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American National Standard Guide for Automated Electromagnetic Interference Measurements

Accredited by the American National Standards Institute

Sponsored by the
Accredited Standards Committee on Electromagnetic Compatibility, C63

IEEE

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American National Standard Guide for Automated Electromagnetic Interference Measurements

Accredited Standards Committee on Electromagnetic Compatibility, C63

accredited by the

American National Standards Institute

Secretariat

Institute of Electrical and Electronics Engineers, Inc.

Approved 24 June 2004 by the

American National Standards Institute

Abstract: U.S. consensus guideline for automation of conducted and radiated EMI compliance measurements is provided in this guide. This document does not include mandatory specifications for automation tools (i.e., application software, automated test equipment, computers and peripherals). Where possible, the guidance provided herein is harmonized with other national and international standards used for similar purposes.

Keywords: conducted emissions, data analysis tools, data handling, exploratory measurements, facility integrity, final measurements, prescans, probability of signal intercept, radiated emissions, sweep times, scan rates

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Introduction

This introduction is not part of ANSI C63.22-2004, Guide for Automated Electromagnetic Interference Measurements.

This introduction provides some background on the rationale used to develop this guide. This information is meant to aid in the understanding and usage of this guide.

This guide describes, in general terms, the use of automatic test equipment and the automation of measurements of electromagnetic emissions. It is intended for the following:

- Individuals or organizations who plan on automating Electromagnetic Interference (EMI) measurements and acquire that application software from a supplier.
- Individuals or organizations who acquire EMI application software from a developer for resale to other individuals or organizations.
- Individuals or organizations who determine the feature set for EMI application software.
- Individuals or organizations who perform automated EMI measurements.
- Software suppliers interested in providing high-quality software to acquirers.

This guide is designed to help individuals or organizations:

- Determine the appropriate feature set of EMI automation software
- Validate the settings of software parameter used to perform measurements
- Determine requirements for test equipment to be used in an automated system
- Determine characteristics of automated test systems for a given test environment

This guide is intended to satisfy the following objectives:

- Promote consistency within organizations in acquiring third-party software from software suppliers
- Provide useful guidelines for the implementation of automated test systems
- Provide useful practices on the determination of necessary software features to automate specific tests
- Provide useful practices on the use of software tools for data acquisition and data analysis purposes
- Assisting individuals and organizations judging the quality and adequacy of supplier software

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At the time that the Accredited Standards Committee on Electromagnetic Compatibility, C63, approved this guide, it had the following membership:

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American National Standard
Guide for Automated Electromagnetic Interference Measurements

1. Overview

1.1 Scope

The purpose of this document is to provide guidelines for the use of automatic test equipment (ATE) for the measurement of electromagnetic emissions of electronic, electrical, and electro-mechanical equipment. It is intended to be a companion document to ANSI C63.2-1996[1] and ANSI C63.4-2003 for making accurate and repeatable automated emissions measurements from 9 kHz to 1 GHz according to commercial Electromagnetic Interference (EMI) regulations. As such, it addresses automated measurement processes, automatic test equipment, and measurement integrity aspects. Furthermore, the importance of a test plan will be outlined. Although intended for automatic testing, these guidelines also apply to semiautomatic measurements where only parts of a test may be automated.

1.2 Application

The purpose of an automated EMI test system is to increase the efficiency, consistency, and repeatability of both engineering and compliance testing. Successful automated testing requires well-defined automated measurement processes that are appropriate for a specific test goal and ensure measurement integrity.

By automating measurements, the test efficiency can be enhanced and the repeatability of the data collection process improved. Automated measurement processes take care of direct measurement activities such as rotating a turntable, tuning a signal generator or EMI receiver over a frequency range, or changing antenna height and polarization, and thus improve efficiency. Measurement integrity is primarily concerned with the accuracy and repeatability of the results rather than the speed of execution. The integrity of radiated emissions test data, collected on an Open Area Test Site (OATS), is especially difficult to ensure due to the presence of ambient signals and influences of weather conditions on the results. Measurement integrity considerations also address general concerns such as control of EUT operating modes during the test, EUT layout, test system configuration, and data storage and analysis. All these aspects are labor-intensive, prone to errors, and may lead to a lack of repeatability. Automated measurements can overcome many of these issues and improve the quality of test results by ensuring consistency and repeatability. However, a detailed analysis of necessary test procedures and careful definition of measurement algorithms, based on manual measurements, are mandatory for a successful deployment of application software.

[1] Information on references can be found in Clause 2.

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When automating EMI measurements, it is essential to ensure data integrity, especially in the case of performing compliance measurements. Measurement instrument settings and all relevant parameters like antenna factors, cable losses, etc., must either be stored along with the test results or the access to these parameters is to be restricted. This will ensure that no changes can be made after the measurement data is taken which would invalidate the test results or make an appropriate interpretation impossible.

ATE can consist of EMI receivers, spectrum analyzers, signal generators, voltmeters, amplifiers, etc., capable of being remotely controlled by computing equipment which can be any kind of controller or computer. The actual instrument control, data acquisition, presentation of measurement results and documentation is usually done by a dedicated application software, specifically designed for automated emissions testing. Each category of ATE will be described separately and no attempt will be made to provide specific programs or software algorithms. It is up to the individual user to ascertain if the used application software correctly processes measurement data to produce accurate results.

System peripherals like plotters and printers will not be discussed in detail and will only be mentioned when they are used at a certain point in the measurement process to record the acquired results or the data which may have been displayed on a spectrum analyzer or EMI receiver.

Almost all of the functions associated with EMI testing may be automated. However, the option of complete or partial manual override is necessary, particularly for engineering tests. Automated emissions testing still requires the EUT to be configured and arranged first for capturing maximum emissions. This includes the determination of the worst-case operating mode and manual cable manipulation.

One of the basic requirements of an ATE system is its user interface and the ease of use provided by it. An operator shall have EMI measurement knowledge, but a high degree of expertise should not be mandatory to run the actual test. However, the test process and selection of the individual steps to be automatically executed needs to be defined by a knowledgeable user. When defining an automated test process, it is recommended that the following factors be taken into account:

— The measurement process should be sufficiently flexible to allow some customizing of the test procedure without jeopardizing the integrity of the test results or consistency of the reporting. This should include quick overview tests with relatively low-frequency resolution and frequency accuracy to capture the emissions profile of an EUT and high resolution and accuracy measurements for the actual determination of the emission frequencies and amplitudes.

— Common repetitive tasks such as maximizing signals, applying correction factors, and generation of test reports should be performed automatically.

— The measurement data should be presented in a manner such that further corrections are not required.

— Results should be stored in a central database or other electronic format for future use and reference.

— Manual interaction with the test system should be possible at all times, or after completion of certain steps, in the automatic measurement procedure.

— The automated test system should be sufficiently flexible and expandable in its frequency range coverage to address future requirements.

— The data format should be compatible with a database program and, if applicable, be acceptable to regulatory authorities.

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2. References

The following standards shall be used when implementing this standard. When the standards are superseded by an approved revision, the revision shall apply.

ANSI C63.2-1996, American National Standard for Electromagnetic Noise and Field Strength Instrumentation, 10 Hz to 40 GHz—Specifications.[2]

ANSI C63.4-2003, American National Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz.

ANSI C63.7-1992, American National Standard Guide for Construction of Open-Area Test Sites for Performing Radiated Emissions Measurements.

ANSI C63.14-1998, American National Standard Dictionary for Technologies of Electromagnetic Compatibility (EMC), Electromagnetic Pulse (EMP), and Electrostatic Discharge (ESD).

CISPR 16-1-1 (2003), Specification for Radio Disturbance and Immunity Measuring Apparatus and Methods—Part 1-1: Radio Disturbance and Immunity Measuring Apparatus.[3]

CISPR 16-1-2 (2004), Specification for Radio Disturbance and Immunity Measuring Apparatus and Method—Part 1-2: Radio Disturbance and Immunity Measuring Apparatus—Ancillary Equipment—Conducted Disturbances.

ISO/IEC 17025:1999, General Requirements for the Competence of Testing and Calibration Laboratories.[4]

3. Definitions

The following definitions apply specifically to the subject treated in this document. For additional definitions, see ANSI C63.2-1996, ANSI C63.4-2003, ANSI C63.14-1998, CISPR 16-1-1 (2003), and *The Authoritative Dictionary of IEEE Standards, Seventh Edition* [B1].

3.1 alternate test site: An alternate test site used for radiated EMI compliance testing and complying with the requirements in ANSI C63.4-2003.

3.2 conducted emissions test site: A test site used for conducted EMI compliance testing and complying with the requirements in ANSI C63.4-2003. A conducted emissions test site includes LISNs installed according to the requirements documented in ANSI C63.4-2003.

3.3 facility: A complete installation involved in testing, including the actual site, measurement instruments, and support equipment.

3.4 frequency accuracy: Accuracy with which the measuring instrument can determine the frequency of an unknown signal.

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[2] ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

[3] CISPR documents are available from the International Electrotechnical Commission, 3, rue de Varembé, Case Postale 131, CH 1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). They are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/)..

[4] ISO publications are available from the ISO Central Secretariat, Case Postale 56, 1 rue de Varembé, CH-1211, Genève 20, Switzerland/ Suisse (http://www.iso.ch/). ISO publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

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3.5 intercept: The detection of an intermittent, impulsive, or slowly varying emission with an EMI receiver.

3.6 list: A tabulation of test data, measurement system settings, limit values or test facility parameters.

3.7 maximum hold function: An EMI receiver or spectrum analyzer function which retains the maximum amplitude value, measured during consecutive sweeps, at each display point in the selected frequency span. The implementation of this function requires a digital display.

3.8 measurement band: A frequency range defined by transducer parameters, spectral characteristics of signals, or software algorithms to achieve a certain measurement goal.

3.9 open area test site: An outdoor measurement location used to perform radiated EMI compliance testing. Requirements for their acceptability and construction are called in ANSI C63.4-2003 and ANSI C63.7-1992 respectively.

3.10 receiver: A measuring instrument that meets the requirements called out in ANSI C63.2-1996 or CISPR 16-1-1 (2003).

3.11 scan rate: The ratio of the selected frequency span and the measuring instrument's sweep time setting.

3.12 scanning receiver: A measuring instrument that complies with the requirements called out in ANSI C63.2-1996 or CISPR 16-1-1 (2003), as applicable, and does not cover a frequency range in discrete frequency steps but continuously tunes across it

3.13 semi-anechoic chamber: A shielded enclosure with a reflecting ground plane and absorber lining on all walls and the ceiling.

3.14 signal identification: The numerical, audibl,e or visual process of identifying two or more signals to be either from different or the same origin.

3.15 site: The environment in which measurements are performed; it includes the ground plane, weather protection, shielding, absorbers, support structures, and surroundings as well as ambient signals.

3.16 sweep time: The time required by the measuring instrument to electronically tune across a selected frequency span.

4. General guidelines for automated measurements

Care should be taken by the automated test system designer in obtaining a thorough understanding of all elements of the measurement process, as well as of the measurement system to be used in the data collection process. The performance of a measurement with a lack of such knowledge may result in the acquisition of erroneous and/or invalid data.

The general automated test system can be divided into four distinct sections. These are 1) the transducer and signal conditioning section, 2) the verification section, 3) the signal measurement section, and 4) the control and data processing section. Though identified as separate entities for clarity in this document (see Figure 1), it should be noted that in many modern EMI test systems, a single equipment item may contain elements of multiple sections as identified here.

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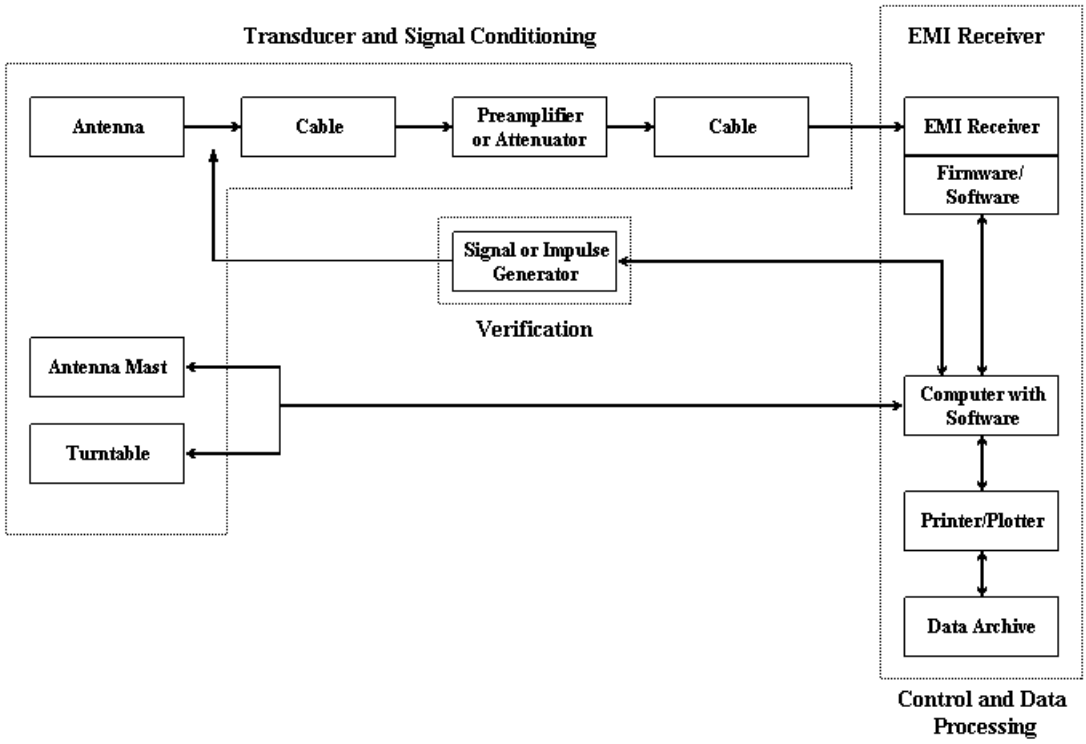


Figure 1—Elements of an automated radiated emission test system

4.1 Transducer and signal conditioning section

The transducer and signal conditioning section of the system consists of all elements that are placed in front of the input connector of the EMI receiver. The function of this section of the system is to intercept the maximum signal levels emitted from the EUT, and transmit this energy to the receiver in a measurable form. These elements can include antennas or *line impedance stabilization networks* (LISNs), cables, the antenna selection RF switch (if multiple antennas are used to cover the appropriate frequency range), and any preamplifiers or attenuators (external to the EMI receiver) necessary to bring the signal levels to be measured to within the dynamic range of the receiver. In addition, included in this section is the antenna tower, and the EUT turntable, which are used to determine the maximum emission levels based on antenna height and polarization as well as EUT orientation relative to the measuring antenna.

4.2 Verification section

The verification section of the emissions measurement system is necessary to ensure that data is collected with a functioning test system and the required tolerances, as per the applicable test specification, are met. The verification section consists of a stable signal source, which should be traceable to national calibration standards (e.g., NIST or other local standards reference organization), the associated cabling, and a dedicated manual or automated procedure. The verification procedure presents a means of quickly demonstrating that most elements of the measurement system, from the transducer output port to the data presentation, perform within previously defined tolerances that are acceptable by the standard to which testing is being performed. It should be noted that this process is not intended to be a detailed true test of the performance characteristics of the receiving system, but merely a means to check the tolerance of the

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frequency and amplitude calibration. It does not address many additional and important EMI receiver parameters.

