01 Oct 1995

Stop That Noise

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Recommended Citation

T. Van Doren et al., "Stop That Noise," *IEEE Potentials*, vol. 14, no. 4, pp. 35-39, Institute of Electrical and Electronics Engineers (IEEE), Oct 1995.
The definitive version is available at https://doi.org/10.1109/45.468227

Stop that noise

EMI—frustrating for many; a rewarding career for a few

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Jane's car is between two trucks as she drives across a bridge over the Mississippi River. Suddenly the car's air bag inflates, Jane loses control of the car and crashes into the side of the bridge. She awakens four days later in a hospital bed.

Derrick hears thunder while downloading his "favorite" photo from his favorite World Wide Web site. His monitor screen flashes, then goes dark. Derrick thinks God may be trying to tell him something.

A radiation sensor at a nuclear power generating plant sounds an emergency alarm. Twenty-six days later, after submitting 1800 sheets of paperwork and losing $46,000,000 of income, the plant is restarted.

A tree limb falls on Jim's car hood. After a little metal bending and a new paint job, the car hood looks like new; however, now the radio is noisy. Maybe the antenna needs a little straightening?

What is electromagnetic compatibility?

Electromagnetic compatibility (EMC) is the ability of a device or system to operate without causing electrical interference and without being susceptible to electrical emissions. Ann's computer causes a very annoying pattern of lines to appear on her television screen. The computer and the television are not electromagnetically compatible. Is the computer radiating too much electromagnetic energy, or is the television too susceptible to electromagnetic energy in the environment?

When an incompatible situation exists, the blame is usually placed on the emitter of the electromagnetic energy, rather than the receiver. The source of the emissions may be to blame, if the source is exceeding allowed levels. But, if the emitter is within allowed levels, then the responding system may be too susceptible.

When an amateur radio operator's transmissions interfere with a neighbor's television reception, the neighbor usually complains about the transmitting radio. He does not think the problem is the inadequate selectivity of his television receiver's filter. When we hear the local AM broadcast station on our telephone, we blame the station rather than the cheap phone we bought.

The proliferation of emitters and receivers

The number and bandwidth of noise sources and susceptible systems have increased dramatically thanks to cheaper and faster digital electronics. The consequence is that both noise emission and noise susceptibility problems are increasing. High-speed electronics are employed to control everything from household appliances to aircraft, and can act as unwanted emitters and receivers of electromagnetic interference (EMI).

Intentional emitters within a home include cordless phones, wireless intercoms, security systems, and automatic garage door openers. Unintentional emitters include any appliance with an electric motor (vacuum cleaner, mixer,-washing machine, hair dryer, refrigerator, etc.), arcing switch contacts, light dimmers, microwave ovens, personal computers, or any appliance with a microprocessor.

New trucks often have electronically shifted transmissions instead of manually shifted. The long cables which connect the control circuits in the truck cab to the transmission can act as an antenna to transmit interference from the digital control circuits to the external world, or to receive interference from the external environment. The electronic transmission control can act as a transmitter in some frequency ranges, and a receiver in others. The electronic control may transmit interference at a frequency used for mobile communications between the truck and its dispatching base. In another frequency band, the transmission control cable may pick up interference while the truck drives past a radio tower, causing the truck to randomly shift gears.

New airplanes use electronic and optical control signals instead of mechanical and hydraulic linkages. During takeoffs and landings on all commercial flights, the Federal Aviation Administration regulations stipulate that all portable passenger electronics must be turned off. Electronics, such as laptop computers and compact-disc players, can radiate electromagnetic interference that may be received by cables connecting control circuits in the cockpit with mechanical systems throughout the aircraft. A malfunction may result in an erroneous change of a flap position. This has potentially catastrophic consequences if the aircraft is only a few hundred feet off the ground.

The proliferation of high-speed digital electronics presents an electromagnetic compatibility challenge for circuit designers in all areas of application. Circuits and systems must meet regulations on electromagnetic interference, such as those imposed by the U.S. Federal Communications Commission and the European Community. Further, many companies have self-imposed requirements in order to avoid lawsuits that might result from product failure.

