

Design and Implementation of the FAST Integrated Testing Anechoic Chamber (Postprint)

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Abstract

Through the selection and optimized design of wedge-shaped absorbing materials, the comprehensive test microwave anechoic chamber for the FAST project has been constructed. It meets the requirements of military standard (GJB151B) and civil standard electromagnetic compatibility testing, and satisfies antenna test environment requirements in the frequency band above 500 MHz. It provides the required electromagnetic environment and test conditions for electromagnetic compatibility and antenna performance testing of the Five-hundred-meter Aperture Spherical radio Telescope (FAST). By effectively eliminating external electromagnetic waves and various internal reflection interferences, reliable and standardized test data can be obtained. This comprehensive test microwave anechoic chamber can meet the electromagnetic compatibility testing and antenna testing requirements of national standards and related international standards, enabling 3-meter method testing and environmental assurance for antenna performance tests.

Full Text

FAST Engineering Comprehensive Test Microwave Anechoic Chamber: Design and Implementation

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Abstract

Through careful selection and optimization design of wedge absorbing materials, we have successfully constructed the FAST engineering comprehensive test microwave anechoic chamber. This facility meets both military standard (GJB151B) and civilian electromagnetic compatibility (EMC) testing requirements, while also satisfying antenna testing environmental specifications for frequencies above 500 MHz. The chamber provides the necessary electromagnetic environment and test conditions for conducting EMC and antenna performance tests for the Five-hundred-meter Aperture Spherical radio Telescope (FAST). By effectively eliminating external electromagnetic waves and various internal reflection interferences, the chamber ensures acquisition of reliable and standardized test data. The comprehensive test microwave anechoic chamber fulfills EMC and antenna testing requirements of both national and relevant international standards, enabling both 3-meter method testing and antenna performance test environment assurance.

Keywords: comprehensive test microwave anechoic chamber, FAST, absorbing material

1. Introduction

The Five-hundred-meter Aperture Spherical radio Telescope (FAST), a national major scientific and technological infrastructure facility, was completed in September 2016 and is currently undergoing commissioning and trial observations, having already achieved preliminary scientific results [1]. FAST's exceptional sensitivity makes it highly susceptible to electromagnetic interference from its own electrical and electronic equipment, making EMC design and rectification critically important [2].

The foundation of EMC design and rectification lies in testing and evaluating the EMC characteristics of interfering equipment [3], which cannot be accomplished without microwave anechoic chambers [4]. The FAST site is located in the Dawodeng depression in Pingtang County, Qiannan Prefecture, Guizhou Province—a remote mountainous area with an exceptionally quiet radio environment, making it an ideal location for astronomical observations. Telescope construction and operations require a series of EMC testing, maintenance, and research activities, representing long-term and time-consuming work. To accommodate multifunctional requirements—including radiation impact detection for control equipment (such as power distribution, cable drives, actuator controls, and feed cabin equipment, all requiring EMC certification for access) and calibration testing of microwave components like the FAST feed—constructing a multipurpose comprehensive test microwave anechoic chamber is essential. This facility will provide effective support for FAST's normal operation while making efficient use of existing laboratory infrastructure at the site.

2. Design and Implementation

2.1 FAST Comprehensive Test Microwave Anechoic Chamber Performance Specifications

The FAST comprehensive test microwave anechoic chamber is located in Laboratory No. 2 at the FAST observation base, with a planned floor area of 12.0 m \times 12.0 m. As a multipurpose facility, it must meet military standard GJB151B test requirements, civilian 3-meter method EMC test requirements, and small antenna testing requirements.

