

The electromagnetic environment of hospitals: how it is affected by the strength of electromagnetic fields generated both inside and outside the hospital

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Summary. Most problems with the electromagnetic environment of medical institutions have been related to radiated electromagnetic fields and have been constructed from reports about electromagnetic interference (EMI) with electronic medical equipment by the radio waves emitted from mobile telephone handsets. However, radiated electromagnetic fields are just one of the elements. For example, little attention has been placed on problems with the electric power source. Apparatus for clinical treatment and diagnosis that use electric power sources have come into wide use in hospitals. Hospitals must pay careful attention to all elements of the electromagnetic environment. Herein, I will show examples of measurements and measuring methods for radiated electromagnetic fields, static magnetic fields, and power-source noise, common components of the medical electromagnetic environment.

Key words: electromagnetic fields, electric power supplies, equipment and supplies, hospital.

Riassunto (*L'ambiente elettromagnetico negli ospedali: come è influenzato dalla potenza dei campi elettromagnetici generati all'interno e all'esterno dell'ospedale*). La maggior parte dei problemi con l'ambiente elettromagnetico all'interno di istituzioni mediche, sono stati sino ad ora messi in relazione ai campi elettromagnetici radiati, come risulta da molti lavori riportati in letteratura circa l'interferenza elettromagnetica prodotta dalle onde radio emesse da telefoni cellulari su dispositivi medici elettronici. Tuttavia i campi elettromagnetici radiati sono soltanto uno degli elementi. Ad esempio poca attenzione è stata finora posta sulla problematica dell'interferenza con una sorgente di energia elettrica. Poiché i dispositivi medici, per la terapia e la diagnosi del paziente, che utilizzano una sorgente di energia elettrica, sono sempre più utilizzati negli ospedali, quest'ultimi debbono porre particolare attenzione a tutti gli elementi dell'ambiente elettromagnetico. In questo lavoro vengono riportati esempi di misure e metodi di misura delle componenti elettromagnetiche più comuni che si possono trovare in un ambiente medico: campi elettromagnetici radiati, campi magnetici statici e noise dovuto a sorgenti di energia elettrica.

Parole chiave: campi elettromagnetici, fonti di energia elettrica, apparecchiature e forniture ospedaliere.

INTRODUCTION

Most problems with the electromagnetic environment of medical institutions have been related to radiated electromagnetic fields and have been constructed from reports about electromagnetic interference (EMI) with electronic medical equipment by the radio waves emitted from mobile telephone handsets [1-6]. Regulations for use and hospital guidelines for mobile telephone handsets have been issued in many countries.

In Japan, over 95 million sets of cellular phones were in use as of the end of March, 2006 (75% diffusion rate) [7]. The increase in use has raised attention to the issue of radiated electromagnetic fields. The Ministry of Internal Affairs and Communications

of Japan has done studies almost every year since 1996 to respond to this issue and has released many reports concerning the influence of EMI by cellular phones, wireless LANs, RF-ID tags (electronic tag), etc. on medical equipment. However, the electromagnetic environment does not consist solely of radiated fields. The electromagnetic environment in a clinical setting has many components such as:

- electromagnetic field;
 - electric power supply;
 - grounding;
 - surge (thunder, static electricity);
 - static magnetic field
- with radiated electromagnetic fields just one of the elements.

Although hospitals must pay attention to each component of the electromagnetic environment, the level of attention that needs to be devoted to each component differs. For example, the attention necessary to deal with problems with the electric power source is low, because the power sources currently available are more stable than earlier sources. Apparatus for clinical treatment and diagnosis that use electric power sources have come into wide use in hospitals. When misused, the possibility of stoppages increases. The environment in which medical treatment is given at home is similar, but when a patient or family member operates medical equipment, their knowledge of electric installation is far inferior to the knowledge of hospital professionals, and thus problems that might occur in this environment must be addressed.

Herein, I will show examples of measurements and measuring methods for radiated electromagnetic fields, static magnetic fields, and power-source noise, common components of the medical electromagnetic environment.

RADIATED RADIO FREQUENCY ELECTROMAGNETIC FIELDS

Introduction

The possibility of EMI with electronic medical equipment caused by radio waves coming from outside the hospital has been reported [8]. We also reported the poor shielding capacity of a concrete wall [9]. Because communication and broadcasts using radio waves are expected to increase, radio wave intrusion from outside will increase. In this section, we reported an experience to determine the radio wave frequency environment surrounding a modern urban hospital, published in [10]. Incoming radio waves were recorded at various positions in a hospital under construction, and these results will be also shown.

Methods

When evaluating the electromagnetic environment if there is no information about surrounding electromagnetic fields, three measurements should be done to determine the origin of irradiation and its possible effect on medical equipment. An accurate measurement method using an actual example is given.

