

Improving Signal Integrity in Time Domain Measurements of Antenna Boresight Fields

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Abstract—Radiated electric field of an antenna, normalized to the asymptotic far field, is investigated as a function of distance. Far fields are extracted from sampled near fields in the boresight direction by minimizing the mean square error between the sampled fields and the fields fitted with a power series in $1/r$ where r is the distance between the antenna and the field point. Computed results are presented over a range of parameters such as the frequency, and the maximum distance between transmit and receive apertures, by optimizing the number of field samples and their spacing.

I. INTRODUCTION

Antenna pattern measurements in time domain using a pulse signal and Fourier transform can provide broadband frequency domain pattern data. In addition, by using range gating techniques, it is possible to eliminate reflections from the floor, roof and the ceiling. Thus time domain measurements can be inexpensive, fast, and provide reasonable accuracy. De Jongh et al. discuss advantages and disadvantages of time domain antenna measurements [1]. A comparison of antenna patterns measured by them in time domain and frequency domain shows very good agreement. A method of correcting the pattern errors in time domain measurements due to multipath signals, using the super resolution technique, MUSIC is presented by Marti-Canales and Lighart [2]. Mohammadian et al. simulated a Vivaldi antenna in time domain using the full wave computer program, MicroStripe, and produced a good comparison to the experimentally measured gain in frequency domain [3]. Several researchers have shown that a single antenna with a large reflecting ground plane in front can be used for accurate time domain pattern measurements, e.g., [4-6].

In some applications there is a need to know the transfer function of an antenna in a certain frequency range of interest in the main beam region, or to be more specific in the boresight direction. In this case one transmits a time domain waveform from the antenna under test (AUT) and receives the signal from a known receive antenna or horn. From the received signal and the receive antenna transfer function it is possible to determine the transfer function of the AUT. Alternatively if the transfer functions of the antennas are known, from the received signal it is possible to synthesize the transmitted signal. In the above-mentioned applications it is important to keep the distance ‘ r ’ between transmit and receive antennas such that the far field criterion is met for the highest frequency present in the time domain waveform. The

rule of thumb for the far field distance is $2D^2/\lambda$ where D is the largest linear dimension of the antenna and λ is the wavelength. The far field radiation from an antenna in the frequency domain is a spherical wave that exhibits $\exp(-jkr)/r$ dependence on r . Here $k=2\pi/\lambda$ is the wavenumber in free space. Since all frequency components have the same r dependence, their relative amplitudes are independent of r . Furthermore $\exp(-jkr)$ type phase dependence results in the same phase velocity for all the frequency components and therefore the spacing r is responsible for a time delay $\tau = r/c$, where c is the velocity of light, between the input and output waveforms. If the spacing r does not satisfy the far field criterion, it can be shown using spherical wave theory that the radiated field varies with r in the form of a series in powers of $(1/r)$ [7]. The higher order terms in powers of $(1/r)$ introduce amplitude and phase errors in the measured transfer function of an antenna, thereby resulting in distortions in the signal. Thus there exists a need to understand the effects of radiated fields at distances less than the far field distance, and errors introduced at such distances. This paper presents results of a study on errors introduced in fields at intermediate distances and a method for correcting such errors.

II. NORMALIZED BORESIGHT FIELDS

We consider radiation from a $24\lambda_h \times 24\lambda_h$ aperture. The field normalized to $\exp(-jkr)/r$ will approach a constant value as the distance r approaches infinity. A further normalization of the fields with this asymptotic value will make the normalized field at infinity unity. Figs. 1 and 2 show the variation of such normalized values of the amplitude and phase of the electric field respectively as a function of distance. Two different aperture distributions were considered. In both cases the distribution in the vertical direction is uniform. The horizontal distribution in one case is uniform whereas it has a sinusoidal variation in the other. The aperture phase is uniform in both cases. It may be seen that the phase reaches the asymptotic value more slowly and hence even when measurements are carried out at the conventional far field distance of $2D^2/\lambda$ the distortions resulting from the phase errors may not be negligible. Tapered aperture distributions represent a smaller value of the effective aperture and hence their field values are closer to the asymptotic values. Figs. 3 and 4 illustrate the received voltage in an $8\lambda_h \times 8\lambda_h$ aperture due to radiation from a $24\lambda_h \times 24\lambda_h$ aperture as a function of frequency for different

values of spacing normalized to D^2/λ_h . Here λ_h is the wavelength at the highest frequency of 12 GHz. Both transmit and receive apertures are assumed to have uniform distribution. Phase values are found to deviate significantly from the asymptotic value, especially at high frequencies.

