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Antenna Gain Evaluation Based on Weighting Near-Field Measurements

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***Abstract*— Antenna gain is generally extracted from near-field measurements when the size of the measuring site (anechoic chamber or open area test site) does not meet the far-field constraints that include both distance and probe size limitation. Near-field measurements are usually performed by scanning the field on a closed surface around the antenna with a small size probe. In this paper, we show that the distance averaging method that we have previously proposed for gain evaluation in a multipath environment can also be employed for measurements in the near-field zone. We introduce an alternative technique to extract the gain by applying weighting functions on the near-field data when the size of the probe cannot be neglected compared to the wavelength. We validated our method by comparing the results to the gain measured at distances in the far-field region.**

Keywords*— *Antenna gain; near-field measurements; weighting functions; averaging method

I. Introduction

Gain measurements are usually performed by placing a calibrated probe as far from the antenna under test, as far-field constraints would be fulfilled. Compliance with that limitation might not be possible when large antennas are measured. Several measuring techniques, based on processing data scanned in the near-field zone, have been developed [1], [2], [3]. Most of those methods use small probes placed on a surface surrounding the antenna under test and near-field to far-field transforms are applied on measured data.

We have previously presented [4], [5], [6] a method for antenna gain evaluation in a multipath environment, based on averaging data measured at different distances between the probe antenna and the antenna under test. Weighting on measured data was solely used to compensate the effects of the propagation, as it would be in the far-field region.

In this paper, we show that distance averaging can successfully be applied on a data set entirely acquired in the near-field zone with a probe of a size comparable to the wavelength. An alternative technique for processing near-field data, based on weighting functions, is proposed.

We firstly set up a far-field limit for transmission between two antennas of finite sizes. Then we define the weighting functions to be applied on the near-field measured data, in order to remove the effect of the phase deviation between different pairs of source points and field points.

The method was validated by comparing weighted data measured in the near-field region to data measured on a set of distances mostly in the far-field region.

II. Near-field transmission between two finite size antennas

Let us consider the transmission between two linear dipoles of a total length $2h_1$ and $2h_2$, respectively (Fig. 1).

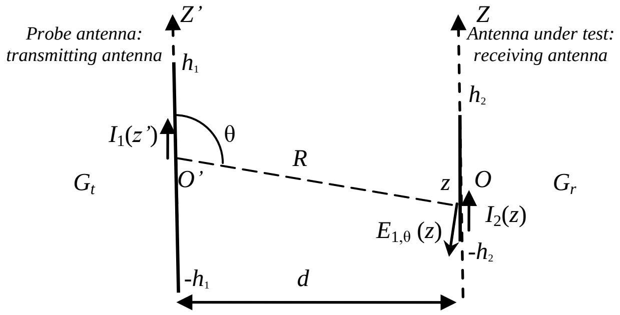


Fig. 1 Near-field transmission between two linear dipoles

Separation between different field regions has been defined [7] by taking into account the antenna size in terms of wavelength. Those limits apply to the field computed in a specific point; however, at high frequencies the size of the probe might not be as small as to be assimilated to a point.

Since the probe antenna size is comparable to the size of the antenna under test and to the distance between the two antennas, the definition of the far-field range as given for a single antenna should be revised. The maximal phase deviation between two waves incident on the receiving antenna occurs when the field point is located on its top i.e., $z=h_2$, and the source points are located one at the same height as the field point and the other one at the bottom end of the transmitting antenna, respectively; that is, $z_1'=h_2$ and $z_2'=-h_1$.