EMC Microwave Anechoic Chamber Requirements [5]:

1. **Normalized Site Attenuation (NSA):** For 3-meter distance testing, the quiet zone has a diameter of 2 m and height of 2 m. The measured NSA deviation from theoretical values must be within ± 4 dB from 30 MHz to 1 GHz.
2. **Site Voltage Standing Wave Ratio (SVSWR):** In the 1 GHz-18 GHz frequency range, with 3-meter test distance, the quiet zone (2 m diameter \times 2 m height) must have SVSWR ≤ 6.0 dB.
3. **Field Uniformity:** On a hypothetical 1.5 m \times 1.5 m vertical plane, 75% of field strength amplitude deviations must be within 0-6 dB.
4. **Background Noise:** When testing in the microwave anechoic chamber with the equipment under test (EUT) powered off but auxiliary equipment powered on, the measured internal electromagnetic environment level must be 6 dB below the limits specified in GJB151A-97 or 10 dB below CISPR 22/CLASS-B limits.

Antenna Microwave Anechoic Chamber Requirements:

1. **Quiet Zone Performance:** While primarily designed for 3-meter method EMC testing, this chamber also accommodates antenna far-field testing with the following specifications (no requirement below 500 MHz):
 - 500 MHz-1 GHz: better than 20 dB
 - 1-3 GHz: better than 25 dB
 - 3-6 GHz: better than 35 dB
 - 6-10 GHz: better than 45 dB
 - 10-18 GHz: better than 50 dB
2. **Quiet Zone Cross-Polarization Level:** -25 dB (> 1 GHz)
3. **Field Amplitude Uniformity:** ± 2 dB longitudinal, ± 1 dB transverse

2.2 Antenna Test Absorber Layout Design

2.2.1 Microwave Anechoic Chamber Technical Specifications

- Operating frequency: 0.5-18 GHz

- Chamber dimensions: 11 m × 8 m × 7.2 m (L × W × H)
- Maximum test distance: R = 5 m
- Quiet zone dimensions: 1.0 m × 1.0 m × 1.0 m
- Transmit antenna gain:
- Microwave anechoic chamber quiet zone performance:

2.2.2 Far-Field Test Microwave Anechoic Chamber Simulation Quiet Zone Performance Calculation Conditions: - Operating frequency: 0.5-18 GHz - Chamber dimensions: 11 m × 8 m × 7.2 m (L × W × H) - Quiet zone dimensions: 1.0 m × 1.0 m × 1.0 m - Test distance: R = 5 m - Maximum measurable antenna aperture D at different frequencies:

Quiet Zone Performance Simulation: The quiet zone performance design employs the internationally accepted ray-tracing method for simulation calculations. Based on chamber dimensions, absorber layout, and transmit/receive antenna positions, relevant parameters are input into microwave anechoic chamber performance simulation software to evaluate chamber performance.

(a) Determination of Quiet Zone Center and Main Reflection Zone Absorber Height: Through simulation optimization design with different quiet zone center positions and absorber heights, we determined that the quiet zone center should be 3.6 m from the rear wall at a height of 2.5 m. The chamber walls and ceiling use FAH-1600 absorbing material, while the Fresnel zone on the floor uses 700 mm high FA-700 high-performance pyramidal absorbers, with other areas using 500 mm high FA-500 high-performance pyramidal absorbers.

(b) Simulation Design Results for Quiet Zone Performance: After repeated calculation and optimization, the final quiet zone performance calculation results for this microwave anechoic chamber are:

2.2.3 Structural Design Structurally, the comprehensive test microwave anechoic chamber includes a 3-meter method shielded room plus two auxiliary shielded rooms (measurement control room and power amplifier room), all rectangular in shape. The layout and structural dimensions are shown in Figure 1 [Figure 1: see original paper]. The comprehensive microwave anechoic chamber also includes power supply systems, signal filters, power filters, wedge absorbers, ferrite tiles, turntables and control systems, antenna lifting platforms and control systems, fire protection, video monitoring, etc. The shielded rooms share common walls to reduce the number of signal transition plates and signal cable lengths.

The entire six-sided grid frame constitutes the self-supporting structure of the shielded microwave anechoic chamber. The main frame design underwent detailed and reliable structural calculations, considering frame deformation control and structural stability issues, with full consideration of seismic fortification at intensity level 8.

