THE *ISOFILTER*™ * TECHNIQUE: EXTENSION TO TRANSVERSE OFFSETS

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ABSTRACT

The ***IsoFilter***™ Technique is a novel method of isolating the radiation pattern of an individual radiator from among a composite set of radiators that form a complex radiation distribution. This paper demonstrates that the technique is viable and applicable to cases where the individual radiator of interest is near the boundary of the minimum sphere that encloses the entire collection of sources.

Keywords: Spherical Near-Field Measurements, Near-Field Pattern Measurements,

1.0 Introduction

The usual type of SNF filtering provides for elimination of the effects of unwanted extraneous signals from the patterns produced by imperfect spherical near-field scanning, [1]. Spherical modal of radiating fields includes the feature that in the process of performing the SNF transform, filtering may be performed in the modal domain. It is intuitively clear that this feature can be used to suppress the effects of room reflections upon a spherical near field measurement provided that one acquires the near-field data under over-sampled conditions. In fact in the MI-3046 Software and the underlying SNIFTD Fortran code, this feature is further specialized to filter individually in the azimuthal modal index variable m, and in the polar modal index variable n!

Through the use of a special filtering algorithm the requirement that the radiating antenna of interest be located at the center of the scanning sphere can be relaxed and the filtering can be selective of a radiating antenna that is offset from the crossing point. We term this more general method The ***IsoFilter***™ Technique. It was described in a previous companion paper entitled The ***IsoFilter***™ Technique: Isolating an Individual Radiator from Spherical Near-Field Data Measured in a Contaminated Environment [2]. In that paper the case of an antenna offset along the z-axis as shown in Fig. 1, was addressed. Here we address the more general case with the antenna offset to a general location anywhere within the measurement sphere, as illustrated in Fig. 2. Both Figs. 1 and 2 are illustrated for the case of a vehicle-mounted antenna. The method is applicable to isolating any individual source of radiation from among any collection of radiating sources.

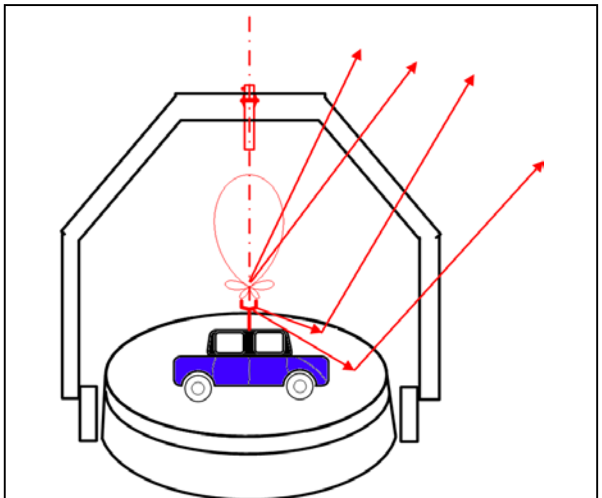

Figure 1. Schematic of Vehicle-Mounted Antenna Test with Gantry And Azimuth Turntable. Note the Offset of the Antenna Above the Ground-Plane

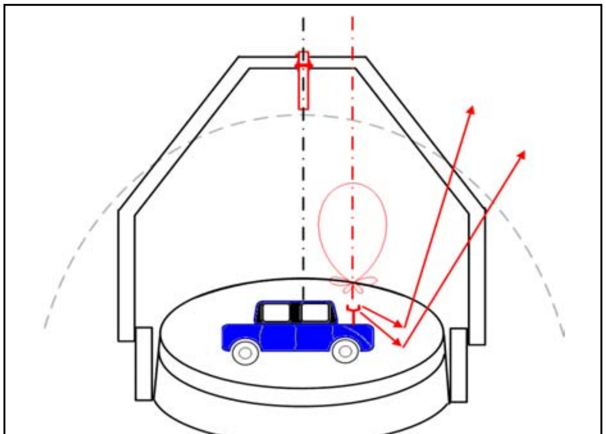

Figure 2. Schematic of Vehicle-Mounted Antenna Test with Gantry And Azimuth Turntable. Note the Offset of the Antenna from the Crossing Point of the Axes

2.1 Results of Extending the *IsoFilter*™ Technique

Fig. 3 shows a schematic of a simple radiating source and its associated radiation pattern. In typical applications, this source is an electrically small antenna in which the dimensions of the radiation structure are no larger than a few wavelengths. Such a radiating antenna will have very wide beamwidth and a lot of spillover radiation outside of its main beam.

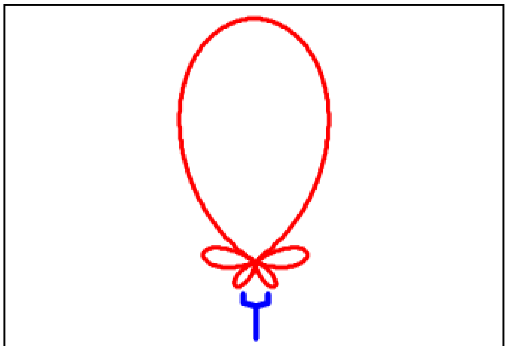

Fig. 3. Schematic of a Bare Antenna and Its Radiation Polar Diagram

Now let this antenna be mounted upon or within a large structure; an example might be a ground plane or a turntable forming a spherical near-field gantry range.. The experimental data we will analyze corresponds to this configuration. A schematic of the resulting configuration is shown in Fig. 4 below. A ground plane is often thought of as extending to infinity. Alternatively, realistic ground plane would be electrically large;and probably round in shape.