The electric field intensity induced by radio waves coming from outside the hospital was measured in Fukuoka, an urban area with a population of 1.3 million. The hospital building is 56 m high and has 11 above ground floors and one basement floor. Because it is only 3.2 km from Fukuoka International Airport, the height of the building is regulated by aviation law, and there are no buildings exceeding 56 m around the hospital. The equipment used for the three measurements consisted of a bi-conical antenna (BBA9106, Shuwartz-Becke), a log-periodic antenna (KBA601A, Kyoritsu Electronic), a double-ridged guide antenna (3115, EMCO) and a spectrum analyzer (8566B, Hewlett-Packard).

The frequency distribution of the electric field intensity was measured at six points on the 1st, 4th, and 11th floors. The measured frequencies ranged from 30 MHz to 3 GHz. Electric field intensity was measured at vertical and horizontal polarizations over 360 degrees with slow antenna rotation, and the strongest electric field intensity was recorded. Measurement was performed on a Sunday, and the weather was fine.

In order to confirm the reproducibility of the measured values, we again measured electric field intensity after a 6-week interval. This measurement was done at the point on the 11th floor where the strongest field was recorded in the first measurement. Because no strong electric field intensity was observed at frequencies lower than 300 MHz in the first measurement, the measured frequency range was set from 300 MHz to 3 GHz. Measurement was performed on a Sunday, and the weather was fine.

Measurement was also done to determinate the source of incoming radio waves in areas where especially strong electric field intensity was observed, with the intensity measured every 45 degrees. Because no wave at the frequency of the strongest intensity we had previously noted was found in the area near the subject hospital, we continued our search for the antenna on foot and by map.

Even though the main radio wave transmitting station was identified by use of the second measurement, in order to investigate in detail the distribution of the electric field intensity, measurements were done with horizontal and vertical polarization at three points on the southeast side of the building. Because of the prefecture government office building between the measurement points and the radio wave transmitter, angles and visibility differed at every measurement point. Electric field intensity tended to be stronger as the measurement point was moved higher, with the highest intensity found in the ward on the highest floor. For all measurement points, when the intensity was 3 V/m or higher in either polarization, measurement was also done one floor lower. Otherwise, if the intensity of both polarizations was under 3 V/m, measurement on the floor below was not done. The threshold value was the electromagnetic compatibility marginal value of the general electronic medical equipment specified in IEC 60601-1-2 [11]. Because the frequency of the radio waves that induced the strongest electric field intensity was known by the measurement results, the frequency range for measurement was set from 2.5 GHz to 3.2 GHz. The measurement was performed on a Sunday, and the weather was cloudy.

Results

The number of radio waves coming into the hospital at electric field intensities higher than 0.1 V/m (100 dB μ V/m) increased as the measurement point location became higher (12 radio waves at 1st floor, 19 at 4th floor and 28 at 11th floor, as reported in table 2 of [10]). Electric field intensity exceeding 3 V/m, the compatibility marginal value of general elec-

tronic medical equipment in a radiated electromagnetic field, was observed on the 11th floor.

After six weeks, we found that the maximum value was almost the same as that of the first measurement, indicating that the observed radio wave was not temporary, but was regularly coming into the hospital building. From the 45 degree measurements, the source of the transmission was determined to be from the southeast. The maximum intensity was 5.01 V/m (134 dB μ V/m). Investigation of all strong radio wave transmitting sites in a southeasterly direction from the hospital found the airport surveillance radar (ASR) at Fukuoka International Airport to be the probable source.

The measurements done to investigate in detail the distribution of the electric field intensity, gave a maximum value of 199.53 V/m (166 dB μ V/m) in a position on the 10th floor which is not covered by the prefecture government office building. In the same position on 6th floor, the electric field intensity decreased to below 3 V/m as well as on 10th floor in a position covered by the prefecture government office building.

Discussion of irradiated radio waves

The frequency distribution of incoming radio waves changes with height, position of measurement, and the direction of the receiving antenna. There are 14 cellular phone base stations (the minimum distance is approximately 200 m) within 2 km of the hospital. Since none of the measuring crew used cellular phone handsets, the 800 MHz and 1.5 GHz band radio waves were thought to be from cellular phone system base stations. The maximum radio wave from a cellular phone system base station was observed on the 4th floor. UHF television signals (500 MHz to 600 MHz) were also observed on all floors.

A strong electric field intensity was observed periodically at frequencies of 2.79 GHz and 2.87 GHz. The source was thought to be the ASR antenna at Fukuoka International Airport, the only ASR antenna transmitting strong electric waves within 5 km to the southeast of the hospital. The ASR antenna, which transmits radio waves at a 500 kW power output using 2.79 GHz and 2.87 GHz radio waves, is located at the Fukuoka International Airport [12]. ASR transmits and receives by rotating a parabolic antenna. The electric field intensities of 2.79 GHz and 2.87 GHz observed on the 11th floor [10] were almost 20 times the immunity standard of life support equipment set by IEC 60601-1-2. Without modification of the building, EMI with electronic medical equipment could have been a serious problem.

