A Comparative Study on Time-Modulated Uniform Circular Arrays in Terms of Total Sideband Power Loss

Ertugrul Aksoy
Faculty of Engineering, Department of Electrical&Electronics Engineering,
Gazi University, Turkey

Abstract

In this paper, performance comparison of six different time-modulated planar array configurations for phased arrays in terms of sideband power consumption is presented. The circular geometries have been selected as array geometries due to relatively minimal change of beam width and sidelobe level in azimuth scan which is highly preferred especially in direction of arrival estimation, phased and adaptive antenna applications. While all geometries are concentric and zero-phased, they hold 36 isotropic elements. The results obtained shows that the uniform circular centerd array (UCCA{1:35}) configuration is preferable over other compared geometries for the reference scenario due to the lack of power loss wasted in sidebands.

Key words: Time-modulation, linear arrays, differential evolution algorithm, sideband suppression.

1. Introduction

In recent years, smart antenna systems which have many sub application fields and environment adaptive features attract great attention of both telecommunication industry and research society. Basically in terms of generated beams smart antenna systems may be gathered in two main groups: phased array systems and switched beam arrays. The scanning feature of phased array systems is based on the principle of shifting a generated single beam electronically towards the desired point of space without any mechanical action and switched beam arrays are the systems whose operation are based on the principle of deciding which of the predefined beams to be active. The electronic beam steering operation of phased arrays are performed by setting the complex excitations of the whole array in order to turn the main beam towards the desired direction [1,2].

Beside this conventional time independent array architecture, the time concept also may be used as an additional parameter for the antenna arrays. This concept has been demonstrated for the first time under the name of time modulation in order to design low/ultra low sidelobe pattern arrays with the principle of periodically turning on and off of the array elements [3, 4]. Despite the time modulation concept enriches the design possibilities, has brought the losses resulting from the periodic switching as a problem. The harmonic frequencies that the loss occurs is termed as sidebands and these losses occur in sidebands are tried to be reduced indirectly through different switching sequences [5-9]. Additionally, this suppression process is considered as an

Corresponding author: Address: Faculty of Engineering, Department of Electrical&Electronics Engineering, Gazi University, 06570, Ankara/TURKEY. E-mail address: ertugrulaksoy@gazi.edu.tr, Phone: +903125823356 Fax: +903122213202

optimization problem and different algorithms such as differential evolution [5, 6] or particle swarm [9] are used in optimization process.

In addition these indirect sideband suppression studies Bregains *et. al.* expressed the total sideband power wasted in harmonics as a finite summation for a time modulated linear array in 2008 [10]. By this study, the sideband power for infinite numbered harmonics has become to be directly calculated. However, the equation suggested by Bregains *et. al.* is only a form that only remains valid for linear arrays which symmetrically switched around zero. Afterwards this equation is adapted to a planar array placed on uniform rectangular grid by Poli *et. al.* but this equation is also in a form that is written for a specific geometry [11]. This problem is solved by Aksoy and Afacan by directly generalizing the equation proposed by Bregains *et. al.* to shape independent planar geometries [12]. However, this innovation presented by Aksoy and Afacan is just provided a generalization on geometry basis and all these works produce appropriate results for switching sequences distributed symmetrically around zero. As a remedy to this problem Aksoy and Afacan rewrote the power equation in a switching type independent form [13]. In this way, an equation have emerged that can produce accurate results independent from the geometry as well as switching type.

In this paper, six different time-modulated planar antenna array geometries are investigated with the configuration and switching independent power equation that the final version is already given by Aksoy and Afacan and a performance comparison is made for these arrays in terms of total power radiated in sideband. Uniform circular array (UCA {36}), uniform circular centered array (UCCA{1:35}) and planar uniform circular array (PUCA {1:12:23}, PUCA {12:24}, PUCA {6:12:18} and PUCA {1:6:12:17}) circular geometries which consist of 36 isotropic radiators are selected as the array configurations to be compared and the comparisons are conducted on a explanatory reference interference suppression problem. The outline of the study is as follows. A brief mathematical background of array factor and time modulation concept is given in Sec. 2, the obtained results and related discussion are presented in Sec. 3 and finally the study is concluded with Sec. 4.

2. Mathematical Background

2.1 Array Geometries and Array Factors

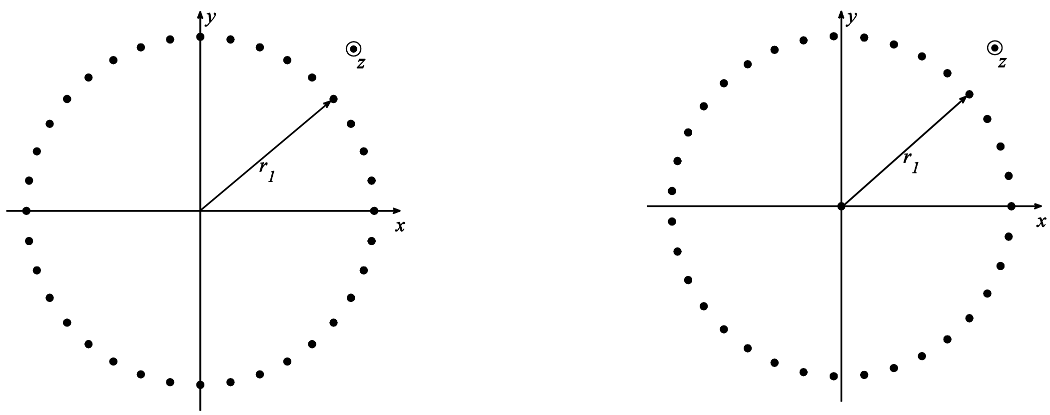
Consider an isogonic circular array whose elements are placed symmetrically on x-y plane as shown in Figure. 1.a. For this array the array factor may be defined as [2]:

$$F(\theta,\varphi) = \sum_{n} W_{mn} \exp\{jkr\sin\theta\cos(\varphi-\varphi_n)\}. \tag{1}$$

