OPEN SITE ELECTROMAGNETIC EMISSIONS MEASUREMENTS

Introduction

Radiated electromagnetic emissions (EME) measurements are frequently performed on an open-area test site to satisfy many commercial and non-military government EME measurement requirements. Typical of these requirements are the ones found in the Rules and Regulations of the FCC, Part 15 Subpart J, and its appendix. Open-area test site measurements assure reliable, repeatable results. Test criteria for radio services under protection are met—without having to compensate for shielded enclosure effects, without having to resort to incompletely-developed test methods or equipment, and without expensive anechoic chambers. In this article we will briefly discuss the test apparatus, the test site, and the tests needed to evaluate EME in the range of frequencies from 30 MHz to 1 GHz.

THE MEASUREMENTS

There are three general areas into which this topic may be sorted. These are the test apparatus needed, the test site, and the actual testing. A weakness in any of these areas can create test results which are of little or no value; these all are important and must be carefully considered before tests are begun.

Test Apparatus

The following listed apparatus or test equipment is needed as a minimum:

1. accurately calibrated antennas in good condition;
2. good quality signal cables, accurately calibrated and in good condition; and
3. accurately calibrated EME analyzer(s) to cover the necessary frequency range.

The antennas must be linearly polarized, such as tuned dipoles, biconical or other broadband dipoles, log-periodic, or horn antennas. The antennas must have been accurately and recently calibrated by the manufacturer, a standards laboratory, or the user. The antennas should be checked before each use to assure that they have not been damaged or have not deteriorated since the last use.

Signal cables used to connect the test antennas to the EME analyzer should be of good quality and in good condition. Cables which have "non-contaminating" jacket material and a double layer of shields will give the best service. RG-55 and RG-9 are two of the older versions of this type of cable that are recommended. RG-55 is smaller, lighter, and easier to handle, but it is much lossier than the larger RG-9 at the higher frequencies. Modern versions of these cables are RG-223 and RG-214 respectively. The losses in the cable are important for two reasons. First, they must be accounted for in the reduction of the test data, and second, high losses may degrade the overall test system sensitivity to the unacceptable point. Whatever cables are used must be free of kinks, cuts, bruises, or other damage and must have been recently calibrated, so that their losses versus frequency are accurately known and can be used in reducing the test data. As with the antennas, the cables should be inspected and checked for condition before being used.

EME analyzers may be those expressly designed for such measurements, and as specified in ANSI C63.2, or they may be spectrum analyzers. The ANSI C63.2 specified instruments are recommended for general EME measurements. They have carefully controlled characteristics and are designed for such use. These instruments are especially recommended for use by people just getting started in EME measurements, because it is more difficult to accidentally make "bad" measurements with these instruments than with spectrum analyzers. Many spectrum analyzers have "front-end" overload and distortion problems, image rejection problems, aliasing problems, and other potential "traps" for the inexperienced user, especially when used out-of-doors in a relatively high ambient noise environment. Most spectrum analyzers do not have the bandwidths and detector functions needed to meet the requirements of many test standards and regulations. This author is aware of only three that do.

The Test Site

There are three attributes of an open-area test site that are of primary importance. These are the size and obstruction-free area of the site, the ground plane characteristics, and weather protective enclosures.

The minimum size of the site and its obstruction-free area is a function of the measurement distance to be used. Most regulations and standards specify measurement distances of three, ten, or thirty meters, but a few specify 100 or 300 meters. If the equipment under test (EUT) is small enough to be easily picked up and turned around by hand, or if the site is equipped with a turntable, the site may take the form of an ellipse with the EUT at one focus and test antenna at the other. The distance between the foci is the measurement distance and the size of the ellipse is such that its major axis is twice the measurement distance and its minor axis is the measurement distance multiplied by the square-root of three. This is the minimum obstruction-free area for the site. The terrain within this area should be as flat as possible and must be free of any obstructions, such as bushes, trees, and metal objects, which could reflect the radiated EME coming from the EUT. There must be two and only two paths for the EME to follow in getting from the EUT to the test antenna. One is the direct path from the EUT to the antenna, and the other is via the major reflection off the ground plane between the EUT and test antenna. The inclusion of any other path will make the tests invalid. There must be no metal fence around the perimeter of the area, nor any other major reflecting object, such as a wall or a vehicle at the edge of the ellipse. To assure that multiple reflections from many objects near the site do not cause problems with the measurements, more obstruction-free area is needed around smaller sites surrounded by many reflectors. For a three-meter site, walls of buildings or similar reflectors should be about eight times the measurement distance away from the site. For example, satisfactory performance cannot be obtained from a site set up in a parking lot with many metal vehicles near it. As the site gets larger, the nearness of major reflecting objects gets less critical so that a building located near the minimum obstruction-free area of a 30-meter or larger site would probably not cause significant problems.

