

INTRODUCTION

With the release of 3GPP Release 16, mmWave phased-array antenna technology will play a more crucial role in 5G wireless communication. The 5G NR FR2 communication system can satisfy the requirements of some 5G applications, such as enhanced mobile broadband (eMBB), massive IoT connectivity (mMTC), and ultra-reliable low latency communication (uRLLC), etc. For either the non-standalone (NSA) or the standalone (SA) network system, the application of mmWave technologies become inevitable.

Today, wireless experts have already envisioned a 6G communication concept, in which satellite communication will be connected with terrestrial communication to form a new wireless communication network. As the number of global commercial satellites starts to increase, low earth orbit satellites will provide high-speed internet access covering the whole world.

The mmWave phased-array antenna can be widely used in both satellites and ground terminals, which demands the need for a rapid calibration and testing tool for phased-array antennas.

Meanwhile, in the field of automotive radars, the development of unmanned vehicles requires a higher level of accuracy for various types of detection radars. To scan the specified angle range, automotive radars will also employ phased-array antenna technologies.

Foreseeably, the testing demands for mmWave phased-array antenna will grow rapidly. Unlike the traditional antenna, the phased-array antenna has multiple-beam pointing status to be tested, which will increase the testing time dramatically. Conventional test methods are challenged to satisfy these increasing testing requirements.

RAYBEAM TEST SYSTEM

The RayBeam multi-functional mmWave test system supports phased-array calibration, antenna measurement, and system test in one system. Its multi-beam-positions test function makes phased-array antenna measurement fast and simple. The RayBeam 5000 system is a high-end solution for large AUT (such as a spaceborne antenna) with high precision. The RayBeam 1900 is a compact size and mobile system which can be delivered quickly and is plug-play; it is suitable for mobile device (such as satellite user terminal, mmWave UE, automotive radar) R&D and production test. The RayBeam 600 is a planar near field scanner system; it is a cost-effective solution for phased-array antenna calibration and antenna measurement.

The measurement error of a near-field system comes from four major categories and nearly 18 sources; they include test probe errors, mechanical scanning positioning errors, test system errors, and measurement environment errors. We adopt a variety of innovative technologies in probe sampling, mechanical scanning positioning and probe antenna designing, and system calibration to ensure the accuracy of near field testing.

Theoretically we solve the problems of how-to measurement EIRP and G/T values in the near field, and this theory has been



verified in practice. The antenna characteristic test and system performance test can be completed on one system which dramatically improves the test efficiency and overcomes the bottleneck of the large-scale phased-array antenna and satellite user terminals' mass-production testing.

HIGH EFFICIENCY- MULTIPLE BEAM POSITIONS TEST

Compared to relatively low-frequency antennas, mmWave phased-array antennas have a narrower beam width and shorter wave lengths, so their sampling resolution would be much higher. Meanwhile, an active phased-array-antenna usually has multiple test ports and multiple beam pointing status (each status represents an antenna pattern in the main lobe direction). It is necessary to test multiple-beam pointing status (beam position). These will dramatically increase the total testing time for a single antenna array. With the conventional test method, an engineer must test every status for each port one by one, and as a result, the test efficiency is quite low. For example, a 10x10 antenna array can be tested in one week.

The RayBeam system can support parallel tests for multi-ports and multi-beam positions. By controlling the AUT to change the beam direction, and fast switching the test ports simultaneously, the system can concurrently test multi-ports and multi-beam positions by full scanning for the AUT. This method can dramatically improve test efficiency.

RayBeam's field source reconstruction method optimizes the sampling algorithm for the NF-FF transformation. Compared to the conventional uniform sampling method, this new method can improve the test efficiency by 20%~50%. So, for a white-box measurement of a phased-array antenna, the RayBeam system

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LOW CROSS-POLARIZATION PROBE ANTENNA

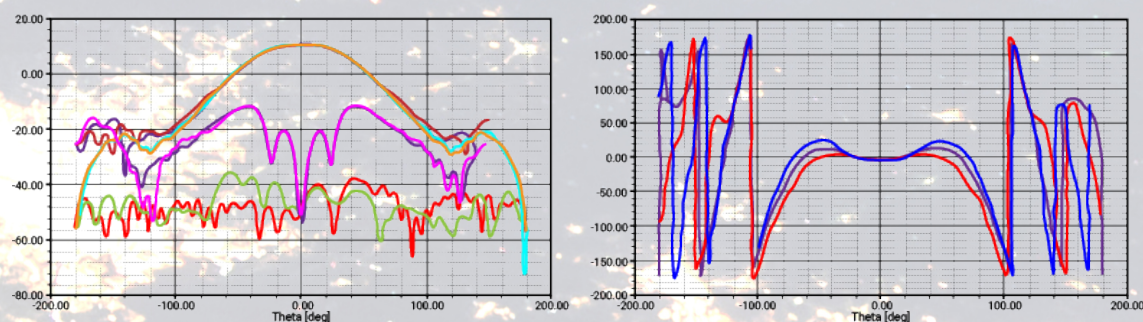


performance, dual-polarized corrugated horn antenna (see *figure 2*) for RayBeam. Its phase centers for all planes are consistent.

