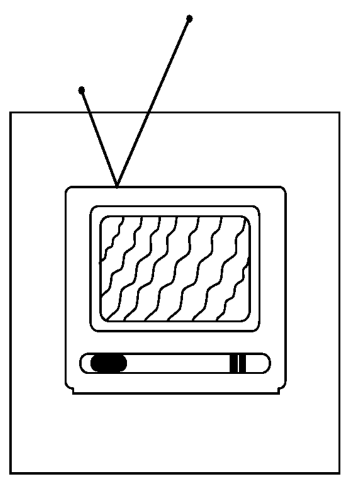
Electromagnetic Interference and Wireless Devices 12

As new radio devices and wireless systems proliferate, particularly at low power levels and in nontraditional applications, and with the increasing numbers of other passive electronic devices in society, radio frequency interference among them may become an increasing problem. As devices become smaller, people are increasingly likely to carry and use them in situations unanticipated by designers. Nonradio electronic devices such as personal computers have not necessarily been designed to be immune from wireless telecommunications emissions, and can also cause interference to radio receivers.[1] This chapter discusses how wireless devices and systems may interfere with each other as well as with other electronic equipment and identifies some possible solutions.

FINDING

Interference between different wireless systems and between wireless systems and other electronic devices is potentially serious, but also is amenable to technical and regulatory solutions. Wireless devices can cause interference to electrical components and vice versa, and as new generations of digital radio equipment become widely used, these problems may increase in the short term. However, installation of lower power microcells, improved shielding, and electrical design techniques can usually mitigate most interference problems. In cases where other solutions are not feasible, carefully targeted use restrictions may be required.



[1] Causes of interference include high clock rate timing pulses used in computers, video games, etc., and their harmonics.

BACKGROUND

Any short length of wire in an electronic circuit or in an integrated chip can act as an antenna when exposed to radio waves and give rise to electric currents that may interfere with the normal operation of the circuit.[2] This potential electromagnetic interference (EMI) is an inherent property of radio or television transmissions, electric motors, and household switches, as well as natural phenomena

[2] K. J. Clifford, et al., "Mobile Telephones Interfere with Medical Electrical Equipment," *Australian Physical & Engineering Sciences in Medicine*, vol. 17, No. 1, 1994, p. 23.

such as lightning, aurora borealis, and sunspot activity.[3] To protect against it, shielding—either in a metal case or special shielded wire—or better circuit design is necessary. Most of the time designers anticipate problems, and build devices not subject to interference when used as directed. However, there are cases in which devices are not shielded adequately against EMI, many involving medical devices.

While many of the reported EMI problems involve older analog radio transmitting devices, the wireless industries are increasingly turning to digital transmission formats to improve quality and increase capacity. This transition may pose new EMI problems because digital equipment may interact with other devices in unpredictable ways. For example, digital Global System for Mobile Communications (GSM) handsets and Time Division Multiple Access (TDMA) telephones emit higher strength peak electric fields than do analog telephones, while maintaining the same average power levels.[4] This scheme results in better transmission and reception at a lower average power output—extending battery life—but it may also cause greater interference than analog phones. The increasing use of spread spectrum, including Code Division Multiple Access (CDMA) technologies, has also led some engineers to predict that, with a large number of users, interference between competing devices may make the systems unusable.

INTERFERENCE WITH MEDICAL DEVICES

Medical devices can be affected by interference from radio devices, including cellular telephones, and this has recently become a public issue.[5] Pacemakers, apnea monitors, blood-gas pumps, hearing aids, wheelchairs, and electronic imaging devices have reportedly been interrupted or interfered with in the presence of cellular telephones or other radio devices.[6] In some cases, deaths have occurred, though none have been attributed to cellular telephones. In spring 1995, pacemaker wearers were warned not to use new digital cellular phones because of interference problems.[7]

Specific problems have surfaced with new digital mobile telephones and hearing aids. Time division digital transmissions can produce loud audio tones in some hearing aid models and other analog

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[3] EMI effects increase with power and decrease with distance.