By assuming that $d \geq 3(h_1+h_2)$ the path length difference between the two incident waves can be expressed as

$$R_{\max} - d \cong \frac{(h_1+h_2)^2}{2d}. \qquad (1)$$

As for a single antenna the maximal phase deviation can be set at $\pi/8$ [7] as a reasonable error margin. It comes out that the far-field range for the configuration given in Fig. 1 is

$$d \geq \frac{8(h_1 + h_2)^2}{\lambda}. \tag{2}$$

Let V_0 be the voltage at the output of the receiving antenna. A normalized, output voltage can be defined by compensating the effects of the propagation i.e., delay and attenuation. The normalized voltage can be computed based on the mutual impedance [8] as

$$\begin{aligned} V_{0,norm} &= d \exp(jk_0 d) V_0 \\ &\propto d \int_{-h_1}^{h_1} \int_{-h_2}^{h_2} I_1(z') I_2(z) \sin^2\theta \frac{\exp[-jk_0(R-d)]}{R} \mathrm{d}z\, \mathrm{d}z' \\ &= d^3 \int_{-h_1}^{h_1} \int_{-h_2}^{h_2} I_1(z') I_2(z) \frac{\exp[-jk_0(R-d)]}{R^3} \mathrm{d}z\, \mathrm{d}z'. \end{aligned} \tag{3}$$

An asymptotic, far-field figure can be computed when $d \to \infty$,

$$V_{0,norm}^{\infty} = d \exp(jk_0 d) V_0 \propto \int_{-h_1}^{h_1} \int_{-h_2}^{h_2} I_1(z') I_2(z) \mathrm{d}z\, \mathrm{d}z'. \tag{4}$$

One can compute from (3) and (4) weighting functions that near-field measurements should be multiplied by in order to assess the far-field. For a given direction one can define on both receiving and transmitting antennas constant, equivalent current distributions along the main axis of polarization. The weighting functions can be written as

$$F(f,d) = \frac{V_{0,norm}^{\infty}}{V_{0,norm}} = \frac{4h_1h_2}{d^3 \int_{-h_1}^{h_1} \int_{-h_2}^{h_2} \frac{\exp[-jk_0(R-d)]}{R^3} \mathrm{d}z\, \mathrm{d}z'}. \tag{5}$$

Eventually, the gain of the antenna under test, G_r is found from the scattering parameters and from the gain of the measuring antenna, G_t as follows:

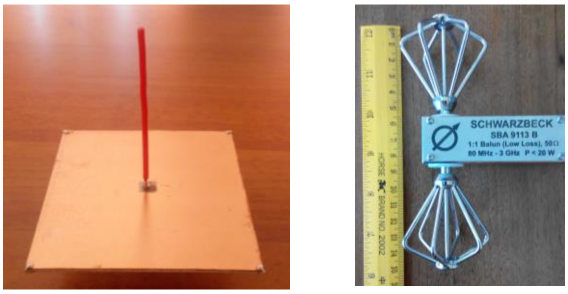
$$G_r = \frac{|F(f,d)|^2}{G_t} \left(\frac{4\pi d}{\lambda}\right)^2 \frac{R_0}{R_{a_2}} \frac{|S_{21}|^2}{|1 - S_{22}|^2 \left(1 - |S_{11}|^2\right)} \tag{6}$$

where R_0 is the normalizing impedance and R_{a2} is the real part of the input impedance of the antenna under test.

III. Results

We consider a typical setup consisting of an antenna under test, a probe antenna, and a vector network analyzer. Measurements were performed in a reflection free environment in order to only investigate the impact of the near-field zone. As an antenna under test, we took a monopole on a square ground plane. The monopole was 8.4 cm high and the side of the ground was 10 cm long (Fig. 2a). The antenna under test resonates around 800 MHz and 2.4 GHz. A calibrated, biconical dipole was employed as a probe antenna (Fig. 2b). The total height of the biconical dipole was $2h_1$=14 cm.

By taking into account a full size image for the monopole under test the far-field region at 1GHz, as given by (2) starts at 68 cm between antennas.



a) b)

Fig. 2 Experimental setup: antenna under test (a), and probe antenna (b)

We performed two sets of measurements: one for distances between antennas ranging from 100 to 140 cm, and the other one for distances comprised between 15 and 60 cm. The distances in the first set are all in the far-field zone for frequencies up to 1.6 GHz; the second measuring range is completely below the far-field limit at 1 GHz and above.

The weighting functions resulting from (5) for both sets are shown in Fig. 3 and Fig. 4, respectively.

