International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Report ITU-R SM.2180
(09/2010)

Impact of industrial, scientific and medical (ISM) equipment on radiocommunication services

SM Series

Spectrum management

International Telecommunication Union

Foreword

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REPORT ITU-R SM.2180

Impact of industrial, scientific and medical (ISM) equipment on radiocommunication services

(2010)

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1 Introduction

The industrial, scientific and medical (ISM) equipment for non-communications applications has been extensively used for various purposes, i.e., drying, melting, heating, welding, thawing, cooking, tempering, soldering, brazing, moulding, imaging, and so on.

Recently, ITU-R developed the Recommendation ITU-R SM.1056 regarding the protection of radio services from the emission radiated by the ISM equipment. The emission limits for ISM equipment recommended by ITU-R has reference to the limits of the International Special Committee on Radio Interference (CISPR) Publication 11. It is known that the limits of CISPR 11 are based on the interference model provided in CISPR 16-4-4.

It is expected that both ISM equipment and radio transceivers are used in close proximity with each other since the number of these RF devices is on the increase. Thus, there is a need to examine impact of the ISM equipment on radio services.

2 Definition and frequency bands

This section is concerned with:

1. the definitions of ISM;
2. the frequency bands;
3. interference from ISM equipment as given in the Radio Regulations (RR).

The following is excerpted from the RR regarding the three items:

1. Definition

"**1.15** *industrial, scientific and medical (ISM) applications* (of radio frequency energy): Operation of equipment or appliances designed to generate and use locally radio frequency energy for industrial, scientific, medical, domestic or similar purposes, excluding applications in the field of telecommunications."

2. Frequency bands

"**5.138** The following bands:

6 765-6 795 kHz	(centre frequency 6 780 kHz),
433.05-434.79 MHz	(centre frequency 433.92 MHz) in Region 1 except in the countries mentioned in No. 5.280,
61-61.5 GHz	(centre frequency 61.25 GHz),
122-123 GHz	(centre frequency 122.5 GHz), and
244-246 GHz	(centre frequency 245 GHz).

are designated for industrial, scientific and medical (ISM) applications. The use of these frequency bands for ISM applications shall be subject to special authorization by the administration concerned, in agreement with other administrations whose radiocommunication services might be affected. In applying this provision, administrations shall have due regard to the latest relevant ITU-R Recommendations.

5.280 In Germany, Austria, Bosnia and Herzegovina, Croatia, The Former Yugoslav Republic of Macedonia, Liechtenstein, Montenegro, Portugal, Serbia, Slovenia and Switzerland, the band 433.05-434.79 MHz (centre frequency 433.92 MHz) is designated for industrial, scientific and medical (ISM) applications. Radiocommunication services of these countries operating within this band must accept harmful interference which may be caused by these applications. ISM equipment operating in this band is subject to the provisions of No. **15.13** (WRC-07)".

"**5.150** The following bands:

13 553-13 567 kHz	(centre frequency 13 560 kHz),
26 957-27 283 kHz	(centre frequency 27 120 kHz),
40.66-40.70 MHz	(centre frequency 40.68 MHz),
902-928 MHz	in Region 2 (centre frequency 915 MHz),
2 400-2 500 MHz	(centre frequency 2 450 MHz),
5 725-5 875 MHz	(centre frequency 5 800 MHz), and
24-24.25 GHz	(centre frequency 24.125 GHz)

are also designated for industrial, scientific and medical (ISM) applications. Radiocommunication services operating within these bands must accept harmful interference which may be caused by these applications. ISM equipment operating in these bands is subject to the provisions of No. **15.13**."

3. Interference from ISM equipment

"**15.12** § 8 Administrations shall take all practicable and necessary steps to ensure that the operation of electrical apparatus or installations of any kind, including power and telecommunication distribution networks, but excluding equipment used for industrial, scientific and medical applications, does not cause harmful interference to a radiocommunication service and, in particular, to a radionavigation or any other safety service operating in accordance with the provisions of these Regulations[1].

15.13 § 9 Administrations shall take all practicable and necessary steps to ensure that radiation from equipment used for industrial, scientific and medical applications is minimal and that, outside the bands designated for use by this equipment, radiation from such equipment is at a level that does not cause harmful interference to a radiocommunication service and, in particular, to a radionavigation or any other safety service operating in accordance with the provisions of these Regulations[1]."

3 Applications of ISM equipment

In accordance with Recommendation ITU-R SM.1056, examples of ISM applications are as follows:

Induction heating equipment (below 1 MHz)

– Domestic induction cookers.
– Metal melting.
– Billet heating.
– Tube welding.
– Soldering and brazing.
– Component heating.
– Spot welding.
– Selective surface heat treating of metal parts.
– Semiconductor crystal growing and refining.
– Seam bonding of auto body surfaces.
– Package sealing.
– Heating strip steel for galvanizing, annealing and paint drying.

[1] **15.12.1** and **15.13.1** In this matter, administrations should be guided by the latest relevant ITU-R Recommendations.

RF dielectric heating equipment (1-100 MHz)

– Veneer and lumber drying.
– Textile drying.
– Fibreglass drying.
– Paper and paper coating drying.
– Plastic pre-heating.
– Plastic welding and moulding.
– Food post baking and drying.
– Meat and fish thawing.
– Foundry core drying.
– Glue drying.
– Film drying.
– Adhesive curing.
– Material preheating.

Medical equipment

– Short-wave and microwave diathermy and hyperthermia equipment.
– Electrical surgical units (ESU).
– Magnetic resonance imaging (MRI).
– Ultrasonic diagnostic imaging.

Microwave equipment (above 900 MHz)

– Domestic and commercial microwave ovens.
– Food tempering, thawing and cooking.
– UV paint and coating curing.
– Rubber vulcanization.
– Pharmaceutical processing.

Miscellaneous equipment

– RF excited arc welders.
– Spark erosion equipment.

Laboratory and scientific equipment

– Signal generators.
– Measuring receivers.
– Frequency counters.
– Flow meters.
– Spectrum analysers.
– Weighing machines.
– Chemical analysis machines.
– Electronic microscopes.
– Switched mode power supplies (not incorporated in an equipment).

Table 1 shows various applications of ISM equipment by operating frequency.

TABLE 1

Example applications of ISM equipment

Frequency (MHz)	Applications
Below 0.15	Industrial induction heating (welding and melting of metals) Ultrasonic cleaning (15-30 kHz) Medical applications (ultrasonic diagnostic imaging)
0.15-1	Induction heating (heat treating, package sealing, welding and melting of metals) Ultrasonic medical diagnostics
1-10	Surgical diathermy (1-10 MHz dampened wave oscillator) Wood gluing and wood curing (3.2 and 6.5 MHz) Valve induction generators production of semi-conductor material RF arc stabilized welding (1-10 MHz dampened wave oscillator)
10-100	Dielectric heating (the majority operate on frequencies in the ISM bands at 13.56, 27.12 and 40.68 MHz, but many also operate on frequencies outside the ISM bands): – Ceramics – Foundry core drying – Textile drying – Business products (books, paper, gluing and drying) – Food (post baking, meat and fish thawing) – Solvent drying – Wood drying and gluing (veneer and lumber drying) – General dielectric drying – Plastic heating (die sealing and plastic embossing) Medical applications: – Medical diathermy (27 MHz) – Magnetic resonance imaging (10-100 MHz in large shielded rooms)
100-1 000	Food processing (915 MHz) Medical applications (433 MHz) RF plasma generators Rubber vulcanization (915 MHz)
Above 1 000	RF plasma generators Domestic microwave ovens (2 450 MHz) Commercial microwave ovens (2 450 MHz) Rubber vulcanization (2 450 MHz) RF excited ultraviolet curing

4 Characteristics of radiation

In general, the radiation characteristics of ISM equipment depend on operating frequency, waveform of RF source, structure of radiator, surrounding structure of radiator, etc. Also, the radiation characteristics depend on distance from ISM equipment. Using the conventional antenna theory, the space surrounding a radiator is subdivided into three regions:

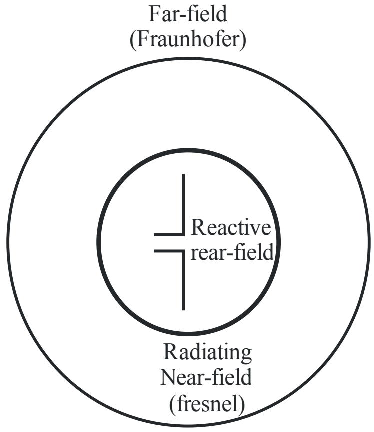
a) reactive near-field;

b) radiating near-field (Fresnel);

c) far-field (Fraunhofer) regions as shown in Fig. 1. Therefore, the radiation characteristics impacting on radiocommunication devices may be different according to the distance between radiators and victims.

FIGURE 1

Field regions of an antenna



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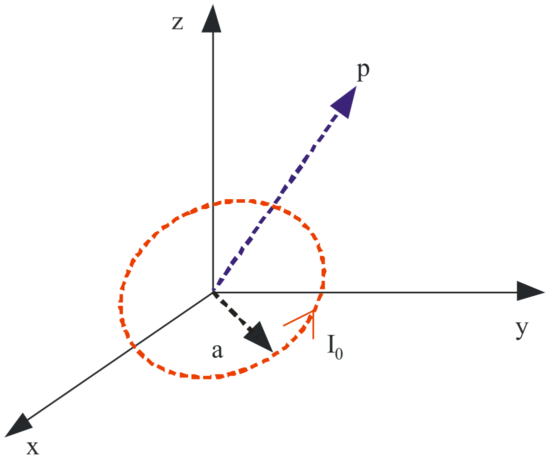
4.1 Induction heating

Induction heating is a process which is used to bond, harden, or soften metals or other conductive materials with the application of the transformer theory. When an alternating electrical current is applied to the primary of a transformer, an alternating magnetic field is created. According to Faraday's Law, if the secondary of the transformer is located within the magnetic field, an electric current will be induced, which is called an eddy current. In basic induction heating equipment, the coil serves as the transformer primary and the target conductor to be heated becomes a short circuit secondary.