Within a wide-angle range covering the whole DUT, the antenna has the characteristics of high beam symmetry and low cross-polarization, which ensures high precision measurements for a precision phased-array antenna.

Using the compensated calibration for the antenna, the RayBeam near field system can reduce the influence of the probe antenna pattern on the sampling result.

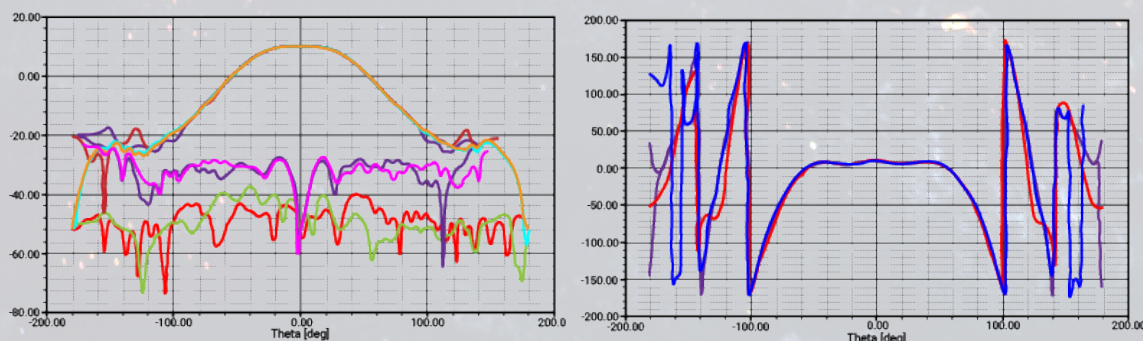
This method is especially useful for a large DUT or AUT off-center situation, where the sampling error caused by the probe is decreased, so the far-field pattern can be retrieved more accurately. Please refer to *figures 3 and 4*.



(a) Amplitude Pattern@28GHz

(b) Phase Pattern@28GHz

Figure 3: Conventional Corrugated Horn Antenna Performance



(a) Amplitude Pattern@28GHz

(b) Phase Pattern@28GHz

Figure 4: GTS Corrugated Horn Antenna Performance

HIGH PRECISION TEST

The RayBeam system design was verified with rigorous system-level hardware simulations. This test system has been improved in many ways, such as the customized mmWave probe antenna which is wideband, low RCS, and low cross-polarization.

The system includes new generation EPP absorbers which are durable, stable, moisture-proof, and dust-free; and a precise and wave-transparent turntable which can effectively reduce signal occlusion and improve test efficiency.

Together with the optimized NF-FF transformation algorithm, the RayBeam system's test result can be correlative with a large direct far-field test system. It can not only be consistent with lab simulations but also achieve similar performance to that of an expensive and complicated dual-reflector CATR system. Some samples are shown in figures 5 and 6.

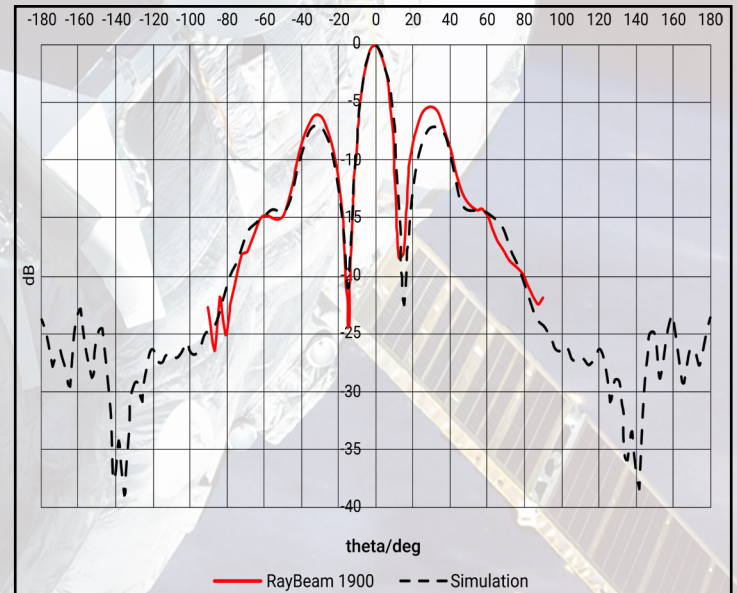
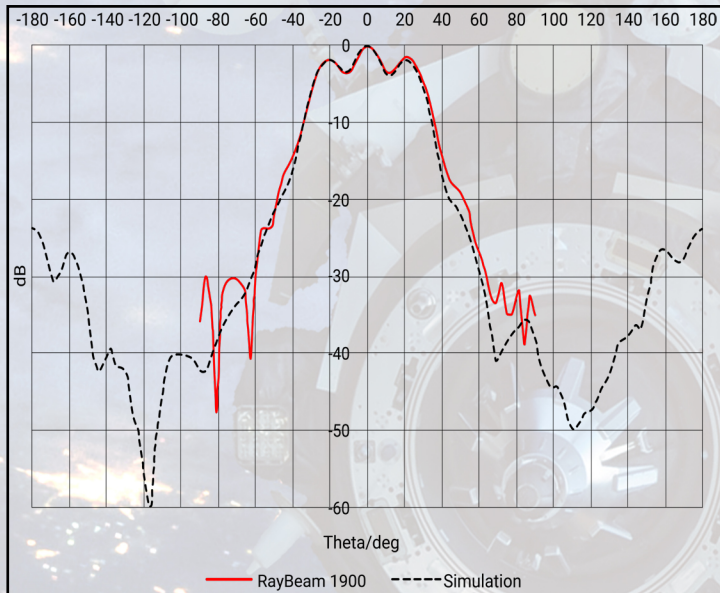