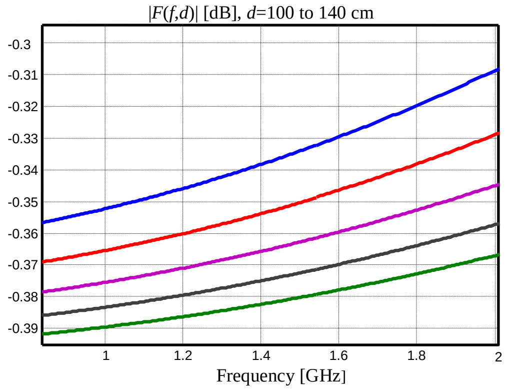


Fig. 3 Weighting functions for d=100 to 140 cm

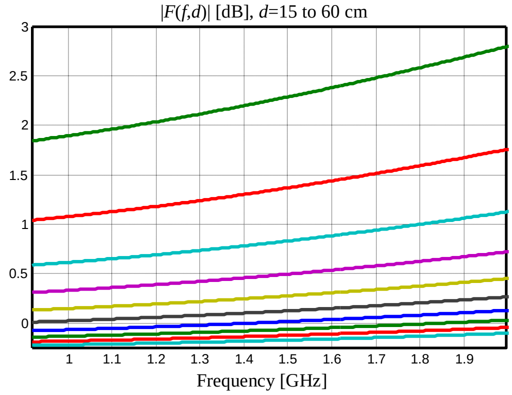


Fig. 4 Weighting functions for d=15 to 60 cm

For distances in the first set (100 to 140 cm) and for a frequency range of 0.85 to 2 GHz the magnitude deviation between any two weighting functions does not exceed 0.1dB. Conversely, the weighting functions for the second set spread over 3 dB for different distances.

In Fig. 5 we show the measured, normalized transfer factor i.e., $(d/d_0)\cdot|S_{21}|$ for 5 distances ranging from 100 to 140 cm. We denoted by d_0 a reference distance that we set at 1 m.

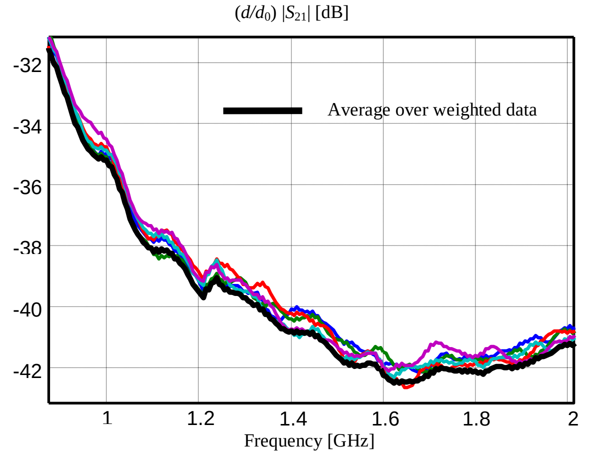


Fig. 5 Normalized, transfer factors for d=100 to 140 cm

The results for different distances are very close one to the other for frequencies of up to 2 GHz. A gain figure, mainly corresponding to the far field zone, can be extracted by averaging data over the entire set of distances, in order to reduce the measuring uncertainty.

Fig. 6 shows the normalized, transfer factor measured for 10 equally spaced distances between 15 and 60 cm.

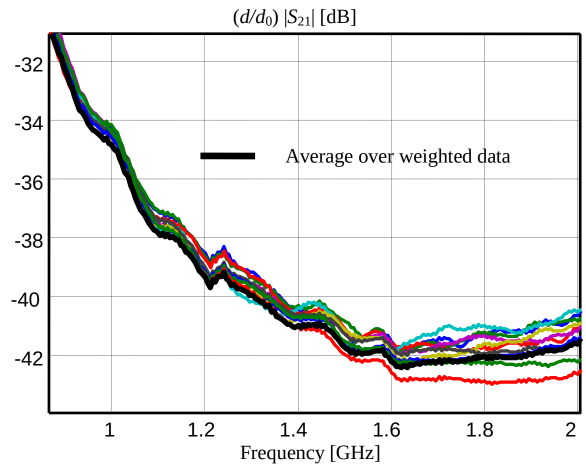


Fig. 6 Normalized, transfer factors for d=15 to 60 cm

The solid, black curve stands for the weighted average computed in terms of power by using the functions given in Fig. 4, that is

$$\overline{|S_{21}|} = \sqrt{\frac{1}{N}\sum_{n}^{N}\left[\frac{d_n}{d_0}\cdot|S_{21,n}|\cdot|F(f,d_n)|\right]^2} \qquad (7)$$

where N is the number of distances in the set.