Over 95 million mobile telephone handsets were in use in Japan at the end of March 2006 [7]. Therefore, many cellular phone base stations are installed at short distances. The base stations are, in many cases, installed on the roofs of buildings or on towers at a height of 30 m to 50 m, the height of the 6th to 10th floors of the hospital. The direction of signals emitted from base station antennas is slightly downward.

The 4th floor, therefore, had the strongest electric field intensity by radio waves from cellular phone base stations (800 MHz band and 1.5 GHz band).

The electric field intensity of a radiated electromagnetic field can be calculated by the following formula (1).

$$E = \frac{K \sqrt{G \cdot Pin}}{r} \quad (1)$$

where Pin is input electric power, G is antenna gain, K is constant, and r is the distance from the transmission source

Therefore, although the observed values were under 3 V/m in this measurement, because the distance between the measurement point and the nearest base station was 200 m, if the base station were nearer, the electric field intensity would be over the standard.

The ASR antenna at Fukuoka International Airport (radar) can be seen from measurement point on the 9th, 10th and 11th floors, even though it is located 3.2 km distant. From the 8th floor down, the prefecture government office building shades the ASR antenna. If the measurement points are located within the perpendicular transmission angle of the ASR antenna and the antenna can be seen from these points with no obstacles around them, the measurement points would be in the Fresnel Zone, where reflective waves amplify the intensity. This would be the cause of the particularly strong electric field intensity measured on the 10th floor compared with the other measurement points. Even on the 8th floor, where the radar antenna cannot be seen, strong electric field intensity was observed. Diffraction and reflection of radio waves are factors in electric wave observation from transmission sources that are not visible. The prefecture government office building located between the measurement points and the transmission source was thought to be shielding the waves.

This study showed various radio waves entering a hospital building at strong electric field intensity. Radio waves from cellular phone base stations and an ASR induced strong electric field intensity. All hospitals, especially those in urban areas, should take protective measures against EMI by incoming radio waves.

ALTERNATIVE MAGNETIC FIELDS

Introduction

As an international standard, the immunity test method for a magnetic field of commercial frequency is defined in IEC61000-4-8. EMC (electromagnetic compatibility) standard for medical electric equipment IEC60601-1-2 states that life-sustaining equipment, such as infusion pumps, should work normally in a magnetic field of 400 A/m and other medical equipment should work normally at 3 A/m.

Although electromagnetic fields have the properties of both electric and magnetic fields, they are enlarged by the property of the magnetic field in the power

supply frequency. Generating a magnetic field around an electric wire through which current is flowing, the magnitude is proportional to the amount of current.

In a large hospital, the number of pieces of medical equipment driven by electric power sources is rapidly increasing, as is the number of computers. Therefore, the demand for electricity is growing, and the amount of contract demand has increased in response to this demand. Because voltage is fixed at 100 V in Japan, an increase in electricity use means an increase in the amount of current, which makes it a factor in increasing the magnetic field strength inside a hospital. Here, I show an investigation of the possibility of EMI by the magnetic field of a power supply.

Methods

We measured the magnetic environment of two rooms in a 25 year old university hospital building. One was a nurse station in a ward above the electricity transformation facility (hereafter "room A"), and the other was right above a telephone exchange room (hereafter "room B").

A gauss meter (HM-320, MTI) and a 3 axis probe (attached to HM-320, MTI) were used for measurement. This apparatus can measure the magnetic flux density of each axis of the probe, x , y , and z , a maximum range of 2 G (= 200 μ T), and with an accuracy of 1 mG. At each point, after measuring the magnetic field of each axis, the actual value was computed according to the formula (2).

$$F_e = \sqrt{F_x^2 + F_y^2 + F_z^2} \quad (2)$$

where, F_x , F_y , and F_z are the magnetic flux densities obtained by the Gauss meter for the three directions.

The measurement points defined were fixed at intervals of 1m in the subject rooms. At each point, magnetic flux density (magnetic field intensity) was measured at 10 cm and 1 m in height from the floor.

Result

A maximum intensity exceeding 290 mG (= 29 μ T $\approx$ 23.09 A/m) at 10 cm from the floor above room A was recorded. The maximum magnetic field detected above room B was 185 mG. This value can make a CRT (cathode-ray tube) screen swing.

To determine the source of the magnetic field found in the nurse station, we checked the position of the wiring in room A. The source was found to be an electric wire with a maximum current of 900 A.

Discussion

In the nurse station, a magnetic field exceeding 20 μ T at maximum was measured. In this environment, malfunctions could occur with some medical electric devices. However, since a magnetic field is in inverse proportion to the square of the distance from the source, only a small area of the nurse station was danger. As for the human environment, the reference level for magnetic field exposure

to the whole body was set at 0.33 A/m at 60 Hz by ICNRP (International Commission on Non-Ionizing Radiation Protection) in 1998 [13]. In the nurse station, the measured maximum magnetic field at 1 m above the floor was 100 mG (= 10 μ T $\approx$ 7.97 A/m). Therefore, this nurse station needed to be protected from this magnetic field.

