The *IsoFilter*™ Technique: A Method of Isolating the Pattern of an Individual Radiator from Data Measured in a Contaminated Environment

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Abstract— **This paper describes a novel method, termed the *Isofilter*™ Technique, of isolating in the measured data the radiation pattern of an individual radiator from among a composite set of radiators that form a complex radiation distribution. This technique proceeds via three successive steps: A spherical NFFF transform on an over-sampled data set, followed by a change of coordinate system followed in turn by filtering in the domain of the spherical modes to isolate a radiating source. The end result is to yield an approximate pattern of the individual radiator largely uncontaminated by the other competing sources of radiation.**

I. 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 analysis 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 a typical spherical near-field software code set, (for example MI Technologies, MI-3046 Software and the underlying TICRA 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. However, employing this feature has several provisos associated with it:

(a) The sources of secondary reflection to be suppressed must be such that there is an upper limit upon the number of spherical modes needed to represent the contaminated data set. Otherwise some of the contamination will be aliased into the desired set of modal coefficients.

(b) Probe scanning data must be over-sampled typically by an over-sampling factor of 2, or so above what the sampling theorem by itself would require. This will approximately double the amount of time required to accumulate the probe scan data set(s).

(c) Desirably, the antenna-under-test should be located near the crossing point of the polar and azimuthal axes of the scanning positioner.

Through the use of a special filtering algorithm this third requirement (c) 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.

II. The *IsoFilter*™ Technique

Recently, 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. The three successive steps in this method are first to over-sample in the scanning data domain and transform to the far field, then to effect a translation of the coordinate origin, and lastly to filter in the domain of the spherical modal coefficients as the far-field pattern is re-computed. It is a straightforward extension of the usual spherical modal domain filtering.

With this technique, we are able to demonstrate 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. To understand more specifically please refer to the next Section.

An Antenna and Reflections from a Ground Plane

Fig. 1 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.

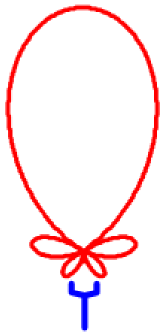

Fig. 1 Schematic of a Bare Antenna and Its Radiation Polar Diagram

Now let this antenna be mounted upon or within a large structure; an example might be a ground plane designed for siting purposes. The experimental data we will analyze corresponds to this configuration. A schematic of the resulting configuration is shown in Fig. 2 below. A ground plane is often thought of as extending to infinity. Alternatively, realistic ground plane would be electrically large; they might be rectangular or round in shape.

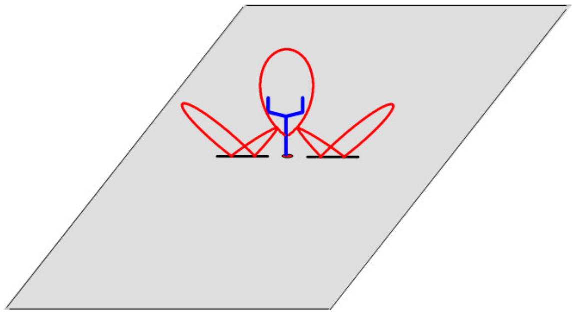

Fig. 2 Schematic of a Bare Antenna and a Ground Plane

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 spherical near-field 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. Please see Fig. 3. 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 cause by the interference from the induced sources.

Often, real-world cases in which the situation described above exists, are realized in large anechoic chambers, on large outdoor ranges or underneath large transparent radome structures.

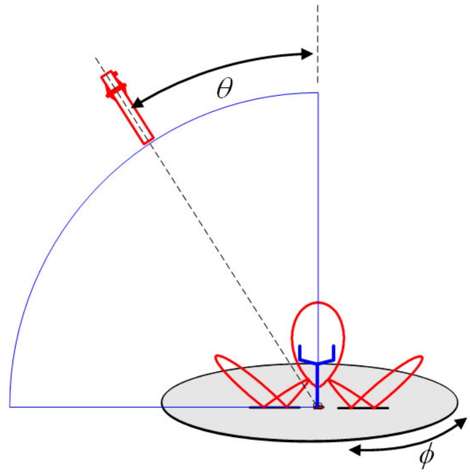

Fig. 3 Schematic of Spherical Near-Field Pattern Measurement of an Antenna Above a Ground Plane with the Influence of the Ground Plane Indicated

Simulation of Ground Plane Effects

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 centered 6 inches above the ground plane is shown. The diameter of the ground plane was 36 inches. The frequency of the radiation used for these tests was 8 GHz.

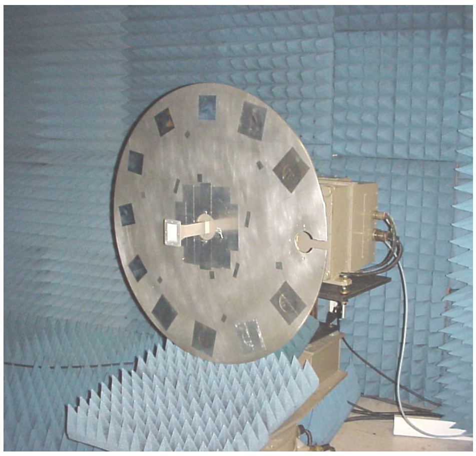

Fig. 4 Photograph of Spherical Near-Field Pattern Measurement Range with a Pyramidal Horn Antenna Above a Ground Plane

Result of Applying the Isofilter™ Technique

The result of the pattern measurement using the spherical near-field technique is shown in Figs. 5,6. The broad symmetric pattern with ripples imposed by the secondary sources is immediately evident. Compare this to Figs. 7,8 where the same cuts are shown after applying the ***IsoFilter***™ technique and the pattern appears with the interference eliminated.