[4] Stewart Fist, "GSM and TDMA digital phones," April, 1994, unpublished manuscript.

[5] Jeffrey L. Silberberg, "Performance Degradation of Electronic Medical Devices Due to Electromagnetic Interference," *Compliance Engineering*, fall 1993, pp. 25-39; "Cellular Telephones and Radio Transmitters: Interference with Clinical Equipment," *Technology for Respiratory Therapy*, vol. 14, No. 5, November 1993; Tom Knudson and William M. Bulkeley, "Stray Signals: Clutter on Airwaves Can Block Workings of Medical Electronics," *The Wall Street Journal*, vol. 223, No. 116, June 15, 1994, pp. A1, A12.

[6] Some documented illustrative examples:

- A fetal heart beat detector picked up radio and CB broadcasts and static instead of heart beats.
- A ventilator malfunctioned due to interference from a guard's walkie-talkie.
- A user of a powered wheelchair had moved to a new home and was showing his friends, also in powered wheelchairs, around the neighborhood. While moving up a hill, the user heard clicking noises and took his hand off the joystick. The wheelchair made a sudden about turn and headed down hill at high speed. The wheelchair would not respond to further movement of the joystick. The wheelchair continued down the hill for about 25 yards, veered left, and went over a cliff. The user suffered a broken hip and several other injuries. His friends' wheelchairs were from a different manufacturer and were not affected. The wheelchair user's new home is several miles away from a radio station and three blocks from a major interstate highway.
- An external defibrillator/pacemaker stopped pacing when an ambulance attendant used a hand-held transmitter too close to the patient. The patient was not resuscitated.

These examples are taken from Jeffrey L. Silberberg, op. cit., footnote 5, pp. 25-39.

[7] Mark Landler, "Cellular Phones May Affect Pacemakers," *The New York Times*, Apr. 29, 1995, p. B1; John J. Keller, "Cellular Phones May Affect Use of Pacemakers," *The Wall Street Journal*, Apr. 29, 1995, p. B1. Medtronic, Inc., a major pacemaker supplier in the United States, advises pacemaker users to turn off portable phones placed in breast pockets, hold phones ten inches away from the chest, and use the phone on the opposite side of the body from where the pacemaker is implanted.

audio devices from up to 100 feet away. The tones can reach 130 dB—the sound of an airplane taking off as heard by a person standing on the runway.[8] The interference lasts as long as the hearing aid is close to the digital phone, but returns to normal when the phone is turned off or moves out of range.

Shielding can reduce the amount of interference hearing aids encounter, but there are limits to what shielding can be done. There are three types of hearing aids, those worn in the ear, outside the ear, and in a pocket and attached by wire. Hearing aids worn in the ear, by far the most popular, are least amenable to shielding, because they are already very small; hearing aids worn in the pocket are most susceptible to EMI, but can be easily shielded.

There are about six million hearing-aid users in the United States today, and the number is projected to increase as the baby-boomer generation ages. It is not known what types of hearing aids (in-ear, on-ear, or pocket), or how many (one or two ears) are used, nor is it known how many hearing-impaired people use cellular telephones. The projected cost of retrofitting hearing aids to eliminate interference is unknown; this may not be feasible given their small size and life span.

The potential for EMI has long been studied and understood by radio engineers and medical technologists, and a substantial body of technical work and engineering expertise exists. Like other forms of electromagnetic interference, shielding devices against electromagnetic radiation and controlling the output levels of emitting devices are the two main ways compatibility is attained. Another is the proper installation and spacing of medical equipment to minimize the potential for interaction.

Standards have been set for both transmitting devices and for shielding of computing and medical devices, based on both lab testing and field experience. Voluntary standards were promulgated in 1979 by the Food and Drug Administration (FDA) specifying that medical equipment should be protected against interference up to seven volts per meter between 450 and 1000 MHz.[9] A more recent standard issued by the International Electrotechnical Commission, one of the main standards' bodies in this area, relaxes suggested permitted exposure to three volts per meter in the frequency range from 26 to 1000 MHz.[10] The Association for the Advancement of Medical Instrumentation, a voluntary standards body in the United States, has convened a committee to address EMI problems.[11] Table 12-1 gives the FDA's 1994 draft suggestions on the minimum distance that should be maintained between transmitters of various power outputs and medical devices with various amounts of shielding.