2.3 Key Technologies and Innovations

The FAST comprehensive test microwave anechoic chamber serves as a multi-purpose facility, presenting several design challenges. EMC microwave anechoic chamber testing requires an ultra-wide frequency band: radiation performance testing spans 80 MHz–40 GHz for military standards and 30 MHz–18 GHz for civilian standards. To meet error requirements compared with open-area test sites, EMC testing requires relatively lower absorber performance than antenna testing—the entire test band only needs -15 to -20 dB absorption performance. However, antenna testing requires a relatively narrow frequency band but demands extremely low quiet zone reflection levels, requiring high absorber performance above -30 dB and even reaching -55 dB.

Currently, two main types of absorbers are used in microwave anechoic chambers worldwide: (1) dielectric materials, i.e., pyramidal absorbers, and (2) magnetic materials, i.e., ferrite tiles. Pyramidal materials can achieve high absorption performance (up to -55 dB) from low frequencies (30 MHz) to high frequencies (300 GHz), but meeting -15 dB absorption at 30 MHz requires approximately 3 m height. Ferrite tiles exhibit excellent absorption performance at low frequencies (30 MHz–1 GHz) but very poor high-frequency performance (see Figure 2 [Figure 2: see original paper]), with only about 6.5 mm thickness—almost negligible compared to pyramidal materials. Their absorption performance above 0.8 GHz cannot meet antenna testing requirements, which is why virtually no antenna microwave anechoic chambers use ferrite tiles for construction (above 500 MHz).

Combining EMC testing and antenna testing in one microwave anechoic chamber is not the optimal choice. To meet FAST's special testing needs, we used large hollow truncated cone absorbers with further optimized design, particularly for high-frequency absorption performance. This new truncated cone absorber, designated FAH-1600, achieves -15 dB absorption performance at low frequencies (30 MHz) to match ferrite tile performance, while providing above -30 dB absorption at high frequencies (500 MHz and above). This enables it to satisfy both 3-meter method EMC testing and antenna testing requirements. The absorption performance test results are shown in Figure 3 [Figure 3: see original paper]. The actual test curves demonstrate that FAH-1600 truncated cone absorber performance meets or exceeds that of ferrite tiles, fully satisfying construction requirements for FAST's 3-meter method comprehensive microwave anechoic chamber.

Based on comprehensive analysis, we installed 1600 mm high FAH-1600 pyramidal absorbers on all wall and ceiling surfaces of the electromagnetic shielded room. The floor area includes 14.4 m² of movable material, 300 mm high, model FA-300 high-performance pyramidal absorbers, used for CISPR16-1-4(2007) standard testing to satisfy site voltage standing wave ratio requirements. This configuration meets all performance specifications for the FAST comprehensive test microwave anechoic chamber.

2.4 FAST Comprehensive Test Microwave Anechoic Chamber Engineering Implementation

The FAST comprehensive test microwave anechoic chamber project includes five aspects:

1. **Construction:** Built indoors with limited space, all steel materials undergo rust removal and anti-corrosion treatment before use, with anti-corrosion touch-up painting during construction to ensure 工程质量.
2. **Absorber Installation:** After completion of shielded chamber and auxiliary facility installation and qualification, wall and ceiling wedge absorbers are installed.
3. **Finishing Work:** Interior decoration of control and power amplifier rooms proceeds after shielding qualification.
4. **Auxiliary Systems:** Include fire alarm systems, ventilation and air conditioning systems, power supply and distribution systems, signal filters and interface devices, TV monitoring systems, lighting systems, and grounding systems.
5. **Supporting Equipment:** Include turntables, antenna towers, and lifting platforms.

3. FAST Comprehensive Test Microwave Anechoic Chamber Performance Testing

After completion of the comprehensive test microwave anechoic chamber, performance testing was conducted, achieving excellent results. The testing scenario is shown in Figure 4 [Figure 4: see original paper].