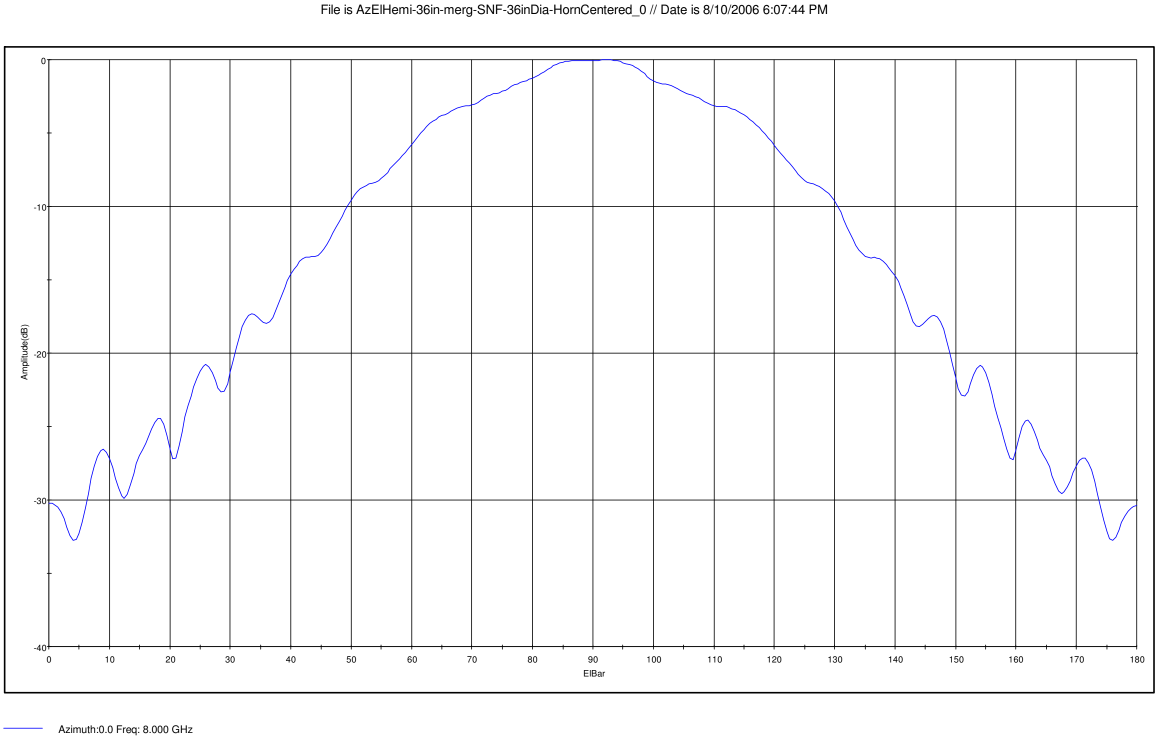

Fig. 5 Elevation Cut of Horn Mounted Above a 36 inch Diameter Ground Plane

Vertical Scale: 40 dB ; Horizontal Scale: 0 - 180 degrees

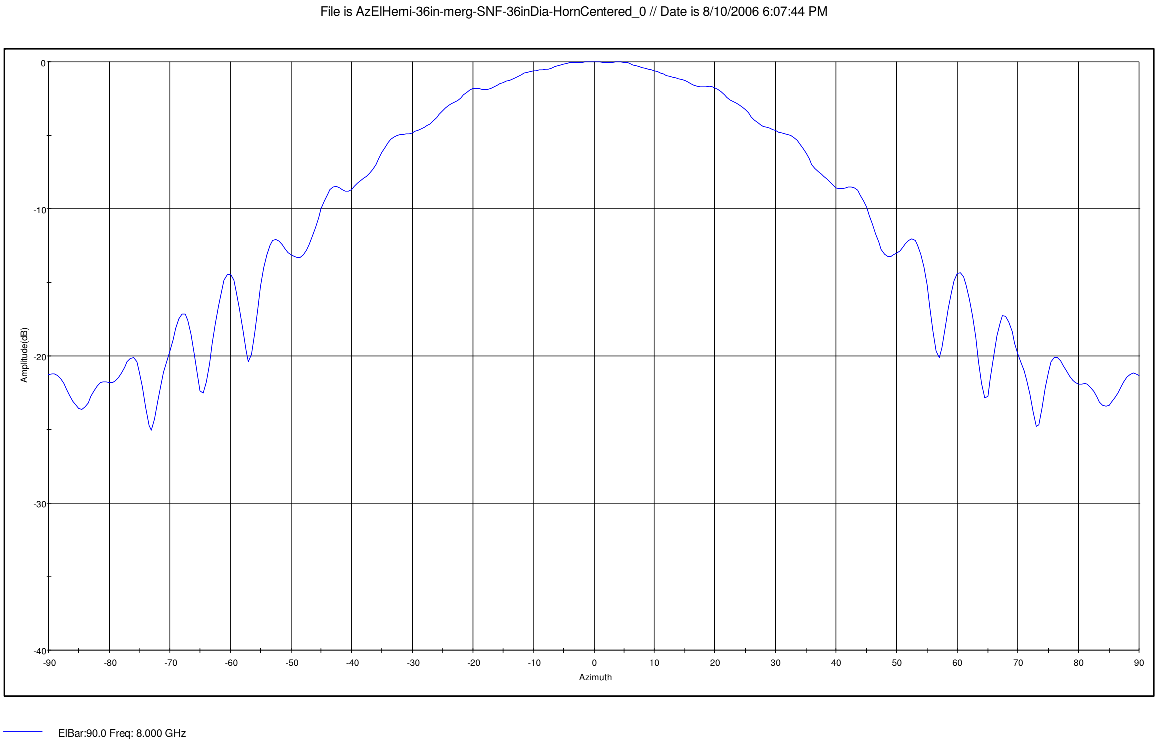

Fig. 6 Azimuth Cut of Horn Mounted Above a 36 inch Diameter Ground Plane