Figure 5: 39GHz Horn xoz cut patterns: RayBeam 1900 Test Results vs. Simulation Values

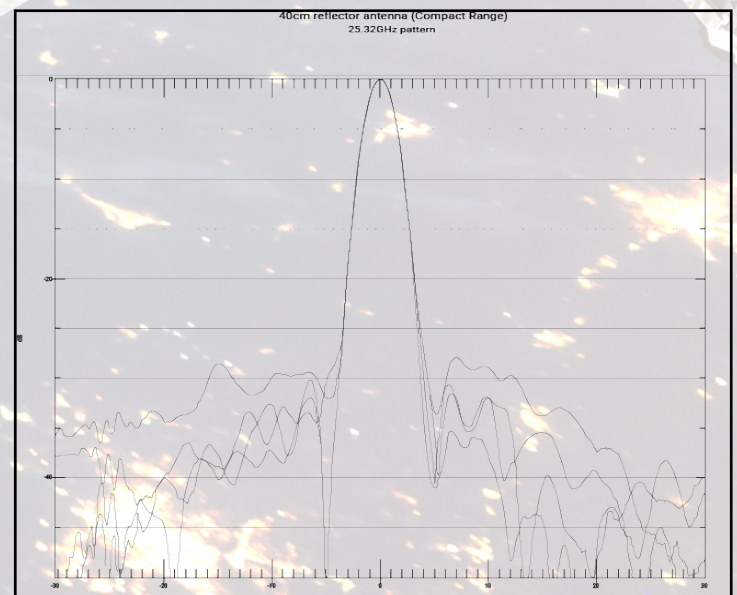
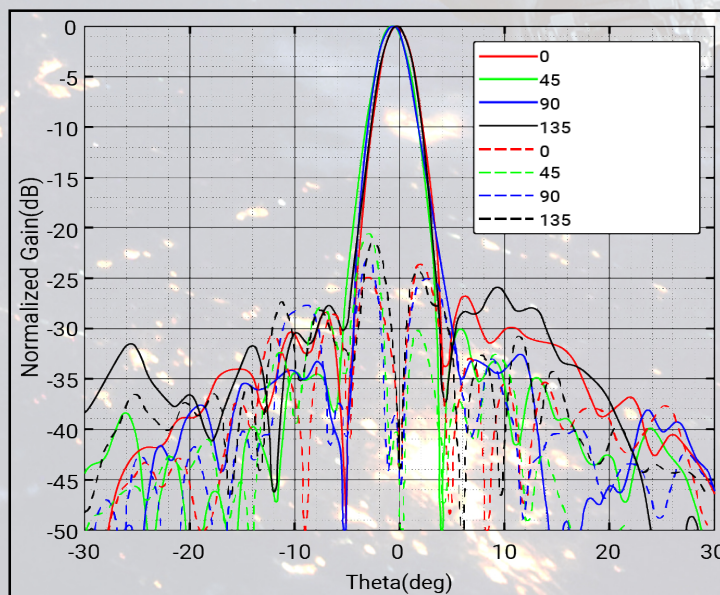


Figure 6: 40cm Reflector Antenna (RayBeam 1900) - 25.32GHz patterns: RayBeam 1900 Test Results vs. Compact Range

RAYBEAM 600 FAST PLANAR SCANNER SYSTEM

The phased-array antenna dynamically changes its beam direction by adjusting the antenna elements' amplitude and phase. All elements need to be calibrated to the phase and amplitude to ensure normal operation of the entire phased-array antenna.

However, as the antenna has grown to include a greater amount of elements, adjusting each element's phase and amplitude will make the whole calibration process inefficient. To improve the phased-array antenna's production and calibration efficiency, reduce test error and labor cost, we developed a phase & amplitude test system which can perform automatic element calibration. Based on the AUT's characteristics, customers can choose the vector rotation method to calibrate the single antenna element and the antenna array, or use the aperture field retrieving method to locate and fix the problem.

