Electromagnetic noise in the clinical environment

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Abstract

In order to introduce information and communication technology (ICT) into the medical / clinical environment and to make its use practical, it is important to constantly improve and maintain the environment in such a way that ICT products function correctly. Almost all ICT products are driven by electric power. Some use electromagnetic waves. It is an environment in which here are various kinds of electromagnetic elements, including electromagnetic noise. It is very important to maintain a safe electromagnetic environment. We have previously presented our concept of the "medical electromagnetic environment", which consists of four elements. In this paper, we first present the elements. Then, a discussion of each element, including examples of measurement or observation, is presented. Our aim is for readers to have access to reference information that demonstrates the mechanisms of noise and to encourage readers think deeply about their actual environment in the various stages of preparation for applying ICT to medicine.

Keywords:

Electromagnetic environment, Electric field, Magnetic field, Electric power supply, Electric grounding

Introduction

In order to safely install Information and Communication Technology (ICT) into a clinical environment, a stable environment is essential if apparatus is to function normally. For instruments or communication technologies containing wireless signals, a stable, safe environment is indispensable. For example, because cutting edge instruments, including medical devices, have been increasingly driven by electricity in recent years, a stable electric power supply is indispensable. Also, it is vital that malfunctions of medical devices by electromagnetic waves be prevented. In order to safely install wireless communications, the prevention of interference by electromagnetic noise is vital. We have previously presented our concept of the "medical electromagnetic environment" [1]. The electromagnetic environment consists of four elements, as shown in Figure 1.

1. Radiated electromagnetic (EM) fields
2. Noisy Electrical power supplies and Grounding (earth)
3. Magnetic Fields (static and alternating)
4. Surges (static discharge, lightning)

Fig. 1 Factors influencing the medical electromagnetic environment

In this paper, we discuss and show examples of each element except for surge. Our aim is for readers to have access to reference information that demonstrates the mechanisms of noise and to encourage readers think deeply about their actual environment in the stages of preparation for applying ICT to medicine.

Radiated electromagnetic fields

Radiated electromagnetic fields have been the focus of much research as one of the main elements of the electromagnetic environment. There are many sources and the intensity of the field often changes over time, with some of sources emitting electromagnetic waves intermittently. Controlling radiated electromagnetic fields in a clinical environment can be difficult. Thus, before introducing wireless communications, it is important to measure the electromagnetic fields of all areas in which these devices will be used. At the same time, caution must be taken to control for the electromagnetic shielding (whether intended or not) of wireless communication environments and for interference with other devices (including medical devices).

Electromagnetic noise intrusion

Cellular phones are in wide use in Japan, with base stations installed throughout the country. The country is also dotted with broadcasting and relay stations for television and radio and public radios for businesses such as taxis and various other wireless communication services. We measured the electric field intensity induced by radio waves that intruded from outside a hospital that was under construction in an urban area of Japan (hereafter, "Hospital A") [2]. The measurement was done in the autumn of 2000 on a cloudy Sunday when no construction work was being done.

Hospital A has 11 floors. An international airport is located 3 km from the hospital and a television broadcast tower 6 km.

There were 14 visible cellular phone base stations at the time of measurement. The distance to the nearest base station was 200 m from the hospital building. The measured maximum electric field by the electric wave emitted by a base station was approximately 1.8 V/m. The maximum electric field of 126 V/m was observed at the side of the highest floor and was caused by the intermittent electric signals emitted by the airport radar. This example shows that if antennas are located near a hospital, measurement of the electric field intensity at various frequencies should be done before using the building. We recommend that every hospital in an urban area or near the origin of electromagnetic wave emission do this type of observation to prevent EMI with medical devices.

Interference between medical devices and wireless communication

Medical devices affecting wireless communication

Wireless communication uses electric waves of various frequencies. Usually, the frequency is restricted by global standards that insure that there is no overlap between devices. The 2.45 GHz band is specified as the "ISM" (Industry, Scientific and Medical) band and permits use for various purposes. IEEE802.11b/g/n and Bluetooth, which are used widely, use the 2.45 GHz band for wireless communications. Electromagnetic waves in the 2.45 GHz band are also used by microwave ovens and microwave therapy equipment used to excite water molecules. Therefore, the possibility is high that wireless communications can be interfered with by the electric field induced by the electromagnetic waves from electronic devices. A falling transfer rate of wireless communication caused by the electromagnetic waves leaked from a microwave oven in operation was observed in our experiment [3]. Our measurement results are shown in Table 1. In each measurement, a suitable receiving antenna was selected, and the antenna was set 3 m from the subject device.

