AMPLITUDE-ONLY MEASUREMENT TECHNIQUE ON STRATEGIC NEAR-FIELD SCANNING SURFACES

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ABSTRACT

The problem of near-field phase retrieval from amplitude-only measurements is faced in this work. A novel hybrid approach is proposed which obtains phaseless information by two co-planar probes simultaneously scanning a single near-field surface. An interferometric procedure is then adopted in conjunction to a minimization technique for retrieving the unknown near-field phase. The proposed approach is experimentally validated on a cylindrical scanning surface with a X-band pyramidal horn used as test antenna. The phase retrieval procedure is also applied to the helicoidal scanning geometry and an efficient far-field transformation directly applied to near-field helicoidal data is developed and numerically validated.

Key words: Antenna measurements; Near-Field; Phaseless techniques.

1. INTRODUCTION

Testing facilities in the radiating near-field region are established today as low-cost and compact environments for antenna far-field characterization. Standard technique is based on a complex near-field probing, but difficulties are encountered to have a reliable phase characterization as long as the frequency increases, unless complex and expensive setup are used. To maintain accuracy at millimeter frequencies, techniques based on near-field amplitude-only measurements have been proposed [1]. They reduce the antenna far-field determination to non-linear estimation problem, which is formulated as the minimization of a proper functional. Near-field phase is obtained from the knowledge of amplitude distributions over two or more scanning surfaces, but the existence of a unique global minimum is not always assured, due to the intrinsic non-convexity of the involved functional. Improved techniques have been introduced to solve these trapping problems, by using the square amplitudes over two distinct surfaces as known data, so defining a cost functional which guarantees the existence of a unique solution [2]. A novel hybrid approach has been recently proposed by the authors [3-4] to retrieve the near-field phase information from the knowledge of amplitude-only distribution on a single measurement surface. Two co-planar probes are used for simultaneously scanning the acquisition region and amplitude information are processed by an interferometric algorithm , but avoiding the need of a reference source as required in standard interferometry. A X-band prototype of the integrated probe is realized and experimentally tested on a cylindrical near-field surface, with a pyramidal horn used as Antenna Under Test (AUT). In order to reduce both acquisition and computation times, a strategic configuration based on a cylindrical helix geometry is also considered. The application of the phase retrieval procedure is particularly simple in this case, since a unique interpolation is required along the helicoidal curve. However, this choice for the scanning surface strongly complicated the far-field computation, as a direct application of the two-dimensional fast Fourier transform (FFT) is not allowed by the helicoidal data arrangement. To solve this drawback, an efficient algorithm is also developed which avoids any intermediate interpolation of the near-field data on cylindrical surfaces and computes the far-field pattern directly from helicoidal samples, by exploiting the Fourier transform shift property. This transformation procedure is numerically tested on a uniform array of Huyghens sources.

2. NEAR-FIELD PHASE RETRIEVAL

The proposed phase retrieval technique processes amplitude information measured by the integrated probe in Fig.1. Complex signals received by two identical measuring antennas are transmitted to a microstrip circuit and summed, both in phase and in quadrature, by two hybrids mounted on the same circuit board. Simple detector diodes (Fig.1) are used to measure the necessary amplitude quantities, namely [3]:

$$|V_1|^2, \quad ,|V_2|^2, \quad ,|V_1+V_2|^2, \quad ,|V_1+jV_2|^2 \qquad (1)$$

where $V_1 = |V_1| \cdot e^{j\varphi_1}$ and $V_2 = |V_2| \cdot e^{j\varphi_2}$ are the voltages at the probes outputs.

The unknown phase shift $\Delta\varphi = \varphi_1 - \varphi_2$ is retrieved by the following interferometric formula [3]:

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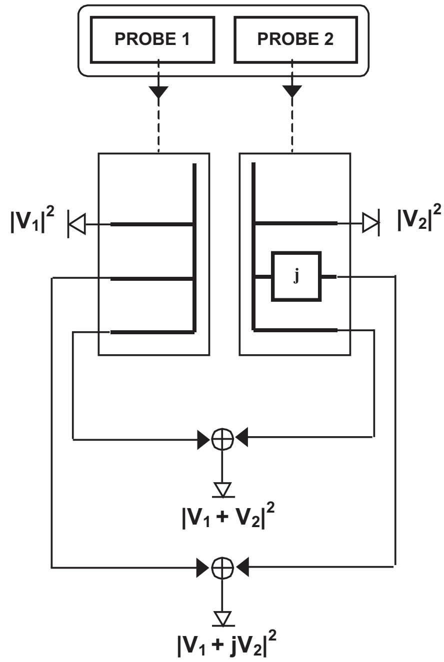

