Advancements in Anechoic Chambers

ACHIM ENDERS
Frankonia GmbH, Heideck, Germany

INTRODUCTION

Radiated EMC measurements, roughly in the range above 10 MHz, depend on well-defined surroundings because unpredictable reflections and interference with any HF sources in the environment corrupt reproducibility and often render test results meaningless. The necessity to minimize undesired reflections and to suppress interference with outside conditions has been satisfied with the development of anechoic chambers. They consist of metal wall shielding and absorbers on the walls. The absorbers convert electromagnetic energy into heat and thus reduce undesirable reflections (echos) from the walls. The conditions for radiation propagation will more or less approach those of an idealized free field, a well-defined standard characterized by the lack of reflections from obstacles and interference. Consequently, developers of EMC radiation standards have endeavored to define terms for field homogeneity in anechoic chambers and set limits for worst-case performance.

Ever-increasing demands on product reliability and safety have led to more comprehensive and stringent EMC standards. Traditional absorber technology is hardly capable of meeting those standards, which must be met by EMC anechoic chambers. It is the purpose of this article to describe the development of such a sophisticated absorber technology. Its superior performance is demonstrated for both new and older absorber-upgraded, 10-m EMI test facilities. Some remarks on compliance tests for field homogeneity and the necessary antenna calibration are also included.

Recent developments in absorber technology result in unique field homogeneity in both new and absorber-upgraded anechoic chambers.

EMI ANECHOIC CHAMBERS: PROBLEMS WITH NEW STANDARDS

Recent EMC regulations for radiated emission testing, such as ANSI C63.4, CISPR 16 and prEN50147-2, have put high demands on field homogeneity. The criterion is the deviation from an ideal free-field transmission factor between a source and a receiving antenna, the so-called normalized site attenuation (NSA). NSA is defined as the maximum transmission factor of the height scan of the receiving antenna in the height range 1 to 4 m.

Especially large anechoic chambers with a standardized source-receive distance of 10 m, complying to the ±4 dB criterion of ANSI C63.4 for worst-case NSA deviation, are by far the best test environments for EMC compatibility evaluation. In this case, additional free-field tests become unnecessary even in critical cases, whereas the standardized distance of 3 m has been shown to cause immense problems.[1] However, only a few 10-m test facilities possessing these properties exist around the world. Even less have demonstrated compliance for large test volume diameters in the range of 4 m or more (which is usually the diameter of the turntable on which the equipment under test is rotated).

There are three main physical reasons for these difficulties. First, due to the large 10-m test distance, transmission amplitudes from a source to a receiving antenna will be lower than for smaller distances. In the lower frequency range, residual reflections from absorber walls have an increasing influence.

Second, due to the large chamber volume, the spectrum of resonances (eigenmodes) is very dense. The performance of absorbers usually degrades in the frequency range below 100 MHz. The eigenmodes of the chamber are therefore insufficiently attenuated, resulting in bad chamber performance.

Third, the field homogeneity must be proven to be within the very tight ± 4 dB worst-case error budget. This applies for all frequency points between 30 and 1000 MHz and every position of the source antenna within the total test volume (the receiving antenna is moved on a fixed line to keep the 10-m test distance constant). If there are residual reflections of the absorber walls in the chamber, the induced field inhomogeneities can be expressed in terms of a standing wave ratio (SWR). One procedure demanded by ANSI C63.4 is a position variation of the source/receive antennas. If the full test volume diameter exceeds 3 m, the maximum or minimum position of the SWR will lie within the test volume range because the latter is on the order of half a wavelength or more in the frequency range above 30 MHz. In fact, this procedure, demanded by ANSI C63.4, forces the inclusion of the worst-case position for NSA deviation, which in turn is not allowed to exceed the ±4 dB error budget.

Consequently, equipping 10-m EMC test facilities to the full standard of ANSI C63.4 poses the highest challenge to absorber technology. It is no exaggeration to say that such a demonstration qualifies the absorber technology for all other absorber applications in EMC as well. Therefore, compliance to other standards, such as the ANSI C63.4 standard for a 3-m EMC test facility, IEC 801-3 immunity standard, or forthcoming standards on fully anechoic chambers without ground planes, can always be guaranteed.

