UNIVERSITY
OF TRENTO

DIPARTIMENTO DI INGEGNERIA E SCIENZA DELL'INFORMAZIONE

38123 Povo – Trento (Italy), Via Sommarive 14
http://www.disi.unitn.it

COMPROMISE PATTERN SYNTHESIS BY MEANS OF OPTIMIZED TIME-MODULATED ARRAY SOLUTIONS

P. Rocca, L. Poli, L. Manica, and A. Massa

January 2011

Technical Report # DISI-11-190

Compromise Pattern Synthesis by means of Optimized Time-Modulated Array Solutions

P. Rocca*, L. Poli, L. Manica, and A. Massa
ELEDIA Group - Department of Information Engineering and Computer Science, University of Trento, Via Sommarive, 14,I-38050 Trento, Italy
E-mail: andrea.massa@ing.unitn.it, Web-page: http://www.eledia.ing.unitn.it

Introduction

Originally, the use of time-modulated arrays was mainly devoted to the synthesis of low and ultra-low sidelobes arrays for the detection of radar signals [1]. Successively, only a few works have considered the use of time-modulated arrays for other applications (e.g., wireless communications [2]), although the first work proposing the use of time as an additional degree of freedom dates back to the 1950s [3]. Such an event has been probably caused by the main drawback of time-modulation that is the unavoidable presence of undesired sideband radiations (SRs) in the radiated field due to the periodic commutation of the RF switches between the on and off states. A detailed analysis on such a topic has been recently presented in [4], where a close-form relationship quantifying the power wasted in SR has been obtained.
In the last decades, thanks to the growing computational capabilities of modern PC, some approaches based on evolutionary algorithms have been proposed for the reduction of the losses due to SRs in time-modulated architectures. More specifically, the differential evolution (DE) algorithm [5] and the simulated annealing (SA) [6] have been considered. Despite the successful results, the potentialities of time-modulated array have been only partially investigated. As a matter of fact, a few works have been devoted to extend the possibilities of applying the time-modulation to array antenna synthesis. In [7], the problem concerned with the synthesis of sum and difference patterns has been discussed. Moreover, different switching strategies and their effects on SR have been shown in [8].
In this paper, the potentialities of time-modulation are further investigated in the framework of compromise array synthesis as an alternative solution to standard compromise methods (see [9] and the reference therein). More in detail, starting from a set of static excitations aimed at synthesizing a user-defined sum pattern at the carrier frequency, a compromise difference beam is generated through a suitable sub-arraying pattern matching procedure [9] by optimizing the pulse durations at the input ports of each sub-array. Successively, the unavoidable SR at the harmonic frequencies is minimized by applying a particle swarm optimization to set the switch-on time instants of each time sequence.

Mathematical Formulation

Let us consider a linear array of N equi-spaced elements laying on the z-axis. The static array excitations α_n , n=0,…,N-1 are fixed to generate a sum pattern whose array factor is expressed as

$$F_{\Sigma}(\theta,\alpha_n)=\sum_{n=0}^{N-1}\alpha_n\, exp(jnkd\, cos\,\theta) \tag{1}$$

where $k=\frac{2\pi}{\lambda_0}$ is the background wave-number, d is the inter-element spacing, and θ is the angular direction with respect to the array axis. The compromise difference beam is then generated by aggregating the array elements into Q sub-arrays and enforcing a periodic on-off sequence $U_q(t)$, $q=1,...,Q$ to the output signal of each sub-array. The rectangular pulse function $U_q(t)$ has period equal to T_p and it holds true that $U_q(t)=1$ for $\mathrm{t_q^1 \le t \le t_q^2}$ (with $\mathrm{0 \le t_q^1 \le t_q^2 \le T_p}$) and $U_q(t)=0$. Moreover, $\mathrm{T_P >> T_0 = \frac{2\pi}{\omega_0}}$. Since $U_q(t)$, $q=1,...,Q$, is periodic, it can be represented through its Fourier series

$$U_q(t)=\sum_{h=-\infty}^{\infty}u_{hq}\, exp(\,jh\omega_p t\,) \tag{2}$$

where $\mathrm{\omega_p = \frac{2\pi}{T_p}}$. Accordingly, the array factor of the difference pattern turns out being the summation of an infinite number of harmonics [4] where the pattern at the carrier angular frequency ω_0 is equal to

$$F_{\Delta}^{(0)}(\theta,c_n,\tau_q)=\sum_{n=0}^{N-1}\alpha_n\sum_{q=1}^{Q}\delta_{c_n q}\tau_q\, exp(jnkd\, cos\,\theta) \tag{3}$$

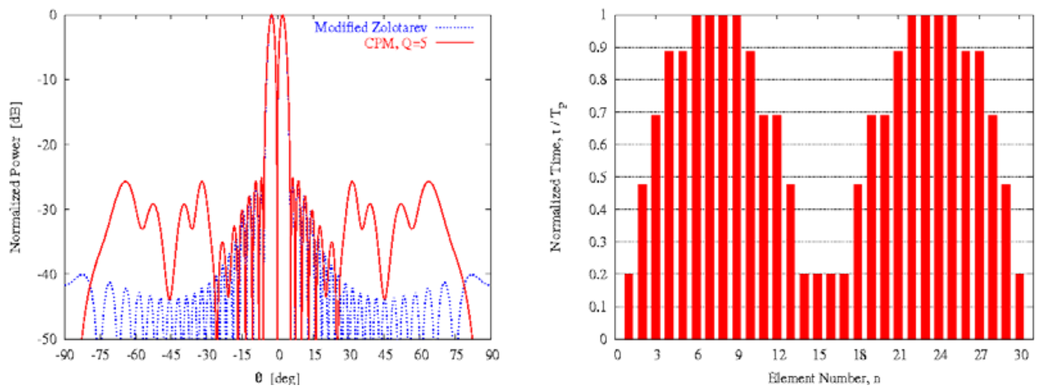
where

$$\tau_q=u_{0q}=\frac{1}{T_p}\int_0^{T_p}U_q(t)=\frac{t_q^2-t_q^1}{T_p}\,. \tag{4}$$

and δ_{cnq} is the Kronecker delta, being $\delta_{c_n q}=1$ if $c_n=q$, and $\delta_{c_n q}=0$ otherwise, where $c_n\in[1;Q]$, $n=0,...,N-1$, are integer values identifying the sub-array membership of the array elements. Differently, the pattern of the harmonic radiations (i.e., $h\neq 0$) is given by

