New methods to reduce leakage errors in planar near-field measurements

F. J. Cano-Fácila, S. Burgos1, M. Sierra-Castañer1

1Radiation Group; Signals, Systems and Radiocommunications Department; Technical University of Madrid
Ciudad Universitaria, 28040 Madrid, Spain; Email: francisco@gr.ssr.upm.es

Abstract—This paper describes two methods to cancel the effect of two kinds of leakage signals which may be presented when an antenna is measured in a planar near-field range. One method tries to reduce leakage bias errors from the receiver’s quadrature detector and it is based on estimating the bias constant added to every near-field data sample. Then, that constant is subtracted from the data, removing its undesired effect on the far-field pattern. The estimation is performed by back-propagating the field from the scan plane to the antenna under test plane (AUT) and averaging all the data located outside the AUT aperture. The second method is able to cancel the effect of the leakage from faulty transmission lines, connectors or rotary joints. The basis of this method is also a reconstruction process to determine the field distribution on the AUT plane. Once this distribution is known, a spatial filtering is applied to cancel the contribution due to those faulty elements. After that, a near-field-to-far-field transformation is applied, obtaining a new radiation pattern where the leakage effects have disappeared. To verify the effectiveness of both methods, several examples are presented.

I. INTRODUCTION

The main objective of any antenna measurement technique is to obtain the antenna radiation parameters with a negligible disturbance level. However, there are always sources of error that reduce the accuracy of the measurement results. Mathematical analysis, computer simulations and measurements tests can be used to estimate the magnitude of each individual source of error or uncertainty and then, combining them, it is possible to obtain the total uncertainty in the final calculated results [1]. In some cases, errors are not only estimated but also they can be reduced by applying some correction procedures based on additional measurements or post-processing techniques.

In this work, two methods to cancel two different leakage errors are presented. There are three main sources of leakage signals: the first one is the crosstalk between the reference and the measurement channels in the receiver. However, this first source of leakage is normally greatly suppressed by using high quality receivers with a good isolation between channels. The second source is due to connectors, faulty cables or components with poor isolation that act as new emitters distorting the far-field pattern. The last source of leakage is the bias error coming from the receiver’s quadrature detector that introduces an imbalance between the two channels. As a consequence, a complex constant is added to every near-field data sample. The bias error is difficult to remove from the near-field data because the level of that constant is usually 60-70 dB below the maximum near-field level. However, when the measured data are transformed to the far-field, the bias error may produce a relatively large error at the center of k-space. The effect on the far-field is more significant if the antenna under test (AUT) has low gain or if the main beam is not steering at boresight, affecting to the side-lobes.

Several methods have been proposed to detect and cancel leakage signals. Leakage due to loose connectors, faulty transmission cables or components with poor isolation can be detected by terminating the lines connected to the AUT or the probe and measuring the signal picked up by the receiver [2]. Then, one easy way to cancel leakage sources is to substitute some components or wrap coax connections with electromagnetic insulation material until the leakage level is reduced. The main drawback of this technique is that several measurements are required. Other alternatives try to reduce the undesired effects without any additional measurement by means of analytical compensation techniques [3]-[5]. The leakage from the receiver bias error cannot be reduced with changes in instrumentation. All the methods, which have been developed to cancel this kind of leakage, predict the constant added to the measured data. Then, the estimated constant is subtracted from the measured data and if it has been well estimated, after transforming the near-field data, its effect on the far-field disappears. The first option to determine that constant is to perform a complete near-field measurement with both the AUT and the probe terminated and the receiver set to its highest level of averaging [6]. If there is no leakage from cables, the signal measured in this way is directly the bias leakage. Other options without requiring additional measurements are based on estimating that constant by averaging all the measured data that are below a given threshold [7] or located outside a certain region [8].

In the present paper, two methods to cancel leakage from cables and receiver’s quadrature detector in planar near-field measurements are proposed. Both methods are based on a diagnostic technique to determine the field distribution over the AUT plane. In the first case, this information is used to
validate the methods by using both simulated and measured field components over the AUT plane.

Each plane wave is multiplied by a term that depends on the propagation vector, \( \mathbf{k} \), and the distance between planes as well as the longitudinal component of the propagation vector, \( k_z \). The next step to calculate the reconstructed field is to reference the last quantities given by (1) to the AUT plane. Each plane wave is multiplied by a term that depends on the propagation vector, \( \mathbf{k} \), and the distance between planes as well as the longitudinal component of the propagation vector, \( k_z \).

