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This short report summarizes the objective, frequency range, allowable limits, required accuracy (if any), apparatus recommended, specific parameters involved, and measurement environment for some selected regulations and standards regarding electromagnetic compatibility measurements. These regulations and standards, either enforced by the U.S. Government agencies or incorporated in voluntary industrial practice, were reviewed and critiqued in 1992. General comments are made here to each of the reviewed standards regarding the physical meaning of, and the technical factors and parameters which may affect, the measurement results. Our own competence at NIST in meeting the measurement requirements is also assessed. When appropriate, an alternative measurement technique developed by NIST, based more on technical soundness than current practice, is offered for possible industry-wide applications.

Key words: electric field, EMC, EMI, emission, magnetic field, measurement methods, regulations (domestic), standards, susceptibility.

1. Introduction

Some selected regulations and standards regarding electromagnetic compatibility (EMC) measurements were reviewed and critiqued in 1992 [1]. These regulations and standards have been either enforced by the U.S. government agencies, such as the Federal Communications Commission and Department of Defense, or incorporated in voluntary industrial practice. Thus, these regulations and standards are restricted to domestic use, excluding all international standards. Because of our own established competence in rf measurements, only the radiated EMC standards are reviewed and summarized. Conducted EMC standards and related measurements are not considered here. For the convenience of users and easy reference, a summary outlining the objective, frequency range, allowable limits, required accuracy (if any), apparatus recommended, specific parameters involved, and measurement environment for each of the reviewed standards is given. When appropriate, an alternative measurement technique developed at NIST and based on a more sound justification than the current practice is brought to the attention of users for possible improvement in measurement accuracy. Since the revision activity of EMC regulations and standards is going on all the time in various committees, it may be impossible to cover all revisions being considered. Therefore, only published and formally adopted standards were reviewed.

2. MIL-STD 461/462

These two military standards were recently revised in 1993 as MIL-STD 461D/462D [2,3].

(2A) <u>Method RE101</u>

1. Objective: To measure the magnetic field radiated from a device or equipment under test (EUT), including its associated cabling.

2. Frequency range: 30 Hz to 100 kHz.

3. Allowable limits in terms of magnetic flux density:
For Navy, they are (a) at a distance of 7 cm from the radiating EUT, 165 dBpT from 30 Hz to 60 Hz, then decreasing to 155 dBpT at 400 Hz, to 112 dBpT at 2 kHz, and to 78 dBpT at 100 kHz; and (b) at a distance of 50 cm from the radiating EUT, 131 dBpT from 30 Hz to 60 Hz, then decreasing to 121 dBpT at 400 Hz, to 78 dBpT at 2 kHz, and to 44 dBpT at 100 kHz.

For Army, they vary, (a) at a distance of 7 cm, from 180 dBpT at 30 Hz to 110 dBpT at 100 kHz, and (b) at a distance of 50 cm, from 146 dBpT at 30 Hz to 76 dBpT at 100 kHz.

4. Accuracy requirement: Not specified. Only small tolerances in distance (±5%), frequency (±2%), or others were allowed.

5. Apparatus recommended: A loop antenna with a diameter of 13.3 cm and 36 turns, line impedance stabilization networks (LISN), and a recording device.

6. Specified parameters and configurations: Placing loop antenna 7 cm or 50 cm from the radiating EUT.

7. Procedures: Varying the loop antenna plane, at two distances of 7 cm and 50 cm, with respect to EUT and scanning the measurement receiver over the applicable frequency range to record the maximum reading.

8. Measurement environment: Placing the EUT on a ground plane, on a non-conductive surface, or in a shielded enclosure with rf absorbers.

9. General comments: While EMC industry has no difficulty of meeting the specified requirements, the important question is the physical meaning of the measurement results. Technical factors or parameters affecting the results include the size (diameter) of the loop, its calibration factor, its orientation with respect to the EUT, the loop-to-EUT distance, and the measurement environment. At the intended frequency range and recommended loop-to-EUT distances of 7 cm and 50 cm, the sensor and EUT are within the near-field region. A minor change in certain configurations may cause huge uncertainties in measurement results. Thus, physical meaning and accuracy of the measured data need to be studied more carefully.