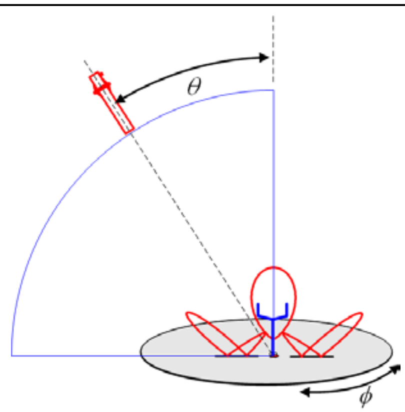

Fig. 4. Schematic of Spherical Near-Field Pattern Measurement of an Antenna Above a Ground Plane with the Influence of the Ground Plane Indicated

The presence of the ground plane and the backlobe spillover radiation combine to form additional secondary radiation caused by the induced currents. When the pattern of the antenna is measured by a probe moving on a arc surrounding the ground plane, both the radiation from the primary source and the radiation from the secondary sources will be picked up by the probe. The result will be a superposition of the two patterns. If the pattern of the primary source is broad and smooth, the pattern of the composite radiator will likely be broad with ripples caused by the interference from the induced sources. Real-world examples of the situation described above are often found in large anechoic chambers, on large outdoor ranges or underneath large transparent radome structures.

To simulate this situation we at MI Technologies set up in a small chamber a model of this configuration. A photograph is shown below in Fig. 4. A horn located 6 inches above the ground plane and offset from the center by 15 inches is shown. The diameter of the ground plane was 36 inches. The frequency of the radiation used for these tests was 8 GHz.

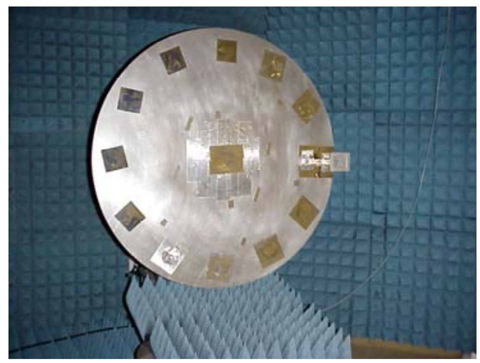

Fig. 4. Photograph of Spherical Near-Field Pattern Measurement Setup. An Offset Antenna Above a Ground Plane.

The result of the pattern measurement using the spherical near-field technique is shown in Fig. 5. The broad symmetric elevation pattern and the broad asymmetric azimuth pattern with ripples imposed by the secondary sources is immediately evident. Compare this to Fig. 6 where the same cuts are shown after applying the ***IsoFilter***™ technique and the pattern appears with the interference almost entirely eliminated.

With this test we have pushed the ***IsoFilter***™ technique to its limit, with the horn radiator near the boundary of the minimum sphere that corresponds to the sample spacing of the acquired data. There is a residual deformation of the beam in the vicinity of –30 to –20 degrees in the azimuth pattern. We are not, at present, able to account for this depletion of energy in the azimuth pattern result. However, we deem as “quite good” the ability of the method to remove the level of contamination that appears in the unfiltered azimuth cut at –80 to –70 degrees. This clearly corresponds to the specular reflection off of the ground plane interfering with the direct rays from the pyramidal horn.

