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(Revision of IEEE Std 139-1952)

IEEE Recommended Practice for the Measurement of Radio Frequency Emission from Industrial, Scientific, and Medical (ISM) Equipment Installed on User's Premises

Sponsor

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Foreword

(This Foreword is not a part of ANSI/IEEE Std 139-1988 IEEE Recommended Practice for the Measurement of Radio Frequency Emission From Industrial, Scientific, and Medical (ISM) Equipment Installed on User's Premises.)

This is a major revision of IEEE Std 139-1952 . It recommends procedures for measuring the radio frequency (rf) energy emitted by industrial, scientific, and medical (ISM) equipment installed, ready for use, in the user's plant or laboratory.

The reader is assumed to be skilled in measuring radio frequency electromagnetic fields and familiar with the measurement equipment used.

This standard recommends techniques for measuring emissions from ISM equipment installed, ready for use, or actually being used, on user's premises; it is not intended for testing equipment on a test site, or as it comes off a production line. While there may be similarities in the measurement of emissions under these two conditions, there are major differences also. Some differences are:

1) The ISM equipment measured on user's premises may have been modified. These modifications may not always have the careful quality control that it is reasonable to expect from new equipment manufactured on a production line. Therefore, this standard provides more testing for prototype verification of compliance than might be considered necessary in a production environment. Hence the recommendation that all equipment be inspected, and its emission spectrum checked, with the “prototype” machines being subjected to more thorough emission tests.
2) The emission from installed ISM equipment may interact with emissions from other rf equipment installed nearby, generating spurious emissions at heterodyne, harmonically related, and other frequencies. The emission at these frequencies must also be checked.

At the time this standard was approved, the Working Group on ISM Equipment Emission Measurements had the following membership:

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An American National Standard

IEEE Recommended Practice for the Measurement of Radio Frequency Emission from Industrial, Scientific, and Medical (ISM) Equipment Installed on User's Premises

1. Scope

This document describes equipment inspection and radio frequency (rf) electromagnetic field measurement procedures for evaluation of rf industrial, scientific, and medical (ISM) equipment installed in the user's facility. The term, “ISM equipment,” as used here, includes equipment that generates rf energy for purposes other than radio communications, to cause physical, chemical, or biological changes; for example, industrial heaters (dielectric and induction), medical diathermy, ultrasonic equipment, rf plasma devices, and rf stabilized welders. These procedures are designed to help ensure that the equipment does not interfere with radio communications, navigation, and other essential radio services. The engineer responsible for the measurements should take all reasonable precautions to ensure that the maximum emission from the ISM equipment under test (EUT) has been measured.

Radio frequency field-strength measurements of installed ISM equipment may be required if any of the following conditions exist:

1) The emission from the EUT was not measured by the manufacturer.
2) Because of its size or special operating conditions, the EUT could not be tested before installation.
3) Installed ISM equipment is suspected of causing interference.
4) ISM equipment has been modified in a way that could affect itsrf emissions.
5) As the equipment ages, there is a question about its continued compliance.
6) There is a question about the safety to nearby personnel because of the emissions from the equipment.

Measurements should be made under the direction of an engineer skilled in making and interpreting rf field-strength measurements. These measurements are made after the equipment is installed and ready for use at its place of use, and after it has been inspected as described in 2.2. The measurement report should generally be kept on file for at least three years after new measurements are made or after the equipment is no longer in use.

There are significant differences between the “open field” or anechoic chamber measurements common in electromagnetic compatibility (EMC) and electromagnetic interference (EMI) work and the on-site measurements of installed ISM equipment. Some of these differences are described below.

1) The measurement conditions are usually more difficult because of crowded measurement locations, reflections from surrounding walls and equipment, and signals from other sources.

2) It is reasonable to take advantage of the shielding provided by walls and other equipment located between the ISM Equipment Under Test (EUT) and the location at which field-strength information is required. While the effect of a single wall may be small, the total effect of other equipment and building structures may be significant. In any case, it is not necessary to make measurements in a way which eliminates the benefits of this shielding. Some equipment is designed to be operated in a shielded enclosure, either because of its own sensitivity to outside interference, or because of its emission characteristics. When measuring the emission from this equipment, take advantage of the attenuation of the enclosure by making the measurements outside the enclosure, with the equipment in its normal operating position.
3) Since the measurement equipment is disconnected, moved, and reconnected many times during a set of measurements, its calibration should be checked frequently.
4) ISM equipment may often be grouped for field-strength measurements, taking one set of measurements for the entire group.
5) Electromagnetic-emission measurements of installed ISM equipment are usually significantly less accurate than laboratory(open field or test chamber) measurements because of lack of control of the measurement environment. The engineer responsible for the measurements should ensure, to the extent practical, that significant inaccuracies do not creep into the measurements from controllable factors. The overall accuracy of the measurements should be taken into account when reporting the results.
6) On-site measurements of installed ISM equipment are usually unique to the particular site because of effects of local shielding. However, they may apply to the same piece of equipment or to identical equipment installed at other sites that provide equivalent shielding and grounding.
7) The emission measured from the ISM equipment is a function ofthe environment surrounding the equipment. In most industrial locations, the environment is likely to change. Therefore, when measuring emission, 1) make sure the environment is typical of its usual operating condition, and, 2) determine, to the extent possible, if probable environment changes will increase emission. If so, the user should be warned. When measuring emission because of suspected electromagnetic interference, the conditions existing at the time of the suspected interference should be duplicated as closely as possible.

2. Measurement Procedures

The measurement requirements and the report requirements depend on the measurement objectives (see 2.1), and they may vary for the different types of ISM equipment and for the frequencies of their emissions.