10. NIST's competence: Our established method of TEM cell in the difference mode [4] or the method of three orthogonal loops under investigation [5], both with detailed measurement procedures and error estimates, can be used to achieve the same objective with much improved accuracy and easier analysis of uncertainties.

(2B) <u>Method RE102</u>

1. Objective: To measure the electric field radiated from an EUT.

2. Frequency range: From 10 kHz to 18 GHz.

3. Allowable limits:
For surface ship and submarine applications, beginning with 70 dBμV/m at 10 kHz, decreasing to 36 dBμV/m at 100 MHz, then increasing to 82 dBμV/m at 18 GHz.

For Navy and Air Force internal applications, beginning with 34 dBμV/m from 2 MHz to 100 MHz, then increasing to 79 dBμV/m at 18 GHz; for Navy and Air Force external applications, the corresponding limits are 10 dB lower than the above limits.

For Navy fixed and Air Force ground applications, starting at 44 dBμV/m from 2 MHz to 100 MHz, then increasing to 89 dBμV/m at 18 GHz.

For Navy mobile and Army ground applications, starting at 24 dBμV/m from 2 MHz to 100 MHz, then increasing to 69 dBμV/m at 18 GHz.

4. Accuracy requirements: Not specified.

5. Apparatus recommended: Linear antennas, LISNs, and a receiver. The antennas are 104 cm rod for 10 kHz to 30 MHz, biconical antenna (137 cm tip to tip) for 30 MHz to 200 MHz, or double ridge horns from 200 MHz to 18 GHz.

6. Specified parameters and configurations: Placing the EUT on a ground plane which is about 80 to 90 cm above the floor; placing the measuring antenna at 1 m from EUT with the rod antenna counterpoise also 80 to 90 cm above the floor but with the centers of biconical antenna and double ridge horn 120 cm above the floor; electrically bond the rod antenna counterpoise to the ground plane.

7. Procedures: Varying the EUT surface to produce maximum radiation toward the measurement antenna. Different antenna positions may be required, depending on the size of the test setup. For frequencies above 30 MHz, both horizontal and vertical polarizations are measured.

8. Measurement environment: Tests are generally made inside a shielded enclosure with absorbing materials.

9. General comments: EMC industry can easily comply with the specified requirements. Technical factors or parameters affecting the measurement results include the antenna length, its length-to-diameter ratio, ridge horn size, the antenna calibration factor, the antenna-to-EUT distance (near field or far field), size of the ground plane, and quantity of the absorbing material. In the low-frequency range, even though the rod antenna is more than 1 m in length, it still is only a small fraction of the operating wavelength. As such, a distance of 1 m from EUT makes the measurement antenna well within the near-field range of the radiator. Yet, the antenna factor used to estimate the electric field is, almost without exception, calibrated in a far-field condition. This certainly will affect the resulting accuracy. Similarly, the biconical antenna used for the middle-frequency range has a fixed length of 1.37 m, varying from 0.137 to 0.913 in wavelength. The antenna height of 1.2 m above the floor is more than 0.5 wavelength for frequencies higher than 125 MHz. Its floor image, even though not perfect, also affects strongly its radiation characteristics. The accuracy of the estimated results, based on the actual measurements and calibration in an ideal environment such as free space, is quite questionable. Even for the double-ridge horn, appropriate near-field corrections are, from time to time, needed for improving the accuracy. Furthermore, the degree of EUT rotation (orientation) as required in this method is very limited in practice. The direction of maximum radiation from EUT is, in reality, unknown. The maximum radiation from an unknown EUT does not automatically point to the direction when the sensing dipole is horizontal or vertical. Finally, the addition of absorbing materials in a shielded enclosure as required in the newest version of the standard

[2,3] definitely makes the measurement results more repeatable with less uncertainty. However, the exact amount and shape of the absorber (frequency dependent) could cause further discrepancy between the measurement result and the real fact.

10. NIST's competence: Combination of our established method of TEM cell operated in the sum mode [4], open site, and the anechoic chamber can achieve the same objective with much improved accuracy and convenient analysis of uncertainties. Detailed measurement procedures and error analysis are available [4,6].

