Proposed Changes and Updates on IEEE Std 1128 - Recommended Practice on Absorber Evaluation

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Abstract— **The last published version of the IEEE Std 1128 is the 1998 edition. It is titled "Recommended Practice for RF Absorber Evaluation in the Range of 30 MHz to 5 GHz". Over the years, the document has been used widely for absorber evaluations in electromagnetic compatibility (EMC) applications as well as in antenna and microwave measurement applications. Besides the obvious frequency range which needs to be expanded to satisfy today's applications, several areas are in need of an update. The proposed document will change the upper frequency limit to 40 GHz (with provisions in the document to potentially extend above 40 GHz based on test methods). Measurement uncertainties were not discussed in the IEEE Std. 1128 – 1998. In the new edition, measurement instrumentation and test methods are expected to be updated with guidance on estimating measurement uncertainties. In the proposed document, a section on absorber evaluations for high power applications is planned, and fire properties and test methods will be included.**

I. INTRODUCTION

IEEE Std 1128-1998 [2] is a "Recommended Practice for RF Absorber Evaluation in the Range of 30 MHz to 5 GHz". There are four categories [1] of IEEE standards under the policies and procedures of IEEE standard association, namely standards, recommended practices, guides, and trial-use documents. In a recommended practice standard, the word "should" is generally used instead of "shall" to indicate the requirements are not mandatory, but preferred. The IEEE Std 1128 is a set of recommended practices for evaluating the performance of RF absorbers typically used in anechoic chambers for antenna and EMC measurements. Absorbers (such as thin sheets used in products for EMI suppressions) are not covered specifically by the standard.

IEEE Std 1128 has proven to be an invaluable tool for absorber users, providers, purchasing agents alike to facilitate specification and evaluation of absorbers. Most users of absorbers are interested in the final chamber performances, not necessarily how some individual pieces perform. Consequently, many view IEEE Std 1128 as a specialty document for absorber providers and chamber designers. While it is true chamber results (typically evaluated as quiet zone reflectivity levels) show aggregated macro level absorber performances. Some applications, for example, rely on absorber level testing. For example, in the military EMC standard MIL-STD-461G [3], chamber requirements are entirely defined by absorber reflectivity specifications with no other system level requirements. Moreover, for end users, it is also important to have an industry-wide set of practices so comparisons can be made with confidence. Many users acquire absorbers separately from chambers, e.g., for retrofitting or refurbishment of existing facilities. It is highly desirable to have some common metrics to compare and evaluate.

Obviously, the title of the standards dictates that the standards prescribe recommended methods for absorber testing on the component level, not on system level chamber quiet zone (QZ) performances. Chamber qualifications are addressed by a plethora of other standards such as NSA requirements in CISPR 16-1-4 [4], ANSI C63.4 [5] for EMC applications and Free-space VSWR reflectivity in IEEE Std 149 [6] for antenna measurements. IEEE Std 1128 intends to direct users to those documents for guidance, and concentrates on test methods for measurements of absorber reflectivity, and other material properties (electrical or fire retardancy).

The IEEE Std 1128 was last published in 1998 under the sponsorship of IEEE Electromagnetic Compatibility (EMC) Society. Absorbers are used in anechoic chambers for conducting radiated EMC compliance measurements. The EMC society has a keen interest in providing guidance and uniform test methods. The frequency range of 30 MHz to 5 GHz in the document title reflects these application goals, because it covers the needs of the EMC standards at the time (1998).

Absorbers are also widely used in antenna and other microwave measurement ranges, for example, in the far-field chambers, compact ranges, and nearfield measurement chambers. There are limited IEEE stipulations or test methods addressing this application (IEEE Std 149 – 1979 is perhaps the only IEEE standard which contains a free-space VSWR method for anechoic chamber level evaluation). Absorber evaluation methods are largely application agnostic. As a result, IEEE Std 1128 – 1998 has become the de facto guides for absorber testing used in antenna chambers. One significant deficiency here is the upper limit of 5 GHz.