The fundamental clock frequency for personal computers has increased from 1 MHz to over 100 MHz. Significant harmonics of the clock and data signals exist at frequencies

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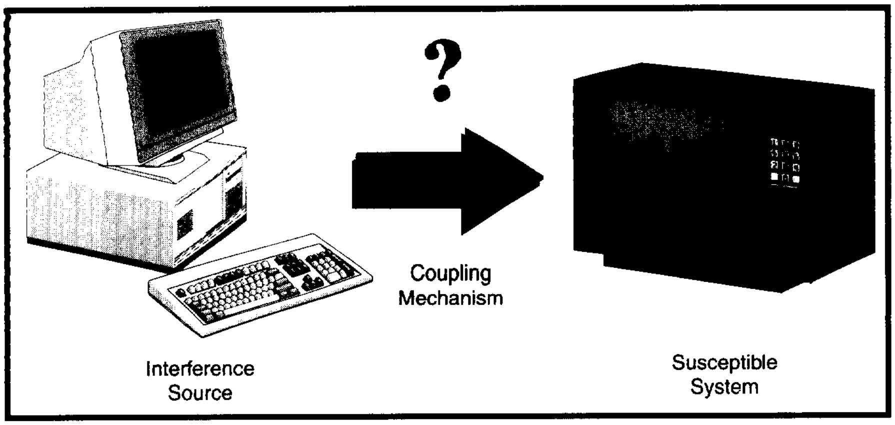

Fig. 1 The basic components of an electromagnetic interference problem

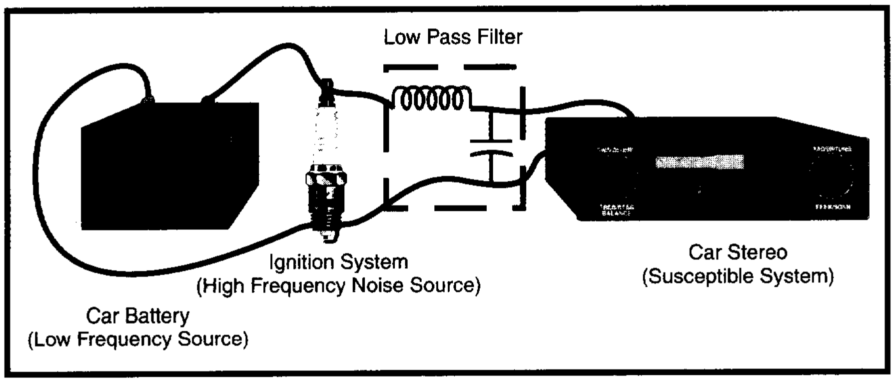

Fig. 2 Conductive noise coupling between a car ignition system and a car stereo, with a low-pass filter added to reduce the coupling

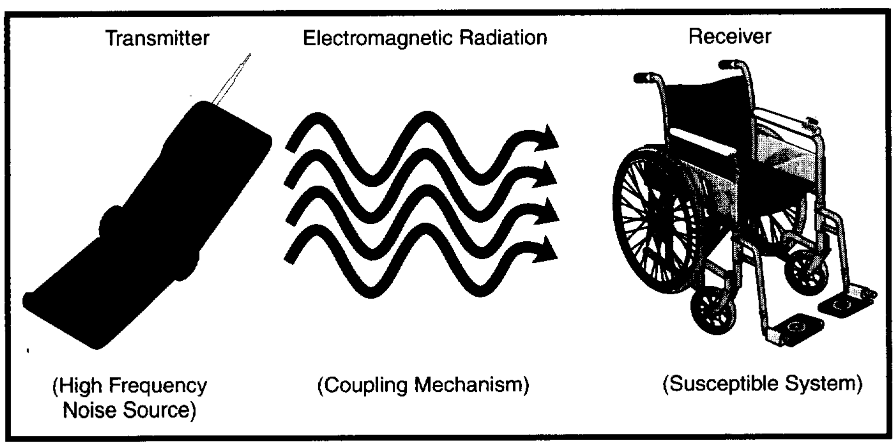

Fig. 3 Electromagnetic radiative coupling from a cellular phone to the control circuits for a battery powered wheelchair

extending beyond 2 GHz. This is a very wide frequency band in which to design circuits that neither cause interference or are susceptible.

Further, digital logic levels are decreasing from 5 V to 3.3 V, and may eventually reach 1 V or less. Lowering the logic voltage level may reduce emissions because the signal strength is decreased. But, the susceptibility to noise is increased due to the smaller noise margin.

