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Antenna Pattern Correction Technique Based on Signal to Interference Ratio Optimization

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***Abstract*— Antenna pattern correction algorithm that is based on optimization of the signal-to-interference ratio (SIR) is presented. In this method, the antenna pattern of the antenna under test (AUT) is measured in the far-field or a compact range several times at different spatial locations. The method is demonstrated with measurements and simulations in a hologram based compact antenna test range at 310 GHz.**

***Index Terms*—Anechoic chambers (electromagnetic), antenna measurements, compact range, error compensation.**

I. INTRODUCTION

THE antenna pattern measurement accuracy in far-field and compact antenna test ranges (CATRs) depends on the quiet-zone field quality. In these ranges, the measurement accuracy can be increased by improving the test-zone field quality either physically or virtually. Sometimes physical improvement is impractical or even impossible.

The test-zone field quality and thus also the measurement accuracy can be increased virtually using antenna pattern correction techniques. Several techniques are reviewed in [1]. The correction techniques employ some additional information about the test range, such as time, frequency, or spatial response of the test range. Some techniques, such as deconvolution technique utilize the probed test-zone field. In this technique the quiet-zone field is determined by measuring an accurately known reference antenna prior to antenna testing [2]. The test-zone field is probed on a sphere enclosing the test object in the methods described in [3] and [4].

The well-known time gating may be the first technique employing the time or frequency response of the test range. Other techniques utilizing time or frequency response are matrix-pencil method [5], oversampled Gabor-transform [6], and a channel equalization technique [7]. In addition, a frequency shift technique that is especially suitable for hologram based compact antenna test ranges, is described in [8].

Several techniques have been presented for obtaining the corrected antenna pattern from the measured spatial response of the test range. The first such a technique is antenna pattern comparison (APC) [9]. In this technique, the antenna pattern of the antenna under test (AUT) is measured several times at different positions in the test-zone. The measured patterns are shifted in angular domain to coincide, and the corrected pattern is obtained by averaging the measured patterns. The feed scanning APC can be used in compact antenna test ranges [10]. In this technique, the range feed antenna is moved instead of the antenna under test.

The novel antenna pattern comparison (NAPC) employs a circle fitting algorithm to a conventional APC data [11]. In this technique the received vectors are normalized such that the desired signal components add in phase. These normalized vectors span a circle, whose center point equals to the desired signal and the radius equals to the interference signal amplitude.

In the virtual array method, the antenna pattern is measured twice [12]. The antenna is kept in place during the first measurement, whereas it is displaced as a function of the rotation angle during the second measurement. The displacement is adjusted such, that the measurements form a virtual array, whose array factor is null towards the main beam.

It is proposed in [13] that the MUSIC [14] algorithm can be used to detect the interference signal directions from the test range spatial response. Then an array is formed, that has nulls towards the interference signals.

One recently introduced technique is the adaptive array based correction technique [15]. In this technique, an adaptive array algorithm is used to obtain the averaging weights for the measured results at each antenna rotation angle. The averaging weights are adjusted such that the desired plane wave is received effectively and the interference signals are greatly attenuated. In this paper we present a more sophisticated algorithm for obtaining the averaging weights. The algorithm presented in this paper is based on maximization of the signal-to-interference ratio (SIR).

The paper is organized as follows: the theory is presented in Section II. Section III presents the algorithm and Section IV shows results. Conclusions are presented in Section V.

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II. THEORY

Let us consider an antenna pattern measurement in a presence of interference. The measurement is repeated N times at different locations in the test-zone as shown in Figure 1.

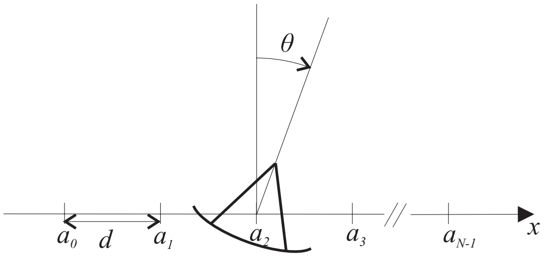

Fig. 1. The antenna pattern measurement is repeated N times at different locations.

