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A Novel Technique for Improving the Accuracy of Antenna Gain Measurements in the Near-Field Zone

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***Abstract* — Antenna gain measurements do not always comply with the constraints of the Friis transmission formula, especially when antennas are not small enough and/or the distance between the antenna under test and the probe antenna is not in the far-field zone. We have previously proposed an alternative method to the near-field to far-field transformations, based on calculating weighting functions to be applied on normalized transfer functions measured at different distances between antennas. The weighting functions were originally calculated by assuming an axial, constant current distribution along the antenna aperture for a given polarization. In this paper, we propose a Method of Moments type approach to extract samples of a more realistic equivalent current distribution. Consequently, new weighting functions are derived, in order to improve the accuracy of our earlier near-field approach. Our technique is validated by measuring two types of antennas.**

***Index Terms*— Antenna measurements, near-field, method of moments, modal expansion.**

I. Introduction

In a previous work [1], we proposed an alternative approach for near-field gain measurements by using a distance averaging method and by defining a set of theoretically derived weighting functions, instead of using near-field to far-field transformations.

The set of weighting functions resulted from a simplified model, where a constant current distribution on both antennas was assumed.

In some cases (e.g., some types of wide-band antennas) such a simplified model yields good results, compared to the figures extracted with a professional system using near-field to far-field transforms [2].

In order to improve the accuracy of our method a more realistic set of weighting functions should be defined from an equivalent current distribution over the aperture of the antenna.

In simulations, current distributions can be calculated by using a method of moments (MoM) approach [3], [4]; the unknown distribution is projected on a set of known basis functions (sometimes sinusoidal) in order to find current samples along the antenna. In measurements, the MoM could be successfully applied to derive a modal, plane-wave expansion of the near-field distribution, in order to assess the antenna gain [5].

In this paper, we propose a MoM approach for extracting samples of an equivalent current distribution along the antenna aperture, for a given direction of polarization. In that case, the right-hand side of the equation to be solved results from the normalized transfer functions [1] measured at different distances between the antenna under test (AUT) and the probe antenna. The basis functions corresponding to the modal terms can be assimilated to elementary current waves with different wavenumbers, i.e., integer multiples of the free space wavenumber.

Our method was validated by measurements on two antennas: a narrow-band monopole and an ultra-wide band, Vivaldi dipole.

II. Theory

A typical configuration for transmission between two linear antennas is shown in Fig.1. We consider one antenna in transmitting mode and the other one in receiving mode.

For a given direction of polarization one can define, without loss of generality an axial, equivalent current distribution on both antennas, as shown in Fig. 1.

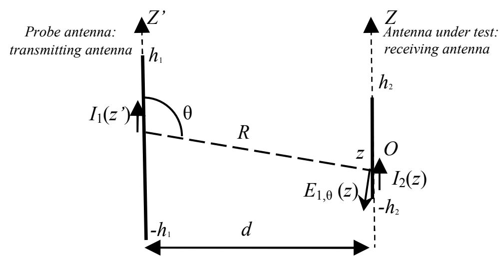


Fig.1. Near-field transmission between two linear dipoles.

A normalized voltage, $V_{0,norm}$ can be defined by multiplying the voltage at the input of the receiving antenna by the current distance between antennas,

$$V_{0,\,norm}(d_k) \propto d_k^3 \int_{-h_2}^{h_2} I_2(z) \left[\int_{-h_1}^{h_1} \frac{e^{-jk_0(R-d_k)}}{R^3} dz' \right] dz \qquad (1)$$

where $I_2(z)$ is the current distribution on the receiving antenna and $\sin\theta = d/R$. The current distribution on the transmitting antenna is still considered constant, since most probes are ultra-wide band antennas.

We expand the unknown current distribution $I_2(z)$ in terms of a set of sinusoidal basis functions,

$$\phi_n(z') = \frac{\sin k_n\left(h_2 - |z'|\right)}{\sin k_n h_2}. \qquad (2)$$

Equation (1) can be written as

$$\frac{V_{0,norm}(d_k)}{d_k^3} = \sum_{n=1}^{N} J_n \int_{-h_2}^{h_2} \phi_n(z) \left[\int_{-h_1}^{h_1} \frac{e^{-jk_0(R-d_k)}}{R^3} \mathrm{d}z' \right] \mathrm{d}z \tag{3}$$

with k_n the wavenumber for the n-th mode i.e.,

$$k_n = \frac{\omega}{c_0 / n} = n\, k_0 \,. \tag{4}$$

As an example, for a patch dipole and for a longitudinal axis of polarization the terms of the modal expansion would correspond to elementary current waves traveling all along the surface; tilt currents are modeled by higher order modes as their phase velocities are actually projected along the axis of polarization (Fig.2). The phase velocity for the n-th order mode is $v_n = c_0 / n$ with $n = \overline{1, N}$.