What causes EMI?

EMI occurs when electrical energy causes a system to malfunction. For EMI to occur, there must be a source of electrical energy, a susceptible system, and a mechanism by which the electrical energy is coupled from the source to the susceptible system (see Fig. 1.).

For example, Ann's computer was the obvious source of the unwanted electrical energy. Her television was the susceptible system. But how did the electrical energy get from the computer to the television? The key to diagnosing and solving an electromagnetic interference problem is determining the noise coupling mechanism. Electrical energy can be transferred from one location to another by four possible mechanisms;

1. conduction,
2. electromagnetic radiation,
3. magnetic fields, and
4. electric fields.

Conductive coupling

Conductive coupling occurs when electrical energy is transferred from a noise source to a susceptible system by two or more conductors, usually metal wires. Figure 2 shows an example of conductive noise coupling. Since the car ignition system and radio draw power from the same 12 VDC source, a time varying noise current can flow on the power leads from the ignition system to the radio and back.

Conductively coupled noise may be reduced by:

1. reducing the intensity of the noise source,
2. providing a filter between the noise source and the susceptible system, or
3. isolating the two circuits so that they don't share a common current path.

A filter either blocks the conducted noise current by using a series impedance, or shunts the current away from the susceptible system by using a parallel impedance. The low pass filter shown in Fig. 2 passes the DC power from the battery to the radio, but attenuates the high frequency ignition noise. If the noise were coupled to the radio by another mechanism, such as electric-field coupling to the radio antenna, then a filter on the DC power leads would be ineffective, waste money, and reduce reliability.

Electromagnetic radiation coupling

The coupling mechanism is usually electromagnetic wave propagation when the electrical energy travels from the noise source to the susceptible system through the air for a distance greater than about a wavelength. Figure 3 illustrates electromagnetic radiative coupling from a cellular phone to the control circuits for an electric wheelchair.

This particular problem has been dis-

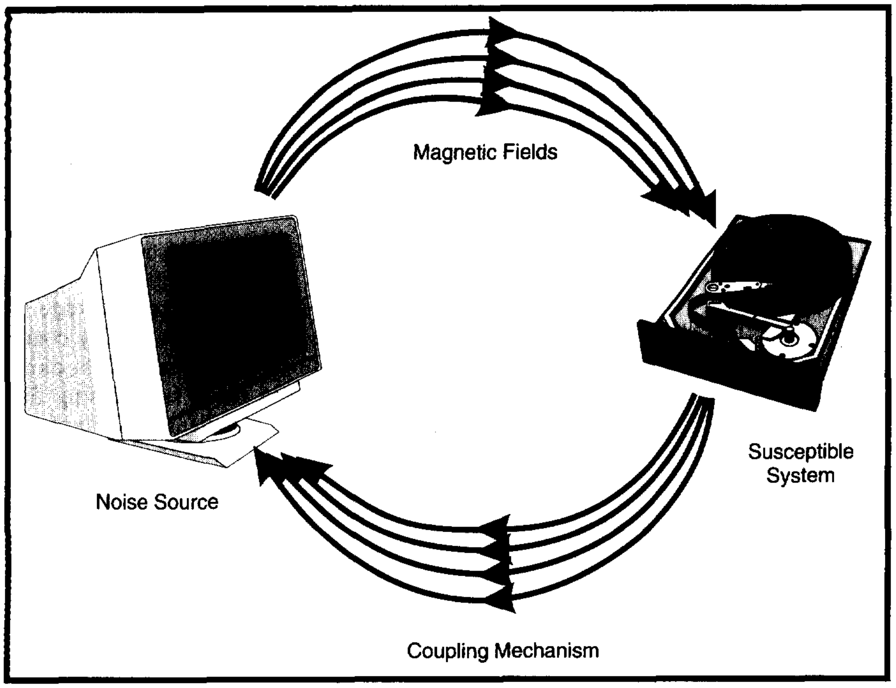

Fig. 4 Magnetic field coupling from the deflection coil of a computer monitor to the read coil of a hard disc drive

cussed recently in newspapers and on television. Legal transmitters, such as cellular phones, two-way radios, citizen-band transceivers, and radio and television broadcast stations, can cause electrical systems to malfunction. The interference is often the result of excessive susceptibility of the malfunctioning system. Cellular phones have caused hospital intravenous fluid pumps to fail. Two-way radios have caused thermocouple temperature controllers to overheat the systems they were intended to protect.