Figure 1. Probe architecture

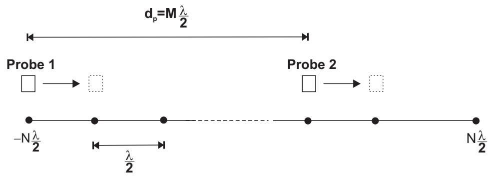

Figure 2. Two-probes movement along a single measurement curve

$$\Delta\varphi = tg^{-1}\left[\frac{|V_1 + jV_2|^2 - |V_1|^2 - |V_2|^2}{|V_1 + V_2|^2 - |V_1|^2 - |V_2|^2}\right] \qquad (2)$$

If we consider a scanning curve with 2N+1 samples (N even, for simplicity) acquired by the measuring probes at a distance $d_p = M\frac{\lambda}{2}$ (Fig.2), eq.(1) provides M independent sets of complex near-field data, with M-1 unknown phase shifts to be determined. For the simple case M=2, two sets are given by the interferometric procedure, on even and odd points, respectively. The single phase shift between them can be retrieved by an interpolation procedure fixing one phase value for the first set and obtaining a reference phase value for the second set by interpolation of two consecutive phases of the measurement sequence [3].

The case $M = 2$ corresponds to a distance $d_p = \lambda$ generally assuring a negligible mutual coupling between the probes, however a value $M > 2$ is in practice required as due to the physical dimensions of the probes. In this case, more than one unknown phase shift must be determined, so a minimization procedure is adopted which finds the intersection between the set of all fields

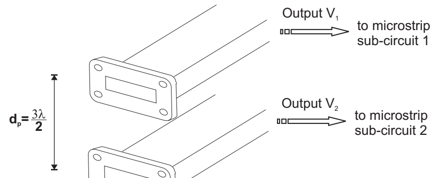

Figure 3. Rectangular waveguides for X-band probe

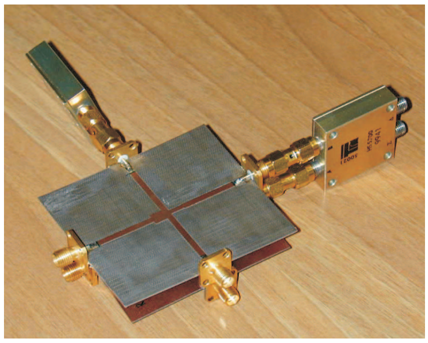

Figure 4. Microstrip circuit and hybrids for X-band probe

compatible with measured data and the set of all fields that the AUT can radiate [4]. In order to have reliable results, a non-redundant representation [5] is adopted in terms of reduced field and the problem of determining the unknown phase shifts is formulated as the finding of the infimum (greatest lower bound) distance between the two sets [4].

2.1. Test case: X-band probe

A X-band prototype of the integrated probe has been realized for experimental purposes. Two rectangular waveguides (Fig.3) have been used as measuring antennas, directly connected to a microstrip circuit (Fig.4) providing the required amplitude information. Due to the presence of flanges, a distance $d_p = \frac{3\lambda}{2}$ (Fig.3) has been adopted.

The effectiveness of X-band probe has been tested on a pyramidal horn having a square radiating aperture of size equal to 5 cm. Amplitude-only measurements at different frequencies within X-band have been performed on a cylindrical near-field surface, by imposing a linear movement of the integrated probe along the cylinder z-axis and a rotation of the AUT along the azimuthal direction.

For the frequency f=8GHz, phaseless data have been collected on a grid of 37x83 points along z and ϕ directions, respectively, with sampling steps $\Delta z = \frac{\lambda}{2} = 1.875cm$ and $\Delta\phi = 4.33^o$. Interferometric formula given by eq. (2) has been used in conjunction with the minimization procedure discussed in [4] to obtain the unknown near-field phase distribution on the measurement surface. A good agreement between directly measured and retrieved near-field phase can be observed in Figg. 5-6. A bad re-