Usually, ISM measurements involve the following steps:

1) Review the measurement objectives to determine the procedures to be followed and the equipment required (see 2.1).
2) Inspect the ISM equipment under test (see 2.2).
3) Determine the measurement locations (see 2.3).
4) Turn on the equipment under test (EUT), let it stabilize, andadjust it for maximum emission (see 2.4).
5) Set up the measurement equipment near the EUT and check its calibration (see 2.5.1 and 2.5.2).
6) Determine the frequency spectrum of the EUT. This information will be used to determine the frequencies at which the field strength will be measured at the locations determined in the third step (see 2.6).
7) Measure the conducted emission from the EUT, if required (see 2.7).
8) Set up the measurement equipment at each of the measurement locations determined in the third step, and measure the maximum amplitude of the emission from the EUT at each frequency identified as significant in the spectrum measurements (see 2.8).
9) Calculate the field strength at desired distances from the EUTand plot the data as required (see 2.9).

2.1 Establish the Objectives of the Measurements

There are many reasons for measuring the emissions from ISM equipment, such as:

1) To determine if the ISM equipment meets the requirements of a local or national regulatory authority having jurisdiction over the emission of rf energy from industrial, scientific, and medical equipment.
2) To evaluate ISM equipment suspected of causing harmful interference to radio communications or navigation services, or to other susceptible equipment.
3) To determine if the ISM equipment emissions might exceed limits set for personnel exposure.

The certifying engineer should develop a test plan which meets the objectives. Although each involves measuring rf fields, the measurement locations, methods, and sensitivity required depend on the measurement objectives. If the measurement objective is to determine compliance with the regulations of a regulatory authority, refer to the latest edition for their requirements since these regulations are revised periodically.

If rf interference is suspected, has the source been localized to one piece of equipment? Determine the frequencies at which interference occurs, and, if possible, the way the interference reaches the target, for example, radiation or conduction. Also, determine which frequencies are used locally for aircraft and naval communications and navigation, for public safety (police, fire, ambulance, and others) and for television and radio (am and fm) broadcasting. Detection of the cause of interference may require careful investigation. Interference may occur in many modes, including:

1) Direct action at the frequency being radiated.
2) Heterodyne conversion or beating of two frequencies, perhaps from different sources, with interference occurring at the sum or difference of the two frequencies.
3) Demodulation of a carrier by a nonlinear element with interference at the frequency of the modulating wave.
4) Direct radiation, conduction, or a combination, for example, conduction along a power line into a victim receiver or conduction along a power line and reradiation into the receiver.

Standards covering personnel safety limits have been established by the ASC[1] C95 Committee[3][2] and the National Council on Radiation Protection and Measurements (NCRP) [8].

Personnel safety measurements of ISM equipment are often made in the near field. Near-field measurements require special care as follows:

- The field may be neither planar nor uniform.
- Since the field amplitude and direction change rapidly in this region, distance and polarization must be measured very carefully.
- The electric and magnetic fields are not necessarily uniformly related in this region. Both should be measured.

Engineers called on to measure rf emissions for personnel safety should make sure that they understand the reasons for the measurements, the standards to be applied, the frequency range of interest, the instrumentation sensitivity required, and whether frequency domain or time domain measurements are required.

If the location of interest is in the near field, measurements are sensitive to the location and sensor orientation, especially for complex sources. Make sure that the measurements are made where the personnel are actually located, and the sensor is oriented for maximum reading (see Appendix B.1).

The C95 Committee, accredited by ANSI and under the Co-Secretariat of the IEEE and the U.S. Navy, has prepared standards on the Human Exposure Safety Levels[3].[3]

[1]American National Standards Institute (ANSI) Accredited Standards Committee (formerly ANSI Committee).
[2]Bracketed numbers correspond to Section 4., Bibliography.
[3]This standard is being revised. When this document is superseded by a revision, the latest revision shall apply. Other standards being prepared deal with measurements. Refer to the latest revision of this and other standards before planning measurements dealing with human safety.

The certifying engineer should ensure that the test plan and the measurement equipment meet the measurement objectives.

2.1.1 Grouping ISM Equipment

Several pieces of ISM equipment located within a limited area may be grouped for rf field measurements and evaluation. Grouping equipment for this purpose is especially valuable when several pieces of equipment are installed at the same time, or when a new one is installed near others, and it is desired to make measurements without turning off the other nearby equipment. This method has the obvious disadvantage of increasing the emission measured, usually by the root-sum-square of the emissions of the individual pieces of equipment.

When calculating emission for a group measurement, assume that the "ISM equipment" is located at the center of the smallest circle which contains all of the equipment in the group.

List on the measurement report all of the equipment that is operating at the time measurements are made. The measurements are made assuming the location of the equipment is in the center of the smallest circle that encloses the group.

If it is not practical to operate all of the equipment in a location at the same time, several sets of measurements may be made with overlapping groups. For example, if there are five pieces of equipment in a location to be evaluated, one set of measurements may be made when numbers 1, 2, and 5 are operating, and a second when 3, 4, and 5 are operating. A separate report should be prepared for each group of measurements. On each report list all of the pieces of equipment operating when the measurements for that report were made.

2.1.2 Prototype Measurements

Prototype measurements refer to extrapolation of the test data from a sample of typical ISM equipment (called "prototypes") to other identical[4] ISM equipment. Prototype measurements can reduce the time and expense involved in testing a group of identical pieces of equipment, especially those modified since purchase. To be prototype tested,all of the equipment must be: 1) identical (including any modifications), and 2) located in areas that provide equivalent shielding and grounding.

Prototype measurements are desirable, for example, when several identical pieces of equipment are installed in a production area, or when several identical pieces of equipment in a production area are modified in the same manner to meet changes in the production process.

Prototype testing consists of the following:

1) The installation inspection of each piece of equipment.
2) The thorough measurement of the electromagnetic emission froma sample of the equipment, either as a group, all operating at the same time, or individually.
3) The measurement of the emission spectrum in at least one location, from each of the pieces of equipment not included in the sample, to determine that its emission is similar to those that were measured thoroughly.