The desired plane wave is assumed to arrive from angle $\theta = 0$ and the interference power spectrum is given by $p(\theta)$. The measurement points are weighted with complex weights and they form an antenna array, whose array factor can be calculated from

$$P_{AF}(\theta) = \sum_{n=0}^{N-1} a_n e^{jnkd\sin\theta} \ . \tag{1}$$

The array pattern at the AUT rotation angle α is given as

$$P_{AP}(\theta) = P_{AF}(\theta) P_{AUT}(\theta - \alpha), \tag{2}$$

where P_{AUT} is the antenna pattern of the AUT. The interference power received by the antenna array at the antenna rotation angle of α is

$$\begin{aligned} I &= \int_{-\pi}^{\pi} \left|P_{AP}(\theta)\right|^2 p(\theta) kd\cos\theta d\theta \\ &= \int_{-\pi}^{\pi} \left|P_{AF}(\theta)\right|^2 \left|P_{AUT}(\theta-\alpha)\right|^2 p(\theta) kd\cos\theta d\theta \end{aligned} \ . \tag{3}$$

Equation (3) can be written as

$$I = \int_{-\pi}^{\pi} \left|P_{AF}(\theta)\right|^2 p_{ef}(\theta,\alpha) kd\cos\theta d\theta \ , \tag{4}$$

where $p_{ef}(\theta,\alpha)$ denotes the noise power spectrum weighted with a shifted antenna power pattern of AUT. Let us define the spatial correlation coefficients for $p_{ef}(\theta,\alpha)$ as

$$H_l(\alpha) = \frac{1}{2\pi} \int_{-\pi}^{\pi} p_{ef}(\theta,\alpha) e^{jlkd\sin\theta} kd\cos\theta d\theta \ . \tag{5}$$

Then the received interference power can be expressed as [16]

$$N(\alpha) = \sum_{n=0}^{N-1}\sum_{m=0}^{N-1} a_n^* a_m H_{n-m} \ . \tag{6}$$

Similarly, the SIR at the antenna rotation angle of α is given by

$$\mathrm{SIR} = \frac{\left|\sum_{n=0}^{N-1} a_n\right|^2}{\sum_{n=0}^{N-1}\sum_{m=0}^{N-1} a_n^* a_m H_{n-m}} \ . \tag{7}$$

By setting the partial derivatives of the above expression to zero, it is found that the signal to interference ratio is maximized when a_n satisfy [16]

$$\sum_{m=0}^{N-1} H_{n-m} a_m = 1 \ . \tag{8}$$

The same result is derived in different way for a statistically optimal beam former in [17]. Finally, the corrected antenna pattern is obtained from

$$P_{COR}(\alpha) = \sum_{n=0}^{N-1} a_n(\alpha) P_{AUT,n}(\alpha), \tag{9}$$

where $P_{AUT,n}(\alpha)$ denotes the nth measured antenna pattern and $a_n(\alpha)$ are the weights calculated for each rotation angle α of the AUT.

III. METHOD

Both, the angular interference power spectrum and the measured antenna amplitude pattern of the AUT are needed in (5). However, the antenna pattern of the AUT is the one that is being corrected. In this method, both the angular interference spectrum and the antenna pattern of the AUT are first estimated from the measured antenna patterns. Then a more accurate, corrected antenna pattern of the AUT is obtained by using the estimates. The amplitude of the antenna pattern is estimated by uniformly averaging the measured patterns as

$$\left|P_{AUT,ESTIMATE}(\alpha)\right| = \left|\sum_{n=0}^{N-1} P_{AUT,n}(\alpha)\right| . \tag{10}$$

The interference power spectrum is estimated from the measured data using antenna pattern comparison (APC) [9]. In our implementation, we estimated the interference spectrum from

$$p(\alpha) = \max_{n} \left| P_{AUT,ESTIMATE}(\alpha) - P_{AUT,n}(\alpha) \right|^{2} . \tag{11}$$

In (11), it is assumed that the discrepancies in the measured patterns are due to interference signals received through the main beam of the AUT at each rotation angle. This assumption holds best for high-gain antennas.