The gain figures resulting from the far-field set and from the near-field set are compared in Fig. 7. An unweighted average on the near-field data is also given, so as to observe the impact of the weighting on the accuracy.

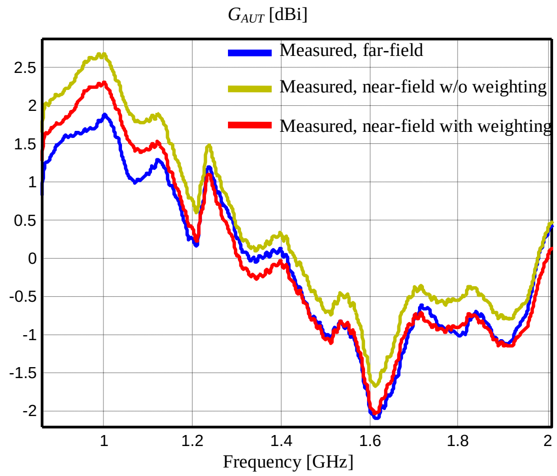


Fig. 7 Gain of the antenna under test

It comes out that weighting on the near-field data results in improving the accuracy of gain measurements by 0.5 dB for frequencies between 1 and 2 GHz. Table I gives the accuracy improvement defined as a difference between the relative error without weighting and the relative error with weighting; the far-field gain was set as a reference for computing both error figures. It can be noted that by using weighting functions the accuracy improves by at least 18% at most frequencies between 900 MHz and 1.9 GHz.

TABLE I. ACCURACY IMPROVEMENT ON GAIN EVALUATION

Freq. [GHz]	Gain, far-field [dBi]	Gain, near-field [dBi]		Accuracy improvement [%]
		w/o weighting	***w. weighting***	
0.9	1.5	2.14	1.76	25.33
1	1.9	2.7	2.3	21.05
1.1	1.1	1.8	1.43	33.63
1.2	0.26	0.77	0.4	142.3
1.3	0.26	0.4	0.03	-34.6
1.4	0.113	0.326	-0.043	50.44
1.5	-1.01	-0.7	-1.068	24.95
1.6	-1.97	-1.54	-1.91	18.78
1.7	-0.8	-0.41	-0.775	45.62
1.8	-1	-0.55	-0.9	35
1.9	-1.093	-0.753	-1.1	30.46

The gain at above 2 GHz resulting from the weighted data is slightly different from the figure measured within the far-field range since the model of constant, equivalent axial currents seems not to be appropriate anymore.

IV. CONCLUSION

We showed that distance averaging can be employed as a valid approach for gain measurements within a distance range entirely below the far-field limit. By applying the weighting functions that we introduced in this paper on measured, near-field data one can accurately assess the gain of an antenna, provided that the probe size is comparable to the wavelength.

Our study was focused on antennas operating at around 1 GHz. The gain could be evaluated for frequencies of up to 2 GHz, based on measurements performed within a distance range of 15 to 60 cm, instead of placing the probe at above 100 cm as the fulfillment of the far-field constraints would require. Furthermore, if one would need to characterize antennas operating at around 100 MHz by applying our technique the measurements might be performed within a distance range of 1.5 m to 6 m. The size of the measuring site (e.g., anechoic chamber or open area test site) can therefore be reduced correspondingly, compared to current far-field approaches.

Future work will focus on developing weighting functions based on a more realistic equivalent current distribution on the antennas. A method-of-moments type approach can be applied to solve equation (3) over a set of distances and therefore to find samples of an axial, equivalent current on the antenna under test.

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