TRADITIONAL ABSORBER TECHNOLOGY

For lack of better alternatives, test chambers for EMC purposes have conventionally been equipped with one of two absorber types: those based on graphite-impregnated polyurethane foams in pyramidal shapes, or soft ferrites in the forms of flat or grid tiles (or hybrids, combinations of both). Pure ferrite solutions have never achieved the necessary performance level for 10-m test facilities and are only used for the less demanding 3-m EMC test facilities.

Solutions with hybrids, as well as with pure pyramidal foam absorbers, suffer from a variety of disadvantages. The two most crucial shortcomings of absorber performance are insufficient absorption capability in the lower frequency range and poor reproducibility of the absorbing material, i.e., its electromagnetic properties. Furthermore, the foams are highly combustible, which results in very expensive fire alarm and protection installations in EMC test facilities. When an EMC test facility is finally disassembled, the question of where to deposit the huge waste volume of such absorbers arises. Some of their substances are harmful to the environment. This question is taken increasingly seriously, as waste management necessarily has an impact on economic calculations.

NEW ABSORBER TECHNOLOGY

Fundamental research in solid state physics has established the fact that the microscopic topology of metal particles in the size range of 10 to 500 nm dispersed in a nonconducting matrix can be advantageously used to adjust the effective conductivity of these heterogeneous materials.[2] Furthermore, it has become evident that the effective conductivity is not proportional to the fraction of metal volume, but rather 4 to 15 orders of magnitude lower than simple proportionality predicts. In other words, an appropriate preparation of tiny metal particles within a suitable matrix serves as a basis for a new class of resistor materials. This discovery was followed by a variety of innovative HF and microwave designs, but the use of EMC absorber applications was ruled out because of the huge material volumes necessary.

Meanwhile, technical processes have been developed by which such tiny metals can also be prepared as quasi two-dimensional arrangements on or within a polymer film serving as a substrate. Again, the resulting film resistance depends on the topology of the metal particles and can be adjusted within a wide range depending on the specific process. Since this kind of "film resistance material" can be produced in large amounts at a reasonable cost, the design of hollow pyramidal absorbers was straightforward. The basic idea is as simple as it sounds: realize a stable pyramidal shape of appropriate size, roughly a quarter of the wavelength corresponding to the lowest frequency to be absorbed, fix the resistance film on it and protect it with a robust covering. This explains many of the advantages of this new type of EMC absorber:

- The mechanical realization of the absorber shape is independent of the absorbing function realized by the resistance film. The cover or coating can be made of a lightweight, non-combustible, weatherproof and otherwise suitable material. In comparison, the film is very thin; the polymer substrate typically has a thickness of 10 μm. Consequently, all the advantages of the "shape material" also hold for the complete absorber.
- The absorbing film is situated on the surface of the absorber and mounted directly on the shape material. Consequently, it can transfer absorbed energy very effectively to its surroundings and the absorber is capable of withstanding very high field strengths.
- The absorbers have very high, long-term mechanical and performance stability levels.
- Transportation volume is low, because the hollow construction allows stacking.

Of course, the choice of all the relevant parameters for the best absorber design is far from trivial; factors such as the geometry of the absorber, the value of the film resistance, the way of fixing the film on the absorber surface, and others must be considered. Solutions have been found by analytical calculations, computer simulations and numerous experiments. Both coaxial waveguides and free-field antenna methods have been used for optimization and tests in real anechoic chambers.

Another advantage of this absorber technology is its superior reproducibility: the value of the film resistance can be precisely adjusted and is constant within a few percentage points even for large production batches. A systematic reflection test in a large coaxial waveguide has proven the reflection coefficient of several thousand absorbers to be equal within the measuring accuracy of ±1 dB.