Since the shape of the induction heating coil is similar to a circular loop antenna, the radiation characteristics of induction heating coil are also similar to those of a circular loop antenna. Especially, since the operating frequency for induction heating is lower than 1 MHz, the wavelength is greater than 300 m, which is very large compared with the radius of induction heating coil. Therefore, the induction heating coil can be considered as a small circular loop antenna.

FIGURE 2

Geometry for circular loop antenna



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When a radiocommunication system locates near the induction heating coil (kr << 1), the predominant electromagnetic fields to influence the device can be approximated as:

$$H_r = \frac{a^2 I_0 \cos\theta}{2r^3} e^{-jkr} \tag{1}$$

$$H_\theta = \frac{a^2 I_0 \sin\theta}{4r^3} e^{-jkr} \tag{2}$$

$$E_\phi = -j \frac{ka^2 I_0 \sin\theta}{4r^2} e^{-jkr} \tag{3}$$

$$E_\phi = E_r = E_\theta = 0 \tag{4}$$

where a is the radius of induction heating coil, k is the wave number, and r is the measurement distance.

The two magnetic fields are in time-phase. However, they are in time quadrature with that of the electric field. Therefore, there is no time-average power flow associated with them. Also, as $r \rightarrow 0$ the strength of the magnetic field is extremely more dominant than that of the electric field. Therefore, equations (1)-(4) are referred to the quasi-stationary magnetic fields.

When measurement position is away from the induction heating system (kr >> 1), the predominant electromagnetic fields can be approximated as:

$$H_\theta = -\frac{(ka)^2 I_0 \sin\theta}{4r} e^{-jkr} \tag{5}$$

$$E_\phi = \eta \frac{(ka)^2 I_0 \sin\theta}{4r} e^{-jkr} \tag{6}$$

$$E_r = H_\phi = E_r = E_\theta = 0 \tag{7}$$

The electric and magnetic fields are in time-phase and inversely proportional to r. The electric and magnetic fields of the small loop in the far-field region are perpendicular to each other and transverse to the direction of propagation. They form a uniform spherical plane wave whose wave impedance is equal to the intrinsic impedance of the medium.

4.2 Dielectric heating

Dielectric heating equipment is to heat targeted dielectric material such as food, textile, lumber, etc. This is accomplished by using microwave radiation to heat polarized molecules within dielectric materials. Dielectric heating equipment consists of a RF power generator such as magnetron, a cavity or chamber, a waveguide, and a RF power controller. In general, the cavity is composed of metal plates and the microwaves produced by magnetron are reflected within the metal wall of the cavity where they are absorbed by dielectrics.

If the dielectric heating equipment is totally enclosed in a metal structure, no radiation is supposed to be emitted from the equipment. Since dielectric materials are placed through a door in the cavity, microwave leakage occurs through the small gap caused by the opening and closing of the door, which serves as aperture antennas. Thus, the radiation characteristics of dielectric heating equipment are similar to those of aperture antennas.

For example, wavelength of microwaves for dielectric heating equipment is around 10 cm~30 m. Domestic microwave ovens use 2.45 GHz and its wavelength is about 12.2 cm. Since this wavelength is not greater than the dimension of the equipment, the aperture size or length becomes comparable to wavelength. The radiation emitted from the dielectric heating equipment may act as the radiation from a phased array antenna.

4.3 Medical applications

Magnetic resonance imaging (MRI), or nuclear magnetic resonance imaging (NMRI), is primarily a medical imaging technique most commonly used in radiology to visualize the internal structure and function of the body. Unlike computed tomography (CT), it uses no ionizing radiation, but uses a powerful magnetic field to align the nuclear magnetization of (usually) hydrogen atoms in water in the body. Radio frequency (RF) fields are used to systematically alter the alignment of this magnetization, causing the hydrogen nuclei to produce a rotating magnetic field detectable by the scanner. Usually, MRI system is installed in a large shielding room to protect outer electromagnetic fields and also emission of RF field outside.

Since the RF coil in MRI forms a curved rectangular loop, the radiation characteristics are similar to a loop antenna. Wavelength of RF signal for MRI is around 3 m~30 m and comparable to the size of RF coil. Therefore, the radiation characteristics are similar to those of a general loop antenna.

The shielding room where MRI locates can be considered as a cavity with small gaps and cables for communication and power supply. The RF coil in MRI becomes a source to excite the cavity and the radiation outside the shielding room occurs through the small gaps and cables. Therefore, the radiation characteristics of MRI are similar to an aperture antenna and a wire antenna.

5 Analysis of potential interference

This section covers:

1. CISPR interference models;
2. CISPR 11 limits;
3. results from some field measurement of radiation.

5.1 CISPR interference models

This section outlines the probabilistic interference model developed by CISPR in order to protect radiocommunication receivers in close proximity to ISM devices. CISPR 16-4-4 provides two models for 1 GHz below or above to determine the limits of radiations emitted by ISM devices by using probability theory. These CISPR models are useful tools for evaluating the impact of ISM devices on the radio services.

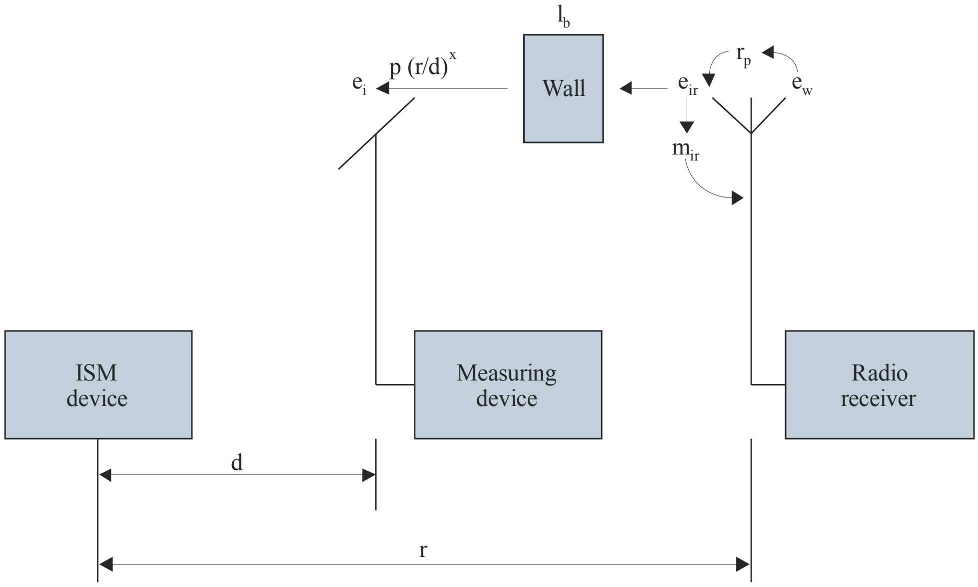
5.1.1 Basic model

The CISPR models are based on the statistical approach. Figure 3 illustrates the basic CISPR model to determine radiation limits for ISM devices. In Fig. 3, e_w is the wanted signal field strength to be protected at a distance of r m in the position of the victim receiver antenna; e_{ir} is the permissible interference field strength in the position of the victim receiver antenna and it is computed by $e_{ir} = e_w/r_p$, here r_p is protection ratio; m_{ir} is the factor for polarization match between polarization of

e_{ir} and polarization of the victim receiver antenna; l_b is the screening factor of buildings or other obstacles; d is the distance between the measuring device and the ISM device; x is the wave propagation coefficient.

FIGURE 3

Block of CISPR model for the calculation of limit of ISM device



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Using these parameters, regulated disturbance field strength for the sources of disturbance at a distance of d, denoted by e_i, is computed as:

$$e_i = p\,[(e_w/r_p)\,m_{ir}\,l_b\,(r/d)^x] \tag{8}$$

where:

p is the complex statistical probability factor, which is computed by the product of $p_1 \bullet p_2 \bullet p_3 \bullet p_4 \bullet p_5 \bullet p_6 \bullet p_7 \bullet p_8 \bullet p_9 \bullet p_{10}$ as follows:

p_1: the probability that the major lobe of the radiation is in the direction of the victim receiver;

p_2: the probability of directional receiving aerials having maximum pick-up in the direction of the disturbing source;

p_3: the probability that the victim receiver is stationary;

p_4: the probability of equipment generating a disturbing signal on a critical frequency;

p_5: the probability that the relevant harmonic is below a limit value;

p_6: the probability that the type of disturbing signal being generated will produce a significant effect in the receiving system;

p_7: the probability of coincident operation of the disturbing source and the receiving system;

p_8: the probability of the disturbing source being within the distance at which interference is likely to occur;

p_9: the probability of coincidence that the value of radiation at the edge of service area for the protected service just meets the limit for the RF disturbance; and

p_{10}: the probability that buildings provide attenuation.

Expressed in logarithmic quantities, equation (8) can be rewritten as:

$$E_i = P + E_w - R_p + M_{ir} + L_b + x \bullet 20 \log(r/d) \tag{9}$$

5.1.2 CISPR model for the frequency range below 1 GHz

The value of p is assumed to be 1 for 1 GHz below. The probability of the actual signal-to-interference ratio, R, at the antenna input port of a receiver being greater than the minimum permissible signal-to-interference ratio, R_p, is equal to a predetermined quality of reception, q, as follows:

$$\Pr\{R(m_R,s_R) > R_p\} = q \tag{10}$$

where:

Pr{ }: the probability function

$R(m_R,s_R)$: the actual signal-to-interference ratio as a function of its mean value (m_R) and standard deviation (s_R)

R_p: the minimum permissible signal-to-interference ratio (protection ratio) and the logarithmic quantity of r_p

q: a specified value representing the reliability of communications.