Table 1 Observed electric waves

Device	Center Frequency	Maximum Electric Intensity (dBμV/m)	Equivalent Channel**
Remote Patient Monitor (Transmitter)	441.3MHz	86.8	
Electric Knife (Monopolar)	500kHz	97.4	
Electric Knife (Bipolar)	461.8kHz	104.5	
Electric Knife (ABC*)	620kHz	91.1	
Microwave Oven A	2.465GHz	121.3	11ch.
Microwave Oven B	2.472GHz	117.2	13ch.

*: Argon Beam Coagulator
**: Due to IEEE802.11b standard

Wireless sources affecting medical devices

Wireless LAN in a clinical setting seldom causes medical devices to malfunction because the output is weak if they are kept within the specified range [4]. Some hospitals currently use wireless LAN communication in most of their wards [5].

To determine the safety limit, we observed interferences (electromagnetic interferences, EMI) with medical devices by wireless LAN [4], and RFID tag reader / writers [6]. Our observation methods are to irradiate signals whose power is stronger than the limit defined by the laws or standards to medical devices by moving a transmitting antenna ever nearer an object until a malfunction occurs or it touches the surface of the device.

By irradiating signals at both 2.45 and 5.2 GHz as used in IEEE 802.11 series wireless LAN, malfunctions were also observed. Details are shown in Table 2. As for PHS, the distance at which interference was noted changed greatly with the direction and position of the irradiation antenna, even when the irradiated radio waves were of the same output and frequency. Hospital staff members should be made aware of this possibility in order to avoid excess fear of EMI.

Table 2 Examples of Observed Malfunctions

a) 2.45 GHz

Device	Malfunction	Distance
Ventilator B	Incorrect numerical display on the ventilation amount sensor	10 cm
Syringe Pump B	Incorrect lighting of the extension tube occlusion status indicator	40 cm
	Stopped with incorrect warning of the extension tube occlusion	10 cm
Syringe Pump C	Stopped with incorrect warning of extension tube occlusion	3 cm

b) 5.2 GHz

Device	Malfunction	Distance
Syringe Pump B	Stopped with incorrect warning of extension tube occlusion	6cm

As an example for checking the safety of medical devices near RF-ID apparatus, we observed EMI using 13.56 MHz radio waves; one of the five frequencies assigned for RF-ID systems. Two kinds of investigations of EMI by magnetic fields were done; one by the field produced by the loop antennas of seven medical devices and the other by the field produced by an IC card reader connected to a personal computers. The magnetic field intensity did not exceed 1 mA/m, even in the area close to a tag reader. One malfunction was observed for one model of syringe pump, and very slight signal distortion was observed in a telemeter and an ECG in the EMI investigation.

Today, ultra wide band (UWB) wireless communication is gaining attention for applications related to body area networks [7]. There is a possibility of interference with UWB wireless communication by the electric waves of intermediate frequencies under other specifications, or by the electromagnetic noise leaked from some apparatus if the output is stronger than expected. Caution and surveying the electromagnetic environment is important [8].

Need for simulation before installing wireless communication devices

Because electromagnetic waves are reflected by metal plates, for indoor wireless communication the structure of the walls and floors has a great influence on electric field propagation

[9]. Wall surfaces differ greatly according to the materials used, such as concrete or metal.

In Japanese hospitals, wireless LAN systems have been introduced to access patient data at bedside. Safe introduction requires surveying the electromagnetic environment in accessible areas and investigating the influence of electromagnetic waves on medical devices. In the survey, investigation of the materials used in doors, walls, and windows is important.

Instead of an actual survey, simulation of the propagation is also able to model the shielding ability for data protection and the prevention of electromagnetic interference.

For simulation, the finite-difference time-domain (FDTD) method has been used for the calculation of electromagnetic fields [10, 11]. We have compared FDTD simulation results with measurement results for 2.45 GHz and 5.2 GHz [12]. The specifications of the simulation are shown in Table 3, and the properties of the materials used are shown in Table 4. Results of the simulation are shown in Figure 2. Measured electric-field intensity under real usage conditions of a laptop type PC are shown in Figure 3. The measurements are performed by moving the PC at 30cm increments; hence, the interference pattern is not shown clearly in Figure 3. In the simulation, not only walls and doors but arrangement of the cabinets was considered. Therefore, the performance of this simulation seems good compared with actual measurement. The measurements agree with the simulations in the attenuation tendency corresponding to wireless LAN frequencies.