PERFORMANCE OF NEW 10-M EMI TEST FACILITY

A new EMC test center was recently built which included a 10-m anechoic chamber. This chamber has inner dimensions of 25 m x 16 m x 9 m (shield) and a turntable with an 8-m diameter. It is equipped with the new absorbers in a non-combustible version so that costly fire-protection measures have become unnecessary. Test results on ANSI C63.4 performance are shown for the most critical lower frequency range from 30 to 200 MHz (Figures 1a and 1b). In both figures all measurement curves are displayed (5 positions on the turntable with two heights of source antenna). It is evident that the values are ANSI-compliant for the 8-m test volume diameter in all positions, which is a remarkable result and has never before been demonstrated for such a large volume.

ANSI C63.4 and related standards allow the omission of the posterior position of the test volume, the values of which are given as dotted lines in Figure 1. Compliance tests usually make use of this facilitation since that position is most critical and often exceeds the ± 4 dB limits, so that an exception had to be admitted in the standards. Here, however, these values are still within ± 4 dB even for an 8-m diameter.

The complete results of ANSI C63.4 compliance testing are also displayed (Figures 2a and 2b). They are summarized as two worst-case NSA deviation curves which result from all data taking the minimum and maximum values at each frequency point (omitting the posterior position). Below 200 MHz, equivalent results for a 4-m test volume diameter are also displayed. This is a more common turntable dimension. Even better performance results with 4 m with an overall worst-case value of 2.4 dB, while the corresponding value for 8 m is 3.2 dB. (The worst-case value of the backmost position is 2.6 dB, not displayed here.) The range above 200 MHz is already within ±1.5 dB for 8 m and therefore has not been additionally measured for smaller diameters.