A verification signal can be generated by a stand-alone signal generator, a receiver's tracking generator, or a calibrated impulse generator. Verification, in its most simplified form, is performed by disconnecting the RF coaxial cable from the system's receiving transducer, and connecting it to the verification signal source. The generator's output frequency shall be tuned over the measurement frequency range of interest and its signal amplitude is measured by the EMI receiver. By comparing the current results with previously recorded and verified data, test system malfunctions can be identified quickly and a determination made if the resultant data still meets required tolerances. Once the verification process has been completed, the signal source is disconnected, and the system's receiving transducer reconnected.

4.3 EMI receiver section

The EMI receiver section of the system consists of one or multiple instruments that perform the actual signal measurement. Specifically, the EMI receiver shall have performance characteristics that meet the requirements of ANSI C63.2-1996 and/or CISPR 16 1-1 (2003). In addition, the receiver shall sufficiently meet the actual requirements for testing an EUT to the applicable regulations, especially in regard to the necessary sensitivity and frequency accuracy.

4.4 Control and data processing section

The control and data processing section of the automated measurement system takes many forms. First, any automated control system within the receiver section shall be considered as a part of this section. This includes not only instrument firmware-controlled processor systems, but any software that can be input directly into the receiver's memory, and thereby operates as an onboard control system. Secondly, this area includes external controllers or computers along with their application software. Finally, consideration shall be given to the data storage and output devices like printers or plotters that are a part of the overall system. The quality and resolution of the graphical test data presentation, as well as any tabular information shall meet the requirements of the applied standards and the overall measurement goal (e.g., visual comparison of different sets of data resulting from EUT modifications).

4.5 Precautions for automating EMI measurements

Much of the tedium of making repeated EMI measurements can be removed by automation. Operator errors in reading and recording measurement values are minimized. By using a computer to collect data, though, new forms of errors can be introduced that may have been detected by an operator. In some situations, automated testing can lead to greater measurement uncertainty in the collected data than manual measurements performed by a skilled operator. Fundamentally, there is no difference in the accuracy with which an emission value is measured whether manually or under software control. In both cases, the measurement uncertainty is based on the accuracy specifications of the components used in the test setup. Difficulties may arise, though, when the actual measurement situation is different from the scenarios for which the software was designed.

For example, an EUT emission adjacent in frequency to a high-level ambient signal may not be measured accurately, if the ambient signal is present during the time of the automated test. A knowledgeable tester, however, is more likely to distinguish between the actual interference and ambient signal; therefore, the method for measuring the EUT emission can be adapted as required. However, performing ambient scans prior to the actual emission measurement with the EUT turned off to record ambient signals present on the OATS can sometimes save valuable test time. In this case, the software may be able to warn the operator of the potential presence of ambient signals at certain frequencies by applying appropriate signal identification algorithms.

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In a situation where the EUT emission is slowly varying in amplitude, the software may not have been set up for a sufficiently long dwell time at the emission frequency to capture its peak amplitude. By knowing or observing the emission characteristics of the EUT during an overview measurement, the operator will be able to specify the relevant frequency scan parameters during software setup for the final test.

Testing an EUT with a low on-off cycle can cause problems in regard to the probability of intercepting its emissions. If the EMI receiver is tuned to frequencies where no EUT emissions occur during the on-cycle, no emissions are recorded. Therefore, multiple scans may be necessary using a "maximum hold" mode to intercept these kinds of EUT emissions.

Improper data may be recorded during an automated measurement when transient ambient signals are captured, such as arc welding transients, during an OATS test or a brief power line transient from heavy equipment switching. An operator either may not see these signals at all during a manual test or recognize their nature and choose to ignore them as being irrelevant to the test.

The process of finding the EUT and cable configuration that yields the worst case emissions is primarily a manual operation. A scanning receiver providing a graphical display of the emission spectrum and signal max hold capability is of great help for observing the changes in amplitudes as cable and equipment layouts are manipulated. The automated measurement of emissions should begin after the worst case EUT arrangement has been set up.

NOTE—This process can only be done through manual manipulation of the cable configuration.[5]

The measurement of a particular radiated emission includes a maximization process involving the rotation of the EUT, scanning the receive antenna over a height range, and changing antenna polarization. This time-consuming search process can be effectively automated, but it shall be recognized that a variety of search strategies may be used which can lead to different results. In case of previous knowledge of the EUT's radiation characteristics, a maximization sequence should be chosen that allows the determination of the worst-case amplitude within the search ranges of the antenna mast and the turntable. For instance, if the EUT emits highly directive signals in the horizontal plane, e.g., due to slots in the case, the turntable should be rotated continuously while taking data with the receiver. A turntable rotation in discrete steps, on the other hand, may not allow the detection of the maximum amplitude or may cause the signal to be missed completely in case the chosen angular increments of the turntable positions are too far apart.

One search strategy might be to rotate the turntable 360 degrees while leaving the antenna at a fixed height to find the angle for maximum emission amplitude. Next, the turntable is rotated back over the full range after the antenna polarization has been changed (e.g., from horizontal to vertical). During this process, test data is taken continuously with the receiver and at the end of the second scan the highest amplitudes, based on turntable angle and antenna polarization, are determined. Then, the worst case positions of the antenna and turntable are selected and the antenna is scanned over the required height range to find the position yielding the maximum amplitude. At this point the emission level is either recorded using the appropriate receiver or spectrum analyzer detector after returning to the maximum emission height, or finer search continues with incremental rotation of the turntable and following incremental height search, to find the maximum emission amplitude at the given frequency with greater precision. Again, it is important to have some understanding of the radiation pattern of the EUT in order to set up the software for an optimum search strategy that finds the maximum of the EUT emission in the shortest time. Variability is introduced into the test result when the final measurement is performed on the slope of the signal rather than on its peak.

[5] Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement this standard.

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4.6 Measurement methodology

4.6.1 Power line conducted emission measurements, 9 kHz to 30 MHz

Measurements of conducted emissions on power lines according to commercial EMI regulations require the use of a LISN. The test process being used is based on the fact, that for many types of EUTs, i.e., Industrial-Scientific-Medical (ISM) equipment and Information Technology Equipment (ITE), both quasi-peak and average detection have to be used to demonstrate compliance with the appropriate regulation. The generic measurement process is depicted in Figure 2. Its main goal is to achieve the shortest overall measurement time possible by applying the required detectors based on previously collected test results.

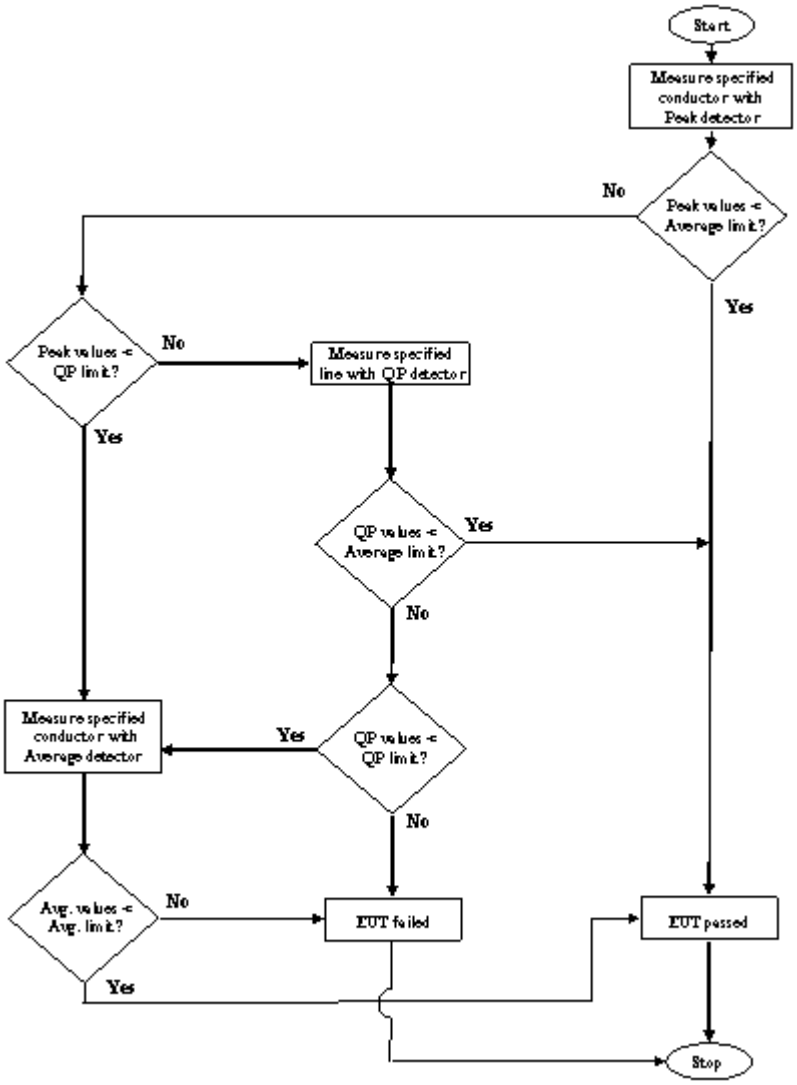


Figure 2—Flow diagram of a conducted EMI measurement

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Prior to commencing the measurement process, test personnel should verify the proper functioning of the measurement system. This can be achieved by measuring a signal source with known output characteristics. The measurement result of this verification process is compared against the expected values; if the differences are within previously defined tolerances the correct functioning of the measurement equipment can be assumed. The result of the system verification should be recorded and documented for later reference.

The EUT is set up according to the applicable standard in its worst-case configuration and arrangement and operated in the mode producing the highest emission levels. Furthermore, precautions shall be taken to avoid interference from ambient signals or to prevent auxiliary equipment from generating excessive emissions themselves. This can be accomplished by conducting the measurement in a shielded enclosure; only the transducers (i.e., LISNs, voltage probes, and current probes) will be placed inside the shielded room along with the EUT and necessary cabling. All other components of the test system, such as EMI receiver and computer, should be placed outside the enclosure to avoid unwanted interference. The measurement process is started by measuring the first conductor of the power line versus ground using peak detection to avoid excessive measurement times of average or quasi-peak detection.

The peak measurement data is compared against the average limit first. If the data is below this limit, the next conductor of the power line can be measured over the frequency range of interest followed by the same limit check. This process is repeated to measure all the conductors required. If all peak measurement data is below the average limit, the EUT complies with the regulation and the test is complete.

If peak measurement data for a conductor exceeds the average limit, the data is compared against the quasi-peak limit. If the peak measurement data is below the quasi-peak limit, the conductor is measured using the average detector. In case the average result is below the average limit, the EUT complies with the regulation. If the average data exceeds the average limit, the EUT fails the test.

If the peak data exceeds the quasi-peak limit, the associated conductor has to be remeasured using quasi-peak detection. The resulting quasi-peak data is then compared against the average limit. In case the quasi-peak data is below the average limit, the EUT is in compliance with the regulation and another conductor can be measured.

If the quasi-peak amplitudes exceed the average limit, the data is compared against the quasi-peak limit. If the data exceeds the quasi-peak limit, the EUT is not in compliance with the regulation. In case the quasi-peak data is below the quasi-peak limit, the conductor needs to be remeasured using average detection. The result is then compared against the average limit line and in case the test result is below the limit, the EUT complies with the regulation; otherwise, the EUT fails the test.

The final result must be recorded in accordance with the applicable standard. For example, per ANSI C63.4-2003, 10.1.8.1, the amplitude and frequency of the six highest signals shall be reported for each current-carrying conductor, unless these emissions are more than 20 dB below the limit.

4.6.2 Radiated emissions measurements, 30 MHz to 1 GHz

Commercial EMI regulations call out an open area test site as the test environment for radiated emissions measurements. Different problems like weather conditions, presence of ambient signals, or nearby reflecting objects are associated with an OATS. Therefore, various alternative test sites, like semi-anechoic chambers, are used to mitigate these problems, but currently the reference test site is still an OATS. Depending on the available test facilities, the measurement process for radiated emission tests might differ. The following paragraph explains some possible approaches, which are depicted in the flow diagram in Figure 3.

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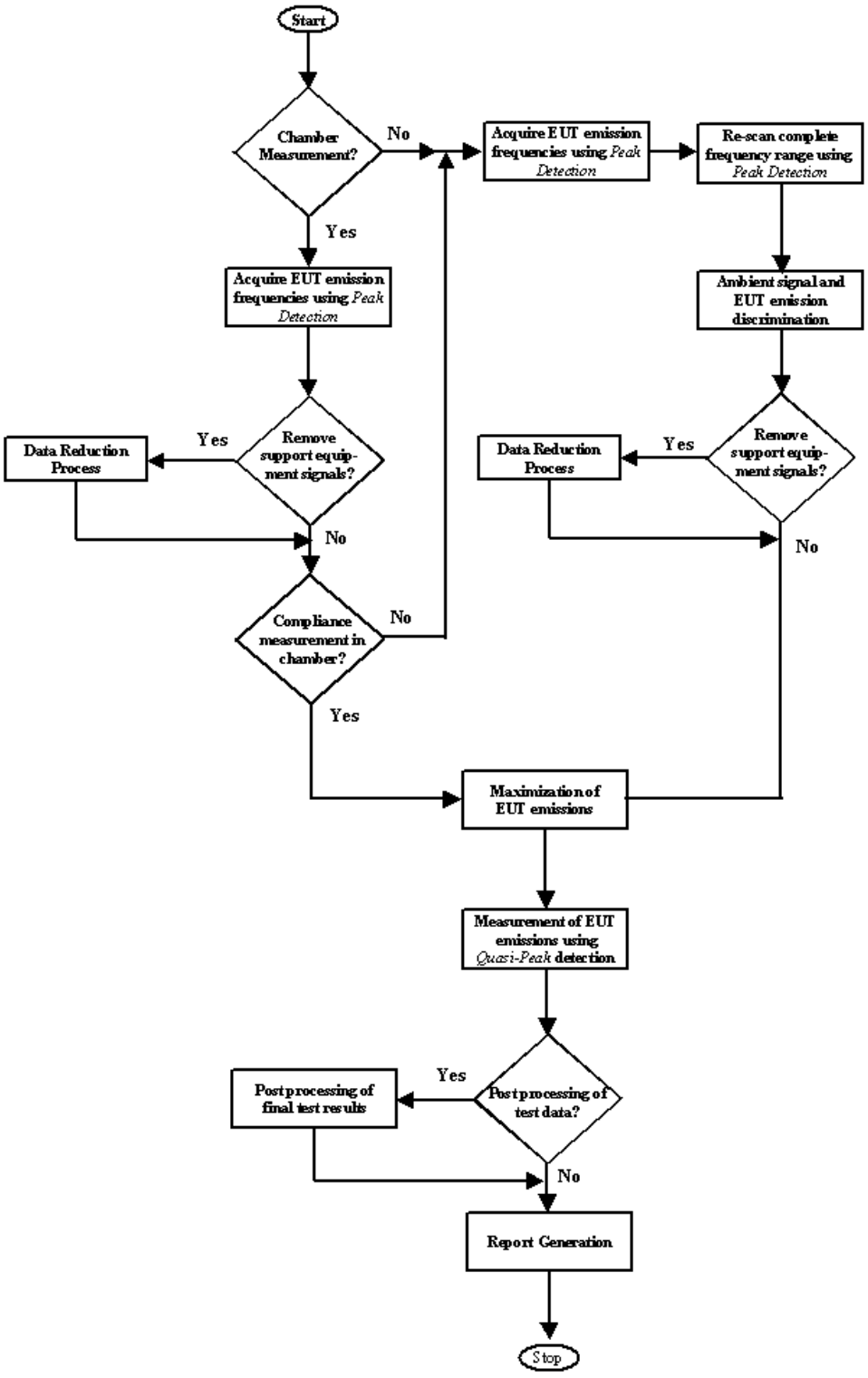


Figure 3—Flow diagram of a radiated EMI measurement

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The fundamental difference between measurements on an OATS and in a semi-anechoic chamber is the identification of ambient signals, which is usually necessary for OATS tests. Ambient signals can mask EUT emissions or be superimposed, possibly leading to erroneous measurement results or wrong interpretation of test data. Shielded rooms which are equipped with absorbing materials on the walls and ceiling provide an environment with sufficient suppression of internal reflections for quick overview measurements. The selection of the absorbing material shall be based on the frequency range of interest.