[8] Michael Ruger, attorney, Baker & Hostetler, Washington, DC, personal communication, Feb. 17, 1995; "TDMA Mobile Phones Accused of Interference," *Microwave Engineering Europe*, March/April 1993, pp. 16-17.

[9] U.S. Food and Drug Administration, Bureau of Medical Devices, "Electromagnetic Compatibility Standard for Medical Devices," BMD Publication No. MDS-201-0004, Oct. 1, 1979.

[10] International Electrotechnical Commission, *Medical Electrical Equipment, Part 1: General Requirements for Safety, 2. Collateral Standard: Electromagnetic Compatibility—Requirements and Tests*, 1993.

[11] Knudson and Bulkeley, op. cit., footnote 5, p. A12.

TABLE 12-1: Proposed Electromagnetic Interference Protection Distance, in Meters

	Immunity level of medical device					
Power rating of radio source and example sources	**Unknown (assume 0.1 voltmeter)**	**1 volt/ meter**	**3 volts/ meter**	**10 volts/ meter**	**20 volts/ meter**	**40 volts/ meter**
0.07 watt Microcell cellular phone	4.6 meters	0.5 meter	0.3 meter	0.3 meter	0.3 meter	0.3 meter
0.01 watt	5.5	*0.6*	0.3	0.3	0.3	0.3
0.1 watt Wireless computer equipment	17.4	1.7	0.6	0.3	0.3	0.3
0.6 watt Portable cellular phone	42.6	4.3	1.4	0.4	0.3	0.3
1 watt	55.0	5.5	1.8	0.6	0.3	0.3
3 watts Transportable cellular phone	77.8	7.8	2.6	0.8	0.4	0.3
5 watts	123.0	12.3	4.1	1.2	0.6	0.3
10 watts	173.9	17.4	5.8	1.7	0.9	0.4
20 watts	246.0	24.6	8.2	2.5	1.2	0.6
50 watts	388.9	38.9	13.0	3.9	1.9	1,0
100 watts State police radio Amateur radio	550.0	55.0	18.3	5.5	2.8	1.4
1,500 watts Amateur radio	2.1 km	213.0	71.0	21.3	10.7	5.3
100 kilowatts FM broadcast TV stations ch. 2-6	17.4 km	1.7 km	579.8	173.9	87.0	43.5
316 kilowatts TV stations ch. 7-13	31 km	3.1 km	1.0 km	309.2	154.6	77.3
5 megawatts TV stations ch. 14-69	123 km	12.3 km	4.1 km	1.2 km	614.9	307.5

To find the minimum recommended protection distance between a medical device and a transmitter from this table, first locate the value in the top row that is closest to the RF immunity of the medical device. Then follow that column down to the row corresponding to the rated power of the transmitter The entry in that cell of the table is the minimum recommended protection distance [in meters] between that medical device and that transmitter.

SOURCE: U.S. Food and Drug Administration, "EMI Protection Distance," draft, Aug. *15, 1994.*

However, with the growing number of both radio and medical devices and their shrinking size, more interference is likely to occur. Because transmission equipment can rarely be altered to reduce interference, regulators think the best solution is for device manufacturers to pay close attention to shielding, working in consultation with the designers and manufacturers of emitting devices.[12]

[12]U.S. Congress, General Accounting Office, *Electromagnetic Interference with Medical Devices,* GAO/RCED-95-96R (Washington, DC: Mar. 17, 1995).

Other measures by themselves may not be sufficient. For example, proposals have been made to restrict the use of wireless devices in hospitals and clinics, but the ubiquity and small size of such devices makes policing difficult. Moreover, health care is becoming more decentralized with sensitive medical equipment increasingly housed in homes and outpatient clinics. Mobile care-givers, in turn, are becoming more reliant on wireless communications to interact with doctors and technicians at hospitals in other locations. This evolution in care-giving requires that medical equipment and wireless communications exist side-by-side. Users of medical or radio devices are generally unaware of field strengths, frequencies, the position, or in some cases even the *presence* of electromagnetic radiation. Warnings, when they do exist, rarely tell users what to do beyond "avoid electromagnetic interference."