Electromagnetic coupling is decreased by:

1. reducing the intensity or bandwidth of the high frequency source,
2. reducing the effectiveness of the transmit or receive antennas,
3. blocking the electromagnetic coupling between the antennas, or
4. reducing the susceptibility of the receiving system.

Filtering the noise source and the susceptible system, and increasing the distance between the transmitting and receiving antennas are common solutions.

A high-frequency noise source may be a legal transmitter, or it may be an unintentional source like Ann's computer. The transmit and receive antennas are often metal objects not intended to be part of a radiating structure. It is usually difficult to determine which metal parts of a complex system are serving as the transmit and receive EMI antennas.

Magnetic-field coupling

Magnetic-field coupling occurs when part of the magnetic flux created by one circuit passes through the loop formed by another circuit. Magnetic-field coupling is shown on an electrical schematic as a mutual inductance. Magnetic fields are caused by electric currents.

The amplitude and the frequency of the current are both important in identifying the extent of magnetic interference. The frequency-current product fI is used to judge how troublesome the current might be for sinusoidal steady state conditions. The time derivative dI/dt is a useful indicator for transient situations. Pulse lasers are a notorious source of both magnetic fields and electromagnetic radiation. For high power pulse lasers a dI/dt of 1000 A/ns is typical. Switch mode power supplies, arc welders, digital circuits, and AC power transformers are a few examples of the numerous sources of magnetic fields.

Figure 4 shows magnetic field coupling between a computer monitor and a disc drive. The deflection coil of the monitor generates a magnetic field to sweep the electron beam across the monitor screen. The read coil of the disc drive may pick up the magnetic field from the deflection coil. Increasing the separation or placing a high permeability metal shield between the monitor and disc drive can reduce the magnetic-field coupling. Another example of magnetic coupling is a tape player in a car receiving magnetic field interference from the currents flowing on a wiring harness located near the radio.

Magnetic field coupling can be decreased by:

1. reducing the intensity or frequency of the noise current,
2. re-orienting or relocating either the source or the susceptible system to reduce mutual inductance,
3. using a shield to redirect the magnetic field, or
4. decreasing the area of the magnetic field generating and receiving loops.

Electric-field coupling

Electric-field coupling occurs when part of the electric flux generated by one circuit terminates on the conductors of another circuit. Electric-field coupling between two circuits is indicated