Vertical Scale: 40 dB ; Horizontal Scale: +/- 90 degrees

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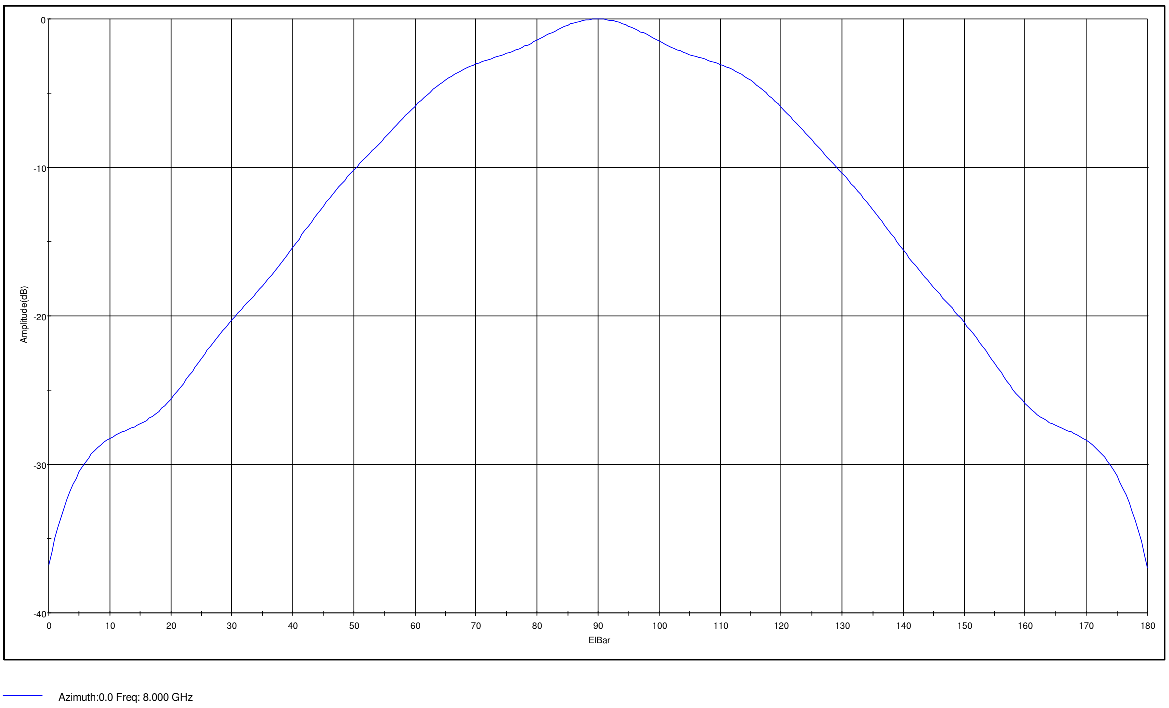

Fig. 7 Elevation Cut Following Application of ***IsoFilter***™ of Horn Mounted Above a 36 inch Diameter Ground Plane