The source of the measured magnetic field was wiring with a current of several hundred amperes in rooms A and B. The amount of current had increased from 200 A to 900 A over 20 years due to increases in electricity demand. In Japan, there are no standards or criteria, other than the criteria for the electric wiring in a common building, concerning the amount of current flowing through wiring. The standards and criteria for magnetic field exposure to the human body are defined only at frequencies of 10 kHz or higher.

STATIC MAGNETIC FIELDS

Introduction

Another type of magnetic field with a possibility of EMI with electronic medical equipment is static magnetic fields. EMI with an artificial heart pacemaker by a static magnetic field was reported [14]. European standard EN 45502-2-1 was formulated to insure that an implanted heart pacemaker would run normally in a 1 G or less static magnet field.

The following is an investigation of EMI by static magnetic fields in which the residual magnetization at electric welds, a possible source of static magnetic fields in a steel structured hospital building, was measured.

Methods

A ward at a university hospital was the subject of this test. At the time of the investigation, the steel framing had been completed, and the interior finish work was being done. We measured magnetic flux density in the emergency treatment room, intensive care unit, coronary care unit, and recovery rooms; all rooms in which a number of pieces of electronic medical equipment would be installed. Magnetic flux density measurement was done 10 cm and 1 m above the floor at each corner of a 1 m grid drawn on the floor of each room measured. Measurement was done on a holiday when there was no construction activity. The weather was cloudy.

The same Gauss meter and 3-axis probe as used in the measurement of the alternative magnetic field were used. Also, the same equation for magnetic flux density calculation at each point as used in the measurement of alternative magnetic fields was used.

Result

Two examples of measurement results are shown in Figure 1. Values on the X and Y axes show the distance of the measurement point from the wall, and the value on the Z axis shows the magnetic flux density. Magnetic flux density changes greatly with slight differences in probe location. Especially strong magnetic

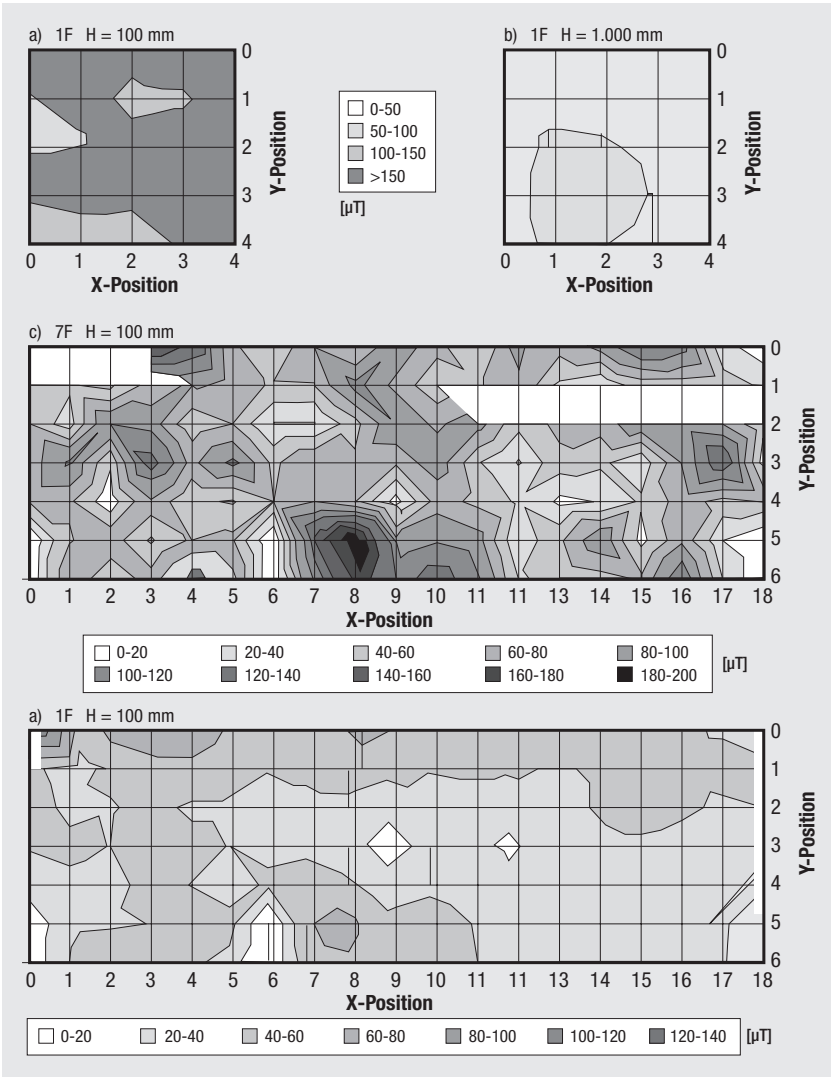


Fig. 1 | Magnetic flux density distribution: a) 100 mm above the floor in the emergency treatment room (1F); b) 1000 mm above the floor in the emergency treatment room (1F); c) 100 mm above the floor in the Neurosurgery ICU (7F); d) 1000 mm above the floor in the Neurosurgery ICU (7F). Reproduced with kind permission from [21]. ©IEEE, 2001.