The ground plane is one of the most important features of an open-area test site. The quality and size of the ground plane can have major impacts on the performance of the test site. The requirements for the ground plane are dictated to a large extent by the size of the test site and its specific use. For testing computer type equipment, or other EUT's that are mounted near the ground plane, on a three or ten meter site, the ground plane should be metal. On the other hand, for testing devices such as garage door opener receivers where the EUT is mounted two meters or more above the ground, a metal ground plane may not be needed if the quality of the earth is good. For measurement distances of 30 meters or more, a metal ground plane is needed only over poor earth. What constitutes good or poor quality earth is somewhat subjective. A good quality earth ground has no buried metal or debris that would make it non-homogeneous. It would be moist with a relative dielectric constant between 15 and 30, a relative permeability of unity and a conductivity between 0.001 and 0.15 siemens per meter. This is the definition of good earth from CCIR Recommendation 527. There have been many other descriptions of "good" earth which differ a little or a lot from the above. One could probably be safe in saying that a soil of dry sand would be a "poor" earth ground plane. Because of the uncertainties introduced by the considerations of good or poor earth ground planes, it is probably wisest to choose a metal ground plane for three- and ten-meter test sites.

The size and smoothness of the ground plane are questions that have been studied by a number of people including the ANSI task group on Open-Area Test Sites under Subcommittee 1 of ANS Committee C63. At the outset of the open-site task*, the group studied many sources of both practical and theoretical information on ground planes. Some sources, such as IEEE Standard 149-1979, "IEEE Standard Test Procedure for Antennas," recommend a range with a specularly smooth ground plane large enough to contain 20 Fresnel zones. After considerable study, the task group believed that a ground plane covering at least the first Fresnel zone was necessary and should be at least as smooth as the Rayleigh criteria. These were then the recommendations placed in the draft ANSI document on Open-Area Test Sites. Since that time, some of the task group members have obtained a great deal of practical experience with site attenuation measurements and have concluded that the size of the ground plane is not nearly so critical as had earlier been believed. For example, Mr. A.A. Smith of IBM has found that a 7m x 7m metallic ground plane appears to be adequate at 30 MHz for a three-meter measurement distance, while the axes of the first Fresnel ellipse for those conditions are long enough to require a ground plane about 10m x 9.5m. The International Electrotechnical Commission (IEC) has specified a ground plane 6m x 9m in IEC Publication 106. The Rayleigh criteria for the ground plane of a three-meter site to be used up to 1000 MHz allows a maximum rms roughness in the ground plane of 4.5cm. This is for a test geometry where the EUT is one meter above the ground plane and the test antenna is scanned over heights of one meter to four meters. This too appears to be less critical than first thought, but there has not been enough collective experience to permit making any difinitive statements about relaxing this criteria.

Weather protection covers are often constructed over open-area test sites to allow the test environment to be controlled for the benefit of the EUT, test equipment, or test personnel. Such covers must be non-conducting at all times to avoid serious discrepancies in the test results. All fasteners, supports, etc. must be non-conductors. A few nails or bolts that are five centimeters or less in length would probably not cause any problems, but in combination, many such fasteners could cause enough scattering to make the test data inaccurate. If the outside of a protective shelter becomes contaminated with dust and debris out of the air, measurement inaccuracies are sure to occur, so such covers must be kept clean. If the surface can be wetted by rain, the cover will become reflective during rainstorms. Remember, the cover is usually within the dimensions of the clear area, so it must not be reflective in nature. It is just as bad to have an undesired reflection from above the site as it is to have one from the side of the site.

*The ANSI task group on Open-Area Test Sites was formed to write an addition to ANSI C63.4 describing acceptable open-area test sites and prescribing methods for characterizing such sites.

