Imaging a Range’s Stray Signals with a Planar Scanner

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Abstract— The fundamental purpose of absorber treatment in an anechoic chamber is to ensure that only the direct-path signal is coupled between the range antenna(s) and the device under test. For many simple and standard geometries, this is readily accomplished with conventional processes and procedures. When the geometry and/or stray-signal requirements deviate from the norm, however, it can be very beneficial to have an easy and reliable way to locate and quantify sources of stray signals.

This paper discusses a straightforward algorithm for creating images of those stray signals in a range when a planar scanner and broad-beamed probe are available in the test zone. Measured data from multiple facilities are evaluated, along with absorber-treatment improvements made based on some of the images produced.

I. INTRODUCTION

A planar X-Y scanner with fidelity suitable for planar near-field (PNF) measurements can be a powerful tool in evaluating stray signals in a chamber [1-3]. Such a scanner is used in PNF measurements to determine the spectrum of plane waves passing through it. In PNF, the AUT is generally very close to the scanner, and all the plane waves are assumed to be associated with the AUT’s pattern. In range imaging, the scanner is located far from the radiating sources, and the spectrum represents the combination of direct-path and scattered radiation approaching the test zone. (Because scattering is reciprocal, we will simplify this discussion to assume that the X-Y scanner is receiving.)

An alternative way of viewing the X-Y scanner (as opposed to PNF) is as a synthetic aperture with an element at every probe location where data are acquired. That synthetic aperture can have its pattern tuned and then be steered anywhere in the scanner’s forward hemisphere (typically with the FFT) to get the signal strength in that direction.

This paper begins by outlining the sampling needed on the X-Y scanner. Subsequent sections are arranged in decreasing order of perceived applicability, starting with typical processing, using the FFT, required on those acquired data to form a useful image. Visualization techniques that have proven helpful are also described, primarily in assisting the interpretation of the image. For scattering from directions near the direct path, it may be useful to remove the direct-path contribution, and one mechanism for doing so is discussed. For scattering from much closer than the test zone’s far field, the spherical focusing technique is then presented. The step of probe correction, a standard part of PNF, is often not needed in chamber imaging, and is briefly discussed. The option of using a polar-coordinate planar scanner is briefly explored. Finally, some examples are shown where images were produced and then used to reduce the stray signals in each range.

II. DATA SAMPLING REQUIREMENTS

The fidelity requirements (planarity, x-y accuracy, etc.) of the scanner are the same as those for PNF.

In general, the sample spacing in X and Y should be <λ/2 at the highest frequency of interest. If λ/ΔX is < 2, then any signals arriving from angles between sin⁻¹(λ/ΔX/2) and 90° will alias into the plot.

The spatial extent of the X-Y scan should typically be the size of the test zone. Larger extents improve the ability to resolve multiple radiation sources, but may underreport the contributions from sources in the near field of the scanner. (Using spherical focusing rather than the FFT can overcome this near-field effect.) If off-axis scattering is only expected in one plane, then a smaller spatial extent can often be used in the other plane to reduce acquisition time.

In many facilities, it will not be practical to mount a scanner at the test zone. In this case, it is recommended to mount the scanner ahead of the test zone, and increase the scan area as necessary to capture plane waves heading toward the test-zone center. This expansion is similar in concept to the critical angle of PNF, where we use a larger scan plane with larger offset from the AUT, and ensures that all plane waves of interest pass through the scan plane toward the test zone.

In this paper, only the copolarized scattering is evaluated, so that it is sufficient to acquire only the copol signal in the test zone. In some applications, the crosspolar scattering will also be important. In those applications, both polarization components should be collected and processed as they are in PNF.

The probe on the X-Y scanner should have a broad beam so that its pattern does not attenuate the stray signals of interest. For the ultimate fidelity, probe correction can be used to overcome this attenuation. If the mounting of the scanner in the facility introduces artificial scattering sources that cannot be easily hidden, then it is often preferable to use an absorber collar that moves with the probe and also attenuates those stray signals. Because the scattering off of this absorber collar
is stationary with respect to the probe, it represents part of the probe’s pattern, and will not introduce spectral content.

For ranges where the range antenna is not in a fixed location, one should repeat the data collection at several of the range-antenna locations. An example of this situation is a spherical near-field range based on an arch or gantry. Because the stray signals are typically bistatic reflections, one must sample a sufficient set of those bistatic geometries.

The use of a planar scanner assumes that all stray signals come from its forward hemisphere. For imaging more than that forward hemisphere, it will generally be necessary to rotate the scanner so that the back wall is in that forward hemisphere. In those geometries it will be advantageous to use probe absorber that blocks the direct-path signal. Because it will be difficult to attenuate that signal sufficiently, it might also be best to use effective azimuth rotations of the scanner of -120°, 0, and +120°. This would cause the back wall and the direct-path contribution to appear in different image locations.

III. DATA PROCESSING

Turning data from an X-Y scanner into an image of the range’s stray signals can be fairly straightforward, especially if the dominant scattering sources are distant in angle from the direct path. Just as in PNF processing, the 2D FFT is the primary tool in finding the spectrum of plane waves. Unlike PNF, however, it is not the first step in chamber imaging.

