PLANAR NEAR-FIELD SCANNING IN THE TIME DOMAIN

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ABSTRACT

The paper provides a theory and a computation scheme for calculating the far-field pattern in the time domain from sampled near-field data over a planar scanning surface. The presented computation scheme is based on a time domain near field to far field formula and computes the time domain far field directly from the time domain near field. Its capability of eliminating finite scan errors is presented here and illustrated by a numerical example.

1 INTRODUCTION

The planar near-field technique is an effective method for measuring the performance of large antennas and other advanced low side-lobe antennas, which cannot be fitted into an anechoic chamber. However, near-field measurement in frequency domain can be excessively long for electrically large and sophisticated antennas, phased arrays and multi-beam antennas in radar. A dramatic reduction in the duration of measurements for such antennas can be achieved by using time domain techniques and time domain near-filed scanning especially. Moreover, the reflections caused by mismatching and undesired multiple reflections in an antenna range can be removed by using time domain gating. In planar near-filed measurements, a scan plane with finite size is used and of course it results in scan plane errors [1]. Those scan plane errors can be partially removed by using time domain gating in the time domain planar near-field scanning as demonstrated below.

2 TIME DOMAIN NEAR-FILED SCANNING THEORY

Two different approaches are used in determining far fields in the half space $z > z_0$ in terms of their values on the plane $z = z_0$. In the first approach, the time domain formulas are obtained by inverse Fourier transform of the corresponding frequency domain formulas [2]. In the second approach, the time domain near-field formulas are derived directly in the time domain. In this paper, we deal with the second approach, which is also able to remove errors caused by using finite scanning plane [3]. Since the derivation of time domain near-filed formulas is quite complicated and extensive, only final formulas and guidelines for computing time domain far fields from near-field samples are presented here. More detailed information for both computation schemes can be found in [2].

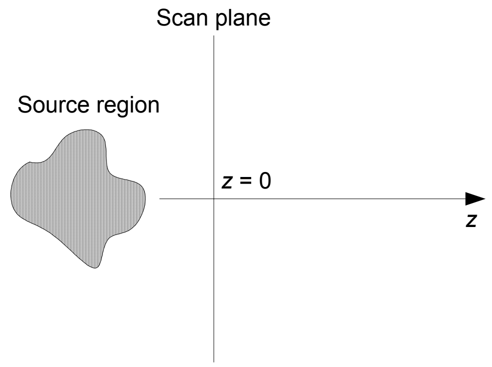

Fig. 1: *Planar scanning geometry*

The planar scanning geometry is shown in Fig. 1 with the finite source region located in the half space $z < z_0$. The fields are specified on the plane $z = z_0$ and we are interested in calculating the fields in the half space $z > z_0$. All fields are assumed to be zero for $t < 0$ and the time dependence of the field for $t \geq 0$ is assumed to be such that their frequency spectrum is finite at $\omega = 0$. This assumption eliminates possible static fields. The part of the space, which is not occupied by the sources, is lossles free space of permeability μ and permittivity ε. In addition to the rectangular coordinates (x, y, z), the usual spherical coordinates (r, θ, ϕ) are defined

$$\begin{aligned} x &= r\sin\theta\cos\phi \\ y &= r\sin\theta\sin\phi \\ z &= r\cos\theta \end{aligned} \qquad (1)$$

The time domain computation scheme simply consists of using the direct time domain formula for the far-field pattern [3]

$$\vec{F}(\theta,\phi,t) = -\frac{1}{2\pi c}\bar{r}\times\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\bar{z}\times\frac{\partial}{\partial t}\vec{E}\left(\vec{r}_0, t+\bar{r}\frac{\vec{r}_0}{c}\right)dx_0 dy_0 \quad , \qquad (2)$$

where $\bar{r} = \bar{x}\cos\phi\sin\theta + \bar{y}\sin\phi\sin\theta + \bar{z}\cos\theta$ is a unit vector in spherical coordinates, $\bar{z}$ is a unit vector in z-axis, c is velocity of the light and $\vec{r}_0 = x_0\bar{x} + y_0\bar{y}$ is a vector of a sampling point on the scanning plane (Fig. 2). This formula uses the time domain near field directly; each point on the scanning plane is represented by a waveform of the electric field. For simplicity, the time derivate of the near field on the scan plane is assumed being known (this is a realistic assumption because some probes actually measure the time derivative of the field).