This phase & amplitude calibration system includes a multi-axis high-precision planar scanning rack. The test probe is mounted on the rack which can perform the planar near-field scanning around the AUT and collect the near-field data. The antenna element's phase and amplitude parameters are adjusted with the vector rotation method or aperture field retrieving method to calibrate the entire antenna array.

The RayBeam 600 is a general-purpose balancing system for the antenna array. It provides phase and amplitude balancing capabilities for phased-array antenna R&D and production tests. It is compact, fast, and simple to use; it is also ideal for satellite user terminal R&D and manufacturing testing.

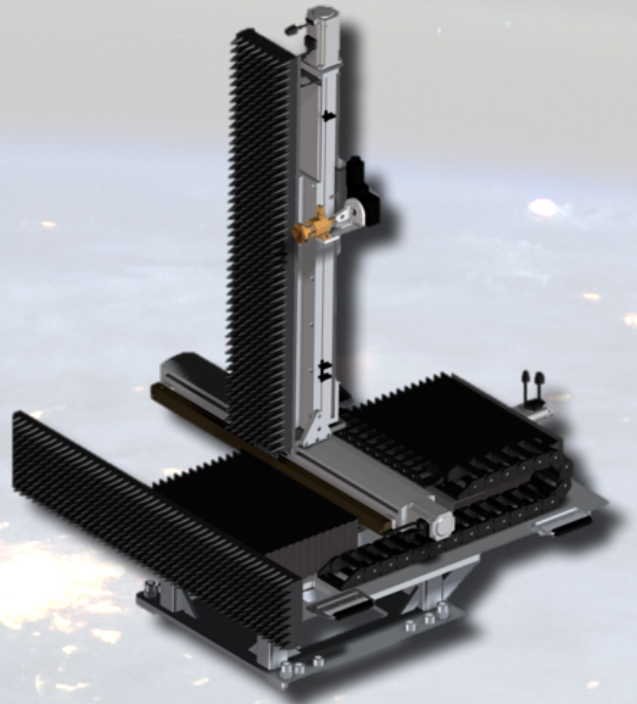


Figure 7: Planar Scanning Rack

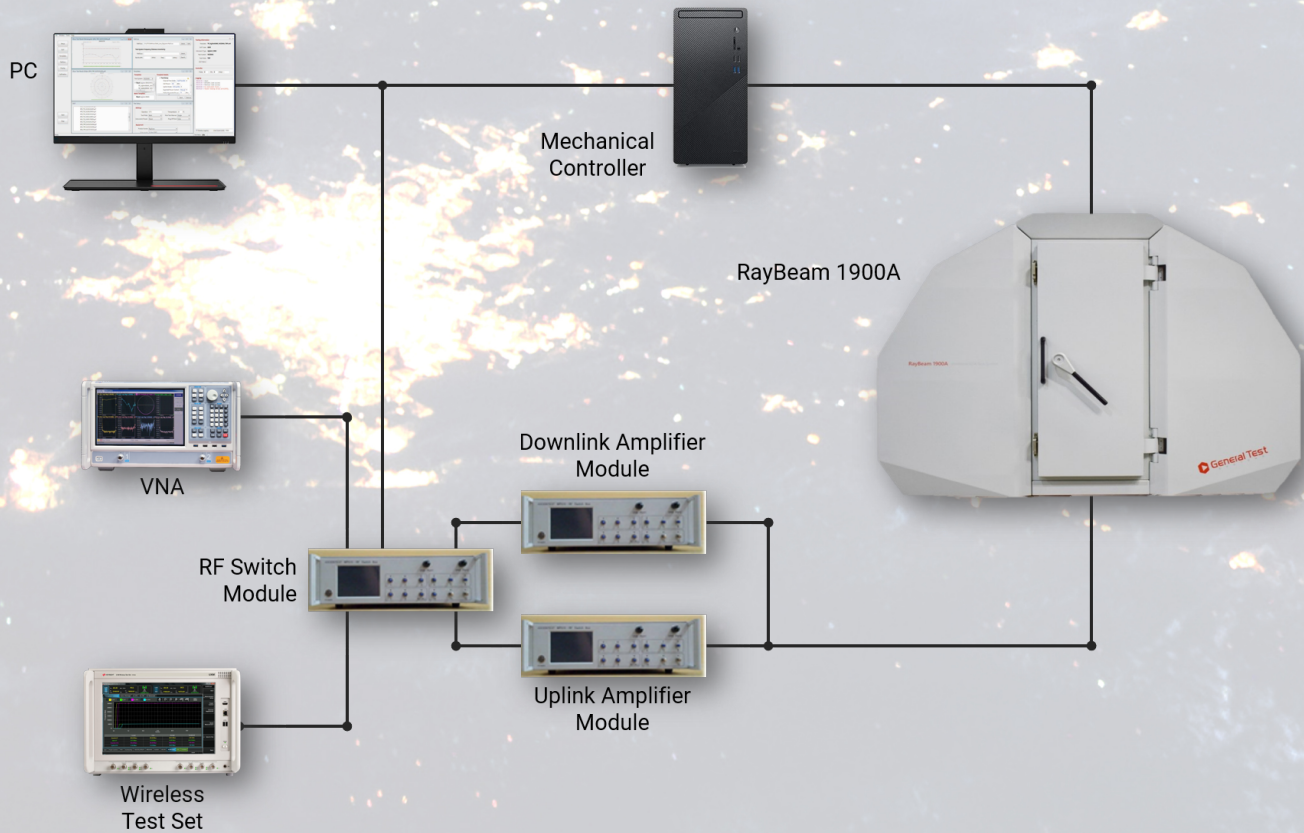


Figure 8: RayBeam1900 System Diagram

