Spherical Near-Field Antenna Measurement Note: Disciplined Measurement Practices

Brian B. Tian
MI-Technologies Inc.
1125 Satellite Blvd, Suite 100, Suwanee, GA 30024
btian@mi-technologies.com, (678) 475-8395

1. Introduction

The number of users involved in spherical near-field (SNF) antenna measurement continues to grow rapidly due to the popularity of this technology. Pressured from competition in today's commercial market, some must perform SNF antenna measurements and produce results before they have an opportunity to gain adequate understanding of the technology and the theory behind it. This note attempts to link some SNF measurement practices to theoretical requirements from a user's perspective and to promote a disciplined approach in measurement practice. Topics covered include range setup, probe alignment, SNF data output and AUT mounting.

To achieve the above goal, we first lay out the coordinate system in which SNF transformation is formulated, and then illustrate in detail how this coordinate system is realized by practical SNF range and probe. We then discuss the interpretation of SNF output data and AUT mounting. We also address possible misunderstandings and misconceptions. To ensure consistency, this note follows a single set of conventions and definitions for symbols and formulations detailed in [1].

2. Defining SNF Antenna Measurement Coordinate System

Figure 1 shows the SNF antenna measurement coordinate system in which the SNF transformation is formulated. It is this coordinate system that governs nearly all aspects of SNF antenna measurement practice to be discussed in this note; therefore it needs to be fully understood.

Refer to Figure 1. This coordinate system consists of range coordinates (x, y, z) or (θ, ϕ, r) and probe coordinates (x', y', z') or (θ', ϕ', r'). The probe coordinates' origin o' is shown at an arbitrary point P (θ, ϕ, r) in the range coordinate. The distance between origins of the two coordinates, o, and o', is the SNF scanning radius A. The probe coordinate **z'** must be aligned with the range coordinate **r**, pointing in the same direction.

Independent of both the range and the probe coordinates is a variable labeled **χ,** the angle between vectors **θ** and **x'**. It is the rotation angle of the probe coordinate about the range vector **r.** In an SNF transformation algorithm that is based on probe modes $\mu = \pm 1$, two sets of SNF scans are needed in order to resolve the transmit coefficients of an antenna under test (AUT). These two scans are normally made at $\chi = 0^o$ and $\chi = 90^o$ respectively. Since **χ** is treated as a vector in SNF transformation formulation, both its magnitude and sign matter to the outcome of an SNF transformation. This dictates that a probe rotate clockwise (CW), facing the probe from origin O, as it turns from $\chi = 0^o$ to $\chi = 90^o$.

It is important to understand that this coordinate system is purely a mathematical framework for SNF transformation formulation only; it involves no physical attributes such as E fields, H fields, polarizations, or geometries of the AUT or the probe. As important as they are in any antenna measurement, physical attributes play no roles in defining this coordinate system. Lack of understanding of this distinction can cause confusion. For instance, some mistakenly perceive $\chi = 0^o$, a coordinate orientation, as the probe being set physically horizontal or vertical. Some use terms of co-polarization or cross-polarization to interpret SNF output when no reference polarization is designated.