For rapid analysis, 2D simulation yields reasonable model fidelity, as shown. Expanding into 3D for this type of calculation can be a significant undertaking due to the computational requirements and new model details [13]. For example, a 1m square simulation in 2D with 2.5mm square cells needs 160,000 cells. In contrast, for 3D a 1m cube simulation with 2.5 mm cube cell needs 64,000,000 cells. For full facility studies, 3D simulations may be as time and cost prohibitive as full spectrum physical testing. However, just as in physical testing, simulations can be deployed in a multi-level approach where zoned higher-resolution 2D analysis is pursued on a per floor basis and lower-resolution 3D models are studied for the full facility.

Noisy Electrical power supplies and earth grounding

If a stable power supply is not distributed to devices driven electrically, it is obvious that their operation will not be stable. A stable power supply is critical, especially for medical devices used for physical examinations and for recording biomedical signals. Here, we consider stability to be "the quality of a power supply." If the power supply is DC (battery), the quality can be considered to be the amount and size of voltage or current surges and the life span of the batteries. In the case of an AC power supply, quality is related to distortion from sine waves and measures to protect against power failures.

Table 3 Specifications of the simulation

Item	Specification
Method	TM-FDTD
Cell size	2.5 mm
Region size	5990 cells×3740 cells (15 m×9 m)
Time step size	5 ps
Total time steps	14000 steps (70 ns)
Frequency	2.442 GHz, 5.200 GHz
ABC*	PML** (8 layers)

*: Absorbing Boundary Condition
**: Perfectly Matched Layer

Table 4 Material properties used for simulation

Material	Relative permittivity	Conductivity (S/m)
Concrete wall	7.0 (2.4 GHz) 7.2 (5.2GHz)	0.081 (2.4 GHz) 0.26 (5.2 GHz)
Gypsum board wall, Wooden door	5.0	0.0084
Metals		∞

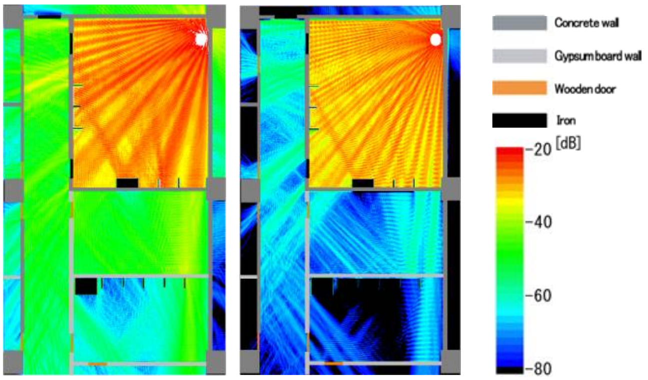

Fig. 2 Simulated electric-field intensity
Left: 2.45 GHz, Right: 5.2 GHz

Fig. 3 Measured electric-field intensity
Left: 2.45 GHz, Right: 5.2 GHz

Noise superimposed on the electric power supply

Some noise is the result of emissions from interconnected apparatus that causes a decrease in the quality of the power supply. In other words, the power supply noise (reflection noise) that an apparatus emits may have a negative influence on an apparatus connected to the same circuit. Also, measures to avoid exceeding the load limit should be carefully considered. Figure 4 is an example of a voltage waveform when a high amount of reflection noise has been superimposed and an overload occurred [14]. Connecting inverters and medical devices to the same circuit should be avoided.