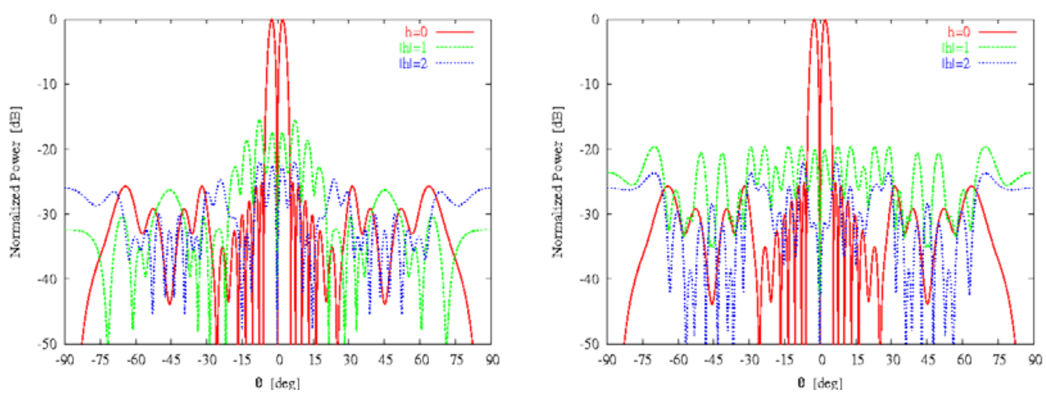
$$F_{\Delta}^{(h)}(\theta,c_n,u_{hq})=\sum_{\substack{h=-\infty\\ h\neq 0}}^{\infty}exp[j(h\omega_p+\omega_0)]\sum_{n=0}^{N-1}\alpha_n\sum_{q=1}^{Q}\delta_{c_n q}u_{hq}\, exp(jnkd\, cos\,\theta). \tag{5}$$

where the Fourier coefficients u_{hq} are function of the switch-on and switch-off instants t_q^1 and t_q^2 or equivalently of the switch-on instants and the pulse duration τ_q thanks to (4). It is worth noting from (3), that it is enough to define the values τ_q, $q=1,\dots,Q$ and c_n, $n=0,\dots,N-1$, to synthesized the compromise pattern at the carrier frequency. Hence, according to the guidelines of [9], the following cost function is minimized



(*a*) Compromise and reference pattern. **(*b*) Element switch-on time.**

Figure 1.



(*a*) Non-optimized SBL. **(*b*) Optimized SBL.**

Figure 2 – Normalized power pattern.

$$\Psi^{(0)}(c_m,\tau_q)=\frac{1}{N}\sum_{n=0}^{N-1}\left\|\alpha_n\left(\frac{\beta_n}{\alpha_n}-\sum_{q=1}^{Q}\delta_{c_nq}\tau_q\right)\right\|^2 . \tag{5}$$

where β_n, $n=0,\dots,N-1$, is set of reference excitation coefficients computed according to classical methods (e.g., Bayliss). Then, in order to reduce the interferences due to SR, only the values t_q^1, $q=1,\dots,Q$, are optimized since the

τ_q, $q=1,...,Q$ are fixed to those computed in (5). Accordingly, a PSO-based strategy is used and a proper functional $\Psi^{(h)}\left(t_q^1\right)$ is minimized measuring the mismatch between the actual sideband level and the desired one.

Numerical Results

For representative purposes, let us consider the synthesis of a $N=30$ array antenna. Starting from a set of static excitations affording a Villeneuve sum pattern with $SLL=-20\,dB$ and $\bar{n}=3$, the compromise difference pattern synthesized through the proposed approach is shown in Fig. 1(a) together with the reference difference pattern (Modified Zolotarev difference pattern) when $Q=10$. The values of τ_q, $q=1,...,Q$ and c_n, $n=0,...,N-1$ are shown in Fig. 1(b), as well. The harmonic frequencies before and after the optimization by means of the PSO strategy are shown in Fig. 2(a) and Fig. 2(b), respectively. It is worth noting how the level of the higher harmonics is reduced.

References

[1] W. H. Kummer, A. T. Villeneuve, 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] H. E. Shanks and R. W. Bickmore, "Four-dimensional electromagnetic radiators," *Canad. J. Phys*., vol. 37, pp. 263-275, Mar. 1959.

[4] J. C. Brégains, J. Fondevila-Gómez, 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.

[5] 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.

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

[7] J. Fondevila, J. C. Brégains, F. Ares, and E. Moreno, "Application of time modulation in the synthesis of sum and difference patterns by using linear arrays," *Microw. Opt. Technol. Lett.*, vol. 48, pp. 829-832, May 2006.

[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.

[9] L. Manica, P. Rocca, A. Martini, and A. Massa, "An innovative approach based on a tree-searching algorithm for the optimal matching of independently optimum sum and difference excitations," *IEEE Trans. Antennas Propag.*, vol. 56, no. 1, pp. 58-66, Jan. 2008.