Reinstatement of the NIST Field Strength Probe Calibration Service

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***Abstract*—After recently completing a five year renovation, the NIST anechoic chamber for radio-frequency field strength measurements was returned to service. Tests of field probe transfer functions can now be performed from 10 kHz to 40 GHz. To validate that the chamber and measurement process maintained continuity, measurements of NIST field probes in the new chamber were compared with measurements in the chamber before renovation and in another test facility at NIST. An uncertainty analysis was carried out on the new measurement process.**

I. Introduction

The Field Strength Metrology Project at the National Institute of Standards and Technology in Boulder, CO has restarted field probe calibration services from 10 kHz to 40 GHz, after a renovation of the anechoic chamber. The National Institute of Standards and Technology in Boulder, CO has served as the nation's link to the SI for radiated field measurements for more than four decades. Renovations began in 2014 on the anechoic chamber in use for generating standard electromagnetic fields from 0.5 – 40 GHz. The positioning system was upgraded with a new rail, motion control, and a robotic arm. New absorber was installed in the main section of the chamber (Figure 1). During the renovation, Field Strength services were unavailable.

II. Overview of the Field Strength Service

The National Institute of Standards and Technology provides SI-traceable measurements of electromagnetic field strength. From 10 kHz $-$ 300 MHz, the standard reference field is generated inside a transverse electromagnetic (TEM) cell [1]. From 300 MHz and to 40 GHz, this field is generated using standard gain horns inside a fully anechoic chamber [2], [3]. The dimensions of the anechoic chamber are 6 x 7 x 8 m, filled with 3 foot pyramidal absorber in the main test volume and 2 foot absorber covering the gantry and edges. The absorber provides > 35 dB absorption from $0.5-40$ GHz. A GHz TEM (GTEM) cell is used for special tests in the range of $0.1-6$ GHz [4].

Tests of the transfer function between probe response and RF field strength for electrically small probes can be requested from shop.nist.gov.

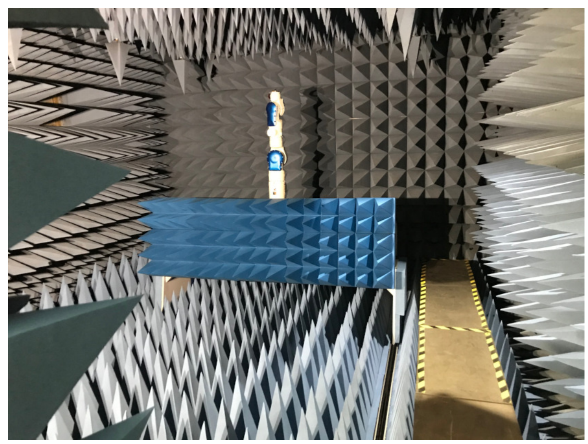

Fig. 1. Photo of the NIST anechoic chamber for field strength probe measurements after the 2014-2019 renovation.

III. Anechoic Chamber Comparison

New (2022) measurements of the NIST probes in the anechoic chamber were compared to two other facilities: the anechoic chamber prior to the renovation (2010) and the GTEM cell. The GTEM measurements were valid for 0.5 - 3 GHz. The 2010 measurements covered 5 - 18 GHz.

NIST uses tapered dipole antennas coupled to diodes and high-resistance lines as check standard probes [5]. These probes have resistively-tapered dipole antennas and beam lead Schottky barrier diodes that can be used from below 10 MHz to at least 40 GHz, depending on the antenna length. For the $0.1-18$ GHz frequency range, 8 mm dipole antennas are used, while for $5-40$ GHz, 6 mm dipoles are used. In this comparison, six 3-axis 8 mm dipole probes were used below 5 GHz (Probes P888102, P888103, P888105, P888106, P888107, P888110). A single axis 6 mm probe was used for 5 GHz and above (P946101).

Standard gain horn antennas are used to generate standard fields in the anechoic chamber [6]. Field probes are mounted on a robotic arm fixed to a mobile gantry. The robotic arm allows for positioning the probe on boresight of the horn either at an ortho-angle or parallel, as well as rotation. The gantry is on linear rails, repeatable to ± 50 μm accuracy, allowing for measurements along boresight with high spatial resolution.