Setting Up The Tests

There are three aspects of the test set up which are important and which frequently are at the cause of invalid test data. Of these, grounding of the EUT and the test equipment may be the chief problem area. The others are the arrangement of the EUT, especially the interconnecting cables, and the test equipment configuration and positioning.

The reference ground plane in a traditional open-area test site is a metallic ground plane placed directly on the surface of the earth, or perhaps on a hard-stand on the surface of the earth. It may be a solid sheet of metal, but is most often a mesh or screen. Ideally, it is made of a non-magnetic metal such as aluminum, but is frequently made of galvanized steel such as "hardware" cloth. It should be on top of the surface with no dielectric covering. In a traditional site there are no large cavities under the ground plane, such as work rooms. Under these conditions, the metal ground plane couples quite tightly to the earth (for radio frequencies) so that the exact details of grounding of the equipment under test and the test equipment are not critical. Variations in the grounding techniques generally do not produce significant effects in measurement accuracy. However, certain grounding and power isolation practices should be observed. These are discussed later along with the test equipment configuration.

The traditional open-area test site is becoming less popular. The current trend is that many open-area test sites are being designed and constructed with work space below the ground plane. When this is done, the details of grounding of the equipment under test and the test equipment become highly critical. Improper grounding of equipment may not cause significant errors to appear in site attenuation measurements, but will cause significant errors to occur in actual EMC measurements. In general, the guidelines are as follows:

- The metal ground plane must be *the* ground reference for the entire site.
- The equipment under test must be bonded to the ground plane (including the third wire safety ground.)
- The antenna cable must be grounded to the ground plane. This must be the ground reference for the test equipment.
- The powerline to the equipment under test should be filtered as it egresses under the ground plane.
- All details must be considered so that the radiated path direct from the equipment under test to the measurement antenna, with the major reflection from the top side of the ground plane, being the *only* path by which energy can couple. Energy from the equipment under test must *not* radiate below the ground plane (e.g. from power or signal lines) where it can couple directly to the test equipment or possibly resonate in the work-room (as a resonant cavity) and be transmitted up stair-wells, conduits, etc., to be picked up by the measurement antenna. If the test site has any of these faults, EMC measurements will not be reliably repeatable between the faulty test site and any other test sites.

The arrangement of the EUT can influence the test results to the extent that an EUT which actually has radiated emissions above the allowable limit will appear to pass the tests. It is important to test the EUT with its peripheral devices or suitable dummy loads connected, with all of the interconnecting cables in place. All cables should be arranged to provide as much radiated emission from them as possible without violating the design parameters of the interconnections. Cable positioning should be adjusted experimentally during the tests to maximize the emissions. If the EUT is designed to be used with peripheral equipment, but no such equipment or interconnections are part of the EUT, then any shielding covers for the interconnection ports should be removed or replaced by dummy covers and connectors to simulate the operating conditions that would exist with external peripheral equipment connected.

The operating parameters and modes of the EUT should be investigated by way of the equipment documentation before commencing the tests to identify the likely worst-case modes and conditions of operation. It is to the manufacturer's advantage to test the EUT in its worst-case mode and configuration to avoid having to solve interference problems after the product is in service at the customer's location.

An additional important consideration in EUT arrangements is one of safety. The EUT should be connected to the metal ground plane well enough to prevent any electric shock hazard to the test personnel! This safety ground connection should be carefully coordinated with the grounding of the EUT discussed above.

Test equipment configuration and positioning can affect the validity of the test results. The position of the test equipment and test personnel should be planned to minimize the perturbing effects they will have on the radiated emissions being picked up by the test antenna.

In many sites, the test equipment and personnel are positioned in a remote control hut outside of the obstruction-free area. This is an ideal situation in terms of the "cleanness" of the measurements, but this almost always requires extra amplifiers in the signal cable from the antenna. Frequently, these amplifiers add to the errors and reliablility problems of the test equipment, and must be dealt with very carefully. Such amplifiers are usually broadband and can easily be overdriven by signals and noise outside of the test equipment bandwidth. In this case, the amplifier gain may be compressed resulting in gross errors in the measured EUT emission levels, or distortion products may arise which either mask the emissions from the EUT or are mistaken for EUT-generated emissions. In any of these conditions, the measurements will be unreliable, perhaps meaningless, but possibly not recognized as invalid by the test personnel.