In PNF, there is a natural amplitude taper as the probe moves away from the nearby AUT. In chamber imaging, the direct-path signal has nearly uniform strength over the entire scan plane. Fourier theory tells us that scan-plane truncation of a uniform signal will result in side lobes throughout the spectrum that start at -13 dB and decay slowly. When looking for stray signals << -20 dB, these truncation effects must be reduced before the FFT.

A common way of dealing with truncation effects is to apply a window [4] to the data (along each axis) before the transform. This window becomes the effective aperture distribution of our synthetic array. Numerous windows exist, each trading off side-lobe level (SLL) and beam width. For scattering from angles far from the direct path, the Blackman-Harris 3-term window applied along both X and Y is often a good default choice. This window has a very broad beam and thus masks sources close to the direct path, but has all side lobes below -60 dB. For more control over the resolution/SLL tradeoff, one could consider the Chebyshev window.

The transform’s magnitude represents an image of the plane-wave spectrum in sine space. The span of the sine-space output will be \( \frac{\lambda}{\Delta X} \), and the output spacing is that span divided by the number of points in the FFT output. That image can be plotted vs. the sine-space coordinates \( K_x/K_0 \) and \( K_y/K_0 \), but it is often easier to interpret when plotted vs. angles. One can always interpolate from the native sine-space grid to a different grid, but it is usually simpler and faster to map the FFT output onto a 2D pin cushion of angular coordinates. None of the images in this paper have been interpolated. For simple plotting tools that require at least an irregular grid, one option is the non-standard Alpha-Elevation coordinate system. In this coordinate system,

\[
\text{Alpha} = \sin^{-1}\left(\frac{K_x}{K_0}\right), \quad \text{Elevation} = \sin^{-1}\left(\frac{K_y}{K_0}\right)
\]

The standard Azimuth angle, on the other hand, is defined as

\[
\text{Azimuth} = \sin^{-1}\left(\frac{K_x}{K_0 \cos(\text{Elevation})}\right)
\]

which does not work as a regular or irregular grid.

Figure 1 shows an image from measured data (with spectral power summed over 4 different source locations) in the Alpha-Elevation coordinate system. This is an irregular grid, where the Elevation coordinate is constant for every row and the Alpha coordinate is constant for every column, but the spacing of each is not constant. Note that the diamond-shaped edge of the image represents the boundary of ‘real space’ in this coordinate system, and physically corresponds to things in the plane of the scanning probe. The color scale of this plot is -50 to -25 dB relative to the direct-path peak, so that the top 25 dB of the desired direct-path beam is a solid color.

![Image from initial measured data](image)

One might wonder how to determine the distance from the scanner to the source of stray signal. The processing outlined herein does not yield distance directly. The location of the scattering source is determined by looking from the scanner center in the direction identified by the image, and seeing what physical range feature lies along that line.

IV. VISUALIZATION

Once one has the image in angular coordinates, the next challenge is to find the physical locations of the scattering sources. Slater [1] correctly describes the output image in terms of a “fish-eye lens.” For a full hemisphere, this description applies regardless of the coordinate system chosen for display. A decoder map like the one in Figure 2 can be very helpful. In this map, selected physical characteristics of the
chamber are plotted in the same coordinates in which the image is produced. This is done simply by first identifying the R vectors [X,Y,Z] of those features. The sine-space vector is then simply R/|R|, and the angular coordinates are computed just as they are for the image. A pair of red dots has been manually plotted in Figure 2 at the Alpha-Elevation coordinates of two stray-signal lobes in Figure 1. The concentric contours represent 10-foot increments of down-range distance, and illustrate the distortion of this projection of 3D space onto a 2D image. The somewhat radial lines show the seams at the tops and bottoms of the walls, plus transitions in absorber treatment. The grid of 32 black dots in the center represents the 32 individual transmitting antennas in this facility. (The image in Figure 1 represents the incoherently combined spectra from the four corner antennas.) The origin of this map is the probe’s phase center when located at the scan-plane center. The [0, 0] angle is defined to be along the scan-plane normal from that origin.

![Alpha-Elevation Aspects from Scanner](image1)

**Figure 2 - Decoder map for Alpha-Elevation**

The full-hemisphere Az-El map for the same range geometry is shown in Figure 3. While this is a more standard angular coordinate system, it is in many ways more distorted than the Alpha-Elevation map.

![Az-Elevation Aspects from Scanner](image2)

**Figure 3 - Az-El Full-Hemisphere Map**

Finally, the equivalent sine-space map is shown in Figure 4. Here we see the familiar unit circle representing the bounds of real angles.

