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Innovative Approaches for Optimized Performance in Time-Modulated Linear Arrays

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Introduction

In time-modulated arrays, time is exploited as an additional degree of freedom for the array synthesis in order to better control the radiated beam. More specifically, by properly turning on and off the array elements according to suitable time sequences, the synthesis of patterns with low side lobe levels (SLLs) [1-2] is obtained and the opportunity of optimizing the array performances in time-varying wireless scenarios enabled. Unfortunately, time-modulated arrays generate undesired harmonics, the so-called sideband radiations (SR), which represent a non-negligible loss of radiated power [3].
In order to overcome such a drawback and to improve the performances of the array, evolutionary optimization approaches have been recently and successfully applied. In [4] and [5], a Differential Evolution (DE) algorithm has been used to optimize the static-mode coefficients as well as the durations of the time pulses leading to a significant reduction of the sideband level (SBL). In [6], the minimization of the SLL at the carrier frequency and of the SBL in uniformly excited time-modulated arrays has been performed by means of a Simulated Annealing (SA) technique. In such a framework, a Genetic Algorithm (GA) based strategy has been considered in [7] to optimize the time sequences where the modulation period was subdivided in shorter time steps.
This paper presents an innovative approach based on a Particle Swarm Optimizer (PSO) aimed at further enhancing the performances of time-modulated linear arrays in terms of SBL reduction. From the mathematical formulation of the problem at hand, it follows that two parameters controls the synthesis process: the *switch-on intervals* (i.e., the durations of the rectangular time pulses of the time modulating sequence) and the *switch-on instants* (the times when the excitation coefficients switch on). More in detail, since the principal pattern at the carrier frequency is a function of the switch-on intervals, whereas the SBL depends by both the parameters, the target of the synthesis procedure is the optimization of the switch-on instants to reduce the SBL for a given principal pattern (i.e., fixed switch-on intervals). In the following, the problem is briefly formulated and some selected results are reported to assess the effectiveness of the proposed approach.

Problem Statement

Let us consider a time-modulated linear array (TMLA) of N isotropic elements lying on the z-axis with constant inter-element spacing d. Moreover, let the array feed with a periodic on-off time sequence $U_n(t)$, $n = 0,\ldots,N-1$. The radiated far-field pattern is given by

$$F(\theta,t) = \exp(j\omega_0 t)\sum_{n=0}^{N-1}\alpha_n U_n(t)\exp(jkndcos\theta) \tag{1}$$

where ω_0 is the central angular frequency, $k = \frac{2\pi}{\lambda_0}$ is the background wave-number, $\alpha_n, n = 0,\ldots,N-1$ are the static array excitations, and θ is the angular position with respect to the array axis. The function $U_n(t)$ has period equal to T_p. Moreover, $U_n(t) = 1$ for $t_n^1 \le t \le t_n^2$ (with $0 \le t_n^1 \le t_n^2 \le T_p$) and $U_n(t) = 0$, otherwise. Moreover, the following condition holds true $T_P >> T_0 = \frac{2\pi}{\omega_0}$. Since $U_n(t)$ is a periodic function, by substituting its Fourier representation in Eq. (1), the arising far-field pattern can be expressed through a summation of harmonic contributions as follows

$$F(\theta,t) = \sum_{h=-\infty}^{\infty}\sum_{n=0}^{N-1} a_{hn}\exp(jkndcos\theta)\exp[j(h\omega_p + \omega_0)t], \tag{2}$$

$a_{hn} = \alpha_n u_{hn}$ being the harmonic coefficients given by the product of the static array excitations α_n and the Fourier coefficients u_{hn} of the sequence $U_n(t)$. From (2), it follows that the beam pattern at the carrier frequency $f_0 = 2\pi\omega_0$ (i.e., $h = 0$) depends on the 0-th order Fourier coefficients

$$a_{0n} = \alpha_n u_{0n};\ n = 1,\ldots,N-1. \tag{3}$$

where $u_{0n} = \tau_n = \frac{(t_n^2 - t_n^1)}{T_p}$ is the normalized time pulse duration of the n-th array element. On the other hand, it is simple to show that the beam patterns of the harmonic frequencies are generated by the excitation coefficients

$$a_{hn} = \frac{\alpha_n}{T_p}\frac{\exp(-jh\omega_p t_n^1) - \exp(-jh\omega_p t_n^2)}{jh\omega_p}. \tag{4}$$

Since $t_n^2 = (\tau_n T_p - t_n^1)$, it turns out that the sideband radiation coefficients can be expressed as a function of the pulse duration τ_n, $n = 0,\ldots,N-1$, as well as of the switch-on time instants, t_n^1, $n = 0,\ldots,N-1$. Starting from such a conclusion, the problem is reformulated as the definition of the switch-on time instants $\underline{t}^1 = \{t_n^1; n = 0,...,N-1\}$ that reduce the SBL for a given set of pulse durations $\tau_n = \hat{\tau}_n$, $n = 0,\ldots,N-1$, chosen to generate a desired pattern at f_0. A strategy based on the PSO is used to minimize the following cost function

$$\Psi(\underline{t}^1) = \sum_{h=1}^{\infty}\left\{ H\left[SBL^{ref} - SBL^{(h)}(\underline{t}^1)\right]\left|\Delta_{SBL}^{(h)}(\underline{t}^1)\right|^2 \right\}, \tag{5}$$

that quantifies the mismatch between the desired sideband level SBL^{ref} and the sideband levels $\mathrm{SBL}^{(h)} = \mathrm{SBL}(\omega_0 + h\omega_p)$, $h = 1, \ldots, \infty$ of the synthesized pattern. In Eq. (5), $\Delta_{SBL}^{(h)}(\underline{t}^1) = \frac{\mathrm{SBL}^{ref} - \mathrm{SBL}^{(h)}(\underline{t}^1)}{\mathrm{SBL}^{ref}}$ and $H(\cdot)$ is the Heaviside step function.