The number of individual pieces of equipment tested as prototypes should be 10% or at least two (whichever is larger) of the number of identical pieces of equipment planned to be installed. This equipment may be tested individually or as a group with one set of measurements. The verifying engineer should, insofar as practical, select the prototype equipment to be tested to be the "worst case", that is, those with the poorest shielding from room walls and other obstructions.

[4]Identical equipment, as used here, means equipment of a common manufacturer, model, type, and characteristics, allowing for the variation that can be expected to arise because of quantity production techniques. If identical pieces of equipment are modified identically, they remain "identical".

Additional identical equipment may be prototype certified based on the detailed measurements on the prototypes, provided: 1) it is properly installed, 2) spectrum measurements show that its emission is similar to the emission of the equipment that was measured thoroughly, and 3) it is located in areas with shielding and grounding at least equivalent to those measured.

The measurement report for the prototype equipment should provide a full description of the detailed measurements (see 2.1.2).

The measurement report for other identical equipment should provide a full description of both the detailed measurements of the prototypes and the spectrum measurements. Prototype measurements made on installed ISM equipment are unique to that equipment at that location. Be careful when applying such measurements to other equipment installed at other locations. Prototype measurements are ideally made on an open field test site, where only the shielding built into the equipment is taken into account. However, this recommended practice covers measurement of emission from ISM equipment installed on user's premises where measurement results are less certain.

2.2 Physical Inspection of ISM Equipment

For the field measurements to indicate the emissions during actual operations, they must be made under actual operating conditions.

The emissions should be measured under other probable operating conditions if the responsible engineer determines that these conditions are likely to result in increased emissions. The equipment operators and maintenance personnel should understand the measures required to prevent excessive emissions during equipment operation and maintenance, and apply them. The certifying engineer should physically inspect the equipment for proper operating conditions and should review operating procedures. The equipment should be operating under its usual operating conditions when measurements are made. Necessary changes should be recommended if the certifying engineer finds that the operating conditions and procedures are incompatible with meeting the emission limits of the measurement objectives. Emissions should be remeasured after the changes are made.

At a minimum, the certifying engineer's inspection should cover the following:

1) Is the equipment installed according to the manufacturer's instructions?
2) Is the grounding effective? Are its connections clean andsecure? Does it comply with applicable electrical codes?
3) Is the high frequency shielding free of deterioration, breaks, or other damage? Are the contact surfaces for all doors and shields, including any external jumpers, free of paint, dirt, corrosion, and other impediments to good electrical contact? Precautions should be taken to ensure that plating at these surfaces is not damaged while cleaning.
4) Are all shielding, doors, panels, and covers securely fastened in their proper place during operation? Are the required number ofmounting screws and fasteners in place and tight?
5) Are electrical bonds between parts of the shield in good condition and secure? Are the contact surfaces free of paint, dirt,and corrosion?
6) Is external wiring, including control wiring, installed in rigid metal conduit, electrical metallic tubing, or flexible metallic conduit if required to ensure adequate shielding? Is all metallic conduit securely fastened and grounded?
7) Are the installation and inspections properly recorded in the maintenance and inspection log? Does it show all modifications and maintenance?
8) Do the operators and maintenance personnel know the precautions they should take to ensure that the equipment is operated to minimize emission?
9) Should the physical layout be changed to meet the emission limits of the measurement objectives? Are there any probable changes in the physical layout that would increase emissions from the facility?

The installation inspection report included with the engineer's measurement report should describe the findings of the inspection in sufficient detail so that, if the equipment is later found to have excessive emission, changes in such factors as shielding, grounding, impedance matching, and operating procedure scan be identified quickly.

2.3 Determine Measurement Locations

Select the measurement locations appropriate to the measurement objectives. To satisfy regulatory authority rules, the measurement locations must be those specified by the authority. To determine interference causes, start near the target of interference. For personnel safety, determine where operating, maintenance, and other personnel are liable to be exposed.

Examine site maps and building plans and visit the site. Select locations near the appropriate distances and directions from the EUT, where the field strength is likely to be the highest. Consider the location of the EUT, the major emission lobes from the ISM equipment, if known,[5] the position of reflecting and shielding materials, and nonshielding windows, doors, and other openings. Corridors walled with conducting material can channel rf fields; take them into account. Conductive building structures and electrical cables, which are integral multiples of 1/4 λ. long, can act as parasitic antennas, reradiating the emission of the ISM equipment. They will complicate the measurement process. Also consider the surrounding terrain. How will it affect measurements of the field radiated by the EUT?

Another factor affecting the measurement location selection is the sensitivity of the measurement system described in A.3.

If compatible with the measurement objectives, the measurements may often be simplified considerably by making them at, or near, the perimeter of the user's facility as recommended in CISPR Publication 11 (1975) [6].

It is often not practical to measure the field strength that the desired distance from the EUT because access is restricted (for example, the location may be on someone else's property) or the measuring equipment may not be sufficiently sensitive to measure the field strength there. Instead, the field strength maybe measured at more convenient locations, as far from the EUT as possible, between the EUT and the desired distance, and the field strength extrapolated to the desired distance. Generally, unless the frequency of the EUT emission is very low, interference measurements (except possibly spectrum measurements) should be made in the far field to simplify calculations.

The E and H field strengths in the near or transition regions may not be related as they are in the far-field region. ANSI/IEEE Std 473-1985 [5] provides information on techniques for field measurements near reflecting surfaces.

2.4 Adjust the Equipment Under Test

The EUT should be turned on and adjusted for maximum emission, compatible with normal operating conditions. Adjust the EUT and its load to produce maximum emission, frequency fluctuation, harmonics, and other spurious output. These adjustments should be consistent with normal operation. If conductive cables associated with the EUT are not fixed in place, move them into the position compatible with normal operation, producing maximum emission. The EUT's radiating frequency should be measured at frequent intervals to determine when it stabilizes. Some industrial heaters may not fully stabilizing a reasonable time since their frequency is determined, to some extent, by the amount of moisture and other characteristics in the material being heated; these change as the material is heated. Here, each field-strength measurement must be made over the range of the frequency of interest. As the material characteristics change during the course of measurement, it may be necessary to readjust the EUT to maximize emission. The readjustment should be noted in the measurement log.

