Electrical Tech Note — 229

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Electromagnetic Field (EMF) Basics

Energy can be transmitted in nature in the form of electromagnetic radiation. 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 x 10^8 mi/s). Light is electromagnetic radiation. Obviously light is transmitting energy because it causes heat in an object when exposed to the sun. Light from the sun is an intense beam of electromagnetic radiation. An object absorbs the light of the sun and the temperature usually rises. Heat radiating from an object is also an electromagnetic wave (infrared radiation) but infrared radiation is at a lower frequency than visible light.

Electric and Magnetic Waves: Electromagnetic radiation is made up of two components; an electric wave and a magnetic wave, both of with are 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 3,000 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 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.*

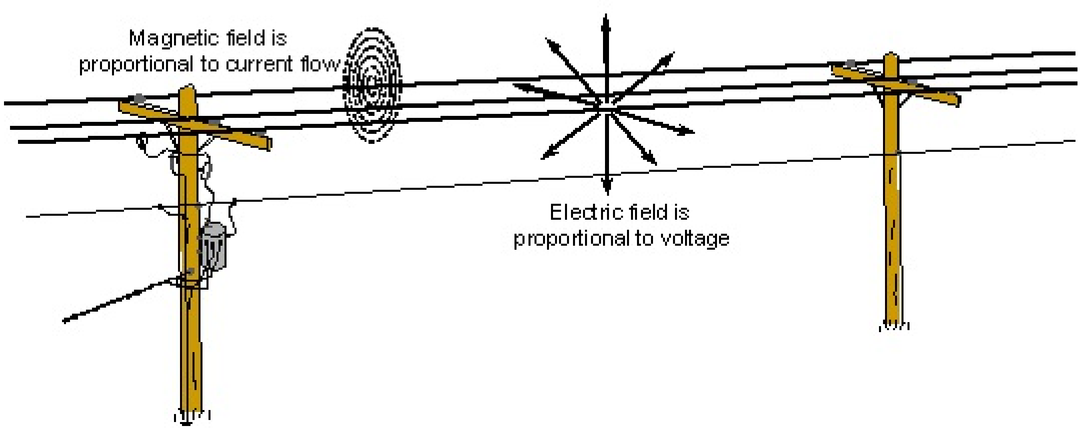

Figure 229.1 *An energized wire with a voltage but no current will produce an electrical field. A wire carrying current with little voltage will produce a magnetic field. A wire with high voltage and high current will produce a strong magnetic field and a strong electric field.*

Induced Current In Plants, Animals, and Humans: High frequency electromagnetic waves transfer more energy than 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 current flow in electrical wires, appliances, and power lines are considered to be extremely low frequency *(ELF) and cannot cause ionization or heating of materials.* In order for extremely low frequency electromagnetic fields to have an effect on plants, animals or humans the EMF must be extremely intense and very close to plants, animals, and humans. There are natural currents that flow in the body of humans and animals as a result of normal body functions mainly caused by the brain and heart. *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 and closeness to the source. 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 such as appliances in the home. The high peaks in the graph could be a person in close proximity to an appliance, office equipment, power tools, or electrical powered machinery.

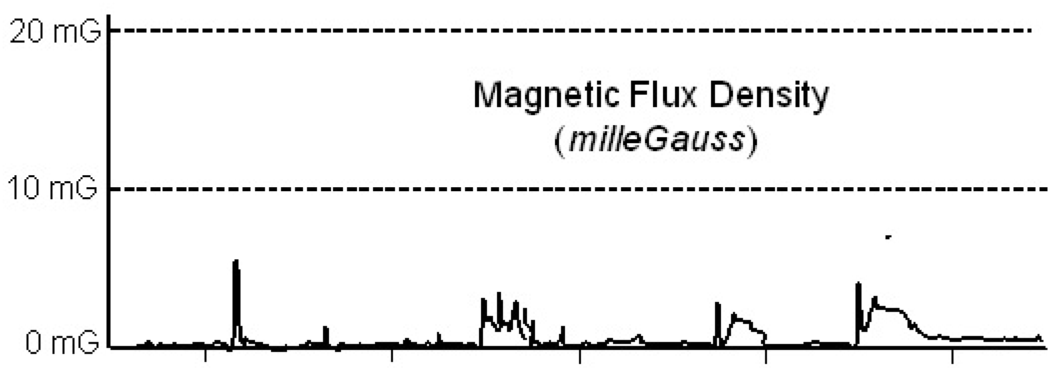

Figure 229.2 Exposure to electrical equipment and appliances typically may result in magnetic flux exposure of this type when in extremely close proximity to the devices.

Magnetic Fields: Whenever an electrical current flows through a conductor there will be a magnetic field built up very close around a conductor. *The strength of this magnetic field is proportional to the level of current*. 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 remain static. Static means it does not move. One unit of measure of magnetic field level is the mille-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 earth magnetic 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 a magnetic field a current will flow (induced) in the conductor. Since the magnetic field around a conductor carrying 60 Hertz current is in constant motion it may induce a current to flow in an extremely close electrical conducting object.