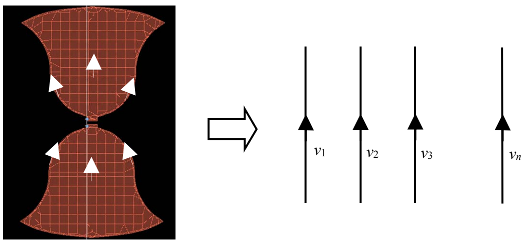


Fig. 2. Equivalent current distribution along a patch type dipole.

Equation (3) can further be written as

$$\sum_{n=1}^{N} J_n G_{n,k} = V_k \tag{5}$$

where

$$G_{n,k} = \int_{-h_2}^{h_2} \phi_n(z) \left[\int_{-h_1}^{h_1} \frac{e^{-jk_0(R-d_k)}}{R^3} \mathrm{d}z' \right] \mathrm{d}z, \tag{6}$$

$$V_k = \frac{V_{0,norm}(d_k)}{d_k^3}, \tag{7}$$

and R is the distance between a source point and a field point i.e.,

$$R = \sqrt{d_k^{\,2} + (z - z')^2} \tag{8}$$

In a matrix form,

$$\mathbf{G} \cdot \mathbf{I} = \mathbf{V}\,. \tag{9}$$

The vector of unknown modal weights, $\mathbf{I}=[J_1, J_2 \ldots J_n]$ can then be extracted as

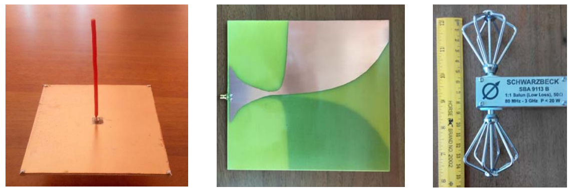
$$\mathbf{I} = \mathbf{G}^{-1} \cdot \mathbf{V} \tag{10}$$

The equivalent current distribution is eventually found as

$$I_2(z) \cong \sum_{n=1}^{N} J_n \phi_n(z). \tag{11}$$

III. RESULTS

In order to demonstrate the accuracy of our method, we measured two types of antennas: a narrow-band, monopole antenna (Fig. 3a), and a Vivaldi, ultra-wide band antenna (Fig. 3b). The monopole antenna was 8.4 cm high and was placed in the middle of a square ground plane with a side length of 10 cm. It resonates around 800 MHz and 2400 MHz. The Vivaldi dipole operates at frequencies over 500 MHz. The probe antenna was a biconical dipole and it operates at above 500 MHz (Fig. 3c).



a) b) c)

Fig. 3. Antennas under test: monopole (a) and Vivaldi dipole (b). Probe antenna (c).

Measurements were performed in an ordinary room inside an office building. For a good accuracy in that multipath site we successively placed the probe antenna in a matrix of 3 by 6 positions. In both cases the distance between antennas ranged from 15 cm to 60 cm.

A realistic, equivalent current distribution on the receiving antenna can be found as described in the previous section.

The equivalent current distribution at different frequencies is shown in Figs. 4, 5 and 6, respectively.

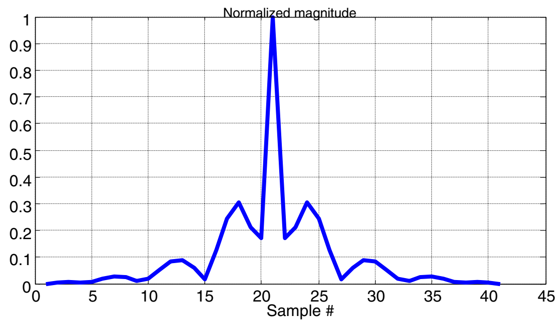


Fig. 4. Equivalent current distribution at 850 MHz.