(2C) <u>Method RE103</u>

1. Objective: To measure the radiated spurious and harmonic outputs from a transmitter.

2. Frequency range: 10 kHz to 40 GHz generally. Specific test frequencies are as follows:

EUT Operational Frequency	Starting Test Frequency
10 kHz to 3 MHz	10 kHz
3 MHz to 300 MHz	100 kHz
300 MHz to 3 GHz	1 MHz
3 GHz to 40 GHz	10 MHz

The ending test frequency is 40 GHz or 20 times the highest frequency generated within the EUT, whichever is less. For EUT using waveguide, the requirement does not apply below 0.8 of the waveguide's cutoff frequency.

3. Allowable limits: Harmonics, except the second and third, and all other spurious emissions are at least 80 dB below the fundamental emission. The second and third harmonics are below 50 + 10 log p (p being the peak power output in watts at the fundamental) or 80 dB, whichever requires less suppression.

4. Accuracy requirements: Not specified.

5. Apparatus recommended: A receiver, attenuators, various antennas depending on frequency, preselector filter, band rejection or high-pass filters, signal generator, and power monitor.

6. Specified setup: Configuring the test setup for signal checking along the measurement path between the transmitter under test and a measuring antenna at a midband fundamental frequency.

7. Procedures: Placing the sensing antenna at a far-field distance from the transmitter and varying its azimuth and elevation positions to record the maximum reading for each frequency, measuring the modulated transmitter power output using a power monitor, and calculating the effective radiated power by adding the EUT antenna gain.

8. Measurement environment: Performing all the measurements in the far-field environment at each transmitter frequency.

9. General comments: The distance required for a sensing antenna in the far-field region of the transmitter for low-frequency measurements (e.g., 30 kHz) will be very large. It may not be practical to perform the measurement in a shielded enclosure. When a conversion from the

measured electric field to power density is desired, the antenna gain or antenna factor provided by the manufacturer may need a near-field correction if a reasonable accuracy is maintained. Furthermore, the EUT gain is generally unknown. Its determination may not be simple.

10. NIST's competence: For frequencies above 300 MHz, the measurement can be performed more accurately inside our anechoic chamber. For lower frequencies, the TEM cell method may be applicable if the EUT size is not too large. Open ground together with the standard receiving dipoles may be useful, if security is not a concern. Our capability for the entire frequency range of 10 kHz to 40 GHz as specified in this standard for measuring the radiated electric field should be assessed as to its adequacy.

Other three test methods concerning emissions (RE04-06 in the older version of the standards) have been deleted in the revised version, as they involve the determination of unintentional emissions from vehicles, engine-driven equipment, or overhead power lines in the surrounding area of a test site. These tests are relatively less important.

(2D) <u>Method RS101</u>

1. Objective: To determine whether equipment can be operated compatibly when it is subject to a radiated magnetic field.

2. Frequency range: 30 Hz to 100 kHz.

3. Threshold limits:
   For Navy, beginning at 175 dBpT from 30 Hz to 60 Hz, decreasing to 165 dBpT at 400 Hz, to 122 dBpT at 2 kHz, and then to 88 dBpT at 100 kHz.

   For Army, beginning at 180 dBpT from 30 Hz to 60 Hz, and then decreasing to 116 dBpT at 100 kHz.

4. Accuracy requirements: None.

5. Apparatus recommended: A signal source, a radiating loop antenna, a sensing loop antenna, a measurement receiver, current probes, and LISNs. The radiating loop is of 12 cm in diameter with 20 turns of #12 insulated copper wire to be able to produce a magnetic flux density of $9.5(10)^7$ pT/A of applied current at a distance of 5 cm from the loop plane. The sensing loop is of 4 cm in diameter with 51 turns of #41 insulated wire.

6. Specified parameter and configuration: Positioning the field-producing loop 5 cm from one of the EUT surfaces and parallel to it.