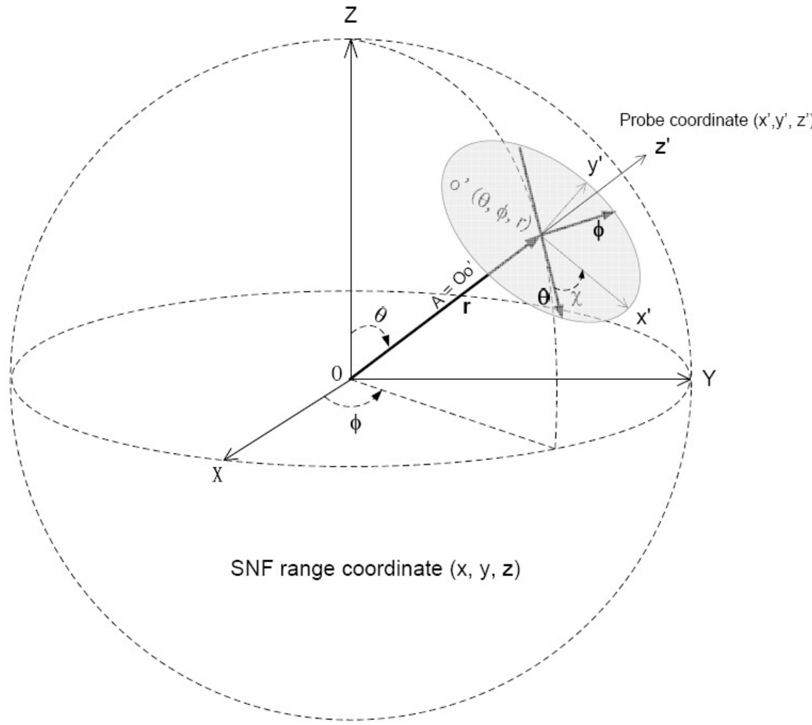

Figure 1 Defining SNF antenna measurement coordinates system

In summary, a SNF antenna measurement coordinate system consists of range coordinates (θ, φ, r) and probe coordinates (θ', φ', r'). The relationship between them is defined through the separation A, alignment **r** and **z'**, and angle **χ**. No physical attributes are involved in this coordinates system.

3. Realizing Range Coordinates

There are many mechanical constructions with which SNF range coordinates (θ, φ, r) can be realized physically. Figure 2 shows one of the most commonly used. It is a roll motion on a mast and offset arm, over an azimuth motion. In this mechanical construction, roll motion provides for φ variation while azimuth for θ.

Both the signs and magnitudes of θ and φ participate in SNF transformation computation, just as was for χ. The signs of θ and φ come from the rotational directions of roll and azimuth respectively. To realize a positive value of φ, roll must rotate CW when looking at the origin from positive z. Likewise, positive θ is realized when azimuth is rotated CW when looking at the origin from positive y. These two directions are marked in Figure 2. If roll rotates in the wrong direction, point P (θ, ϕ, r) which is supposed to read ϕ now reads (360-ϕ), or – ϕ. On the other hand, if azimuth rotates in the wrong direction, point P (θ, ϕ, r) still reads θ, but with roll at $\phi + 180^{o}$ when it should have been at ϕ. The direction convention can be better understood with help of Figure 4 in the next section. An incorrect direction of roll or azimuth may be easily overlooked since an antenna pattern resulting from a rotation in the wrong direction may appear "correct" if it possesses certain symmetry about ϕ.