The estimated interference spectrum and antenna pattern are substituted to (5), and optimal averaging weights a_n are then obtained from (8). The corrected antenna pattern of the AUT is finally calculated using (9).

The interference spectrum and the corrected antenna pattern can be defined only in the angular range in which the antenna pattern is measured. The interference spectrum can be assumed to be zero outside this region especially with high gain antennas. However, the antenna pattern has to be somehow estimated outside this region. For example, we estimated that the antenna power pattern is $-50\,\text{dB}$ outside the angular region that is measured.

The angular range, in which the correction can be effectively performed depend on the measurement positions of the AUT. In addition, the measurement positioning accuracy affects the correction accuracy of the method. These issues are discussed in [15].

A. *Generality of the Method*

The signal to interference maximization procedure itself is very general, and it is applicable for measuring all kinds of antennas in far field or compact ranges. In our implementation, however, the interference spectrum is estimated with the APC method, which is most applicable with high gain antennas. Therefore, if using the method with low gain antennas, the angular interference spectrum should be estimated in a different way or ignored.

IV. VERIFICATION

The verification procedure with the proposed method is the same as that used with the adaptive array based antenna pattern correction technique and a detailed description of the verification procedure can be found in [15]. For convenience, the verification procedure is presented shortly in the following.

The method has been tested in a hologram based compact antenna test range at 310 GHz. A hologram is a diffractive grating structure that is used as a collimating element instead of a reflector or a lens [18]. The hologram operation is intentionally degraded for demonstration purposes. The antenna pattern correction method is demonstrated with a synthetic test antenna and with a physical test antenna. The antenna pattern of the physical antenna is measured conventionally by rotating the antenna whereas the tests with the synthetic antenna are based on measured quiet-zone field and simulated antenna aperture field. The advantage with the simulated antenna pattern measurements is that the true antenna pattern is known.

Both antennas have similar structure: they are based on a 90º offset fed reflector. The reflector diameter is 76.2 mm and it has Gaussian illumination. Both antennas are measured 7 times at different locations. For comparison, the accuracy provided by the proposed method is compared to the accuracy provided by simple uniform averaging of the measured antenna patterns.

A. *Synthetic Test Antenna*

The antenna patterns of the synthetic antenna are presented in Figure 2. The black dashed line is a non-corrected pattern, the black solid line is the true pattern, the gray dashed line is the corrected pattern obtained with uniform weighting and gray solid line is the pattern obtained by the proposed method. The non-corrected pattern introduces spurious side lobes up to 20 dB above the true side lobe level. The pattern obtained with uniform averaging deviates at maximum 3 dB at $-40\,\text{dB}$ level from the true pattern. The pattern corrected with the proposed method coincides almost perfectly with the true pattern; it deviates only 0.1 dB from the true pattern at $-40\,\text{dB}$ level. The errors in the antenna patterns obtained with the uniform averaging and the proposed methods are depicted in Figure 3. The error with the proposed method is up to 30 dB lower than that with the uniform averaging.

