# ADVANTAGES AND DISADVANTAGES OF VARIOUS HEMISPHERICAL SCANNING TECHNIQUES

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*Abstract* - **When performing far-field or near-field measurements on large antennas, it is often necessary to consider the advantages and disadvantages of various mechanical positioning configurations for achieving the required hemispherical scan coverage. Measurement systems employing a single-arm gantry, a dual-arm gantry, a fixed arch moving probe, and a fixed arch multi-probe have been paired with either an azimuth positioner or a vehicle turntable in order to provide hemispherical scanning of the article being tested.**

**This paper will highlight the key characteristics of various scanning methods and provide comparisons among the different techniques. Positioning and system accuracy, speed, stowing capability, calibration, frequency range, upgradability, relative cost and other key aspects of the various techniques will be discussed in detail to help the end user during the system design and selection process. In addition, the paper will highlight novel hemispherical and truncated spherical scanning approaches.**

**In many applications, the success of meeting the measurement requirements often centers on the judicious selection of the positioning subsystem. This paper will provide guidance toward making the proper selection of the scanning concept as well as of the positioning system.**

**Keywords**: Hemispherical Scanning, Spherical Near-Field, Spherical Far-Field, Gantry, Arch

## I. INTRODUCTION

Hemispherical or truncated spherical scanning techniques are typically used for measuring large objects located at ground level. These techniques can be applied to both far-field and near-field antenna measurements. The near-field scanning system can be regarded as a far-field scanning system with a reduced range length. That is, range length less than the usual $2D^2/\lambda$ far-field criterion. Range length is defined as the distance between the transmit and receive antennas, D is the aperture diameter, and $\lambda$ is the wavelength. For spherical near-field measurements, a post-processing transformation step is applied to obtain the far-field radiation characteristics.

Measuring a large antenna or article under test (AUT) poses a number of challenges for proper antenna characterization. Due to the large physical diameter of the AUT, a large positioning system is necessary to provide sufficient spherical coverage. A probe measuring along an arc over a large azimuth positioner is a suitable mechanical configuration for large AUTs. For characterizing antennas integrated into vehicles, such as automobiles, military trucks, or even tanks, a large diameter vehicle turntable under a probe measuring along an arc is suitable to provide hemispherical scan coverage.

There are several configurations that allows for the probe to measure along an arc. Examples are probe mounted on a single-arm rotating gantry [1-2], probe mounted on a dual-arm rotating gantry [3], probe moving on a fixed arch [4-5], and multiple probes on a fixed-arch [6]. For appropriate selection of hemispherical or truncated spherical scanning system, a proper understanding and qualitative analysis among the various options is necessary.

## II. KEY CHARACTERISTICS

For optimal positioning equipment selection for a given application, the following key characteristics must be understood and compared among various spherical scanning techniques: Required frequency range of operation, physical diameter of the AUT, positioning accuracy, speed, stowability, ability to move axis of rotation, calibration, and cost.

Frequency range of operation of the antenna measurement system depends on purpose of the range and its utility. General purpose chambers may require broad frequency coverage from 0.7 GHz to 40 GHz. Special purpose antenna measurement systems, such as an automotive test facility, may require the frequency range to be 0.07 to 11 GHz.

The minimum sphere is the diameter of a sphere that, when centered at the coordinate system origin, fully encompasses the antenna under test. Actual spherical scanning radius (location of the probe's phase center) will be several wavelengths away from the minimum sphere of the antenna under test.

Accuracy of the measurements depends on measurement technique used, frequency range of interest, directivity of the antenna, and many other factors. General purpose spherical near-field antenna measurement systems, which require high frequency operation or high fidelity in measurements need to consider the impact of minimum sampling density required to perform adequate near-field to far-field transformation at the required quality factor [7]. Quality factor is a rule of thumb used to determine the required accuracy of the system based on the minimum angular step required in the measurement grid. For example, if the minimum desired angular measurement step is 0.5 degrees, quality factor of 5 or 10 would result in an angular readout accuracy requirement of 0.1 or 0.05 degrees, respectively, on a spherical positioning system. In order to measure phase, quality factors of 20, 50 or beyond are used based on the wavelength of the highest frequency to determine accuracy of spherical measurement radius for antenna measurements. For spherical near-field measurement at 40 GHz, the wavelength is approximately 0.75 cm. Quality factor of 20 will impose a radius accuracy of 0.037 cm on the positioning system, while a quality factor of 50 would impose a 0.015 cm accuracy requirement.

Speed is also an important factor due to the amount of time required to characterize large AUTs. Depending on the size of the AUT, full hemispherical scan coverage with proper sampling density can be very time consuming, especially for high frequency measurements. Various techniques have been implemented to increase overall measurement speed.

