METHODS TO ESTIMATE AND REDUCE LEAKAGE BIAS ERRORS IN PLANAR NEAR-FIELD ANTENNA MEASUREMENTS

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***Abstract:* This paper describes two methods that can be used to measure the leakage signals in quadrature detectors, predict the effect on the far-field pattern, and correct the measured data for leakage bias errors without additional near-field measurements. One method is an extension and addition to the work previously reported by Rousseau[1]. An alternative method will be discussed to determine the leakage signal by summing the near-field data at the edges of the scan rather than summing below a threshold level. Examples for both broad-beam horns and narrow-beam antennas will be used to illustrate the techniques.**

***Keywords*:** Antenna measurements; Error correction; Planar near-field; Quadrature detector

1.0 Background Information on Leakage Signals

The three main sources of leakage signals in near-field (NF)measurements are cross talk between the measurement and reference channels in the receiver, leakage from transmission lines, and the bias error from the receiver's quadrature detector. Cross talk between the reference and measurement channels in high quality receivers is generally very low and can be reduced if necessary by lowering the signal level in the reference channel. Leakage from cables, connectors and the rf source can be identified and reduced by using well shielded cables, tightening connectors and placing instruments in shielded enclosures. The bias error is generally the largest and most difficult to reduce in the measurement system since it produces a relatively constant amplitude and phase signal at each measurement point. When the measured data is transformed to the far-field (FF) this bias error produces a narrow-beam peak at $k_x = k_y = 0$ that causes a localized peak or dip in both the main and cross component patterns. The effect is most noticeable for low-level cross component patterns and for broad-beam antennas like the horns used for gain standards. Its effect is increased when the scan area is much larger than the physical area of the Antenna Under Test (AUT).

The leakage arising from the receiver bias error cannot generally be reduced with user-available changes in instrumentation. The error arises from very low-level residual offset errors in the wideband quadrature detectors that produce voltages proportional to the real and imaginary parts of the measured signals. The level of the leakage signal also may depend on the measurement frequency and the particular hardware configuration and needs to be checked for each measurement. This type of bias leakage signal is found on all microwave receivers that use quadrature detection for measuring amplitude and phase.

Terminating the transmission lines connected to the AUT or the probe and making a near-field measurement allows measurement of the leakage signal. The measured signal will be a combination of the noise level of the receiver and the leakage signal. A principle plane cut for one such

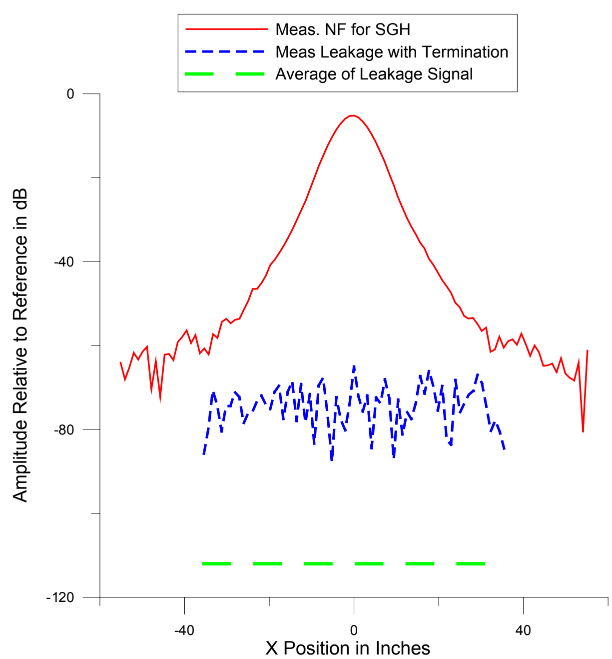

Figure 1. Sample of NF data, leakage data and calculate leakage from average of measurement.

measurement is shown in Figure 1 along with the same cut for the AUT, a standard gain horn (SGH). Depending on the receiver averaging and the random error, the bias leakage signal may be equal to or lower than the measured near-field amplitude. It can be found by calculating the sum of the real and imaginary parts of the measured data. The magnitude of the resulting sum is equal to the bias-signal level and is shown as the third curve in Figure 1.

Another example is shown in Figure 2, where a receiver averaging of 26 msec was used, compared to 0.3 msec for the data of Figure 1. In this case the calculated average is essentially equal to the measured leakage signal.

