Computer Reconstructed Holographic Technique for Phase-less Near-Field Measurement

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Abstract ─ A novel holographic near-field phase-less technique is presented. The measurement system is composed of the antenna under test, the reference antenna, the amplitude scanning measurement system, and the holographic reconstructed algorithm. The interference amplitude of the antenna under test with the reference antenna is measured by the amplitude scanning system. The complex near field of the antenna under test is reconstructed by a computer, where the measured interference is corrected by the multiplication with the virtual spherical reference wave and then filtered in Fourier transformation domain (e.g., plane wave angular spectrum) or the back-projected image space. The reconstruction method is rigorous without traditional Fresnel approximation. The novel technique requires the amplitude on one measurement surface and the computer reconstructed algorithm, while the previous phase less technique depends on two measurement surfaces or extra hardware to provide synthesized-reference-wave. The novel measurement method and reconstruction algorithm could be used in many applications as for the planar near field measurement for example. Simulated results are presented to demonstrate the complex field retrieval method and near-field to far field transformation.

Index Terms ─ Antenna measurements, hologram, near-field, and phase-less measurements.

I. INTRODUCTION

As well known the radiation characteristic of an antenna under test (AUT) is defined at far field distance and is therefore to be measured at the plane wave condition, which could be a physical or digital synthesis quiet zone. Far field range and compact range provide real plane wave where the pattern of the AUT [1] is measured directly. Near-field technique measures the radiation field in the near zone and calculates the radiation pattern [2, 3] employing post-processing near-field far field transformation (NFT) to obtain the synthesized plane wave. Although the phase error from the probe position can be corrected to some extent by employing some optical tracking device, it is very difficult to reduce the cable fluctuation phase error. The excessive cost of vector measurement and the phase accuracy restrict the application of near-field technique, especially for millimeter wave or sub millimeter bands. Phase less techniques are presented to overcome these difficulties, including planar [4, 5] and spherical measurements [6], where the costly phase measurement equipments are no longer required for the conventional NFT. The lack of phase information can be compensated by the additional amplitude on more measurement surfaces. The phase retrieval techniques rely on the wave propagation relationship between the measurement surfaces, e.g., Fourier angular spectrum for planar measurements, spherical modal expansion for spherical measurements. The amplitude scanning

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measurements on more surfaces increase the burden of testing time and iterative reconstruction calculation, especially for electrically large or low side lobe AUTs.

Holography was firstly described by Dennis Gabor for the optical imaging systems. It is a two-step process: (1) recording the interference pattern (only amplitude) from the sum of wave fronts interacted with an object wave and a reference wave; (2) reconstruction of the object wave fronts from the recording. Gabor's holography was developed to the off-axis geometry for avoiding overlap by Emmett Leith and Juris Upatnieks in [7] and [8]. Based on these theories, the holographic near field phase less technique can be multiplied for antenna measurements. An off-axis reference antenna is included in the traditional near field measurement system. The interference amplitude of the AUT with the reference antenna is recorded by the amplitude scanning system. The complex near field of the AUT can be reconstructed by a computer with the measured interference amplitude, where the key process is how to separate and remove these unwanted terms including the reference wave and its complex conjugate. There are some ways such as Fresnel nonlinear phase approximation compensation [9] and synthesized-reference-wave [10-12] for the reference plane wave. Synthesized-reference required extra hardware including the directional coupler and a high quality flexible cable for the inner reference, and a variable attenuator and a phase shifter for the off-axis plane wave. There are some potential disadvantage for this method in the millimeter/submillimeter band because of the phase shifter's accuracy and the fluctuation error of the reference cables. This paper presents a novel near field computer reconstructed hologram (NFCRH), which will overcome the disadvantage in the synthesized-reference-wave holography. The complex near field of the antenna under test is reconstructed by computer, where the measured interference is just corrected by the multiplication with the virtual spherical reference wave and then filtered in the angular spectrum domain and the spatial domain.

In this paper the holographic near field phase less technique is presented for antenna measurements. Section II devotes the detailed concept and the rigorous reconstruction algorithm. Section III shows the simulated results of a medium antenna.