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[5]It is advisable to make preliminary measurements to determine the direction of the major emission lobes, before fixing all of the measurement locations. Determine these lobes by measuring the field strength along several radials (at intervals ≤72°) from the center of the EUT to determine those with the strongest field strength along which thorough measurements will be made. If appropriate to the measurement objectives, these preliminary measurements should be made outside the shielding provided by the building structure. The major lobe for one frequency may be different from that for another. The antenna polarization, orientation, and location along its three orthogonal axes should be varied to determine the maximum field strength near the measurement location.

2.5 Connect Equipment for Spectrum Measurements

2.5.1 Verify Equipment Use and Operation

Set up the measuring equipment near the EUT. Select the antenna for the first frequency band to be checked.

Calibration of narrow bandwidth antennas, such as tunable dipoles, is very sensitive to the distance between the antenna and nearby conducting surfaces, including ground. Use antennas under conditions for which they were calibrated. On the other hand, calibration of broad bandwidth antennas, such as biconical antennas, is not as sensitive to nearby conductors, but their calibration does not have the theoretical support that the dipole has. In any case, follow manufacturer's instructions regarding the calibration and use of antennas and other measuring equipment. Allow measuring equipment sufficient warm-up time to stabilize before making measurements.

Mount the antenna on its support and connect the cables. If it is a tunable antenna, adjust its length following the manufacturer's instructions. Inspect the antenna for bent, damaged, or broken elements. Connectors and cables should be checked frequently; faults in them account for a significant number of measurement errors. Connect the antenna to a detector that is calibrated so that both frequency and amplitude of the received signal can be measured accurately. The field-strength meter is the preferred detector for measurement of actual rf levels. However, other detectors, such as spectrum analyzers or tuned rf voltmeters may be used, provided proper precautions are observed.

Make sure that the detector is used within its recommended amplitude range. Broadband detectors, such as spectrum analyzers, are easily overloaded. If overloaded, their measurements are erroneous. Use preamplifiers to get adequate sensitivity, or filters and at tenuators to prevent overload.

Make sure that the system is operating linearly before taking final measurements. Especially when using spectrum analyzers, check for overload by inserting 10 or 20 dB of attenuation into the input. If the observed signal does not decrease by within one dB of the inserted attenuation, the system is probably overloaded. Operate with sufficient attenuation inserted before the first stage, so that, when more attenuation is inserted, the observed signal decreases by within one dB of the additional inserted attenuation.

Additional information on the measurement system is given in Appendix A.1. Additional information on minimizing measurement errors is given in Appendix B.1.

2.5.2 Verify System Calibration

Because of the large amount of handling that measurement equipment gets, it is important to check the calibration of the complete system each time it is set up for use. A small crystal-controlled oscillator that operates at a known fundamental frequency and is rich in harmonics is useful for this purpose. To check the calibration, measure the field strength from the oscillator, under laboratory conditions, when it is near[6] the receiving measurement antenna. Then, when the equipment is set up at the field location, hold the oscillator at the same distance from the measurement antenna, turn the oscillator on, and read the output on the measurement system. If the signal strength and the frequency approximate those measured under laboratory conditions, you can be reasonably sure that theme asurement system is working properly. Common causes of measurement errors, such as broken leads, loose connections, and incorrect switch settings can be spotted quickly with this method. Spectrum analyzer input-stage overload may also be identified if the EUT and other rf generating equipment that will operate during the measurement phase is operating while the instrumentation is being calibrated.

While this technique should not be depended on for precise system calibration, it does provide a quick and easy method of detecting faults and gross errors in cabling and instrument adjustment.

[6]To minimize the effect of reflections from nearby conducting surfaces, the calibration distance between the oscillator and the antenna should be minimized.

If reflections do not interfere significantly, the reliability of the antenna can be further evaluated by checking its balance and “axial ratio” as the antenna is rotated in the vertical plane containing its elements:

1) When receiving a linearly polarized signal, the angle of minimum response should be 90° from the angle of maximum response and the ratio between responses should be 20 dB or more. The maximum response should occur when the polarization of the antenna matches the polarization of the source.
2) After the antenna has been rotated through 180° from its starting orientation, the measured signal should be the same as at the starting orientation. If either of these two tests fails, the measurements cannot be relied on. Note that the position of the antenna feed line may affect the position and depth of the minimum response, so care in arranging the feed line is important. Generally, the parts of the feed line near the antenna should be perpendicular to the antenna.

2.6 Determine the RF Spectrum

Spectrum measurements provide important information about the emission from ISM equipment, including (1) the frequencies at which the field strength will be measured during the radiated field measurements, (2) emission at unsuspected frequencies, (3) high-order harmonics resulting from distortion introduced by nonlinear elements, (4) parasitic oscillation frequencies, (5) heterodyne (beat) frequencies resulting from interaction with emission from other rf equipment, and (6) modulation frequencies resulting from detection by nonlinear elements, both within and external to the EUT.

Pay special attention to frequencies used locally for distress calling, public safety, and emergency communications, navigation, and entertainment broadcasting.

The following techniques can help determine if the EUT is the source of, or contributor to, a given signal:

1) If rf generation of the EUT can be turned on and off easily, you can determine if the signal disappears when the EUT is turned off.
2) The EUT may have a characteristic “signature” in its signal, which is obvious when it is observed on an oscilloscope or spectrum analyzer, or its audio component is heard on a speaker or headset. Another characteristic signature is the harmonically related distribution of narrow band signals, such as those produced by clock oscillators. To be useful, this signature must affect the major emission from the EUT.