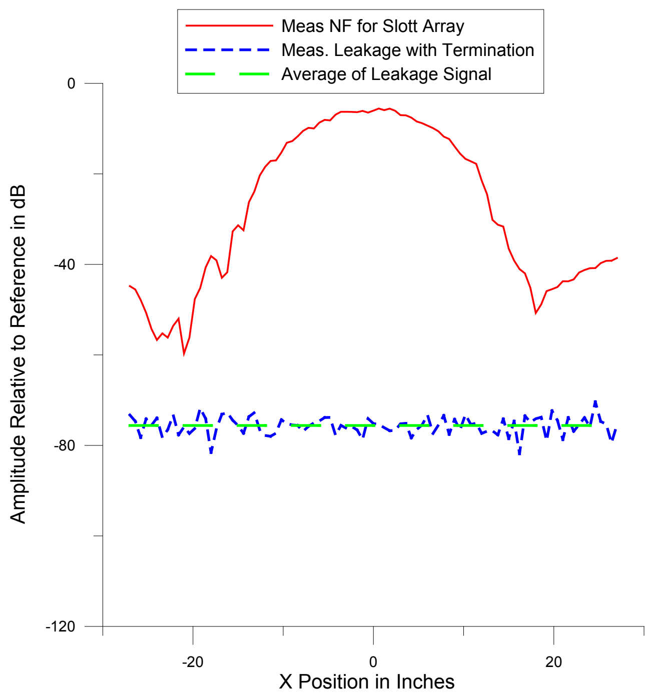

Figure 2. Sample of NF data, leakage data and calculate leakage from average of measurement.

Of more importance than the near-field leakage level is quantifying the effect of the bias leakage on the far-field pattern. This effect will depend on the AUT properties as well as the near-field measurement parameters. As illustrated in Figure 3, the constant amplitude and phase of the bias leakage signal transforms to a narrow beam pattern centered along the Z-axis direction. It will therefore have the major effect on the on-axis gain and the on-axis cross-polarized pattern

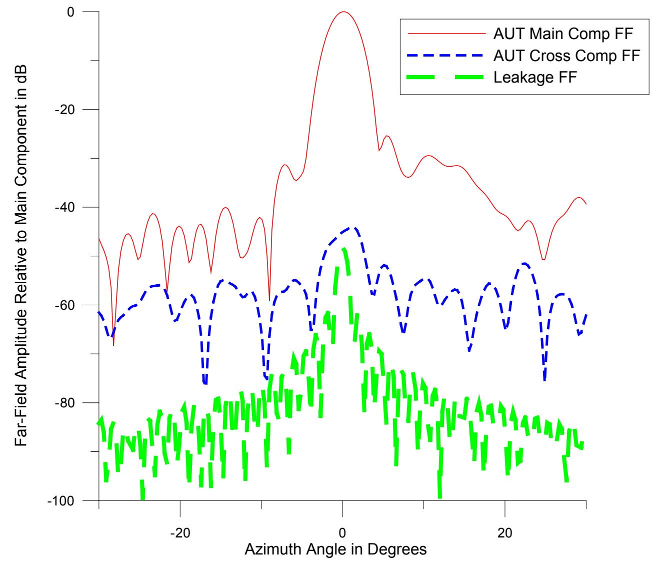

Figure 3. AUT FF pattern and bias leakage far-field for the data in Figure 2.

2.0 Predicting Far-Field Leakage Levels from Limited Near-Field Data

To obtain the bias leakage far-field pattern, a complete near field measurement must be made with the AUT and/or probe cables terminated. This can require valuable measurement time. A method for measuring the leakage level more quickly and predicting the far-field level of the leakage signal is desired. This is easily accomplished with the following process.

With the terminations in place, the receiver is set to its highest level of averaging so that the measured signal level will represent the bias leakage. Measurement of the complete near-field would correspond to the average curves in Figures 1 and 2. The measured signal can then be recorded as a function of time and the effect of tightening connectors or shielding instruments observed directly to reduce the leakage from these sources. When the leakage has been reduced as much as possible, the final level represents the bias leakage near-field amplitude, N_{Leak}. We will denote the corresponding peak near-field amplitude for the AUT measurement as N_{AUT}.

The programs that calculate the far-field patterns compute a peak far-field amplitude that is used in the gain calculation and is defined as

$$F_{AUT} = 10\log\left[\left|\delta_x\delta_y\sum_j B_0{}'\left(\vec{P}_j\right)e^{-i\vec{K}_0\bullet\vec{P}_j}\right|^2\right] \quad (1)$$

The δ's are the data-point spacings in x and y, $B_0'(\vec{P}_j)$ denotes the measured data, $\vec{K}_0$ *and* $\vec{P}_j$ are the transverse part of the propagation and position vectors respectively. Noting that the far-field peak is the product of the near-field voltage times an area; we can approximate the far-field peak from the equation

$$\boldsymbol{F_{AUT}} \approx 10\log(\boldsymbol{N_{AUT}\,A_e})^2 \ , \quad (2)$$

$\boldsymbol{N_{AUT}}$ = Near-field Peak Amplitude,
$\boldsymbol{A_e}$ = Near-field Effective Area of AUT.