Vertical Scale: 40 dB ; Horizontal Scale: 0 - 180 degrees

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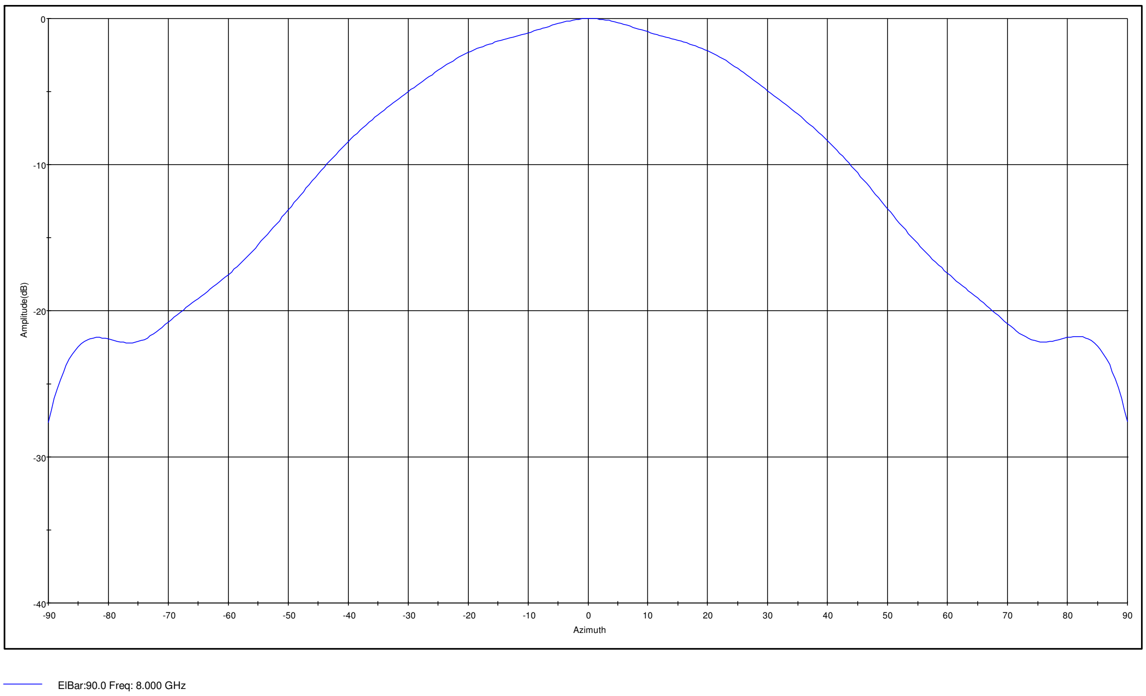

Fig. 8 Azimuth Cut Following Application of ***IsoFilter***™ of Horn Mounted Above a 36 inch Diameter Ground Plan

Vertical Scale: 40 dB ; Horizontal Scale: +/- 90 degrees

Choice of Coordinate Origin and Diameter of Minimum Sphere

To understand yet more specifically how the ***IsoFilter***^{TM} technique works and how it must be applied, consider the following schematic of Figure 9. Three different minimum spheres and their respective diameters are shown:

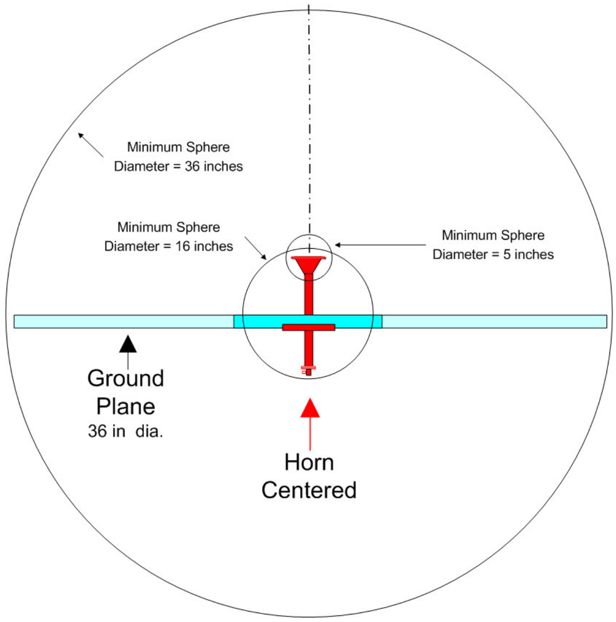

Fig. 9 Photograph of Spherical Near-Field Pattern Measurement Range with a Pyramidal Horn Antenna Above a Ground Plane (Top View of 36 in Diameter Ground Plane)

Three different minimum spheres and their respective diameters are shown:

a. Entire Ground Plane and Primary Horn 36 inches Minimum Sphere Diameter

b. Primary Horn Plus Nearby Ground Plane Surface 16 inches Minimum Sphere Diameter

c. Horn Aperture and Tapered Section 5 inches Minimum Sphere Diameter

When the spherical near-field data was acquired the ground plane and the centered horn were aligned to the coordinates defined by the roll and azimuth axes. The ground plane was centered 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***^{TM} 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 c above, the origin was placed at the center of the aperture of the pyramidal horn. This permitted only the set of sources, allowed by inclusion within the 5 in minimum sphere to contribute to the far-field, The pattern of case c was a more restricted set of radiating sources than the set corresponding to case b.

It is necessary to appreciate the relationship between a spherical modal sum and the minimum sphere diameter of the correspond source of radiation.

Antenna Field Pattern =

$$= \sum_{n=1}^{n_{max}} \sum_{m=-n}^{n} \sum_{s=1,2} \textit{Coefficients x MODES} \quad (1)$$

Here, $$n_{max} = \frac{\pi D_{\min}}{\lambda} + 10 \quad (2)$$

The maximum modal order is limited by the diameter of the sphere that encloses the source(es) of radiation.

To test the use of filtering we ran the three cases that correspond to the three spheres indicated in Figure 9 – Cases a, b and c. The elevation and azimuth cuts corresponding to these three cases are overlaid in Figures 11 and 12. It is quite evident there that in case b there is hardly any improvement in suppression of the reflected signals over case a ! Good improvement appears in case c, for the smallest sphere.