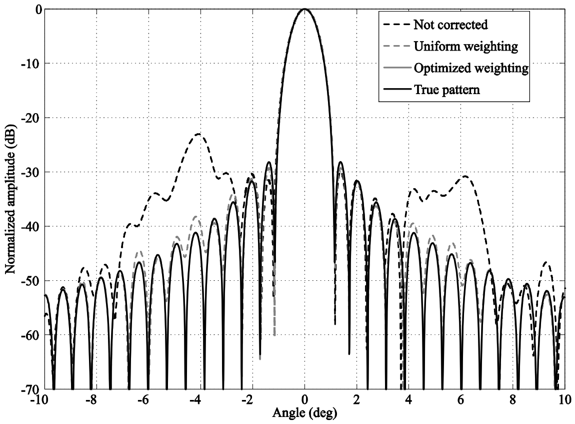

Fig. 2. Non-corrected, corrected, and true antenna patterns of the synthetic antenna. The solid black line is the true antenna pattern, the dashed black line is the non-corrected antenna pattern, the dashed gray line is the corrected antenna pattern obtained with uniform weighting, and the solid gray line is the pattern obtained with the optimized weighting.

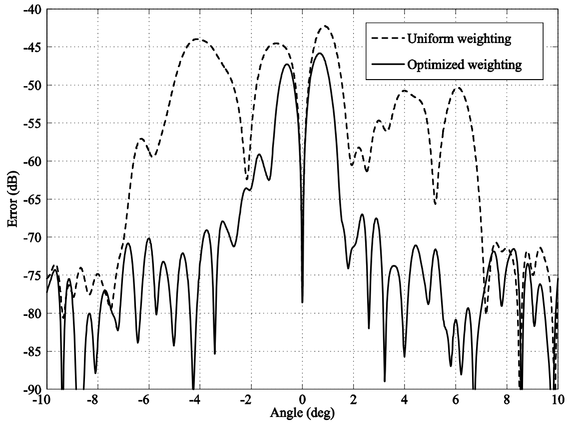

Fig. 3. Error in the corrected antenna patterns. The dashed line is the error in the corrected pattern obtained with the uniform weighting and the solid line is the error in the pattern obtained with the optimized weighting.

B. Physical Test Antenna

The antenna patterns of the physical antenna are shown in Figure 4. The non-corrected pattern has spurious side lobes up to 15 dB above the simulated side lobe level. The pattern obtained with the uniform weighting corresponds best to the simulated pattern. However, a null is filled in the angle of -4° and approximately 4 dB deviation occurs around 7°. The antenna pattern obtained with optimized weighting corresponds better to the simulated pattern, the maximum deviation being only 2 dB.

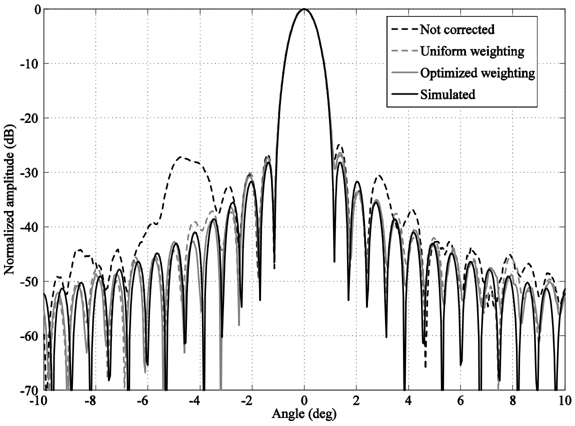

Fig 4. Non-corrected, corrected, and true antenna patterns of the physical antenna. The solid black line is the simulated antenna pattern, the dashed black line is the non-corrected antenna pattern, the dashed gray line is the corrected antenna pattern obtained with uniform weighting, and the solid gray line is the pattern obtained with the optimized weighting.

V. CONCLUSION

An antenna pattern correction technique is presented that is applicable in far field and compact antenna test ranges. In this method, the antenna pattern of the antenna under test is measured several times at different accurately known locations in the test range. The corrected antenna pattern is obtained with a procedure that maximizes the signal to interference ratio in the measurement. The method is demonstrated and verified with measurements and simulations in a hologram based CATR at 310 GHz. The accuracy provided by the method is found to be much better (even 30 dB) than that provided by simple uniform averaging of the measured patterns.

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