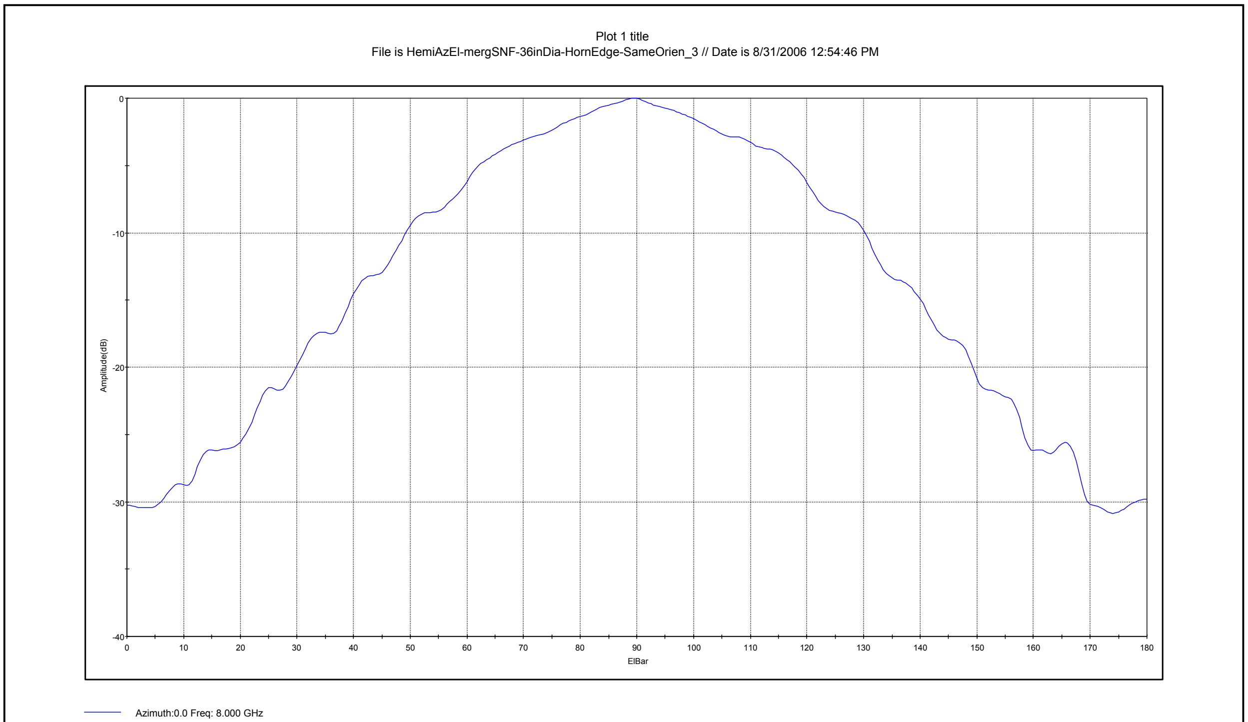

Figure 5a. Elevation Cut of Horn Mounted Near the Edge of a 36 inch Diameter Ground Plane

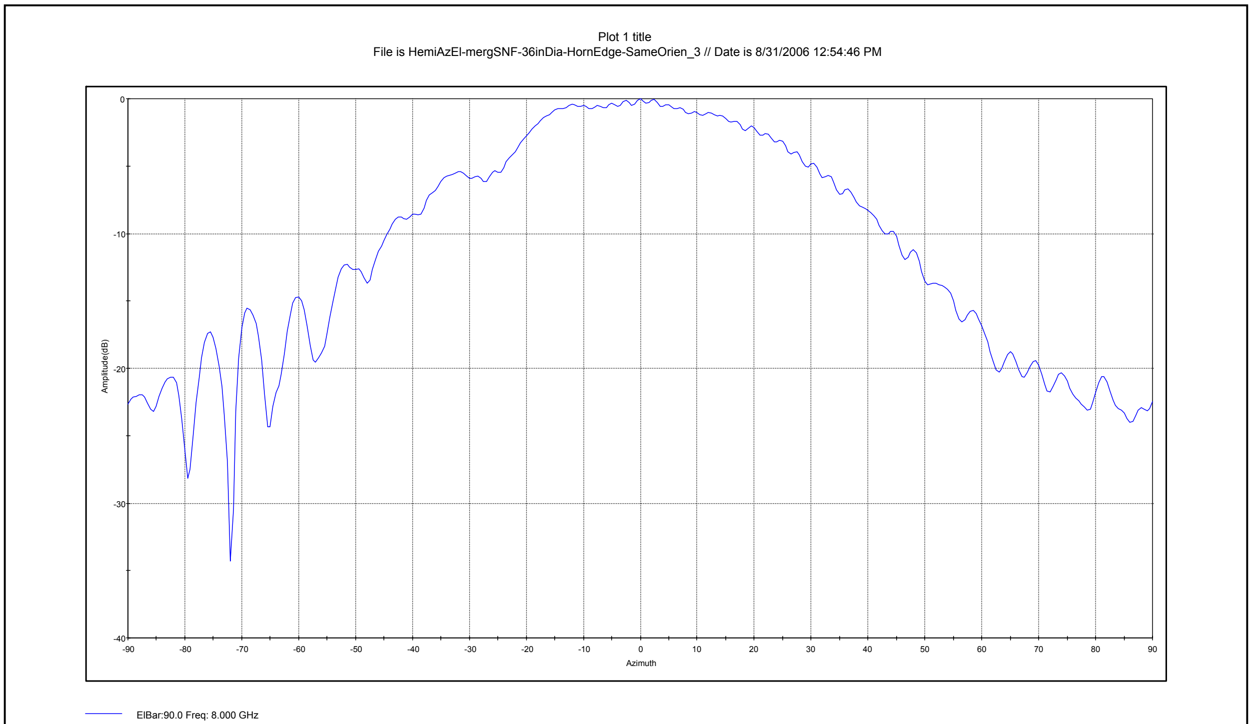

Figure 5b. Azimuth Cut of Horn Mounted Near the Edge of a 36 inch Diameter Ground Plane