Magnetic fields in the ELF range do not travel well in air or a vacuum and the magnetic field around a conductor will weaken very quickly as it travels outward away from a conductor. 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 around the wire is 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.*

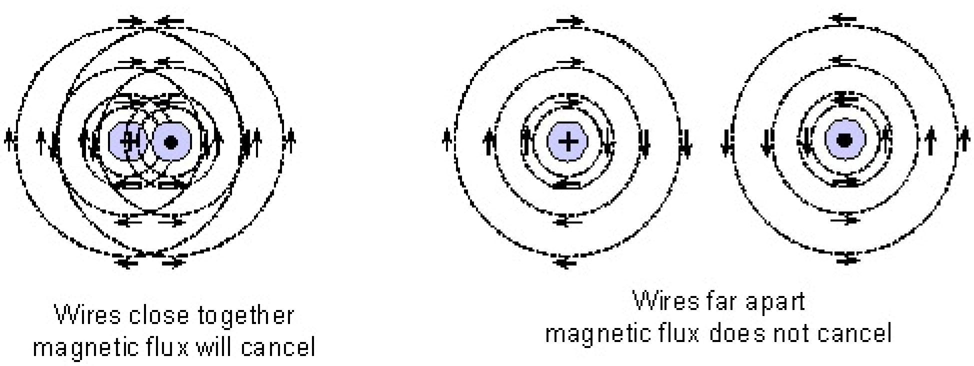

Figure 229.3 *The two small circles at the right are wires of the same circuit carrying the same current but the flow is in opposite directions. A magnetic flux builds up around each wire but the polarity is opposite so the magnetic flux will cancel if the wires are close to each other as illustrated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

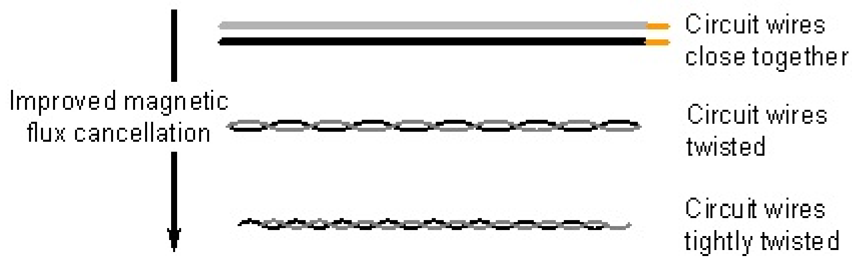

Figure 229.4 *Wires of the same circuit arranged close together will achieve good magnetic flux cancellation. Twisting the pair of wires together achieves even better magnetic flux cancellation.*

Measuring Magnetic Field Level: 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 surrounding the 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. A smaller quantity of magnetic flux is 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 mille-Gauss (mG) where it takes 1,000 mille-Gauss to make up one Gauss. It takes 10 million mille-Gauss (10^7 mG) to equal one Tesla (T).

A device called a **gaussmeter** is a typical meter used to measure magnetic flux density in the typical living environment. It consists of a pick-up sensor through which the magnetic flux will pass. Since a magnetic flux consists of flux lines expanding out into space and getting weaker the farther from the source. In order to get an accurate reading of the magnetic flux at a location a three axis gaussmeter should be used. A *multi-axis gaussmeter* has a sensor that reads from all directions. These meters do not need to be rotated in space to determine the maximum reading.

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 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 and 240 volts at surrounding objects. Alternating current electric power *transmission lines* sometimes operate at up to 765,000 volts.

The strength of an electric field is *measured in* ***volts per meter***. A natural static electric field exists 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. Near the edge of the right-of-way of some transmission lines the electric field strength typically has dropped to less than 2,000 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 a person's 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 a person's 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 a circuit the magnetic field of each conductor will be in opposition and they will tend to cancel each others magnetic field. The *strength of a magnetic field source decreases as the square of the distance from the source.* 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 a point source of magnetic fields reduces exposure. This means if the magnetic field 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 field 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.

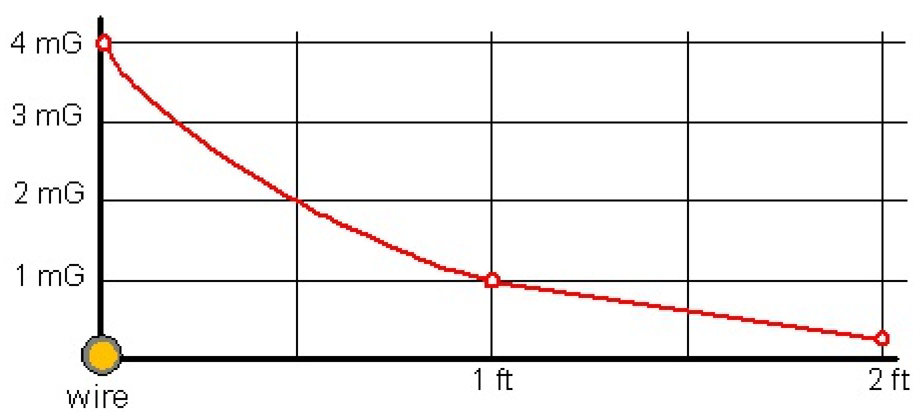

Chart based on a lab test at MSU BAE Dept.

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 field decreases to one fourth the previous magnitude.

Biological Effects of EMF: Epidemiological studies observe possible human effects. Some groups of population were alleged to be exposed to high levels of EMF. An example is persons who live in homes near a transmission line and some further away. Results of such studies are not conclusive but a link to EMF was presumed to be the cause. Many studies have been conducted and thus far no direct link between power lines and other electrical wiring can be conclusively link to these electrical sources.

Conclusion: Power lines, building wiring, home appliances, office equipment, electric power tools and electrical equipment all produce magnetic fields when current flows. 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 static. Research has not found a direct link between health effects from exposure to power lines and wiring produced magnetic and electric fields. 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 conductors that is presumed to cause EMF **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.