Many other aspects of the documents are also in need of updating from the 1998 edition, including equipment, measurement techniques, measurement uncertainties, or alignment with other standards. In August of 2015, a group from chamber and absorber users, absorber manufacturers, and test labs formed an ad hoc group at the IEEE international Symposium on EMC in Dresden, Germany to look at the possibility of updating the standards. Since then, multiple meetings have been conducted in conjunction with the annual IEEE EMC symposiums and AMTA conferences. A Project Authorization Request (PAR) was approved by IEEE on March 3, 2017. The group consists of members from IEEE EMC society, IEEE Antennas and Propagation Society (APS) and AMTA. The group decided to seek sponsorship from both EMC and APS societies, and the working group is now officially recognized as a jointly sponsored IEEE working group.

II. EXISTING AND PLANNED STRUCTURES

The front matter of the IEEE Std 1128-1998 gives a description of the scope. It states, the document provides:

> "Realistic and repeatable criteria, as well as recommended test methods, for characterizing the absorption properties of typical anechoic chamber linings applied to a metallic surface are described. Parameters and test procedures are described for the evaluation of RF absorbers to be used for radiated emissions and radiated susceptibility testing of electronic products, in the absorber manufacturer and/or absorber user environment, over the frequency range of 30 MHz to 5 GHz."

The standard consists of three basic sections

- Instrumentations – discussions on spectrum analyzers, network analyzers, vector voltage meter and EMC antennas
- Material bulk-parameter evaluations on how to measure permittivity and permeability of absorber materials
- Absorber reflectivity measurement methods, including arch method, TEM horn time domain method, waveguide method and coaxial reflectometers.

The IEEE EMC society traditionally places frequency limits in standards for easy identification. The working group adopted to honor the tradition, and change the upper limit of IEEE Std 1128 to 40 GHz. Of course, many of the existing test methods work well without much modification, while some need additional discussions and changes. Test methods do not "magically" cease to work at 40 GHz. The effects are gradual, so discussions and cautions are intended to be included about applicability for frequencies greater than 40 GHz. For frequencies much greater than 40 GHz (for example at W band or above), a study [7] has shown that different considerations might be needed. At present time, the working group does not intend to address issues for millimeter wave range evaluation, as they are beyond the project scope.

Several other aspects are to be addressed. Notably missing from the 1998 edition are high power applications/fire protection properties of absorbers, and measurement uncertainties guidelines. Structurally, the working group plan on re-arranging the document to better reflect the workflow that are likely encountered by potential users of the document. The absorber reflectivity measurements do not appear until Chapter 7 in the 1998 document. It is more logical to move to an earlier chapter. Perhaps discussions on instrumentations, antennas, test conditions and other supporting information can be moved to annexes. The structure in a proposed order is shown below:

- Reflectivity measurements (currently Chapter 7)
- Material bulk-parameter measurements (currently Chapter 6)
- High power applications
- Fire properties and standards compliance
- Chamber level measurements (currently Chapter 8)
- Measurement uncertainties
- Annexes (instrumentations and other supporting information)

III. ABSORBER REFLECTIVITY

Absorber reflectivity is a critical parameter. Two primary types of facilities are used to measure absorber reflectivity, i.e., in a free-space environment or in a guided structure. The arch method is performed in free-space, and is fairly straightforward and intuitive. Transmitting and receiving antennas are set at specular angles of reflection, and at the far field of the test sample ($>2D^2/\lambda$, where D is the aperture size of the antenna, and λ is the wavelength). Test samples are measured against a perfect electric conductor (PEC) plate only, and then with absorbers placed on top of the PEC plate. The difference is the reflectivity. Figure 1 shows a typical setup. The method is still used widely in the industry, and there have not been any major changes in basic test concept. However, the 1998 standard is written based on using a scalar VSWR meter and manual data recording and processing. This does not reflect the prevailing practice today. One of the challenges in this measurement is to isolate the cross coupling between the transmitting and receiving antennas, and to isolate reflections from the open test environment. Vector measurements using vector network analyzers (VNA) are commonplace today. The vector data allows for post processing, such as time domain gating to remove extraneous couplings and reflections. The standards will be updated to reflect the current practice.