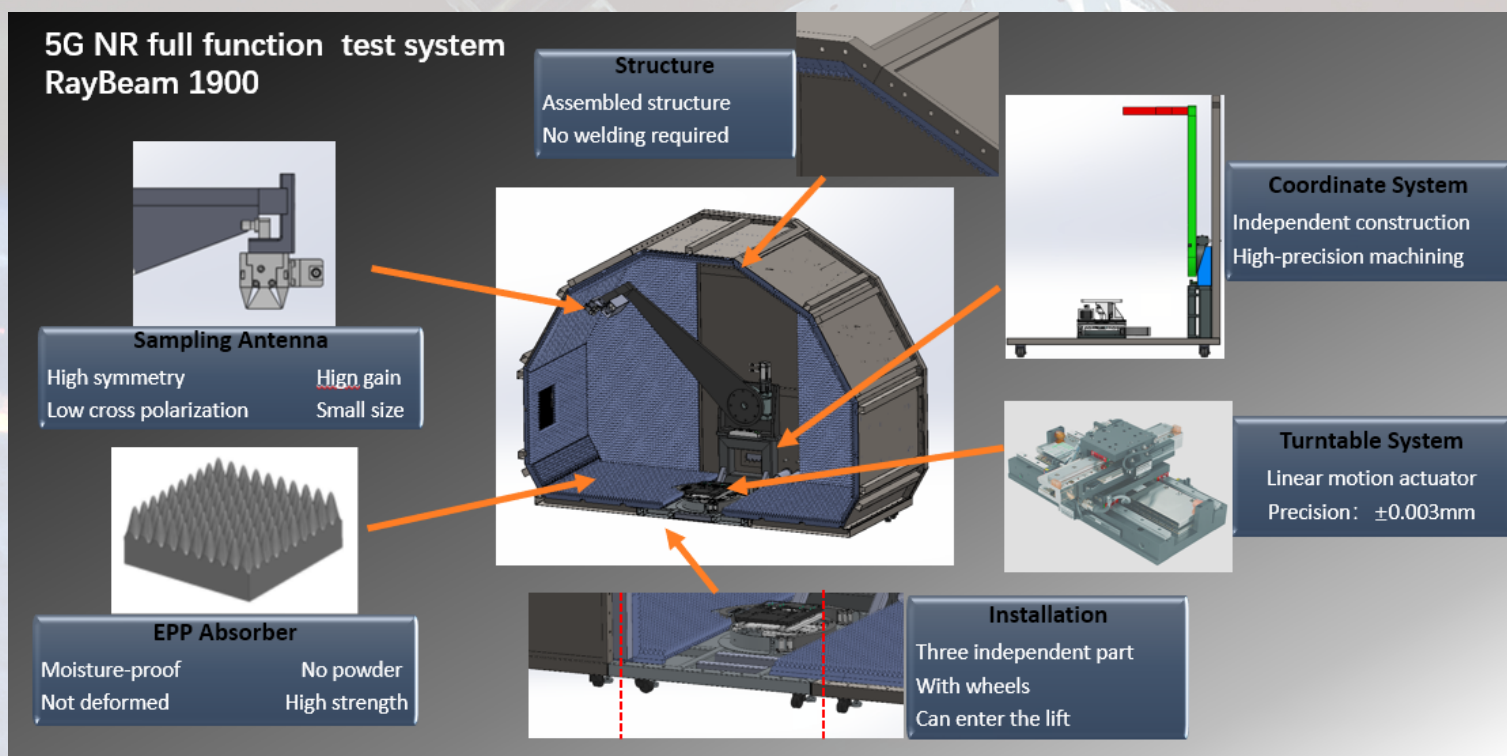


Figure 9: RayBeam 1900 Mechanical Structure

RAYBEAM 1900 COMPACT NEAR FIELD TEST SYSTEM

The RayBeam 1900 is a spherical near field fast measurement system designed for mmWave device R&D and manufacturing tests. It is suitable for various DUTs with phased-array antenna, such as antenna-in-package (AiP), automotive radars, and satellite user terminals. The 1900 supports phase and amplitude calibration, antenna measurement, and system performance tests. To achieve the system design objectives, the system machinery, components selection, calibration methods, and test algorithms have been optimized. The goal is to provide highly accurate measurements for large devices in a small space. Its miniaturized modular design enables convenient transportation and fast integration. The 1900 is suitable for common work-places such as R&D offices and laboratories.