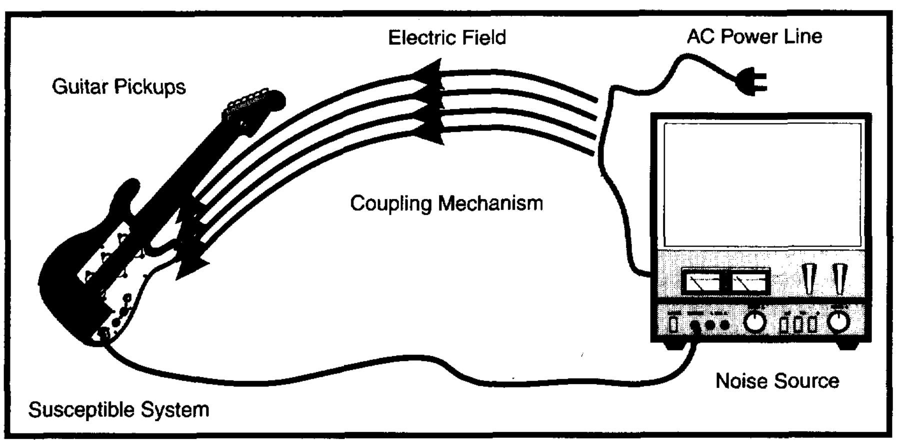

Fig. 5 Electric field coupling from an AC power line to an electric guitar

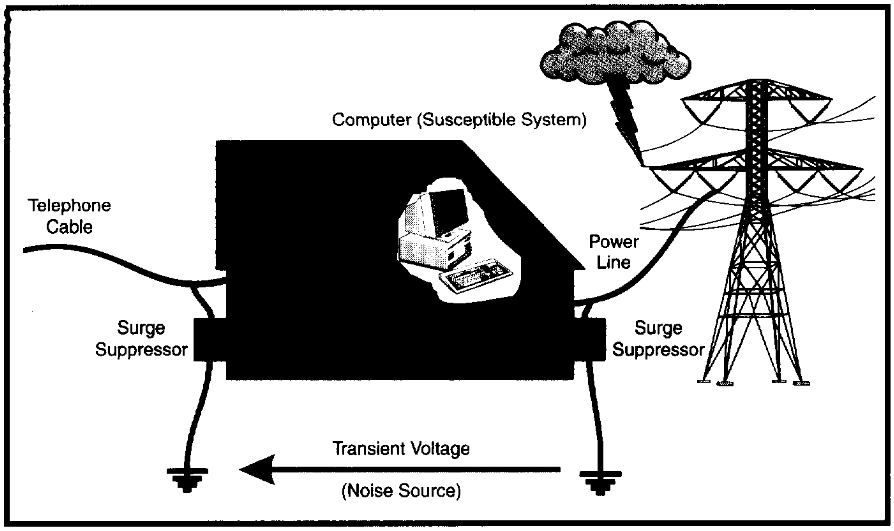

Fig. 6 Improper transient surge protection on the telephone and AC power wires connected to Derrick's computer.

on a schematic diagram by a mutual capacitance between the two circuits. Electric fields are generated when electric charges are physically separated by applied voltage differences. The frequency-voltage product *fV*, or the time derivative of the voltage *dV/dt*, indicate the severity of the electric field generating noise source in the frequency- and time-domains, respectively.

Figure 5 shows electric-field coupling between an AC power line and an electric guitar. The time varying voltage *dV/dt* of the AC line generates the electric field, and the mutual capacitance C, couples the electric field to the guitar pick-up coils. The configuration works as a voltage divider circuit. The noise source voltage divides between the mutual capacitance and the equivalent impedance of the guitar system. The equivalent impedance of the guitar system is the impedance of the pick-up coils in parallel with the amplifier input impedance. A greater noise voltage develops across a susceptible system with a high equivalent impedance.

Electric field coupling can be decreased by:

1. reducing the intensity or frequency of the noise voltage source,
2. reducing the mutual capacitance,
3. reducing the equivalent impedance of the susceptible system,
4. increasing the impedance of the noise current return path, or
5. using electric field shielding.

Some example sources of electric fields are AC power lines, digital circuits, fluorescent lights, de-energizing relay coils, car ignition systems, and electrostatic discharges. Systems very susceptible to electric-field coupling typically have both source and load impedances greater than a few hundred ohms.

Chemical pH measuring systems have both the pH electrode and the amplifier input impedance in the megaohm range. They are very sensitive to electric-field coupled noise due to the high equivalent impedance. Piezoelectric pressure sensors are also very susceptible to electric-field coupling because of the high sensor and amplifier impedances.

Thermocouple temperature measuring systems have sensors with only a few ohms impedance. The parallel combination of sensor and amplifier input impedance is held low by the sensor impedance. This reduces the sensitivity to electric-field coupling. Magnetic-field coupling is usually a more significant noise problem for thermocouples.

Analyzing intro scenarios

The air bag on Jane's car suddenly inflates as she drives across a bridge while between two trucks. This could be an electromagnetic radiation susceptibility problem. The air bag crash detection and detonation circuits are tested to electromagnetic field strengths exceeding maximum anticipated levels. However, though not proven, the truck's and the bridge's steel structure may have formed a resonant cavity. If one truck driver was transmitting on a citizens-band radio at a power level beyond the legal 5 W limit, then an abnormally high electromagnetic radiation level might be created in the resonant cavity. This radiation could have triggered the air bag sensing circuits. These types of suspected electromagnetic interference are difficult to prove. The reason is the large numbers of variables involved and the uncertainty in the value of these variables.

Derrick's computer system was damaged as a result of a lightning transient. When lightning causes damage, the coupling mechanism is usually conductive. Conductive transients can be reduced by a surge suppressing filter. Assume that transient surge protectors were located on both the telephone wires and the AC power wires where they entered Derrick's home (Fig. 6). Notice that the two groups of suppressers are connected to two different ground locations. The transient voltage difference between the two ground locations may have caused Derrick's computer to fail. The telephone and power wires should all be brought into one transient suppresser unit. This way both groups of suppressers can be referenced to the same potential, thus eliminating the voltage difference between the two ground locations. Such devices are readily available.