7. Procedures: Supplying the radiating loop with sufficient current to produce a magnetic flux density at least 10 dB greater than the applicable limit and scanning the frequency range to observe whether the EUT experiences any susceptibility problem; reducing the current to produce a magnetic flux density corresponding to the applicable limit; repeating the same tests by moving the loop around the EUT, and recording any susceptibility.

8. Measurement environment: In a shielded enclosure.

9. General comments: Other factors, which may influence the measured results, include the loop size, its orientation and calibration, the distance at which a prespecified magnetic field is produced, and

possibly the interaction between the loop and the sample. Because of large variations in the magnetic field produced by a loop antenna under the near-field condition, a successful susceptibility test in accordance with this method does not necessarily imply that another test of the same sample at the same distance from the source will also be successful.

10. NIST's competence: A more accurate method for measuring the magnetic field in the frequency range of 10 kHz to 30 MHz with an established uncertainty in the order of 0.5 to 1 dB is available in our laboratory in Boulder, CO. For much lower frequency, measurement service is available in Gaithersburg, MD.

(2E) <u>Method RS103</u>

1. Objective: To determine susceptibility of equipment, subsystems, and systems in the presence of an electric field.

2. Frequency range: 10 kHz to 40 GHz.

3. Threshold limits: Varying from 5 V/m to 200 V/m depending on frequency and type of services (Army, Navy, Air Force; ground, submarine, or inside/outside aircraft).

4. Accuracy requirement: None.

5. Apparatus recommended: Signal source, amplifier, attenuator, directional coupler, transmitting and receiving antennas depending on frequencies, receiver, and power monitor.

6. Specific parameters: Placing the transmitting antenna 1 m from the test setup boundary, with possible multiple antenna positions for frequencies higher than 200 MHz. For frequencies up to 30 MHz, only vertical polarized field is produced. For higher frequencies, both vertical and horizontal fields should be produced for testing.

7. Procedures: Adjusting the signal source applied to the transmitting antenna until the required field is achieved for all test frequencies. The voltage or power at the input terminals of the transmitting antenna required to establish the specified field is monitored and recorded. If susceptibility is noted, record the field and frequency.

8. Measurement environment: Measurements are all performed in a shielded enclosure.

9. General comments: The influencing parameters in this standard include the type and size of the radiating antenna, its orientations with respect to the EUT, the calibrated antenna factor, the EUT size, and the antenna-to-EUT distance. A recommended distance of 1 m between the transmitting antenna and test setup boundary, while practical and convenient, lacks technical basis and will cause large measurement errors.

10. NIST's competence: The TEM cell can be used to generate a far-field or near-field environment [7] for rf susceptibility test with good confidence in estimating uncertainties. Well-characterized anechoic chamber is applicable for high-frequency susceptibility tests. For large-system testing, the reverberating chamber developed at NIST is also suitable for high-frequency application [8, 9]. The hybrid

TEM/reverberating chamber being evaluated is good for very broadband testing [10].

(2F) <u>Method RS105</u>

1. Objective: To determine the ability of the EUT to withstand a transient (broadband) EM field.

2. Threshold limit: A transient waveform of electric field with a peak value of 50 kV/m, a rise time less than 10 ns, and a decay time greater than 75 ns.

3. Accuracy requirement: None.

4. Apparatus recommended: Parallel plate or TEM cell, transient pulse generator, storage oscilloscope with a minimum bandwidth of 200 MHz and a variable sampling rate up to 1 GS/s, terminal protection device, high-voltage probe, D-dot and D-dot sensors with integrators, and LISNs.

5. Specified configuration: Testing the EUT in "its orthogonal orientations whenever possible."

6. Procedures: Placing the EUT at the center of the parallel plate (or TEM cell), applying the pulse starting at 50% of the required peak with the specified waveform and then gradually increasing the peak to its desired value, and monitoring the EUT during and after the application of each pulse for signs of performance degradation and recording the result. When susceptibility is noted, decreasing the pulse amplitude and recording the result when the undesired response no longer present.