The key to the improvement afforded by the ***IsoFilter***^{TM} 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. See Section 3.

Comparison of Suppression of Reflections with the Isofilter^{TM} *Technique to Absorber*

As a baseline measurement, with the horn centered on the ground plane and the ground covered with 5 in absorber, a measurement was made of the "bare" horn and compared to the result obtained with ***IsoFilter***^{TM}. Please see the photo of Fig. 10 and the comparisons of Figs. 13 & 14.

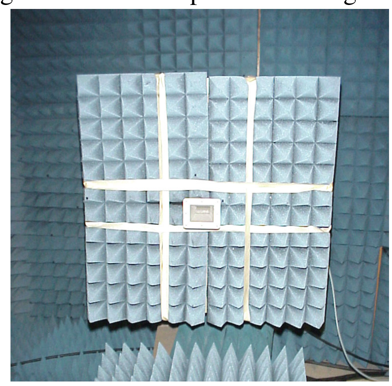

Fig. 10 Photograph of Horn Mounted Above a Panel of Absorber

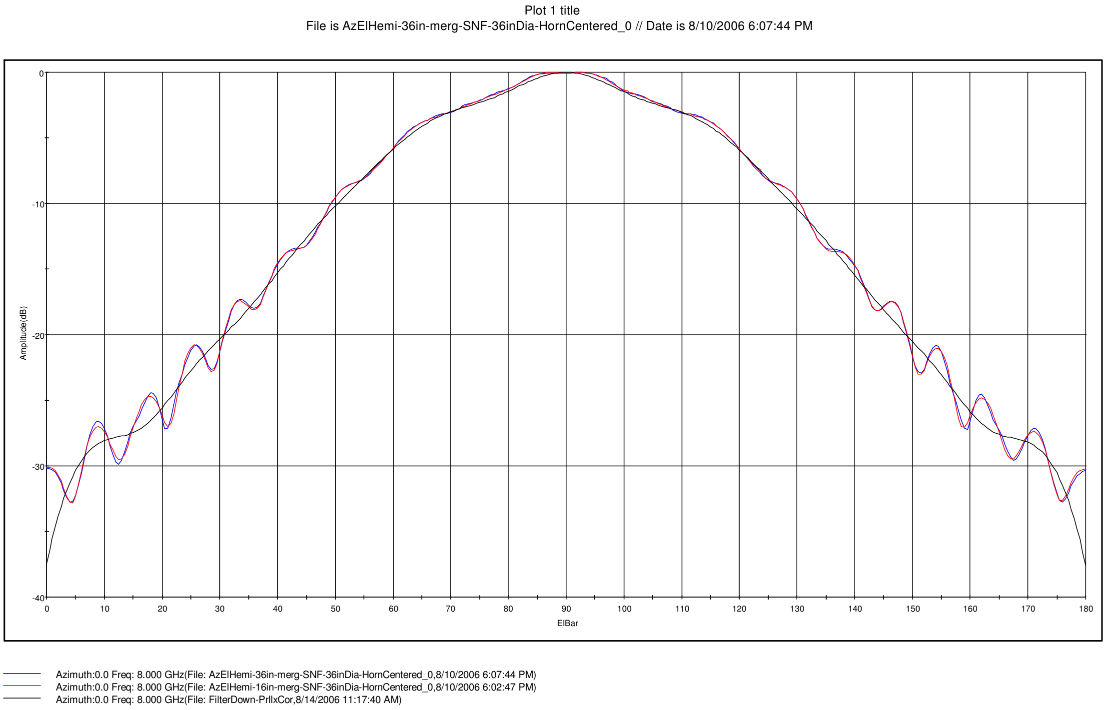

Fig. 11. Comparison of Elevation Cut of Horn Mounted Above a 36 inch Diameter Ground Plane Following Application of ***IsoFilter***™ versus Unfiltered 36 inch Diameter Sphere and Standard Sphere Filtered at 16 inch Diameter