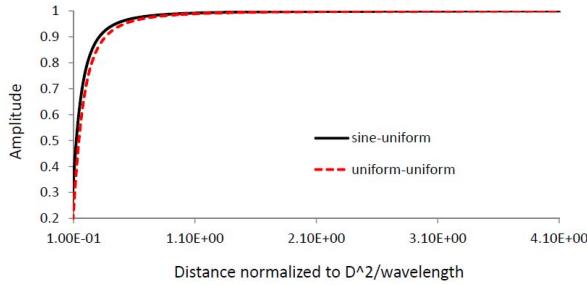


Fig. 1. Normalized value of the radiated electric field amplitude

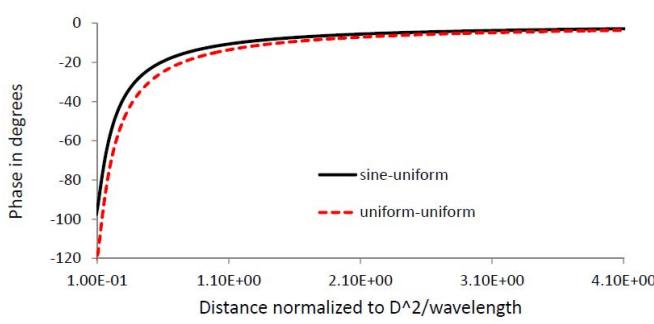


Fig. 2. Normalized value of the radiated electric field phase

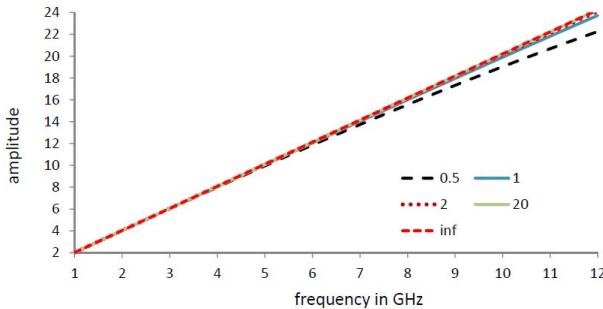


Fig. 3. Amplitude of the received voltage versus frequency

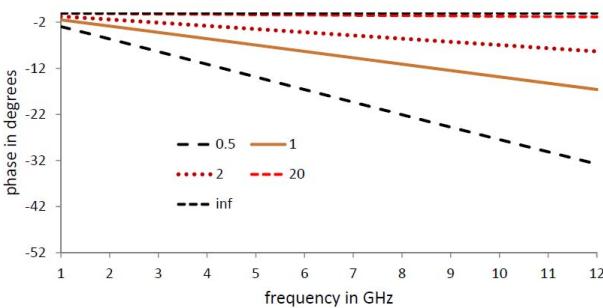


Fig. 4. Phase of the received voltage versus frequency

III. EXTRACTION OF FAR FIELDS

Tamas et al. discuss an averaging method to determine the far field from computed field values at intermediate distances for dipole antennas [6]. We found that such an averaging procedure is not applicable to apertures and other extended antennas. In 1973 Newell et al. presented a technique to determine the far field gain of antennas from measured field values at a number of near field points in the boresight direction [8]. They used a power series representation of sampled fields from which the asymptotic term was extracted. Their work was concerned with the field amplitude and not the phase. We use a similar idea to express the sampled fields in terms of a power series in $(1/r)$ and then minimize the error terms in equations (2) to (5). The normalized field is expressed in (1).

$$V_{rn} = V_r \exp(jkr)r \quad (1)$$

$$e_1 = \frac{1}{N} \sum_{i=1}^N [A_{01} + A_{11}(1/r) + A_{21}(1/r)^2 + \dots - \operatorname{Re}(V_{rni})]^2 \quad (2)$$

$$e_2 = \frac{1}{N} \sum_{i=1}^N [A_{02} + A_{12}(1/r) + A_{22}(1/r)^2 + \dots - \operatorname{Im}(V_{rni})]^2 \quad (3)$$

$$e_3 = \frac{1}{N} \sum_{i=1}^N [A_{03} + A_{13}(1/r) + A_{23}(1/r)^2 + \dots - \operatorname{Re}(1/V_{rni})]^2 \quad (4)$$

$$e_4 = \frac{1}{N} \sum_{i=1}^N [A_{04} + A_{14}(1/r) + A_{24}(1/r)^2 + \dots - \operatorname{Im}(1/V_{rni})]^2 \quad (5)$$

The first term in each of the eqns. (2) through (5) yields the desired asymptotic far field. There are two values of the far field, $V_{m1} = A_{01} + jA_{02}$ and $V_{m2} = 1/(A_{03} + jA_{04})$. This process is repeated for each frequency term in the time domain signal.

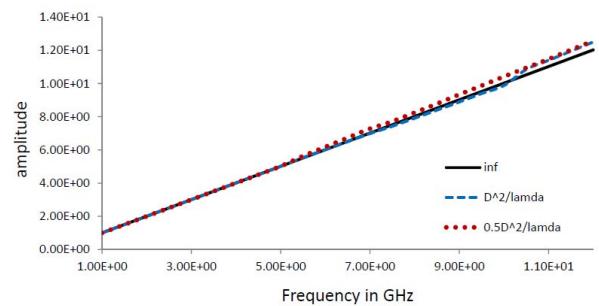


Fig. 5. Extracted far field amplitude

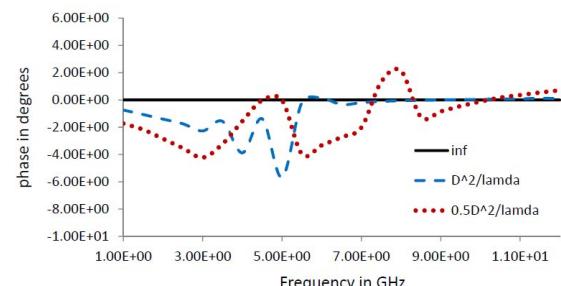


Fig. 6. Extracted far field phase

Figs. 5 and 6 show the extracted far field amplitude and phase as a function of frequency. In this example the amplitude of the transfer function varies linearly with frequency whereas the phase is uniform. Fifteen field samples spaced at a distance equal to two wavelengths at the highest frequency of 12 GHz were employed. The amplitude error is generally small whereas the phase error is somewhat high at certain frequencies. With a greater number of samples over a longer range of distances errors may be reduced.

IV. CONCLUSION

We have investigated the signal integrity issues arising from amplitude and phase errors at different frequency components, especially at high frequencies in antenna measurements. A method of extracting the far field terms from the sampled near field values at the boresight direction was presented. Using such a technique the asymptotic value of each frequency component of a time domain signal can be accurately evaluated. Then by a Fourier inverse transformation one can determine the received time domain signal. Additional examples will be presented in the symposium.

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