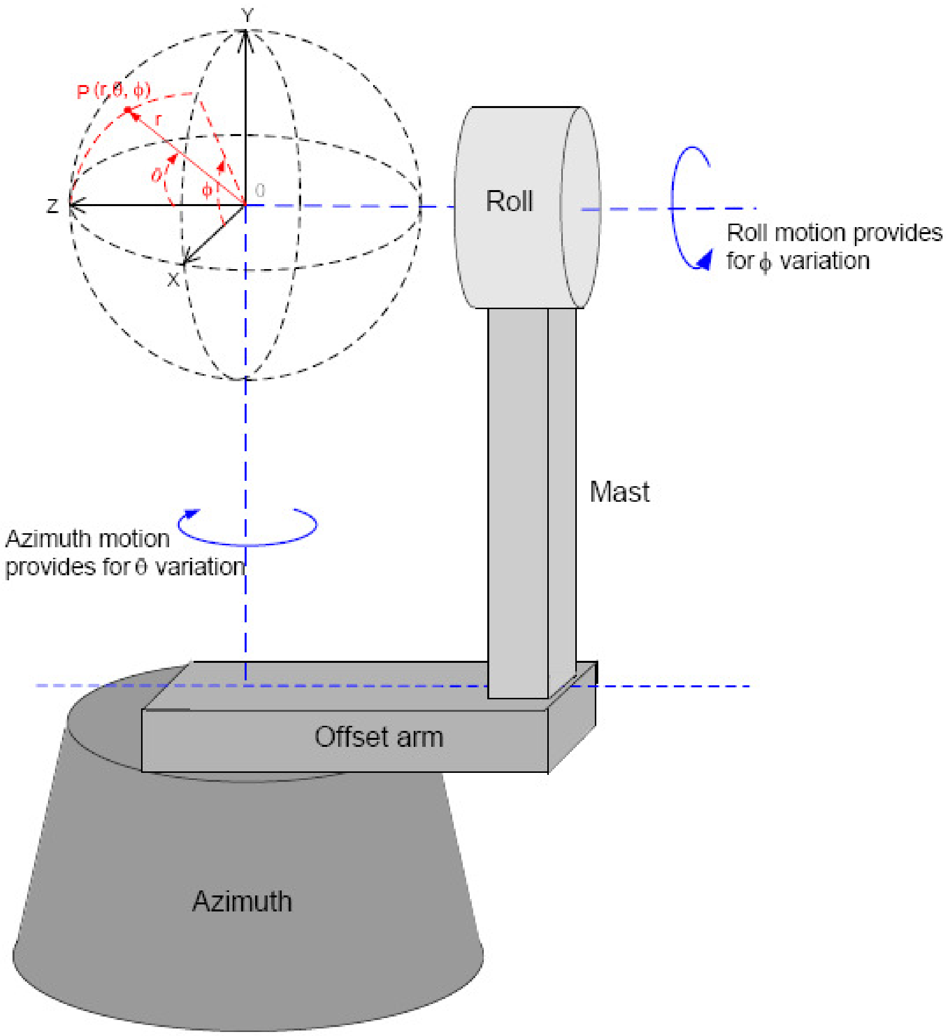

Figure 2 Realizing an SNF antenna measurement coordinate system with motions of azimuth and roll. Roll and azimuth must rotate as indicated to realize positive values for θ and ϕ.

4. Bringing a Real Probe Into Range Coordinate

Recall from Figure 1 that a probe is represented by its coordinates (x', y', z') in an SNF antenna measurement coordinate system. Its relationship with range coordinates has been defined in Figure 1. Therefore, in order to bring a real probe into the range coordinates shown in Figure 2, one must know the probe's coordinates and then align it to the range coordinates in accordance with the defining relationship. Figure 3 shows the coordinates system after a probe, represented by (x', y', z'), is brought into the range realized in Figure 2.

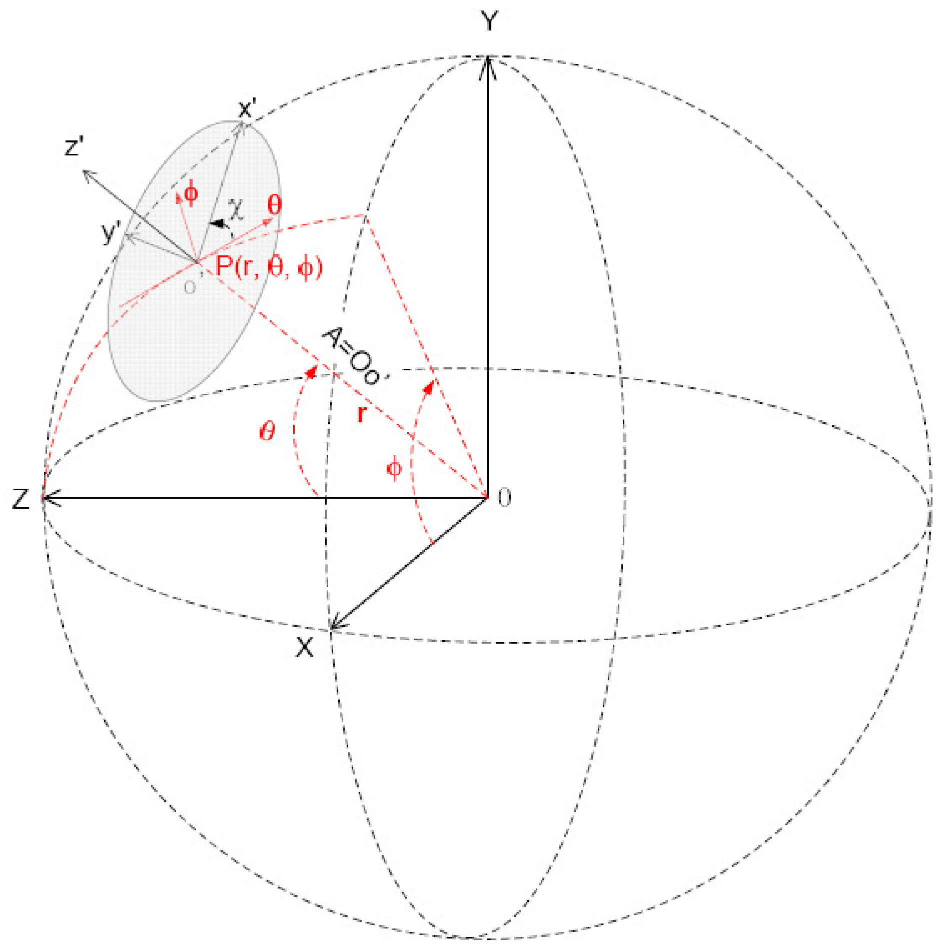

Figure 3 Probe coordinates (x', y', z') are brought into the range coordinates of Figure 2