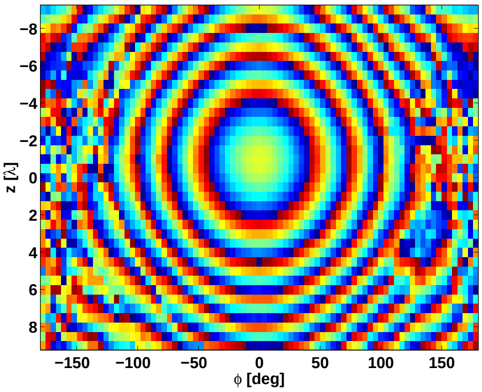

Figure 5. Measured near-field phase on the cylindrical surface

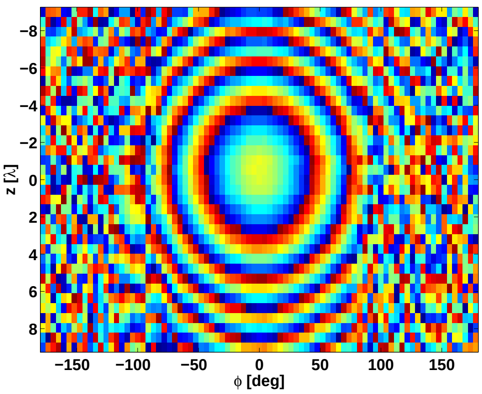

Figure 6. Retrieved near-field phase on the cylindrical surface

construction exists only in the peripheral zone, however the small amplitude values measured in this region have a poor influence in the far-field reconstruction, as shown in Fig. 7 by comparison of H-plane results obtained from retrieved and measured near-field phase.

3. NEAR-FIELD PHASE RETRIEVAL ON STRATEGIC SURFACES: THE HELICOIDAL CASE

In order to reduce both acquisition and computation times, new strategic surfaces have been recently considered, the most promising ones being the bi-polar and the helicoidal configurations. The extension of the phase retrieval procedure to the cylindrical helix geometry has been recently proposed by the authors in [6], where a near-field scanning of the integrated probe is imposed along the helicoidal curve by assuming a distance between the measuring probes as given by the following expression [6]:

$$d_p = r_o\sqrt{2\left(1 - cos(2\Delta\phi)\right)} \tag{3}$$

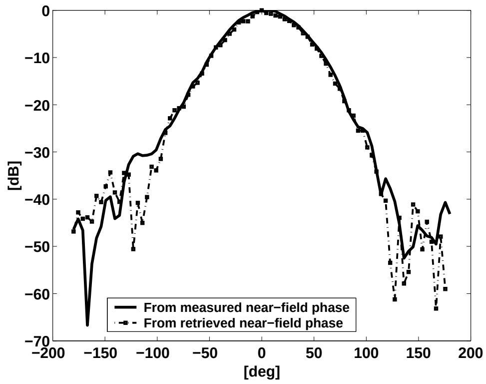

Figure 7. Far-field pattern (H-plane)

In the above relation, the term r_o is the radius of the cylindrical helix, while $\Delta\phi$ is the azimuthal sampling step. As shown in Fig.8, the two probes locations are also shifted along the z-axis by a quantity $2\Delta z$, where $\Delta z = \frac{p\Delta\phi}{\pi}$, p being the helix step, i.e. the distance between two adjacent points along a generatrix. Phase retrieval from amplitude data on the cylindrical helix is easily performed by a simple interpolation procedure along the helicoidal curve, with a significant reduction of the computation time when compared to standard cylindrical geometry. Once obtained the complex near-field on the helicoidal geometry, the subsequent far-field computation is generally an intensive task, since a direct application of the two-dimensional FFT is not allowed as in the cylindrical case. Methods adopted in literature perform an interpolation of the helicoidal measurement points on the equivalent cylindrical grid suitable to the application of the well-known cylindrical near-field to far-field transformation [7,8]. An efficient algorithm has been proposed by the authors in [6] to directly compute far-field pattern from near-field helicoidal data, by application of the FFT and the related shift property. Near-field data are first arranged into a matrix $B \in \mathcal{C}^{M_H x N_H}$ (one matrix for each field component), where M_H is the number of helicoidal revolutions and N_H the number of azimuthal samples for each revolution. By assuming a helix step $p = \frac{\lambda}{2}$, data along each cylinder generatrix result to be spaced of a quantity $\Delta z = \frac{\lambda}{2}$, but a shift Δz_ϕ exists between two adjacent columns.

Now, let us consider the expansion of the measured near-field at coordinates (r_o, ϕ_o, z_o) in terms of a complete and orthogonal set of cylindrical waves, with coefficient $a_n(h)$ and $b_n(h)$ given as:

$$b_n(h)\frac{\Lambda^2}{k}H_n^{(2)}(\Lambda r_o) =$$
$$= \frac{1}{4\pi^2}\int_{-\infty}^{\infty}\int_{-\pi}^{\pi} E_z(\phi_o, z_o)e^{-jn\phi_o}e^{jhz_o}d\phi_o dz_o \tag{4}$$

$$b_n(h)\frac{nh}{k}H_n^{(2)}(\Lambda r_o) - a_n(h)\frac{\partial H_n^2}{\partial r}(\Lambda r)|_{r=r_o} =$$