Finally, using the inverse expression of (1), the electric-field components over the AUT plane, \( E_{\text{P, AUT}}(x,y,0) \) and \( E_{\text{P, Leakage}}(x,y,0) \), can be computed.

\[
E_{\text{P, AUT}}(x,y,0) = \frac{1}{2\pi} \int P_x(k_x,k_y,0)e^{-jk_x x}dk_x dk_y
\]

\[
E_{\text{P, Leakage}}(x,y,0) = \frac{1}{2\pi} \int P_y(k_x,k_y,0)e^{jk_y y}dk_x dk_y
\]
Therefore, after back-propagating the field from the scan plane to the AUT plane ($z=0$), the contribution of the leakage is not well-determined. Nevertheless, we are not interested in that information, but in the AUT contribution and if both contributions are not spatially coincident, a spatial filtering can be applied to cancel that one associated to the leakage. Although this last has not been correctly determined, once it has been filtered out, the leakage contribution is removed and a new far-field pattern without the leakage effect can be calculated.

In principle, the desired contribution is theoretically concentrated in the region where the AUT is located. For this reason, filtering can be applied to cancel the data out of the AUT dimensions, canceling the leakage information. Nevertheless, this assumption is not completely correct. On the one hand, a small field contribution always exists outside the AUT. On the other hand, because the measurement is performed in planar near-field, there is a truncation error that expands the field over the AUT plane when the measured data are back-propagated. To avoid this negative effect, spatial filtering over a larger area must be employed to account for all of the desired data.

To validate this first method, two different examples are presented. The first one takes as input data the values of a simulation of a planar acquisition. The last one uses information of an actual measurement in the planar near-field range of the Technical University of Madrid (UPM).

In this first example, a simulation that considers both leakage and the contribution of the AUT is presented. The AUT is composed of $6 \times 6$ infinitesimal dipoles with a uniform excitation. The separation between the dipoles is $0.5\lambda$ ($3$ GHz), and the planar near-field samples are spaced at $0.5\lambda$ intervals. The number of samples in the scan plane is $100 \times 100$ and the distance from this last plane to the AUT is $d = 6\lambda$. The leakage source has an isotropic radiation and is
located at (0, -2, 0.3) m with 20 dB less power than the excitation of each dipole. After applying the reconstructed process it is possible to detect the presence of the leakage, as shown Fig. 2 within the dashed line. Once this contribution has been canceled by means of a spatial filter of 2 x 2 m, we obtain a new far-field pattern that presents a better agreement with the reference pattern, as depicted in Fig. 3.

In the second validation, data were obtained by using the planar-range measurement system in the anechoic chamber at the Technical University of Madrid (UPM). For the experiment, the probe and the AUT consisted of a corrugated conical-horn antenna and a 5 cm x 7 cm pyramidal-horn antenna, respectively. The antennas were separated by 1.57 m. Moreover, another pyramidal-horn antenna of lower gain than the previous one was placed at (0.82, 1.6, 0.6) m (see Fig. 4) in order to simulate a leakage source. Once all the antennas were mounted, a measurement over a 2.4 m x 2.4 m acquisition plane with a spatial sampling equal to 0.43 λ (13 GHz) was recorded. By using the acquired data, the reconstructed field was computed. Then, a spatial filtering was applied to cancel the effect of the leakage source. Finally, a new far-field pattern was calculated by means of an inverse Fourier Transform of the filtered field, achieving a great improvement, as shown in Fig. 5.

IV. METHOD TO REDUCE LEAKAGE BIAS ERRORS

The second method presented in this paper tries to reduce leakage bias errors without additional measurements. As in [7]-[8], the method is based on an estimation of the constant added to all measured data. Then, the correction is performed by subtracting that estimated constant from the measured data. The main difference of our proposal is the information used to estimate the constant. Because those samples located outside the truncated area where the contribution of the AUT is very large, the error due to this term is small. However, if we select a very low threshold level or a large truncated area, the error associated to this term is not zero. In the opposite case, when selecting a small threshold level or a truncated area, the error due to the contribution of the AUT is very large.

In our method, we propose to use the information on the AUT plane, that is, the estimation is performed after back-propagating the field from the scan plane to the AUT plane. Then, the samples located outside the AUT aperture are employed to calculate the bias constant. By selecting those samples do not contain any contribution of the AUT, the estimation will be better as it is demonstrated in the following.