3.1 Normalized Site Attenuation

Following the test method specified in GB9245-2008 “Information Technology Equipment—Radio Disturbance Limits and Measurement Methods,” we performed vertical and horizontal polarization measurements of normalized site attenuation. Vertical polarization test results are shown in Figure 5 [Figure 5: see original paper].

3.2 Site Voltage Standing Wave Ratio

Requirement: In the 1 GHz–18 GHz frequency range, with 3-meter test distance and quiet zone dimensions of 2 m diameter \times 2 m height, SVSWR \leq 6.0 dB.

Test Method: According to CISPR16-1-4:2008-01 standard, with 3-meter test distance and quiet zone dimensions of 1.5 m diameter \times 2 m height, site voltage standing wave ratio must not exceed 6 dB. Acceptance testing requires an

omnidirectional antenna as the transmitting antenna and an LPDA antenna as the receiving antenna.

Test results are shown in Figure 6 [Figure 6: see original paper], meeting the design requirement of -6.0 dB (two protrusions near 12.5 GHz are caused by test equipment mismatch).

3.3 Site Uniformity

Following GB/T17626.3-2006 “Electromagnetic Compatibility—Testing and Measurement Techniques—Radiated, Radio-Frequency, Electromagnetic Field Immunity Test” requirements, within a $1.5\text{ m} \times 1.5\text{ m}$ vertical plane ranging from 0.8 m to 2.3 m above the test turntable, 75% of 16 test points (100% for four corner points in the 1 GHz-18 GHz range) must exhibit site uniformity within 0 dB to +6 dB, satisfying test requirements. Test results are shown in Figure 7 [Figure 7: see original paper] and Figure 8 [Figure 8: see original paper].

3.4 Background Noise

When testing in the microwave anechoic chamber with EUT powered off but auxiliary equipment powered on, the measured internal electromagnetic environment level must be below GJB151A-97 limits.

3.5 Electromagnetic Shielding Effectiveness Testing

Test Method: GB/T12190-2006 “Method for Measuring the Shielding Effectiveness of Electromagnetic Shielding Enclosures.”

Test Frequencies: 30 MHz, 100 MHz, 345 MHz, 500 MHz, 1 GHz, 2.575 GHz, 18 GHz.

Test results are shown in Table 5 .

3.6 Microwave Anechoic Chamber Quiet Zone Performance

Test Method: GJB6780-2009 “Microwave Anechoic Chamber Performance Test Methods.”

Test Frequencies: 500 MHz, 2 GHz, 5 GHz, 10 GHz, 18 GHz.

This microwave anechoic chamber accommodates antenna far-field testing while primarily designed for 3-meter method EMC testing. Measured data meet design requirements as follows:

(a) Quiet Zone Performance (no requirement below 500 MHz): - 500 MHz-1 GHz: better than 20.6 dB - 1-3 GHz: better than 25.5 dB - 3-6 GHz: better than 35.7 dB - 6-10 GHz: better than 50.8 dB - 10-18 GHz: better than 50.9 dB

(b) **Quiet Zone Cross-Polarization Level:** -29 dB (< 1 GHz)

(c) **Field Amplitude Uniformity:** ± 1.76 dB longitudinal, ± 0.89 dB transverse

Conclusion

Through optimized design of wedge absorbers and selection of 1600 mm high FAH-1600 large hollow truncated cone absorbers for all walls and ceilings, combined with movable high-performance composite pyramidal absorbers on the floor (300 mm/500 mm/700 mm high FA-300/FA-500/FA-700 models), the FAST comprehensive test microwave anechoic chamber integrates EMC testing and antenna testing capabilities within limited indoor space, meeting FAST's special testing requirements. The shielded rooms share common walls, reducing signal transition plates and cable lengths. Through rational layout and strict construction process control, the FAST comprehensive test microwave anechoic chamber has passed performance testing with excellent results. The chamber is equipped with test platforms and instrumentation including EMC test systems and antenna test systems, with major equipment imported and some components shared, meeting relevant standard test requirements across the 8 GHz frequency range.

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Note: Figure translations are in progress. See original paper for figures.

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