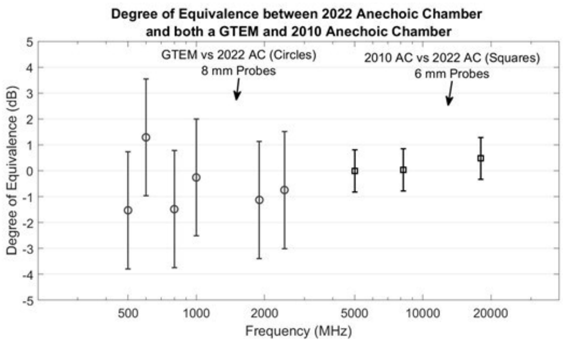

Fig. 2. Degree of equivalence (DOE) between the GTEM and anechoic chamber for the NIST 8 mm dipole probes, and between the 2010 and 2022 anechoic chamber for the NIST 6 mm dipole probe. The 8 mm probe results are the average DOE for the 18 different dipole antennas measured at 8 different field strength values. The error bars are the expanded combined uncertainty (coverage factor k = 2). The standard deviation of the combined 144 comparisons was significantly less than the standard uncertainty.

The GTEM and anechoic chamber measurements overlapped at the frequencies 0.5, 0.6, 0.8, 1.0, and 2.45 GHz. Figure 2 shows the average degree of equivalence [7], [8] between the anechoic chamber and GTEM for the 18 different 8 mm dipole antennas from 0.5–2.45 GHz, and the degree of equivalence between measurements of probe P946101 in 2010 and 2022 at 5, 8.2 and 18 GHz. The GTEM measurements have a significantly higher standard uncertainty, as the field is much less uniform in the GTEM than the anechoic chamber. The combined expanded uncertainty, with a coverage factor of $k = 2$, of the GTEM and anechoic chamber is 2.26 dB, while for the anechoic chambers in 2010 and 2022 it is 0.81 dB. For all the measured points, the degree of equivalence is less than the combined uncertainty.

IV. Uncertainties

The sources of uncertainty for the anechoic chamber measurements were re-evaluated [9], [10], and are shown in Table I. This table shows the maximum values of the uncertainties over the entire frequency range, $0.5 - 40$ GHz. The main sources of error from Table I are the near zone gain of the antenna, reflections in the chamber, calibration of the passive components, and power measurements. We also include the standard deviation of repeated measurements and probe alignment uncertainty. The estimate of near zone gain uncertainty remains unchanged from before the renovation, as the transmitting antennas and process for calculating the gain have not changed, as based on [2], [6], [11]. The uncertainty due to reflections in the chamber was estimated by measuring the variation in probe response at fixed field strength as the

TABLE I
Uncertainties in Anechoic Chamber

Source	Type	Distribution	ui (dB)
Near zone gain of the transmitting antenna	B	Rectangular	0.13
Multipath reflections in chamber	B	Rectangular	0.12
Power measurement	B	Rectangular	0.12
Probe alignment, measurement of horn to probe distance	B	Gaussian	0.06
Measurement of passive devices (directional coupler, cables, waveguides)	B	Gaussian	0.13
Repeatability (standard deviation of measurements)	A	Gaussian, n = 3	0.10
Combined standard uncertainty			0.28
Expanded Uncertainty (k=2, 95 % confidence level)			0.56

probe distance was varied along the boresight of the antenna. This was done at the frequency points measured in Figure 2. Examples of the measured reflections in the chamber are shown in Figure 3 for two different frequencies. By measuring the variation versus position, and choosing a location away from extreme values, we minimize the contribution of the reflections to the overall uncertainty for each chosen frequency. The amount of variation in the field around the chosen test location was within +/- 0.12 dB across the whole frequency range.

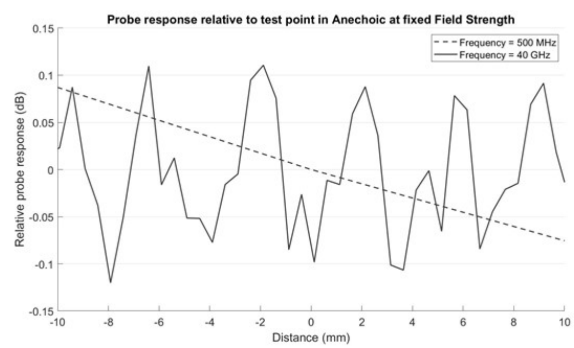

Fig. 3. Change in probe response with probe position, relative to the chosen measurement points for each 0.5 GHz and 40 GHz.

V. Future Outlook

While NIST's Field Strength Service has been restored, we are actively researching new methods for direct SI-traceable field measurements. The most promising avenue remains measurements of microwave fields using Rydberg atomic vapors [12], [13]. These have the potential to provide an independent, absolute measure of RF field strength. These systems will be tested in the new anechoic chamber.

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