Do not limit measurements to harmonics of the fundamental operating frequency. Look for spurious emissions at all frequencies between 10 kHz and the tenth harmonic of the EUT operating frequency, or 1 GHz, whichever is higher. (Spectrum measurements on some highly nonlinear rf systems (plasma devices) showed a stronger signal at the nineteenth harmonic than at frequencies below the tenth harmonic.)

The spectrum analyzer, which displays the amplitude of signals over a wide band quickly, is very useful for detecting spurious emissions. When using the spectrum analyzer, be sure that its input stage is not overloaded. If it is overloaded at any frequency, even one not being displayed, the analyzer may display many internally generated spurious responses which are difficult to distinguish from real external signals.

Repeat the measurements at enough locations around, and, if possible, above the EUT, to ensure that you have identified the frequency of all significant electromagnetic emissions.

While near the EUT, if possible, determine if there is significant emission directed upward from the EUT on, or near, frequencies used locally for aircraft beacons or aircraft communications. If there is, it may be advisable to measure the emission at those frequencies, on the floor or roof above the equipment, to determine if there is a danger of interference with aircraft communications or with navigation.

Calculate the amplitude of the signals at the frequencies at which significant emission was detected. Use the appropriate antenna factor and detector correction factor for the frequency. If the spectrum measurements are made in the near-field, the far-field antenna factor may not apply. Record the frequencies[7] at which there is significant emission. These will be the frequencies at which measurements will be made at the measurement locations previously determined. Often, the spectrum will vary with direction from the EUT, and the signals will attenuate at different rates as the distance from the EUT changes, especially near the EUT. Therefore, it is usually necessary to measure the amplitude at more than one frequency at the measurement locations.

2.7 Measure Conducted Emission

Conducted emission measurements on installed ISM equipment are not usually required if the plant has its own power transformers, unless the equipment is suspected of causing interference within the plant from conducted emissions. If the measurement objectives require that conducted emissions be measured, measure while the measurement equipment is set up near the EUT. Emissions can be conducted a considerable distance from the offending source, along power lines, control cables, and signal cables, and then radiated or enter other sensitive equipment through the line cords.

The best way to measure conducted emissions in power leads is to use a line impedance stabilization network (LISN). The LISN is connected electrically between the EUT and the power line. It provides a standard impedance for rf measurements, helps isolate the EUT from rf signals originating elsewhere in the power system, and provides terminals for connecting measuring equipment. Unfortunately, an LISN with adequate current and voltage rating may not be available, or disconnecting the EUT from the power lines, often a cumbersome procedure, may not be practical. If the background rf noise level on the power line is not excessive, a current probe or a voltage probe may be used to measure conducted rf signals. The current probe is put around the power or signal cable connected to the EUT. Normally, the probe is put around the entire power cable to measure common mode rf signals on the cable. If the probe were placed around an individual conductor, the large power current measurement would be superimposed on the small rf current measurement and the differential mode signal would be measured. The voltage probe is connected between the pair of suspected conductors or between one and ground. Their terminals are connected to the rf meter.

Current and voltage probes lack two important features of the LISN, namely, the standard impedance looking from the EUT toward the power line, and the isolation from rf originating elsewhere in the power system. While these limit the usefulness of the probes for accurate and repeatable measurements, they are useful for determining if the rf noise from the EUT exceeds allowable limits. If the rf energy measured on the power leads exceeds that permitted, a background measurement (with the EUT turned off) should be made. If the square root of the difference between the squares of the two measurements, (measured as volts or microvolts—not decibels) is less than the allowable limit, the equipment may be considered to comply with the requirements.[8]

Since the probes measure the conducted emission into the local power line impedance, they provide site-specific data.

Information on LISNs, current,and voltage probes maybe obtained from ANSI C63.2-1987 [1] and ANSI C63.4 -1981[2].

2.8 Measure Radiated Emission

After the determining the frequency spectrum of the measurement equipment at the measurement locations and recheck its calibration.

[7]The International Telecommunications Union (ITU) has designated certain frequencies for the use of ISM equipment. Regulatory authorities designate various of these frequencies for the use of ISM equipment within their jurisdiction. See the latest regulations of the cognizant regulatory authority for the ISM frequencies applicable to your situation. Usually, there are very few restrictions on equipment operating on these frequencies; the equipment must operate within the defined frequency tolerance and personnel must not be exposed to dangerous rf field levels. All other users of equipment operating on these frequencies are warned that they may suffer interference. If the purpose of the measurements is to determine compliance with the rules of a regulatory authority, unless there is a limit on the permissible emission at these frequencies, there is no reason to measure the rf field at these frequencies except to ensure that the emission is limited to the permissible band. In this case, record measurement sat the non-ISM frequencies at which emission is significant.

[8]This technique becomes less reliable as the background noise on the power line increases, and should not be used if the background noise exceeds the allowable limit.

Measure the field strength at the frequencies identified in the spectrum measurements. Field strength should be measured considering the total electromagnetic field environment. All of the conducting surfaces in the area reflect and block radio signals producing nulls and peaks, making the industrial environment a difficult one for these measurements. It is important to measure the maximum field near the measurement location. Determine the polarization (vertical or horizontal) that gives the strongest signal at the location by moving the antenna in the following directions:

1) Vertically from 1 m above the ground up to 4 m, (preferably even higher) if practical, (for measurements at frequencies above 30 MHz).
2) Horizontally, up to 1/4 λ, if practical, both toward or away from the source, and from side-to-side, in the direction of increasing amplitude.
3) Rotating the antenna both for direction and polarization.

Perform these three steps until the location and orientation for the maximum field strength reading is determined. Repeat this procedure for all frequencies of interest.

Measurements in the near field require special care because the relationship between the E- and H- fields may not be constant. See ANSI/IEEE Std 473-1985 [5] for information on these measurements. Information on measurement equipment may be obtained from ANSI C63.2-1987 [1] and C63.4-1981[2].