flux density was observed at the welds of deck plates, the piping holes of metal deck plates, and the welds of metallic ornaments hanging from the deck plates. Strong magnetic flux density was also observed close to the following points; aluminum sash frame to metallic wall structure welds, the welds of steel girders to each other, and welds of the metal frames in partition walls.

The maximum magnetic flux density observed at each measurement point is shown in *Table 1*. Strong magnetic flux density was observed on every floor. The magnetic flux density exceeded the range of the Gauss meter at 10 cm above the first and seventh floors. The magnetic flux density 10 cm above the floor was higher than at 1 m above the floor at most

Table 1 | Maximum magnetic flux density at each observation point

Rooms	Floor	Magnetic flux density (μT)	
		(H = 100 mm)	(H = 1000 mm)
Emergency treatment room	1F	214.5	77.8
ICU, CCU	3F	-	86.8
Surgical operation room	3F	-	138.6
Common patient bedroom	5F	65.9	83.8
Neurosurgical ICU	7F	210.6	110.6
Recovery room	11F	130.5	112.1

ICU: intensive care unit; CCU: coronary care unit

of the measurement points. For example, the maximum magnetic flux density measured in the recovery room on the seventh floor was 210.6 μT at 10 cm above the floor and 110.6 μT at 1 m above the floor.

Discussion

In the case of static magnetic fields, magnetic flux density is in inverse proportion to the square of the distance from a magnetized point. Therefore, it is possible to prevent EMI by keeping electronic medical equipment away from magnetized welds. When equipment cannot be placed far enough from a weld, de-magnetization [15, 16] or shielding may be necessary. De-magnetization can negate the magnetic energy by emitting the same volume of magnetic energy in a reverse direction to every magnetized point, after investigation of magnetic energy and its direction. Magnetic shielding, such as highly permeable materials, can be used to protect electronic medical equipment from magnetism. However, highly permeable materials are expensive. One standard for safe performance in cases where magnetic flux density is over 80 μT (0.8 G), the standard for CRT [17], is placement from 10 cm to 30 cm above the floor. This is considered the lowest safe installation height for general electronic medical equipment.

In this section, we confirmed that the residual magnetization of welds in a hospital should not be overlooked. Near the electric welds of steel frames and deck plates, strong residual magnetic flux density, which could produce EMI with electronic medical equipment, was found. Therefore, it would be beneficial for hospitals to do residual magnetic-field measurement and to place electronic medical equipment away from strongly magnetized points when strong magnetic fields are found. De-magnetization or magnetic shielding would be helpful for the prevention of EMI.

NOISE SUPERIMPOSED ON POWER LINES

Introduction

The use of mobile medical electronic equipment has increased rapidly in recent years, with many types of medical electronic equipment now including electronic circuits that are driven at low electric power outputs. Because electronic circuits can be damaged by momentary changes in voltage, some types of medical electronic equipment also have rechargeable batteries as a power source. In hospitals, a safe environment for

using equipment should be provided. However, other than introducing laws and standards concerning the installation of power supply apparatus, such as emergency power generators, uninterruptible power supply (UPS), voltage and frequency stabilization equipment (CVCF, constant voltage and constant frequency), and grounding, the quality of electric power has hardly been considered.

Changes of voltage and noise superimposed on the power supply are possible obstacles to the efficient operation of medical electronic equipment [18]. Therefore, we observed the quality of the power supply of electronic medical equipment used in a modern hospital. Because strong installation standards have already been set for large-size medical equipment, only mobile medical electronic equipment, such as infusion and syringe pumps, will be discussed.

Methods

The quality of the electric power supply was observed by recording and comparing voltage waveforms in a new university hospital building. The same five wall sockets were used for all tests, as shown in Table 2.

Immediately after completing the building and before patients were admitted, a recording device, Hioki Memory hi-coder/ Model 8807, was connected to each of the wall sockets and the voltage waveform was recorded before any equipment was connected. After the building was opened to patients, the same recording device was connected to the wall sockets, and the voltage waveforms were again recorded. Before and after opening, recordings were done in an operating room, in a nurse station and at bedside in an intensive care unit (ICU), and a critical care patient room for neurosurgery patients on the 7th floor and in a standard patient room on the 9th floor.

When distortion in voltage waveforms was found, we analyzed the distortion by connecting a hi-frequency power distortion analyzer, the Dranetz Power Platform / Model 3400.