![Kx-Ky Aspects from Scanner](image3)

**Figure 4 - Decoder map for sine space**

A more desirable image would be one that combines the stray-signal image and the chamber geometry. Such an image is shown in Figure 5. Some graphics tools do not support creation of such an image. Figure 5 was produced in MATLAB (and is less distorted than Figure 3 due to the restricted ranges of azimuth and elevation displayed). The radiated signal was an approximated plane wave synthesized from multiple antennas, and that commanded plane wave (in the direction of the green dot near the center of the 32 antennas) was subtracted out.
VI. SPHERICAL FOCUSING

For an indoor range with a large test zone, the contribution from each stray signal will typically be a spherical wave. The FFT essentially focuses its input to each point in a grid of aspects at infinite distance. This is very fast but is poorly suited for imaging spherical waves if the ratio of $\lambda^2$(distance to source) / (scanning aperture size)$^2$ is small. One straightforward alternative is to focus the synthetic aperture to each point of interest in the range. This approach lets one build an output image in any manner desired, perhaps with separate images for the floor, ceiling, and walls, or perhaps conformal to a structure. One would define a grid of $[x_0, y_0, z_0]$ points to image. The focused response $S$ of the probe samples $s(x, y, z)$ at each set of image coordinates would then be [6]:

$$R = \sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2}$$ (3)

$$S(x_0, y_0, z_0) = \sum \sum s(x, y, z)e^{-j2\pi R}$$ (4)

The signal $s(x, y, z)$ might have a window applied and/or the estimated direct-path contribution subtracted prior to this focusing. Note that (4) does not multiply the distance $R$ between the probe and image point. Including that multiplication would better estimate the power radiated from the scattering source, but in range imaging it is usually more important to represent the relative impact on the test zone.

One might be tempted to think that by focusing to a set of finite radii, one could also determine the distance to the scattering source. While this is true in concept, one will quickly find that the range resolution from focusing a single-frequency data set is very coarse [6]. Fortunately, that coarse resolution means that the actual distance to the scatterers need not be known precisely to obtain a useful image.

VII. PROBE CORRECTION

The processing above is extremely similar to PNF processing [1]. In the absence of probe correction, the transform output is very nearly the product of the probe pattern and the spectrum of plane waves passing through the scanned aperture. Very often, the imaging activity is intended to detect the stray signals to be addressed. Provided that the probe has a suitably broad beam, probe correction might not be needed for this activity. If, however, a precisely quantified stray-signal map is needed, then probe correction is advisable. One should note that for spherical focusing, the focused spectrum is only approximately a point-by-point product of probe pattern and the desired spectrum.

VIII. X-Y VS. POLAR

Just as a polar-coordinate planar scanner can be used in PNF, so can one be used to image stray signals. Use of a polar-coordinate scanner is much less straightforward than the use of an X-Y scanner for this purpose, especially when using a dual-ported probe that cannot counterrotate the Phi axis. Figure 6 shows an image from such a scanner. In this example, we were trying to assess the mutual coupling among the multiple range antennas. The estimated direct-path signal has

Figure 5 - Image combined with Az-El decoder map
been subtracted, and a cartoon of the radiating element has been automatically superimposed on the image. The color scale is -45 to -20 dB.

Figure 6 - Image from polar-coordinate scanner

For windowing with a polar-coordinate scanner, the weighting would be done along each radial or diametric scan. For spherical focusing or use in the polar-coordinate Fourier transform [7], a radial weighting is appropriate to equalize the area associated with each RF sample.

When combining linear and rotary axes to form a plane-polar scanner, such as a field probe and a roll axis, it is important that the assembly is suitable for PNF measurements as stated in Section II. The key parameters tend to be planarity, readout accuracy, axis intersection, and the radial-axis offset.

IX. EXAMPLES

Figure 7 shows the improvement relative to Figure 1 after looking at those spots on the floor and then addressing issues found there. In this case, the scattering was from off-axis floor absorber that was taller than the treatment along the range centerline. This presented surfaces visible to both the transmit and receive antennas, and the flat surface tended to scatter the signal upward. The remedy was to continue the taller absorber treatment across the range centerline.

Figure 7 – Image after retreatment

Figure 8 shows another combined image in the same chamber as Figure 5. This represents eight incoherently summed spectra (4 range antennas, H and V pol). The direct-path signals were not subtracted. The color scale is -50 to -25 dB relative to the spectral peak. The mapping of angular aspects to range features is shown in Figure 9. Nearly every stray signal suggested by the image is scattering from or through a conventional absorber treatment. This treatment was intended for higher frequencies and is being replaced as a result of these measurements. The two poorly resolved red lobes under the four direct-path lobes are due to floor bounce. The four sets of lobes in the corners of the image represent scattering off of wedge absorber installed parallel to the range axis. The top-center lobes represent ceiling bounce.

Figure 8 – Combined image in second range
Several empirical retreatments were attempted on the floor and lower walls to address the stray signals seen in Figure 8. The final results are shown in Figure 10. The acquisition parameters were slightly different, but it is clear that the retreatments lowered several stray signals’ contributions.

Figure 10 - Improvements to Figure 8

X. CONCLUSIONS

A planar scanner located in the test zone can be a powerful tool for assessing and perhaps lowering a range’s stray-signal levels.

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REFERENCES