Using the model shown in Fig. 3, the R can be expressed in terms of the wanted signal, the disturbing signal, the propagation losses and the antenna gain as follows:

$$R = E_w(m_w,s_w) + G_w(m_{Gw},s_{Gw}) - [E_i(m_i,s_i) + G_i(m_{Gi}, s_{Gi}) - L_o(m_{Lo},s_{Lo}) - L_b(m_{Lb},s_{Lb}) + M_{ir}(m_{Mir},s_{Mir})] \text{ dB} \tag{11}$$

where:

E_w: the actual field strength of the wanted signal at the position of the radio receiver's antenna as a function of its mean value (m_w) and the standard deviation (s_w)

E_i: the field strength of the disturbance signal at the measurement distance d on a test site as a function of its mean value (m_i) and standard deviation (s_i)

G_w: the actual value of the radio receiver’s antenna gain for the wanted signal as a function of its mean value (m_{Gw}) and standard deviation (s_{Gw})

G_i: the actual value of the radio receiver’s antenna gain for the disturbance signal as a function of its mean value (m_{Gi}) and standard deviation (s_{Gi})

L_o: the actual value of the factor which takes account of the attenuation of the disturbance field strength on its propagation path to the position of the radio receiver's antenna when it is propagated through free space without obstacles as a function of its mean value (m_{Lo}) and standard deviation (s_{Lo}) in relation to the measurement distance d on the test site:

$$L_o = x \bullet 20 \log(r/d)$$

L_b: the actual value of the factor which takes account of the attenuation of the disturbance field strength caused by obstacles in its propagation path as a function of its mean value (m_{Lb}) and standard deviation (s_{Lb}) relative to the value for free-space propagation

M_{ir}: the actual value of the factor for polarization match between the disturbance field strength e_{ir} and the receiving antenna of the victim receiver as a function of its mean value (m_{Mir}) and standard deviation (s_{Mir}). When the receiving antenna polarization matches the polarization of e_{ir}, the absolute value (m_{ir}) equals 1 and it becomes less than 1 in all other cases. Since M_{ir} and the related mean value (m_{Mir}) are used in logarithmic terms, their quantities are equal to or smaller than 0 dB. Thus a negative sign is always given.

If all random variables (RV) in the right-hand side of equation (11) are Gaussian RVs and mutually independent, then the distribution of RV becomes Gaussian with mean (m_R) and standard deviation (s_R) as follows:

$$m_R = m_w + m_{Gw} - m_i - m_{Gi} + m_{Lo} + m_{Lb} - m_{Mir} \tag{12a}$$

$$s_R = (s_w^2 + s_i^2 + s_{Gw}^2 + s_{Gi}^2 + s_{Lo}^2 + s_{Lb}^2 + s_{Mir}^2)^{1/2} \tag{12b}$$

Equation (11) can be rewritten by normalization as follows:

$$P[R(m_R,s_R) > R_p] = F[-(Rp - m_R)/ s_R] = q \tag{13}$$

Here, F[ ] is the distribution function (DF) of Gaussian distribution with mean $m = 0$ and standard deviation $s = 1$. By using the inverse of Gaussian DF, denoted by F^{-1}[ ], the mean of R is obtained by:

$$m_R = R_p + t_q s_R \tag{14}$$

where $t_q = F^{-1}[q]$.

Next, substituting (12a) and (12b) into (14), then after some manipulations, the following result is produced as:

$$m_i = m_w + m_{Gw} - m_{Gi} + m_{Lo} + m_{Lb} - m_{Mir} - R_p - t_a(s_w^2 + s_i^2 + s_{Gw}^2 + s_{Gi}^2 + s_{Lo}^2 + s_{Lb}^2 + s_{Mir}^2)^{1/2} \tag{15}$$

Because the mean of RV E_i shall be below the limit, E_{Limit}, we have:

$$\Pr\{E_i < E_{Limit}\} = F[(E_{Limit} - m_i)/ s_i] = b \tag{16}$$

Applying F^{-1}[ ] to (16), E_{Limit} is expressed as:

$$E_{Limit} = m_i + t_b s_i \tag{17}$$

The t_b is F^{-1}[b]. Here, the m_{Lo} is rewritten as:

$$m_{Lo} = x \bullet 20 \log(r/d) \tag{18}$$

The x is the wave propagation coefficient which determines the actual free-space attenuation rate.

Finally, combining (15), (17) and (18), E_{Limit} is computed as:

$$E_{Limit} = m_w + m_{Gw} - m_{Gi} + x \cdot 20\log(r/d) + m_{Lb} - m_{Mir} - R_p$$

$$+ t_b s_i - t_a(s_w^2 + s_i^2 + s_{Gw}^2 + s_{Gi}^2 + s_{Lo}^2 + s_{Lb}^2 + s_{Mir}^2)^{1/2} \qquad (19)$$

In general, t_a and t_b are assigned by 0.84, respectively, in accordance with Recommendation CISPR 46/1 (see CISPR 16-4-3), to satisfy the condition that 80% of series-produced device should meet the disturbance limit.

Table 2 illustrates a representative example of the limit calculated by using the CISPR model below 1 GHz.

TABLE 2

An example of the limit calculated by CISPR model below 1 GHz

Actual field strength of the wanted signal, E_w		Actual value of the radio receiver's antenna gain for wanted signal, G_W	
Mean value, m_w (dB(μV/m))	Standard deviation, s_w (dB)	Mean value, m_{Gw}(dB)	Standard deviation, s_{Gw} (dB)
16	2	0	0.1
Actual value of the radio receiver's antenna gain for disturbance signal, G_i		Actual value of the factor which takes account of the attenuation of the disturbance field strength, $L_o = x*20*\log_{10}(r/d)$	
Mean value, m_{Gi} (dB)	Standard deviation, s_{Gi} (dB)	Mean value, m_{Lo} (dB)	Standard deviation, s_{Lo} (dB)
0	0.1	16.47817482	0.1
Actual value of the factor which takes account of the attenuation of the disturbance field strength caused by obstacles, L_b		Actual value of the factor for polarization match, $M_{ir\_}$(dB)	
Mean value, m_{Lb} (dB)	Standard deviation, s_{Lb} (dB)	Mean value, m_{Mir} (dB)	Standard deviation, s_{Mir} (dB)
1	0.1	−0.880	0.1
Field strength of the disturbance signal, E_i		Limit for disturbance measured, E_{limit} (dB(μV/m))	
Mean value, m_i (dB(μV/m))	Standard deviation, s_i (dB)		
21.948	0.1	23.7496	

Measurement distance, d(m)	Average distance between disturbance source and the receiving antenna, r(m)
3	20
Exponent which determines the actual free space attenuation rate, x (1 or 1~1.5)	Protection Ratio, R_P (dB)
1	9
$a = Pr\{R \geq Rp\}$, $t_a = F^{-1}(a)$	$b = Pr\{E_i \leq E_{Limit}\}$, $t_b = F^{-1}(b)$
0.84	0.84

5.1.3 CISPR model for the frequency range above 1 GHz

For the frequency range above 1 GHz, seven probabilities or influence factors are considered in CISPR 16-4-4. However, the statistical interference model is obtained by using the similar step in § 5.1.2 as:

$$E_{Limit} = m_w - R_p + m_{P1} + m_{P2} + m_{P3} + m_{P4} + m_{P5} + m_{P6} + m_{P7}$$

$$+ t_b s_i - t_a(s_{P1}^{\ 2} + s_{P2}^{\ 2} + s_{P3}^{\ 2} + s_{P4}^{\ 2} + s_{P5}^{\ 2} + s_{P6}^{\ 2} + s_{P7}^{\ 2})^{1/2} \tag{20}$$

E_{Limit}: the mean value of the permissible disturbance field strength at a specified distance, *d*, from the disturbance source

m_w: the minimum value of the wanted field strength at the edge of the service area of the radio service concerned

R_p: the minimum acceptable value of the signal-to-disturbance ratio (i.e. the protection ratio) at the receiver's antenna port or feeding point

m_{P1}/s_{P1}: the expected mean and standard deviation values that the major lobe of the disturbance field strength is not in the direction of the victim receiver

m_{P2}/s_{P2}: the expected mean and standard deviation values that the directional receiving antenna does not have its maximum pick-up in the direction of disturbance source

m_{P3}/s_{P3}: the expected mean and standard deviation values that a signal to noise ratio of the mobile receiver in a respective radio service area can be improved by keeping a certain distance to the disturbance source

m_{P4}/s_{P4}: the expected mean and standard deviation margins that the disturbance signal is below the limit

m_{P5}/s_{P5}: the expected mean and standard deviation values that the type of disturbance signal generated will produce a significant impact on the receiving system

m_{P6}/s_{P6}: the expected mean and standard deviation values that the disturbance source is located in a distance to the receiving system within which interference is likely to occur

m_{P7}/s_{P7}: the expected mean and standard deviation values that buildings provide a certain degree of additional attenuation.

In CISPR 16-4-4, m_{P5} is computed as:

a) $B_{want} < B_{noise} < B_{meas}$

$$m_{P5} = 10 \log(B_{want}/B_{noise})$$

where:

B_{want}: the bandwidth of the considered radio receiver for the wanted signal

B_{noise}: the bandwidth of the broadband disturbance

B_{meas}: the measurement bandwidth of measuring device.

The relationships are as follows:

b) $B_{meas} < B_{noise} < B_{want}$

$$m_{P5} = 10 \log(B_{noise}/B_{meas})$$

c) $B_{noise} > B_{meas}$ and B_{want}, respectively,

$$m_{P5} = 10 \log(B_{want}/B_{meas})$$

The value of m_{P6} is calculated by x•20 log(r/d) and the exact values of other parameters used in equation (20) are unfortunately not known. We believe that the parameters except for m_{P5} and m_{P6} would be determined by practical experiment and experience.

Table 3 gives a representative example of the limit calculated by using the CISPR model above 1 GHz.