Results

The recorded voltage waveforms immediately after completion of the building and after patients were admitted are shown in Figure 2. Although distortion can already be seen in some of the voltage waveforms immediately after completion of the building, distortion increased after various pieces of mobile medical

Table 2 | Locations of the subject wall sockets

Room/area (floor)	The tested socket
Operating room (3F)	A wall socket connected to UPS
ICU; a single room (3F)	A bedside socket connected to UPS
ICU; a nursing station (3F)	A socket connected only to the general power supply
A critical care patient room for neurosurgery patients (7F)	A bedside socket connected to UPS
A standard patient room (9F)	A bedside socket connected to UPS

UPS: uninterruptible power unit; ICU: intensive care unit.

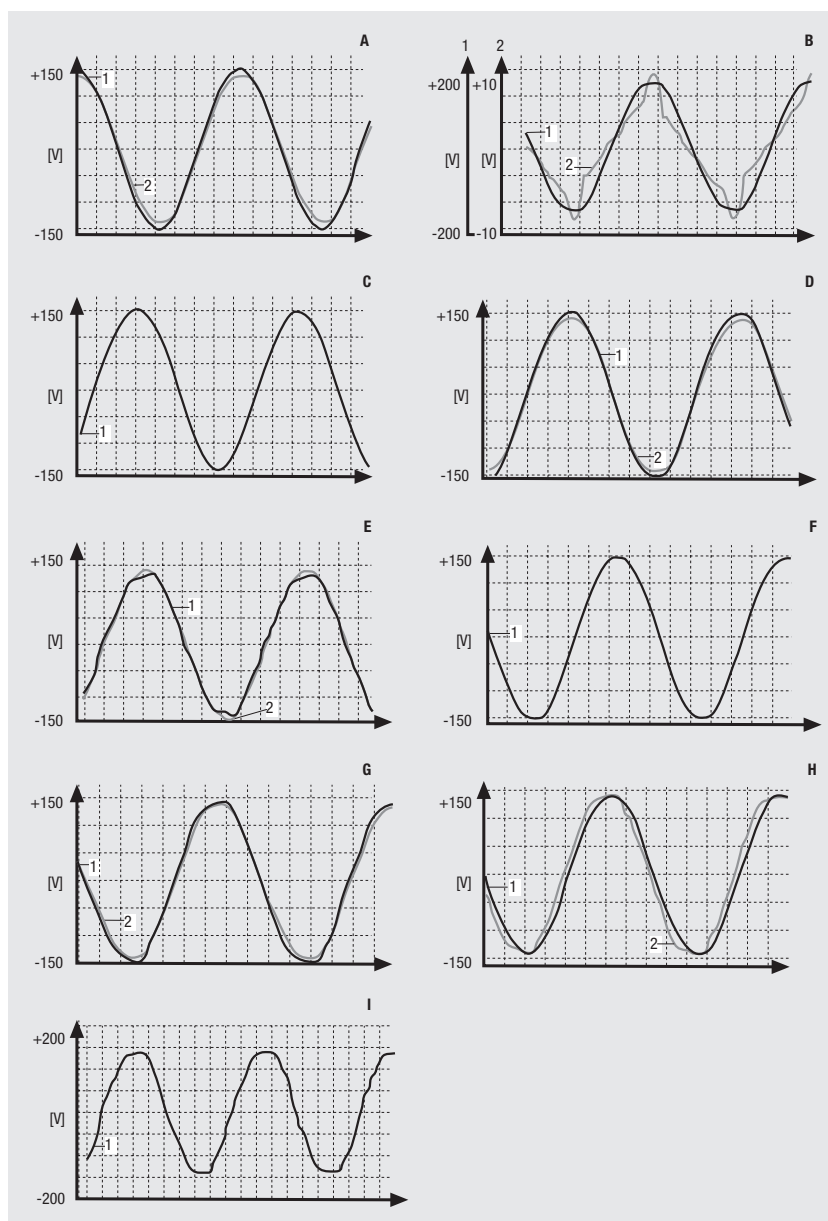


Fig. 2 | Panels a) and b): Power supply waveforms at a wall socket in a surgical operating room. a) After completion of the new hospital but before opening; 1 (bold): Observed voltage, 2 (thin): Reference sine wave. b) During a surgical operation (operation for a patient with a hernia); 1: Voltage, 2: Current. Panels c and d): Power supply waveforms at a bedside wall socket in an ICU single room. c) Immediately after completion of the new hospital, but before opening. d) After opening the hospital; 1 (bold): Observed voltage, 2 (thin): Reference sine wave. Panel e) Power supply waveforms at a wall socket in an ICU nursing station. Several PCs were connected and in operation; 1 (bold): Observed voltage, 2 (thin): Reference sine wave.; Panels f) and g): Power supply waveforms at a bedside wall socket in a seventh floor, critical care patient room. f) Immediately after completion of the new hospital, but before opening; g) After opening the hospital; 1 (thin): Reference sine wave, 2 (bold): Observed voltage. Panel h): Power supply waveforms at a wall socket in a standard patient room on the ninth floor; 1 (bold): Observed voltage, 2 (thin): Reference sine wave. Panel i) An example of distortion of the power supply waveform with 10 sets of syringe pumps connected to the same wall socket.

equipment were connected. The largest distortion was observed in a nursing station in the ICU (Figure 2, panel e). The minimum voltage was 96 V.