Stowability is a factor that has become important due to increase in requirements for multipurpose measurement ranges. Due to significant investment made, multiple measurement requirements are often imposed on a single chamber. In some applications, the same chamber is required to perform spherical near-field and far-field measurements. This might involve a gantry over a vehicle turntable and a far-field source tower. During far-field measurements, the gantry may need to be stowed below the turntable. Ease of stowability or removal of the spherical scanning system from the chamber has become more important in recent times.

Variable height of the rotation axis of the probe is sometime required, especially when quasi-far-field and near-field measurements are desired from the same set of hardware. Single-arm gantry and dual-arm gantry system has been delivered with variable height axis option when required. This feature is useful to certain AUTs as well as for mitigating the issues caused by standing wave between the probe and the AUT.

Some spherical scanning systems require significant initial and routine periodic calibration in order to maintain the accuracy of the system. Fixed-arch multi-probe systems, for example, require alignment and calibration of each probe during initial installation and periodically. Calibration cost and the time required to perform this task must be considered as part of the overall initial investment and operating cost of the system.

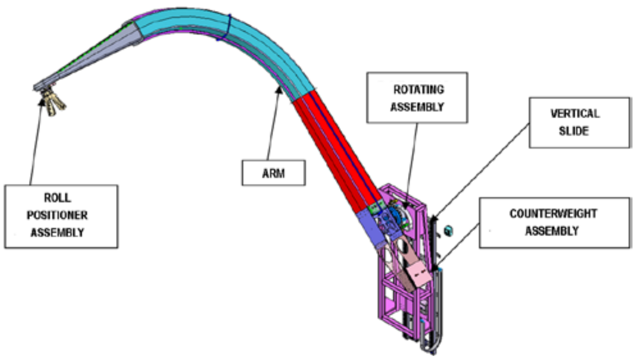
Cost of the system will depend predominantly on requirements imposed on the above-listed key characteristics and the scanning system chosen.

### III. SINGLE-ARM GANTRY

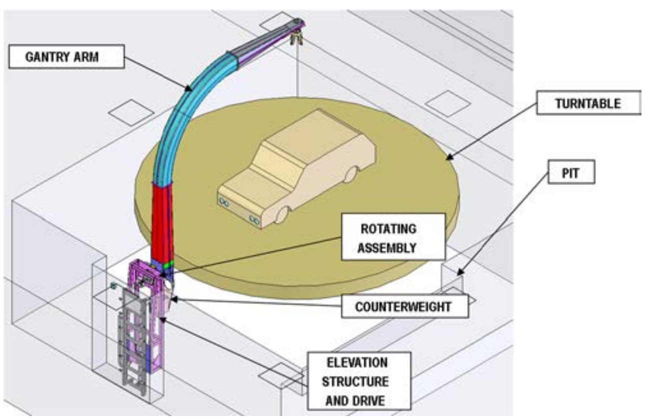
A Single-arm gantry system is shown in Figure 1. It offers several important advantages over other positioning systems. The cost of this system is relatively low and it is easy to implement in a relatively small foot print. This system can be easily stowed below grade level. Due to its simplicity and durability, it has been used in many permanent outdoor applications.

**Figure 1: Single-Arm Gantry**

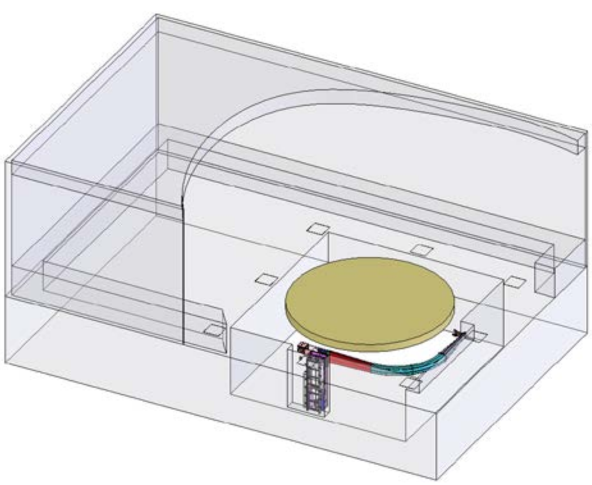
Figure 2 shows an example of a single-arm gantry system installed on a vertical slide. This allows the gantry rotation axis to be lowered in order to stow the gantry below the floor when necessary. Variable height mechanism also allows the rotation axis of the gantry arm to vary as necessary for specific measurement requirements.




(a) Gantry on Vertical Slide Details




(b) Measurement Configuration



(c) Stowed Configuration

**Figure 2: Single-Arm Gantry on a Vertical Slide**

Due to its simplicity and predictable behavior of the positioning system, only a simple initial calibration & routine maintenance may be required.