The RayBeam 1900 can be connected with a VNA (or signal generator and spectrum analyzer), radar simulator, and wireless test set respectively through an RF switching unit. The system diagram is shown in figure 8. The Mechanical Structure is shown in figure 9. Both the up and downlinks contain low-noise amplifier circuits, which can effectively increase the system dynamic range to 60dB. The 3D pattern is shown in figure 10.

SYSTEM MECHANICAL FEATURES

Compact Size: The chamber's exterior dimensions are 2.74m×1.62m×2.06m. It is composed of three separate wheeled parts, and each part can be lifted in an office elevator (typical dimensions: 0.9m×1.4m×2m). The chamber is pre-assembled and calibrated at the factory, then transported and integrated on-site. The on-site integration can be finished within one day. Its sampling system has semi-spherical and full spherical scanning options.

Precise Linear Drive Motor: The turntable adopts a linear drive motor which has a small volume and high precision (better than

0.01mm). Its accuracy is much better than the conventional drive method, which can meet the strictest requirements of amplitude and phase calibration for mmWave chips, base stations, and other phased-array products.

Independent Turntable and Positioning Mechanism: The turntable and the spiral arm are integrated with the system's main reference frame as a whole. This mechanical part is precisely machined and isolated from other system components. Such a design ensures each system core component's mechanical accuracy and independence, and protects its performance from being affected by the ground flatness, shielding enclosure deformation and manual installation error, etc. The design also reduces the system assembly and transportation influence on the system accuracy.

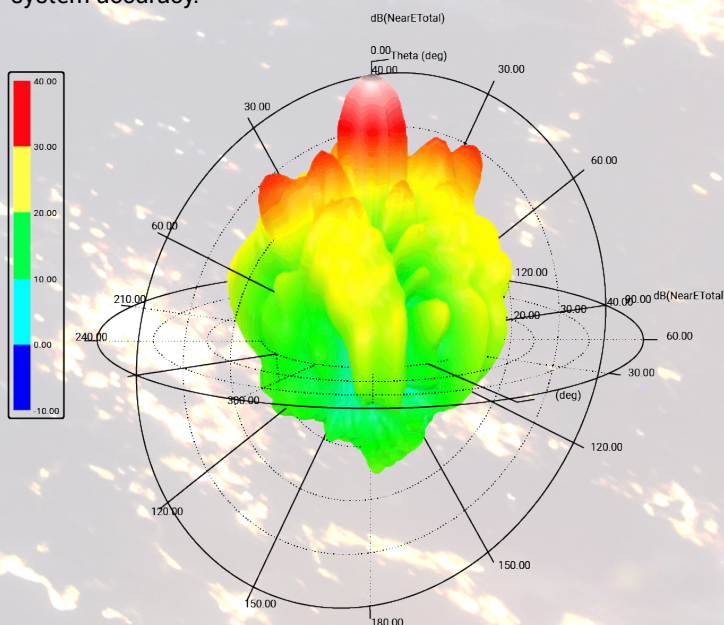


Figure 10: RayBeam 1900 3D Pattern

RAYBEAM 5000 SPHERICAL NEAR FIELD TEST SYSTEM

The RayBeam 5000 (see figure 11) is a cutting-edge spherical near field system for large-scale phased-array antenna and full-satellite testing. The AUT aperture size can be up to 1.5 meters wide (or 5 feet). The maximum load-bearing weight of the turntable is 500kg (or 1100 lbs) and can perform multi-port and multi-beam positions, and system performance tests. It uses the HCR series of high-precision standard tracks made by THK of Japan. With a positioning accuracy better than 0.02° , the sampling track has a stable structure, heavy-duty capability, and robust design. The probe is driven by a sliding mechanism, mounted on the arched track, which performs semi-spherical scans for the whole AUT.

An azimuth turntable is located at the center of the arched track, and the AUT mounting platform of the turntable is horizontal, which facilitates the placement of an active phased-array antenna connected with complex Electrical Ground Support Equipment (EGSE). Meanwhile, the turntable can be horizontally moved in two dimensions, with accuracy better than 0.01mm . This function is useful for an AUT's fine position adjustment.

The entire turntable is also equipped with an adjustment mechanism for setting azimuth/elevation angles and horizontal plane offset, which can be used for calibration with the scanning rack's coordinate system during the system's initial installation.