7. Measurement environment: Tests to be made exclusively inside the parallel or TEM cell.

8. General comments: Field uniformity inside a parallel plate (or TEM cell) and its perturbation by the presence of an EUT should be analyzed to estimate the measurement uncertainty. The plate space and the EUT size relative to the test available test area are important factors which may affect the accuracy. Requirements of less than full three orthogonal EUT positions may not be sufficient to evaluate the overall susceptibility.

9. NIST's competence: The TEM cell is definitely more suitable for performing the necessary measurements, as it has no opening for hazard concerns. Field uniformity inside the TEM cell due to disturbance by the EUT and the measurement uncertainty have been analyzed and documented [11].

Two other old 461/462 standards (RS02 and RS04) were omitted in the revised version.

3. MIL-STD 285

1. Objective: To determine the attenuation characteristics (electric or magnetic field) of shielding enclosure.

2. Frequency range: 100 kHz to 10 GHz in general; only three sub-bands for actual measurements.

3. Limit: Not specified; just record the shielding effectiveness (SE) for frequencies under test.

4. Accuracy: Not specified.

5. Apparatus recommended: Signal source, attenuator, detector, and low-impedance vertical loops (both transmitting and receiving) of 0.3 m in diameter for the sub-band frequency of 150 kHz to 200 kHz; or high-impedance vertical rod antennas of 1.04 m in length for the sub-band frequency of 200 kHz to 18 MHz; or tuned vertical dipoles around 400 MHz.

6. Specified parameters: For measuring the magnetic-field attenuation, the loops are placed 0.3 m away from the enclosure wall with the transmitting loop placed outside the enclosure while the receiving loop inside the enclosure wall. For measuring the electric-field attenuation, the transmitting rod is placed 0.3 m outside the enclosure wall, and the receiving rod is placed 0.3 inside the enclosure wall. For 400 MHz, the tuned transmitting dipole is placed at least 1.83 m outside the enclosure wall and the receiving tuned dipole 0.05 m inside the enclosure wall.

7. Procedures: For the same antenna configurations and input powers, the fields are measured with and without the enclosure present. The ratio of these fields represents the shielding effectiveness of the enclosure.

8. Measurement environment: In a laboratory.

9. General comments: The measurement of attenuation characteristics of an enclosure or of a material is known to depend not only on the material itself, but also on the wave type generated by a transmitting antenna (plane wave vs. near-field wave, wave polarization and propagation direction, the environment in which the antenna is placed, etc.), the location of the receiving antenna and the environment, and the calibration factors of both antennas. The response of a receiving antenna placed inside an enclosure represents the vector sum of the direct wave passing through the enclosure wall being evaluated and the reflected components from the other walls. This situation is similar to the case of making measurements inside a shielded room. Thus, the measurement accuracy for this standard is very difficult to estimate.

10. NIST's competence: NIST has conducted a theoretical study in this area together with a proposed flanged coaxial holder to measure the SE of a material [12-14]. One of our approaches, based the far-field concept, yields repeatable results. The method was adopted by ASTM in 1989 (Std D4935-89) after successfully being verified by other participants. Similar measurement techniques for obtaining the shielding properties of gaskets and containers [15], or based on a near-field environment have also been under preliminary study. Further study in these areas by NIST to develop a reliable method and fixture for obtaining better and repeatable measurement results will benefit the EMC industry.

4. MIL-STD-1344A, Method 3008

1. Objective: To measure the shielding effectiveness (SE) of multicontact connectors.

2. Frequency range: 1 to 10 GHz.

3. Limit: None specified; just record the measurement results on SE for different types of connectors.

4. Accuracy requirements: Not specified.

5. Apparatus recommended: Signal source capable of producing an output power of minimum 1 W, isolator, frequency counter, directional couplers, power meters, 50-Ω loads, attenuators, long wires to be used as the transmitting and reference antennas.

6. Specified parameter and configuration: Prepared an EUT (a shielded connector) and placed it in an approximate position inside a mode-stirred chamber.

7. Procedures: Two measurements for each frequency are made to obtain the average power received by the reference antenna and the average power received by the EUT (connector).