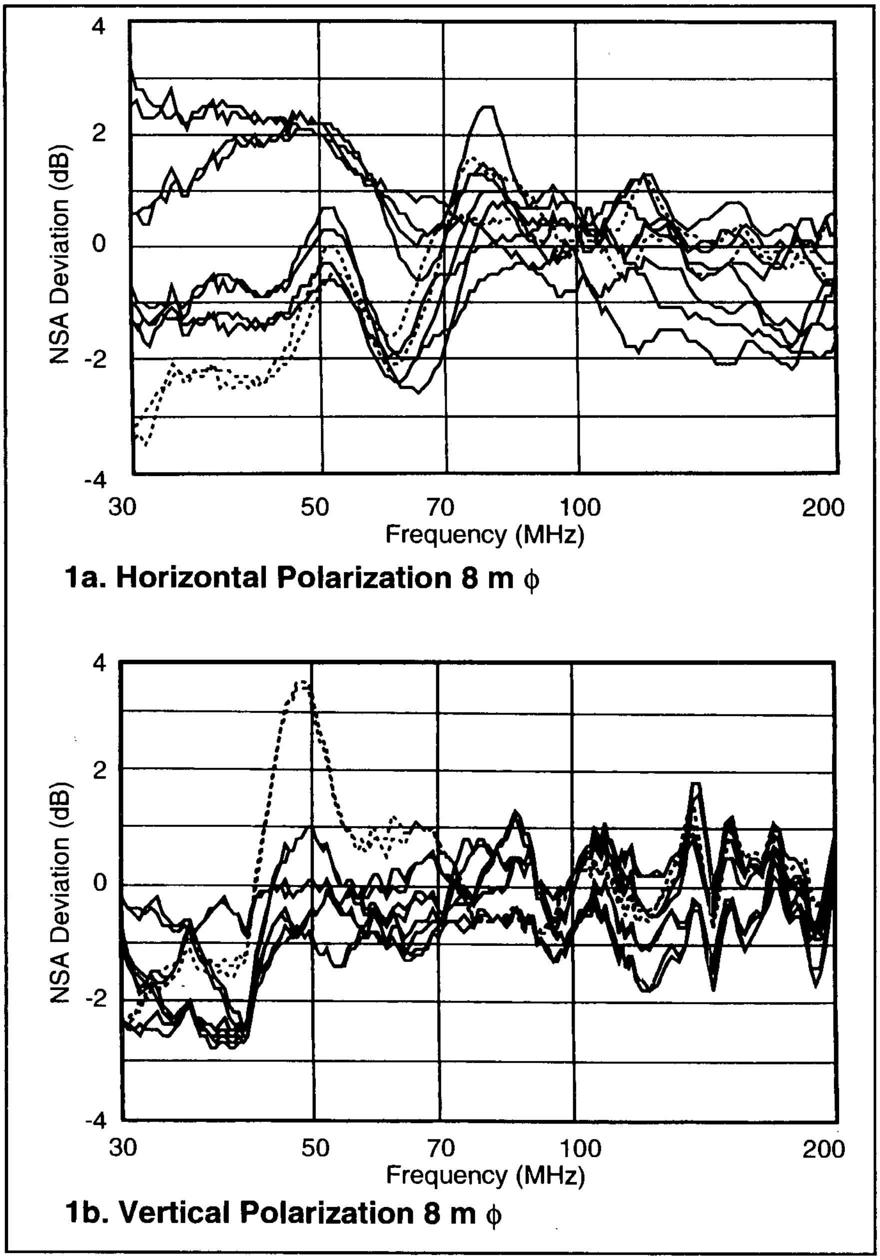

Figure 1. *Ten-meter EMC Anechoic Chamber: Complete set of NSA deviation curves according to procedure of ANSI C63.4 in the critical range 30 to 200 MHz for 8-m test volume diameter. Dotted lines represent the backmost position (usually omitted as permitted by ANSI); solid lines represent the middle, foremost and two side positions within the test volume; two source antenna heights each.*

In addition to absolute values, other interesting features are the variations in NSA deviation depending on the position of the source antenna on the turntable. This NSA deviation range is much narrower for the 4-m than for the 8-m test volume diameter, especially in horizontal polarization. This could be the first indication that the larger NSA deviations for 8 m are induced by near-field coupling of the source antenna in the two side positions to the nearby absorbers. This is confirmed in Figure 1a by the fact that the four upper curves below 60 MHz correspond to the side positions. One is now measuring the alteration of the radiation characteristics of the source

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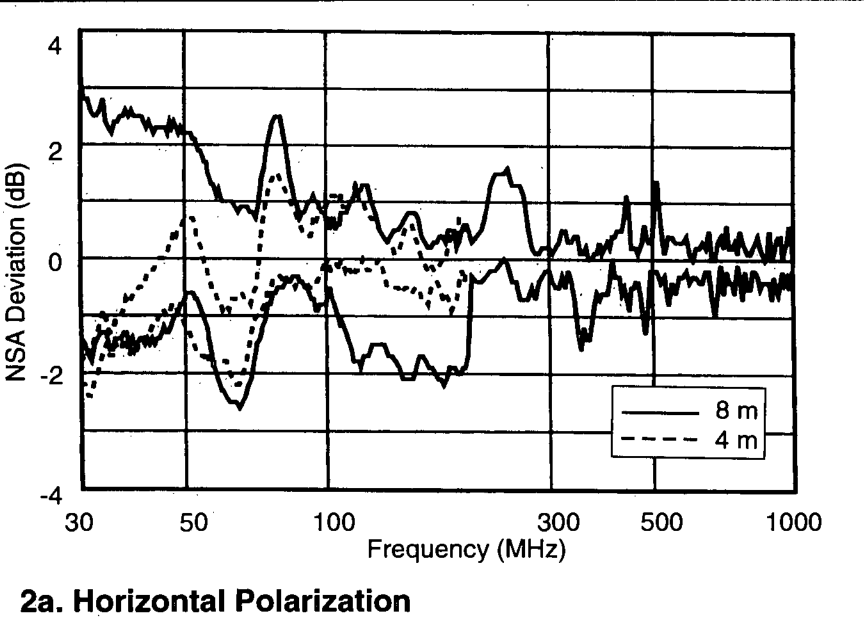