If a semi-anechoic chamber is available which does not meet the normalized site attenuation (NSA) criteria, it cannot be used as a direct substitute for an OATS for radiated emissions compliance measurements. However, relevant EUT emission frequencies can be detected in such a facility and stored in a list without any interference from ambient signals. This part of the measurement process, known as *prescan* or *exploratory measurement*, is started after the EUT has been set up according to applicable standards in its worst-case operating mode and arrangement. An exploratory measurement allows the fast compilation of relevant EUT frequency lists using peak detection. Amplitude information is of secondary interest in this case because chamber deficiencies, such as room resonances and reflections, might alter the emission amplitudes. The size of such chambers sometimes does not allow for complete height scans of the antenna and/or the use of the appropriate test distance. This also has an impact on the measured amplitude values. Another important parameter of an exploratory measurement is the necessary frequency accuracy; measurements with high-frequency accuracy require high- frequency resolution, which leads to longer test times. However, very high frequency accuracy is usually necessary in case the prescan signals are to be remeasured on an OATS. In this case, high-frequency accuracy will speed up the EUT signal identification in the present ambient spectrum.

After the exploratory measurement a second step might be necessary, depending on the EUT configuration and the test situation. This part, known as *Data Reduction*, can be used to eliminate signals from the prescan list, which are not generated by the EUT, but by auxiliary equipment necessary to ensure normal operation of the actual EUT. For instance, a network router as the EUT requires a LAN traffic generator to be connected during the measurement. This device emits signals itself, which are present during prescan, and therefore will be measured and stored. However, a data reduction process can eliminate these kinds of frequencies using signal comparison techniques, if those signals are known beforehand and saved in separate lists. The output list of the data reduction process then serves as the input to the two remaining processes necessary to complete the radiated EMI compliance measurement; signal maximization and measurement and possibly post processing.

For semi-anechoic chambers, which do not meet the normalized site attenuation criteria, the compiled and reduced frequency lists have to be processed further on an OATS or in an a semi-anechoic chamber suitable for EMI compliance measurements. In this case, the EUT will be set up as before and the measurement will be carried out according to the requirements called out in the applicable regulation. The full spectrum is to be investigated again on the OATS to ensure that no relevant emissions went undetected during the exploratory measurement; the frequency list is to be amended with all newly found significant EUT emissions. Then the maximum amplitudes of only those EUT frequencies in the list are determined involving antenna height scans, antenna polarization changes, and EUT position changes relative to the receiving antenna. This maximization process is usually carried out using peak detection to save measurement time. In case broadband signals need to be maximized, quasi-peak detection may be used as well during this process. After determining the worst-case positions of the antenna height, polarization and turntable angle, measurements at these positions are made with the required detector, i.e.; quasi-peak and/or average detection. These final amplitudes are compared against the appropriate limits. The result of this comparison determines if the EUT complies with the applied regulation. In a last step of the measurement process, a post processing procedure can be applied, if necessary. This way documentation needs can be met by using sorting or comparison techniques.

These modified lists are used in a report generation process along with information about the EUT, the test facility, measurement equipment, etc., to produce the test report.

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If the exploratory measurement was conducted in a semi-anechoic chamber which meets the NSA requirements for alternate test sites, the compliance measurement may be completed in this environment without taking the reduced prescan frequency list to an OATS. Maximization of the emission amplitudes and their final measurement using the appropriate detector are done under conditions called out in the applicable regulations.

If no semi-anechoic chamber is available for either exploratory measurements or full compliance tests, a very elaborate ambient discrimination process is required to identify the EUT signals within a crowded ambient spectrum. The initial prescan process is different from the approaches outlined previously. After the EUT has been set up in the worst-case configuration, the prescan process is initiated, which leads to the detection of both EUT and ambient signals since both types of signals are present during the measurement. A shorter test distance between the EUT and the measuring antenna, e.g., 3 m, can be used to improve the detection of EUT emissions in the ambient spectrum and the determination of relevant frequencies. All signals found during this exploratory measurement process are stored in a list, which is used in a numerical ambient discrimination process, to eliminate ambients. This process requires a second signal list containing the ambient signals present on the OATS. Such an "ambient list" shall be compiled in a separate measurement. Ideally, an ambient list is compiled over a certain period of time to ensure its completeness. Furthermore, periodic updates of these lists are necessary to keep them current. Dedicated application software can improve the measurement efficiency by eliminating previously identified ambient signals. This automatic elimination process shall involve a sophisticated signal identification process, which addresses possible amplitude and frequency variations between ambient and EUT signals as well as frequency accuracy considerations. A conservative approach is necessary to retain signals which cannot be uniquely identified as either an ambient or an EUT emission. These cases have to be investigated by a skilled operator; the automatic comparison can help to reduce the number of these cases and thus reduce the time required for manual interaction. After all ambient signals have been removed from the prescan list, the remaining EUT signals are saved in a separate list. Care must be taken to avoid eliminating emissions that are superimposed by ambient signals. The comparison of the ambient list with the prescan results before the data reduction will indicate the frequencies common to both lists. A manual verification should be performed to ensure the retention of all relevant EUT signals. The remaining emissions are maximized and measured as previously outlined. Post processing as well as the report generation address various documentation requirements and are the last steps to complete the radiated measurement. For further details see clause 7.3.4.

5. Test equipment

5.1 Automated test equipment

5.1.1 Control equipment

Control equipment includes the computer that is used to control the primary measuring equipment as well as any peripheral equipment like printers and plotters. In addition, the application software, which performs the automated test and associated computations, is also part of this equipment category. Any computer hardware and application software capable of performing the necessary control functions and computations is acceptable.

5.1.2 Primary measuring equipment

The primary measuring equipment category includes measuring devices that can be remotely controlled by a computer over an interface bus controller and send measurement data back to the computer when requested. These instruments are usually automatically tuned and capable of measuring voltages frequency-selectively. Examples include remotely controllable EMI receivers, spectrum analyzers, or frequency-selective voltmeters. These instruments have to meet the specifications called out in ANSI C63.2-1996 and/or CISPR 16-1-1 (2003). If power meters or signal sources are necessary to accomplish a certain measurement task, they are also classified as primary measuring equipment.

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Each primary measuring equipment is subject to calibration with traceability to a national or international calibration authority or a standards reference organization. At a minimum, the equipment manufacturer's suggested calibration cycles should be observed. Ideally, the measurement traceability and calibration requirements called out in ISO/IEC 17025 (1999) should be met.

5.1.3 Peripheral equipment

Peripheral equipment includes devices to vary the test setup like turntables and antenna towers, as well as devices like printers or plotters to generate hard copies of test reports or EMI receiver or spectrum analyzer screen printouts. In general, these devices do not require periodic calibration. While turntables and variable height antenna towers do not require calibration, the laboratory and test personnel should periodically verify the proper performance and accuracy of these devices.

5.1.4 Transducers

Transducers include antennas, LISN, voltage probes, absorption clamps, current probes, and cables used to connect the transducer to the primary measuring equipment. All transducers shall comply with the requirements of ANSI C63.2-1996, ANSI C63.4-2003, CISPR 16-1-1 (2003) or other applicable specifications.

In most cases, these type of devices are not remote controllable. In case they are equipped with a remote control interface (e.g.; LISN or absorption clamp), all control or power line leads should be properly filtered to eliminate interference effects from the ATE and external ambient signals. For use on an alternate test site, the filtering should be applied at the boundary (e.g. the wall) of the test site.

Typically, transducers are passive devices that do not exhibit overload characteristics due to high signal levels. If active transducers are used, it is necessary to prevent overload conditions and thus avoid erroneous measurements. A mathematical correction of the measured signal levels to account for overload situations is not permissible. Linear operation of the transducers and the measurement system itself has to be ensured by proper signal conditioning, e.g., by using filtering and/or attenuation.

The application software should include a transducer library containing the appropriate calibration factors of the transducers in the signal path (e.g., antenna factors, cable loss, switch insertion loss, etc.). At a minimum, these factors need to be determined either based on the manufacturer's suggested calibration cycle (for instance, in case of antennas) or verified according to applicable standards. Ideally, the measurement traceability and calibration requirements called out in ISO/IEC 17025 (1999) are met. These factors shall cover the entire frequency range for which the transducer is defined. It is recommended that a minimum of 5 calibration points be used for each frequency octave. The application software shall use interpolation to determine factors between calibration points. The type of interpolation, logarithmic or linear, to be used with a transducer shall be included as part of the calibration data.

5.2 EMI receiver

As a minimum, these devices shall meet the requirements called out in ANSI C63.2-1996 or CISPR 16-1-1 (2003). For a receiver to be used in an automatic test system, it shall be remotely controllable and be able to transfer measurement results back to a computer over an interface bus. Furthermore, state-of-the-art equipment incorporates many measurement and signal analysis functions, which are available for both manual use and under software control.

In addition, EMI receivers often contain an internal reference signal generator and RF switching circuitry to enable self-calibration checks and adjustments, which can be performed under computer control. If such built-in calibration features are not available in the receiver, the required hardware shall be provided externally to the receiver as part of the automated emissions measurement system.

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A scanning EMI receiver is electronically tuned over a selectable frequency span, which allows quick coverage of wide frequency ranges. A stepped EMI receiver covers the frequency range of interest by consecutively tuning the instrument to discrete frequencies in predefined steps. In both cases, the measured signal amplitude is observed either on an analog meter or a digital display. Signal amplitudes and associated frequencies shall be readable by the system controller.

If a stepped EMI receiver is used, it is recommended that the frequency step size be smaller than 50% of the used resolution bandwidth, with the minimum dwell time being spent at each tuned frequency. The peak detector should be used in the initial measurement with this type of instrument to identify critical emissions. The receiver's autoranging capability can be used during the measurements to ensure proper signal conditioning and thus avoid overload conditions due to high-level narrowband and broadband signals.

The maximum emission levels encountered during the entire process of executing one or multiple sweeps shall be recorded. If the receiver itself does not have a function to retain and display the maximum level, an external means shall be provided by the application software or specific hardware. This can be accomplished by a direct plotting device showing the measurement traces superimposed, or a memory device, which can store the data acquired in all of the scans, and select the highest value at each collection frequency. Application software, however, can read back all measurement data at the end of each scan or single-point measurement and more efficiently search for maximum amplitudes while new measurement data is acquired by the receiver.

5.2.1 Spectrum analyzers

A spectrum analyzer is a heterodyne receiver in which the *local oscillator* (LO) is swept across a certain frequency band. The input signal is fed into a mixer where it mixes with the local oscillator signal. If any of the mixed signals falls within the pass band of the *intermediate frequency* (IF) filter, it is further processed, detected by the detector circuit, digitized and used as the vertical deflection on a display. A ramp generator provides the tuning voltage for the LO as well as the horizontal deflection for the display. The horizontal axis of the display is calibrated in frequency. This allows the determination of the absolute frequency of any signal displayed, and the frequency difference between any two signals. The vertical axis is calibrated in amplitude. Most spectrum analyzers offer the choice of a linear scale, calibrated in volts, or a logarithmic scale calibrated in dB. In both cases, the top line of the graticule, the reference level, is assigned an absolute amplitude value through calibration techniques. The values of all other amplitude locations on the graticule are determined by using scaling techniques like "dB/Division". This allows both the measurement of absolute amplitudes and amplitude differences between signals.

The analyzer should be of the type that provides a "Max Hold" trace, where the highest level encountered at any given frequency point during the series of sweeps is displayed. Care should be taken that the sweep time is chosen long enough to avoid uncalibrated measurements. Modern spectrum analyzers have built-in functionality to determine the fastest sweep time possible based on the selected frequency span and the chosen IF and video filters. A warning will be issued, in case the selected sweep time is shorter than the minimum sweep time determined by the spectrum analyzer.

It is recommended that a minimum amount of preselection be inserted prior to any active stages of the instrument, especially the first mixer at the front-end. This minimizes the possibility of system overload due to unanticipated "out-of-band" signals. This is of particular importance when performing radiated emissions measurements on an OATS. The ATE used must be able to measure emissions from the EUT correctly, despite the presence of high-level ambient signals on an OATS. It is not permissible to simply reduce the measurement reading by an amount equal to the ambient level at any frequency. As a minimum, pass band filtering should be included in the overall measurement system configuration, between the antenna terminal connection and any other instrument in the signal path, except for any attenuation external to the receiving instrument. External attenuation, if necessary, should be the first component in the RF signal path, placed immediately after receiving antenna if possible. If system noise floor considerations permit an external attenuator, it can also be placed at the receiver input. The preselection filters shall be

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properly tuned such that their center frequencies are aligned with the tuning frequency of the spectrum analyzer in order to avoid measurement errors.

5.2.2 Detector functions

The three detectors most commonly used in EMI measurements are the peak, quasi-peak, and average detector.

With spectrum analyzers or scanning receivers, peak measurement values are obtained when the post-detection filter (i.e., video filter) setting is wider than the receiver's *resolution bandwidth* (RBW) filter setting. Peak detection is the most common detection method used to evaluate electromagnetic emissions quickly. The peak and quasi-peak detected signal amplitudes are always larger than or equal to the average detected signal amplitude. Therefore, it is ideally suited to acquire the worst-case emission amplitudes in the frequency range of interest. However, the final compliance measurement most often requires quasi-peak and/or average detection. With a previously performed peak measurement, the use of the quasi-peak detector or average detector can be limited to those frequencies exceeding an applied limit.

Average measurement results are obtained with a spectrum analyzer or scanning receiver when the video filter bandwidth is much narrower than the resolution bandwidth. The corresponding averaging time T_{avg} is related to the *video bandwidth* (VBW) by

$$T_{avg} = 1 / (2*\pi* VBW) \qquad \text{(e.g., } T_{avg} = 160 \text{ ms for } VBW = 1 \text{ Hz)} \tag{1}$$

For automated measurements, the video bandwidth setting shall be chosen sufficiently narrow to achieve the required averaging effect. However, the selection of the narrowest available setting, e.g., 1 Hz, may cause excessively long measurement times and may, in fact, not be required, depending on the emission's lowest frequency component. A successive decrease of the video bandwidth settings, starting from wider bandwidths while observing amplitude changes can lead to the optimum selection of the video bandwidth while maintaining the fastest measurement time possible for an average measurement. A dedicated algorithm can accomplish this task and thus save considerable measurement time.