MAXSIGN100 ANTENNA/OTA AUTOMATIC TEST SOFTWARE

The MaxSign100 system's control and test automation software is based on the .NET Framework 4.0 platform, fully complies with CTIA test standards, and is kept up to date with the latest standards. MaxSign100 provides a wide range of applications, flexible configurations, smooth test processes, stable operation, and a simple but friendly GUI. It can meet different test requirements in different product stages and cover the whole product life cycle, ranging from R&D, pre-conformance, and conformance to QA in manufacturing.

- Supports 3D measurement, cut selectable 2D measurement, and single point measurement (see figures 12 and 13)
- User-defined test step, test angle, and test configuration
- Simply select any test point then review all test data of it
- Wide variety of test assistant functions, such as anti-drop-call, auto-recall and abnormal situation warnings. Improves the test processes' reliability and smoothness

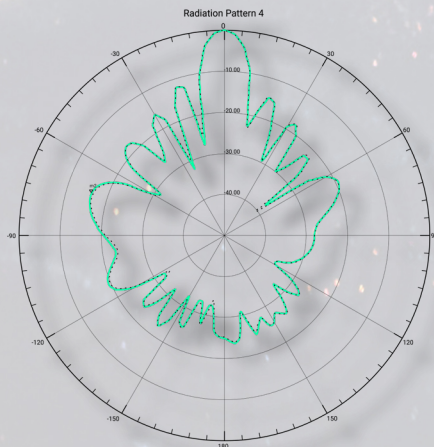


Figure 12: RayBeam 2D Pattern

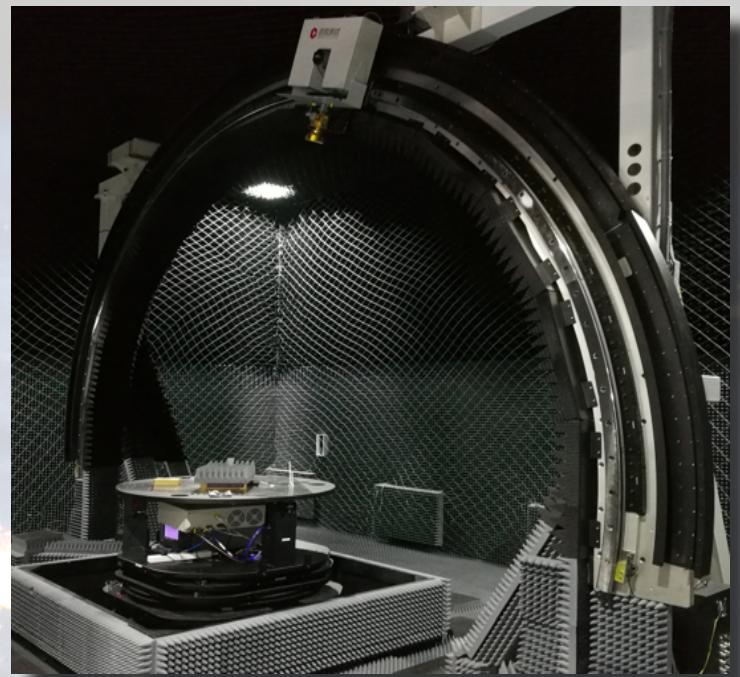


Figure 11: RayBeam 5000 (Inside View)

- Comprehensive raw test data and log files management. The test process is traceable and cannot be modified
- Batch processing function supports creating task lists, which enable continuous and automated tests
- Resourceful built-in templates, with preconfigured parameters that are compatible with different instruments and test platforms. Simple manipulations effectively prevent operational errors
- Supports 3D display, antenna pattern arbitrary angle rotation, viewing, and cutting, which helps R&D engineers to analyze and diagnose problems intuitively

