Far-Field Antenna Pattern Estimation from Near-Field Data Using a Low-Cost Amplitude-Only Measurement Setup

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Abstract—In this paper we report some results on the estimation of the far-field of an antenna by using a low-cost amplitude-only near-field measurement setup. A simple experimental setup is used to measure the intensity of the near-field of the antenna under test (AUT) on two planes. The measured intensity of the near field is then numerically processed to determine the far-field pattern. The results confirm the validity of the approach.

Index Terms—Amplitude-only measurements, antenna measurements, near-field techniques, near-field far-field transformation, phase retrieval.

I. INTRODUCTION

Antenna diagnostics from the measurement of the amplitude and phase of the near-field over a plane is a well-established and reliable technique at microwave frequencies [1]. The near-field measurements (in amplitude and phase) are then processed by using efficient algorithms based on the FFT (Fast Fourier Transform) in order to evaluate the far-field.

However, in the last few years effective algorithms for estimation of far-field patterns from amplitude-only near-field measurements have been developed [2]–[7]. These techniques are of interest at millimeter frequencies for testing of electrically large focusing antennas in radiometric and radioastronomic applications. In fact, as long as the frequency increases, the measurement of the phase of the near-field becomes more and more inaccurate. The main factors affecting the phase measurement of the near-field are the mechanical movement and the temperature changes of the cables connecting the receiver to the probe, the probe positioning errors, the inaccuracies in the planarity of the scanning surfaces and the stability and accuracy of the transmitter and receiver. Moreover, less expensive cables can be adopted. All such factors, therefore, allow to simplify and to reduce drastically the overall cost of the entire setup. Finally, the algorithm that we adopted, accurately described in [5], requires a computation effort compatible with the performance of up-to-date personal computers, so that the overall computational cost is also low.

The results reported in this paper were obtained from data collected using a planar near-field facility of the Microwave Laboratory of the University of Napoli "Federico II". The setup consists of the scanning system, the RF part, the data acquisition equipment and the personal computer which controls all of the system.

II. THE NEAR-FIELD MEASUREMENT SYSTEM

The setup consists of the scanning system, the RF part, the data acquisition equipment and the personal computer which controls all of the system.

The components of the scanning system (Fig. 1) are low-cost optical benches, consisting of a vertical linear positioner (PP,
Physik Instrumente PI M-900.455) mounted on a platform over a horizontal linear positioner (PI M-900.454), allowing a maximum scanning area of 60 cm x 60 cm. The probe antenna (PR) is fixed to the vertical positioner platform by means of customized probe holders. The linear positioners are driven by two computer-controlled identical DC motors (PI M-427.00). The antenna under test (AUT) is placed on a positioning system consisting of a z-positioner 100 cm long (HP), a vertical x-positioner (VP) and an optical tilt-rotation platform (TRP). The tilt-rotation system allows the AUT to be positioned parallel to the plane in which the near field is scanned, while the z-axis positioner allows varying the distance between the scanning plane and the AUT so as to collect sets of intensity data over different planes. The vertical column positioner allows a rough x-position control, while a finer positioning is obtained by the TRP. The scanning system and the z-positioner are fixed on an optical table (OT).

Because the setup is not located in an anechoic chamber in order to minimize the main reflection contributions, different types of absorbing panels (AP) are employed. Flat absorbers are positioned on the antenna under test and the probe holders, while pyramidal absorbers cover the table and the lateral sides of the system.

The signal source (SS) is a sweep oscillator generator (HP 8350B sweep oscillator connected to an HP83550A). A scalar network analyzer (NA, HP 8757C) is used as amplitude detector and is connected by a GP-IB interface to a computer.

A 486-DX personal computer (PC) is used to control all the operations of the system and to acquire data by a customized computer program, written in Quick Basic language. During the initialization procedure various parameters can be selected, such as the working frequency, the microwave generator output power, and the number and the spacing of the measurement points.

The first mechanical performance requirement is the accuracy of locating the probe in the scan plane. It depends on the random positioning errors and the bending of the horizontal positioner. The data available for a 1000-mm long positioner
Fig. 3. Normalized contour plot of the measured near field amplitude over the plane at $z = 400$ mm ($20\lambda$); axes and contour levels as in Fig. 2.

gives a maximum random error less than 80 µm. In our case, since the positioner is shorter, the error should be lower; so that the above-mentioned value can be considered an upper bound. The maximum positioning error due to horizontal positioner bending, depending also on the probe weight, is within 30 µm. Probe vibrations were avoided by stopping the probe on the measurement point and waiting for the acquisition. The second mechanical parameter is the uncertainty on the $z$-positioning of the measurement plane, that was limited within 100 µm.

As previously reported, room reflections were minimized by using absorbing panels that were carefully positioned around the measurement system and covered the main part of the positioning system metallic components.

A rough evaluation of the precision and repeatability of the measurement was obtained by collecting the amplitude of the field along a line in the same nominal measurement points many times. The antenna under test was a standard gain horn Narda model 639 radiating at 15 GHz. The measurement has been performed along the $y$ axis, passing through the center of the scanning region, in 16 points equispaced from each other by .225 wavelengths. The AUT and probe were not removed from during the tests, while the electronic instrumentation was re-calibrated before each measurement. The experimental results show a maximum difference between the data lower than $-25$ dB.