When measuring the emission at more than one point along a radial, it is good practice to perform a preliminary calculation of the field strength while still at the measurement location, so that the results can be checked for reasonableness, and the measurements remade if an error is discovered. The measurements should be considered suspect if those made in the far field along a given radial from the EUT do not fall between that expected from an inverse cube and an inverse linear relationship with the ratio of the distances between the EUT and the measurement location. The measurements will normally be between an inverse square and inverse linear relationship. However, the attenuation may be greater, depending on frequency and terrain.

2.8.1 High Background Levels

If the broadband background level on a measurement frequency is high, measure it with the EUT turned off. Then measure the total field strength with the EUT turned on. The contribution of the EUT can be calculated in μV/m, since the total field strength is the root-sum square of the constituents (the signals are uncorrelated). Unfortunately, when the background noise increases, the absolute error in its measurement usually increases and the error in the actual signal may become very large. For example, if the signal plus noise is 100 μV and the noise alone is 90 μV, the actual signal is about 44 μV. But if the noise alone is incorrectly measured as either 94 μV or 86 μV, an error of only about ±4.4%, the actual signal may appear to be 34 μV or 51 μV, an error of about -23% or+16%.

2.8.2 Overhead Measurements

If the spectrum measurements showed a possibility of aircraft communications or navigation interference, measure the emission in a line extending up from the EUT, vertically and at several points near vertically above the EUT, to determine if there is a significant field strength on these frequencies. This measurement can be made with a portable calibrated detector on the roof over the equipment.

2.9 Calculate and Plot Data

After all of the measurements have been made, calculate the field strength at the desired locations. If the field strength is measured at a distance other than that desired, determine the field strength at the desired distance by either:

1) Assuming a conservative 1/d attenuation factor, or,
2) Determining the actual attenuation factor by measuring the field strength at three or more distances from the EUT, along the radial from the EUT that includes the measurement location with the largest field strength. If

the measurements made at three distances are compatible, additional measurements are not usually necessary. If, however, the measurements are not compatible, perhaps because they were made in the near field, or, because of local field perturbations, additional measurements should be made.

These measurement locations should be as far apart as practical, and, unless the frequency of the EUT is very low, they should all be in the far field. They should be made at points that characterize the conditions of the area through which emission will be extrapolated. That is, if the area between measurement location and EUT is filled with equipment and steel partitions, while the area between measurement location and the desired distance is an open field, the additional measurements should be made in the open field.

The data obtained in these measurements can be used to determine the field strength at the desired distance either graphically or analytically.

Careful analysis is required to determine the validity of the extrapolation technique used for measurements made in the near or transition regions.

3. Report of RF Field Measurements

The report on rf measurements should identify the equipment under test and its location, and describe the results of the measurements accurately and clearly. It consists of the following parts:

1) Identification of the equipment under test and its location.
   a) Manufacturer, model and serial number
   b) Nominal operating frequency
   c) Nominal rf power rating
   d) The type of equipment under test (for example, ultrasonic, industrial heaters)
   e) Building address, floor, and room or column number.
2) Certification by the engineer responsible for making the measurements, that the equipment meets the measurement objectives, if it does. This statement should include the following:
   a) A short description of the tests performed
   b) The operating conditions which must be observed to ensure that emission during normal operation meets the objectives
   c) The date the measurements were made
   d) Date of evaluation
   e) Signature of evaluating engineer
   f) Name and business address of the evaluating engineer.
   g) If the equipment does not meet the objectives, a statement to that effect, and, if appropriate, the steps that should be taken for compliance.
3) Identification and qualifications of those who made and supervised the measurements.
4) Identification of measurement equipment used, including last calibration date.
5) Physical inspection report (a description of the conditions found during the physical inspection and while making the emission measurements). This description may be useful in analyzing the cause if subsequent measurements of the rf emission from the ISM equipment indicate significantly different emission. Photographs may be very useful. The description should include the following:
   a) Condition of the EUT
   b) Grounding method and location
   c) Shielding used, attachment method, and condition
   d) Power source
   e) Cover attachment method and condition
   f) Shielding contact surface condition
   g) RF gaskets used and condition

   - h) Cable type, shielding, dressing, location, orientation, condition
   - i) Any other items noted that would be likely to affect rf emission, either radiated or conducted.
6) Measurement data.
   - a) A map or diagram of the part of the facility involved in the field measurement, showing the measurement locations and the EUT location
   - b) A chart of the measurements made, including:
     - 1) Measurement location, keyed to site map
     - 2) Date, day of week, and time of day of measurements
     - 3) Unusual environmental conditions that could affect the measurements, for example, high ambient electrical noise level, snow and ice accumulation, heavy rain
     - 4) Equipment used for the specific measurement
     - 5) For each frequency measured (as determined in the spectrum measurements):
       - a) Measured values
       - b) Signal polarization
       - c) Elevation above ground of antenna when measuring peak signal, if appropriate
       - d) Calibration factors for the system-antenna, cables, and detector
       - e) Calculated field strength
       - f) Field strength extrapolated to the desired measurement distance from the EUT, if measurements were made at a different distance
       - g) The amplitude of the electromagnetic field permitted by the objectives at the specified distance
   - c) Sample calculations and equations, with the assumptions on which their use is based
   - d) Other data required to meet the objectives, for example, graphs of the measurement data:
     - 1) Field strength versus frequency.
     - 2) A polar graph of the rf field pattern, extrapolated to (or measured at) the desired distance from the EUT.[9] The objective limit at this distance for the EUT should also be plottedon the same graph.
     - 3) Field strength versus distance along the radial of maximum emission shown in the polar graph.[10] This plot should show the field strength from a point near the equipment to the desired distance (extrapolated, if necessary) from the equipment. Include this plot if it is used to extrapolate or interpolate the field measurements.
     - 4) Amplitude variations in the measured field strength resulting from moving the receiving antenna within the $\lambda/4$ volume (referred to in 2.8). This data would show the effects of multipath caused by reflections from walls, furniture, and other obstructions, within the measurement environment and give relevant information for estimating the magnitude of the measurement uncertainties associated with the results obtained.
   - e) A report of the rf energy, voltage, or current, conducted into the power line (if required).