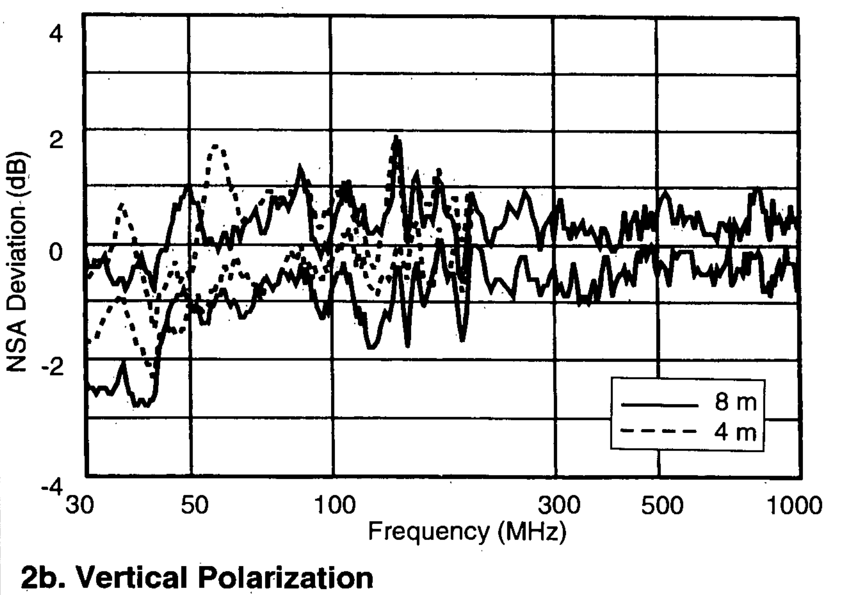

Figure 2. *Ten-meter EMC anechoic chamber: min./max. worst-case NSA deviations according to ANSI C63.4 (backmost position omitted); 8-m test volume diameter (solid lines); 4-m test volume diameter (dotted lines, only 30 to 200 MHz).*

antenna and not a chamber property. Of course, that makes no difference for the ANSI results, but the conclusions are different: the absorber performance does not have to be improved; the degradation is simply a consequence of the limited chamber space surrounding the huge 8-m test volume diameter.

ABSORBER-UPGRADED 10-M EMI TEST FACILITY

Anechoic chambers which predate the new field homogeneity standards most often are unable to meet those requirements. The question arises as to whether an absorber-upgrade on the basis of the new technology discussed here can improve performance to the necessary level (although the geometrical chamber layout often poses problems). In such cases new absorber equipment represents the only possibility to obtain a compliant chamber and to keep costs at a minimum.

A chamber exists having inner shield dimensions of 22 m x 20 m x 8.5 m and a turntable diameter of 3 m. Originally it was equipped with traditional pyramidal foam absorbers of 1.2 m in height. As a consequence, it did not comply with the new ANSI standard; the ±4 dB criterion was met only far above 100 MHz. After installation of an absorber upgrade, the chamber was fully compliant according to the dotted curves of Figures 3a and 3b, demonstrating worst-case values of 3.2 dB (same value for backmost position; the range 200 to 1000 MHz was within ±1.2 dB, not displayed here). It should be mentioned that upgrade costs were minimized by retaining foam absorbers on less critical wall regions.

PROBLEMS AND REMARKS ON FIELD HOMOGENEITY MEASUREMENTS

Normalized site attenuation (NSA) is a well-defined transmission factor and is the basis for field homogeneity measurements. NSA is exactly calculable assuming the following idealized conditions: an idealized site with a perfect and infinite ground plane, no obstacles in the surroundings and well-defined antenna behavior. The latter point is the crucial one: the behavior of a pair of antennas must be known, including their mutual coupling, their height-dependent coupling to the ground plane, and their respective antenna factors, which describe the conversion from electric field strength through the antenna balun into a voltage at the outcoming coaxial cable or vice versa. In practice, this calculation can be done with sufficient accuracy only for dipole antennas.