8. Measurement environment: All tests are made inside a mode-stirred chamber.

9. General comments: The important factors to be considered in this measurement are the selection of sample multicontact connectors, identification of the coupling mechanism with which the field penetrates into the connector, understanding of the field generated inside a mode-stirred chamber, the location of the test sample placed inside the chamber, and interpretation of the test results. The relative uniformity of electric fields generated inside a mode-stirred chamber depends on the chamber size, frequency, the number of modes existing in a given chamber, mode density, and the quality factor (Q) as a function of the chamber material.

10. NIST's competence: We have made theoretical and experimental studies on the mode-stirred chamber [8, 9]. Chambers with different sizes and made of different materials have been characterized for other agencies. Test results of whole systems have been found satisfactory. We are in a good position for making meaningful evaluation of measurement accuracy by this method.

5. FCC Title 47, Part 15, Subpart J

1. Objective: To determine the unintentional electric field radiated from computing devices.

2. Frequency range: 30 MHz to 1 GHz.

3. Limits: 30 μV/m for 30 to 88 MHz, 50 μV/m for 88 to 216 MHz, and 70 μV/m for 216 to 1000 MHz at a distance of 30 m for Class A devices (commercial, industrial, and business); 100, 150, and 200 μV/m for the same respective frequency bands at a distance of 3 m for Class B devices (consumer).

4. Accuracy requirements: Not specified.

5. Apparatus recommended: A tuned half-wave dipole. At the lower frequency end such as 30 MHz, the dipole length will be 5 m, which may not be practical. In this case, another linearly polarized antenna may be used, provided that the result obtained with such an antenna is correlatable with that obtained with a tuned half-wave dipole.

6. Specified parameters: The dipole must measure both horizontal and vertical polarizations. The antenna height (from the feed point) above ground is to be varied, depending on the antenna-to-EUT distance, to measure the maximum radiated field. For distances up to and including 10 m (for Class A), the antenna height is varied from 1 to 4 m. At the

distance of 30 m, the antenna height is varied from 2 to 6 m. At intermediate distances from 10 to 30 m, it may be necessary to adjust the minimum antenna height down to 1 m, except that, for a vertical dipole, the minimum antenna height has to be increased so that the bottom half of the dipole clears the ground surface by at least 25 cm. If the specified measurement distances of 30 m (Class A) and 3 m (Class B) are impractical, different distances may be allowed if the test results are correlatable with the specified distances according to the inverse-distance relationship.

7. Measureocedures: For each frequency and antenna distance, record the maximum radiated field when the antenna height is adjusted. Detailed procedures are described in FCC MP-4 "FCC Procedures for Measuring RF Emissions from Computing Devices." Recently, rule changes by FCC permit the use of ANSI C63.4-1991 to replace FCC MP-4.

8. Measurement environment: The measurement is to be made in an open flat area. A ground screen is highly recommended, but not mandatory. If a radiating device and the measurement equipment cannot be set up on an open site, testing is permitted at the user's premises. In this case, the measured emissions are unique only to that particular installation.

9. General comments: The important parameters relevant to this standard include the size of ground screen, the antenna calibration factor, antenna distance relative to the EUT, and test environment. Response at the receiving dipole is a vector sum of the emission radiated directly from the EUT placed on an open site and that due to the ground image. When the direct component from the measured result is extracted, a perfect ground has always been assumed. This certainly constitutes an approximation. Also, a commercially available dipole is exclusively calibrated in the far field. The effect on measurement accuracy when the dipole is within the near-field range of the EUT is usually not estimated. Estimation of emissions at 30 m or 3 m from measured data obtained at near-field distances, based on the inverse-distance relationship, may produce additional error. The environment in the surrounding area of a test site, such as scattering objects, obstacles, vegetation, and others is another factor to be considered in this method of measurement.

10. NIST's competence: Since our open site has been thoroughly characterized, it can be used as a standard site for evaluating the performance of a user's site. The calibration factor of a dipole with different length-to-diameter ratios obtained in a near-field environment has not been available. The work in this area may be desirable if more accurate measurement results are demanded.