All data for the following should be identified appropriately:

1) Measurement frequency or range
2) Polarization of receiving antenna
3) Orientation of receiving antenna
4) Type, location, routing, and orientation of signal leads
5) The height of the receiving antenna above ground
6) Location of the receiving antenna with respect to the equipment under test
7) Units of measurement, for example, MHz, dB (μV/m), μV/m, m.

[9]For regulatory compliance and interference determination objectives, use the measurements made at the frequency with the largest amplitude that is not in an ISM band.

[10]This technique becomes less reliable as background noise on the power line increases and should not be used if the background noise exceeds the allowable limit.

4. Bibliography

[1] ANSI C63.2-1987, American National Standard Specifications for Electromagnetic Noise and Field Strength Instrumentation, 10 kHz to 1 GHz.

[2] ANSI C63.4-1981, American National Standard Method of Measurement of Radio Noise Emission From Low-Voltage Electrical and Electronic Equipment in the Range of 10kHz to 1 GHz.

[3] ANSI C95.1-1982, American National Standard Safety Levels With Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz.

[4] ANSI/IEEE Std 100-1988, IEEE Standard Dictionary of Electrical and Electronics Terms.[11]

[5] IEEE Std 473-1985, IEEE Recommended Practice for an Electromagnetic Site Survey (10 kHz to 10 GHz).

[6] CISPR Publication 11 (1975), Limits and Methods of Measurement of Radio Interference Characteristics of Industrial, Scientific, and Medical (ISM) Radio Frequency Equipment (Excluding Surgical Diathermy Apparatus), International Electrotechnical Commission.[12]

[7] CISPR Publication 16 (1987), CISPR Specifications for Radio Interference Measuring Apparatus and Measurement Methods.

[8] NCRP Report No. 86 (1986), Biological Effects and Exposure Criteria for Radio Frequency Electromagnetic Fields.[13]

[9] ROBERTS, WILLMAR K. A New Wide-Band BALUN, *Proceedings of the IRE*, Vol 45 pp. 1628–1631, 1957.

[10] SAE-AIR-1509 (1978), Antennas and Antenna Factors: How to Use Them.[14]

[11] TAGGART, H. E., Radiated EMI Instrument Errors, *EMC Technology*, vol 1, no 4, pp 36–45, Oct 1982.

[11]ANSI/IEEE publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY, 10018, or from the IEEE Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ, 08855-1331.
[12]CISPR publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.
[13]NCRP publications are available from the Publications Department of the NCRP, 7910 Woodmont Avenue, Suite 800, Bethesda MD 20814.
[14]SAE publications are available from the Order Department of the Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

Annex A Measurement System Characteristics

(Informative)

A.1 Antenna Selection

(These Appendixes are not a part of ANSI/IEEE Std139-1988, IEEE Recommended Practice for the Measurement of Radio Frequency Emission From Industrial, Scientific, and Medical (ISM) Equipment Installed on User's Premises, but are included for information only.)

Many regulatory authorities have specified the antennas listed in Table A.1 for standard measurements.

Table A.1 —Antenna Selection

Frequency Range	Antenna
20 Hz–18 MHz	Shielded balanced loop
18 MHz–30 MHz	Shielded loop or calibrated tuned half-wave dipole
30 MHz–1 GHz	Calibrated tuned half-wave dipole
> 1 GHz	Broadband linearly polarized horn

However, for practical *in situ* measurements, smaller broadband antennas are commonly used. The antennas used for these measurements should generally be:

1) Rugged and portable
2) Easily set up, taken down and moved
3) Linearly polarized so they can measure signal polarization easily
4) Calibrated for the conditions under which they are used, for example, near conducting surfaces.

To facilitate measurements by reducing the amount of equipment and the number of antenna changes and adjustments required, it is often desirable to use broadband antennas. In any case, they must be used in accordance with their manufacturer's recommendations and calibrated for the conditions under which they are used.

More information on antennas used for these measurements may be obtained from ANSI/IEEE Std 473-1985 [5] and SAE-AIR-1509 (1978) [10].

A.2 Detectors

To ensure proper receiver characteristics, equipment used should comply with ANSI C63.2-1987 [1].

The field strength meter is the preferred detector for measurement of actual rf levels. However, other detectors, such as spectrum analyzers, calibrated receivers, or tuned rf voltmeters may be used, provided proper precautions are observed.

Make sure that the detector is used within its recommended amplitude range. Broadband detectors, such as spectrum analyzers, are easily overloaded. If overloaded, their measurements are erroneous. Use preamplifiers to get adequate sensitivity, or filters and attenuators to prevent overload. Make sure that the system is operating linearly before taking final measurements. Especially when using spectrum analyzers, check for overload by inserting 10 or 20 dB of attenuation into the input. If the observed signal does not decrease by within one dB of the inserted attenuation, the system is probably overloaded. Operate with sufficient attenuation inserted before the first (input) stage, so that, when more attenuation is inserted, the test is passed.

Allow the measuring equipment to warm up before making measurements. Follow the manufacturer's recommendations scrupulously in this regard or the measurements will not be reproducible.

A.3 Measurement System Sensitivity

If the rf field from the EUT is at, or exceeds the specified limit, the measurement system must be able to detect it clearly, regardless of other electromagnetic fields (noise) in the area. Therefore, select the measurement location so that, if the field strength at the specified distance is 6 dB below the specified limit and a 1/d attenuation is assumed, the measuring equipment can measure the field strength at the measurement location so that, if the field strength at the specified distance is 6 dB below the specified limit and a1/d attenuation is assumed, the measuring equipment can measure the field strength at the measurement location.