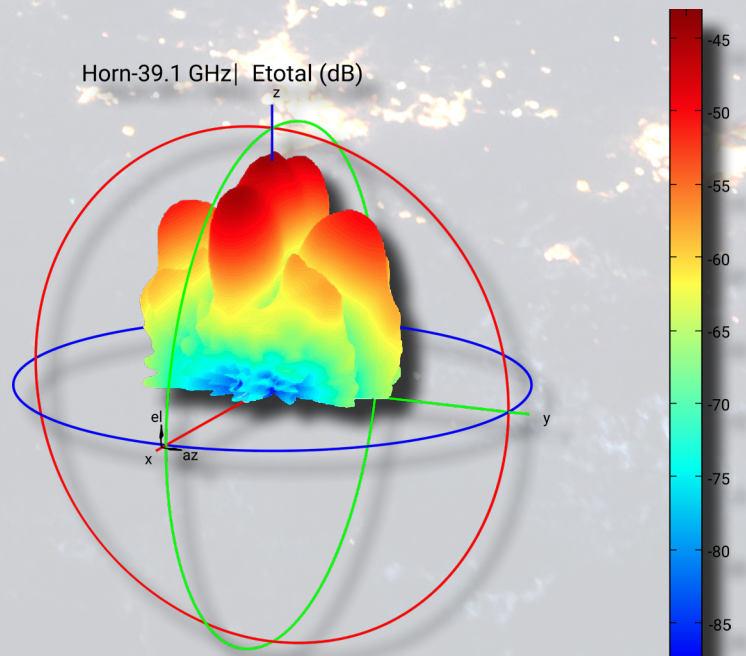


Figure 13: RayBeam 3D Pattern

TECHNICAL SPECIFICATIONS

		RayBeam 600	RayBeam 1900	RayBeam 5000
General	Function	Phased-array antenna measurement / System performance measurement/Amplitude and phase calibration		
	Application	mmWave device / chip (AIP) / automotive radar / satellite antenna & user terminal measurement		
	Technology	FF/Planar NF-FF	FF/Spherical NF-FF	FF/Spherical NF-FF
	Frequency Band	10GHz~40GHz (8GHz~50GHz option)	10GHz~40GHz (8GHz~50GHz option)	8G~50GHz (1GHz~50GHz option)
	Measurement Item	■ Antenna measurement: radiation pattern (amplitude & phase), beam pointing/width, null position/depth, sidelobe position/level, cross polarization, circular polarization ratio, etc. ■ System Performance: G/T, GD, SFD, EIRP, EIS, EVM, ACLR, SEM, etc. ■ Amplitude & phase calibration(for phased-array antenna)		
	Shielding	>80dB		
DUT	Max Size	Φ95×28 (cm)	Φ95×28 (cm)	Φ400×200 (cm)
	Antenna Array Max Size	60×60 (cm)	50×50 (cm) 10x10 (cm) (calibration)	150×150×150 (cm)
	Max Weight	50kg	50kg	500kg
QZ	Size	60×60×60 (cm)	50×50×50 (cm)	150×150x150 (cm)
	Reflection Level	< -40dB (typical)		
Probe Antenna	Test Distance	10~250cm	110cm (75cm option)	250cm
	Scan Range	x/y: ±50cm	±100° (±170°cm)	±90°
	Scanning Accuracy	≤ ±0.01mm	≤ ±0.05°	≤ ±0.02°
	Cross Polarization ratio	≤ -40dB		
Turn table	Rotation Range	Azimuth: ±5° Elevation: ±5°	0°~360°	0°~180° Z
	Rotation Accuracy	≤ 0.01°	≤ 0.05°	≤ ±0.03°
	X/Y Axis		■ Movement range: ±50mm ■ Movement accuracy: ±0.01mm	
	Z Axis	■ Movement range: 50mm Z axis ■ Movement accuracy: ±0.1mm		
Absorber	Base Material	EPP (expended polypropylene) / Honeycomb absorber (high power option)		
	Height	100mm (200mm option)	60mm (100mm option)	100mm (200mm option)
	Power Tolerance	1.2kW/m² (10kW/m² option)		
Chamber	Dimensions (L×W×H)	500×300×300cm	274 ×162 ×206cm	800×690×500cm
	Door Size	16×65cm	16×65cm	Custom
	Weight	300kg	800kg	

HARDWARE MODULES

E1910 Shielding enclosure	Chamber, shielding door, lighting system, ventilation system, RF switch/interface unit, RF Cable, system Controller, etc.
E2110 mmWave absorber	EPP Foaming polypropylene material 300×300×100mm
E2111 High power mmWave absorbers	Honeycomb, power tolerance $\leq 10\text{kW/m}^2$
E1920 Scanning and positioning system	Spiral arm, high precision turntable, Up/down convertors, LNA, Switching
E1930 Scanning and positioning system	Arched track, high precision turntable, Up/down convertors, LNA, Switching
CH0712 test probe	7.5-12GHz Corrugated horn
CH1218 test probe	12-18GHz Corrugated horn
CH1826 test probe	18-26.5GHz Corrugated horn
CH1040 test probe	10-40GHz Corrugated horn
CH3350 test probe	33-50GHz Corrugated horn
VD0107 test probe	1 -7.5GHz Vivaldi

SOFTWARE MODULES

E1960 Base module	System Control, Instrument Drivers, Direct FF Sampling Test, 3D Pattern/Display, Test Reporting
E1970 NF-FF module	Near field to far field transformation on hemisphere
E1980 Fast test module	Test acceleration algorithm based on field source reconstruction for phased array antenna fast testing

INSTRUMENTS SUPPORTED

Spectrum Analyzers	Keysight, Rohde & Schwarz
Network Analyzers	Keysight, Rohde & Schwarz
Signal Generators	Keysight, Rohde & Schwarz

SERVICE & SUPPORT

System calibration	One free calibration at system delivery
Product warranty	Free for the first year
Software upgrade	Free for the first year



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