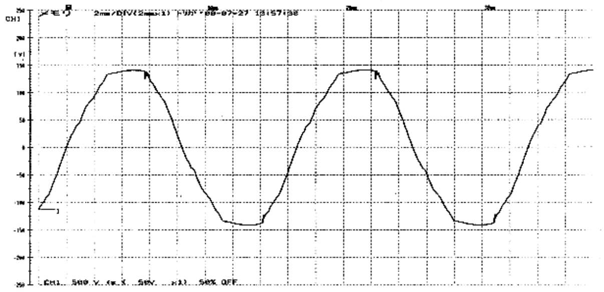

Fig. 4 An example of the voltage waveform when 12 sets of infusion pumps were connected to one outlet

Momentary and continuous power failure

Power failures can be momentary or continuous. We previously reported an investigation of medical devices that not only stopped, but that had the setup information disappear because of a momentary power failure of less than 0.5 second (voltage dip) [15]. Medical devices, especially life-sustaining devices, should be equipped with an uninterruptible power supply (UPS). As a measure against power failures that continue for a long time (several minutes or more), a backup power supply system is required. However, because hospital managers will be forced to deal with ever increasing ICT use in the future, an emergency electric supply system that covers the computer systems, servers, a minimum number of terminals, and the minimum necessary network will be required and should be independent of the one for medical devices. Although there are specifications for emergency electric power sources for the power supply to medical equipment in Japan [16], there is nothing for hospital information systems.

Poor electrical grounding

Grounding (earth) can also be considered a form of power supply equipment. Especially in the medical scene, grounding contributes greatly to prevention of disturbance of the stability of measurement apparatus and to preventing shock (micro and macro-shock). In Japan, although there are required standards [16], electrical grounding is often not properly done. Even in hospitals, many outlets that do not have a grounding terminal (2P electric outlet) can be found. Also, there are many examples of connection to a 2P outlet using an adapter for the plug of a medical device that has a grounding terminal (3P plug). An example of an improper connection is shown in Figure 5.

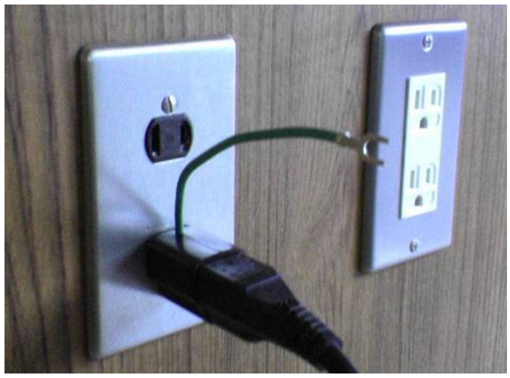

Fig. 5 Example of an improper ground connection (Left: Example of a improper connection, a 3P plug connected to a 2P outlet using an adapter Right: a 3P outlet)

Magnetic fields

Static magnetic field

Although a static magnetic field has little direct influence on wireless communications, it may affect the operation of devices. Influence on devices such as video monitors or electronic microscopes have been shown, especially on devices with a cathode-ray tube (CRT) display. We observed a static magnetic field by the residual energy generated by welding points in Hospital A [17]. A magnetic field exceeding 200 microT was observed at a point 10 cm above the floor. This magnetic field is sufficient to cause video and color distortion on CRT displays.

Alternating magnetic fields

Here, the frequency of an alternating magnetic field is assumed as lower than 9 kHz, which is the lower limit of the IEC61000-4-6 specification. It includes the commercial frequency (50 Hz / 60Hz in Japan). In a high frequency alternating electromagnetic field, the influence of the electric field is greater than that of the magnetic field. A strong alternating magnetic field can be seen near electric wires from substation facilities through which a large amount of current flows in many cases. We measured an alternating magnetic field at a maximum of 29.4 microT 10 cm above the floor of a room directly above the electric supply room in a hospital ("hospital B") that was constructed 25 years ago [18]. This magnetic field was caused by the remarkably increased amount of current necessary for hospital operation in the years since the time of installation. The point we measured is also approximately 1.5 m above the non-shielded power line from a substation through which a huge amount of current, hundreds of ampere, flows.

Because a magnetic field is in inverse proportion to the square of the distance from the source, when a minimum fixed distance is kept from the source, safety can be maintained. However, the maximum magnetic field, observed 1 m above the floor, exceeded 10 microT. At this intensity, waving of the picture of a CRT display was observed. This room has been remodeled and the magnetic field 10 cm above the floor is now less than 1 microT

Conclusion

We summarized the electromagnetic environment of the clinical/medical setting, which is rarely taken into consideration when planning is done to introduce medical ICT. It is our hope that engineers and developers will take more care in developing and maintaining the on-site electromagnetic environment of their apparatus and communication systems. Also, we hope to see future systems that are easier to use and that have a stable environment.

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