objects, even humans and animals. Magnetic fields in the ELF range do not travel well in air or a vacuum, and therefore, the magnetic field around a conductor will weaken quickly as it tries to travel outward from a conductor as illustrated in *Figure 229.5.* A good way to reduce exposure to magnetic fields is to stand a short distance from the source. Magnetic fields can be reduced by grouping all wires of a circuit, such as the electrical wiring in a building. The magnetic fields of the wires of the same circuit tend to cancel each other when the wires are close together.

Figure 229.3 shows two wires carrying current that are perpendicular to the page. The magnetic flux builds up around the wire in a circular pattern as shown in *Figure 229.3.* The strength or density of this magnetic field depends upon the level of current flowing in the wires. The magnetic flux weakens quickly as it extends out into the surrounding air. According to the laws of physics, this magnetic flux has a polarity or direction. If the current in the wire on the right of *Figure 229.3* is coming towards the observer, the magnetic flux lines will have a counter-clockwise orientation or polarity. The wire on the left in *Figure 229.3* has current of the same circuit flowing away from the observer. The magnetic flux around that wire has a clockwise orientation or polarity. By moving the two wires very close together, the magnetic flux of one wire nearly cancels the magnetic flux produced by current flow in the adjacent wire, as illustrated by the pair of wires at the far left of *Figure 229.3.*

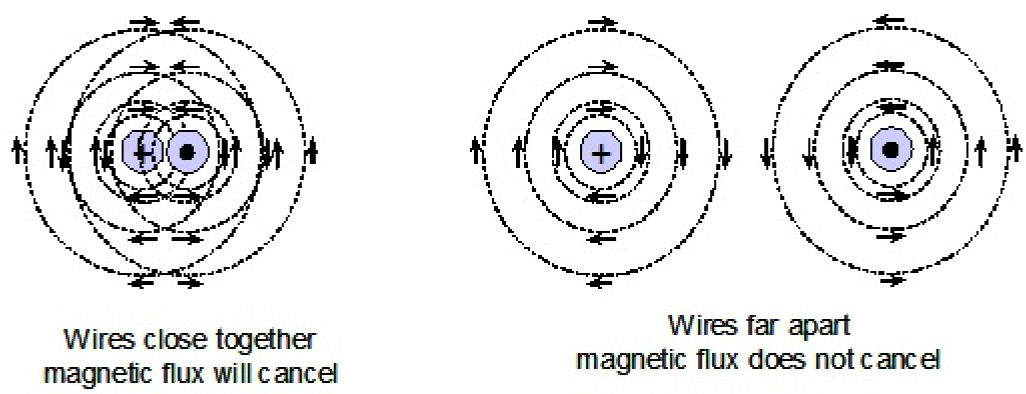

Figure 229.3 *The two small circles at the right are wires of the same circuit carrying the same current, but the flow is in opposite directions. A magnetic flux builds up around each wire but the polarity is opposite so the magnetic flux will cancel if the wires are close to each other as illustrated at the left*.

If all of the wires of a circuit are arranged close to each other, and assuming all of the current of that circuit is contained within those wires, the magnetic flux produced by current flow will cancel and will be hard to detect a short distance from the wires. Power lines on poles operate at high voltage and must be kept further apart making it more difficult to achieve total cancellation of the magnetic flux when current is flowing. For some applications magnetic flux cancellation for pairs of wires can be improved by twisting the wires around each other as shown in *Figure 229.4.* This is frequently the case for communications cables and computer network cables. This is done to prevent the signal in one pair of wires from affecting the signal in the adjacent pair of wires (cross-talk). The more times the cables are twisted per inch the better the magnetic flux cancellation. Some of these techniques are necessary for high speed communications circuits, but are impractical for electrical power circuits.