II. CONCEPT AND ALGORITHOM

As shown in Fig. 1, the signal from one coherent source is allocated to the antenna under test and reference antenna through a directional coupler, the interference field in the scanning area (planar, cylindrical, or spherical surface) is measured by a magnitude scanning probe. The control and process of measurement system is realized by a computer. The near-field amplitude and phase of the antenna under test is reconstructed by a virtual signal processing algorithm described in flow.

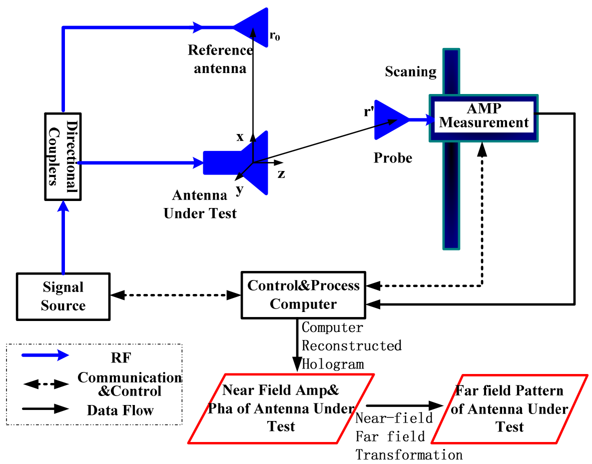


Fig. 1. Flowchart of holographic phaseless algorithm working with amplitude only data on one surface.

When the magnitude probe is scanning in near-field, the interference field in the scanning surface is summed coherently by the radiation field of test antenna and reference antenna, which can be expressed as,

$$E_g(\mathbf{r}') = A(\mathbf{r}')e^{j\phi(\mathbf{r}')} + Be^{-jk|\mathbf{r}_0-\mathbf{r}'|}/|\mathbf{r}_0-\mathbf{r}'|. \quad (1)$$

In which E_g is the interference field, $A(\mathbf{r}')$ and $\Phi(\mathbf{r}')$ is the amplitude and phase under test in any scanning position, separately. B is the unbalance factor between two channels. $e^{-jk|\mathbf{r}_0-\mathbf{r}'|}/|\mathbf{r}_0-\mathbf{r}'|$ is the reference spherical wave, $\mathbf{r}_0$, $\mathbf{r}'$ is the position vector of the probe and the reference source where the antenna under test is set to the zero position. k is the wave number in free space.

The amplitude obtained by the measurement system can be expressed as,

$$\begin{aligned}\left|E_{hf}(\mathbf{r}')\right|^2 &= [A(\mathbf{r}')e^{j\phi(\mathbf{r}')} + Be^{-jk|\mathbf{r_0}-\mathbf{r}'|} / |\mathbf{r_0}-\mathbf{r}'|]\times \\ &[A(\mathbf{r}')e^{j\phi(\mathbf{r}')} + Be^{-jk|\mathbf{r_0}-\mathbf{r}'|} / |\mathrm{r}_0-\mathbf{r}'|]^* \\ &= A^2(\mathbf{r}') + B^2/|\mathbf{r_0}-\mathbf{r}'|^2 \\ &+2BA(\mathbf{r}')/|\mathbf{r_0}-\mathbf{r}'|\cos[\phi(\mathbf{r}')+k|\mathbf{r_0}-\mathbf{r}'|]\ .\end{aligned} \quad (2)$$

The reconstruction step is implemented by a computer for the hologram. The reconstructed field E_r can be obtained when $|E_{hf}|^2$ is corrected by the multiplication with the virtual reference across the scanning surface,

$$\begin{aligned}E_r(\mathbf{r}') &= |\mathbf{r_0}-\mathbf{r}'|\,e^{-jk|\mathbf{r_0}-\mathbf{r}'|}\times\{A^2(\mathbf{r}')+B^2/|\mathbf{r_0}-\mathbf{r}'|^2 \\ &+2BA(\mathbf{r}')/|\mathbf{r_0}-\mathbf{r}'|\cos[\phi(\mathbf{r}')-k|\mathbf{r_0}-\mathbf{r}'|]\} \\ &= BA(\mathbf{r}')e^{-j[\phi(\mathbf{r}')+2k|\mathbf{r_0}-\mathbf{r}'|]} \\ &+[A^2(\mathbf{r}')|\mathbf{r_0}-\mathbf{r}'|+B^2/|\mathbf{r_0}-\mathbf{r}'|]e^{-jk|\mathbf{r_0}-\mathbf{r}'|}+A(\mathbf{r}')Be^{j\phi(\mathbf{r}')}.\end{aligned} \quad (3)$$