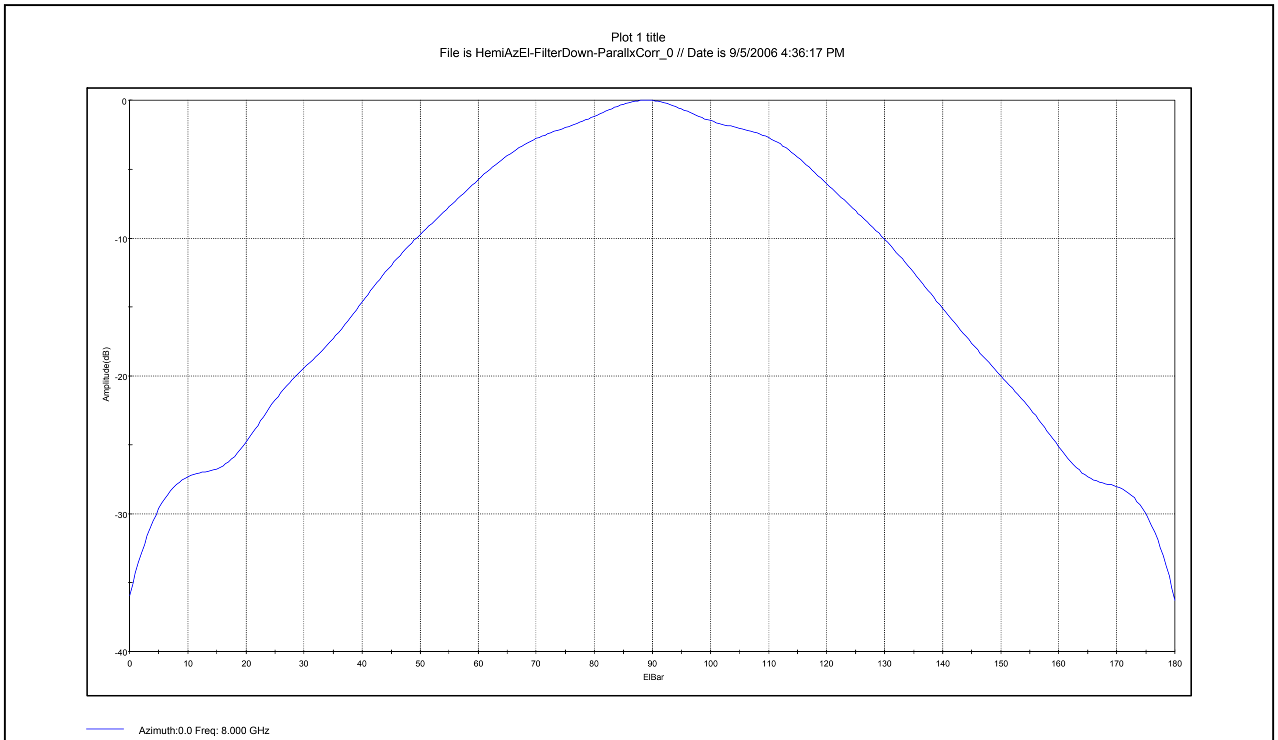

Figure 6a. ***IsoFilter***™'ed Elevation Cut of Horn Mounted Near the Edge of a 36 inch Diameter Ground Plane