Eqn. (2) can be converted to the double summation by means of the sampling theorem

$$\vec{F}(\theta,\phi,t) = -\frac{1}{2\pi c}\bar{r}\times\sum_{m=-N_x}^{N_x}\sum_{n=-N_y}^{N_y}\bar{z}\times\frac{\partial}{\partial t}\vec{E}\left(\vec{r}_{0mn}, t+\bar{r}\frac{\vec{r}_{0mn}}{c}\right)\Delta x_0\Delta y_0 \quad , \qquad (3)$$

where $\vec{r}_{0mn} = m\Delta x_0 \bar{x} + n\Delta y_0 \bar{y}$ is a sampling point on the scan plane and $\Delta x_0 = \Delta y_0 = \lambda_{min}/2$. This formula represents a time-domain sampling theorem that requires one to sample the time domain near field at a spatial sample spacing of $\lambda_{min}/2$, the same spacing is required by the frequency-domain computation scheme [1].

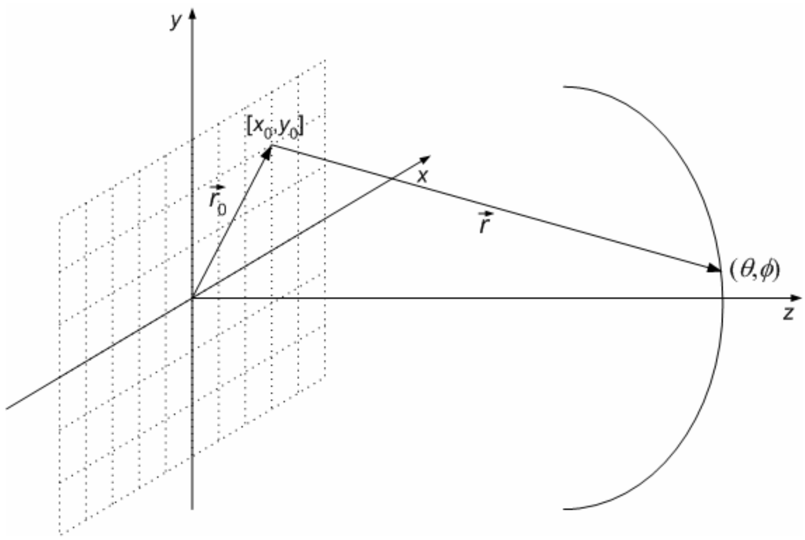

Fig. 2: *Geometry of the scanning plane and far-filed points*

3 NUMERICAL EXAMPLE

Properties of the near-field time-domain scanning using time-domain computation scheme are shown in the following numerical example for the acoustic point source. The formula for the acoustic field can be obtained from (3) by replacing $\bar{z} \times \vec{E}$ with Φ, $\vec{F}$ with F and $\bar{r}\times$ with $-\cos\theta$, respectively.

Acoustic point source antenna is located at $\vec{r}_1 = -d\bar{z}$ ($d > 0$), and its field is given by

$$\Phi(\vec{r}, t) = \frac{f\left(t - |\vec{r} - \vec{r}_1|/c\right)}{4\pi|\vec{r} - \vec{r}_1|}, \tag{4}$$

where $f(t)$ is the Gaussian time function

$$f(t) = e^{-\frac{4t^2}{\tau^2}}, \tag{5}$$

where τ equals to the half of the signal width. The signal width is defined such that $|f(t)| < 0.002\,|f(0)|$ for $|t| > \tau$. Its spectrum is approximately zero for $\omega > 12/\tau$ and therefore $\omega_{max} = 12/\tau$. The point source is located at $\vec{r}_1 = -d\bar{z}$, where $d = 2\lambda_{min}$, and the scan plane is taken to be a square of side length 10*d* located in the plane $z = 0$ (Fig. 3).

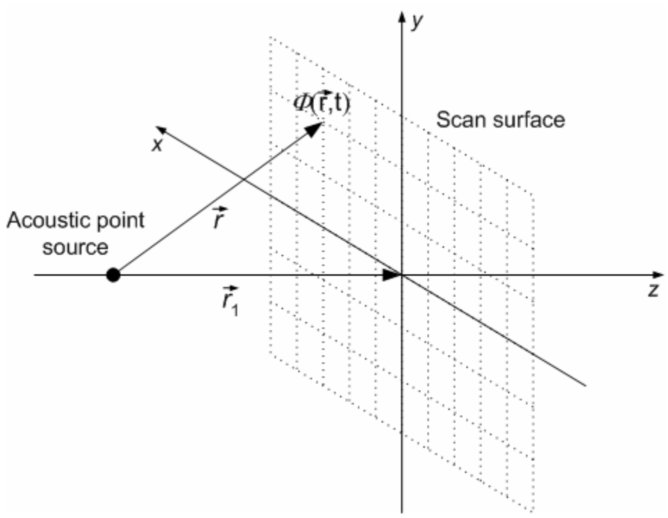

Fig. 3: *Geometry for the acoustic point source near-field computation*

Results for the far-field pattern obtained from the acoustic version of the time domain formula (3) are in the following figure (Fig. 4) compared to the exact curve. Curves for theta below 40 degrees have some visible differences in its slope but approximates the exact curve well on the interval $-0.5\tau < t < 2\tau$. For times $t > 2\tau$, it is negative and erroneous.