TABLE 3

An example of the limit calculated by CISPR model above 1 GHz

<table>
<tr><td colspan="2">Actual field strength of the wanted signal, (E_W)</td><td colspan="2">Gain of disturbance source, P_1(dB)</td></tr>
<tr><td>Mean value, m_w (dB(μV/m))</td><td>Standard deviation, s_w (dB)</td><td>Mean value, m_{P1} (dB)</td><td>Standard deviation, s_{P1} (dB)</td></tr>
<tr><td>16</td><td>2</td><td>3</td><td>0.1</td></tr>
<tr><td colspan="2">Gain of victim antenna, P_2(dB)</td><td colspan="2">Victim is mobile, P_3(dB)</td></tr>
<tr><td>Mean value, m_{P2} (dB)</td><td>Standard deviation, s_{P2} (dB)</td><td>Mean value, m_{P3} (dB)</td><td>Standard deviation, s_{P3} (dB)</td></tr>
<tr><td>3</td><td>0.1</td><td>5</td><td>0.1</td></tr>
<tr><td colspan="2">Emission below limit, P_4(dB)</td><td colspan="2">Type of emission broadband correction, P_5(dB)</td></tr>
<tr><td>Mean value, m_{P4} (dB)</td><td>Standard deviation, s_{P4} (dB)</td><td>Mean value, m_{P5} (dB)</td><td>Standard deviation, s_{P5} (dB)</td></tr>
<tr><td>1</td><td>0.1</td><td>1.000</td><td>0.1</td></tr>
<tr><td colspan="2">Distance to victim, P_6(dB)</td><td colspan="2">Building attenuation, P_7(dB)</td></tr>
<tr><td>Mean value, m_{P6} (dB)</td><td>Standard deviation, s_{P6} (dB)</td><td>Mean value, m_{P7} (dB)</td><td>Standard deviation, s_{P7} (dB)</td></tr>
<tr><td>16.478</td><td>0.1</td><td>4.000</td><td>0.1</td></tr>
<tr><td colspan="4">Limit for disturbance measured, E_{Limit} (dB(μV/m))
40.3398</td></tr>
</table>

<table>
<tr><td colspan="2">Measurement distance, d(m)</td><td>Average distance between disturbance source and the receiving antenna, r(m)</td></tr>
<tr><td colspan="2">3</td><td>20</td></tr>
<tr><td colspan="2">Exponent which determines the actual free space attenuation rate, x (1 or 1~1.5)</td><td>Protection ratio, R_P(dB)</td></tr>
<tr><td colspan="2">1</td><td>9</td></tr>
<tr><td colspan="2">$a = Pr\ \{R \geq Rp\},\ t_a = F^{-1}(a)$</td><td>$b = Pr\{E_i \leq E_{Limit}\},\ t_b = F^{-1}(b)$</td></tr>
<tr><td colspan="2">0.84</td><td>0.84</td></tr>
<tr><td colspan="3">s_i</td></tr>
<tr><td colspan="3">0.1</td></tr>
<tr><td colspan="3">B_w, B_n, B_m m_{P5}</td></tr>
<tr><td>$B_w < B_n < B_m$</td><td>$B_m < B_n < B_w$</td><td>$B_m < B_n$ or $B_m < B_n$</td></tr>
<tr><td>10 $\log_{10}(B_w/B_n)$</td><td>10 $\log_{10}(B_n/B_m)$</td><td>10 $\log_{10}(B_w/B_m)$</td></tr>
</table>

* B_w: is bandwidth of the considered radio service for the wanted signal.
B_n: is bandwidth of the broadband disturbance.
B_m: is bandwidth of the measurement receiver.

5.2 Review of CISPR limits

CISPR Publication 11 presents the radiated limit of ISM equipment in terms of the magnitude of the magnetic or electric field vectors. Measurements on the limits are carried out under the specific detection mode of measuring receiver, i.e. peak, quasi-peak, average, and weighted detection. In order to see if these limits are able to protect radio services from ISM equipment, the field strength expressed in (dB(μV/m) is required to be converted to the received power expressed in dBm.

$$P_R(\text{dBm}) = E(\text{dB}(\mu\text{V/m})) + G_R(\text{dBi}) - 20\ \log F(\text{MHz}) - 77.2 \qquad (21)$$

where:

P_R: received power of radio station (dBm)

G_R: the gain of received antenna (dBi)

F: the received frequency of radio station (MHz).

The categorized CISPR 11 limits are composed of a combination of Groups 1, 2 and Classes A, B. Definitions of Groups 1, 2 and Classes A, B can be found in §§ 4.1 and 4.2 of CISPR Publication 11 (Edition 4). Group 1 and Classes A and B are ISM devices that can be placed near radiocommunication stations, however most of ISM devices operating near radiocommunication stations are Group 2 and Class B.

Given that Group 2 and Class B is considered as an environment where ISM equipment can be used near radiocommunication devices, this section covers the limits of this combination.

The following three figures illustrate the radiation limits given in Tables 4, 7, and 8 of CISPR Publication 11 (Edition 4, June 2004), respectively.

FIGURE 4

Magnetic field limits of Group 2 and Class B below 30 MHz
(Measurement distance is 10 m and detection mode is Quasi peak)

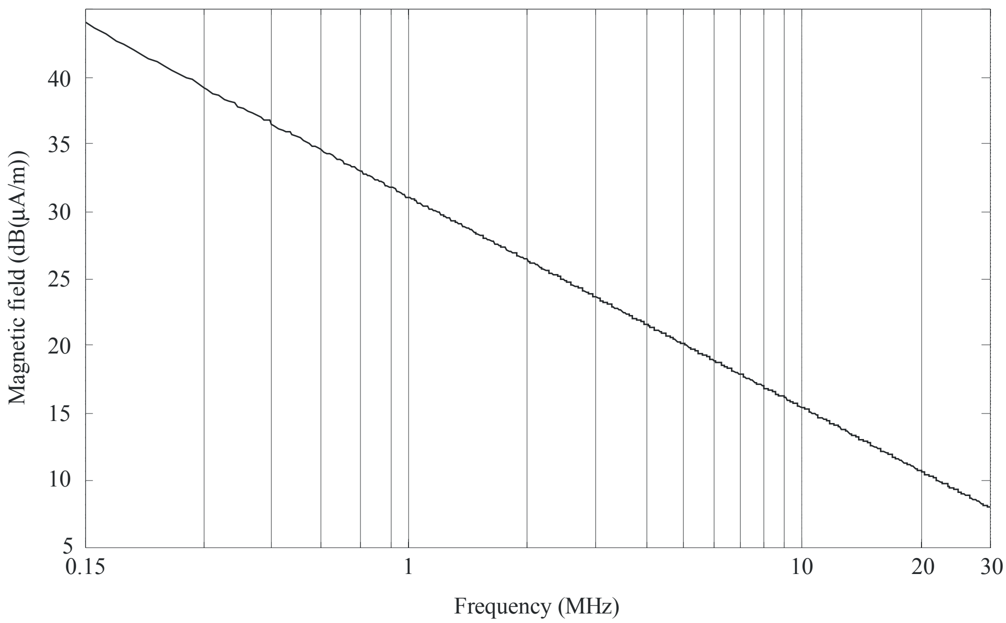

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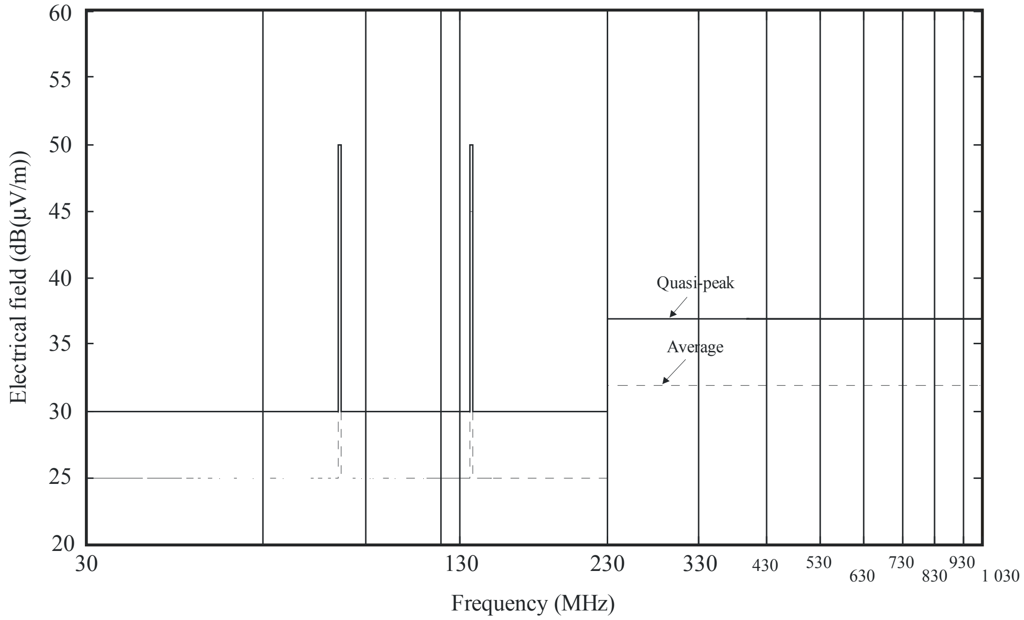
FIGURE 5

Electrical field limits of Group 2 and Class B between 30 MHz and 1 GHz (Measurement distance is 10 m and detection mode is Quasi peak and average for magnetron driven equipment)*



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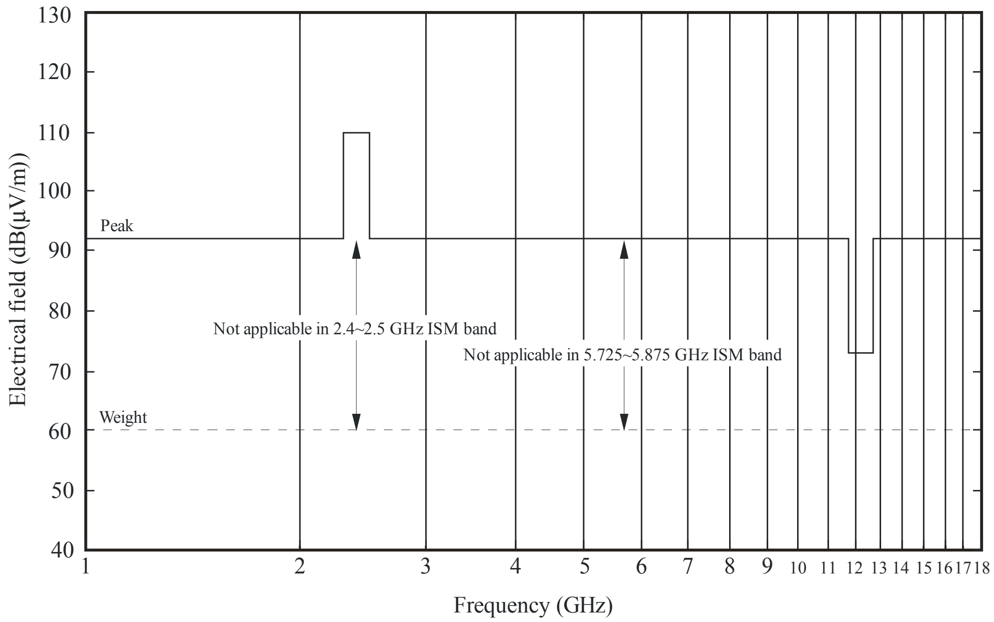
* At the transition, the more stringent limit applies.