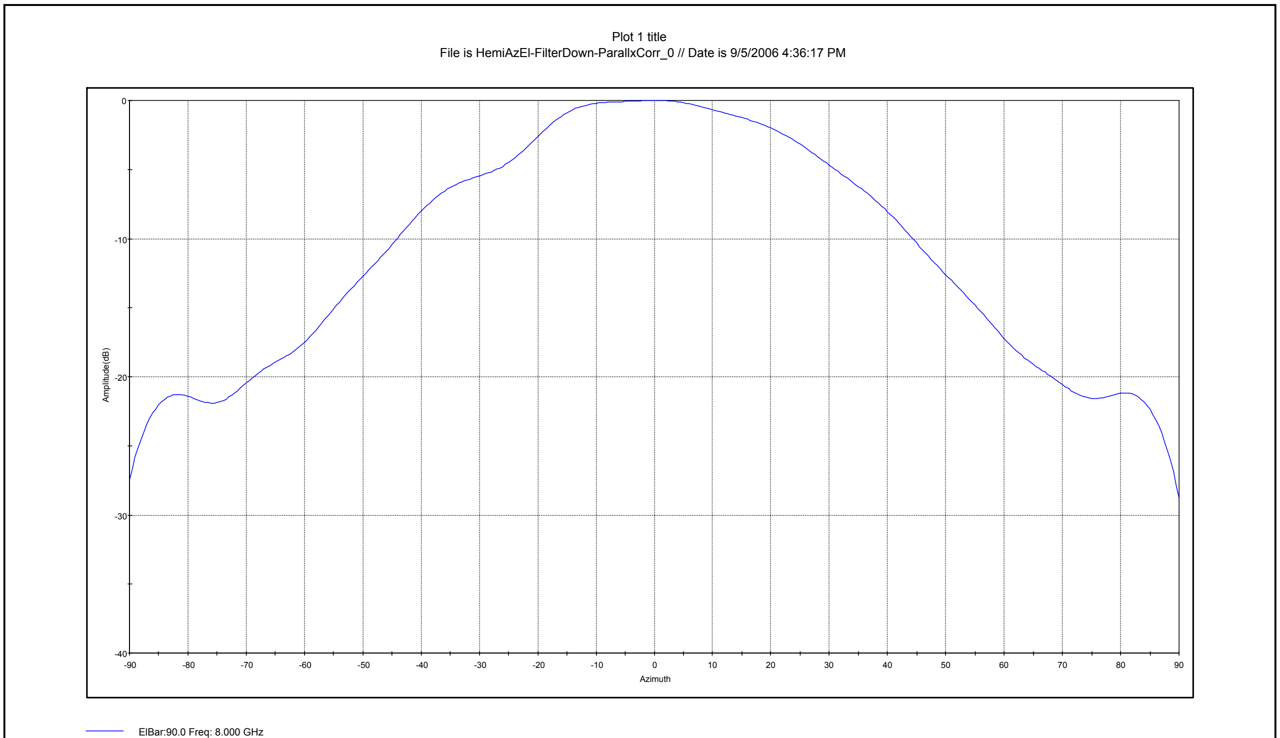

Figure 6b. ***IsoFilter***™'ed Azimuth Cut of Horn Mounted Near the Edge of a 36 inch Diameter Ground Plane

2.2 Choice of Coordinate Origin and Diameter of Minimum Sphere

To understand how the ***IsoFilter***™ technique works when extended to arbitrary displacements within the minimum sphere, and how it must be applied, consider the following schematic of Figure 7. Two different minimum spheres and their respective diameters are shown. The first is a large and inclusive sphere that encloses the entire ground plane and the offset horn. The second is a small sphere that selects only the horn aperture and it tapered section.

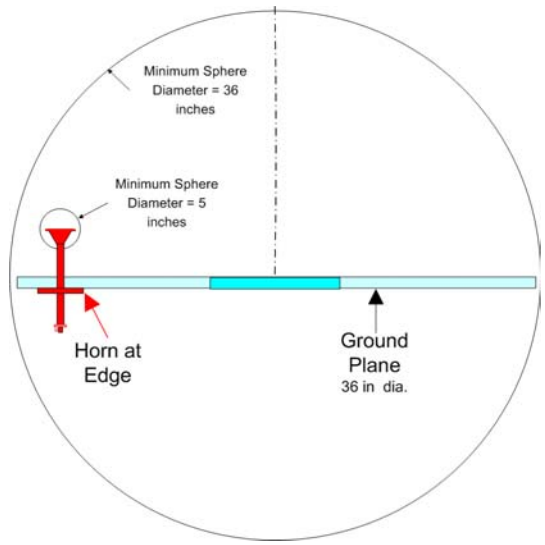

Figure 7. Large and Inclusive versus Small and Highly Selective ***IsoFilter*** Settings Described by Minimum Sphere Diameters
(Top View of 36 in Diameter Ground Plane)

These two cases are labeled a and b:

a. Entire Ground Plane and Primary Horn
   36 in Minimum Sphere Diameter
b. Horn Aperture and Tapered Section
   5 in Minimum Sphere Diameter

When the spherical near-field data was acquired, the ground plane was aligned to the coordinates defined by the roll and azimuth axes. The ground plane was centered the on roll axis of the test positioner with its surface made precisely perpendicular to the axis. The ground plane was also aligned so that its front surface contained the azimuth axis. Thus the origin of the spherical coordinate system in which the data was acquired was located at the center of the front ground plane surface.

The ***IsoFilter***™ technique allows one to place the origin of the coordinate system for the output pattern in locations other than on the front surface of the ground plane. Thus for case b above, the origin was placed at the center of the aperture of the pyramidal horn. This aperture was offset by 6 in above the surface of the ground plane and by 15 in away from the center of the ground plane. This set of sources included within the minimum sphere and thus permitted to contribute to the far-field pattern was a more restricted set than the set corresponding to case a.

To understand how the filtering process works, it is necessary to appreciate the relationship between a spherical modal sum and the minimum sphere diameter of the corresponding source of radiation.

$$\textit{Antenna Field Pattern} = \sum_{n=1}^{n_{\max}} \sum_{m=-n}^{m=n} \sum_{s=1}^{s=2} \textit{Coefficients x MODEs} \tag{1}$$

Here

$$n_{\max} \approx \frac{\pi D_{\min}}{\lambda} + 10 \tag{2}$$

The maximum modal order is limited by the diameter D_{min} of the sphere that encloses the source(es) of radiation. The key to the improvement afforded by the ***IsoFilter***™ technique is the translation of the origin from the face of the ground plane to the center of the horn aperture. This is accomplished by a mathematical computation following the SNF transform to the far field for the full composite radiator and before applying the modal filter in the spherical coefficient domain.

To test the use of the ***IsoFilter***™ technique, we first ran three cases that corresponded to the horn mounted at the center of the ground plane. These cases were described in a previous paper [2]. Here we show the results extended to the case of the offset location of the horn, when it is mounted near the edge of the ground plane.

2.3 Comparison of Suppression of Reflections with the *IsoFilter*™ Technique to Absorber

As a baseline measurement, with the horn centered on the ground plane and the ground plane covered with 5 in absorber, a measurement was made of the "bare" horn and compared to the ***IsoFilter***™ result. Figure 8 shows a photograph of this "bare horn" configuration. Fig. 9 shows overlaid patterns of the offset horn compared to the "bare horn."