A radiation sensor shuts down a nuclear power generating plant causing a $46,000,000 loss of income. After considerable investigation, it was proven that there was no radiation leakage. The sensor was giving a false output. This problem recurred about once a year. The infrequency was good because of the financial loss with each occurrence; however, this made diagnosing the problem very difficult.

The problem was solved by first methodically reviewing all conditions of the plant operation just prior to the false alarm. Several possible interference sources were located. The most likely sources seemed to be two 100 HP water pumps that were used to flood the nuclear reactor area in case of excessive temperature. The pumps were started every six months to insure that they were operational. The sensor false alarm did not occur every time the pumps were started, which made the identification of the pumps as the noise source difficult.

The AC power wiring to one pump was found to be in a cable tray immediately above the tray carrying the DC voltage and signal wiring for the radiation detector. The signal wire pair was *twisted to reduce* magnetic-field interference, but the DC voltage wire pair was not twisted. The signal output from the radiation sensor was strongly dependent on the DC voltage input. Magnetic-field coupling from the motor wiring into the sensor DC voltage wiring was the suspected mechanism. Replacing the DC voltage wiring with a twisted pair reduced the mutual inductance (the magnetic-field coupling) between the DC wiring and the motor wiring, and fixed the problem. The solution to this real-life noise problem was simple, but the diagnosis took over two years.

Why did the tree limb that damaged Jim's car hood affect the noise in his car radio? The ignition system is a strong source of electric fields. The monopole antenna is an excellent receptor of electric fields. A metal car hood that makes good electrical contact to the rest of the car frame can serve as an electric-field shield between the high-voltage ignition system and the car antenna.

The electric-field coupling (mutual capacitance) may be increased, if the car hood makes a poor electrical contact to the frame. The closed hood was supposed to press against copper strips fastened to the frame. These strips were damaged when the tree limb bent the hood, and were not repaired. A poor electrical contact between the hood and frame resulted, increasing the electric-field coupling to the antenna.

Becoming an EMC expert

Fixing electrical noise problems is often called "black magic." This is especially true when the coupling mechanism and the reason a solution works are not completely understood. The most common noise solution technique is "trial-and-error." The "trial-and-error" method is time consuming, expensive and very frustrating.

To solve electromagnetic compatibility problems, a person needs common sense, the right education, some experience, a logical diagnostic procedure, good observation skills, a sense of humor, persistence, and an occasional bit of luck. The right education means a good understanding of basic circuit theory, electromagnetic theory, system concepts, electrical modeling, electronic circuits, transmission lines, and a little antenna theory.

Most people pursue some other career, because they lack confidence in their ability to apply electromagnetic concepts to noise problems. A logical diagnostic procedure begins with attempting to locate where the noise is entering (for susceptibility) or leaving (for emission) a system. After the location is determined, the coupling mechanism (conductive, electromagnetic, magnetic, or electric) must be determined. Once the coupling mechanism is determined, then the various solution techniques for that mechanism are evaluated. Education and experience allow a person to develop their own personal diagnostic style.

There is currently a shortage of people with the ability to predict and diagnose electrical noise problems. EMC engineers have employment possibilities wherever highspeed digital or low-level analog circuits are designed or manufactured. This would include the aircraft, automotive, computer, communication, control, and defense industries. If you are willing to accept the challenge, then you could have a rewarding career as an EMC expert.

Read more about it

- World Wide Web page at the Electromagnetic Compatibility Laboratory of the University of Missouri-Rolla, Address http://www.emclab.umr.edu/
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Dr. Tom Van Doren is a professor, Dr. Todd Hubing is an associate professor, Dr. James Drewniak is an assistant professor, Dr. Fei Sha is a visiting professor, and Mr. David Hockanson is a graduate student with the Electromagnetic Compatibility Laboratory of the Electrical Engineering Department at the University of Missouri-Rolla. Together, with other graduate and undergraduate students, they form a team that solves electromagnetic compatibility problems for corporations and government agencies. Recently investigated problems include aircraft, automotive, computer, semiconductor, power generation, process control and communications industries.