FIGURE 6

Electrical field limits of Group 2 and Class B between 1 GHz and 18 GHz (Measurement distance is 3 m and detection mode is Peak*, **)



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* Peak measurement requires resolution bandwidth of 1 MHz and video signal bandwidth higher or equal to 1 MHz.

** Weighted measurements with a resolution bandwidth of 1 MHz and a video bandwidth of 10 Hz.

Figures 7 and 8 present the received power of radio station with antenna gain 0 dBi in application of the conversion formula (20) focusing on conversion on the electrical field limits.

FIGURE 7

Conversion on the electrical field limits of Group 2 and Class B between 30 MHz and 1 GHz

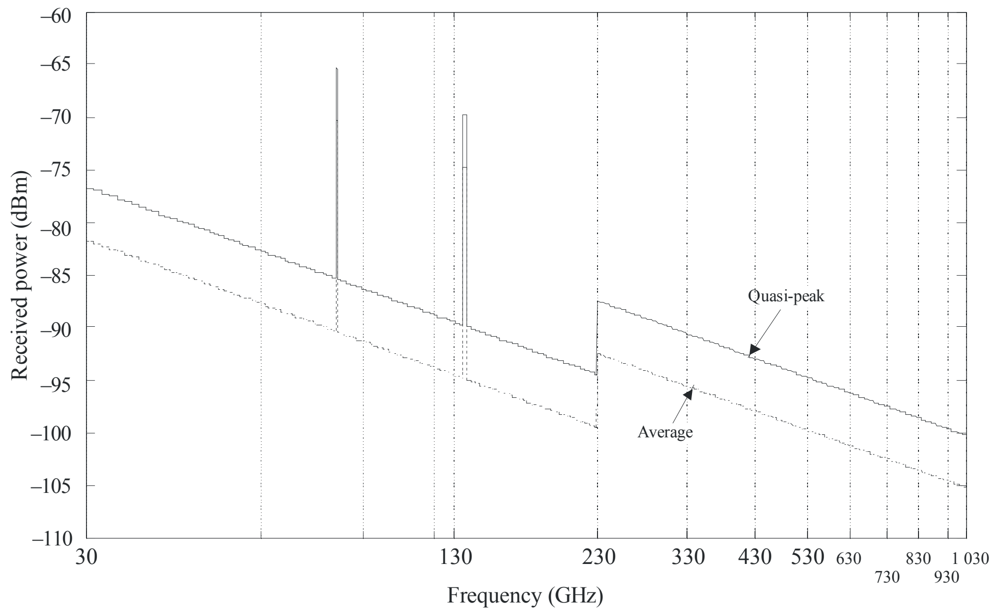

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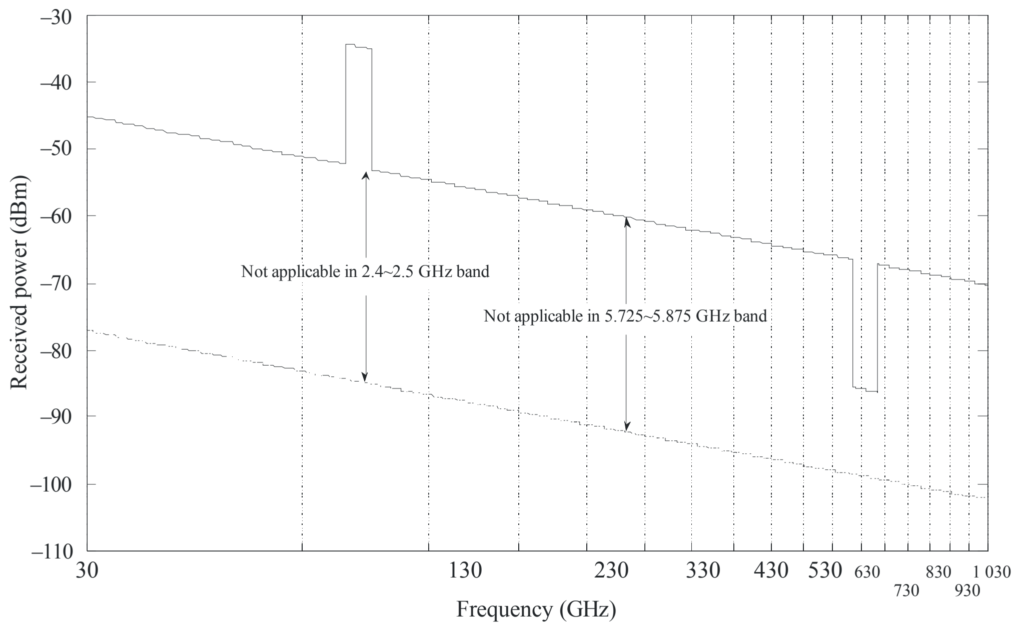
FIGURE 8

Conversion on the electrical field limits of Group 2 and Class B between 1 GHz and 18 GHz



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In Fig. 8, when compared with the other received power applied to 1~18 GHz frequency bands, the received power at 2.3~2.4 GHz is high so that interference on radio service may take place. CISPR publication 11 has a note for the frequency band 2.3-2.4 GHz, indicating that administrations may require more stringent radiation limits than those of CISPR 11 for avoiding harmful interferences to radiocommunication service.

According to the latest papers concerning electromagnetic interference, the present CISPR emission limits have been developed to protect analogue radiocommunication services rather than digital radiocommunication services. The SNR of analogue radiocommunication services is different from that of digital radiocommunication services. With regard to the impact of ISM equipment on the digital radio services, it is required that ITU-R should provide the CISPR with the characteristics and protection criteria of the digital radiocommunication systems. Therefore, it is necessary to review whether the present limits of CISPR Publication 11 make ensure that digital radio receivers are adequately protected or not.

5.3 Characteristics and protection criteria of radiocommunication services

In order to evaluate the performance degradation of radiocommunication services due to the radiation generated by ISM equipment, knowledge of the protection criteria and technical characteristics of potentially affected radiocommunication systems is required. The relevant ITU-R Recommendations and Reports are listed in Attachment A8 of Report ITU-R SM.2057 (Studies related to the impact of devices using ultra wideband technology on radiocommunication services). These lists may not be up-to-date as some of these Recommendations and Reports may have been modified or their statuses have been changed. This attachment also contains technical characteristics and protection criteria of potential victim systems from input contributions and from liaison statements of various ITU-R Working Parties in the study period. These characteristics and criteria are intended to aid interference calculations of devices using ultra wide band technology, however they are also be applicable in the study of emissions of ISM equipments. The responsible ITU-R Working Parties may have developed or adopted different values since then.

In the course of study on the emissions of short range devices, the Working Party 1A received protection criteria, characteristics and service quality objectives for various services from the other Working Parties as follow:

– Recommendation ITU-R SM.1754 – Measurement techniques of ultra-wideband transmissions.
– Recommendation ITU-R SM.1755 – Characteristics of ultra-wideband technology.
– Recommendation ITU-R SM.1756 – Framework for the introduction of devices using ultra-wideband technology.
– Recommendation ITU-R SM.1757 – Impact of devices using ultra-wideband technology on systems operating within radiocommunication services.
– Recommendation ITU-R RS.1346 – Sharing between the meteorological aids service and medical implant communication systems (MICS) operating in the mobile service in the frequency band 401-406 MHz.
– Report ITU-R SM.2057 – Studies related to the impact of devices using ultra-wideband technology on radiocommunication services.
– Recommendation ITU-R M.1739 – Protection criteria for wireless access systems, including radio local area networks, operating in the mobile service in accordance with Resolution 229 (WRC-03) in the bands 5 150-5 250 MHz, 5 250-5 350 MHz and 5 470-5 725 MHz.

– Recommendation ITU-R M.1767 – Protection of land mobile systems from terrestrial digital video and audio broadcasting systems in the VHF and UHF shared bands allocated on a primary basis.
– Recommendation ITU-R M.1823 – Technical and operational characteristics of digital cellular land mobile systems for use in sharing studies.
– Report ITU-R M.2039-1 – Characteristics of terrestrial IMT-2000 systems for frequency sharing/interference analyses, contains some protection requirements like SNR values, receiver reference sensitivities and interference thresholds for the various IMT-2000 systems.
– Recommendation ITU-R BT.1786 – Criterion to assess the impact of interference to the terrestrial broadcasting service (BS).
– Report ITU-R BS.2104 – FM modulator interference to broadcast services.
– WP 4A is developing a set of relevant information including system characteristics and service quality objectives for FSS and BSS in the 3.4-31 GHz range to enable WP 1A to conduct its technical studies and assess the impact of SRDS on FSS and BSS and means to ensure adequate protection of these services (see Attachment of Document 1A/145 for the set of preliminary information).
– Recommendation ITU-R RA.769 – Protection criteria used for radio astronomical measurements.
– Recommendation ITU-R RA.314 – Preferred frequency bands for radio astronomical measurements.
– Recommendation ITU-R RA.517 – Protection of the radio astronomy service from transmitters operating in adjacent bands.
– Recommendation ITU-R RA.611 – Protection of the radio astronomy service from spurious emissions.
– Recommendation ITU-R RA.1031 – Protection of the radio astronomy service in frequency bands shared with other services.
– Recommendation ITU-R RA.1237 – Protection of the radio astronomy service from unwanted emissions resulting from applications of wideband digital modulation.
– Recommendation ITU-R S.1432 – Apportionment of the allowable error performance degradations to fixed-satellite service (FSS) hypothetical reference digital paths arising from time invariant interference for systems operating below 30 GHz.