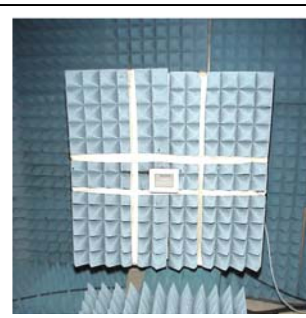

Fig. 8. Horn Mounted AboveAbsorber

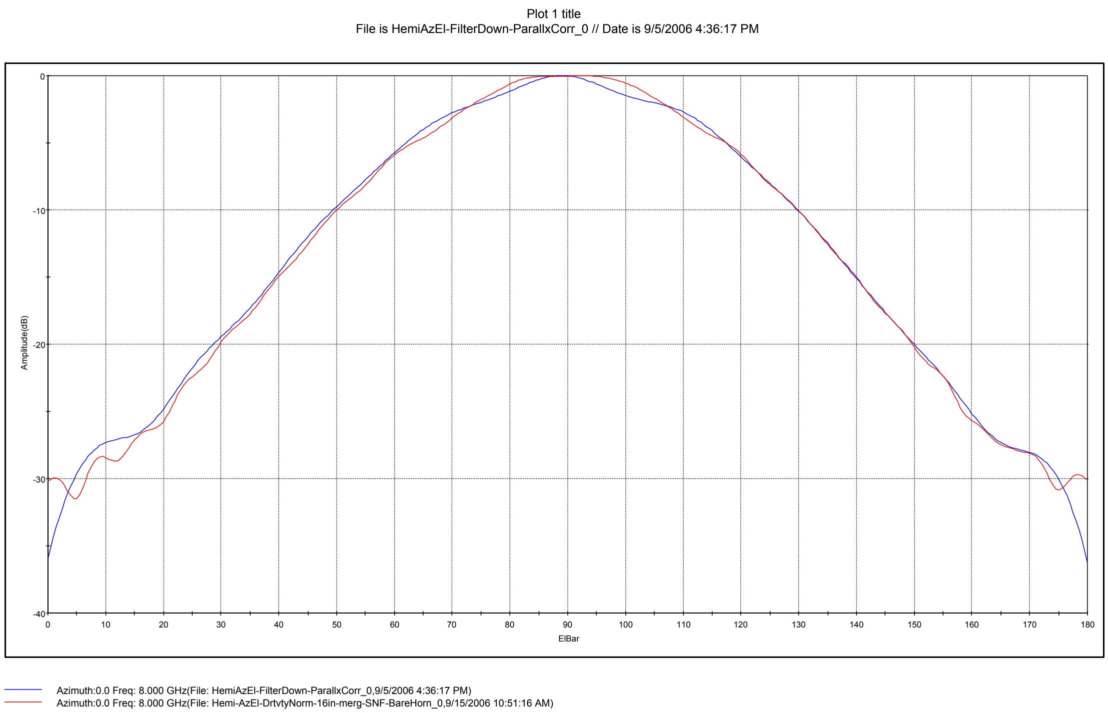

Figure 9a. ***IsoFilter***™'’ed Elevation Cut of Horn Mounted Near the Edge of a 36 inch Diameter Ground Plane
versus
Centered Horn Mounted with Absorber Covering the Ground Plane.