6. FCC Title 47, Part 18

1. Objective: Try to set the EMI emission limits for the industrial, scientific, and medical (ISM) equipment.

2. Frequency range: All frequencies above 9 kHz except a few prohibited bands reserved for other purposes (490 to 510 kHz, 2.17 to 2.194 MHz, 8.354 to 8.374 MHz, 121.4 to 121.6 MHz, 156.7 to 156.9 MHz, and 242.8 to 243.2 MHz).

3. Limits: Variable depending on power level; generally less restrictive than those in Part 15; unlimited radiations allowed for a set of specific frequencies (6.78, 13.56, 27.12, 40.68, 915 MHz; 2.45, 5.8, 24.125, 61.25, 122.5, and 245 GHz with small tolerances).

4. Accuracy requirements: Not specified.

5. Apparatus recommended: Similar to those in Part 15.

6. Specified parameters: Similar to Class B devices in Part 15.

7. Procedures: Similar to those in Part 15; Details are given in MP-5, "Methods of Measurements of Radio Noise Emissions from ISM Equipment." However, these procedures are not mandated.

8. Measurement environment: Over an open site or in a laboratory.

9. General comments: Unlimited emissions for certain frequencies as described above could cause EMI problems to other co-located equipment. The average annual number of verified complaints on interference from ISM equipment in recent years has been over 100, representing about less than 1% of the total annual number of verified complaints from all man-made sources of interference.

10. NIST's competence: Comments given for Part 15 also apply here.

7. ANSI C63.2-1987 (revised from 1980)

1. Objective: To describe the requirements for instrumentation to be used to measure electromagnetic noises and fields.

2. Frequency range: 10 kHz to 40 GHz.

3. Basic apparatus: A manually or automatically tuned frequency-selective voltmeter with other appropriate devices such as measuring antennas and current probes. Specific antennas are recommended for different frequency bands. They are rod or loop antennas (0.01 to 30 MHz), tuned dipoles (30 to 1000 MHz), biconical antenna (30 to 220 MHz), log-periodic and conical log-spiral (220 to 1000 MHz), conical log-spiral (1 to 10 GHz), double-ridged waveguides (1 to 18 GHz), and matched waveguide horn (18 to 40 GHz).

4. Physical parameters to be measured: Electric field, voltage and current, in peak, quasi-peak, rms, or average values, narrow band or broadband (impulsive noise), and frequency.

5. Accuracy requirements: ±2 dB in volts, ±3 dB in fields, and ±2% in frequency.

6. Specific requirement: The rejection ratio to signals at frequencies more than 20% from the tuned center frequency is 60 dB minimum throughout the frequency range of the instrument.

7. General comments: This is a recommended set of requirements, based on technical considerations to improve the measurement accuracy, for voluntary compliance. This is the document also specifying a measurement accuracy. While the suggested set of antennas is adequate to cover the entire frequency range, calibrating antennas by different means could still cause some consistency problem. Some of the antennas are physically and electrically large. Perturbation on the measured fields due to their own presence should be carefully evaluated.

8. NIST's competence: The broadband probes together with an optical sensing system to minimize the disturbance on measured fields, which were

recently developed at NIST are applicable in this area to reduce the measurement uncertainty [16, 17].

8. ANSI C63.4-1981 (newly revised in 1991)

1. Objective: To set uniform methods for measuring rf noise emissions from low-voltage electrical and electronic equipment.

2. Frequency range: 9 kHz to 30 GHz.

3. Measuring instruments and others: The rf noise meters used in the measurements, the accuracy requirements, and calibration procedures are to conform to the requirements of ANSI C63.2-1987.

4. Test environments: An open-field test site with an elliptically shaped ground plane, a laboratory at the user's premises, or a shielded enclosure at frequencies below its lowest resonant frequency.

5. EUT preparation: The equipment under test is to be configured and operated in a manner to maximize its rf noise characteristics in a typical application. Power and signal distribution, grounding, interconnecting cables, and physical placement of equipment should also simulate a typical, practical condition.

6. General comments: All specific recommendations contained in this document have been carefully made. It represents a significant contribution from the technical community.