Spectrum analyzers normally display measured signal amplitudes on a logarithmic scale. For average measurements, a linear display mode shall be selected to display the true average values of signals. A reduced video bandwidth used with a logarithmic display mode causes a smoothing effect on the displayed data trace and tends to attenuate the amplitudes of broadband signals. This is a very effective operating mode to identify stable, narrowband signals in a crowded spectrum.

Trace averaging is another way to achieve averaging with spectrum analyzers or scanning EMI receivers. It can be used either in combination with a linear amplitude display to measure the average values of signals, or in logarithmic display to smooth the trace data and to enhance the display of narrowband signals. This method requires a digital display. It involves a mathematical process that averages the new amplitude value with previously averaged data at each display point. Averaging is accomplished over two or more sweeps on a point-by-point basis. The following expression is applied to calculate the new averaged data:

$$A_{avg} = (1/n)\, A_n + ((n-1)/n)\, A_{prior\ avg} \tag{2}$$

where

A_{avg} is the new average value
$A_{prior\ a}$ is the average from prior sweep
A_n is the measured value on current sweep
n is the number of current sweep

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Thus, the display gradually converges to an average over a number of sweeps. While trace averaging has no effect on the sweep time, the time to reach a given degree of averaging is about the same as with video filtering because of the number of sweeps required.

Quasi-peak detection is inherently a time-consuming detection mode because of the required detector time constants. The characteristics of this detector are defined in ANSI C63.2-1996 and CISPR 16-1-1 (2003).

5.2.3 Scan rates and sweep times

5.2.3.1 Spectrum analyzer scan rates

Two conditions need to be met to ensure that signals are not missed during automatic scans over frequency spans:

1) The total measurement or observation time shall be larger than the intervals between intermittent signals.
2) The number of frequency scans during the observation time should be maximized to increase the probability of intercepting intermittent signals.

The frequency scan rate, defined as the ratio of frequency span to the sweep time for a single sweep of the spectrum analyzer, is limited by the instrument's resolution bandwidth, the video bandwidth setting, and the selected frequency span. If the scan rate is chosen too fast for the given instrument state, erroneous measurement results will be obtained. Therefore, a sufficiently long sweep time needs to be selected for the selected frequency span. From an efficiency point of view, the sweep time should be as short as possible, though, for highest probability of intercepting all types of signals, the number of scans during the observation time should be maximized. The observation time has to be selected according to the periodicity at which interfering signals occur.

When determining the minimum sweep time for measurements with a spectrum analyzer or scanning EMI receiver, based on a given instrument's settings and using peak detection, two different cases have to be distinguished. If the video bandwidth is selected to be **wider** than the resolution bandwidth, the following expression can be used to calculate the minimum sweep time:

$$ST = (K * SP) / (RBW)^2 \quad (3)$$

where

ST is the sweep time
SP is the frequency span
RBW is the resolution bandwidth
K is the constant of proportionality; this constant assumes a value between 2 and 3 for synchronously-tuned, near-Gaussian filters. For nearly square, stagger-tuned filters, K has a value between 10 and 15.

In case the video bandwidth is selected to be **equal or less** than the resolution bandwidth, the following expression can be used to calculate the minimum sweep time:

$$ST = (K * SP) / (RBW * VBW) \quad (4)$$

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where

ST is the sweep time
SP is the frequency span
RBW is the resolution bandwidth
VBW is the video bandwidth
K is the constant of proportionality; (see legend for equation 3 for value ranges)

Most spectrum analyzers and scanning EMI receivers automatically couple the sweep time to the selected frequency span and the bandwidth settings. Sweep time is adjusted to maintain a calibrated display. The automatic sweep time selection can be overridden in case longer observation times are required, e.g., to intercept slowly varying signals.

Table 1 shall be used to determine minimum scan times for scanning EMI receivers which meet the requirements called out in ANSI C63.2-1996 or CISPR 16-1-1 (1999). The values can also be used with spectrum analyzers, which meet the IF filter and quasi-peak detection requirements of ANSI C63.2-1996 or CISPR 16-1-1 (2003).

Table 1—Minimum scan rate for scanning EMI receivers and spectrum analyzers using peak and quasi-peak detection

	Minimum scan rate	
	Detection mode	
Resolution bandwidth	**Peak**	**Quasi-peak**
200 Hz	100 ms/kHz	10 s/kHz
9 kHz	100 ms/MHz	200 s/MHz
120 kHz	1 ms/MHz	s/MHz

5.2.3.2 Scan rates for stepping receivers

Stepping EMI receivers are consecutively tuned to single frequencies using predefined step sizes. While covering the frequency range of interest in discrete frequency steps, a minimum dwell time at each frequency is required for the instrument to accurately measure the input signal. The receiver design itself and the internal firmware (e.g., the switching speed of the internal synthesizer and autoranging algorithms) have a considerable impact on this minimum dwell time. Furthermore, the selected detector, e.g. peak or quasi-peak, determines this time period as well.

The following example explains how to estimate the minimum scan time necessary to cover a certain frequency range in discrete frequency steps. It is assumed that a minimum dwell time of 17 ms at each frequency is required to capture the maximum amplitude of a 60 Hz signal using peak detection. Furthermore, it shall be verified that this dwell time is greater than its minimum value, determined by the receiver design. In order to avoid missing narrowband signals, a frequency step size less than or equal to (≤) 50% of the used resolution bandwidth is chosen. Under these assumptions, the scan time ST_{min} for a stepping receiver can be calculated using the following equation:

$$ST_{min} = DT * SP/(RBW * SS) \quad (5)$$

where

DT is the minimum dwell time at each frequency
SP is the frequency span
RBW is the resolution bandwidth
SS is the frequency step size (as a fraction of RBW); maximum value is 0.5.

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5.2.4 Probability of signal intercept

The probability of intercepting a signal with a duration T_{on}, seconds, and a number of occurrences of meter per second using a scanning EMI receiver or spectrum analyzer is given by the following equation:

$$P = 1 - \exp[-m * T_{on} * T_{obs}/ST] \text{ for } T_{on} < ST \quad (6)$$

and

$$P = 1 \text{ for } T_{on} > ST \text{ and } n * T_{obs} >> m * T_{on} \quad (7)$$

where

T_{on} is the duration of signal (s)
m is the number of occurrences per second (1/s)
T_{obs} is the observation or total measurement time (s)
ST is the sweep time (s)
n is the number of scans taken per observation time (1/s).

The probability of detection is increased by increasing the observation time and by reducing the scan time, thereby maximizing the number of scans, n, taken during the observation time. For example, the probability of intercepting the signal with a duration T_{on} = 100 ms and an occurrence of m = 1/s, is P(1) = 10% for a single scan, P(10) = 63% for 10 scans, and P(50) = 99% for n = 50. To ensure efficiency of the measurement, the shortest scan time should be chosen as outlined in 5.3.3. The consideration of probability of intercept is particularly important in automated EMI measurements since the execution, data logging, and reporting are done with a minimum of user interaction. If sweep times are not carefully chosen by knowledgeable test personnel, the detection of slowly varying signals may not be possible and their presence cannot be revealed by evaluating the test data after completion of the automated test. It must be ensured that all signals are intercepted during a compliance measurement.

5.2.5 Frequency resolution and frequency accuracy

Frequency resolution is the ability of the spectrum analyzer or EMI receiver to separate two input sinusoids of different frequency into distinct responses. Since input signals, measured with a spectrum analyzer or swept receiver, trace the instrument's IF filter frequency characteristics, the responses shown on the display are not infinitely narrow as suggested by the Fourier analysis. This implies that the narrowest bandwidth in the signal processing chain of the instrument determines its frequency resolution. If two signals are far enough apart, their traces are not superimposed and thus they can be identified as two separate signals. Obviously, a narrow IF bandwidth, often specified as the 3 dB bandwidth, yields a higher frequency resolution. The 3 dB bandwidth specifies how closely spaced two equal-amplitude sinusoids can be and still be resolved. In this case, there will be about a 3 dB dip between the two peaks traced out by these signals. The signals can be closer together before their traces merge completely, but the 3 dB bandwidth is a good rule of thumb for resolution of equal-amplitude signals.

If two signals have different amplitudes, the bandwidth selectivity has to be considered. Often, the selectivity is specified by the shape factor, which is defined as the ratio of the 60 dB bandwidth to the 3 dB bandwidth. A lower shape factor indicates steeper filter skirts, which is desirable for better resolution of two signals with different amplitudes. Therefore, the probability of losing the smaller signal under the skirt of the response traced out by the larger is less. However, these filters cause more ringing when measuring broadband signals like pulses, and their response time is longer forcing longer measurement times.

When making EMI measurements in accordance to commercial EMI standards, the resolution bandwidth, along with the filter shape, is called out in the applicable standard, and thus cannot be changed. For this reason, the frequency resolution of the measurement is predetermined as well.

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The frequency accuracy with which the spectrum analyzer's or receiver's LO can be tuned is the main factor in determining the frequency accuracy. However, the IF can also affect the accuracy of a frequency measurement if the resolution filter bandwidth is not precisely centered at the IF. Then, the peak of the signal response will not be displayed at the correct frequency, even if the LO is perfectly accurate. The absolute frequency accuracy includes different sources of errors of which the frequency span uncertainty is the most important one. This error describes the linearity with which the LO can be swept over the required frequency band.

When the measurement process requires a high-frequency accuracy, for example when performing preliminary measurements to identify the frequencies of EUT emissions, as described in 4.6.2, the smallest frequency span possible must be used since it will yield the greatest frequency accuracy. Algorithms in the application software can determine the required span width to ensure a predefined frequency accuracy. For this purpose, the frequency range of interest is divided up into sub-spans, which are measured consecutively. This allows quick coverage of wide frequency ranges with high frequency accuracy. A typical frequency uncertainty to be expected is approximately 2% of the used frequency span; this means, that a single span measurement from 30 MHz to 1000 MHz would yield a frequency uncertainty of approximately 18.4 MHz (2% of 970 MHz). This frequency accuracy, for example achieved during a fast exploratory measurement, would make a measurement on an OATS very difficult because the identification and measurement of the emissions by simply tuning the receiver to the predetermined frequency will not be possible. On the other hand, measurements using larger frequency spans are useful, for example, when an overview of the emission spectrum envelope is to be determined quickly.

5.2.6 Receiver overload

The input RF amplifier and the first mixer of an EMI receiver are broadband devices that can be overloaded by large sinusoidal and impulsive signals. This may lead to spurious responses and/or amplitude compression of the measured signal. Distortion caused by narrowband signals is generally harmonically related to these signals. The intermodulation-distortion-free dynamic range of narrowband signals is defined as the amplitude difference between the receiver's noise floor and two equal-amplitude signals whose third-order products are just equal to the noise floor. If RF preselection, i.e. filtering, is introduced in front of the mixer, signals outside the filter pass band will be attenuated. Thus, an out-of-band rejection of 40 dB immediately enhances the spurious-free dynamic range by 40 dB. This is achieved without using extra RF attenuation, which, in turn, would reduce the receiver's sensitivity. Therefore, the use of additional attenuation is not an alternative, especially when low-level emissions have to be measured in presence of high-amplitude signals.

The broadband dynamic range is determined by the time-domain peak amplitude of the input signal and the overload amplitude level of the distorting device. If no RF preselection is used and a pulse is applied to a receiver, some attenuation may be necessary to lower the pulse's amplitude to a value below the mixer overload level. However, for commercial EMI compliance measurements, which utilize fixed resolution bandwidths according to applied regulations, an increase in input attenuation can lower the pulse amplitude to a value below the noise floor of the receiver, making the measurement impossible. When using preselection and applying a pulse, only a portion of the pulse spectrum lies within the pass band of the preselection filter, and the voltage at the input mixer is dependent on the preselector bandwidth. The filtering process does not change the spectral intensity of the pulse, but the voltage of the pulse at the preselector filter output will be reduced by a substantial amount. Therefore, less input attenuation will be needed to prevent mixer overload, which directly results in an increase of broadband dynamic range. This improvement in broadband dynamic range is related to the pulse width of the signal to be measured and the impulse bandwidth of the preselector.

6. Power-line conducted emission measurements, 9 kHz to 30 MHz

This clause addresses the main issues associated with the automation of power-line conducted emission measurements in particular and any conducted emission measurement in general. A number of international standards now specify conducted emission measurements on signal lines that can take full advantage of the

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automation issues presented here. Both fully automated measurements and semi-automated measurements will be addressed, since a need exists for each.

Conducted emission measurements are, in contrast to radiated measurements, relatively easy to automate. If the test is performed in a shielded room with filtered incoming power lines, most signals observed are EUT related. The EUT must be set up in accordance with the requirements called out in ANSI C63.4-2003. After the worst case EUT operating mode and cable layout has been determined manually, no further search is required to find the worst-case emissions, other than measuring all the required lines and searching for the maximum amplitude in the different sets of test data.

6.1 Elements of automated test system

LISNs and voltage probes are the transducers used to determine conducted emission voltages. Emission voltages are measured on up to three line conductors and the Neutral conductor. A safety earth conductor choke may have to be switched in and out, based on previously measured amplitudes. This can be done manually or under software control, based on the LISN's capability. It is desirable, but not necessary, to be able to switch the input of the receiver automatically between the different conductors during the automated test. The measurement software shall be able to store transducer loss correction factors for all LISN settings and possible cable loss, should they be needed.

The following data files are usually required for an automated conducted emission measurement:

1) Transducer files that contain all the necessary correction factors (e.g., cables, LISN)
2) Limit files containing the limits called out in the applicable standards
3) EUT files that contain a full description of the EUT and its support devices
4) Report template files containing the name(s) of the test personnel, facility information, listing of test equipment, date, time, and environmental information
5) Data files containing test results for a particular EUT in graphical and/or tabular format
6) Test definition files that contain a description of the test process and the equipment settings used

It is important that any printout of the above files by the automated system includes a unique identifier of this file to ensure that all pertinent data can be linked to the printed final report, which may include all or parts of the information of each file. For audit purposes which usually require the exact replication of the measurement at a later point in time, this linkage is essential as well. Traceability can be achieved using a sequential numbering system or a user-definable naming convention for file titles. Furthermore, the software itself and its revisions need to be traceable. Hence, its serial number, revision, and revision date should be part of a standard test report template.

Any change to a report or its components, once it has been compiled, needs to be identified and documented. Some form of data revision is necessary to identify that the data under review has been modified or corrected. This ensures that changes can be appropriately traced without major effort.

6.2 Measurement environment

Most commercial EMI standards allow for conducted emission measurements to be performed either inside a shielded enclosure or in an open area. Sometimes individual countries specifically stipulate the use of shielded enclosure while others allow for both. The key problem with measurements outside a shielded room is the need to ensure that ambient signals do not prevent proper measurement of the power line conducted emission levels. This usually can be accomplished by initially measuring the ambient signal levels with a suitable load attached to the LISN or by filtering the power input to the LISN as described in 6.2.2. This preliminary test allows the identification of ambient signal levels, which exceed the specified

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test limit before the EUT is measured. It should be noted that no mathematical correction of emission amplitudes is allowed to account for the presence of high-level ambient signals.