Clearly, incorporating shielding into medical devices early in the development process is essential. Other measures may provide some help in minimizing interference problems: promulgating strong standards, limiting radio devices in well-identified areas, and providing good consumer education of the dimensions of EMI.

Regulatory and Legislative Initiatives

In October 1994, the Subcommittee on Information, Justice, Transportation, and Agriculture of the House Government Operations Committee held hearings on medical device interference from wireless and cellular devices.[13] The Federal Communications Commission (FCC) and FDA have primary oversight responsibilities for this area, and have consulted frequently on design and standards issues. However, legislative interest in this issue appears to have precipitated action in the industry to address EMI problems. For example, the Cellular Telecommunications Industry Association (CTIA) and the Health Industry Manufacturers Association have jointly funded a Center for the Study of Wireless Electromagnetic Compatibility at the University of Oklahoma to study medical device interference. This center convened a Forum on Electromagnetic Compatibility in September 1994, which discussed these issues.

The Hearing Aid Compatibility Act of 1988 required that all telephones be made compatible with hearing aids by 1991.[14] However, in a concession to the cellular telephone industry, the act excluded mobile phones. The act did permit the FCC to revisit the issue at a later date, with the presumption that new technologies would be made compatible with hearing aids. The FCC has determined that PCS equipment will be exempt from compliance with the act, noting that U.S. operators who choose GSM will use a different frequency than their European cellular counterparts, that few hearing-aid users will be affected, and that cost-effective solutions to mitigate interference are available.[15] There is some concern in the hearing-aid users' community that PCS operators will choose GSM as their standard. The FCC has convened an advisory committee to examine this issue.

INTERFERENCE WITH AIRCRAFT CONTROL SYSTEMS

Although there are no documented cases of civilian airline crashes caused by cellular telephone or other interference, electronic devices may pose

[13] U. S. Congress, House of Representatives, Committee on Government Operations, Subcommittee on Information, Justice, Transportation and Agriculture, 103d Congress, "Do Cellular and Other Wireless Devices Interfere with Sensitive Medical Equipment? Are Pacemakers, Hearing Aids, Apnea Monitors, Blood Pumps and Other Sophisticated Medical Devices Affected by Outside Electromagnetic Interference (EMI) from Cellular And Other Wireless Devices?" photocopied hearing statements, various witnesses, Oct. 5, 1994.

[14] 47 U.S.C., sec. 610. FCC regulations on hearing aid compatibility can be found in 47 CFR, sec. 68.4.

[15] Letter from Hon. Reed Hundt, Chairman of the FCC, to Sen. Bob Packwood, Chairman, Committee on Commerce, Science, and Transportation, Subcommittee on Communications, Apr. 12, 1995.

problems to airplane control systems.[16] Of the approximately 100 reported cases of alleged interference, about one-third appear to have some validity, according to technical experts.[17] FAA regulations hold the airline companies responsible for setting policies on the use of portable electronic devices; given the difficulty in assuring safe operation under all operating conditions, all airlines have decided to prohibit the use of any electronic devices during take-offs and landings.[18]

Inside an aircraft, radio transmitters, such as cellular telephones, can induce transient currents in wires and even be amplified in the aluminum airframe, because any unshielded metal can act as an antenna. CTIA is currently testing cellular telephones in planes to certify their safe use on the ground. (In addition, cellular telephone use on commercial aircraft in flight is not allowed because a single cellular telephone at even moderate altitudes would tie up many terrestrial cellular base stations simultaneously, since many base stations could be "seen" simultaneously by an airborne cellular telephone.)