For a typical antenna, the near-field effective area will be less than the actual physical area of the antenna and approximately equal to the conventional effective area. If the leakage signal has a constant amplitude and phase independent of the probe position, as produced by the receiver bias error, the near-field effective area is the full scan area. If the leakage varies in amplitude and phase as a function of position, as caused by cable leakage, the near-field effective area will be less than the full measurement area. Therefore, from Equation (2)

$$10\ \log\left(\frac{F_{Leak}}{F_{AUT}}\right) \le 20\ \log(N_{Leak}) - 20\ \log(N_{AUT}) + 20\ \log\left(\frac{A_e\left(Leak\right)}{A_e(AUT)}\right) \quad (3)$$

The AUT near-field effective area can be estimated from the physical area of the antenna or calculated from the far-field peak and Equation (2) after completing the near-field measurements. Then from the observed leakage near-field amplitude and Equation (3) we can determine the leakage far-field peak relative to the main and cross component patterns.

The third term in Equation (3) referred to as the leakage gain defines the increase in relative amplitude between the leakage signal and the AUT signal between measured near-field and calculated far field. Note that this term is proportional to the square of the effective areas and not measurement areas. For typical measurements, the measurement area is much larger than the AUT to reduce errors due to truncation and to maximize the angular coverage. This can result in a leakage gain on the order of 25 to 50 dB and illustrates why it is important to measure the bias leakage level and correct for it where possible.

The correction is performed on the measured data using a script that subtracts a constant amplitude and phase signal from the measured data. If the leakage signal has been correctly measured, the result is a data set that should show little if any effect on the far-field pattern. Figures 4 and 5 show examples of two cases where the leakage signal has the large effect. Figure 4 shows the main component peak for a broad beam antenna such as a standard gain horn typically used as a gain reference. Figure 5 shows an example of the cross-polarized pattern characteristic of many antennas.

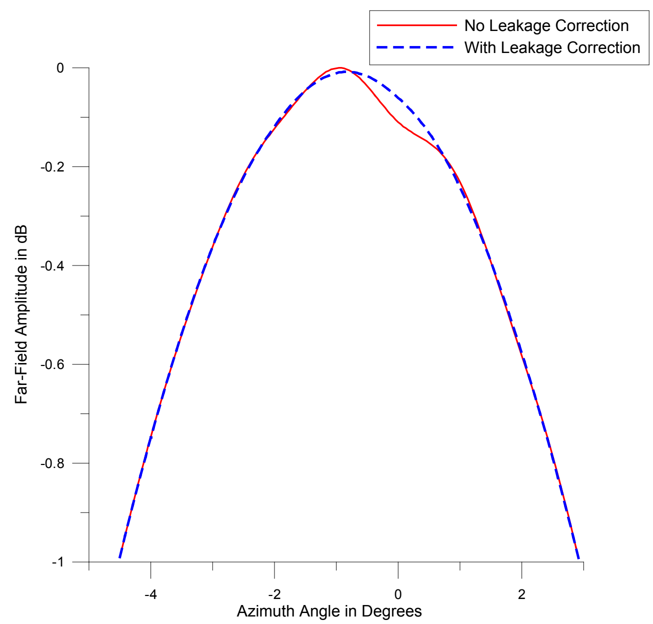

Figure 4. Illustration of leakage correction on the main component of a horn antenna.

In the first case, the effective area of the horn is relatively small and measurements are generally made over a large area to reduce the effect of truncation. As a result the leakage gain in Equation (3) is on the order of 40 dB. The leakage error can cause uncertainties on the order of 0.1 dB in the far-field pattern for the horn measurement, which is significant for a gain-standard antenna.