5.4 Field measurement of radiation

This section covers the results of ISM radiation measured in:

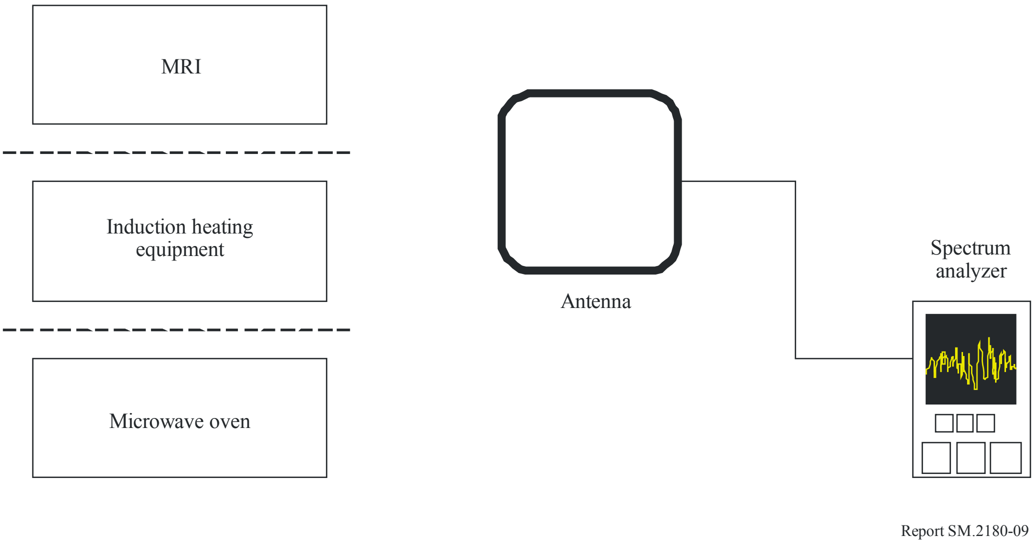
1. MRI;
2. induction heating equipment;
3. microwave oven.

To examine the radiation power leaked from ISM equipment, the spectrum measurements were made on the condition where MRI and induction heating equipment were turned off/on and where microwave oven was measured in the absence/presence of 1 000 ml of water as load.

The measurement setup as shown in Fig. 9 is used at hospitals and industrial factories to measure the ISM signal. Since the objective of this measurement is to observe only the received ISM signal at an actual circumstance being used in a simple manner, the measurement method employed cannot be applied to certifying the ISM equipment. It is, however, known that there are several measuring methods available for the certification of ISM equipment as given in FCC OST MP-5, EN55011, and so on[1]. It should be noted that a measurement method must be followed to obtain measured results that can be validated. A test report is highly recommended to validate the measurements.

FIGURE 9

Measurement configuration



A loop antenna, an active directional antenna, and a horn antenna are used for the measurement of radiations of MRI, induction heating equipment, and microwave oven, respectively.

5.4.1 Magnetic resonance imaging

As seen in the below pictures taken at a hospital using an MRI device, measurements were made with a loop antenna in vertical and horizontal polarization modes, respectively, with the distance between MRI and a measuring device being about 3 m.

With the measurement spectrums in Attachment 1, results measured at 5 hospitals are as follows:

Table 4 shows the frequencies where the strongest ISM emission takes place and the corresponding measured emission values at each hospital. The measurements were made with a loop antenna at 3 m distance except one site. The strongest ISM emission in the presence of the leakage signals from MRI rooms is about −34 dBm at 63.8 MHz. This ISM signal may cause harmful interference to the broadcasting service at this frequency or to other radiocommunication services with high sensitivity using 63.8 MHz frequency[2]. Further investigations should be carried out to determine the impact on radiocommunication services inside hospitals as each service has its own protection criteria.

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[1] See reference [16].

[2] These measurements were performed in situ whereas CISPR 11 specifies the radiated emissions on a test site. Therefore, these values cannot be directly compared with the radiated limits in CISPR 11.

TABLE 4

Measurement results of MRI at 3 m* (resolution bandwidth of 100 kHz)

	OFF		ON	
	Frequency (MHz)	**Measured value (dBm)**	**Frequency (MHz)**	**Measured value (dBm)**
MRI A	127.717	−70.40	127.782	−48.38
MRI B	63.85	−78.49	63.848	−34.36
MRI C	63.74	−70.15	63.83	−61.91
MRI D	62.50	−80.51	63.85	−51.69
MRI E(1)	63.76	−73.68	63.86	−53.82

(1) Measurement distance for MRI E is 10 m.

5.4.2 Induction heating equipment

Figure 9 shows examples of measurement of the radiated emission generated by the induction heating equipment with 50 kW and 3 kW power at 3 m distance.

The emission values −43.58 dBm and 9.84 dBm in Table 5 shows that the leakage signal from the induction heating equipment is likely to disturb radio service because the sensitivities of many radio receivers generally range from −100 dBm to −80 dBm.

TABLE 5

Measurement results of induction heating equipment at 3m distance (resolution bandwidth of 100 kHz)

	OFF		ON	
	Frequency (MHz)	**Measured value (dBm)**	**Frequency (MHz)**	**Measured value (dBm)**
Induction heating equipment A	39.6	−74.03	20.7	−43.58
Induction heating equipment B	75.6	−56.37	25.23	9.84

The measured radio spectrums are presented in detail in Attachment 2.

5.4.3 Microwave oven

Figure 10 shows a radio spectrum of microwave oven with 1 250 W power in the absence/presence of 1 000 ml of water as load. The measurements were made with a horn antenna at 3 m distance in a semi-anechoic chamber. It is observed in Fig. 10 that the side lobes of two spectrums are different. It is noted that the microwave oven with the water load complies with the radiation limits of CISPR Publication 11.

FIGURE 10

Measurement spectrum of microwave oven

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Observed near 2.35 GHz in Fig. 10, the value −35 dBm may cause harmful interference to IMT systems using 2.3~2.4 GHz frequency. A report was also released by NTIA[3], which provides the characteristics of radio spectrums generated by microwave ovens outside of 2.4 ~ 2.5 GHz ISM frequency band. Given the radio spectrum measurements of NTIA, interference may take place between microwave oven and the IMT systems using 2.3 ~ 2.4 GHz and 2.5 ~ 2.69 GHz frequencies. It is therefore needed to further study the establishment of stringent limits on microwave ovens to protect the IMT systems from the radiation emissions of microwave ovens.

6 Conclusion

The report introduces the interference analysis method and the radiation limits of ISM equipment developed by CISPR. Since the emission limits of CISPR Publication 11 are derived on the basis of the SNRs of radiocommunication services, these limits have been playing an important role for administrations to protect radiocommunication service from the radiation produced by ISM equipment successfully.

Yet, according to the latest papers concerning electromagnetic interference, the present CISPR emission limits have been developed to protect analogue radiocommunication services rather than digital radiocommunication services. The SNR of analogue radiocommunication services is different from that of digital radiocommunication services. Thus, the ITU-R is invited to provide CISPR with the characteristics and protection criteria of the digital radiocommunication systems.

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3 See reference [15].

References

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Attachment 1

Measurement results of MRI

This attachment presents the radio spectrums of the five MRI signals when they are turned off and on.

FIGURE 11

Example of a measurement of the emission of MRI signal

a) Vertical polarization

b) Horizontal polarization

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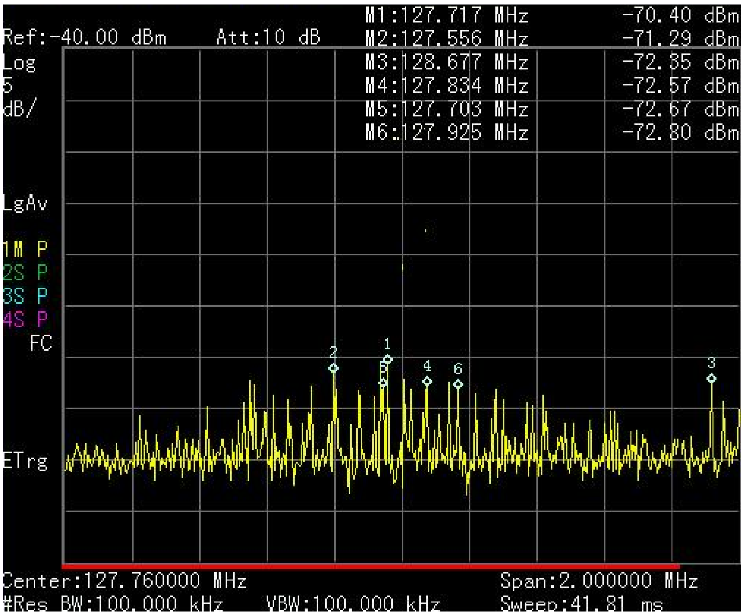
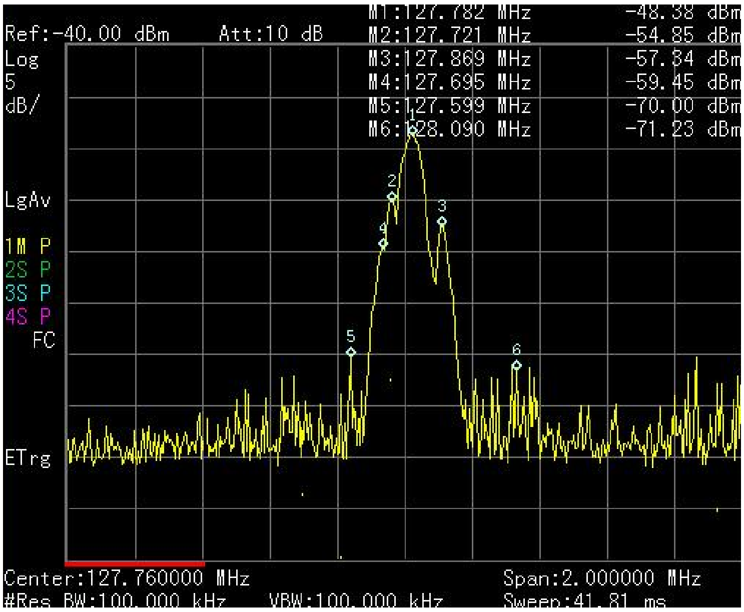
FIGURE 12