The major disadvantage of the single-arm gantry system is its native accuracy. Although, lightweight and high stiffness composite materials are used to fabricate gantries, the probe end sees translational and angular deflections during gantry motion from 0 to 90 degrees as shown in Figure 3. Due to the positioning issues, these systems are limited to operation at low frequencies. High accuracy antenna measurement is not possible without the application of positioning correction techniques [8-9]. Due to fairly repeatable behavior of deflection as a function of gantry angular position, simple correction, using an error lookup table, in some cases will be sufficient to increase overall system accuracy.

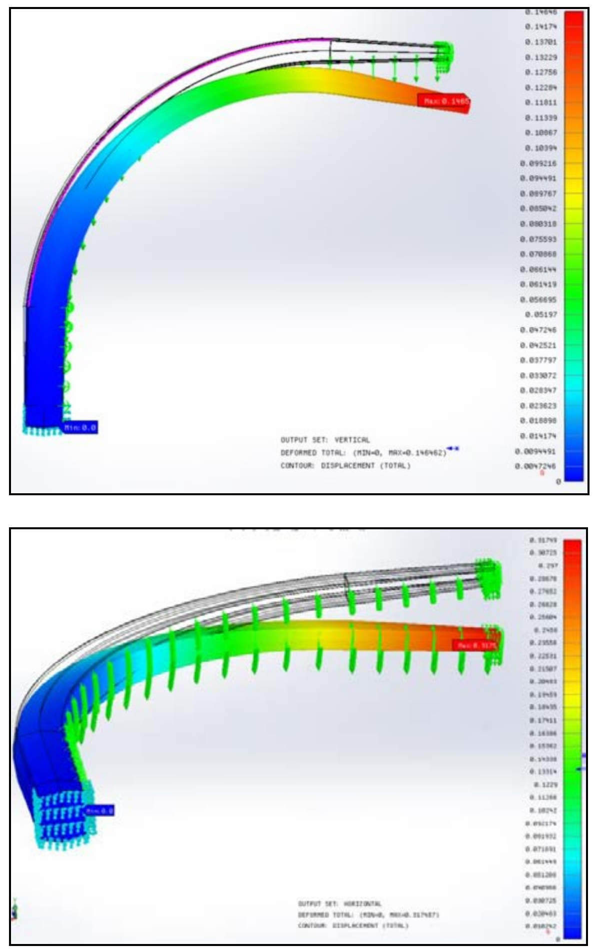


**Figure 3: Deflections in a Gantry-Arm**

Due to large moving mass at the probe end and the limited stiffness of the gantry structure, scanning speed in elevation is also limited. Compliance in the structure also does not allow for rapid stepping of this axis for scanning applications.

## IV. DUAL-ARM GANTRY

Dual-arm gantry system, as the name implies, utilizes dual support system and dual drive system to support the probe and move it along a circular path as shown in Figure 4. Dual-arm gantry systems have been developed to minimize angular & translation deflection associated with single arm gantry system.

**Figure 4: Dual-Arm Gantry**

Dual-arm gantry systems will subject the probe to much lesser angular & translation deflections when compared to a single-arm gantry system. Due to a relatively small foot print, this system can be stowed away below ground. This system, however, has more complexity due to the fact that the gantry is supported and driven from two ends. The alignment of the two axes and synchronization of the two drive systems are very critical for proper functioning of the system. Hence, this system is more expensive than the single-arm gantry.

## V. FIXED-ARCH MULTI-PROBE

Fixed-arch multi-probe spherical antenna measurement system provides the benefit of fast antenna measurements. An example of such as system is shown in Figure 5. However to cover broad frequency band & to minimize probe change, broadband dual-polarized feeds are typically installed in an angular grid. In order to achieve the required resolution, a large number of feeds must be mounted with complex RF switching network to perform spherical antenna pattern measurements. This system is typically capable of working up to 18 GHz. Due to the geometric configuration, such systems are typically limited to a pair of frequency bands. Figure 5 shows probes of one frequency band installed on the right half of the fixed arch. This approach requires extensive calibration due to the use of multiple probes. The cost can be high, especially depending on the frequency of operation, size of the minimum sphere required, and the number of probes required for high fidelity measurements. Further, these systems require frequent calibration that can become expensive over the long term.

