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Excitation amplitudes tolerance analysis for linear arrays with phase-only tapering

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Abstract

A study on the dispersion in the values of amplification within a linear phased arrays is presented. In a phase-only array in which the phase distribution is optimized the amplitudes of each radiating element should be the same.

Indeed real world amplifiers have a dispersion in their parameters leading to variable amplification factors. In this paper a Monte Carlo statistic analysis on how this variability reflects in the radiation pattern is be analyzed.

1 Introduction

Large antenna arrays used for space applications and in particular for telecommunication applications, have often to fulfill complex masks in order to guarantee specific nationwide coverages on the Earth [1]. This can be obtained with shaped reflectors, reflectarrays but is often achieved with active arrays [2], that is antenna array where each element, or small group of elements, is backed by its own amplifier, since these latter provides the highest flexibility and reconfigurability [3].

Especially for space applications, where available power is severely limited, keeping all feed amplitudes constant allows to maximize the DC-to-RF efficiency of the amplifiers and hence of the whole transmission system. Phase-only synthesis of the radiation pattern is hence a must, even if this effectively halves the degrees of freedom available for attaining the side lobe levels (SLL) and the beam shaping desired. The phase-only synthesis task is hence more complex.

On the other hand, on the realized antenna, feeding amplitudes won't be uniform as in the ideal case, for the intrinsic dispersion in the characteristics of the amplifiers in the beam forming network [4].

The statistical analysis of the impact of this parameter dispersion will be matter of the present study.

2 Statement of the problem

The array factor formula of a linear phased array of N isotropic elements placed along the z-axis of a Cartesian reference in points $z_n = nd$ and with θ the angle measured from the broadside direction, is:

$$P(\theta) = \sum_{n=1}^{N} a_n e^{j\frac{2\pi}{\lambda}nd\sin(\theta)} e^{j\Phi_n} \tag{1}$$

being Φ_n and a_n the feeding phases and amplitude, respectively, of the n-th element. As in [5], the phase distribution is here obtained via an optimization procedure which relies on an analytic expression of the phases as a linear combination of basis functions $f_k(z)$ whose $K \ll N$ coefficients α_k are optimized via a stochastic optimization [6]:

$$\Phi_n = \sum_{k=1}^{K} \alpha_k f_k(2z_n/D) \tag{2}$$

being D the overall array length, so that $2z_n/D \in [-1,1]$.

The amplitude values a_n in (1) should be all equal, and such are considered in the optimization [5] but, in a real world application, they will be dispersed around a nominal value according to a Gaussian distribution characterized by an average value μ and variance σ^2 expressed as:

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}, x \in R \tag{3}$$

A Monte Carlo analysis will be implemented, generating statistics over M uncorrelated evaluations for the patterns of arrays whose feed amplitudes are randomly selected within the aforementioned range. In this paper real dispersion characteristics for a FET in GaN technology working at 28 GHz with an expected amplification of 12.710 dB are used with a standard deviation $\sigma = 0.483$ dB, as in [7].

3 Results

Results in this section are given, as a first test-case, for the phase-only optimization of an array $D = 16\lambda$ long ($d = 0.5\lambda$ and $N = 33$) having to comply to a rectangular

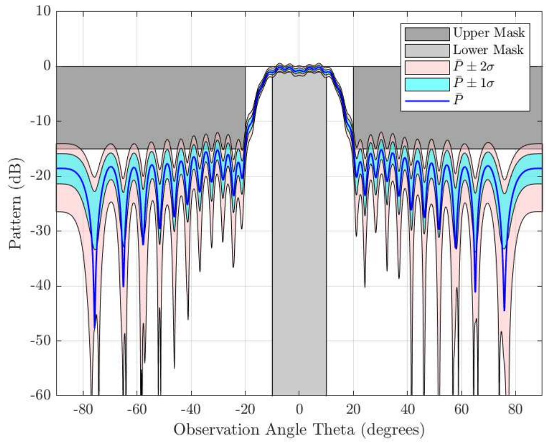

Figure 1. Post processed pattern with 1σ and 2σ dispersion range around the average value for D = 16λ array length