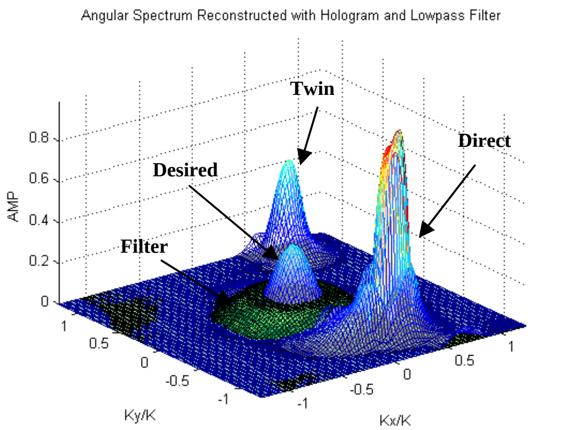
The reconstruction method is rigorous without Fresnel approximation [9]. Because the paraxial approximation is in conflict with the off-axis holography, the previous work using a spherical reference wave has been carried out with limited success [10]. Here a novel holographic near-field reconstruction technique is presented to overcome these limitations. The first two in equation (3) contain the space modulated carrier of reference signal, the off-axis design of reference signal leads to a higher spatial carrier, and makes the wave under test, the direct wave and the twin-wave reconstructed by holographic separable in spatial spectrum domain and the aperture back-projected. Both the amplitude and phase of the antenna under test are all low-frequency signals and varying slowly. They can be obtained through low-pass filtering. So we do Fourier transform for E_{h}, and then extract the low-frequency information. For a low gain antenna with the wide spatial spectrum it is not easy to separate the reconstructed spectrum. The holographic spectrum can be back-projected to the aperture where the reference source and under test is resolved by the imaging technique [13-16]. Finally, when the unwanted item have been filtered out the amplitude and phase of the antenna under test can be reconstructed by the inverse transform for the far field pattern.

III. SIMULATION RESULTS

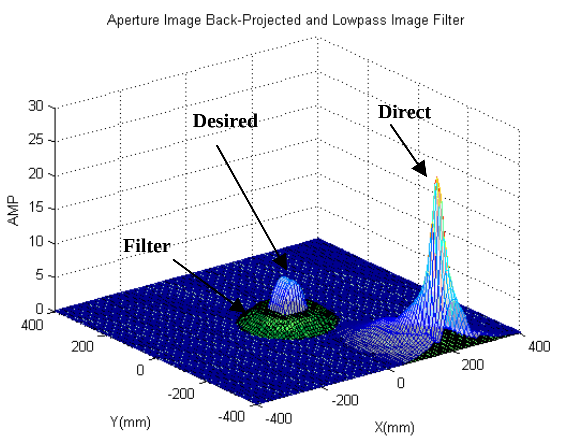
Simulations have been done for a pyramidal horn as the antenna working at 15 GHz. The aperture field has been assumed to be a cosine function in the H-plane (oriented in the *x*-axis) with the dimensions *a* = 100 mm, and an uniform distribution in the E-plane (oriented in the *y*-axis) with the dimensions *b* = 70 mm. The near field amplitude and phase can be calculated by Rayligh-Sommerfeld formula [15] at a measurement plane (with the dimensions 800 mm × 800 mm, the sampling step 8 mm, which is less than λ/2, the distance 265 mm to the aperture under test). The antenna under test is set to zero position and the reference point source locates *x* = 175 mm and y = -360 mm. The interference amplitude of the antenna under test with the reference wave can be summed as the measurement value of the scanning probe.

The field reconstructed with hologram can be obtained using equation (3). These results can be transformed to angular spectrum by fast Fourier transformation (Fig. 2 (a)) where the spatial frequency is normalized to wave number, or back-projected to the aperture (Fig. 2 (b)) using near field imaging. The unwanted items can be separable and filtered out using low pass filter from the signal under test. In the angular spectrum domain these terms is separated in the k_x and k_y axis locations, while the imaging space is in the *x* and *y* axis. Because the reference antenna just locates at one point, it is easier to separate them in *x* and *y* space than in angular spectrum.