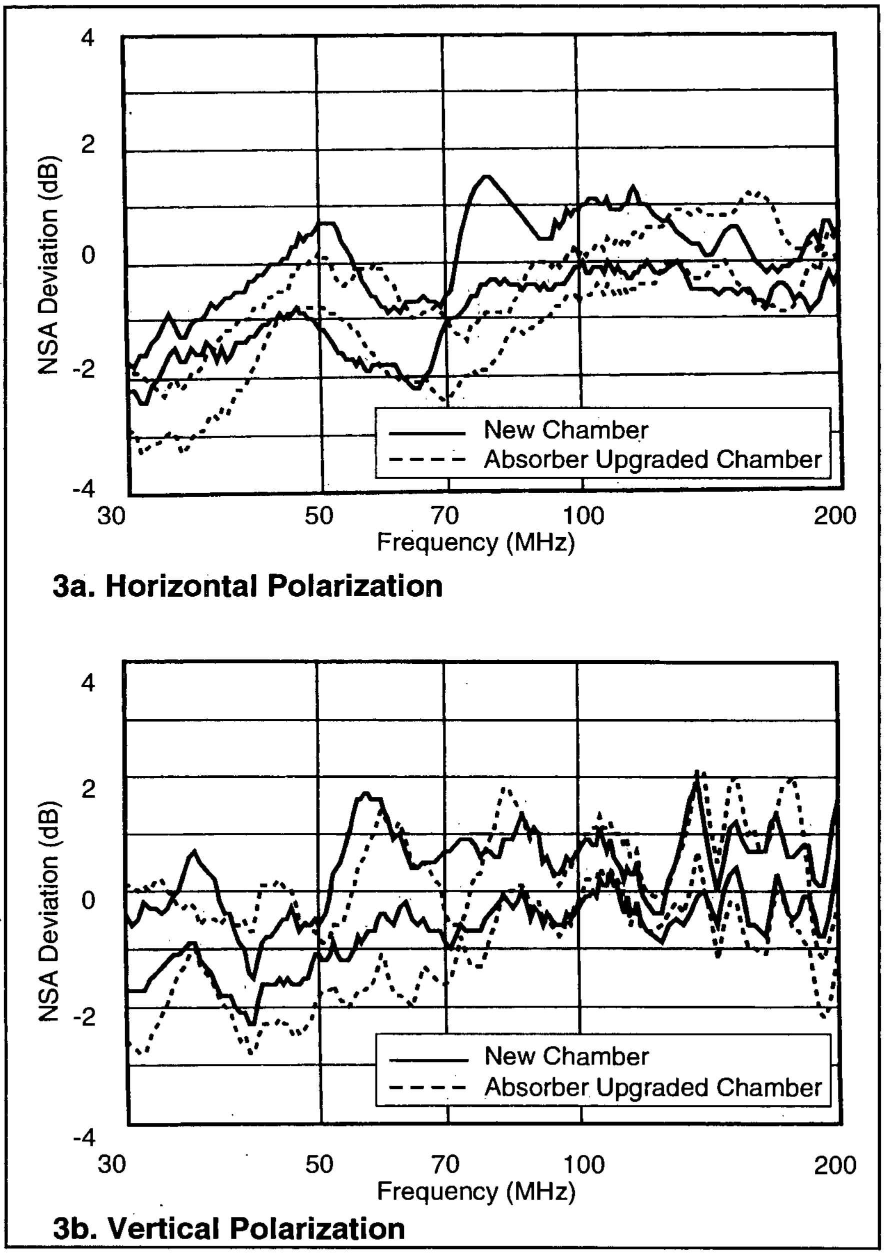

Figure 3. *Comparison of min./max. worst-case NSA deviations according to ANSI C63.4 of two different 10-m EMC anechoic chambers in the critical range 30 to 200 MHz. New chamber with 4-m test volume diameter (solid lines); older chamber after absorber upgrade with 3-m test volume diameter (dotted lines).*

The disadvantages of dipole antennas are obvious: they are not broadband and their dimensions in the lower frequency range are often too large to be used in anechoic chambers. The only reasonable procedure is the following: a free-field site is qualified by comparing measured dipole transmission factors with exactly calculated NSA values, which is quite a cumbersome procedure. If this comparison is satisfactory and no additional problems are caused by interference with external HF sources, the site can serve as a reference for calibrating broadband antennas as are used in chambers.

The calibration of broadband antennas calls for further discussion. If a reference site has a guaranteed calibration accuracy of ± 2 dB (a very good value), an individual calibration of single antennas as described in the standard ANSI C63.5 gives an uncertainty of ±4 dB because two antennas must be used for transmission measurements. This is already the total error budget of ANSI C63.4, so that individually calibrated antennas are out of the question for such a test.