Vertical Scale: 40 dB ; Horizontal Scale: 0 - 180 degrees

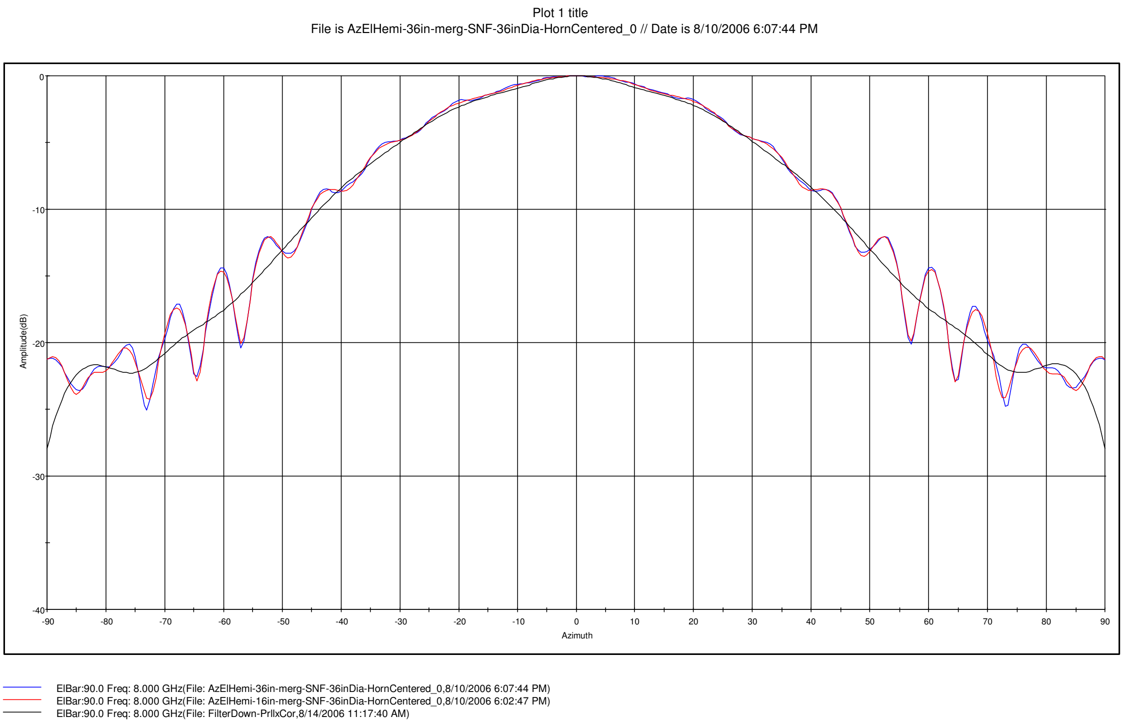

Fig. 12. Comparison of Azimuth Cut of Horn Mounted Above a 36 inch Diameter Ground Plane Following Application of ***IsoFilter***™ versus Unfiltered 36 inch Diameter Sphere and Standard Sphere Filtered at 16 inch Diameter

Vertical Scale: 40 dB ; Horizontal Scale: +/- 90 degrees

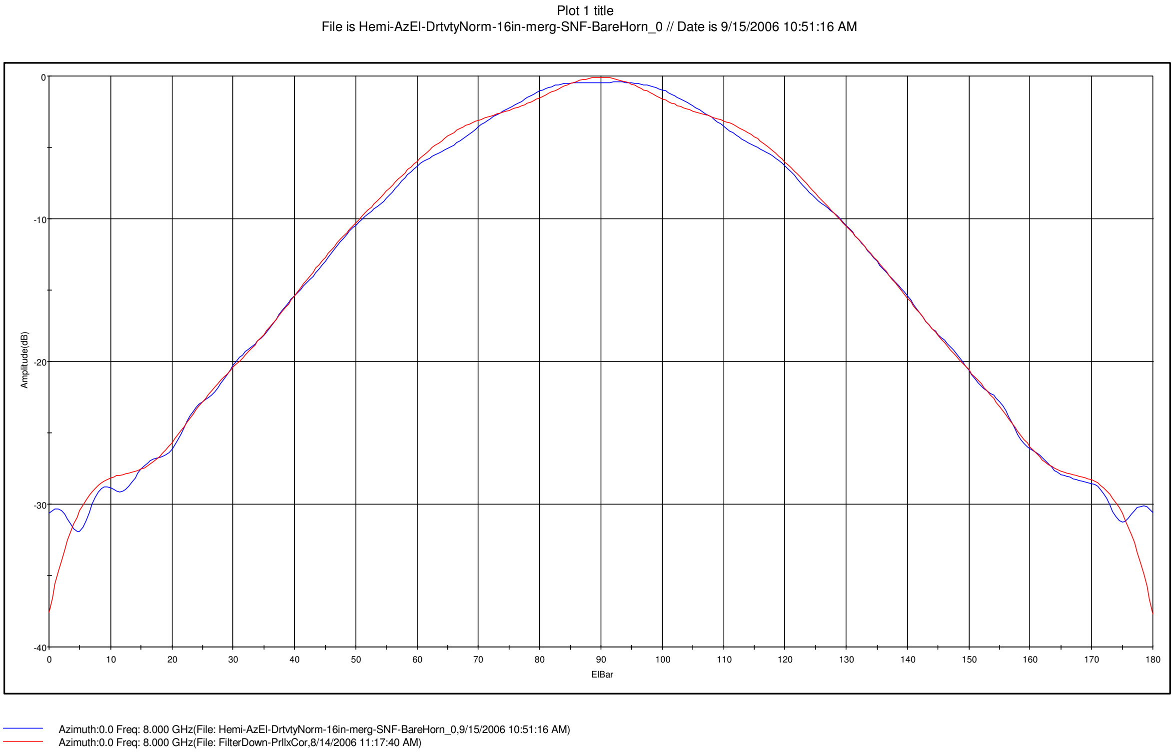

Fig. 13. Elevation Cut Following Application of ***IsoFilter***™ for the Horn Mounted Above a 36 inch Diameter Ground Plane versus Horn Mounted Above a 24 inch Square of Absorber and Conventionally Filtered to a Sphere of 16 inch Diameter