III. EXPERIMENTAL RESULTS

The adopted near-field phase reconstruction algorithm is accurately described in [5] where a flow-chart of the algorithm is also reported. The unknown of the problem is the transverse component $E(u, v)$ of the source spectrum, where $u = \beta \sin \theta \cos \phi$, $v = \beta \sin \theta \sin \phi$, $\beta = 2\pi/\lambda$, $\lambda$ being the wavelength. The unknown $E(u, v)$ is represented by a sampling series involving a finite number of samples in the visible domain [5]. The phase retrieval algorithm searches for the global minimum of an objective functional which represents the square distance between the measured square amplitude near-field distributions over two planes and the reconstructed ones. The minimization is performed by means of a standard
locally convergent minimization scheme. Consequently the crucial problem of the existence of local minima arises and critically affects the reliability of the reconstruction since it leads to a false solution [6]. This problem can be solved by increasing the amount of independent square amplitude data [5], [6]; this can be pursued by measuring the square amplitude of the near field over two scanning planar surfaces, adequately spaced from each other. The algorithm is very efficient and of low computational cost, thanks to the use of the FFT algorithm [5].

The experimental results of this section refer to the voltages received by the probe. This does not affect the reliability of the experimental validation of the algorithm. In fact, since the examples at hand concern the probe and the antenna under test having an aperture field $y$-directed, the relationship given for the near-field equally holds for the near-zone voltage [8]. However, if required, the effect of the probe can be taken into account by considering the relation between the PWS (Plane Wave Spectrum) $\tilde{E}$ and the voltages received by the probe either during the minimization [9] or at the end of the phase retrieval procedure.

The first radiating system consists of two phase-fed pyramidal horns (Narda model 639 working at P-band), having an aperture area $55 \text{ mm} \times 38 \text{ mm}$, radiating at $15 \text{ GHz}$. The two horns were placed at $x = -5\lambda$, $y = 0$, and $x = 5\lambda$, $y = 0$ respectively with the longer side along the $y$ axis. As probe we adopted a standard open-flanged waveguide.

The squared amplitude of the voltages received by the probe has been measured over two planes at distances of $5\lambda$ and $12\lambda$ respectively from the aperture plane in $109 \times 109$ points, equispaced from each other by $225\lambda$. The limited extent of the scanning area leads to a rather high truncation of the measured data, mainly over the second surface (about $-20 \text{ dB}$) as shown in Fig. 2.

The 201 unknown complex samples of the voltage spectrum in the visible domain $u^2 + v^2 \leq \beta^2$ are spaced with steps $\Delta u = .0066\beta$ and $\Delta v = .25\beta$, since the voltage spectrum band is about $12.5\lambda \times 2.5\lambda$.

Since the phase information for the near field is not available, the reliability of the result obtained by the solution algorithm is evaluated by comparing the square amplitude voltage measured over a third scanning at a distance of 20 wavelengths
from the aperture plane (Fig. 3) with the one determined from the retrieved spectrum (Fig. 4). The overall precision of the reconstruction of the amplitude near-field functions is related to the measurement errors, and it has been observed to be of the same magnitude on the three surfaces and equal to $-25$ dB according to the precision achievable by the measurement setup.

As a second test source, we consider an in-focus fed parabolic reflector with a circular aperture of radius 13.5 cm, working at the frequency of 10 GHz. The square amplitude voltages have been measured over two planes at distances of $7\lambda$ and $14\lambda$ respectively from the aperture plane, in $77 \times 77$ points equally spaced from each other by a quarter of wavelengths.

The 225 unknowns samples of the voltage spectrum are uniformly spaced in the two directions with the same step $\Delta u = \Delta v = 0.1/3$ since the voltage spectrum band is $5\lambda \times 5\lambda$.

For this test case, the reliability of the retrieved results has been evaluated by comparing the measured phase of the near-zone voltage over one of the scanning planes with the one reconstructed by the approach. In this case the phase distribution of the near field is available because of the temporary availability of a vector network analyzer.

The satisfactory precision of the spectrum retrieved from amplitude-only data can be appreciated by comparing the retrieved voltage spectrum (dotted line) with the one computed from the amplitude and phase near field collected over the first plane (dashed line), in the cut planes $u = 0$ and $v = 0$ respectively (Figs. 5 and 6).

IV. CONCLUSION

The results show a good performance of systems based on low-cost scanning systems and amplitude-only measurement equipment using the near-field phase retrieval approach. An investigation of the stability of the algorithm with respect to low accuracy data assumes a great importance in view of its application to new amplitude-only measurement strategies based on the thermographic detection of the intensity of the near-field [10].

Finally, it can be noted that an extension of the approach, which allows overcoming the necessity of the second scanning surface, is currently set up. This new approach is based on the choice, as data of the problem, of the squared amplitude of the voltages received by two different probes, moving over a single scanning surface [11]. For this approach, the number of independent data required to ensure the reliability of the solution algorithm is obtained thanks to the difference between the far-fields radiated by the two probes.

REFERENCES

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