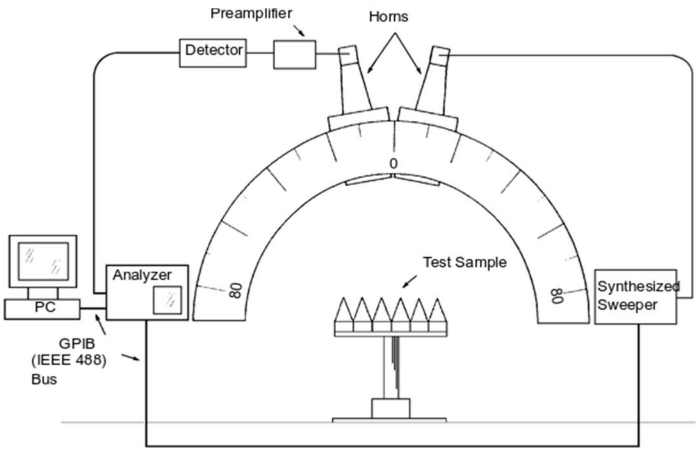

Figure 1. Arch method setup (Figure 20 in [2]).

As the frequency reaches lower (below 1 GHz), the arch radius becomes impractically too large to satisfy the far field condition. Additionally, the sample size is recommended to be greater than 10λ. 10λ is 3 m at 1 GHz, which is at the upper limit of a practical setup. For this reason, guided wave structures are preferred by most labs at these lower frequencies. Two methods are given in the standards. One is a flared waveguide method (Figure 2) where a TE_{10} mode wave is launched from one end, and absorber samples over a shorting plate provide the load at the other end. The wave impedance in the waveguide is not equal to the free-space impedance of 377 Ω. For TE_{10} mode, the impedance in the waveguide η_{10} is given by:

$$\eta_{10} = \frac{\eta_0}{\sqrt{1-\left(\frac{\lambda}{2a}\right)^2}},$$

where η_0 is the free space wave impedance of 377 Ω,
λ is the free-space wavelength,
a is the width of the waveguide.

A study showed that for an error of 2 dB when measuring 30 dB reflectivity, a is required to be at least 2λ, or 20 m at 30 MHz (to approximate a plane wave). On the other hand, the upper frequency is limited by the appearance of higher order modes (which is related to the size a). These two factors limit the frequency range and applicability of the configuration. Most users prefer an alternative configuration using a coaxial reflectometer where TEM mode is dominant. In the next edition, this preferred arrangement should be listed as the first (and recommended) method, instead of being listed behind the flared waveguide configuration. Figure 3 shows an example of a coaxial reflectometer. The center pin of the coax is a square prism with the same cross-sectional size as that of an absorber tile (for example 2’ x 2’). Eight tiles are required to make a reflectivity measurement. The 1998 edition provides a rather general description of the measurement procedure. Because the characteristic impedance of such a coaxial line is approximately 60 Ω, time domain gating using a VNA is needed to remove the discontinuity when connected to a 50 Ω system. One of the issues of time domain gating through digital signal processing is the so called “edge effects”, where the data at the band edges is unreliable after gating. The standard recommends a start frequency of at least 10% of the frequency range below the lowest frequency of interest. However, 30 MHz is a critical frequency point for most EMC absorber evaluations. There is not enough frequency range below 30 MHz to be “discarded”. Studies [8,9] have shown the edge effects are quite pronounced at 30 MHz, and the results are dependent on the algorithm and analyzers used. The next edition of IEEE Std 1128 intends to address the edge effects and provide more guidance on this issue.

The standard also discussed higher order modes and upper usable frequency limit, and warned that severe errors will occur if measurements are attempted for frequencies above 600 MHz. Recent studies [8,9] have compared numerical simulated results obtained in a reflectometer vs. using a plane wave excitation. These results indicate that the reflectometers can be used effectively up to 900 MHz or above depending on the absorbers loading and reflectivity levels. It is expected that next edition will update the discussions based on these newer findings.

The 1998 edition devotes much attention to direct time domain methods to measure absorber reflectivity using a pulse generator and a digital scope. Specifically, two methods were detailed – one is an in-situ setup in an anechoic chamber using two TEM horn antennas in a bi-static configuration; the other is a mono-static configuration. The descriptions are informative, and the methods are useful for researching and debugging purposes. For example, they can help to understand how installed absorbers impacting chamber performances. These tests are however not widely used for absorber evaluations in the industry because of the amount of absorber samples required, uncertainties and accuracies of the method, and complexity of the setups. It is the opinion of the authors that these sections should be moved to an informative annex.