In theory, a probe's coordinates (x', y', z') can be aligned with the range coordinate (x, y, z) at an arbitrary location (θ, ϕ, r), for example, at point P (θ, ϕ, r) as shown in Figure 3. However, a majority of ranges fix their probe at the range's horizontal centerline as shown in Figure 4. To move point P (θ, ϕ, r) of Figure 3 to a probe that is fixed at this particular location of Figure 4, azimuth must move by θ and roll by ϕ in CW facing the origin from positives of their respective axis. This is the reason behind the convention of roll and azimuth rotation directions given in Figure 2.

Since the range's azimuth rotation plane is normally installed horizontal to the earth (perpendicular to gravitational force), θ plane of point P (θ, ϕ, r) of Figure 4 is now in this horizontal plane. As a result, x' must lie horizontal to achieve $\chi = 0^o$, and vertical to achieve $\chi = 90^o$. This does not necessarily mean that a probe must lie physically horizontal to achieve $\chi = 0^o$, and vertical to achieve $\chi = 90^o$, because probe's physical orientation depends on how x' axis lies for this particular probe. Take Open-Ended Waveguide (OEWG) probe shown in Figure 5 as an example. In this figure, x' lies along its broadside in one (a) but its narrow side in another (b). As a result, to achieve $\chi = 0^o$, a probe must align physically horizontal for a probe of coordinates (a), but physically vertical for a probe of coordinates (b). A probe coordinate is that coordinate in which the probe data, that is to be used in the SNF transformation, is calculated or measured. Therefore, a probe's coordinate is decided at the time when its probe data is produced. Note also that probe data can take different forms depending on how an SNF transformation algorithm is implemented. They can be a set of receiving coefficients, radiation patterns or E and H field expressions.