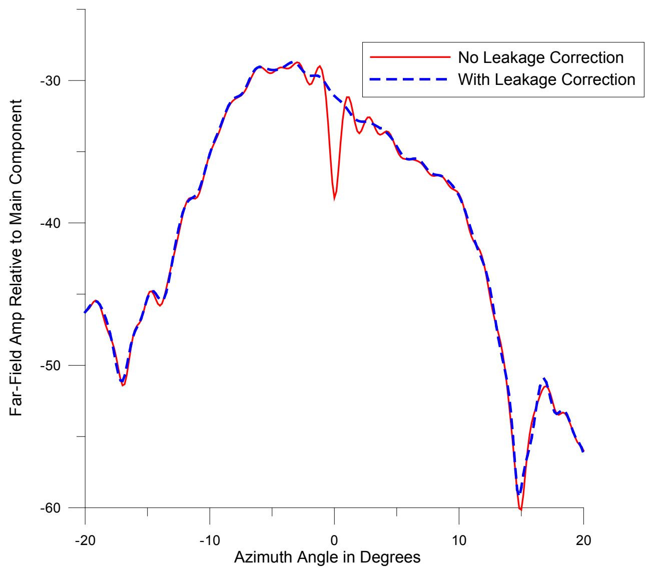

Figure 5. Illustration of leakage correction on the cross component far-field pattern.

In the second case, the far-field amplitude for the cross-polarized pattern is generally 30 to 50 dB below the main-component. With leakage gains of 30 to 50 dB the far-field leakage becomes comparable to the cross component, resulting in the null on-axis shown in Figure 5. Since the cross-polarized pattern may often have an on-axis null like this, it is difficult to tell whether it is due to leakage without performing the correction.

3.0 Detecting Bias Leakage Signals in Measured Data

There are times when near-field measurements may be recorded without first measuring the leakage signal with either a complete near-field scan or with the receiver averaging maximized. After transforming to the far-field the user may see far-field pattern characteristics such as Figures 4 and 5 or need to quantify the leakage error level for a complete error analysis. In such cases it would be very desirable to have a method for estimating the bias error leakage using only the measured near-field data. Rousseau[1] reported on such a method to estimate the bias leakage level by averaging all of the complex near-field points that are below a given threshold level given by the equation,

$$\bar{b} \cong \frac{1}{N_0} \sum_m b_m(\bar{P}), \tag{4}$$

where N_0 is the number of data points below the threshold level and m is defined such that

$$\left|b_m(\bar{P})\right| \le T_0 \ \max\left[\left|b_m(\bar{P})\right|\right], \tag{5}$$

where T_0 is the threshold level. Since the results will depend on the threshold used in Equation (4), the calculation is generally carried out for a sequence of thresholds that begins near the lowest recorded amplitude and increases to within –20 to –30 dB of the peak near-field amplitude. An example of the results of such a calculation for a horn antenna is shown in Figure 6. The plateau in the curve at the –78 dB level for thresholds in the range from -45 to –25 is a strong indication of the leakage amplitude level. A similar curve is generated to determine the leakage phase. In a number of tests, the threshold method worked well for horn-type antennas. In other cases there was not a distinctive plateau that provided a clear definition of the leakage amplitude and phase.

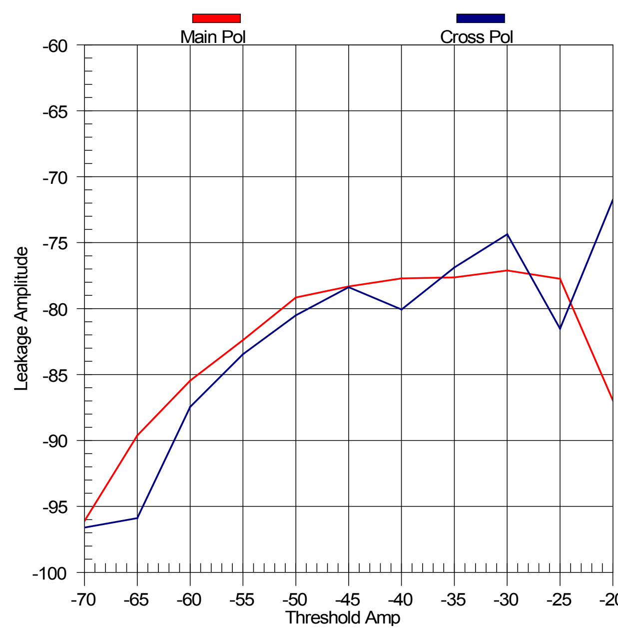

Figure 6. Example of threshold calculation method for determining bias leakage level.

As a result, an alternative method has been developed that calculates the leakage level by determining the change in the on-axis value of the main and cross components when a given number of rows and columns of data are truncated from the near-field data. On close inspection, it was found that the end result of this calculation was the same as Equation (4) except that the sum is performed over the truncated data rather than over the data below a certain threshold.

$$\bar{b}' \cong \frac{1}{N_T} \sum_{R,C} b_{R,C}(\vec{P}) \qquad (6)$$

where **R** and,**C** are the indices within the truncated region. The calculation can be carried out efficiently using the truncation feature built into the software. When this calculation is used on the same near-field data used in Figure 6, the result for the amplitude is shown in Figure 7. The truncation covered approximately the same region of the measured data as the threshold method. In general, the two methods usually gave very similar results, but in some cases, the truncation method was easier to interpret since the curve was flat over a larger region and did not require identifying a plateau region.