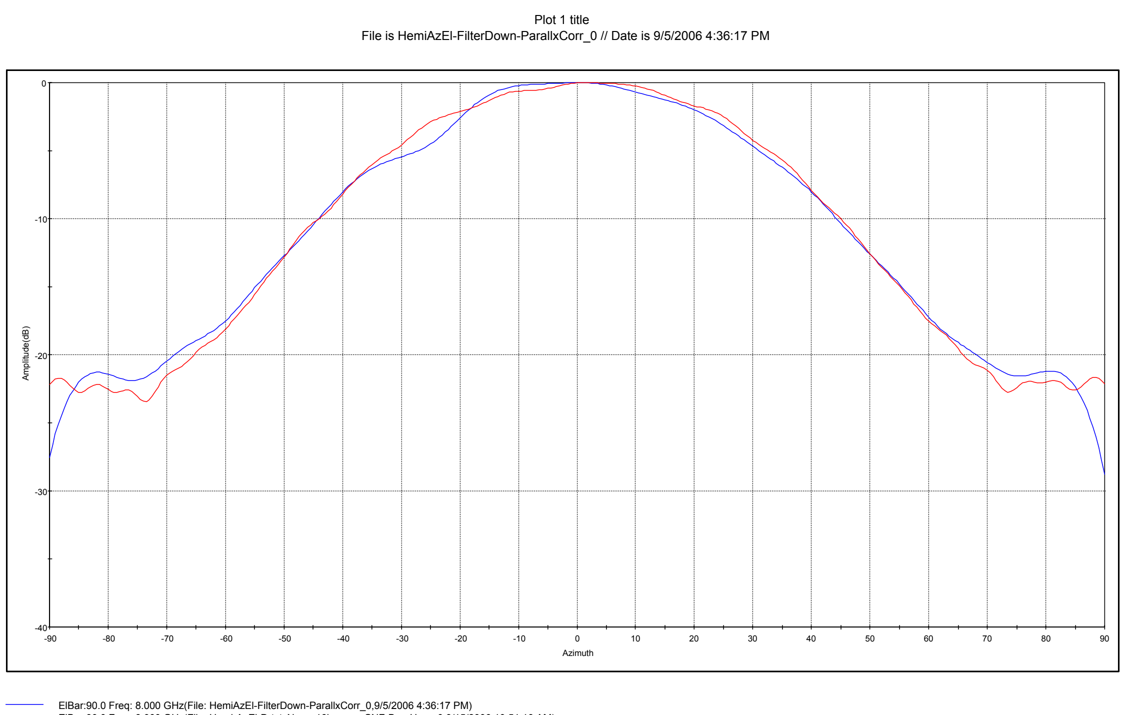

Figure 9b. ***IsoFilter***™'’ed Azimuth Cut of Horn Mounted Near the Edge of a 36 inch Diameter Ground Plane
versus
Centered Horn Mounted with Absorber Covering the Ground Plane.

Examining the patterns of Fig. 9, one can see that the peak-peak ripple is on the order of 8 dB at a pattern level of –20 dB. This corresponds to an equivalent stray signal from the ground plane of –20 –14 ≈ -34 dB that is virtually eliminated from the pattern. The absorber performs equivalently. Three-inch absorber at 8 GHz has a reflectivity rating of approximately 35 dB. Thus the ***IsoFilter***™ technique which appears to be equivalently as good, can therefore be said to have suppressed the reflections off the ground plane as well as 35 dB absorber. Another way of analyzing this result is to observe that the pattern discrepancy in Fig. 9b at -25° off axis, is approximately 1.5 dB at a level of –4 dB. This corresponds to an equivalent stray signal level of –4 dB – 20 dB ≈ -24 dB. Thus the ***IsoFilter***™ technique eliminated stray signals down to –24 dB. The difference between these two numerical results is due simply to the method of analysis.

3.0 Method of Translating the Origin of the Coordinate System Computationally

The method by which the coordinate origin is translated is based upon a very general theorem well known to all who have studied electromagnetics: In the asymptotic limit as the distance from a source of radiation becomes infinite, the far electric and magnetic fields separate into a product of a simple scalar function of the distance r and a vector function of direction:

$$\lim_{r \to \infty} \vec{E}(r,\theta,\phi) \;\to\; \frac{e^{ikr}}{kr}\vec{F}(\theta,\phi) \qquad (3)$$

The SNF transform yields the quantity $\vec{F}(\theta,\phi)$, which is not modified by a shift of coordinate origin. Furthermore, in the limit the amplitude factor $1/kr$ is not changed either. If we want to find the far electric field in a coordinate system that is shifted to another origin designated by a vector $\vec{r}_0$ we have only to modify the phase factor. Please see Fig. 10. The difference in the distance to the far-field sphere from the measurement origin as compared to the translated origin is simply

$$R^{FF} - R^{FF'} = d_0\cos\theta + \rho_0\sin\theta\cos(\phi-\phi_0) \qquad (4)$$

If we substitute from this equation (4) into (3) above, making use of the relations

$$\theta' = \theta \qquad \phi' = \phi \qquad (5)$$

we find we can write, in the translated coordinate system that

$$\lim_{r' \to \infty} \vec{E}(r',\theta',\phi') \;\to\; \frac{e^{ikr'}}{kr'}\vec{F}\,'(\theta',\phi') \qquad (6)$$

where

$$\vec{F}'(\theta',\phi') = e^{ik(d_0\cos\theta+\rho_0\sin\theta\cos(\phi-\phi_0))}\vec{F}(\theta',\phi') \qquad (7)$$

To accomplish the translation, we simply modify the phase of each point in the far electric field by the amount corresponding to the distance appropriate for the angle θ at which that point lies.

$$\varphi^{FF\,'} = \varphi^{FF} + d_0\cos\theta + \rho_0\sin\theta\cos(\phi-\phi_0) \qquad (8)$$

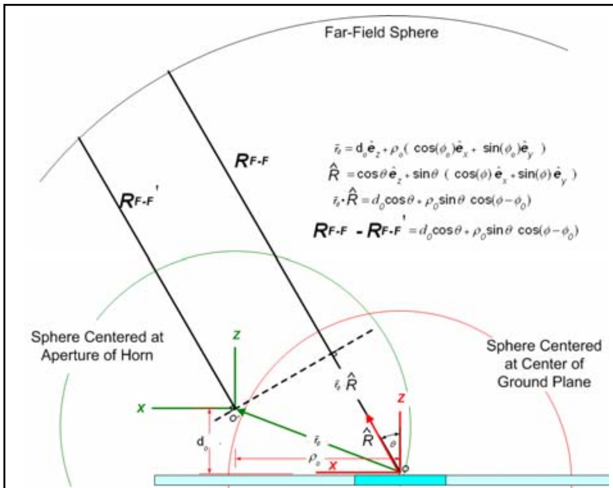

Fig. 10. Schematic Illustrating Difference in Distance to Far-Field Spherical Surface from Origins of Coordinate Systems Located at Center of Ground Plane and Center of Horn Aperture Plan View from Above