In some sites, the test equipment may be nearby the test antenna. If so, the equipment and test personnel must be positioned out to the side of the test antenna along a line that is perpendicular to the path from the EUT to the test antenna position. The antenna cable should drop vertically down to the ground plane, and lying on the ground plane, should then go as directly as possible over to the test equipment. It is best to keep the amount of metal nearby the antenna to a minimum so the test equipment should be placed on a non-metallic stand or table, and sheltered from the sun or other weather in a non-metal hut or tent. The power cables to the test equipment should lie on the ground plane and be routed along the perpendicular from the antenna mast to a power connection off the ground plane and outside the obstruction-free area. This power source should be isolated from the EUT power source by filters effective in the measurement frequency range. As mentioned earlier, the filter should be referenced to the metal ground plane. The test equipment should be connected to the power through an isolation transformer so that a single ground can be used for the test equipment. This same precaution should be taken in isolating the test equipment power in the situation mentioned earlier for a site where the test equipment is remoted outside the obstruction-free area.

The antenna cable shield should be connected to the ground plane near the base of the antenna mast. This should be the single ground point for the test equipment. The antenna cable, at its antenna end, should be routed from the terminals of the antenna elements perpendicular to the elements and horizontally in the direction opposite to the EUT for a distance of about one meter before dropping to the ground.

Testing - Getting the Data

Several test activities and considerations are important to getting reliable data from the tests. These concerns are rotating the EUT, height-scanning the test antenna, manual vs. automatic testing, and the effects of ambient noise. Of these concerns, the rotation of the EUT and height-scanning the test antenna are fundamental needs.

During the record tests, an infinite number of combinations of EUT position, test antenna height, and frequency appear to be needed to satisfy the "words" found in most test standards. Some preliminary testing will put practical bounds around this "boundless" problem. A preliminary spectrum search should be performed using a probe or antenna close to the EUT. The object of this search is to find out what the potential "problem" frequencies are in the EUT and to become familiar with the audio and video characteristics of the EUT emissions as they are evident in the audio and/or video channels of the test equipment. This search should normally be done in the laboratory prior to traveling to the open-area test site. It can be done relatively quickly and will save valuable time out on the test site. The preliminary spectrum search done close to the EUT in the laboratory eliminates many frequencies from further testing but identifies the problem frequencies that need to be tested, leaving only the direction, height and levels of maximum emissions to be determined at the test site.

Rotating the EUT during testing is necessary to find the maximum emisson level at any test frequency. The EUT can be rotated by picking it up and turning it to a new position relative to the test antenna, or alternately, by setting up the test antenna and equipment on several radials around the EUT. These are both time-consuming procedures and both have the weakness that the direction of maximum radiation may be missed. The preferred method of rotating the EUT is on a turntable capable of continuous rotation. If this arrangement is used, the technique of letting the EUT continuously rotate at a rate of from one to three revolutions per minute while monitoring the test equipment will assure finding the maximum emissons levels from the EUT.

Height-scanning the test antenna is also necessary to find, reliably, the maximum emission levels from the EUT. The direct and ground plane-reflected waves combine at the test antenna, and at any given antenna height, may either add to or subtract from each other depending on the test geometry, frequency, and radiation characteristics of the EUT. In extreme cases, complete cancellation can occur at some test antenna height. By varying the antenna height, these cancelling effects are avoided, so that the maximum emissions levels are measured. The test antenna is usually scanned over a one to four meter range of heights for test distances of three and ten meters, and a range of heights from two to six meters is used for 30-meter test distances. Some regulations and standards may require other ranges of heights.

When the test antenna is vertically polarized, it may not be possible to get it as low as one meter above the ground if it is a large antenna such as a resonant dipole. For this reason, most regulatory authorities allow tuned dipoles to be adjusted to the length that is required for use at 80 MHz, and used at that length for all frequencies 80 MHz and below. However, the calibration data for most tunable or adjustable dipoles is not valid for this condition, so special antenna calibration may be needed.

Manual or automatic methods may be used in making the tests. There are trade-offs to be made in selecting the approach to use. If tuned dipole antennas and other non-automated test equipment are used, the test data during the EMC tests will be manually measured and recorded point-by-point, frequency-by-frequency. A recommended procedure for doing this by the substitution method is included in Part 15 Subpart J of the FCC Rules and Regulations. Such a method is relatively time-consuming and thus expensive, but can produce much more accurate measured data as compared to automatic methods. The manual method can be used even with broadband antennas and automatic test equipment in the interest of obtaining data of high accuracy, but this is usually not done if automatable test equipment is available since automatic methods are less time-consuming and thus more cost-effective.