Vertical Scale: 40 dB ; Horizontal Scale: 0 - 180 degrees

Fig. 14. Azimuth Cut Following Application of ***IsoFilter***™ for the Horn Mounted Above a 36 inch Diameter Ground Plane versus Horn Mounted Above a 24 inch Square of Absorber and Conventionally Filtered to a Sphere of 16 inch Diameter

Vertical Scale: 40 dB ; Horizontal Scale: +/- 90 degrees

Comparing the azimuth patterns of Figs. 6 and 8, one can see that the peak-to-peak ripple in Fig 6 is on the order of 5 dB at a pattern level of –20 dB. This corresponds to an equivalent stray signal from the ground plane of –20 –16 ≈ -36 dB that is virtually eliminated from the pattern of Fig. 8. The absorber performs equivalently. Three inch absorber at 8 GHz has a reflectivity rating of approximately 35 dB. Thus the ***IsoFilter***^{TM} technique, which appears to be equivalently as good, therefore can 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. 10 at ~ 80° off axis, is approximately ± 1 dB at a level of –22 dB to –28 dB. This corresponds to an equivalent stray signal level of (–25 dB) + (–25 dB) ≈ -50 dB. Thus the ***IsoFilter***^{TM} technique reduced the stray signal from -36 dB down to –50 dB, or by approximaely 15 dB. The difference between these two numerical results is due simply to the different methods of analysis.

III. 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 the time-harmonic domain of electromagnetics: In the asymptotic limit as the distance from a source of radiation becomes infinite, the far electric (and magnetic) fields each separate into a product of a simple scalar function of the distance r and a vector function of the direction angles θ & φ:

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

The SNF transform yields the quantity $\vec{F}(\theta,\phi)$. In the limit, the amplitude factor (1/kr) is unaffected by the shift of the coordinate origin. For example, if we want to find the far electric field in a coordinate system that is shifted along the z-axis by a distance d_0 we have only to modify the phase factor. Please see Fig. 15. (The general case is depicted in Fig 16.) The difference in the distance to the far-field sphere from the measurement origin as compared to the translated origin for a shift along the z-axis is simply

$$R^{FF} - R^{FF}{}' = \lim_{r,r' \to \infty} (r - r') = d_0 \cos\theta \qquad (4)$$

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

$$\theta' = \theta \quad \text{and} \quad \phi' = \phi \qquad (5)$$

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

$$\vec{F}\,'(\theta',\phi') = e^{ikd_0\cos\theta}\vec{F}(\theta',\phi') \qquad (7)$$

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:

$$\varphi^{FF}{}' = \varphi^{FF} + kd_0 \cos\theta \qquad (8)$$

This adjustment of the data led to the results in Figs. 7. & 8. 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 in which d_0 becomes as large as $D_{min}/2$, the corresponding Nyquist sample spacing is reduced to ½(λ/D_{min}). In the original natural coordinate system, this would appear to be a case of over-sampling !

The algorithm for the ***IsoFilter***^{TM} 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.

IV. Application to Ranges for Vehicles

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]. The antenna is offset above the ground plane. The ***IsoFilter***^{TM} software isolates the antenna and its immediate environment to enable computation of the pattern of the antenna alone, eliminating the effects of reflections from the more distant portions of the vehicle and the turntable itself. We expect that iterating filtered pattern results will be able to assist a user in determining from measurements just what portion of a vehicle is contributing to the full pattern.

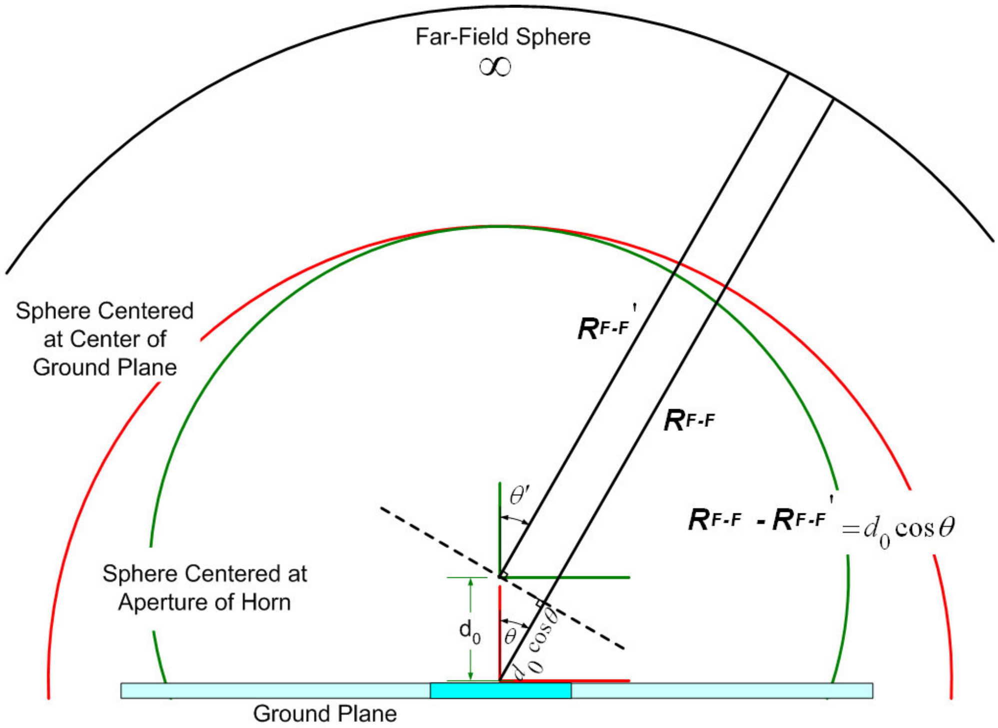

Fig. 15. Schematic Illustrating Difference in Distance to Far-Field Spherical Surface from Origins of Coordinate Systems Located at Center of Ground Plane and Center of Horn Aperture when the Horn is Located on the Z-Axis.