IV. FIRE TESTS AND HIGH POWER APPLICATIONS

Absorbers convert EM energy to heat. In high power incident field applications, excessive heat buildup is a fire safety concern. The 1998 edition does not address this aspect of absorber evaluation, and this topic will be new additions in the next revision.

Naval Research Lab (NRL) produced a test report NRL-8093 in 1977 related to fire testing of urethane absorbers [10]. Five performance tests were described and the first 3 are fire safety related, and the other two are related to chemical toxic gas emissions. The three fire tests are briefly introduced below:

- Test 1: Resistance to electric stress and ability to withstand electrical overload or short. Two 240 V ac (capable of 8 A) leads are inserted into samples of a defined size for 60 s. The test specimen must self-extinguish to pass.
- Test 2: Ease of ignition and flame propagation, and ability to self-extinguish to open flame. Five 2 in or

larger cubes are tested. An open flame is directed at the bottom center of sample for 30 s. Flame is to be moved and kept on the sample if the sample shrinks away. Specimen must self-extinguish within 60 s to pass.

- Test 3: Smoldering test and ability to self-extinguish (flameless ignition source). A cartridge heater is inserted into a sample, and the temperature is raised to 600 °C and left in for 5 minutes. A separate thermocouple is inserted 1” from the heater. The test is considered over only when all visible smoldering has ceased, and the second thermocouple must stay under 450 °C +/- 10 °C at all time.

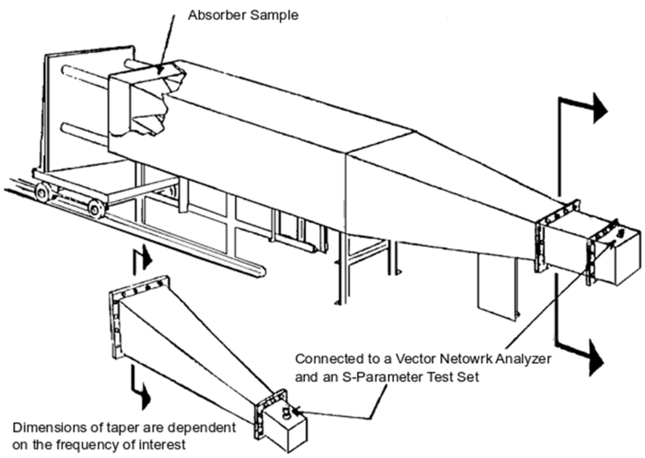

Figure 2. Flared waveguide measurement setup (Figure 32 in [2].

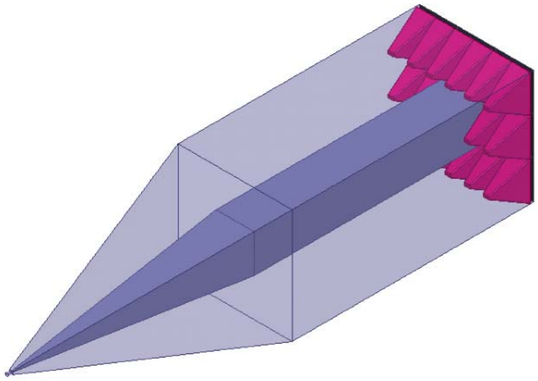

Figure 3. An example of coaxial reflectometer.

These tests have become the industry standards for urethane foam absorbers. Unfortunately, they can be misused and misquoted. The tests are clearly catered to urethane foams (as indicated by the document tile), but some have misused them. For example, if applied to polystyrene foam materials, the plastic melts away from probes in Test 1 and 3 (so probes are not making direct contacts after the initial insertion), and can entirely burn away in Test 2 (is it considered self-distinguishing if the test piece is completely burned away in the 60 s allotted time?). Argumentatively, they “pass” the NRL 8093 Test 1, 2 and 3, but clearly do not demonstrate any fire safety aspects of the material. It is intended that the IEEE Std 1128 will address the issue with better definitions.

Other fire test standards are often quoted by absorbers suppliers and users. For example, DIN 4102 Part 1 (B2) [11] is a small flame test for building materials. The specimen is vertically suspended, and is subjected to edge and/or surface exposure from a gas flame for 15 s. Pass/fail is based on droplets and flame spread distance in a set time. Other fire standards could also apply, e.g., EN 13501 [12], DIN 4102 (15/16) [11], UL 94 [13], and ASTM E84 [14]. These fire tests are expected to be referenced or discussed in the new edition of IEEE Std. 1128.