First of all, the field distribution over the AUT plane is calculated taking into account the three different contributions

\[
\bar{E} = \frac{1}{N_{\Omega_u}} \sum_{x,y} E_{\text{meas}}(x,y,d)
\]

where \( \bar{E} \) symbolizes the estimated constant, \( \Omega_u \) represents the region employed in the estimation and \( N_{\Omega_u} \) is the number of samples in that region. Because the measured data contain the contribution of the AUT, noise and the bias constant, the last expression in (7) can be rewritten as (8) indicates.

\[
\bar{E} = \frac{1}{N_{\Omega_u}} \left( \sum_{x,y} E_{\text{AUT}}(x,y,d) + \sum_{x,y} n(x,y,d) + \sum C \right)
\]

where \( E_{\text{AUT}}(x,y,d) \) is the AUT contribution, \( n(x,y,d) \) stands for the noise and \( C \) is the bias constant added to every measured data. Because the noise is an independent and space-stationary variable, the second integral will be zero. Therefore, the estimated constant is equal to:

\[
\bar{E} = \frac{1}{N_{\Omega_u}} \sum_{x,y} E_{\text{AUT}}(x,y,d) + C = \varepsilon + C
\]

As deduced from (9), the estimation carried out with the methods proposed in [7]-[8] introduce an error due to the contribution of the AUT. By selecting a very low threshold level or a large truncated area, the error associated to this term is small, but the number of samples is also small and therefore, the second integral of noise is not zero. In the opposite case, when selecting a large threshold level or a small truncated area, the error due to the contribution of the AUT is very large.

In our method, we propose to use the information on the AUT plane, that is, the estimation is performed after back-propagating the field from the scan plane to the AUT plane. Then, the samples located outside the AUT aperture are employed to calculate the bias constant. Because those samples do not contain any contribution of the AUT, the estimation will be better as it is demonstrated in the following.

First of all, the field distribution over the AUT plane is calculated taking into account the three different contributions

\[
P(k_x,k_y,d) = \frac{\Delta x \Delta y}{2\pi} \sum_{x',y'} E_{\text{AUT}}(x',y',d) e^{j(k_x x+k_y y)} + \sum_{x',y'} n(x',y',d) e^{j(k_x x+k_y y)} + \sum_{x',y'} C e^{j(k_x x+k_y y)}
\]

where \( \Omega_u \) is the scan surface and \( \Delta x \) and \( \Delta y \) are the sample spacing in the x- and y-directions.

\[
E_{\text{sp,AUT}}(x,y,0) + n_{\text{sp}}(x,y,0) + \frac{\Delta x \Delta y}{2\pi} C e^{j(k_x x+k_y y)}
\]

(11)
As deduced from (11), the field distribution on the AUT plane has three terms. The first one is the AUT field, which is concentrated on the AUT aperture. The second term is the noise, which is identically distributed over the reconstructed surface. The last one is a constant proportional to the bias constant. Therefore, averaging all the samples located out of the AUT dimensions, we obtain the following result

\[
\vec{E} = \frac{1}{N_{\Omega_x}} \left( \sum_{i=N_{\Omega_x}}^{N_{\Omega_y}} E_{\text{ap}}(x_i, y_i, 0) + \sum_{i=N_{\Omega_x}}^{N_{\Omega_y}} n_{\text{ap}}(x_i, y_i, 0) + \sum_{i=N_{\Omega_x}}^{N_{\Omega_y}} C e^{j\phi} \right) = C e^{j\phi} \tag{12}
\]

where \( \Omega_x \) is the reconstructed region outside the AUT dimensions and \( N_{\Omega_x} \) represents the number of samples in that region. In the previous expression, the two first summations are zero because the AUT field, \( E_{\text{ap}}(x_i, y_i, 0) \), is theoretically zero in \( \Omega_x \) and the mean of the noise is zero. Consequently, after obtaining the average of the samples located outside the AUT aperture, the only step required to determine exactly the bias constant is to multiply by \( e^{j\phi} \).

An example is presented in order to validate this second method. In this example, the reference measurement of the pyramidal-horn antenna of the previous section was employed. Then, a complex constant with 60 dB less amplitude than the maximum of the measured data and phase equal to 45° was observed from these results, a better estimation is obtained by subtracting that constant from the measured data. Both methods are based on obtaining the field distribution on the AUT plane and they can be applied without additional measurements.

**ACKNOWLEDGMENT**

This work has been developed thanks to the Spanish FPU grant for Ph.D. students and the financing of the Crocante Project (TEC2008-06736-C03-01/TEC).

**REFERENCES**