When using a shielded enclosure, all measuring equipment like spectrum analyzers or EMI receivers and necessary control equipment can be placed inside the room, along with the LISN and the EUT. In this case, it is necessary to verify that the automated measurement system does not introduce errors into the measurement results by generating excessive emissions of its own. If all measurement and control equipment are placed outside the shielded enclosure, this problem can be eliminated. This approach can cause a significant ground loop problem resulting in an increase of measured conducted emission levels and thus a possible erroneous evaluation of the EUT. By applying proper isolation techniques, the ground loop problems can be minimized or avoided altogether.

6.2.1 Grounding and isolation requirements

It is imperative that all components of the automated measurement system have a ground connection, which is isolated from facility power in order to maintain a single utility ground connection. One possibility to achieve this goal is to power all automated measurement equipment from a high-capacity isolation transformer. Any equipment that is connected to a remotely controllable spectrum analyzer or EMI receiver via a shielded bus cable, where its shield is connected to the chassis at both ends (e.g., GPIB cable), needs to be grounded but also isolated from the utility ground connection. Furthermore, any coaxial connection through the wall of the shielded room will require DC isolation as well.

DC isolation can be achieved by using a capacitively grounded RF-feedthrough. At high frequencies, the coaxial connection is effectively grounded and will protect the shielding integrity of the room. At low frequencies (below 10 MHz), the coaxial connection is isolated and thus prevents low-amplitude ambient currents and EUT-induced currents from flowing on the coaxial cable. Low-level induced currents flowing on the coaxial cable, which connects the LISN to the EMI receiver, may interfere with very low-level emissions and thus cause measurement errors.

Typical emission limits for Class A equipment are approximately 1 mV across 50 Ω, or 20 μA. Any leakage currents from the EUT (which can be up to 3.5 mA) may also flow on the measuring coaxial cable. Depending on the transfer impedance of the coaxial cable, the unintended current may be superimposed on the current or voltage to be measured resulting in measurement errors. Above 1 MHz, high-quality coaxial cable will have an adequate transfer impedance to minimize this problem. Measurement accuracy can be further improved by using semi-rigid coaxial cable for conducted emission measurements.

When conducted emissions measurements are performed on an OATS, the coaxial cable or its conductive fittings should not be grounded to the ground plane or wire screen after it is grounded to the LISN. If current probes are used to perform conducted emission measurements and the single ground connection is at the receiver end, no ground connection should occur anywhere else along the coaxial cable including inadvertent grounding of the body of the current probe itself.

6.2.2 Filtering of the LISN power source

Shielded enclosures are usually equipped with power line filters to ensure that no external noise is present on the power mains at levels near the applicable limit. When using an OATS to perform conducted power line emission measurements, some form of power line filtering is generally required to reduce ambient emissions to levels below the specified limit line.

Sometimes ambient signals will couple directly onto the EUT power cable routed between the LISN and the EUT resulting in ambient levels above the limit line. The length of the power cable can affect the ambient levels as well. When testing large systems, care has to be taken to minimize the length of the power cable to that called out in the applied standard. Most commercial and military standards specify either one or two meter maximum lengths. In larger systems where only one localized group of LISNs is

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used, the power cables are often routed over greater lengths to connect all the systems components. This added length could pose a problem by causing excessive pickup of ambient signals.

6.2.3 Power-line conducted emission measurements above 30 MHz

Currently, most conducted emissions measurements cover a frequency range up to 30 MHz. However, for some specific applications, the frequency range may be extended much higher. For example, specific conducted measurements in the automotive industry have to be made up to 108 MHz. When the length of the power line cable exceeds 5–10% of quarter-wave resonance, standing waves may adversely affect these measurements. Shielded enclosures can also lead to erroneous results if significant room resonances are present, due to lack of effective absorbing materials in the frequency range of interest.

NOTE—Some testing requirements specify the addition of ferrite longitudinal impedance loads when making measurements. These loads also reduce the likelihood of cable resonances during the conducted emission measurement.

The effect of standing waves can also occur on the coaxial measuring cable, which connects the LISN to the EMI receiver's input. Therefore, the length of this cable should not exceed one to two meters inside the shielded room, especially if no absorbers are used inside the shielded enclosure. It is also important that sufficient attenuation, e.g., 10 dB, be used at the LISN port to account for impedance mismatches between the receiver input and the output port of the LISN. This is of particular importance if the measurement cable length exceeds 5–10% of the wavelength at the highest frequency to be measured.

6.3 Measurement modes

The actual measurement methodology depends on the regulation to be applied. In case the standard calls out both a quasi-peak and average measurement, Figure 2 depicts a generic conducted emission test procedure that includes the following steps:

1) If the measurement is not performed in a shielded room, an ambient search is performed with the EUT turned off. Ambient signal data is stored for further processing and future reference. When measuring the EUT, a signal discrimination process needs to be employed to ensure the correct interpretation of measurement results. By comparing signals based on their frequency, frequency accuracy, amplitudes and their possible variations, this task can be greatly reduced by applying appropriate algorithms. This reduces operator interaction and hence yields high efficiency.

2) The conductor specified, e.g., Neutral vs. Reference Ground, is first measured using peak detection. This allows fast scanning with the EMI receiver and thus provides a quick overview of the emission spectrum of the EUT.

3) If the peak measured emission amplitudes are below the average limit, the LISN can be switched and another conductor, e.g., Phase to Reference Ground, to be measured using peak detection. If no amplitude exceeds the average limit on all conductors to be measured, the EUT complies with the standard.

4) In case peak-measured emissions exceed the average limit, but not the quasi-peak limit, they should be remeasured using average detection first. In case the average measurement on either conductor yields results exceeding the average limit, the EUT does not comply with the standard. If the average measurement result is below the average limit, a quasi-peak measurement needs to be performed next. The EUT is in compliance with the regulation, if the quasi-peak amplitudes do not exceed the quasi-peak limit.

   This approach ensures the shortest test time possible by applying the peak detector first and the quasi-peak detector last. Average detection, being considerably faster than quasi-peak detection is used to determine if a time consuming quasi-peak measurement is necessary. If EUT average detected emissions fail the average limit, the product does not comply with the standard.

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Therefore, from a compliance measurement point of view, the test process can be stopped at this point in time.

6.3.1 Quasi-peak and average detection

Measurements using quasi-peak detection are inherently slow because of the detector's charge and discharge constants and the analog meter time constant. These values are specified in CISPR 16-1-1 (2003) and require long measurement times for the circuitry to fully respond to the input signal and to produce a valid result. The peak detector, on the other hand, allows much shorter measurement times and may be used to rapidly acquire initial test data. Since peak detected amplitudes always represent the highest possible values, quasi-peak and average testing will yield either the same amplitudes for narrowband signals or lower amplitudes in case of broadband signals. This important fact can be effectively used to quickly determine compliance with quasi-peak and/or average limits. If the peak measured values are above the limit, they shall be followed by measurements with the appropriate detector. In case both a quasi-peak and average limit need to be met, two measurements need to be performed to demonstrate compliance. A dedicated application software can make the necessary decisions to ensure test efficiency and automate the measurement to a very high degree.

6.3.2 Intermittent versus steady state emissions

Most EUTs generate steady-state power line conducted emission levels that can be measured with an automated measuring system without concern for time variation of the emission. However, some EUTs, like appliances and copiers, vary their load as a function of time. Not only will the steady-state levels change with time, but the load changes may generate intermittent emission levels as well. In such a case, the EUT needs to be specially configured to generate these intermittent emissions repeatably in order to measure them. The detection of the presence of such signals usually requires some manual interaction to determine the appropriate receiver scan rate or dwell time for the measurement; therefore, it is not possible to fully automate the conducted emissions test under these circumstances.

6.4 Reporting capabilities

A graphical representation of the measurement results is preferable for conducted emissions measurements, since the signals are often broadband in nature and thus cover a wide frequency range. The tabular representation of broadband emissions requires either proper selection of the signal's frequency and amplitude, which is difficult to achieve automatically, or recording of an impracticably large number of data points. Thus, a graphical representation of the conducted emissions spectrum envelope, which contains the worst-case amplitudes measured on all conductors, together with the applicable limits, is the easiest and most reliable method to document the test results. In case the signal frequencies are determined, the EUT spectrum can be represented as a sequence of individual lines at the emission frequencies where the individual line height indicates the measured amplitude. In this case, a tabular representation is also adequate. Furthermore, a logarithmic frequency display is preferred to present the measurement data along with the limits in a form called out in most regulations.

7. Radiated emission measurements, 30 MHz to 1 GHz

In this clause, two possible approaches to the automated radiated emission test are discussed, based on the test environment. The differences are mainly due to the presence of ambient signals on an OATS. This fact requires additional steps in the overall measurement process to avoid erroneous measurement results and ensure their proper interpretation.

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7.1 Influence of measurement environment

The OATS is the test environment called out by commercial EMI regulations to perform radiated EMI compliance measurements. An OATS, which is not weather-protected with non-RF reflective material, has different problems associated with it such as weather conditions, reflecting objects close-by, or ambient signals. Therefore, alternate test sites like semi-anechoic chambers are discussed as well.

7.2 Modification of the test procedure

A survey of the electromagnetic environment on an OATS represents a complex and lengthy task. Measured ambient signals change their attributes like spectral occupancy or amplitude based on many different parameters. Therefore, certain measurement procedures have to be applied during these surveys to get an accurate assessment of ambients present at the OATS. If a semi-anechoic chamber is available, in addition to the OATS, a preliminary EUT frequency list can be compiled and remeasured at the OATS under conditions called out in regulations to finally determine the compliance of an EUT.

7.2.1 Compilation of ambient signal lists

Ambient signal measurements are preferably made using a scanning receiver instead of stepped receiver to save test time, and yet capture all signals present. If these receivers are equipped with a swept display, intermittent signals can be detected relatively easily, especially if a “Max-Hold” trace mode is available to dynamically retain the maximum amplitude measured during the survey. The antennas used during the measurements shall be varied in height (ideally, the height scan range called out in the EMI regulations), because reflections will cause an amplitude variation based on height. Furthermore, the antenna polarization has an impact on the result, given that linearly polarized antennas are used.

Depending on the survey goal, the overall test time has to be defined. A thorough compilation of ambient signals, for instance in tabular form, requires many measurements over a certain period of time. In general, longer overall tests lead to a more accurate representation of the ambient spectrum. Individual ambient lists, which result from these surveys, can be generated either for different times of the day or combined into a single master list. Signal processing can be applied to determine the characteristics of ambient signals. If a signal is not found during one ambient scan but is not recorded during a second ambient measurement, a list comparison would identify this ambient signal as either intermittent, which means the signal is non-periodic and therefore not always present, or impulsive. Impulsive signals require special attention in regard to the selection of the measurement time to ensure interception of the signal. If the pulse repetition frequency of a signal is not known, repetitive scans of the frequency range of interest can miss signal components, depending on the ratio of the selected EMI receiver scan rate and the repetition frequency of the pulse.

A scanning receiver intercepts the spectral components of impulsive signals at different locations in the spectrum, when the scan time is not harmonically related to the signal’s *pulse repetition frequency* (PRF). The correct identification of intermittent and impulsive signals often times requires an experienced operator for final decision making. However, the number of signals which need operator attention can be significantly reduced by a thorough list comparison. If signals in different lists have to be compared to find out if they are identical, a rather sophisticated algorithm shall be used because an identification solely based on nominal signal frequency and amplitude is not sufficient. A major factor in this determination process is the frequency uncertainty associated with the signal frequency.

The automatically recorded frequency uncertainty is related to the measurement receiver hardware specification. However, for the numerical signal comparison, frequency and amplitude variations have to be user definable to accommodate different goals of the mathematical comparison. For instance, if only a fraction of the frequency uncertainty shown in a list is specified for use during a signal comparison, the likelihood of finding fewer identical signals is higher. This approach is useful, when an EUT emits stable

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signals, because then only the frequency uncertainty due to the measuring equipment has to be considered. If the EUT generates drifting or modulated signals, the frequency uncertainty should be defined as a multiple of the receiver frequency uncertainty to ensure meaningful results.

Signal lists are a very powerful tool to discriminate between the actual emissions from an EUT and ambient signals, if frequency, frequency uncertainty, and amplitude information are considered during this process.

7.2.2 Use of a semi-anechoic chamber

If a semi-anechoic chamber is available in addition to the OATS, frequently a different measurement approach is taken. Since many chambers do not meet the criterion for normalized site attenuation called out in regulations, and therefore cannot be used to make final compliance measurements, they are used to compile frequency lists of the EUT emissions. Usually, this is a fairly fast process because of the absence of ambient signals. This list is then taken to an OATS and remeasured according to regulations to obtain emission amplitudes employing correct test procedures, including the antenna height scan and EUT rotation.

A software tool to perform these exploratory measurements and generate the EUT frequency lists also has to provide options for the frequency accuracy of the measurement itself. If scans are taken over a wide frequency range, e.g., 30 MHz to 200 MHz, the frequency uncertainty will be fairly high, but the overall measurement time is minimized. However, it may be difficult to locate these emissions, especially in a crowded ambient spectrum. This situation can be improved by dividing the frequency range to be covered into multiple subranges, which are individually scanned (see 5.2.4). However, this approach leads to a longer overall test time.

A different test methodology addresses this problem by first taking a scan over the entire frequency range, including all the specified movements of the antenna tower and the turntable. This measurement is made as fast as possible using the receiver's peak detection. Its purpose is the detection of "quiet zones" in the spectrum, where only low level or no signals are present. These quiet zones are determined based on a predetermined threshold. The result is mapped against the subranges, which are necessary to achieve a certain frequency accuracy. If a subrange does not contain any signals of significant amplitude, it will not be remeasured during the following actual prescan test. Therefore, test time can be saved by only making final measurements in significant areas of the test frequency range.

7.3 Radiated emissions test procedure

In general terms, a radiated EMI compliance measurement can be divided into four major steps, which include all activities to be carried out during the measurement. Two of these steps will always apply, the others might be applicable based on the present measurement environment.

First, data will be gathered using an EMI receiver. If a swept receiver is used, actual signals are discerned numerically and stored in lists. If both ambient and EUT signals are contained in a list, a separate discrimination process is necessary to reduce the signals to EUT emissions only. Only these are processed according to applicable EMI regulations involving the maximization of amplitudes and measurements with appropriate detectors (e.g., quasi-peak or average detection).

When all relevant EUT emissions have been maximized and measured, additional processing of the results might be necessary to meet documentation requirements (e.g., only signals with the 10 highest amplitudes have to be documented). This procedural approach avoids very long test times due to limiting the number of signals to be maximized and measured. This can be accomplished by applying data reduction processes, which may include amplitude versus limit checks and signal discrimination. The four procedural parts, which generically define the overall test procedures, are Prescan, Data Reduction, Maximize/Measure and Post Processing.