If accurately calibrated broadband antennas are available, along with automatic test equipment such as computer or calculator operated field strength meters or spectrum analyzers, automatic measurements may be made. Such equipment can be programmed to make the necessary measurements, store and reduce the data, and print or plot the results with a considerable time-saving over manual methods. While the resulting data may not be quite as accurate as properly and carefully measured manual data, it is very much faster and more complete. Typically, manual measurements are made at discrete frequencies with the potential of missing frequencies where there may be problems with the EUT, while automatic measurements may be made continuously with frequency and antenna position thus showing any problems that may exist.

The ANSI draft document on Open-Area Test Sites gives procedures for making site characterization measurements either way. These procedures can be adapted to EMC measurements also. The EMC test engineer must decide what is appropriate. Either or both methods may be used depending on the situation, including any regulatory requirements.

Adjustable, tuned dipole antennas have been traditionally used in taking measurements for meeting the rules and regulations of the FCC, and for measurements in accordance with military standards. Below a frequency of 80 MHz, these antennas are long and cumbersome to use and at all frequencies above 80 MHz they must be readjusted for each frequency at which measurements are made. More recently, in military standards, broadband antennas such as biconical dipole antennas, log-periodic antennas, and conical log-spiral antennas have been specified. This was done in the interest of speed of measurement, ease of use, etc., all aimed at more cost effective EMC testing. Many EMC engineers and test personnel are currently using broadband antennas for commercial measurements, with the same cost-effectiveness or time-efficiency objectives.

There are two types of adjustable, tuned dipole antennas available today. One is adjusted so that it is resonant at the frequency of use (truly tuned to resonance), and the other is adjusted so that its length is one-half wavelength at the frequency of use. Note that these are different lengths for the same "tuned" frequency, and if each dipole antenna is not correctly adjusted, its calibration data will not be correct. That is, the calibration data for a dipole that is supposed to be adjusted to resonance will be useless if that antenna is adjusted to one-half wavelength, and similarly, the calibration data for a dipole that is supposed to be adjusted to one-half wavelength will be useless if the antenna is adjusted to resonance. Furthermore, some dipole antennas have never been tested or calibrated on any kind of antenna range; their performance curves ("calibration") having been derived from theory. Such data ignores the balun and other losses in the antenna and is not correct.

Broadband antennas avoid the adjustment problems mentioned above with tuned dipole antennas. In most cases, the manufacturers of broadband antennas arrive at the antenna calibration by measurement rather than by theory. For example, SAE ARP 958-1968 is often used for antenna calibration. The user of the broadband antenna must determine that it has been calibrated under conditions that are appropriate for its use, i.e., an antenna calibration developed at a distance of one meter for use in MIL-STD-461/462 test work will probably not be useable for measurements at three or ten meters in the FCC equipment authorization program. Also, circularly polarized antennas are not acceptable for use in the FCC (and many other) equipment authorization programs.

Ambient noise in the open-area test site may cause considerable trouble for the test operator in getting a reliable test of the EUT. The ambient noise can be in the form of broadband noise, narrowband carriers, or a combination of both. Different approaches are needed to deal with the different types of noise. In both cases, a pre-knowledge of the characteristics of the EUT emissions will be quite helpful in separating the EUT emissions from the ambient noise. The audio and/or video channel of the test equipment should be monitored during all tests to provide the means of identifying an emission as either EUT or ambient.

If the ambient noise all happens to be well below the emissons limit that is applicable to the test, then the test can be completed without concern for the ambient noise level. This will not usually be the case, however. There are a number of possible approaches to overcoming the ambient noise problem. One is to select a time of day for making the measurements when local transmitters are quiet. This is inconvenient but effective in some situations. Generally, the approaches used should be based upon the differences in the characteristics of the EUT emissions and the ambient noise including near-field and far-field relationships where they exist. Also, the test engineer should not neglect the effects of different bandwidths and detector functions in the test equipment when used to exploit the different signal and noise characteristics mentioned above. Finally, the overriding consideration is that the approach taken must be carefully engineered since it must be defensible with the authorities administering the regulations and standards under which the EMC tests are being performed.

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