Quasipeak measurement is required by some regulatory authorities. Other regulatory authorities, for example, the United States Federal Communications Commission, require the use of line average detecting equipment. ANSI C63.2-1987 [1] and CISPR Publication 16 [7] provide information and specifications for radio interference measuring apparatus and methods for quasipeak and average measurements.

A.4 Measurement System Bandwidth

Unless other values are specified, the minimum bandwidth of the measuring system at -6 dB should be the values given in Table A.2. However, for time domain measurements of complex waveforms, a much wider bandwidth may be necessary. For example, to characterize a 15 kHz sawtooth signal, the measurement system should be fiat within 1 dB between the fundamental frequency (15 kHz) and at least the tenth harmonic (150kHz).

Table A.2 —Minimum Bandwidth (-6 dB) of Measurement System (for Frequency Domain Measurements)

Frequency	Bandwidth
10 kHz–150 kHz	200 Hz
150 kHz–450 kHz	9 kHz
450 kHz–30 MHz	9 kHz
30 MHz–1 GHz	100 kHz
> 1 GHz	1 MHz

Additional information on measurement equipment may be obtained from ANSI C63.2-1987 [1] and C63.4-1981[2].

Annex B Minimizing Measurement Errors

(Informative)

Ensure that the measurement equipment is in proper working condition, that it has been calibrated at the intervals recommended by the manufacturer, and that it is used properly. The use of a "check calibration" procedure to identify errors in equipment connection and broken conductors, or other damage, was discussed earlier, in 2.5.2.

B.1 Antenna Problems

Antenna problems can arise from the following:

1) Incorrect setting of adjustable elements
2) Bent or broken elements
3) Use of the antenna at wrong frequencies
4) Use of an incorrect antenna, for example, a dipole antenna for H-field or a shielded loop for an E-field measurement, or an antenna with inadequate bandwidth
5) Being too close to the ground or other nearby conducting surfaces
6) Use of "far field" antenna factor in the near field.

Voltage standing wave ratio (VSWR) for a tuned antenna varies widely over a comparatively small frequency range, and affects the antenna factor [11]. Many of these problems are reduced significantly when broadband antennas are used. However, their calibration may require more care than calibration of tuned antennas. The user should balance the additional care required in using a dipole against the additional work in calibrating a broadband antenna.

A more difficult problem occurs when an antenna is used to measure a field that is not:

- Very nearly planar across the antenna's "aperture"
- Traveling normal to the plane of the antenna
- Uniform (in amplitude) across the antenna's aperture.

Under these conditions, the measurement will show a smaller value than is correct, because the antenna averages the field strength across its aperture. If the field is not uniform, an electrically small antenna will indicate the field across its aperture more accurately than will a large one.

B.2 The Antenna Factor

The antenna factor provided by the manufacturer may include the effect of the cables which connect the antenna to the calibrated detector [4]. If not, the cable effect must be added. Determine if it has been included for your antennas. Recalibrate the measurement system if an extension cable is used, because of its effect on the system calibration, both by increasing the cable losses and because of the possibility of impedance mismatch.

B.3 Detector Problems

Detector problems frequently arise from:

1) Input and mixer stage overloading. The input and mixer stages of a broadband detector, for example, spectrum analyzer, may be overloaded if the integrated sum of all of the signals in the pass band of the input filter exceeds the limit of the linear range of the stage, even if no single signal overloads it. When this occurs, the displayed amplitude will not change proportionately with input signal, and frequency components, not

present in the input, may be generated and displayed. All measurements made while the input stage is overloaded are suspect.

2) Inadequate calibration
3) Abuse since the last calibration
4) Errors in use:
   a) Incorrect switch settings
   b) Insufficient instrument warm-up time. (Most spectrum analyzers and calibrated receivers should warm up for 15 to 30 minutes before use. The manufacturer's instruction manual gives the required warm-up time.)

B.4 Data Collection and Processing Problems

Data collection and processing problems can arise from errors in data recording, programming, collection of inadequate data, and errors in supplying calibration data to the data processing system.

B.5 Interface and Cable Errors

Interface and cable errors usually result from impendance mismatch, which has been reported [11] to be the most significant cause of instrumentation errors. Other problems result from cable losses, conductor breakage and short circuits, and dirty and oxidized contacts.

B.6 Impedance Mismatch

Impendance mismatch results when the two connected components, for example, cable and detector, do not present matching impedances to each other. For impedances to be matched, if the impedance is pure resistance, the resistance looking into the load should equal the resistance looking into the source. If the impedance contains a reactive component, the resistances should be equal, and the capacitive reactance of one should equal the inductive reactance of the other.

At a mismatch, part of the signal is reflected back toward the source, resulting in "standing waves". The greater the mismatch, the greater the reflection, and the smaller the part of the signal measured. Coaxial cables often suffer damage in use because of kinks and crushing. The damage (usually a change in capacitance caused by compression of the cable insulation) is often not visible; however, it results in a change in impedance that causes standing waves, reflected from the damage location. A minimum of 10 dB attenuation should be maintained either internal to the measuring device (spectrum analyzer, receiver, rf voltmeter, or field strength meter), or external at the detector input or measuring device input, if possible.

The impedance of narrow band antennas, such as tunable dipoles, is affected by the frequency and distance from nearby conductors, such as the ground and walls. For the field strength measurements to be accurate, measure the antenna factor, which includes these effects, under the same conditions as the field strength measurements. Broadband antennas are not as sensitive to these effects as are tunable dipoles.

B.7 Baluns

Baluns, used to match balanced to unbalanced lines, are another source of impedance mismatch. Most do not maintain a constant impedance over a wide frequency range [9]. It may be necessary to use several to cover a wide frequency range.