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7.3.1 Exploratory measurements (prescans)

This initial step in the overall measurement procedure serves multiple purposes. Therefore, this part of the overall measurement has to be performed at all times. The use of a scanning receiver is recommended for this phase of the testing, in that it provides a means of quickly acquiring data. Prescan places the least number of restrictions and requirements upon the test system. The purpose of this type of data gathering process is to gather a minimal amount of information upon which the parameters of additional testing or scanning will be based. This test mode is the initial step which can be used to test a new product, where the familiarity with its emission spectrum is very low. For additional details see ANSI C63.4-2003, 8.3.1.1.

One application for a prescan is recording the EUT emissions on an OATS, along with all ambient signals. The resultant list serves as a basis for further signal discrimination and processing.

If a semi-anechoic chamber that meets all requirements for test sites called out in regulations is available, prescan is used to collect EUT signal data. In this case, all the signals found during the measurement are solely emissions from the EUT, which can be processed directly without any further signal discrimination and data reduction.

A third application for the exploratory measurement procedure is the preliminary compilation of suspect lists in semi-anechoic chambers, which are to be remeasured on an OATS to meet all the regulatory requirements of the measurement. This approach allows the quick identification of EUT emissions in the presence of the ambient spectrum. However, the test process must ensure that all relevant EUT emissions are investigated. This can be accomplished by another scan on the OATS to verify the completeness of the suspect list.

In general, prescan resembles a data acquisition procedure used to determine where in the frequency range of interest significant signals are located. Depending on the goal of this measurement, antenna tower and turntable movement may be necessary as well as improved frequency accuracy, frequency resolution, and data reduction through amplitude comparison. These factors define the measurement sequence during the execution of prescan. In any case, the results will be stored in a signal list for further processing.

Frequency resolution is determined by the number of horizontal points of the instrument's digital display and the selected frequency span. For example, a measurement of a frequency span of 970 MHz (1000 MHz–30 MHz) would result in a frequency resolution of 970 kHz, using 1001 display points. This means that signals with a frequency spacing of less than 970 kHz cannot be resolved; they will appear as a single response on the instrument's display. Segmentation of the frequency range of interest will improve the frequency resolution, but lengthen the measurement time.

When an exploratory measurement is made to quickly obtain information on an EUT's unknown emission spectrum, frequency scanning should be performed with the required 120 kHz bandwidth using peak detection and at the highest scanning rate possible. The scan is performed repetitively over the frequency band of interest, to improve the probability of intercepting any spectral components emanating from the EUT. The scan rate should be chosen according to the considerations in 5.3.3.1.

If an antenna tower and/or turntable is used in the measurement system, data should be gathered with these units in a stepped movement mode. This means, data is taken with the receiver only after the positioners have been moved to predefined positions. In case of the turntable, the data collection may be performed at suitable angle increments or at 22.5° increments per ANSI C63.4-2003. The number of angular positions should ensure that no significant signals are missed during the exploratory measurement. The antenna height and polarization should be set according to the measurement distance and frequency ranges in Table 2. The listed preset tower positions are a function of antenna distance from the EUT, frequency, and polarization. Further information on exploratory radiated emission maximization procedures can be found in Annex D of ANSI C63.4-2003.

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Table 2—Suggested antenna positioning for prescan interception of emissions levels

Measurement distance (m}	Frequency range (MHz)	Antenna height (m)	Antenna polarization
3	30–100 100–250 250–1000 30–100 100–250 250–1000	1 1 & 2 1, 1.5 & 2 2.5 1 & 2 1 & 1.5	Vertical Horizontal
10	30–200 200–300 300–600 600–1000 30–100 100–200 200–400 400–1000	1 1 & 3.5 1, 2 & 3.5 1, 1.5, 2 & 3.5 4 2.5 & 4 1.5, 2.5 & 4 1, 1.5 & 2.5	Vertical Horizontal
30	30–500 500–800 800–1000 30–300 300–800 800–1000	1 1 & 3.5 1, 2.5 & 3.5 4 2.5 & 4 1.5, 2.5 & 3.5	Vertical Horizontal

The recommended antenna heights assume a radiation source height between 0.8 m and 2 m; the use of these antenna height settings will limit the maximum error to 3 dB (see CISPR 16-1-2 (2004), 4.1.3). For large EUTs, the receiving antenna may have to be positioned in several horizontal and vertical locations, relative to the EUT surfaces, to ensure appropriate coverage; the number of locations is dependent on the ratio of antenna beamwidth and physical size of the EUT.

7.3.2 Data reduction

The second step in the overall measurement process is only necessary if the test is performed on an OATS. Up to two ambient signal lists should be available for automatic reduction of the number of signals in an input list. Another application for this subpart of the overall process is the removal of signals emitted by auxiliary equipment. During a compliance measurement, the EUT shall operate in its normal mode. This may require system simulators or other auxiliary equipment. If these auxiliary equipment signals reside in a separate list, they will be treated like an ambient signal list in a numerical sense, because the comparison techniques involved are identical for both types of data reduction.

In certain frequency ranges, especially the FM band, an acoustic ambient discrimination is very effective. This requires signals to be demodulated to be able to listen to their modulation content. Experienced EMI test personnel can tell if a signal in question is an ambient or EUT signal by listening to it. As this capability is useful in some frequency ranges but not in others, these ranges should be defined by the user, since the receiver has to be tuned to the frequencies in question and demodulation applied. If a list contains a larger number of signals and acoustic discrimination is needed, it can be a rather lengthy process. However, if the frequency ranges for tuning and listening can be specified, only signals within these ranges will be demodulated. The results of the data reduction process are stored in a separate signal list for further processing.

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7.3.3 Maximize/measure

The third subpart of the overall test process will always be applied to an input signal list, because the signals' highest amplitudes have to be found by moving the antenna height, changing the antenna polarization, rotating the EUT, and possibly changing EUT states. After the worst-case positions have been detected, the appropriate receiver detector shall be used for the final measurement. Since this part of the overall test is very time consuming, only significant EUT signals should be processed.

The sequence of movements of the tower and turntable, as well as change of the polarization, are the key contributing factors to the overall measurement time. A thorough investigation of the search pattern is necessary to avoid excessively long test times. A software product can assist in determining the test times, based on speed information of the tower and turntable in the measurement system. Furthermore, a graphical representation of the movement sequence along with the verbal description of each individual step supports the user during the test procedure definition phase to decide on the following parameters:

— The type of positioner movement (step or scan)

— The initial starting point of each search (e.g., table starts always at 0 degrees or tower is always reset to 100 cm)

— The overall sequence (e.g., set polarization first, then set tower to a specific height, then rotate EUT).

After locating the worst-case positions of the tower and turntable, measurements are made using either the quasi-peak or average detector. Before these measurements are set up, the current signal amplitude, which has been obtained with the peak detector, should be compared to the appropriate limit. This avoids quasi-peak or average measurements of signals, whose peak amplitudes are already below a given limit. The result of this maximization and measurement process is stored in an output list. All signal attributes like worst-case antenna height and turntable angle, polarization along with uncorrected and corrected peak, quasi-peak and average amplitudes, signal characteristics (e.g., CW, low modulation, high modulation, intermittent, etc.) are recorded. Furthermore, measurement data taken during the maximization process should be viewable in a polar and height plot.

If signal lists are archived, ideally the polar and height information of each signal should also be saved along with all other signal attributes. This greatly enhances the repeatability of measurements and is particularly useful in audit situations, because stored radiation patterns can be compared with current ones. Differences in the test setup can be identified easily by overlaying two radiation patterns.

7.3.4 Post processing

The last part of the test procedure addresses documentation requirements. The functionality for the definition of sorting and comparison routines, which are automatically applied to input lists in consecutive order, should be provided. The corrected peak, quasi-peak, or average signal amplitudes can be used as a sorting and/or selection criteria. The results are stored in separate output lists or combined in one and are available for documentation purposes and further processing.

Depending on the individual measurement situation, one or multiple subparts have to be executed interactively instead of automatically. For example, in almost all cases, an automatic prescan routine is appropriate to collect signal data and store it in a list. The Data Reduction part may require manual interaction, for example, when signal attributes other than frequency, frequency uncertainty and amplitude have to be used for a list comparison. This can be done interactively but not during automatic operation. For that reason, the mode of execution should be selectable for each individual subpart; automatic concatenation of subprocedures will aid in reducing overall test time and should also be available as an option.

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7.3.5 Data analysis tools

Different analysis tools are needed for a variety or reasons. For example, a polar and height plot indicates the characteristics of the maximized signal, including a possible superposition of an ambient signal and an EUT emission. Only the combination of a polar and height plot, ideally visible side by side, will reveal the specifics of emissions, because the information in both graphs complements each other. In case of signal superposition, the polar and/or height plot exhibits either:

— An overlaying ripple on top of the smoother emission contour due to a varying ambient signal amplitude,

— Or some “spikes”, which are caused by intermittent ambients.

This graphical data analysis tool is also useful to verify the proper function of EMI fixes, which might be necessary in case the EUT failed a compliance test. By overlaying several polar and/or height plots, a trend in the change of the radiation pattern can be determined, indicating effects of the implemented modifications.

Another software tool is a zooming capability. Data taken during a prescan measurement can be graphically presented in a window as a compressed trace of maximum signal amplitudes. Thousands of data points can be gathered during the actual prescan measurement, which are stored in computer memory and are available for analysis purposes. Tools such as this can be used to quickly identify areas of high EUT emissions and zoom in on those to further analyze potential problem signals.

The simultaneous display of trace and signal data allows a fast identification of newly measured signals and possible amplitude changes. Ambient discrimination, fast verification of measurement setup (i.e., effects of changing cable layout), and EMI troubleshooting are accomplished faster and easier with this tool.

7.4 Test definition

All the information necessary to define a complete radiated EMI measurement shall be organized into categories, which should be presented in the sequence a measurement is usually specified. A dedicated test editor can provide the top level interface through which all the parts of the definition process are accessible. This interface should only be available to users with the appropriate security level, which can be assigned in an administration part of the program. Users, who do not have access to the definition area, can only execute previously defined tests. The different categories used in the test definition process provide a structured description of a complete radiated EMI measurement. These categories are as follows:

a) **Equipment**: The definition of all the components of the used measurement system like cables, antennas, switches, receiver, tower, turntable, EUT, etc.

b) **Limits**: A group of one or multiple limit values, which might also have a margin associated with them.

c) **List definitions**: The software should be able to discern signals in traces and store them in signal lists. The layout of individual lists shall be specifiable by the user, meaning the list name as well as the number and content of the visible columns (e.g., corrected and/or uncorrected peak, quasi-peak and average amplitudes, antenna height, antenna polarization, turntable angle, signal class, etc.) can be different for each list.

d) **Measurement parameters**: The definition of receiver settings being used to measure signals in a list. Different detectors can be used for measurements at fixed frequencies as well as scans over frequency ranges.

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e) **Maximization process**: The specification of the sequence of antenna tower and turntable movement, including the change of polarization and possibly the state of the EUT. The reference positions of the movements along with their mode, i.e., scan or step, are also included.

f) **Test procedure**: The specification of the actual measurement procedure, using the definition of up to four subprocedures (see 7.3). The execution mode, i.e., automatic or interactive, is also included. Dedicated interfaces providing all the necessary information allow easy and efficient definitions or modifications without any additional programming effort.

g) **Test report**: The test results, acquired during a measurement, can be saved in files selectively in tabular and graphical form along with applied correction factors and system information. These files should be imported into commercially available word processors for compilation of final test reports.

The test editor is the central interface to completely define measurements, which can be saved in a special library for future use. When a measurement definition is retrieved from the test library, all the information of the seven categories is automatically loaded from their individual libraries and the test can be executed. The hierarchical library concept minimizes potential rework, which might be necessary; for instance, in case a different maximization routine has to be used due to different EUT characteristics or a measurement system component needs to be changed. Only the affected category needs to be modified to reflect the change, all other categories remain unchanged.

8. Measurement integrity

The results of an automated measurement are inherently more repeatable than those achieved using a manual system. Test system setup, data acquisition, calculation, and reporting errors are virtually eliminated by using well designed and manually verified code. However, the integrity and verification of test results are primary concerns in automated testing.

Many factors affecting measurement integrity are common to both automated and manual test systems. For convenience, these factors may be grouped into three categories: 1) test facility, 2) data handling, and 3) test documentation. This is shown in Figure 4. The test facility, including measurement equipment and the test site itself, shall have consistent characteristics and be either calibrated to reliable standards or verified according to accepted regulations. Data considerations include all aspects of data acquisition and data processing like mathematical correction of measured amplitudes. Data analysis and archiving of test data as well as complete test reports are also part of this category.

When using ATE-based test systems, a very high number of interactions occur between the computer running the application software and the remotely controlled measurement instruments. Usually, communication is achieved through a dedicated interface allowing both instrument control and transfer of measurement data. Most failures regarding remote control and data transfer can be automatically detected and will result in a failure of the overall system operation. In addition, the application software should provide some means of operator input verification and a plausibility check to avoid erroneous system setups. For example, the device description file of each component of the measurement system should include, for example, the frequency range for its calibrated use and other device specific limitations like the maximum movement range of an automated antenna tower or turntable, and its specific correction factors (e.g., frequency response of a cable, antenna factors, preamplifier gain, etc.). This information is used to verify the test definition before the test is being executed. Also, whenever the operator is requested to enter information, for example, during the actual test execution, a plausibility check should be performed by the program to avoid the execution of an incorrectly specified measurement.

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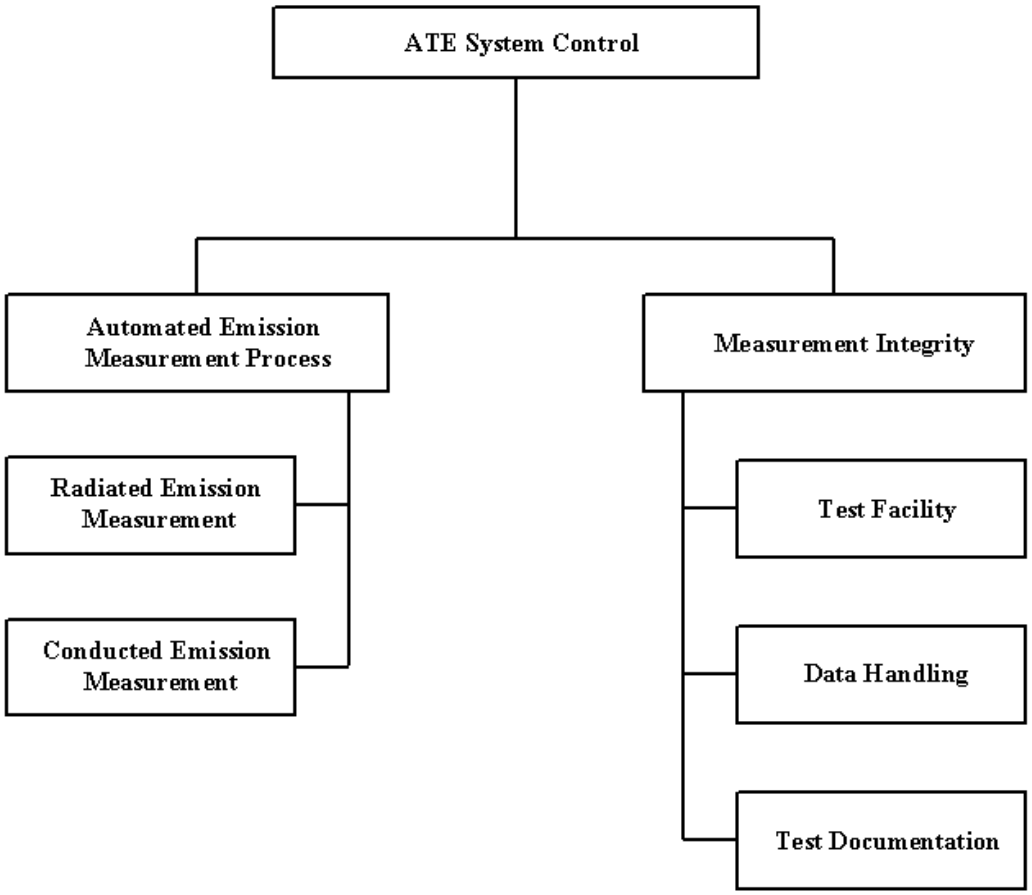


Figure 4—Factors affecting data quality of an ATE-based test system

The reliable storage and archiving of test data is another concern of particular importance for ATE systems. Due to the efficiency and productivity of ATE systems, the amount of raw data produced during a test can exceed the quantity acquired with a manual system by several orders of magnitude. It is important to retain the raw data as well as the reported data. This simplifies auditing procedures, system troubleshooting, and the correction of calculation errors later on, if necessary. For this reason, the data archiving process needs to be carefully designed to ensure flexibility, consistency, and future expansion. If not given thorough consideration, data archiving can actually lead to a loss of information.