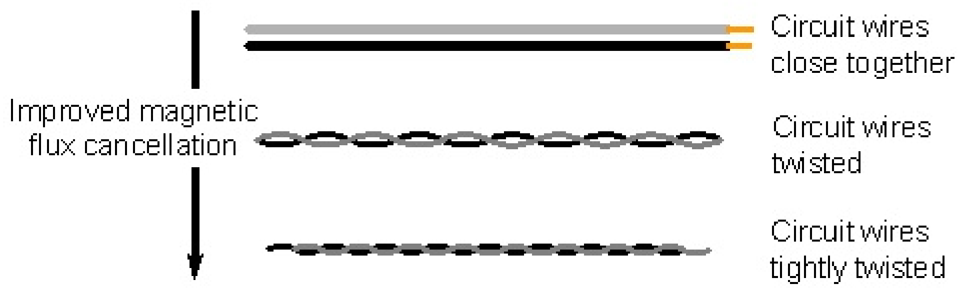

Figure 229.4 *Wires of the same circuit arranged close together will achieve good magnetic flux cancellation, by twisting the pair of wires together achieves even better magnetic flux cancellation.*

Measuring Magnetic Field Strength: The standard SI metric unit of measure of magnetic flux is the Weber (Wb). The stronger the source, which may be a magnet or electrical current flow in a conductor, the more magnetic flux that surrounds that source. The quantity of interest is not the total amount of magnetic flux, but the amount or strength at a given point. This is called magnetic flux density and the standard SI metric unit of measure is Webers per square meter (Wb/m^2) which is equal to one Tesla (T). This is a very large quantity for purposes of measuring magnetic flux density in the typical living and working environment, so a smaller quantity is used for this purpose, the Gauss (G). It takes 10,000 Gauss to make up one Tesla (T). In most cases even the Gauss is too big so common environmental measurements of magnetic flux density are in milli-Gauss (mG) where it takes 1000 milli-Gauss to make up one Gauss. It takes 10 million milli-Gauss (10^7 mG) to equal one Tesla (T).

A device called a gaussmeter is the typical meter used to measure magnetic flux density in the environment. It consists of a pick-up sensor through which the magnetic flux will pass. Since a magnetic flux consists of flux lines stretching out into space from a source, there is a spacial relationship to the gaussmeter. In order to get an accurate reading of the magnetic flux at a point, the meter should be rotated to several orientations until the maximum reading is found. A multi-directional gaussmeter has a sensor that reads from all directions. These meters do not need to be rotated in space to get an accurate reading at a point.

Electric Fields An electric wave or field is also a component of electromagnetic radiation. The electric field is the result of a difference in voltage between two objects. The greater the voltage difference, the greater will be the electric field between the objects. There will be an electric field around the cord to a lamp even though the lamp is turned off and there is no current flowing. Any wire with a voltage applied to it will produce an electric field between it and any adjacent object that is at a different voltage. *The strength of an electric field is proportional to the voltage difference between two objects*. Some electric fields are considered static because the polarity of the voltage (plus or minus) on the objects does not change and the magnitude changes only slowly. There is a static electric field between the surface of the earth and the upper atmosphere. Electric fields near power circuits are alternating with the polarity changing from plus to minus and back to plus again 60 times per second. Typical wiring in a house operates at 120 volts to surrounding objects. Electric power transmission lines sometimes operate at up to 765,000 volts.

The strength of an electric field is *measured in volts per meter*. There is a neutral static electric field near the surface of the earth of about 200 volts per meter. When a thunderstorm passes overhead, the static electric field near the surface of the earth can rise to as high as 50,000 volts per meter. The 60 Hertz alternating electric field directly beneath a 765,000 volt power line may be as high as 10,000 volts/meter. Near the edge of the right-of-way for the transmission line the electric field strength typically has dropped to less than 2000 volts/meter.

A person sometimes can feel the presence of an electric field as the hair on the skin begins to stand out or vibrate. A static charge can be produced by combing your hair in dry weather. The charge on the comb is strong enough to pick up small pieces of paper and to make your hair stand up as the comb is moved close to a person's body. This is a static electric field and it can also cause clothing to cling to your body in dry weather.

It is fairly easy to shield electric fields. Buildings and trees are fairly effective at shielding humans and animals from electric fields. Electric fields do not easily penetrate biological materials. A person or an animal may feel a mild shock when touching a metal object near or beneath an electric transmission line. This shock condition can be easily eliminated by grounding the object to the earth.