Discussion

Causes of voltage waveform distortion

Fluctuation and unusual outputs of generated voltage and current may be caused not only by supply side sources (primary side), but also at the terminal side (secondary side). In many cases, medical electronic equipment includes motors, discharge tubes, and electronic circuits. When these types of equipment are connected to a wall socket, they may cause voltage distortion that would be transmitted toward the primary side. Hereafter, we refer to this type of electromagnetic noise as “reflective noise.”

Because reflective noise is transmitted over power

supply lines, there is little decrease in the noise and it seldom disappears completely. However, when circuit breakers are placed in the wiring or transformers or relay switches are inserted, little noise is transmitted to the primary side. Therefore, even if reflective noise is caused by electronic equipment, voltage distortion will only influence wall sockets branched from the same circuit breaker.

In this observation, several desktop-type personal computers (PC) were used in the nursing station in the ICU. These PC would seem to have been the main cause of the distortion increase. As a result of analysis of the distortion, high frequency noise was found on the voltage waveform. This type of power supply distortion is called “high frequency distortion” or “harmonics” [19]. “High frequency distortion” of the power supply has increased with the spread of

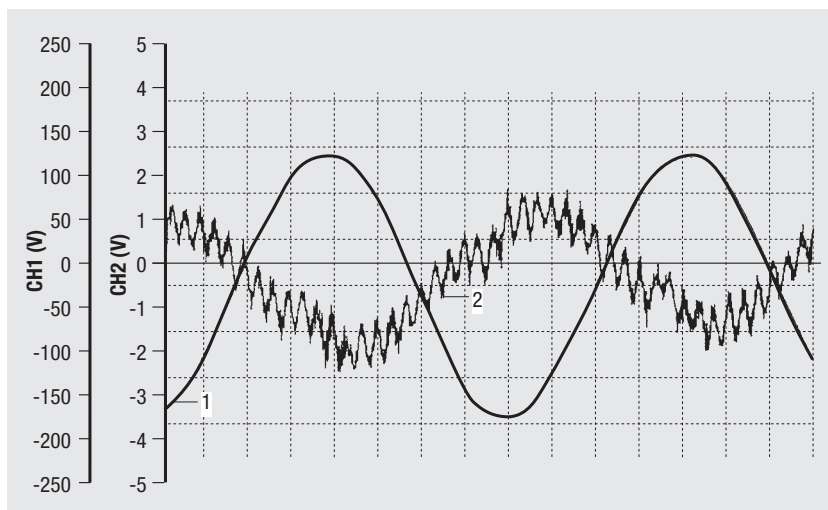


Fig. 3 | An example of distortion of the voltage waveform by induction by a power line. 1: Observed voltage. 2: Subtraction of observed voltage from reference sine wave.

electronic devices and computers in recent years. An example measured in another hospital is shown in *Figure 2, panel i*. This example is of a voltage waveform taken from a wall socket from which ten sets of syringe pumps, all in operation at the same time, received their electric power supply. In this case, 5% or more voltage change was observed. The cause of this distortion was high frequency voltage emission by the electronic parts in the pumps, such as inverters or by components that change the alternating current into direct current.

Other factors of power supply distortion

Besides the voltage changes observed above, the following is an example of a known factor in voltage/current distortion. If distortion is caused by two or more overlapping factors, the distortion rate becomes larger.

- 1) Electromagnetic induction by high current power lines (“Induction”). *Figure 3* is an example of the voltage waveform distortion of a commercial power supply caused by power supply lines used for elevators. In this example, two power supply lines are branched from different circuit breakers. However, because the power lines were very

close, electromagnetic induction occurred and the voltage waveform of the general power supply was distorted. Distortion at almost the same frequency as the power supply frequency is a typical feature of voltage change caused by power lines, lines for motors, and air compressors.