Furthermore, ATE-based measurements carry a more subtle concern: without the constant interaction between test personnel and measurement system, the operator's expertise to detect unexpected problems quickly is potentially lost. Earlier in this document, recommendations have been made to retain this capability in specific situations. Manual interaction can be achieved in different ways. Software-enabled interrupts, for instance, can provide a possibility to react to a certain situation detected by the software. The application software should also provide the capability to define certain parts of the measurement process as a manual step in the overall procedure (e.g., discrimination between ambient and EUT signals on an OATS). Certain software tools like a graphical receiver interface should be available to support the operator in achieving a special measurement task. This ensures higher productivity and reproducibility, even in the case of the manual execution of a certain measurement step. Beyond such predetermined

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situations, there are a variety of spontaneous situations that can arise. For example, a cable connection may fail during the antenna tower movement, an electrostatic discharge may generate a spurious reading, or an unmonitored circuit in the EUT may fail.

Therefore, it is still necessary to monitor the test execution, even if an ATE-based measurement system is used. At a minimum, the results of a test series should be reviewed immediately after its completion to detect any anomalies.

8.1 Facility integrity

The ability of a test facility to produce accurate and repeatable results is dependent on many different parameters, as shown in Figure 5. These factors are related to the construction of the site and the environment, as well as the accuracy and suitability of the test system. Other parameters to consider in this category are the electromagnetic environment, namely, the presence of ambient signals on an OATS, the test process being used and its documentation, as well as the design and feature set of the application software.

8.1.1 ATE calibration

One of the most common sources of measurement errors is the use of uncalibrated measurement system components. This may be caused by test instruments, which exceeded their calibration cycle specified by the manufacturer. In this case, the estimation of the measurement error introduced by the measurement instrument itself, and thus the overall uncertainty statement of the test data, may not be valid any longer. For this reason, it is imperative that calibration cycles for instruments like receivers, power meters, signal sources, antennas, etc. are closely observed. The application software should provide a means for tracking these dates. The calibration data shall be stored with test data and be included in test reports. Other devices in the signal path like cables, switches, or external attenuators can be verified by measuring their characteristics and comparing these test results against manufacturer supplied data. In general, these system components do not have an associated calibration cycle. Nevertheless, a repetitive check of the performance is necessary to ensure measurement integrity and repeatability.

In case a measurement system component is out of calibration or not performing as specified, the extent and effect of this condition shall be determined. If this condition can affect the compliance statement of an EUT with the applied standard (for example, the EUT may fail due to new correction factors), formal notice shall be given to all parties affected by it. If this effect cannot be determined, all affected EUTs shall be re-tested.

It is important to distinguish between the internal and external calibration of measurement equipment. They serve different purposes and cannot replace each other.

8.1.1.1 External calibration

As components of test instruments age and equipment undergoes changes in temperature or sustains mechanical stress, critical performance gradually degrades. This phenomenon is called *drift*. When it happens, test results become unreliable and an EMI compliance assessment of an EUT may be erroneous. While drift cannot be eliminated, it can be detected and contained through the process of calibration.

This type of calibration consists of a set of operations, usually specified by the equipment manufacturer, which establish, under specified conditions, the relationship between values indicated by the test instrument and the corresponding known values of the measurand. This process may simply involve the determination of deviation from nominal errors or include correction (adjustment) to minimize errors. The results of a calibration process permit the estimation of errors of the instrument's indication. Sometimes the result of a calibration is expressed as a calibration factor or as a series of factors in the form of a calibration curve. This type of calibration is necessary to ensure the instrument's specified performance. A periodic calibration against reference standards provides the required traceability to national or international

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standards of measurement. In most cases, this elaborate process is performed by either the equipment manufacturer or a qualified calibration laboratory, which uses the calibration procedures specified by manufacturer.

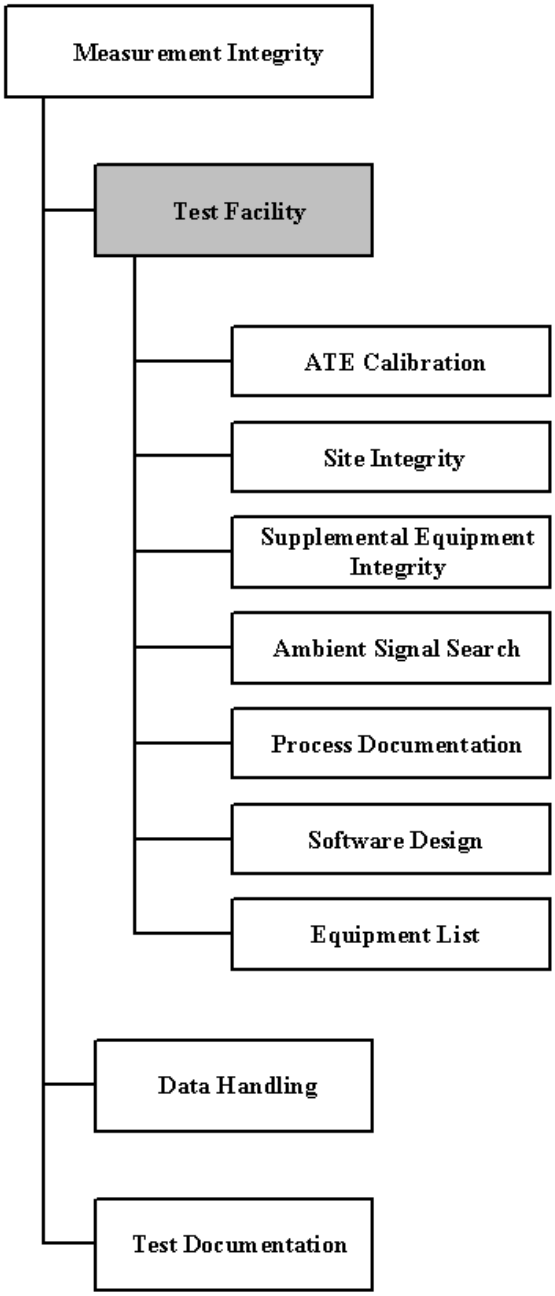


Figure 5—Facility integrity parameters

This form of calibration ensures consistency and compatibility of measurements because the measuring equipment is tested against standards of higher accuracy. These reference standards are traceable to national standards through an unbroken chain of comparisons that ends at the agency responsible for maintaining and developing a country's measurement standards. The demonstrable linkage to national

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standards (which can include several comparison steps), with known accuracy, represents traceability. See ISO/IEC 17025:1999 for further information.

8.1.1.2 Self-calibration

Many measurement instruments like EMI receivers have self-calibration routines built into their firmware. Usually these self-calibration procedures require stable, known signals which are generated by internal calibration signal generators. Data generated during the execution of the self-calibration routine is necessary for correct instrument operation. Therefore, its use is necessary to ensure the correction data is current and appropriate for the environment and the instrument's present state. In case of an EMI receiver, its frequency and amplitude accuracy can be improved by either correcting measurement data numerically or changing parameters of internal control circuitry. Many, but **not** all, factors contributing to frequency and amplitude uncertainty are taken into consideration. For example, the frequency sweep time and frequency span accuracy can be improved. Correction factors for IF bandwidth centering and switching, IF gain settings, switching between logarithmic and linear paths, RF attenuator uncertainty and logarithmic amplifier are also generated. The use of these internally generated correction factors are often required to meet the instrument's specifications. This assumes that the instrument goes through an external calibration process within the specified calibration cycle. Here the instrument's built-in calibration signal sources are adjusted, and the frequency response and many more parameters are tested.

Running a self-calibration after the manufacturer's recommended warm-up time has elapsed is an integral part of good measurement practice. The execution can be controlled by the application software or by the instrument itself, and should be done right before a measurement is started. In case the instrument is kept in a relatively stable environment, for example in a laboratory, it is sufficient to use the self-calibration once a day. A self-calibration shall be performed whenever the instrument experiences significant environmental changes such as temperature (± 5 °C), humidity, shock, or vibration (which may occur during shipping or transport). This is particularly important if the self-calibration routine was last performed in a different environment.

8.1.1.3 System verification

Verification procedures are used to confirm the operation of an EMI measurement system. They consist of function tests, which check the overall system to be operational but do not necessarily verify that all measurement system components meet their specifications. Function tests are quick tests designed to verify basic operation of an instrument or a system. They include operator's checks and operation verification tests. An operator's check performs a basic functional test of a measurement system component like a receiver or cable, uses minimal test equipment if any, and is run on a regular basis by the user. Its purpose is to detect broken instruments or components; it does not verify performance to specifications. An operator's check may be internal to an instrument (for example, the "Cal Check" function of an EMI receiver); the procedure is executed by the instrument itself and may not require any external equipment or standard.

Performance tests are the procedures used to verify that an instrument meets its specifications. Operational verification tests are typically subsets of these performance tests. The purpose of operational verification tests is to verify instrument operation quickly with reasonable confidence. They usually execute faster than calibration procedures because fewer points and parameters are tested, or a test system that is less accurate than the test system used for calibration procedures is utilized.

For example, for a radiated emission measurement, an operator's check is often used to verify the functionality of the measurement system path consisting of antenna cables, EMI receiver, switches, and any additional components like external filters, switches, or attenuators. The receiving antenna is replaced by a calibrated signal generator feeding a known signal into the antenna cable. In case a remotely controllable signal source is used, the generator can be tuned to numerous frequencies to cover the spectrum of interest and the EMI receiver is tuned accordingly. An amplitude reading is recorded at each frequency point and all the data is stored in tabular form. The current data is then compared to previously recorded values to determine any unusual drift or malfunction of a component in the signal path.

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8.1.2 Site integrity

The measurement site is an integral part of the EMI test system for radiated emissions measurements. Therefore, it shall be treated like any other measurement system component in terms of verification of its suitability and performance. For further information on verification intervals, see 5.4.6.2 in ANSI C63.4-2003 and 8.5 in ANSI C63.7-1992 for weather-protected OATS.

A quick operation verification test of the OATS integrity should be conducted more frequently. This allows a timely detection of changes of OATS-like ground plane disruptions, changes of weather protection structures, and introduction of nearby reflecting objects. The simplest method uses a known signal source, and a known receiving antenna to compare the current site condition with a previously measured result. Such tests should be done in vertical polarization, since it is more sensitive to site anomalies than horizontal polarization. This verification procedure has the additional benefit of checking the entire signal path, if the regular test setup is also used for verification.

8.1.3 Auxiliary equipment integrity

In addition to the measurement site and the test instruments, many other active and passive system components are part of the signal path and can therefore affect the measurement results. These devices include antennas; LISNs; current and voltage probes; cables, connectors and adapters; external attenuators and preamplifiers, limiters; filters, and switches. All these system components shall be calibrated, or frequently verified, to assure accurate measurement results. A quick check using a known signal, which is fed into the measurement system at the transducer connection point, can be used to verify the operation of all components in a signal path. Transducers like antennas, LISNs, and voltage or current probes need to be calibrated which require different measurement procedures.

8.1.3.1 Transducers

The requirements and recommendations for calibrating and verification of transducers like antennas, LISNs, current and voltage probes can be found in ANSI C63.4-2003 and its referenced standards.

Measurement antennas present additional handling and record-keeping tasks because each antenna is individually calibrated. Since antenna factors, even for the same antenna type, can vary considerably, the use of the appropriate antenna factors is essential for achieving correct test results and ensuring repeatability of the measurement. Since antennas are frequently changed, either because of frequency range limitations or for calibration and maintenance purposes, care shall be taken that the correct antenna factors are being used. This can be achieved by defining a library of antenna factors in the application software. A plausibility check of the antenna frequency range and the defined measurement frequency range should be performed. This check eliminates the use of an antenna outside of its calibrated frequency range. The serial number of an antenna as part of a data file header can be used to identify the antenna factor set and link it to the physical antenna being used for the measurement. The data file header should also be available for documentation purposes in a test report.

When a new antenna is added to the antenna library, the following information should be included:

a) Type
b) Manufacturer
c) Model Number
d) Serial Number
e) Calibration Date
f) Calibration Cycle
g) Recommended interpolation method (linear or logarithmic)

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h) Frequency range (independent of factor list)

i) Factor and frequency units (if applicable).

A graphical representation of the antenna factors, based on the entered tabular information, is very desirable because it immediately reveals any errors made during the manual entry of the factors. Furthermore, the antenna factor at any frequency can automatically be determined by the selected interpolation method.

8.1.3.2 Cabling

The insertion loss of cables, including any waveguides, used in the signal path can be significant, particularly for long cables or at high frequencies. These parameters shall be determined in the frequency range of interest, preferably in a swept frequency measurement (discrete frequency measurements may be used if the frequency step size is small). At frequencies determined by the physical dimensions of cables, the frequency response may include sharp, high-attenuation responses which need to be detected and applied correctly to the data measured with the EMI receiver.

Typical system cabling may consist of several individual cables, including their connectors, possibly adapters, and rotary joints to allow for rotation of one cable with respect to a mating cable. Individual connectors and adapters cause small amounts of attenuation due to reflections at impedance discontinuities.

More than any other part of the measurement system, the cabling is subject to movement and damage that could affect the integrity of measurements. The application software should be able to verify the integrity of the cabling. This can be done with the previously mentioned quick check.

8.1.3.3 Attenuators

Attenuators external to the measurement instruments are often included in the signal path, typically at the connection between the antenna and the cable to improve any impedance mismatch. Attenuators are individually calibrated and therefore the attenuation values used in the application software to correct the measurement data numerically shall match the actual attenuator being present in the measurement chain. The operation of external attenuators can be verified as part of the measurement signal path using a quick check.