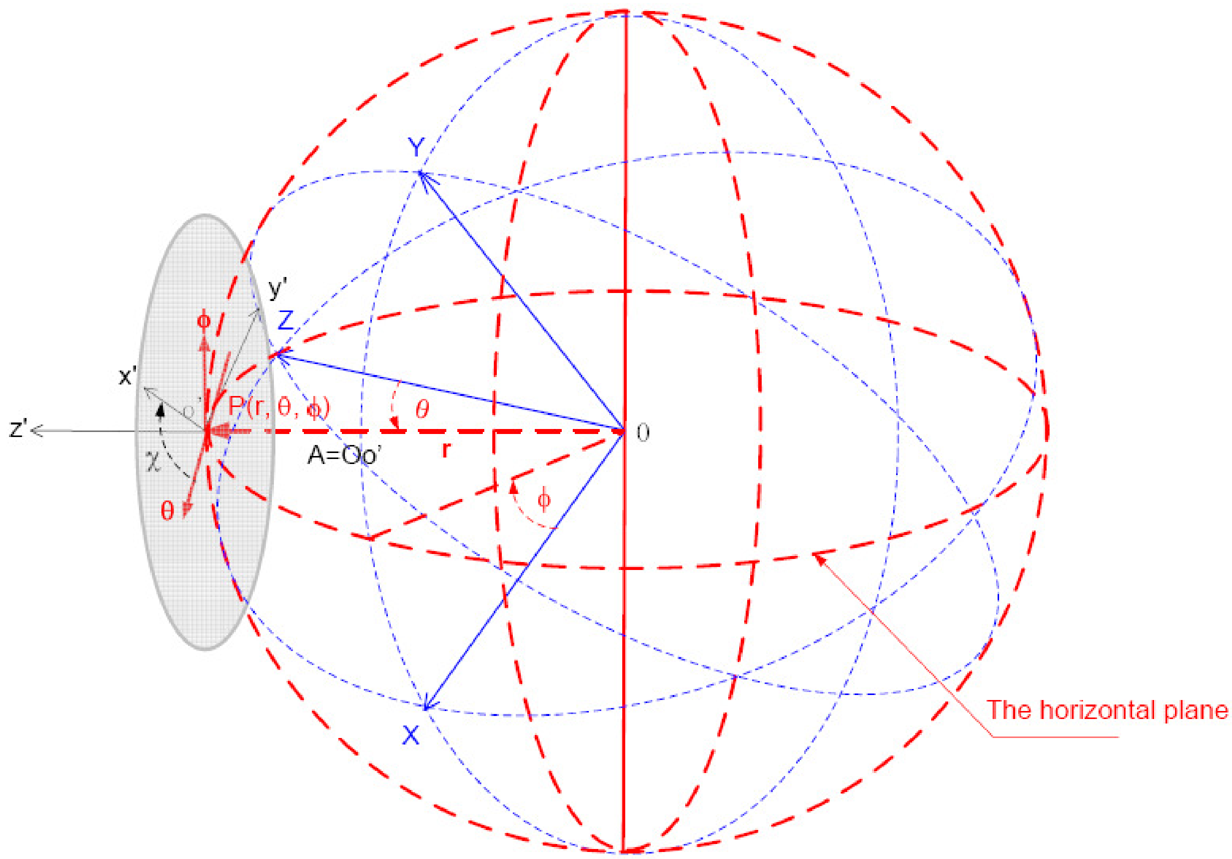

Figure 4 Most ranges fix the probe at horizontal plane centerline. The probe coordinate location P (θ, ϕ, r) has to move by θ and ϕ respectively from that of Figure 3.

Finally, one should pay close attention to the direction of axis z'. As defined in Figure 1, **z'** must align with and point in the same direction of **r**, which means that **z'** must point into the probe. However, the majority of theoretical expressions and measurement probe data are given with **z'** pointing outward. A prominent example is the OEWG theoretical model given in [2]. Its coordinates are shown in Figure 6 (a). Notice **z'** pointing outward. In this case, one must convert the probe data into the one that is expressed in coordinate of Figure 6 (b) where z' is reversed. Note that, in so doing, x' must be reversed as well to conform to Cartesian coordinate's right-hand rule.

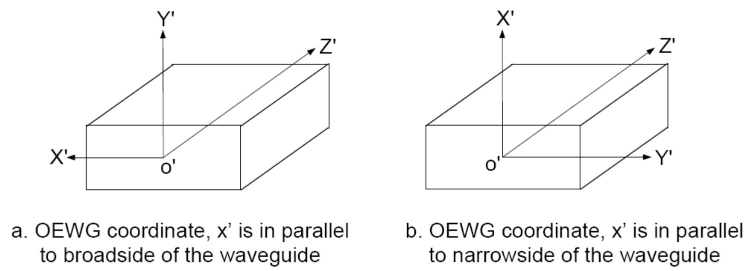

Figure 5 Same open-ended waveguide (OEWG) may be modeled in two different coordinate systems with one being x' parallel to broadside and another narrowside. Z' is chosen to point inward to conform to requirement of SNF antenna measurement convention.

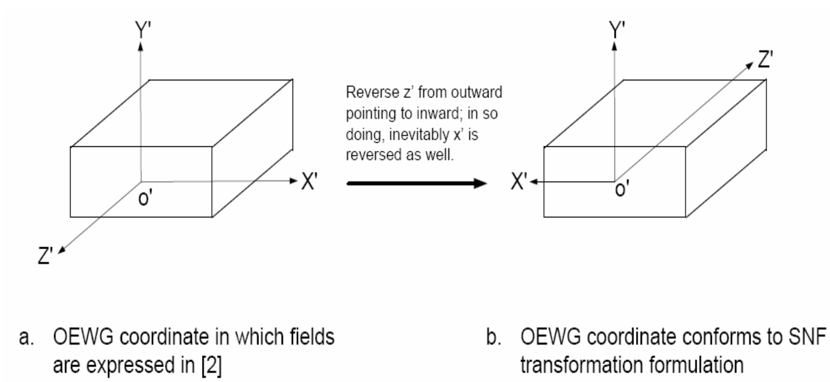

Figure 6 Reference [2] expresses OEWG fields in coordinate (a). In order to be used as probe data required by the standard SNF transformation formulation, the fields must be expressed in the coordinate of (b), where both x' and z' are reversed.