There are currently no established methods to stress-test absorbers under high power RF incident fields. In such measurements, temperature inside the absorbers is monitored as a function of varying levels of RF illumination. The highest internal temperature reached establishes the absorber’s power handling limit. Users are likely interested in the steady state case when the absorbers reach temperature equilibrium with the surroundings (if this is not the intention, test exposure time would need to be clearly stated), so test time and ambient temperature are undoubtedly important. Base materials, such as polyurethane, polystyrene, or polyethylene foams have different temperature limits. The absorber constructions (shape and size of the absorbers) and material structure (e.g., honeycomb substrate, close cell or reticulated foam) can also affect the temperature. In actual measurements, the distance between the source antenna and absorbers is typically short (for example, < 1 m) because of the high field level needed. The test distance is shown to have an impact (as compared to far field/plane wave condition) [15]. Test frequencies can affect the power distribution in the absorber, and have a significant influence on temperature contours and highest temperature in the absorber [15]. The intention of the standard is to provide guidance and at least bring attention to the effect of these influencing factors.

V. BULK-PARAMETER MEASUREMENT

In IEEE Std 1128, Chapter 6 is dedicated to absorber bulk-parameter (permittivity ε and permeability μ) measurement. The first part essentially describes the homogenization [16] analysis by treating a large area of periodic absorber array as a one-dimensionally inhomogeneous multilayered structure. At low frequencies where the period (e.g., the distance between pyramids) is small compared to wavelengths, the individual cone shapes are no longer important. The array can be treated equivalently as a layered structure with each layer consisting of a solid material (mixed from varying proportions of absorber and air). For typical pyramids, simple mixing rules, such as Maxwell Garnett formula [17], have proven to be sufficiently accurate to calculate the effective properties. For more complex geometries (such as wedged hollow absorbers with possible different side wall thicknesses), a more sophisticated rule is needed. The current IEEE Std 1128 has not discussed material mixing, which is necessary to complete an analysis. Those discussions can be expanded in the next revision.

The second part of Chapter 6 discusses the actual measurement of material properties using a coaxial transmission line. The S-parameters (S_{21} and S_{11}) are given in terms of the relative complex permittivity and permeability (ε_r and μ_r) of a test specimen. The solution can be obtained by root finding, for example, using the well-known Nicholson-Ross-Weir (NRW) algorithm [18,19], or a numerical iterative method. NRW algorithm utilizes closed form expressions to calculate ε_r and μ_r. It requires both S-parameters (S_{11} or S_{21}). For non-magnetic dielectric materials (ε_r only), it might be more convenient to measure only one of the S-parameters. The iterative method may be more expeditious in these and other cases. The current standard does not provide any details of the inversion process. It would be beneficial to offer a more detailed treatment.

Bulk-parameter can be measured not only in TEM transmission lines, but also other systems, such as TE_{10} rectangular waveguide or free-space systems. An additional consideration is the difference in the propagation characters (for example, the TE_{10} mode rectangular waveguide impedance varies from the TEM case). The current discussion is for a TEM setup, which is limited by higher order modes in the coax fixture (thus the upper frequency limit of 1000 MHz). The standard can be expanded to waveguide and focused beam free-space systems [20] for higher frequency applications.

VI. SUMMARY

IEEE Std 1128 - 1998 has served as a valuable tool for absorber evaluations for both EMC and RF/microwave antenna measurement communities. Many aspects including test methodology, equipment and frequency coverages have become dated since the publication in 1998. Additionally, absorber testing for fire safety in high power applications has not been addressed. The topic is planned to be included in the next edition. Uncertainties topic is not specifically discussed along with the test methods, which is also in need of updating. A working group co-sponsored by IEEE electromagnetic compatibility society and antennas and propagation society was formed in 2017 to update the standard. The working group is collecting information and background documents, and is expected to become much more active in drafting the standard in the coming year. Interested parties/persons are encouraged to participate in this open group and contribute to the next revision of the standards.

ACKNOWLEDGEMENT

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