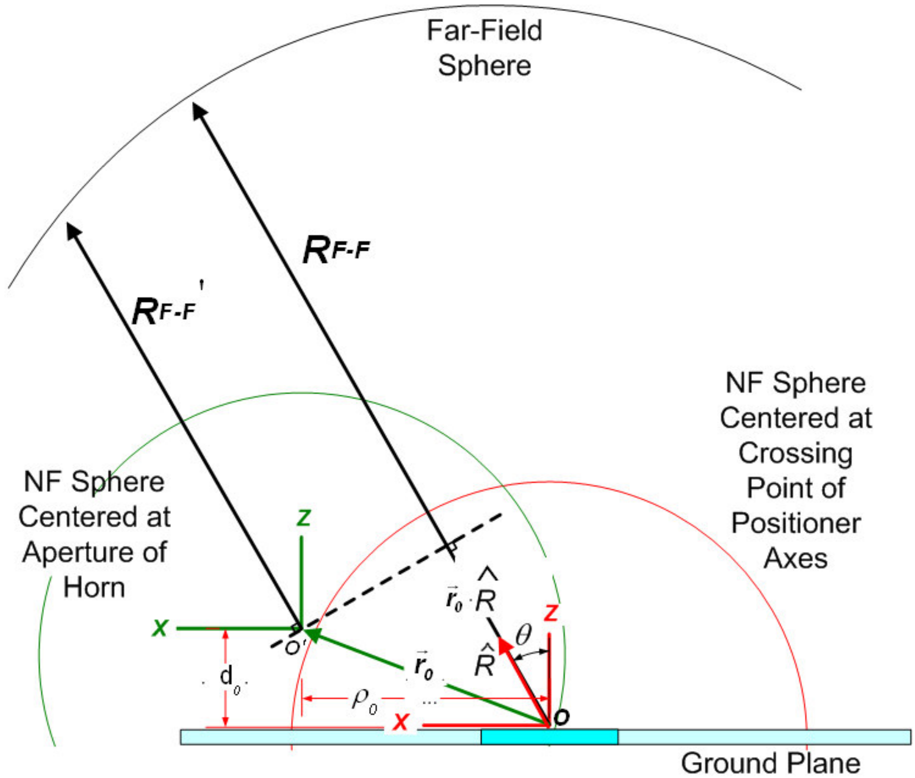

Fig. 16. Schematic Illustrating Difference in Distance to Far-Field Spherical Surface from Origins of Coordinate Systems Located at Center of Ground Plane and Center of Horn Aperture when the Horn is Located at a General Point Not Restricted to the Z-Axis.

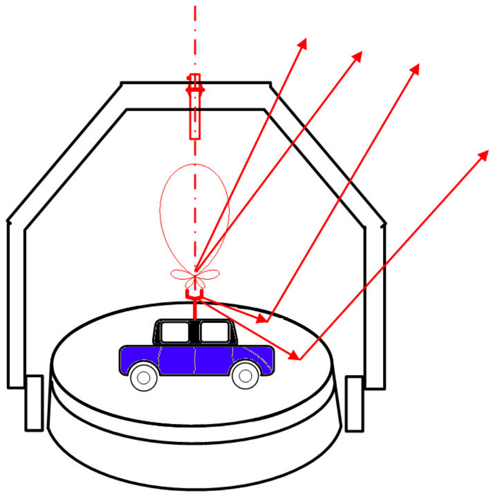

Fig. 17. Schematic of Vehicle-Mounted AntennaTest with Gantry And Azimuth Turntable. Note the Offset of the Antenna Above the Ground-Plane

V. CONCLUSIONS

We have shown how to augment the standard process of spherical modal filtering to obtain radiation pattern data that is largely free of the effects of reflections from nearby objects. The technique utilizes a computational method for translating the coordinate origin to a location within the volume occupied by an individual radiator; this enables the use of a smaller set of spherical modes to represent the pattern of the individual radiation source. This method, which we have termed the ***IsoFilter***™ technique, can be very useful in determining the pattern of the individual radiator alone even though the measured data set was collected with contaminating reflections present.

ACKNOWLEDGMENT

The author wishes to acknowledge helpful discussions with Mr. Jeff Fordham leading to the development of the ideas presented here.

REFERENCES

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

[2] D.W. Hess, D.G. Bodnar, "Ground Plane Simulation and Spherical Near-Field Scanning for Telematic Antenna Testing," in AMTA Symposium Digest 2004, *Antenna Measurement Techniques Assn , October* 2004, Atlanta, Georgia, U.S.A.

[3] 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 was posted on the MI Technologies web site at http://www.mi-technologies.com/.