5. Interpreting SNF Output Data

There are many ways that the results from a SNF transformation can be, and have been, presented to users. One way is to output electromagnetic fields expressed in equations (A1.1) and (A1.2) given in [1].

$$\vec{E}(r,\theta,\phi) = \frac{k}{\sqrt{\eta}} \sum_{csmn} Q_{smn}^{(c)} \vec{F}_{smn}^{(c)}(r,\theta,\phi) \qquad (1)$$

$$\vec{H}(r,\theta,\phi) = -ik\sqrt{\eta} \sum_{csmn} Q_{smn}^{(c)} \vec{F}_{3-s,m,n}^{(c)}(r,\theta,\phi) \qquad (2)$$

Since visual presentation of vectors $\vec{E}$ and $\vec{H}$ can be cumbersome, outputs are often organized and presented as scalar in individual r, θ and ϕ components. They can, of course, be presented in x, y, or z components as well through some coordinate transformation. One may also choose to produce one set of output components for s = 1 and another for s = 2. In this format, one set of $\vec{E}$ and $\vec{H}$ would be TE mode while another TM mode. Depending on the components (or total sum of them) chosen for a particular data presentation, antenna patterns can appear radically different.

Further complications may arise when adding outputs that are based on the so-called input-output probe concept [1] to the family of possible presentations of SNF transformation results. Input and output probes are a pair of imaginary probes that sample the AUT's radiation at given radius r, one at the "input" and another at the "output". The purpose of this concept is to speed up computation of output data by making use of FFT and numerous time saving strategies and algorithms already in place at the time of SNF transformation. Most likely, the output data are presented in two sets: output probe's responses at $\chi = 0^o$ and $\chi = 90^o$ respectively. If a simple electrical dipole is chosen as the input-output probe pair, its response is given by equation (2.152) [1].

$$w = \frac{\sqrt{6\pi}}{2}\frac{\sqrt{\eta}}{k}E_z(0,\theta,\phi) \qquad (3)$$

This response is directly related to E field in parallel to the dipole. Further more, if the coordinate of the dipole is conformed to the probe coordinate system and the alignment convention previously defined, and properly normalized, the response at $\chi = 0^o$ will be the E-field's θ component and $\chi = 90^o$ the ϕ component.

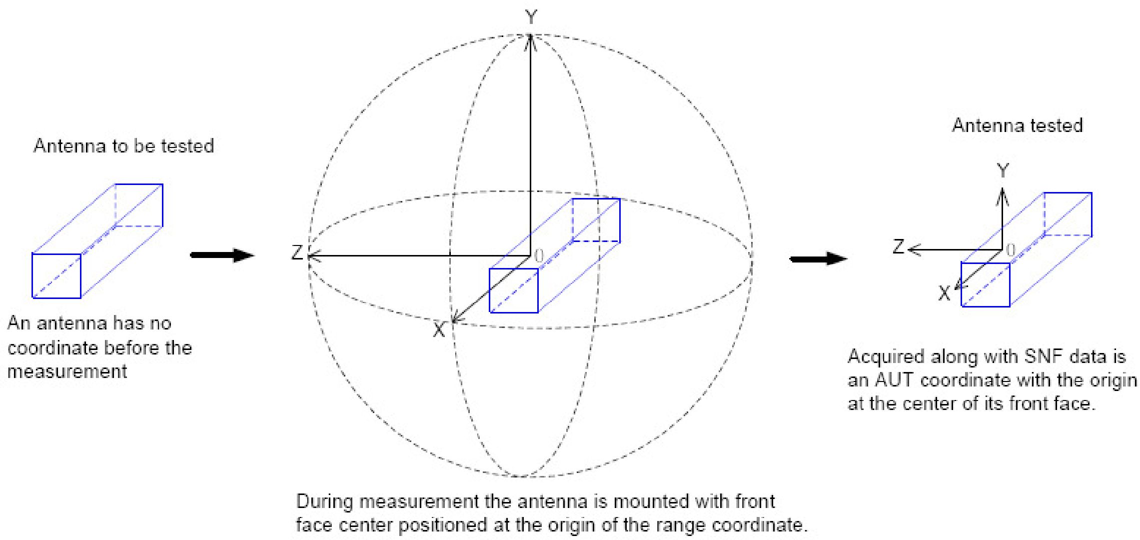

Figure 7 Antenna has no coordinates system until after SNF antenna measurement. This antenna acquires its coordinate through AUT mounting. In this case, it is mounted with the front face center at the range coordinate origin.