To this day, the only solution showing sufficient accuracy is the procedure of dual antenna factor calibration which must be individually performed for both horizontal and vertical polarization.[3] In short, it can be described as making exactly the same measurements on the reference site and in the anechoic chamber: use the same antenna pair, the same cable layout and the same measurement procedure for the determination of the transmission factors on the reference site and in the anechoic chamber. The deviation of the two measurements will give the NSA behavior of the chamber.

The data displayed in Figures 1 to 3 were determined using the dual antenna factor calibration. Additionally, use was made of phase-stable antenna cables which were armed with numerous ferrite tubes to suppress reflection currents on the outside of the cable shielding. The transmission factor was measured with a vector network analyzer, and a 12-term full error calibration was performed at the coaxial ports at the ends of the antenna cables. A biconical antenna pair was used in the range 30 - 200 MHz, a log-per antenna pair in the range 200 - 1000 MHz.

In Figures 4a and 4b two different ANSI C63.4 compliance tests for the same anechoic chamber are compared. Both are based on the dual antenna factor calibration method with the details mentioned above. Biconical antennas of equal type were used but with two completely different sets of electronic equipment. One is described above, the other uses a small battery-powered comb generator. The latter is directly mounted at the feed point of the source antenna, so that no source antenna cable is needed, and a spectrum analyzer serves as a receiver. Since the reference site in both cases was at the same location, calibration errors induced by the site and consequently, compliance test results, should nearly be equal. This is indeed the case and demonstrates the accuracy and the confidence level which can be achieved with the dual antenna calibration method. As can

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be seen in Figures 4a and 4b, the agreement between the two results is nearly perfect for horizontal and rather good for vertical polarization.

This confidence level confirms that the differences between the results of two different chambers displayed in Figures 3a and 3b are reliable. This allows further conclusions to be reached concerning the two 10-m EMC test facilities that were examined. They have very different geometrical dimensions (25 m x 16 m x 9 m and 22 m x 20 m x 8.5 m). In accordance with the fact that the dominant contribution to NSA deviations is caused by chamber resonances in the frequency range below 100 MHz, the corresponding chamber differences are a measure for this influence. Worst-case values are not much larger than 1 dB. This is consistent with the width of the max./min. ranges of NSA deviations as a measure of the homogeneity of the field within the test volume. This range is also less than ±1 dB. Both these facts are evidence that the chamber-induced errors are smaller than 1 dB. Consequently, the general behavior shown in Figures 3 and 4 is dominated by the residual calibration errors which are induced by the imperfections of the reference site.