A potential problem with American Mobile Satellite Corp.'s (AMSC's) transportable telephone is that it will operate at a frequency adjacent to that used by the Global Positioning Satellite (GPS) system, which will serve as the basis of the new generation of air traffic control systems in the United States. Operating such a telephone in an airplane may jam the GPS navigation system. The FCC, the National Telecommunications and Information Administration (NTIA), and the Federal Aviation Administration (FAA) have established a procedure with AMSC and other interested parties to address this problem; a memorandum of understanding that was concluded in November 1994 provides the means to prevent interference and allows AMSC to proceed with its system's deployment.[19]

Interference could be more serious between portable electronic devices and digital flight equipment, including navigation systems. These systems work with digital bit streams, which can be thought of as strings of ones and zeros. Interference might occur by inducing spurious currents and thus introducing new data to the normal data stream. Such data would probably be rejected by error-correcting routines in current avionics, resulting in an interruption rather than a deviation of normal aircraft control systems, but it is difficult to know with certainty that this would always occur. Even devices that are not designed as radio transmitters emit electromagnetic radiation. This has led to concern that uncontrolled use of any electronic device might cause interference. One recently publicized case involved a pilot who believed that a CD player in use in the first-class compartment interfered with the normal operation of the aircraft during landing.[20]

Because analog avionics systems are not dependent on data streams, they are not susceptible to such interference. Thus, where a digital cellular telephone may affect new Airbuses or Boeing planes, it is unlikely to affect an older Boeing 727. On the other hand, newer aircraft use fiber optic cabling for control systems and more fault-toler-

[16] Jerry Hannifin, "Hazards Aloft," *Time*, Feb. 22, 1993, p. 61.

[17] For example, verifiable cases of interference might resemble the following: when the flight crew notices something unusual occurring to the airplane, together with a passenger's use of an electronic device, they ask the passenger to turn the device off, and note whether the problem has disappeared. They then ask the passenger to turn the device back on to see if the interference occurs again. If it does, then this is an event to be explained. However, efforts to duplicate such effects on the ground have all been unsuccessful. John Sheehan, Pfaneuf Associates, CTIA consultant, chair of RTCA Special Committee 177, personal communication.

[18] The RTCA, an advisory body to the FAA on electronic matters, is meeting to set standards for electronic device emissions in aircraft in the wake of concern about consumer electronic devices. It expects to issue its report on nonradio device interference in the spring of 1995.

[19] Memorandum of Understanding between the FCC, NTIA, and the FAA, "Addressing Out-of-Band Emission Requirements for the Mobile-Satellite Service," effective Nov. 19, 1994.

[20] Jerry Hannifin, "Hazards Aloft," *Time*, Feb. 22, 1993, p. 61.

ant architectures, making them less susceptible to radio interference.

It is extremely difficult and costly to model these internal interference problems. Because there are so many variables—the type of emitting device; its power, frequency, and modulation schemes; the effectiveness of its filters; its place in the aircraft, the location of sensitive instruments, the location of wire or airframe with respect to the emitting device, and the activity the aircraft is performing (e.g. landing or cruising at altitude)—determining all the conditions for trouble-free operation of portable devices is nearly impossible.

UNANTICIPATED INTERACTIONS AMONG LARGE, COMPLEX SYSTEMS

A general issue in electromagnetic radiation is the unintended effects of radio waves. These involve compatibility problems that can, for the most part, be solved either by shielding devices, keeping radio waves away from people and sensitive equipment, or changing the modulation scheme emitting devices use. However, with widespread deployment of small radio devices with complex operating characteristics, it is possible that at some point there will be interference leading to a system failure. Because of the large number of devices, the variety of ways they are used, and the complexity of the possible interactions, it is unlikely that every combination can be tested and potential problems anticipated.

New technologies will continue to be introduced that cannot be tested in all real-world situations. A recent example: the operator's manual for European-model BMW automobiles advises owners not to use a digital (GSM) cellular telephone while driving the car, because it may interfere with the car's electrical system and lead to premature deployment of the airbags. While this particular problem is no doubt fixable, it is one indication of the kinds of surprises that may crop up from time to time as wireless telecommunications technologies play a larger role in a complex technological world.