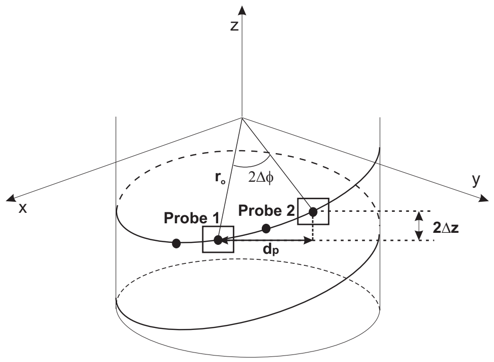

Figure 8. Probes positions in the helicoidal scanning configuration

$$= \frac{1}{4\pi^2}\int_{-\infty}^{\infty}\int_{-\pi}^{\pi} E_\phi(\phi_o, z_o)e^{-jn\phi_o}e^{jhz_o}d\phi_o dz_o \qquad (5)$$

In the above relations, k is the free space propagation constant, $\Lambda = \sqrt{k^2 - h^2}$ and $H_n^{(2)}(...)$ is the Hankel function of the second kind of order n. Once computed the expansion coefficients, the far-field is obtained by the asymptotic evaluation of the cylindrical wave expansion.

In the helicoidal case, the numerical implementation of integral appearing in relation (4) can be expressed as [6]:

$$I_n(h) = \sum_{r=0}^{N_H-1}\sum_{s=0}^{M_H-1} E_z(r\Delta\phi, s\Delta z + r\Delta z\phi)e^{-j\frac{2\pi nr}{N_H}}e^{j\frac{2\pi hs}{M_H}} \qquad (6)$$

After some manipulations, the above relation can be written as [6]:

$$I_n(h) = \sum_{r=0}^{N_H-1}\widetilde{E}_z(r\Delta\phi, h)e^{-j\frac{2\pi nr}{N_H}}e^{-j\frac{2\pi hr\Delta z_\phi}{M_H}} \qquad (7)$$

where the term $\widetilde{E}_z(r\Delta\phi, h)$ represents the Discrete Fourier Transform (DFT) of the column r in matrix B. After application of the Fourier transform shift property, the expression $\widetilde{E}_z(r\Delta\phi, h)e^{-j\frac{2\pi hr\Delta z_\phi}{M_H}}$ can be easily identified as the DFT of the sequence $E_z(r\Delta\phi, s\Delta z)$, translated by a quantity $r\Delta z_\phi$ and corresponding to the FFT of column r in the cylindrical case. The algorithm steps for the computation of integral $I_n(h)$ can be summarized as follows [6]:

1. perform FFT on the columns of near-field helicoidal data;
2. apply the Fourier transform shift property to the transformed columns;

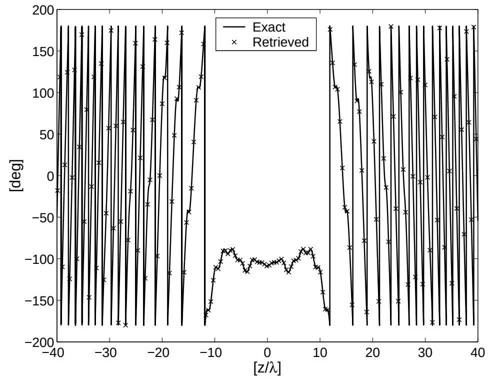

Figure 9. Comparison between exact and retrieved near-field phase along the helicoidal curve

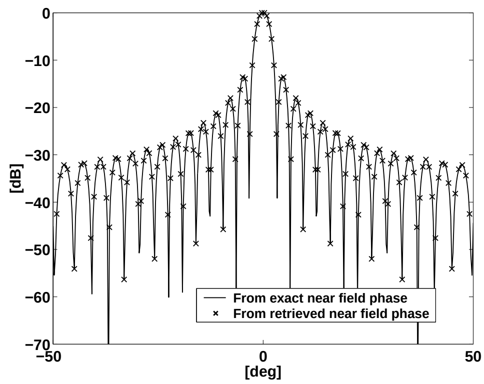

Figure 10. Far-field (E_θ component): comparison of results from exact and retrieved near-field phase

3. perform FFT on the rows of matrix obtained from previous steps.

The procedure is obviously applied also for the computation of integral in (5) involving E_ϕ component. Numerical validations of the proposed near-field to far-field transformation procedure have been performed on a uniform array of 37 elementary Huyghens sources 0.5λ spaced and z-polarized. Amplitude-only near-field has been simulated on a cylindrical helix of radius $r_o = 21.5\lambda$ and height $h = 120\lambda$, at an angular step $\Delta\phi = 4.38^o$. The phase retrieval procedure has been successfully applied to obtain the unknown near-field phase reported in Fig.9, which results to be in good agreement with the exact phase. The effectiveness of the far-field computation algorithm has been also proved by comparison (Fig.10) of far-field results obtained from direct and retrieved near-field phase.

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