7. NIST's competence: Same as that for ANSI C63.2-1987.

9. Conclusions

We have summarized the important points of 12 domestic EMC-related regulations and standards, enforced by the U.S. government agencies or recommended by the voluntary industrial committees. The important points extracted from these standards include the objective, frequency range, allowable limits, required accuracy, recommended apparatus, specific parameters or configurations, measurement procedures, and environment in which the measurements are performed. General comments from the viewpoints of technical justifications, physical meanings of the data, and measurement accuracy are made for each of the reviewed standards. At the same time, the capability and measurement competence at NIST/Boulder to support U.S. industry are assessed. When appropriate, alternative measurement techniques to yield better or more meaningful results with sound reasons are suggested for possible application and adoption by the industry.

10. References

[1] Ma, M.T. EMC standards and regulations: a brief review. Natl. Inst. Stand. Technol. NISTIR 3989; 1992, May.

[2] Requirements for the control of electromagnetic interference emissions and susceptibility. MIL-STD-461D; 1993, January 11.

[3] Measurements of electromagnetic interference characteristics. MIL-STD-462D; 1993, January 11.

[4] Ma, M.T.; Koepke, G.H. A method to quantify the radiation characteristics of an unknown interference source. Nat. Bur. Stand. (U.S.) Tech. Note 1059; 1982, October.

[5] Novotny, D.R.; Masterson, K.D.; Kanda, M. An optically linked three-loop antenna system for determining the near-field radiation characteristics of an electrically small source. IEEE Int. Symp. on EMC; August 1993; Dallas, TX.

[6] Ma, M.T.; Kanda, M.; Eds. Electromagnetic compatibility and interference metrology. Nat. Bur. Stand. (U.S.) Tech. Note 1099; 1986, July.

[7] Ma, M.T.; Larsen, E.B.; Crawford, M.L. Electromagnetic fields with arbitrary wave impedances generated inside a TEM cell. IEEE Trans. Electromag. Compat., vol. EMC-33, no. 4, 358-362; November 1991.

[8] Crawford, M.L. Evaluation of a reverberating chamber facility for performing EM radiated field susceptibility measurements. Nat. Bur. Stand. (U.S.) NBSIR 81-1638; 1981, February.

[9] Ma, M.T. Understanding reverberating chambers as an alternative facility for EMC testing. J. Electromag. Waves & Appl., vol. 2, no. 3/4, 339-351; 1988.

[10] Ma, M.T.; Crawford, M.L. Facilities for improving evaluations of electromagnetic susceptibilities of weapon systems and electronic equipment. Natl. Inst. Stand. Technol. NISTIR 89-3928; 1989, November.

[11] Kanda, M. Theoretical and experimental investigations of electromagnetic field distortion due to a perfectly conducting rectangular cylinder in a transverse electromagnetic cell. Nat. Bur. Stand. (U.S.) Tech. Note 1028; 1981, April.

[12] Wilson, P.F.; Ma, M.T.; Adams, J.W. Techniques for measuring the electromagnetic shielding effectiveness of materials, Part I -- Far-field source simulation. IEEE Trans. Electromag. Compat., vol. EMC-30, no. 3, 239-250; August 1988.

[13] Wilson, P.F.; Ma, M.T. Techniques for measuring the electromagnetic shielding effectiveness of materials, Part II -- Near-field source simulation. IEEE Trans. Electromag. Compat., vol. EMC-30, no. 3, 251-259; August 1988.

[14] Adams, J.W.; Vanzura, E.J. Shielding effectiveness measurements of plastics. Nat. Bur. Stand. (U.S.) NBSIR 85-3035; 1986, January.

[15] Adams, J.W. Electromagnetic shielding of rf gaskets measured by two methods. IEEE Int. Symp. on EMC; August 1992; Anaheim, CA.

[16] Kanda, M.; Driver, L.D. An isotropic electric-field probe with tapered resistive dipoles for broad-band use, 100 kHz to 18 GHz. IEEE Trans. Microwave Theory and Techniques, vol. MTT-35, no. 2, 124-130; February 1987.

[17] Randa, J.; Kanda, M.; Melquist, D. Possible designs for electric-field-strength probes for millimeter waves. Nat. Bur. Stand. (U.S.) NBSIR 88-3084; 1988, February.