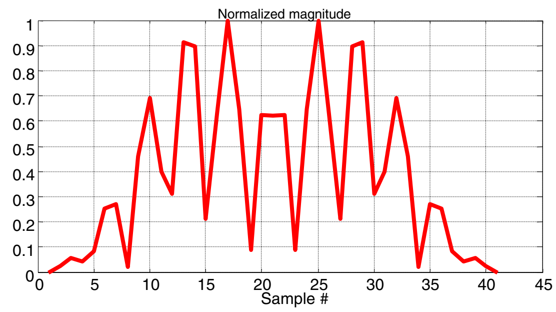


Fig. 5. Equivalent current distribution at 2.4 GHz.

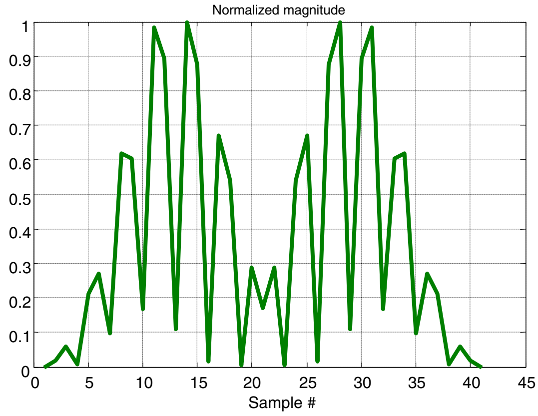


Fig. 6. Equivalent current distribution at 3 GHz.

Figs. 7 and 8 show the weighting functions found by using the method of moments approach for the monopole antenna and for the Vivaldi dipole, respectively.

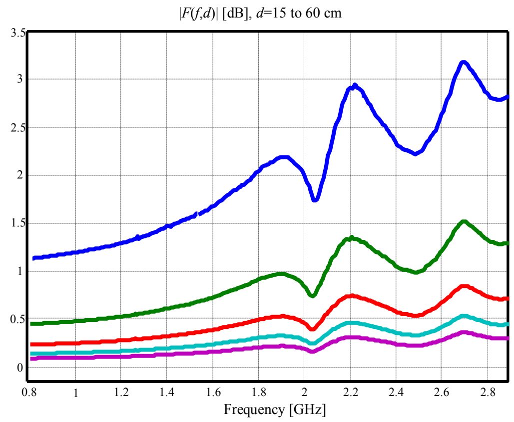


Fig. 7. Weighting functions for the monopole antenna, d=15 to 60 cm.

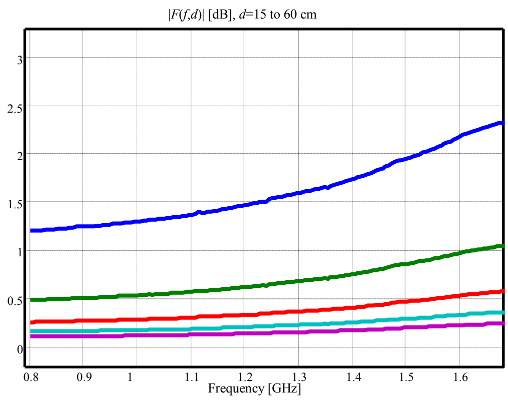


Fig. 8. Weighting functions for the Vivaldi antenna, d=15 to 60 cm.

The normalized, transfer functions and the average over the weighted data are shown in Fig. 9 for the monopole antenna and in Fig. 10 for the Vivaldi dipole, respectively.

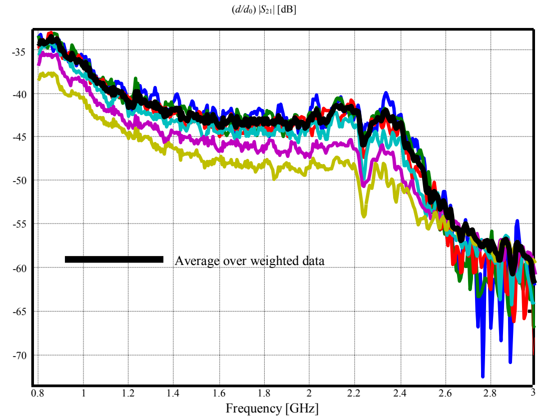


Fig. 9. Normalized, transfer functions for the monopole antenna, d=15 to 60 cm.