Reducing Exposure to Magnetic Fields: If there are two wires in close proximity one carrying the return current of the circuit, the magnetic field of each conductor will be in opposition and they will tend to cancel each others magnetic field. The strength of the magnetic field decreases with the square of the distance from the wires. This means if the magnetic field next to a wire is measured at 4 mG, the magnetic field will only be 1 mG one foot away and only 1/4 mG two feet from the wire. As the distance from the source is doubled, the strength of the magnetic flux is divided by four as illustrated in *Figure 229.5.*

The internal magnetic field strength inside an induction motor is about 1.5 Tesla. Such devices are considered to be point sources of magnetic flux. Magnetic field strength in the vicinity of a point source tends to decrease with the cube of the distance. Working several feet from point sources of magnetic fields will reduce exposure. This means if the magnetic filed strength six inches from an appliance is 50 mG, the magnetic field strength one foot away will be reduced to approximately 6 mG. Two feet away the magnetic filed strength will be less than 1 mG.

Magnetic fields can easily penetrate biological materials. Shielding can be produced by placing an electrical conducting material between the source and the object being shielded. Shielding for magnetic fields can be accomplished but it is impractical in most cases. Instrumentation wires are often protected from external magnetic fields by surrounding the wires with a thin metal foil shield around the wires and grounded at both ends.

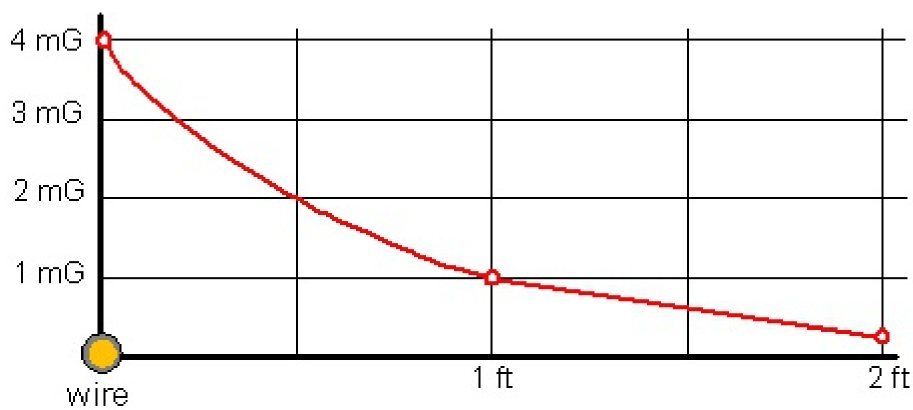

Chart based on a lab test at MSU BAE Dept.

Figure 229.5 The magnitude of the magnetic field level decreases rapidly as the distance from the source increase. As the distance from the source doubles, the magnitude of the magnetic filed decreases to one fourth the previous magnitude.

Biological Effects of EMF: Epidemiological studies observe human health and evaluate whether groups of people that have potentially high exposure to EMFs have a greater chance for developing a disease like cancer than groups without such exposure. An example is persons who live in homes near a high voltage transmission line. Results of such studies are not conclusive, but a link between increased risk of developing some types of cancer and magnetic field exposure cannot be discounted. Many studies have been conducted and thus far no direct link between power line and building wiring produced magnetic fields have been found.

An electric field is enhanced near projections such as the upper part of the human or animal body. For example a person standing in a uniform unperturbed electric field of 10 kV/meter (10,000 V/m) can have an actual field strength at the top surface of a human head of 180 kV/meter. Current densities are in the range of less than a micro-ampere per square centimeter when humans are exposed to strong electric fields that may be found in the environment. *Thus far studies have not shown a link between exposure to electric fields and health problems with animals and humans*.

Conclusion: Power lines, building wiring, home appliances, office equipment, electric power tools and electrical equipment all produce magnetic fields when current flows and an electric field when a voltage is present. These magnetic and electric fields are different than most natural magnetic and electric fields in that they are in constant motion while most natural fields are either static or only in motion for a short time. Research has not found a direct link between exposure to power line and wiring produced magnetic and electric fields, however, some epidemiological studies do indicate a link to magnetic fields cannot be discounted. Air is a poor conductor for magnetic fields and field strength decreases rapidly as the distance from a source increases. It is the current flow through a conductor that produces a magnetic field not the voltage. Current flow near home appliances, power tools, and office equipment generally produce the greatest human exposure to magnetic fields. Generally a few inches away from these sources the magnetic field strength is very small.