8.1.3.4 Limiters

The first amplifier in a signal path or the measurement instrument is often at risk from damage due to overloads. The purpose of an RF limiter is to protect these system components by limiting the power of the input signal. However, the limiter itself can be damaged if the input power is sufficiently high. While this can occur when measuring an intentional RF source, it usually happens during conducted measurements with a LISN. A high-power pulse may be coupled into the signal path if the EUT power requirements suddenly change, for example, when power is applied or removed from the EUT. This can also happen when switching the mode of a multi-conductor LISN.

The limiter’s failure often results in a different level of signal attenuation rather than signal elimination. This failure is difficult to detect during the measurement process. It can be observed during a verification test, which requires a variable attenuator to be inserted into the signal path ahead of the limiter. If a change of the attenuation causes a corresponding change in the signal indication on the receiver, the limiter is not introducing unwanted attenuation.

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8.1.3.5 Preamplifiers

Oftentimes a low noise preamplifier is included in the measurement path to improve the system noise figure. Since the gain of an amplifier, especially a wideband amplifier, is not constant over its frequency range, it needs to be determined as a function of frequency. A swept frequency measurement is preferable to be able to detect and record sharp variations in the frequency response curve. These factors need to be applied to the data measured by the EMI receiver. Proper functioning of a preamplifier can be verified with a quick check under software control.

The use of a preamplifier requires additional caution to keep the input signal levels below the amplifier's compression point. Otherwise, it may be driven into gain compression and thus cause erroneous measurement results. Furthermore, preamplifiers can cause distortion products in case strong and/or multiple input signals are present at the same time. In this case, signals will be recorded by the application software, which are not emissions caused by the EUT, but generated by the test system itself. An attenuator placed at the preamplifier input can be used to determine an overload situation or identify preamplifier distortion products. When varying the attenuation, a corresponding amplitude change shall be observed on the receiver display; then the preamplifier is not in saturation. Distortion products change their amplitudes at a certain ratio, relative to the attenuator change. For harmonic distortions, caused by a single high-level signal, the harmonics change at a ratio given by their order; for example, the second harmonic changes twice as much and the third harmonic three times as much relative to the attenuator change. In case of intermodulation distortion caused by two signals at the preamplifier input, the distortion products change three times as much relative to the attenuator setting change, assuming both input signals have the same amplitude.

8.1.4 Ambient search

An ambient search should be conducted to identify and record ambient signals present on an OATS. This can be done under software control by scanning the frequency range of interest using a swept receiver. During this measurement, the antenna height and polarization should be varied according to the EMI regulation, which is applied during the EUT measurement. All relevant signal attributes need to be recorded in an ambient list. Along with frequency and amplitude of the ambient signal, the antenna height and polarization for the measurement, test date and time, frequency uncertainty and other parameters shall be included.

Although stationary local emitters are easily identifiable, an update capability shall be available to add new ambient signals detected during testing or maintenance. The compilation of a meaningful ambient list is a lengthy process because over time intermittent signals will also be included. Furthermore, different ambient lists may be required to accurately represent the electromagnetic environment on an OATS, based on the time of the day.

During the measurement process, the ambient list can be compared to a list of the EUT signals. This way EUT and ambient signals can be identified which involves elaborate signal matching algorithms. Furthermore, signal masking conditions or superpositions can be determined before maximizing a signal. However, intermittent ambients, which occur during an automated test and are not yet logged in the ambient list, may temporarily mask EUT emissions and thus require re-testing of selected signals after evaluation of the measurement data.

8.1.5 Process documentation

The purpose of a process document is to promote consistently accurate operations, regardless of who is performing the operation at any particular time. It should assure that only qualified personnel perform each operation; that each person performs the operation in a manner consistent with the intent of the facility; and that data is correctly generated, stored, and processed.

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All operations outlined in this document should have a documented description of the process used in the operation and maintenance of the facility. In general, this document will contain the specification and requirements for the facility; a description of the construction of the facility; personnel requirements and qualifications; instructions for operating the facility during testing, calibration, verification and maintenance; procedures for hardware, software and documentation development and configuration tracking; and descriptions of data handling procedures.

8.1.6 Software design

The application software is a key component of a productive ATE system. The complete system shall be suitable to accomplish a wide range of testing, analysis, reporting and interactive tasks. This can be achieved by providing a application-specific user interface, including and tabular and graphical representation of measurement data, control interfaces for EMI receivers, antenna towers and turntables, data analysis tools, and data exchange capabilities with other commercially available programs. Furthermore, auxiliary functionality like easy data and test file storage and retrieval, on-line documentation capability, system security with different access levels, and extensive internal plausibility and error checking is necessary to ensure consistency of testing, data integrity, and high throughput. Furthermore, an extensive and detailed on-line Help facility, which also includes examples, shall be provided to allow for quick problem resolution and to minimize system downtime.

Software development should be based on published and commonly accepted guidelines like the IEEE Software Engineering Standards. This will result in a high-quality application software which can be tested, verified and validated in a defined way. However, the level to which these standards are applied to a software project depends on many factors. For example, if the software is sold commercially, these standards have to be applied more rigorously than in a case where it is designed for in-house use only. Then, company-internal quality standards can be used as guidelines during the design cycle.

Several steps should be taken to assure that the software meets its needs. A thorough analysis and written documentation of its capabilities, derived from practical measurement experience, is necessary before the implementation phase. This leads to the documentation of the overall operation of the software on a functionality level. Furthermore, a modular software structure can be implemented which ensures flexibility, efficient use of code, high quality, and future expandability. The quality assurance process, applied to the software, shall include measurement integrity tests, thorough checking of the user interface, tests to ensure proper communication with remotely controllable measurement equipment, checking of error handlers, and tests for the exchange of data or communication with other applications.

To ensure continuous improvement of the software, reports of failures, errors, and requested enhancements should be compiled on an on-going basis. Future revisions of the automation software should address these issues and include appropriate solutions. Special care shall be taken to avoid erroneous measurement results due to incorrect software actions; measurement integrity shall be the ultimate design goal of the software. A quick response to measurement integrity problems which includes the notification of the current users along with suggested remedial actions is very important for the successful use of automation software.

For quality assurance reasons, the history of the software shall be documented and maintained. A software revision control system should be implemented in case of a larger software project. This allows easy identification of changes between software revisions and facilitates parallel development of software modules.

The operating manual of the automation software shall clearly identify the expected knowledge and experience level of the user. Such a statement should include the assumptions made about the theoretical knowledge of EMI, familiarity with the used test equipment, and the knowledge of applicable standards. The future user may be required to complete a specific training to be able to correctly use the software and to use its features to the fullest extent. It is imperative for the user to understand the intent of implemented functions, their impact on measurement results, and their limitations. By completing a dedicated training, misunderstandings can be avoided which may lead to inefficiencies and erroneous test results.

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8.1.7 Equipment list

The application software shall provide a means of storing information of the facility's measurement equipment. This ensures data integrity and repeatability since measurements can be repeated using the same instruments. Furthermore, test reports should include a list of all instruments being used to measure an EUT, which can be extracted from the detailed equipment list. Capability and calibration information about the test equipment is necessary to demonstrate the validity of the results. This equipment list can also be used to track calibration cycles of system components to avoid the use of an uncalibrated instrument.

It is recommended that the minimum amount of information per system component includes the manufacturer's name, model number, serial number, calibration date, calibration interval or next calibration due date, and the asset or calibration identification number.

8.2 Data handling

One advantage of an automated EMI measurement system is the capability to acquire and store large amounts of test data during the actual measurement process. This data can be analyzed after completion of the measurement process and used for many different purposes. The compilation of a final test report usually requires only a limited amount of data to demonstrate compliance with an applicable regulation. However, for future audit testing this additional data makes it relatively easy to detect any changes and their causes in the emission profile of a product. For example, if polar plots of an EUT's radiated emission spectrum are stored and the plot of a current radiated emission spectrum is overlaid, variations can be detected very quickly. Extensive sets of raw data can also be used to analyze the EMC characteristics of an engineering prototype or evaluate modifications to a product with confidence. The backup data can also be used in situations of customer complaints about RF interference to determine the source of interference. In all these cases, it is difficult to predict which signals will ultimately be of interest. Thus, the recording, presentation, and archiving of larger amounts of test data has added importance to the automation of EMI measurement systems. The overall data handling process includes various activities, as depicted in Figure 6.

Three different categories of data shall be recorded for each measurement and their relationship be maintained permanently. This can be accomplished by either keeping all the information together in one file or record of a data base, or by linking the individual pieces together unambiguously, for example, in a linked list. The three categories are 1) the test results 2) the complete measurement system state and 3) the EUT state and configuration. By archiving these different data sets together, test results can be analyzed and documented at a later point in time and measurements repeated under previous conditions. For this reason, easy and reliable storage and retrieval of test results and associated data is a necessary feature of any EMI measurement automation software.

8.2.1 Recording

The application software of an ATE system shall assure that the measurement data is properly stored on a non-volatile medium such as a disk or tape for archiving purposes. A backup copy of test results should be made in regular intervals using a different medium. However, operating system functions or separate utility programs can be used to accomplish this task. Furthermore, an evaluation of the hard disk's condition should be performed frequently. This includes surface scans, identification of bad clusters, and defragmentation, if applicable. On-going system maintenance outside of the application program is necessary to provide a high level of system reliability and to avoid data loss and system down time.

Data storage on a non-volatile medium, performed by the application software, should use the same approach as the operating system. Often times, directory trees can be defined to specify the data storage location. This way, a logical hierarchy can be defined by the user reflecting either groups of products being tested or different tests to be performed. Any deviation from the method provided by the operating system usually makes the software harder to use and can cause confusion among users.

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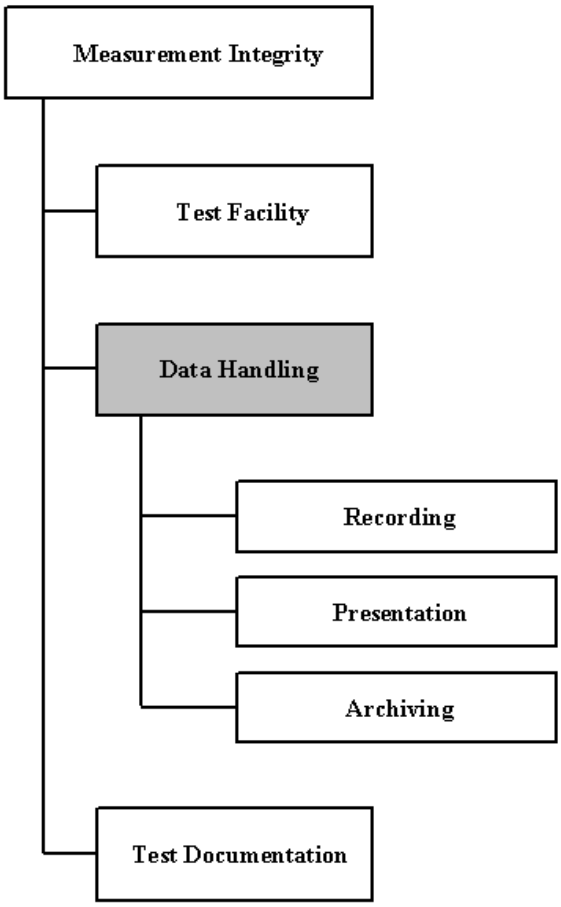


Figure 6—Data handling parameters

The communication between the system controller, for example, a PC running the application software, and the remotely controllable measurement instruments is usually done through a standardized interface and communication protocol. A widely used method is the IEEE 488.2 GPIB interface whose handshake protocol provides very high reliability of data transfer. If other methods of communication are being used, the validity of transferred information, which includes both control commands and test data, needs to be checked by the application program or one of its submodules.

8.2.2 Presentation

Data presentation in tabular format is very useful for data evaluation. The format of signal lists shall be flexible and changeable, even after the actual test is completed. All relevant signal attributes need to be available for display: signal frequency, frequency uncertainty, corrected and uncorrected peak, quasi-peak and average amplitudes, antenna factors, cabling correction factors, limit values, actual amplitude margin, antenna height and polarization, turntable angle, date and time of measurement, key receiver settings, “Pass/Fail” indication for each signal, and a comment field. The order of the columns should be user definable to accommodate specific sorting of signals. In addition, a graphical presentation of certain results provides an even higher level of insight when used along with signal lists. Both ways of data representation complement each other and are required to ensure proper interpretation of measurement results. For example, a spectrum envelope trace, consisting of the highest emission amplitudes measured during the test process, gives the complete worst-case condition in the spectrum of interest. The display of relevant limit lines enhances the graphical representation further because problem areas can be easily identified. However, this spectrum envelope graph does not provide information about the worst case conditions under

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which the amplitude of a certain emission has been measured. This type of information is kept in a corresponding signal list. A graphical representation of test data is usually very helpful to get a quick broad overview of an EUT's emission profile; the detailed analysis of individual signals in this profile can be performed using the signal information in the corresponding list.

A combination of these two presentation methods provides an additional powerful analysis capability. In a graphical representation showing a data trace, lines can be displayed representing signals in a selected list. The line length can represent the peak amplitude saved in the list and quasi-peak and average values can also be represented at the same signal frequency, for example, by using different symbols. This allows quick identification of differences between a list and a data trace and can be used to identify ambient and EUT signals or to distinguish between EUT and support equipment signals. By looking at differences in amplitude of signals in a trace and in the list, superposition situations can be identified, which would not be possible by just examining the trace or signal list alone. Furthermore, the effect of product design changes can be evaluated over the whole frequency range by comparing actual trace data with previously recorded signal list information.

For documentation purposes, a line graph of the investigated frequency spectrum showing the emissions of the measurement as a single line is very useful. The line length indicates the measured amplitude and an indication of the detector used for the test is required as well. This graph should also include the applicable limit lines. An emission list with key signal attributes should be included to provide specific details.

8.2.3 Archiving

The retention of test reports, even beyond the product's life, may be required for regulatory or legal reasons. Archiving measurement data and test reports electronically is the preferred method because it provides many advantages like future automated analysis of previous test data, easy auditing, and quick retrieval. However, electronic archiving presents some unique problems. Magnetic media such as floppy disks and, particularly, tapes can lose the stored information over time in case it is not refreshed at appropriate intervals. Another potential source of data loss is the accidental erasure of the media due to high ambient magnetic fields. Scheduled data backups can minimize these risks by providing two or even more copies of the data archive. Disaster recovery plans typically require two copies of all important information, which are stored in separate locations.

A second potential risk of electronic archiving is the obsolescence of the computer-readable media being used for storage. When support for a medium is no longer available, the data archive has to be transferred to a new medium. While this process can require considerable computing time, it will also involve personnel to plan the data transfer, select appropriate new media, and implement a strategy for future media compatibility.

8.3 Test documentation

Many facilities generate final test reports, for example, for regulatory submission, in an automated way as one of the last steps in the overall test process. This capability should be provided by application software because it increases efficiency, assures consistency in reporting, and avoids inaccuracies and transcription errors. This kind of documentation is also useful for tracking trends in emissions levels and compliance margins over a range of products and within a certain time period. The required tools to accomplish this task should include transfer of text, tabular and graphics data as files to other applications such as word processors and spread sheets for further processing. A self-contained report generator, which allows the inclusion of all the necessary data, should be provided for compilation of a quick, preformatted report to obtain a hard copy of test results or for electronic storage and routing.

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Annex A

(informative)

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