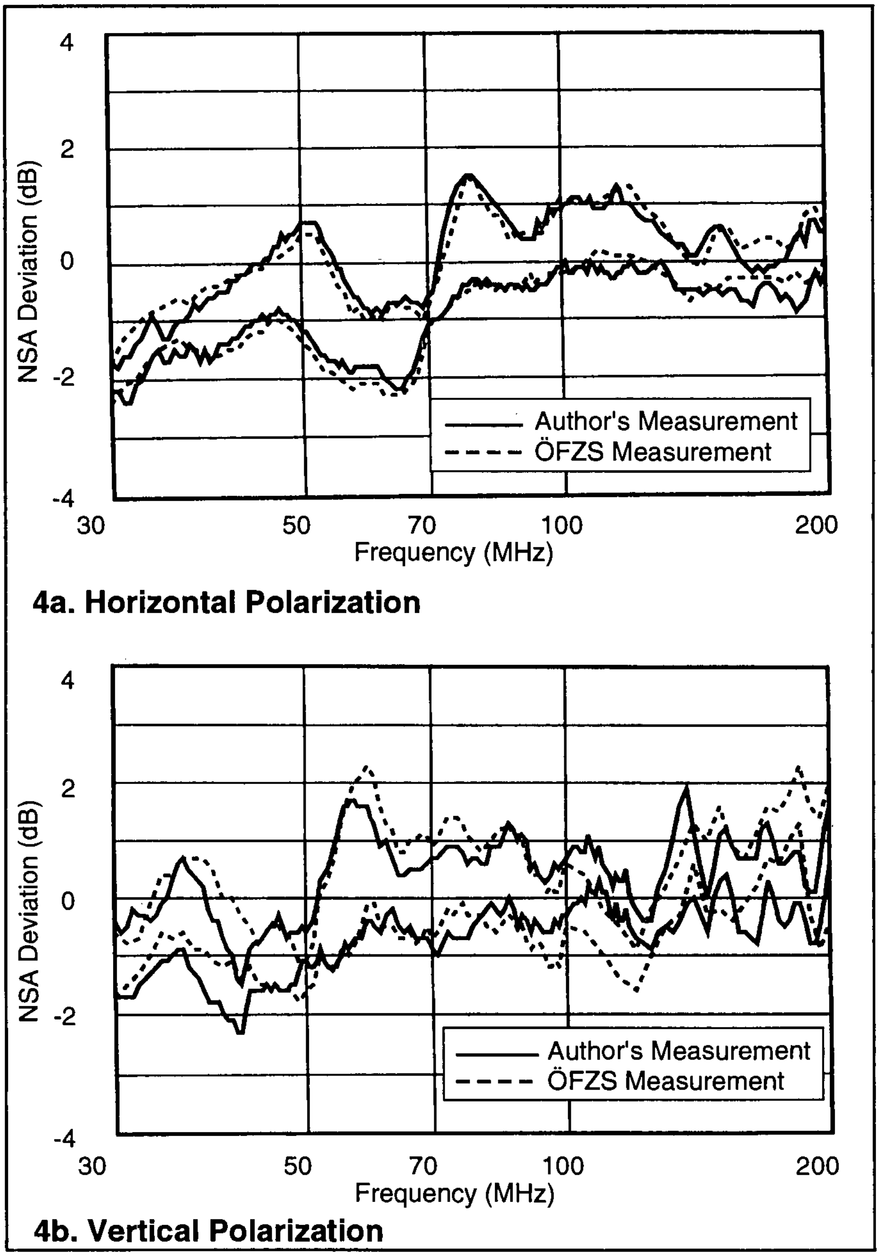

Figure 4. *Comparison of two independently performed ANSI C63.4 compliance tests (min./max. worst-case NSA deviations) in 10-m EMC anechoic chamber with 4-m test volume diameter: measurements made by the author (solid); measurements made by ÖFZS (dotted, by courtesy of Österreichisches Forschungszentrum).*

SUMMARY

It is evident that the new absorber technology using quasi two-dimensional resistance material sets a new standard in performance for EMC anechoic chambers. Such a field homogeneity could never be achieved by traditional solutions using ferrites, graphite-impregnated foams or combinations of the two. Of course, the new technology can also be combined with ferrites in the form of hybrid absorbers in very small chambers. However, recent research has shown that the height of pyramidal absorbers based on the new technology can be reduced to the range of 1.40 m to 1.70 m without sacrificing ANSI C63.4 compliance. Consequently, limited space in existing chambers should not pose serious problems for absorber upgrades with pyramidal absorbers.

Other advantages associated with

the new technology, including improved fire resistance, result in very inexpensive solutions for both new EMC test chambers and absorber upgrades in older ones. Recent investigations have studied the properties of field homogeneity in the case of real devices with complicated radiation patterns.[4] Such devices are the main matter of interest for EMC in the first place. The new absorber technology shows even higher performance in realistic situations.

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***DR. ACHIM ENDERS** studied physics and medicine. He received the degree of Dipl.-Phys. from the Universität Köln in 1984 and a Ph.D. in experimental physics in 1989. Since then he has worked at the Universität Köln on basic research and has served as a scientific consultant to industry. His professional experience and research activities have been in the areas of material science and biophysics, including a variety of HF, microwave and EMC measurements and applications. This article is based on his work as a consultant for Frankonia GmbH. In July he begins a new position as head of the EMC research institute at the Technical University of Braunschweig. Mr. Enders is an active member of national and international committees involved in the development of EMC standards. He is author or co-author of over 30 scientific publications and holds seven patents. +49 221 4704986.*