Radio spectrum of MRI equipment A



a) Turned off



b) Turned on

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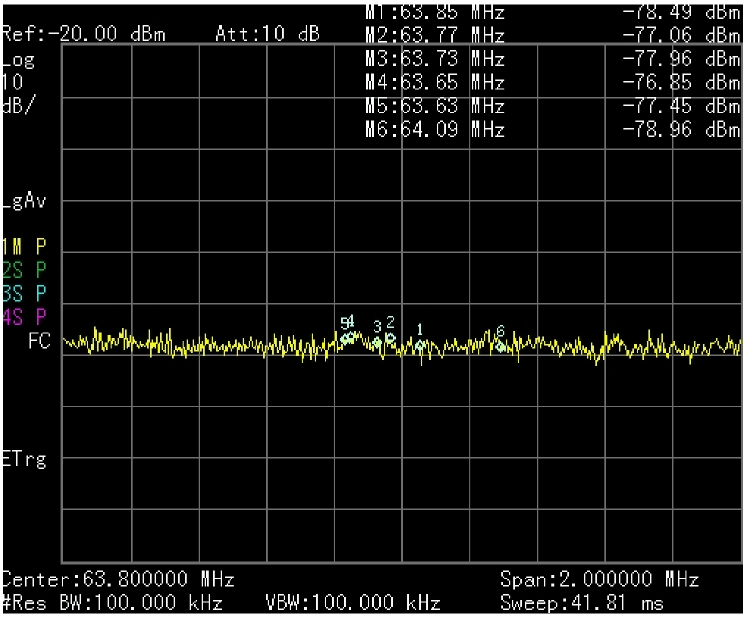
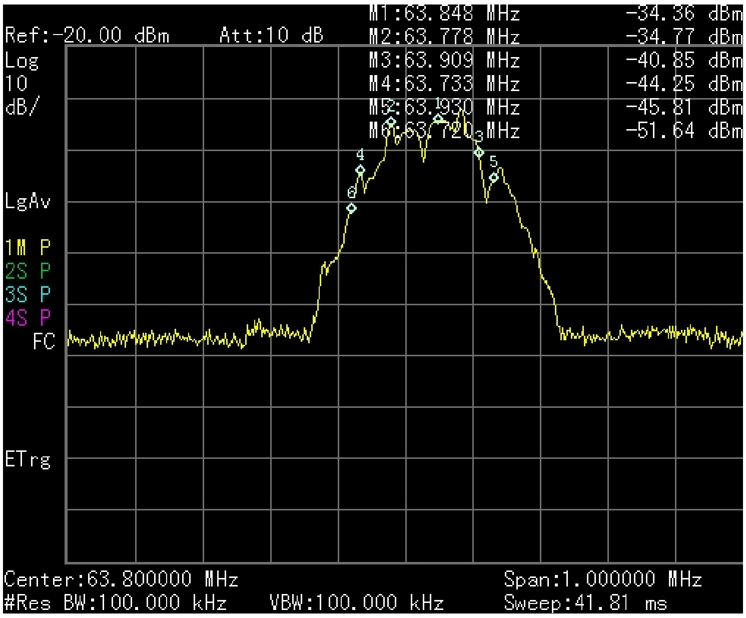
FIGURE 13

Radio spectrum of MRI equipment B



a) Turned off



b) Turned on

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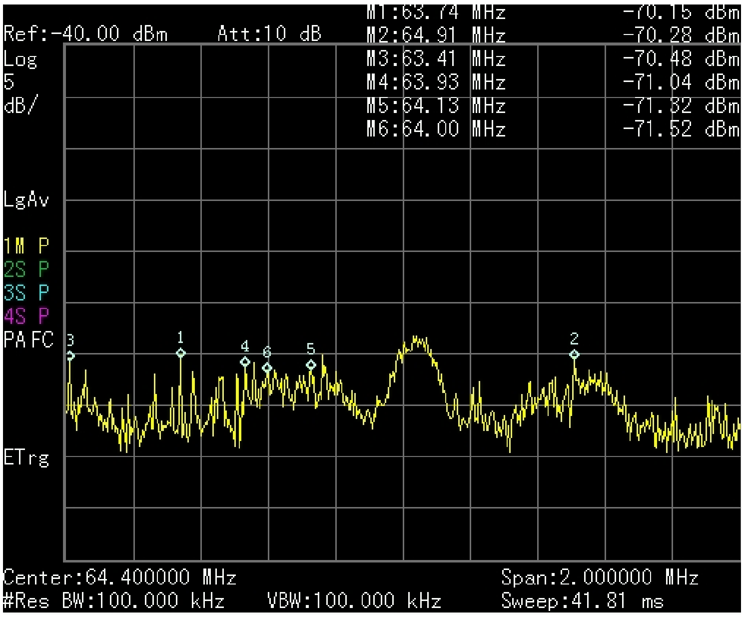
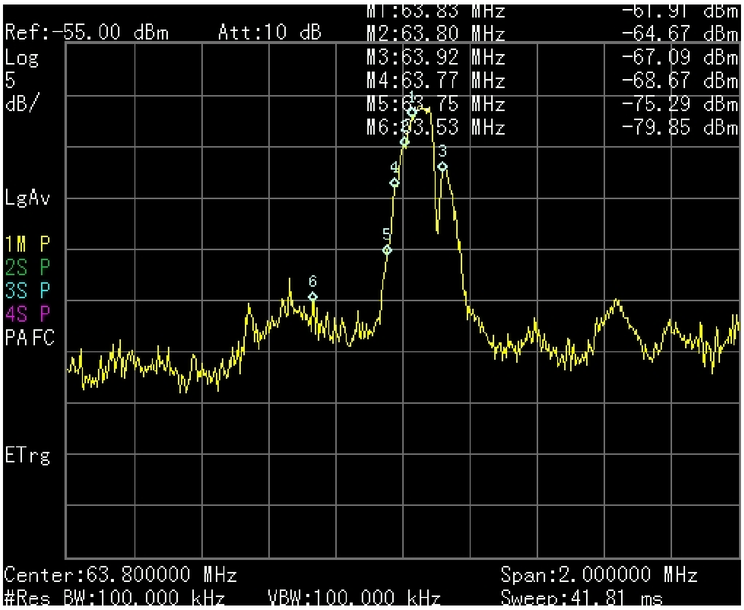
FIGURE 14

Radio spectrum of MRI equipment C



a) Turned off



b) Turned on

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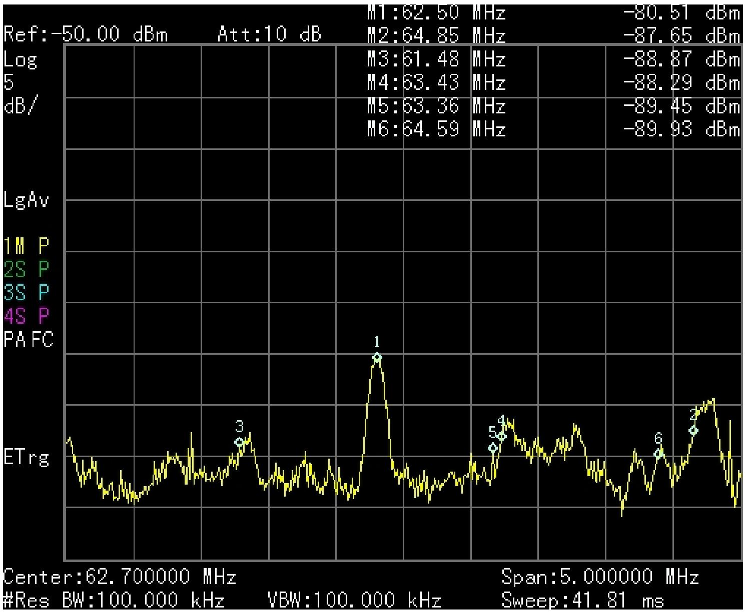
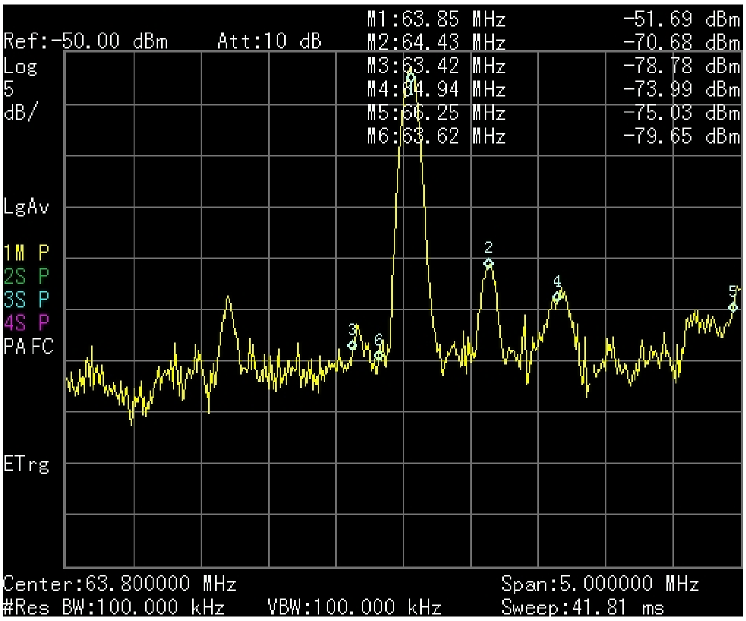
FIGURE 15