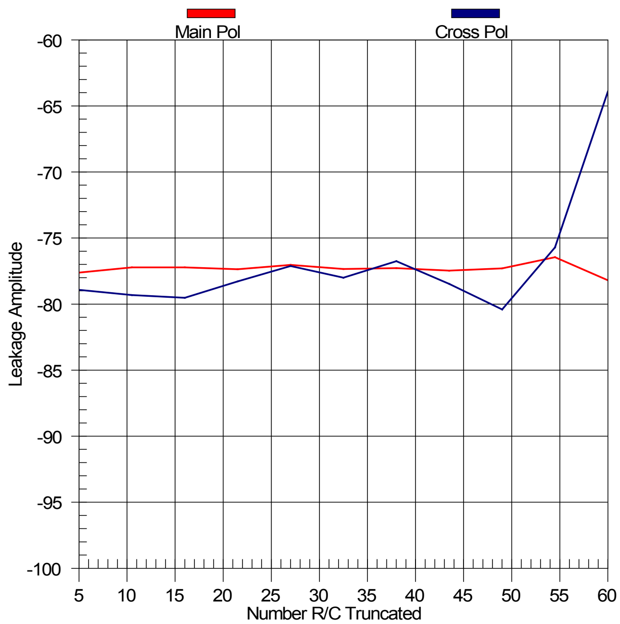

Figure 7. Example of truncation calculation method for determining bias leakage level.

It is not clear why the truncation method appears to work better in some cases. One possibility is illustrated in Figure 8, which shows a schematic comparison of the data that is summed in the two methods. The horizontal lines represent the "slices" of data that are summed in the threshold method. At the low levels, there may be very few points to sum and the threshold method does not sum all adjacent measured points. As a result, the sum may not converge to the constant-leakage level until the threshold is above the region where there are oscillations in the data. The "slices" of data that are summed in the truncation method are represented by the vertical lines. Adjacent points are always summed and the far-out points contribute very little to the main beam. The truncation sum will then converge sooner to the leakage level even in the region where there are oscillations in the data.

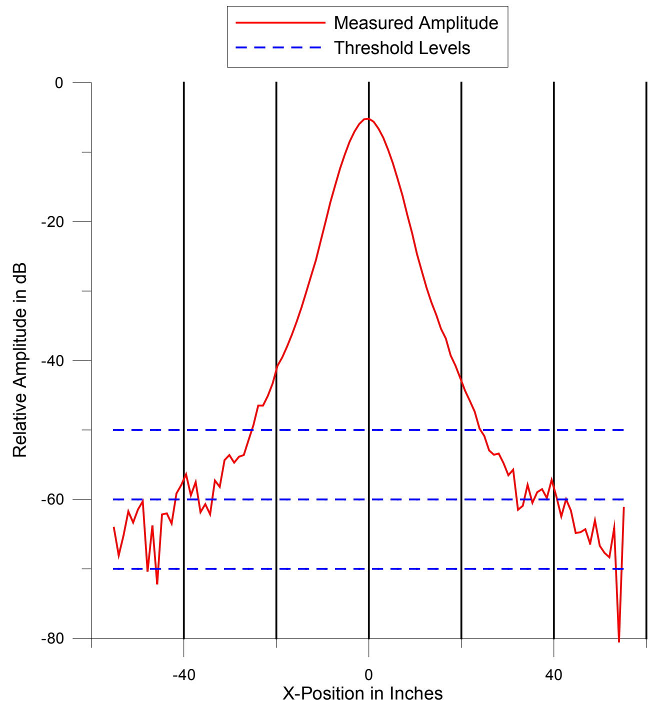

Figure 8. Near-field amplitude and summation regions for two methods.

4.0 Conclusions

Two methods have been demonstrated for measuring the bias leakage level and predicting its effect on the far-field pattern. The first method uses a single measurement with the receiver on high average and provides a direct measurement of the leakage amplitude and phase. Equations can then be used to calculate the effect on the far field, and the leakage can also be subtracted from the measured data. In the second method, the bias leakage signal is determined by summing the measured data using either the threshold or truncation method. Once it has been measured, it can be subtracted from the measurement to reduce or eliminate far-field errors.

5.0 References

[1] Rousseau, P. R., "An algorithm to reduce errors in planar near-field measurement data, AMTA Proceedings, Oct. 1999, pp 269-271.