The complex near field reconstruction achieved by the angular and the image filter is show in Figs. 3 and 4, where the locations are the vertical and horizontal line in the measurement plane. These results show a high degree of agreement in the H-plane, however the level of agreement in the E-plane is reduced using angular filter. This is due to the point reference source location near to E-plane with a wider angular spectrum. The higher agreement has been obtained using image filter both in the E-plane and H-plane over the range ±asin (0.7) = ± 44.4°, which is near to the valid angle of NFT because those unwanted items can be removed more clearly due to the point source's spatial localization. Moreover, it can be seen that the calculated far field pattern is reconstructed from the complex near field. The accuracy of reconstructed far field can be reduced by the unbalance between the reference and test channels. The comparisons are shown in Figs. 5 and 6.

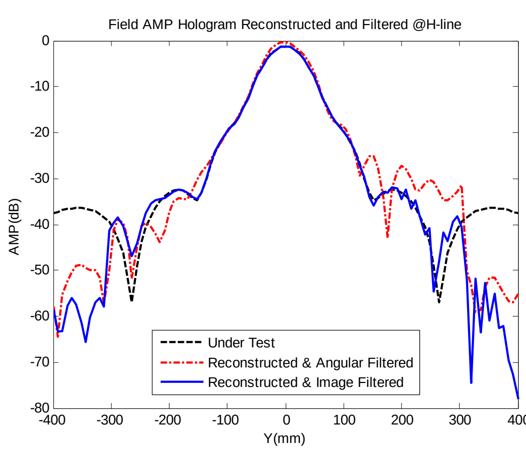


(a) Reconstructed and calculated angular spectrum of reconstructed field E_r.

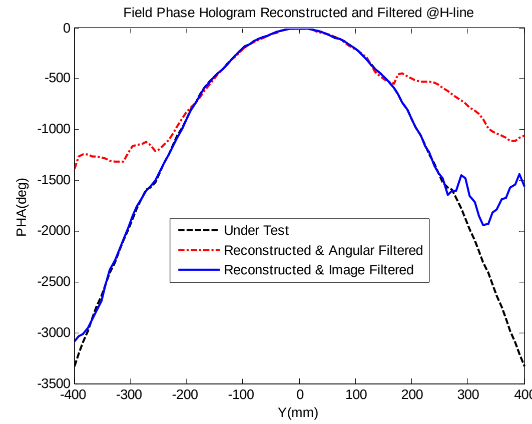


(b) Reconstructed and calculated aperture image of reconstructed field E_r.

Fig. 2. Calculated results for reconstruction and filtering.

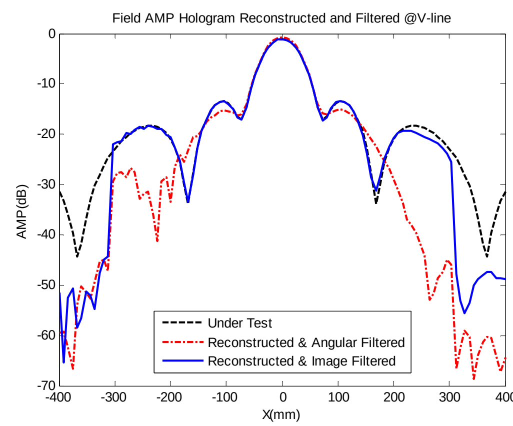


(a) Amplitude

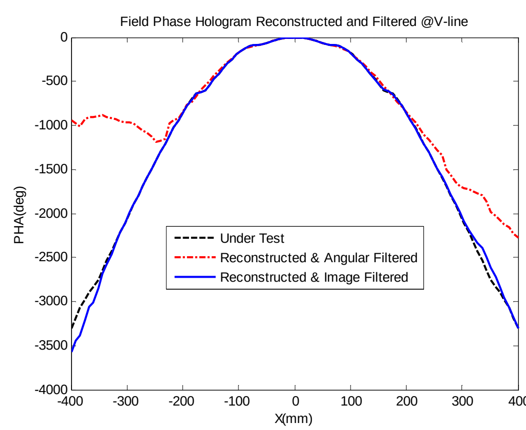


(b) Phase

Fig. 3. Near field amplitude and phase hologram reconstructed and angular/image filtered in the horizontal line.