Numerical Assessment

In order to give some indications on the effectiveness of the proposed approach, let us refer to the test case dealt with in [8]. More in detail, a $N = 16$ linear array with inter-element spacing $d = \frac{\lambda}{2}$ is considered. The pulse durations τ_n, $n = 0, \ldots, N-1$ have been chosen to generate a Chebyshev pattern with $\mathrm{SLL} = -30[\mathrm{dB}]$. According to the proposed strategy, the PSO has been used to optimize the SBL of the first harmonic frequency (i.e., $|h| = 1$), since the power content of spurious radiations significantly reduces at higher frequencies. The optimized switch-on instants together with the pulse durations are given in Tab. I. The values of one half of the array elements are reported, since the array is symmetric with respect to its center.

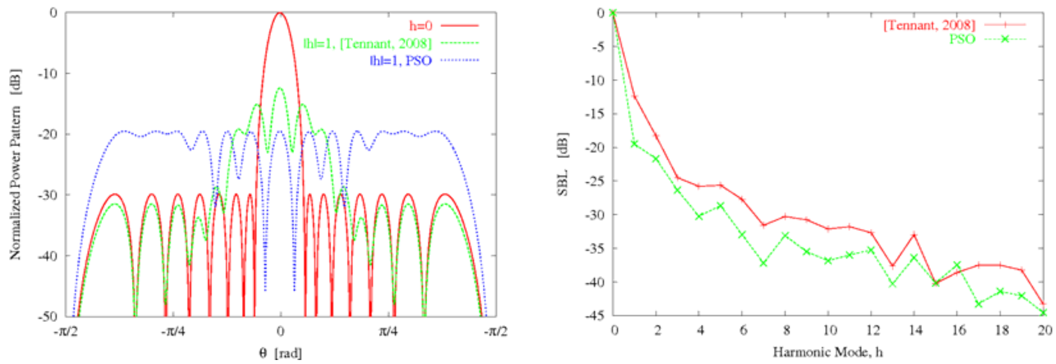
n	1	2	3	4	5	6	7	8
$\hat{\tau}_n$	1.0000	0.9530	0.8643	0.7435	0.6034	0.4577	0.3194	0.2950
t_n^1	0.0000	0.7401	0.6611	0.4256	0.5943	0.3000	0.6290	0.9776

Table I: Normalized time-pulse durations and switch-on instants.

Moreover, Figure 1(a) shows the principal pattern and the sideband radiation at $|h| = 1$ in correspondence with the solution in [8] and after the optimization with the PSO strategy, as well. It is worth noticing that, by properly modifying the switch-on instants, the proposed technique is able to spread the power of the first harmonic on a wider range of angles. As a consequence, the SBL is reduced of more than $7[\mathrm{dB}]$ from $-12.3[\mathrm{dB}]$ down to $-19.5[\mathrm{dB}]$. Such a behavior is still confirmed also at higher harmonics as shown in Fig. 1(b) where the values of the SBLs for the first 20 harmonics are reported.

Conclusions

In this paper, an innovative approach for the reduction of the sideband level in time-modulated linear array has been presented. First, the proposed strategy has been mathematically justified showing that the SBL can be lowered by modifying the switch-on instants. Accordingly, a PSO has been used to minimize a suitable cost function quantifying the mismatch between the actual pattern features and the desired ones. Preliminary results have show that such a technique effectively works and it turns out to be a suitable methodological approach to the optimization of the performances of time-modulated arrays.



(a) (b)

Figure 1: Main patterns and first harmonic patterns (a) and behaviors of the corresponding SBLs (b).

References

[1] W. H. Kummer, A. T. Villenueve, T. S. Fong, and F. G. Terrio, “Ultra-low sidelobes from time-modulated arrays,” *IEEE Trans. Antennas Propag.*, vol. 11, no. 6, pp. 633-639, Nov. 1963.

[2] R. W. Bickmore, “Time versus space in antenna theory,” in *Microwave Scanning Antennas*, R. C. Hansen, Ed. Los Altos, CA: Peninsula, 1985, vol. III, ch. 4.

[3] J. C. Brégains, J. Fondevila, G. Franceschetti, and F. Ares, “Signal radiation and power losses of time-modulated arrays,” *IEEE Trans. Antennas Propag.*, vol. 56, no. 6, pp. 1799-1804, Jun. 2008.

[4] S. Yang, Y. B. Gan, and A. Qing, “Sideband suppression in time-modulated linear arrays by the differential evolution algorithm,” *IEEE Antennas Wireless Propag. Lett.*, vol. 1, pp. 173-175, 2002.

[5] S. Yang, Y. B. Gan, and P. K. Tan, “A new technique for power-pattern synthesis in time-modulated linear arrays,” *IEEE Antennas Wireless Propag. Lett.*, vol. 2, pp. 285-287, 2003.

[6] J. Fondevila, J. C. Brégains, F. Ares, and E. Moreno, “Optimizing uniformly excited arrays through time modulation,” *IEEE Antennas Wireless Propag. Lett.*, vol. 3, pp. 298-301, 2004.

[7] S. Yang, Y. B. Gan, A. Qing, and P. K. Tan, “Design of uniform amplitude time modulated linear array with optimized time sequences,” *IEEE Trans. Antennas Propag.*, vol. 53, no. 7, pp. 2337-2339, Jul. 2005.

[8] A. Tennant and B. Chambers, “Control of the harmonic radiation patterns of time-modulated antenna arrays,” *Proc. 2008 IEEE AP-S International Symp.*, S. Diego, California, USA, July 5-12, 2008.