Finally, we stress that the spatial orientations of all outputs have been clearly and completely defined by the range coordinate system. It can be a source of confusions and ambiguities if referring to any set of outputs as being co- or cross-polarized when no spatial orientation is specified as its polarization reference. After all, co- or cross-polarization only has meaning if its reference polarization is known to the user. It is true that there exists common polarization reference systems such as the Ludwig definitions, or some may loosely designate the probe's E-field polarization as such reference. But the SNF outputs in their native forms as discussed conform to very few of them directly.

6. Mounting the AUT

Unlike a probe, the AUT possesses no predefined coordinate of its own within an SNF transformation formulation framework. An SNF antenna measurement is made and its transformation data are expressed exclusively in range coordinates. Spatial data from an AUT scan and its transformation acquired with any SNF range have little value unless range coordinates are transferred to the AUT. It is the AUT mounting that defines a spatial relationship between AUT geometry and range coordinates and is therefore the only way to enable coordinate transfer from range to AUT. Figure 7 depicts an example of such a transfer.

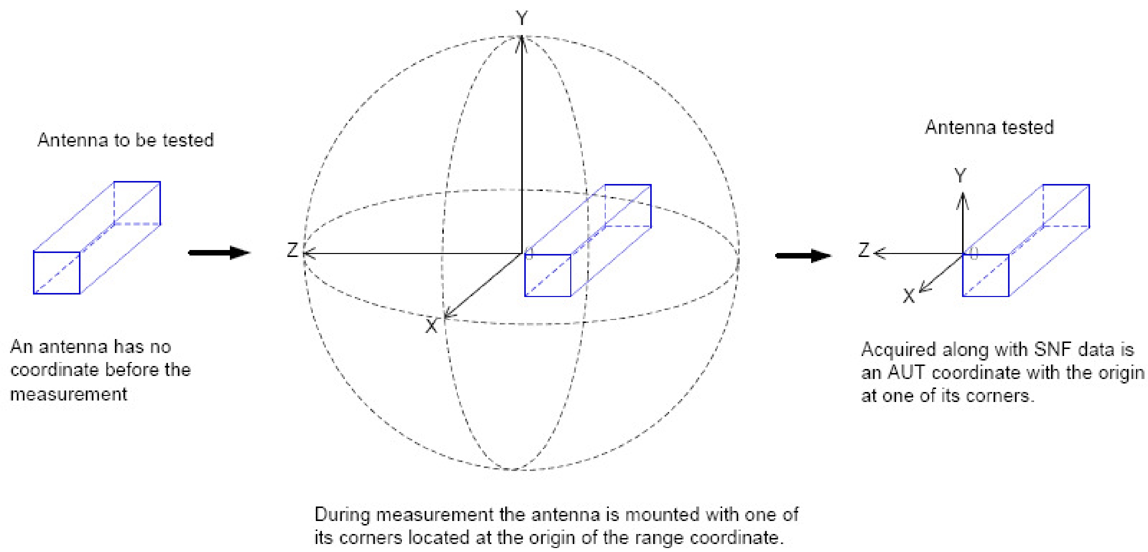

Figure 8 The antenna has no coordinate until after an SNF antenna measurement. It acquires its coordinate through AUT mounting. In this case, it is mounted with one corner at the range coordinate origin.

The above statement on AUT mounting implies that different AUT mounting leads to a different AUT coordinates. This is highlighted by comparing Figure 7 and Figure 8, where because of mounting difference, same AUT acquires different coordinates, one with its origin at the center of the front face (Figure 7) while another is at one of its corners (Figure 8).

Reference

[1] J. E. Hansen, *Spherical Near-Field Antenna Measurements*, Peter Peregrinus Ltd, 1988

[2] A. D. Yaghjian, “Approximate Formulas for the Far Field and Gain of Open-Ended Rectangular Waveguide”, IEEE Trans. AP, Vol 32, NO 4, April, 1984, pp378-384.