Radio spectrum of MRI equipment D



a) Turned off



b) Turned on

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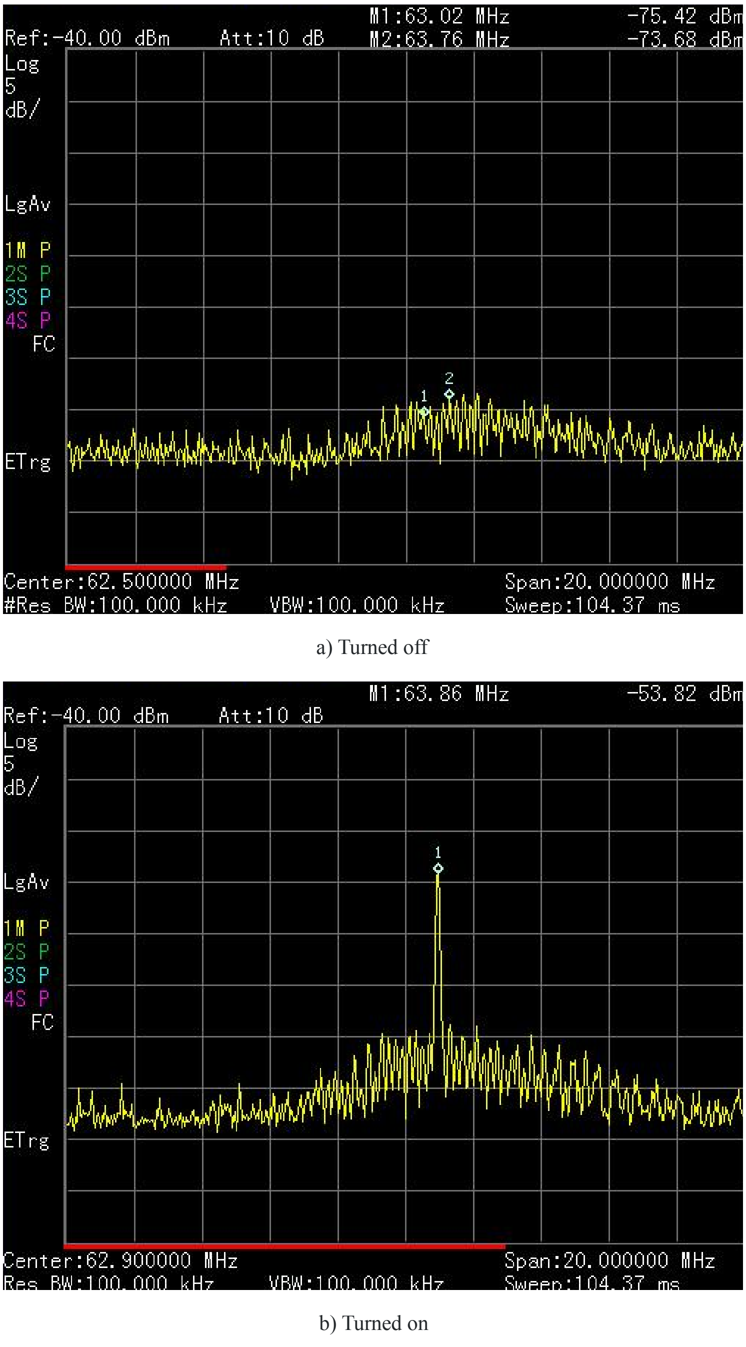
FIGURE 16

Radio spectrum of MRI equipment E



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Attachment 2

Measurement results of induction heating equipment

This attachment provides the radio spectrum of two induction heating equipment when they are turned off and on.

FIGURE 17

Examples of induction heating equipment

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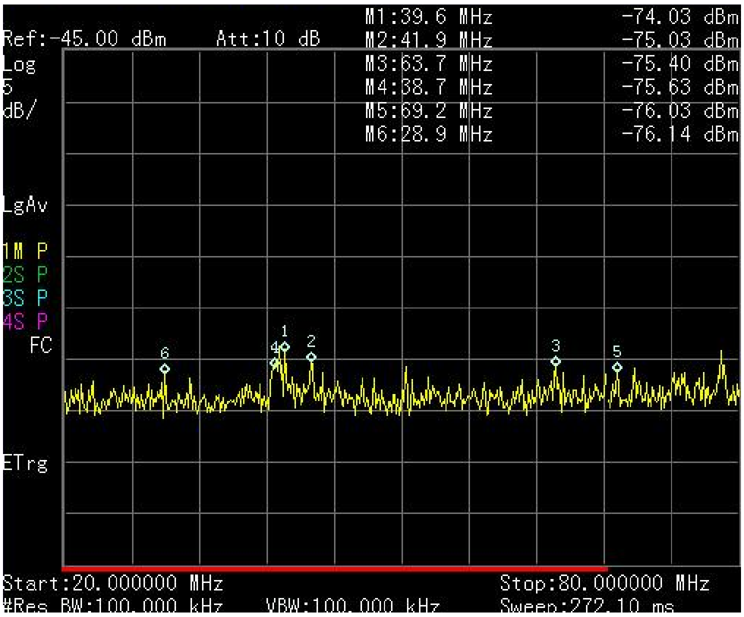
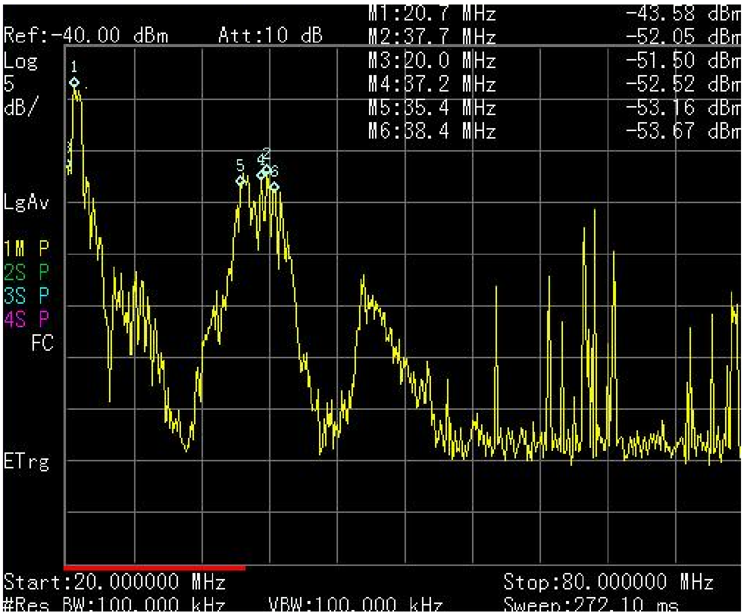
FIGURE 18

Radio spectrum of induction heating equipment A



a) Turned off



b) Turned on

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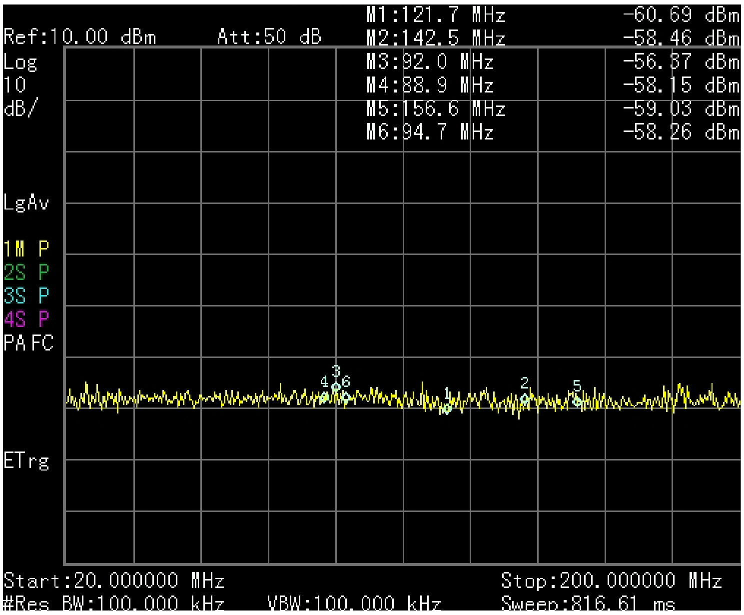
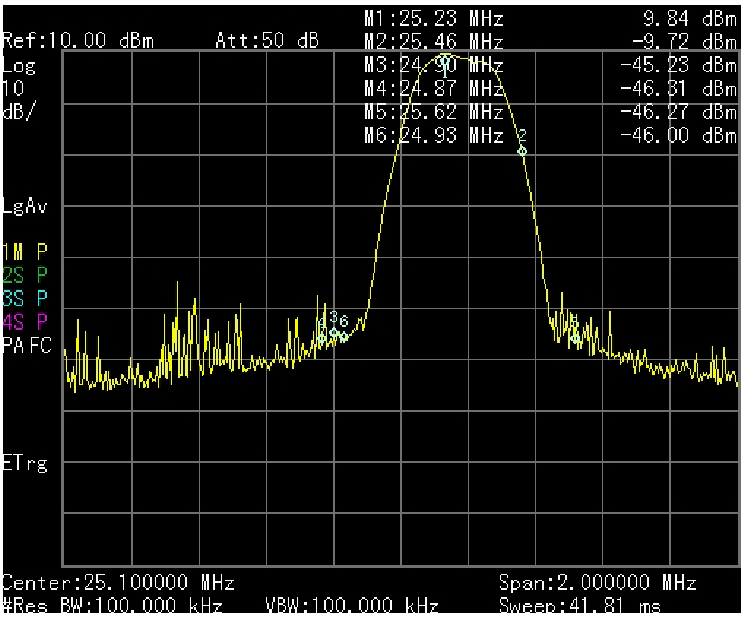
FIGURE 19

Radio spectrum of induction heating equipment B



a) Turned off



b) Turned on

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