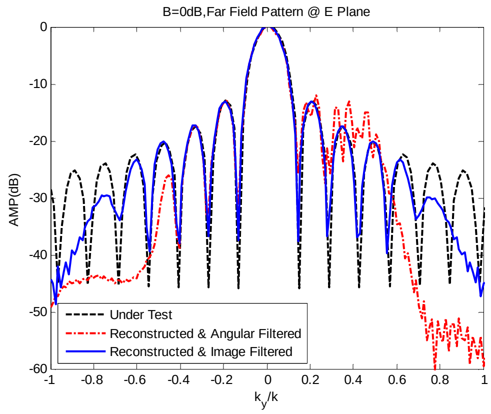


(a) Amplitude

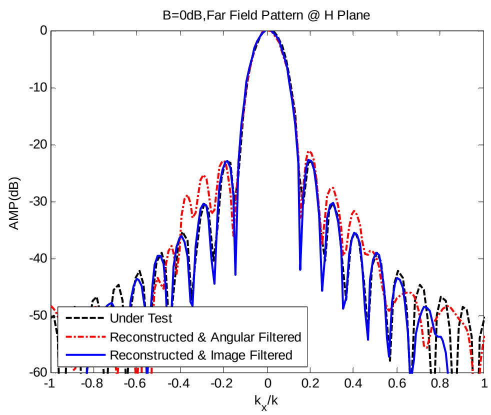


(b) Phase

Fig. 4. Near field amplitude and phase hologram reconstructed and angular/image filtered in the vertical line.



(a) E-Plane



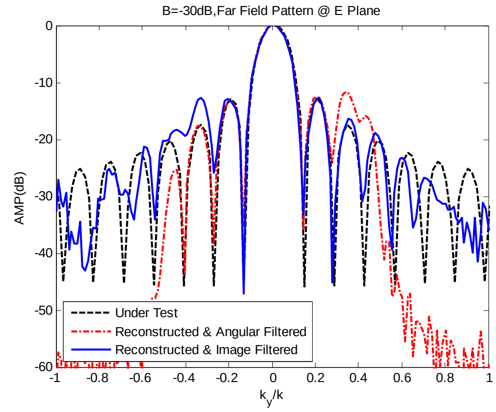
(b) H-Plane

Fig. 5. Calculated far field pattern from the reconstructed complex near field of the pyramidal horn under test in the E-and H-Planes (B = 0 dB).

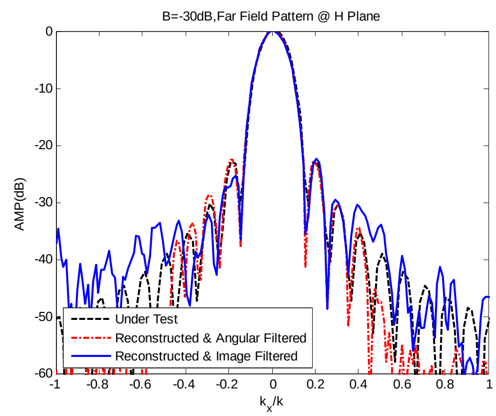
IV. CONCLUSION

A holographic near-field phase less technique using the computer reconstruction algorithm to determine the complex near field and the far field pattern has been proposed in this paper. The innovation of the technique lays in the reference correction and the filter methods. In comparison with the previous technique, it does not require two measurement surfaces or extra hardware.

The effectiveness of the technique has been verified by numerical simulations using an aperture antenna with the medium gain. The results have been shown that the approach can provide the accurate near field and far field. The comparison of the filter methods show that the back-projected image filter more fits to the medium-gain antenna than angular spectrum filter. The accuracy of the reconstruction algorithm and filter methods has been confirmed by comparison of the results with the true value from the aperture.



(a) E-Plane



(b)H-Plane

Fig. 6. Calculated far field pattern from the reconstructed complex near field of the pyramidal horn under test in the E-and H-Planes (B = -30dB).

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