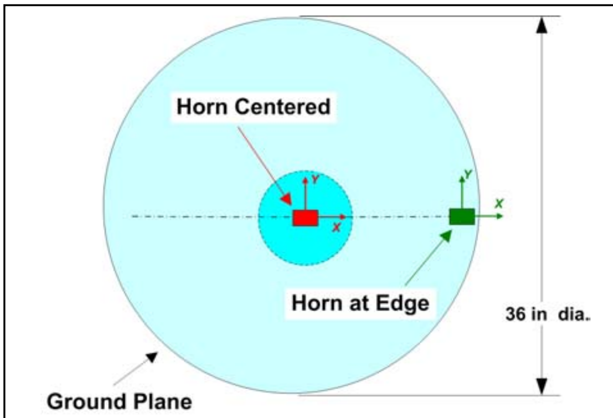

Fig. 11. Schematic Illustrating Difference in Locations of the Pyramidal when Centered and when Located at the Edge of the Ground Plane. Front View, Along the Roll Axis, of Ground Plane

This adjustment of the data led to the results in Fig. 6.

The quantities d_0, ρ_0, ϕ_0, in equation 8 specify the location of the horn upon the circular ground plane in cylindrical coordinates: d_0 is the height of the aperture above the ground plane surface along the z-axis; ρ_0 is the distance of the aperture from the axis of the ground plane which is coincident with the roll axis of the test positioner and ϕ_0 is the angle of the horn aperture location measured from the x-axis of the positioner's coordinate system. Please see Fig. 10. For the case discussed here, d_0=6 inches, ρ_0=15 inches, ϕ_0= 0 degrees.

In performing the translation of centers, it is necessary to respect the requirement for making the sample spacing consistent with the dimension of the minimum sphere in the translated coordinate system. In the natural coordinate system in which the data is acquired, the SNF theory requires that sample spacing be such that $\Delta\theta$ & $\Delta\phi < \lambda/D_{min}$, where λ/D_{min} radians corresponds to the Nyquist sampling interval. However in the case of the translated origin, in which the radius becomes as large as D_{min}, the corresponding Nyquist sample spacing is reduced to $\frac{1}{2}(\lambda/D_{min})$. In the original natural coordinate system, this would appear to be a case of over-sampling !

The algorithm for the ***IsoFilter***™ technique, then follows:

1. Acquire a SNF data set, sampled at the Nyquist spacing -- covering most of a spherical surface surrounding the composite antenna, then transform to the far field. The sample spacing upon output must be consistent with the λ/D_{min} rule in the translated coordinates, implying a smaller Nyquist sample.
2. Adjust the phase of the far field to effect a translation of the origin to the location of a radiator of interest.
3. Filter the translated field to a minimum sphere diameter consistent with the electrical size individual radiator.

3.0 Summary The *IsoFilter*™ Technique

Over the past several months, we have developed a filtering technique that provides for suppression and elimination of the effects of unwanted extraneous signals from the patterns produced in spherical near-field scanning. . It is a straightforward extension of the usual spherical modal domain filtering.

With this technique, we have demonstrated that a radiating-source of the composite antenna can be selected for computation of its individual far field from among the entire set of participating sources. Rather than computing the far field of the radiating composite antenna defined by a volume centered upon the crossing point of the positioner axes, we have found that we can center the spherical volume on the antenna, making the filtering process selective of the antenna alone. We have found that from the near-field pattern of the composite antenna we are able to recover to a close approximation, the pattern of the individual antenna alone. The composite antenna consisted of the primary radiating source plus induced sources. In this case these induced sources were comprised of currents induced on the conducting ground plane by the spillover radiation of the primary radiator.

In practical applications the measurement of a horn mounted above a ground plane is analogous to the case one would have when measuring an antenna mounted on the roof of a vehicle using a gantry-over-turntable positioning system, [2], [3]. The antenna is offset above the ground plane. The special ***IsoFilter***™ software isolates the antenna and its immediate environment to compute the pattern of the antenna alone, filtering out the effects of the more distance portions of the vehicle and the turntable itself. Iterated pattern results can assist a user in determining from measurements just what portion of a vehicle is contributing to the pattern.

4. REFERENCES

[1] J.E. Hansen, Editor, Spherical Near-Field Antenna Measurements, Peter Peregrinus Press, London, UK, 1988.

[2] D.W. Hess, The ***IsoFilter***™ Technique: Isolating an Individual Radiator from Spherical Near-Field Data Measured in a Contaminated Environment, Post-Deadline Paper, AMTA 2006, Austin TX. Following AMTA 2006 it will be posted on the MI Technologies web site at http://www.mi-technologies.com/.

[3] D.W. Hess, D.G. Bodnar, Ground Plane Simulation and Spherical Near-Field Scanning for Telematic Antenna Testing, AMTA Symposium 2004 Digest, Antenna Measurement Techniques Assn., October 2004, Atlanta, Georgia, USA.

5. ACKNOWLEDGMENT

The author wishes to acknowledge helpful discussions with Mr. Jeff Fordham.

6. FOOTNOTES

*The term ***IsoFilter***™ is a trademark of MI Technologies.

*Application for patent protection has been made, covering the aspects of the ***IsoFilter***™ technique described here.