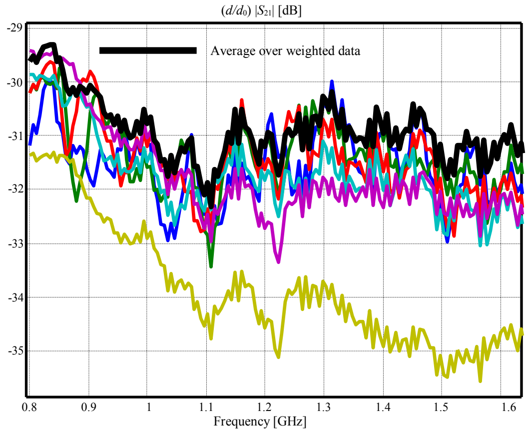


Fig. 10. Normalized, transfer functions for the Vivaldi dipole antenna, d=15 to 60 cm.

Gain variation over the frequency range of interest is given in Figs. 11 and 12. On the same diagram we show both simulated and measured results. Measurements were performed both in a multipath site with our single-probe technique [2] and in an anechoic chamber with a multiprobe professional system using near-field to far-field transforms. Data measured in the multipath site was processed in two different ways: as an arithmetic mean over the normalized transfer functions without using any weighting function, and as an average calculated with the weighting functions given in Figs.7 and 8, respectively.

The simulation was performed with professional software using the method of moments for solving the electromagnetic field equations.

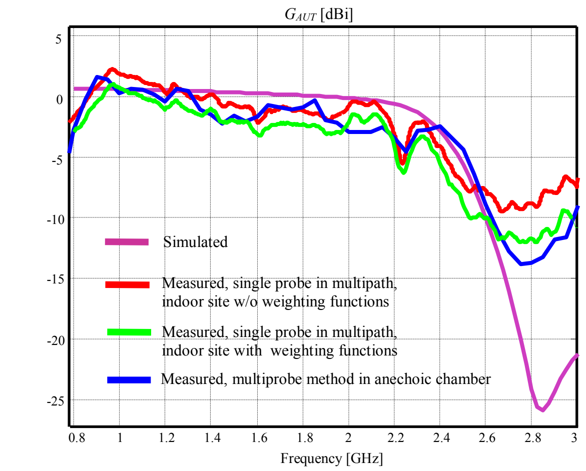


Fig. 11. Gain of the monopole antenna.

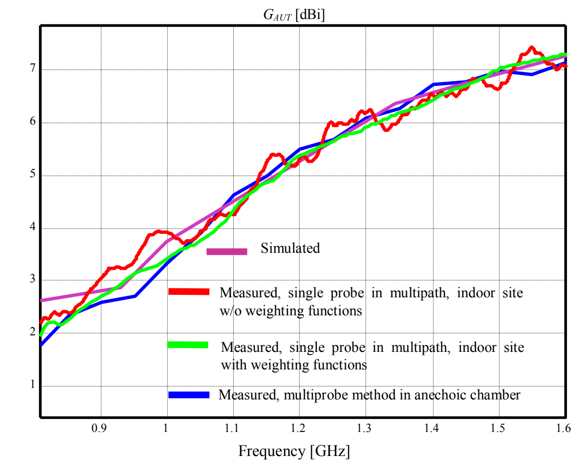


Fig. 12. Gain of the Vivaldi dipole antenna.

IV. CONCLUSION

Antenna gain can be accurately extracted in the near-field zone by defining an equivalent current distribution along the antenna aperture. The Method of Moments (MoM) type approach that we propose in this paper can be integrated with the distance averaging method that we have previously presented, in order to find samples of the equivalent current distribution. Compared to our earlier work, such a realistic source model provides gain figures closer to those resulting from a professional measuring system based on multi-probe scanning inside an anechoic chamber and near-field to far-field transforms.

A root mean square (RMS) error can be calculated over the frequency range of interest, in order to assess the accuracy of a measuring system based on our approach, compared to the professional system. As an example, a RMS error figure of 1.15 dB is found for the monopole antenna when assuming a constant current distribution on the AUT; conversely, an error figure of 0.21 dB is found when the equivalent current distribution is extracted with the MoM approach that we propose in this paper. As expected, the accuracy improves for narrow-band antennas more than for ultra-wide band antennas since in the first case the current distribution has a stronger dependence on the frequency. For the Vivaldi dipole almost the same error figure (around 0.5 dB) is found for both types of current distributions.

It should be emphasized that our method requires an a priori knowledge of the AUT geometry and size; as a result it might be not applicable to embedded antennas.

V. REFERENCES

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