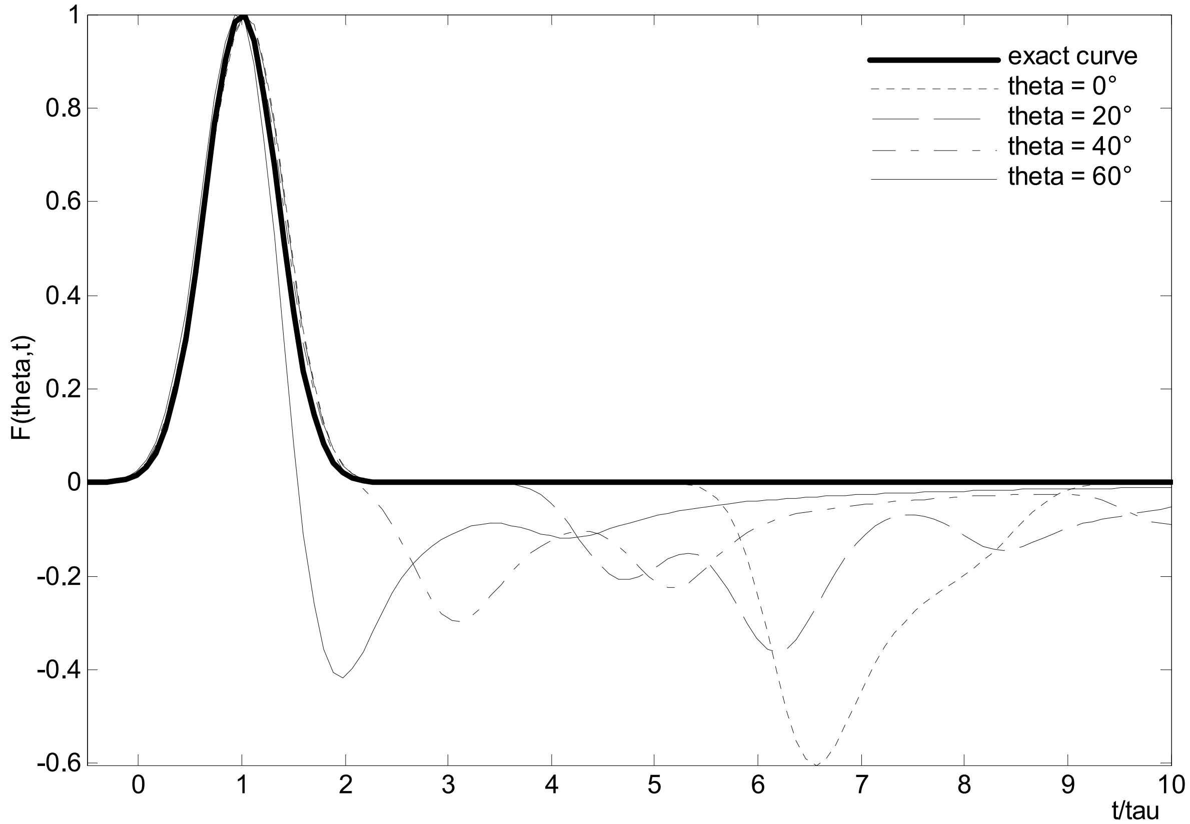

Fig. 4: *Far-field patterns for a Gaussian point source*

The erroneous behavior is due to the finite scan plane. This observation is confirmed by the fact that the time between the arrival of the direct signal ($t \cong -0.1\tau$) and the arrival of the erroneous signal ($t \cong 5.2\tau$) for the theta 0° is equal to the time it takes the signal to travel the distance from the source to the midpoint of the edges on the scan plane (Fig. 2) [3]. By increasing theta, the erroneous part is moving towards the earlier times, and for $\theta > 40°$, the erroneous part is already overlapping with the exact far field (Fig. 4). By increasing scan plane dimensions, one can move the erroneous parts to the later times and separate the exact far-field pattern for greater theta. By enlarging scanning plane two times, to side length of $20d$, we are able separate erroneous part for $\theta < 50°$. Is obvious, that enlarging planar scanning plane to get more accurate results for wider space angle is very inefficient.

4 CONCLUSION

The planar time-domain near-field antenna measurement is a very efficient method for radiation pattern measuring of the directive broadband antennas. And is unsuitable for narrow-band antennas because its transient response is to long for pulse signal. The time-domain near-field antenna measurement requires less time for measurement over a wide frequency band compared to the frequency-domain near-field measurement. From one measurement one can get radiation pattern for all frequencies of interest. Further time-domain near-field measurements, unlike single frequency near-field measurements, are able to eliminate finite scan errors. Last but not least by using time-domain measurement we can determine how much the antenna affect a shape of the input pulse signal.

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