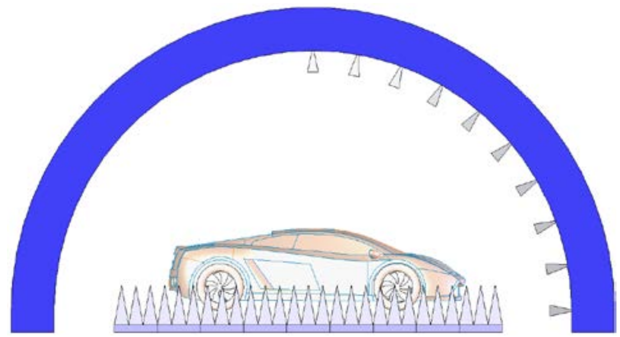


**Figure 5: Fixed-Arch Multi-Probe**

## VI. FIXED-ARCH MOVING PROBE

In this configuration, the probe moves along a circular path on a fixed arch. The AUT is mounted on an azimuth positioner under the arch such that the turntable center is coincident with the arch center. A typical fixed-arch moving-probe system is shown in Figure 6. These systems offer significant advantages over other spherical scanning techniques. These systems can be designed and installed very precisely in order to perform high frequency measurements (40 GHz and above) with extremely high fidelity [4]. The main advantages of these systems are superior accuracy, wide frequency range of operation, and relatively low cost depending on frequency of operation. The disadvantages are difficulty to stow, relatively slower acquisition speeds (which can be increased by increasing the turntable speed), and complexity in installation for high frequency measurements.

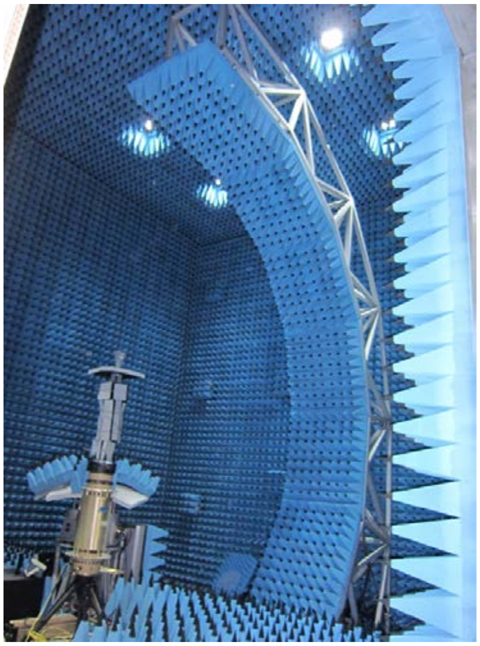


**Figure 6: Fixed Arch Moving Probe**

## VII. System Comparison

Qualitative comparison among the various mechanical systems available for spherical scanning of AUTs is provided in Table 1.

**Table 1. Key Characteristics of Various Hemispherical Scanning Systems**

| Characteristics | Single-Arm Gantry | Dual-Arm Gantry | Fixed-Arch Multi-Probes | Fixed-Arch Moving-Probe |
|---|---|---|---|---|
| Accuracy | Low | Medium | Low to Medium | Highest |
| Speed | Acceptable | Acceptable | Fastest | Acceptable |
| Frequency of Operation | Low | Medium | Medium | Highest |
| Maximum Frequency (≥26.5 GHz) | No | No | No | Yes |
| Ease of Stowability | Highest | Highest | Medium | Low |
| Calibration | Moderate | Moderate | Extensive | Moderate |
| Total cost of Ownership | Low | Low to Moderate | High | Moderate |

The user can use this as a guideline to prioritize the key characteristics and determine the appropriate system that would meet the measurement goals.

## VIII. Novel Approaches

Recent development in position error-correction techniques and post processing of irregular spherical scan probe data for proper near-field to far-field transformation can be applied to systems that have low native accuracy and hence are lower in cost. Further, these techniques can be used to increase measurement fidelity at higher frequencies than the mechanical system would have otherwise supported.

Figure 7 shows a single-arm gantry system that has a radial and cross range motorized axis at the probe end to correct for translational errors associated with structural deflections during 0-90 deg. movement. A laser tracker can be used for routine calibration by mapping the deflections and creating an error-correction table that would be used during measurements.

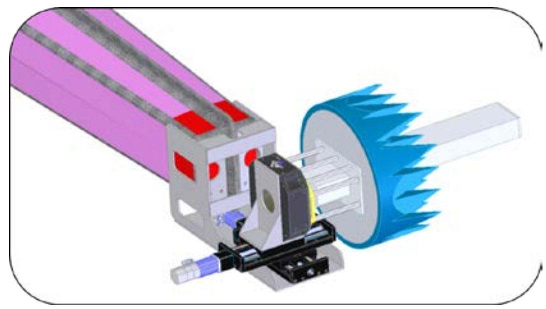


**Figure 7: Probe on Radial and Cross-range Slides**

Another approach is to simply characterize the position of the probe during acquisition using a laser tracker system and implement a software correction of the irregular spherical scan data for proper near-field to far-field transformation. Accuracy using this approach is function of the accuracy of the tracking laser system and software post processing. Other techniques include having a laser tracker system in the position loop to correct for positioner error in real-time.

## IX. Summary

Spherical scanning methods are useful in both near-field as well as far-field measurements of large AUTs. The techniques discussed have all been used successfully. Proper selection of the required system depends on the primary objectives and requirements of the system. Key characteristics of the various systems have been discussed to help provide a useful guideline to the end-user.

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