- 2) Noise derived from phase differences (“transient”). The noise derived from phase differences is referred to as “transient” [18]. Other than voltage noise including surges or sags, the phase of power supply waveforms has been barely been considered in Japan. As for hospitals in Japan, extraordinary power supply installation requirements are imposed by standards in some areas (*Table 3*): Japan Industrial Standards (JIS) (T1001 [19] and T1022 [20]). When the electric power supply from an electric power company is cut, hospitals with private electric generation capability change to their private generator. If the phase of the sine waves differs, the voltage may drop to a low level at the time of change. Moreover, the electric power company may sometimes change the equipment in a power transmission route or a substation, and a phase difference may arise from these changes. However, low voltage when continued for a few

Table 3 | Installation requirements for emergency power supply equipment in Japanese hospitals

Room (purpose of use)	Installation of general/special extraordinary power supply	Installation of instant special extraordinary power supply
Operating rooms	Required	Required
ICU, CCU, NICU, LDR, cardiac catheterization rooms, recovery rooms, rooms for hemodialysis, rooms for first-aid	Required	Depend on needs
Sterile, patient rooms; delivery room	Required	Depend on needs
Rooms other than above	Depend on needs	Depend on needs

• Japanese hospitals are required to install one or both types of extraordinary power supply according to the medical electronic equipment to be used. ICU: intensive care unit; CCU: coronary care unit; NICU: neonatal intensive care unit; LDR: room for labor, delivery and recovery.

cycles (about 0.1 seconds) is sufficient to be detected by the voltage sensor of medical electronic equipment. Any voltage loss may cause equipment stoppage.

Important considerations in investigations of power supply

- Directors of hospitals whose buildings have been newly built or repaired should not only check to see that the power supply system meets the requirements for power supply waveforms, but also insure that wall sockets are safe before starting use. Data taken before the hospital is put in operation can be useful when problems occur. The initial recorded voltage/current waveforms can be used for later reference.
- Recording devices with a short time interval (high frequency sampling) should be used in waveform investigations or high frequency noise will not be detectable. An example is shown in *Figure 4*. The same power source waveform was recorded using two recording instruments: a) a waveform recorded by equipment with 3 kHz sampling, and b) a waveform recorded with 50 kHz sampling.

- If voltage decreases, overload and superimposed noise should be distinguished, as they are derived from different causes.

In this section, I mainly investigated the changes in the power supply voltage. Using medical electronic equipment in a carefully controlled environment improves the safety and quality of clinical medicine. All who operate or manage medical electronic equipment, such as doctors, nurses, clinical engineers, and administrative staff, should carefully monitor the electrical environment. When performing delicate measurements, such as brain-wave measurement, we must be careful of not only electromagnetic waves superimposed on cables etc., but also of other aspects of the power supply.

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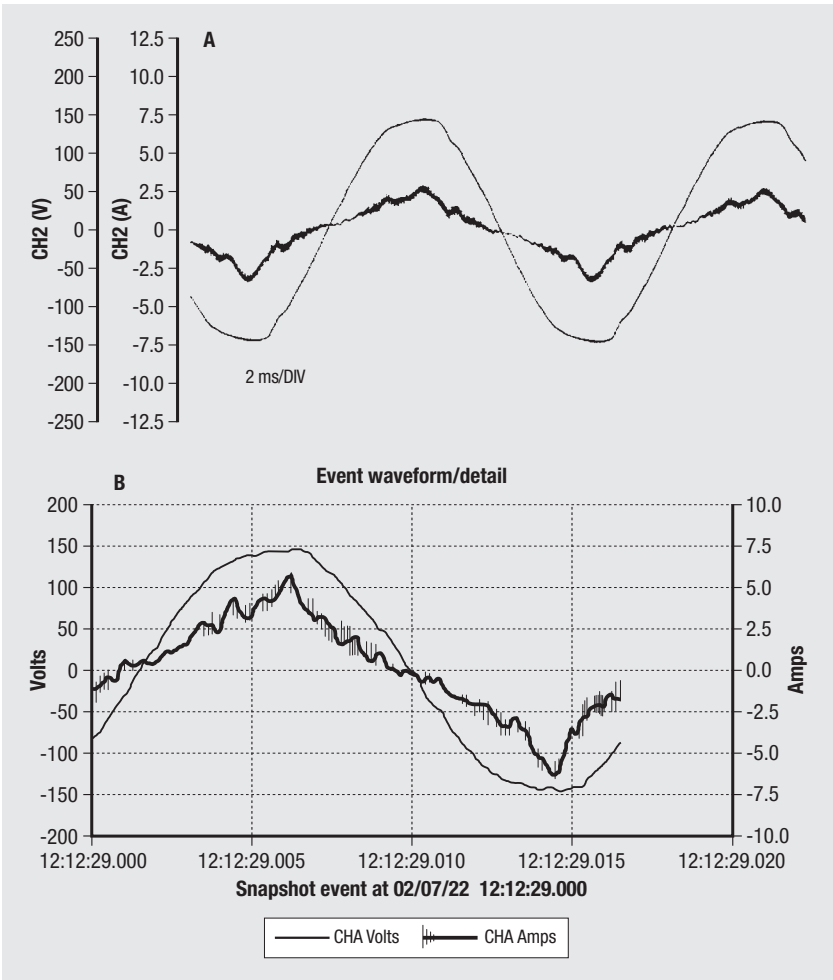


Fig. 4 | An example of recorded voltage and current distortion as measured by two pieces of recording equipment. Waveforms recorded at 50 kHz sampling. A: Voltage. B: Current. Waveforms recorded at 3 kHz sampling.

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