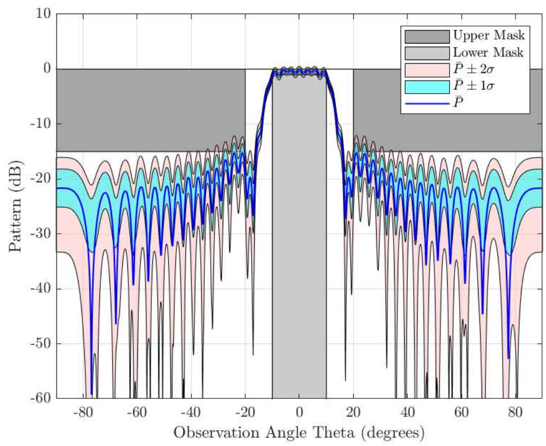

Figure 2. Post processed pattern with 1σ and 2σ dispersion range around the average value for $D = 20\lambda$ array length

mask for the pattern. The statistic is obtained considering $M = 200$ sets of 33 random uncorrelated amplitude values. Fig. 1 depicts the masks to be satisfied as well as the average pattern and the pattern dispersion interval for 1σ and 2σ. These intervals contains 68% and 95% of the evaluated cases, respectively. The out-of-mask of the pattern are evident both for the 1σ and 2σ variance limits.

A longer linear array D = 20λ, d = 0.5λ with N = 41 elements is hence sinthesized for the same rectangular mask and variance. Results are presented in Fig. 2. It is apparent how the longer array has, given the same dispersion of the amplifiers, a smaller dispersion in the pattern, with very limited out-of-mask.

Fig. 3 presents error bars (average and variance) for the statistic computed for the feeding amplitudes on the $M =$ 200 evaluations. Indeed, increasing the number of evaluations the mean value will tend to the expected amplitude

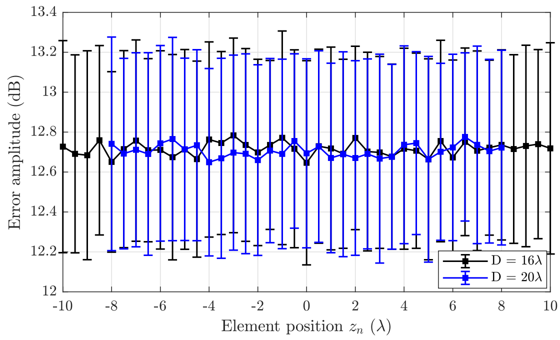

Figure 3. Error bar of amplitude dispersion range for a statistic of $M = 200$ evaluations for the $D = 16\lambda$ and $D = 20\lambda$ cases (μ = 12.710 dB, $\sigma = 0.483$ dB)

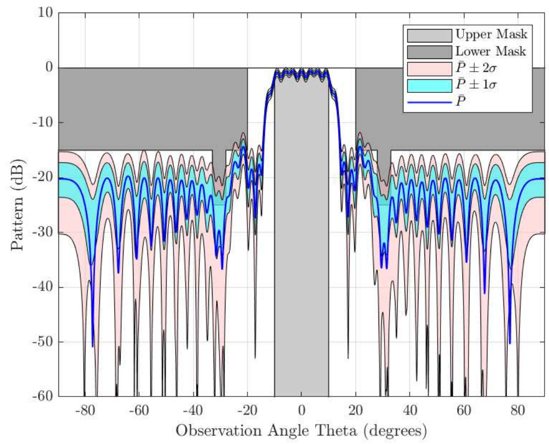

Figure 4. Post processed pattern with 1σ and 2σ dispersion range around the average value for a mask with localized reduced radiation

value.

For the longer $N = 41$ array, a further optimization is done to find the phases complying with a mask exhibiting two small angular ranges (centered at $\theta = \pm 30°$) where radiation, is to be reduced to -25dB that is 10dB less than in the surroundingSLL region. Also in this case statistical analysis is reported, in Fig. 4.

Tab. 1 shows the computed compliances of the masks for the average pattern and 1σ and 2σ dispersion interval considering the upper and lower implemented masks U_m and L_m for the analyzed cases. It is apparent how the larger array has a better compliance for the same variance in the feed amplitudes.

4 Conclusion

A Monte Carlo analysis of the pattern variations in linear arrays with phase-only pattern synthesis due to front-end

Table 1. Compliance of the envelope pattern

	Mask	D = 16λ	D = 20λ	D = 20λ Notch
average	U_m	100.0	100.0	94.78
	L_m	99.17	99.00	91.28
1σ	U_m	86.67	92.23	89.73
	L_m	95.67	96.45	87.56
2σ	U_m	46.75	80.12	85.79
	L_m	91.84	92.06	85.29

amplifier characteristic dispersion has been investigated.

Worst cases, defined in terms of statistical envelops have been analyzed and designed suggestion to minimize the problem have been suggested.

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