Here, W_n, φ_n and $k = 2\pi/\lambda$ represents the complex excitations of array elements, the azimuth angle of n^{th} element and the wavenumber, respectively. This definition is valid for isogonic uniform circular arrays and equation (1) which may be used for UCA{36} becomes:

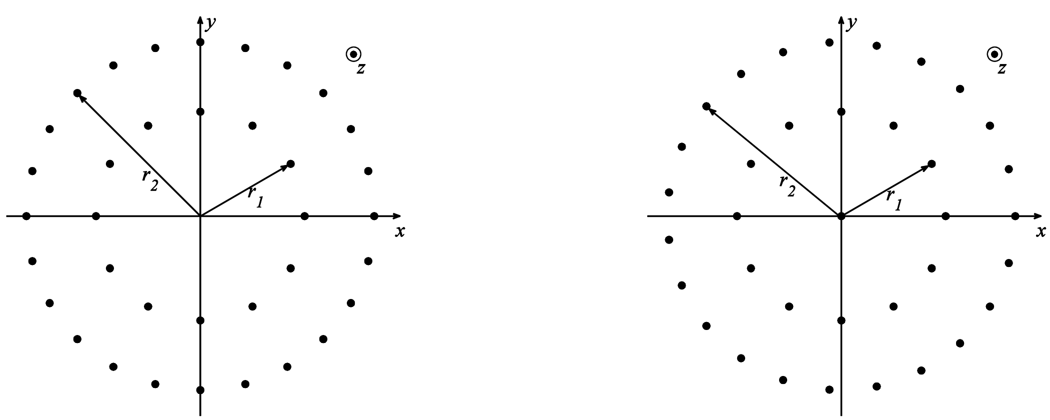
$$F(\theta,\varphi) = 1 + \sum_{n} W_{mn} \exp\{jkr \sin\theta \cos(\varphi - \varphi_n)\} \tag{2}$$

for UCCA{1:35} (Figure 1.b). The radius of UCA{36} is set to $1.7\lambda_0$ where λ_0 represents the operation wavelength and for this radius the interelement spacing between adjacent elements is $\approx 0.296\lambda_0$. The radius of UCCA{1:35} is set to same as UCA{36} ($1.7\lambda_0$) and in UCCA{1:35} configuration since the array elements are arranged around the central element, the element density in the outer ring is reduced, hence the interelement spacing between array elements become $\approx 0.305\lambda_0$.



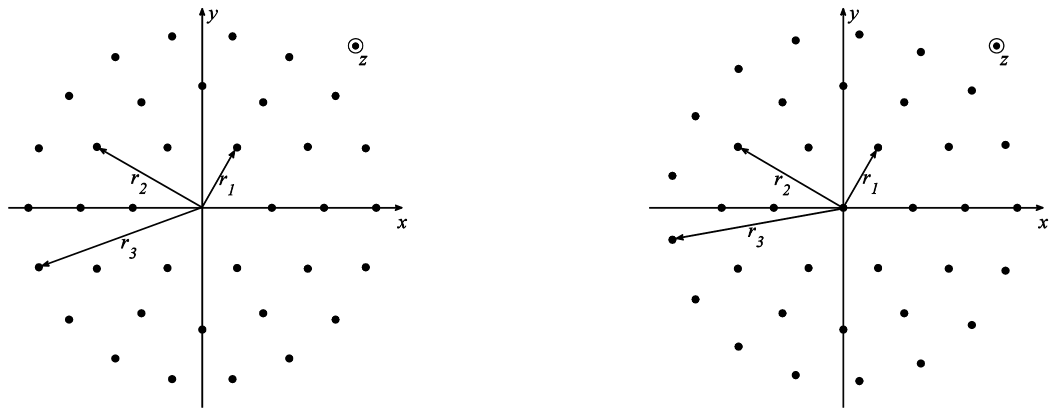
(a) (b)

Figure 1. 36 element circular array geometries: (a) UCA{36}, (b) UCCA{1:35}



(a) (b)

Figure 2. 36 element circular array geometries: (a) PUCA {12:24}, (b) PUCA {1:12:23}



(a) (b)

Figure 3. 36 element circular array geometries: (a) PUCA {6:12:18}, (b) PUCA {1:6:12:17}

PUCA {12:24}, PUCA {1:12:23} and PUCA {6:12:18}, PUCA {1:6:12:17} geometries are depicted in Figure 2 and Figure 3, respectively. The array factors of these geometries are defined as:

$$F(\theta,\varphi) = \sum_{m}\sum_{n} W_{mn}\exp\{jkr_m \sin\theta \cos(\varphi - \varphi_{mn})\} \tag{3}$$

for PUCA {12:24} and PUCA {6:12:18} and:

$$F(\theta,\varphi) = 1 + \sum_{m}\sum_{n} W_{mn}\exp\{jkr_m \sin\theta \cos(\varphi - \varphi_{mn})\} \tag{4}$$

for PUCA {1:12:23} and PUCA {1:6:12:17}. In equation (3) and equation (4) W_{mn} and φ_{mn} represents the complex excitations and azimuth angle of n^{th} element of m^{th} ring, respectively. The inner and outer ring radii are taken for PUCA {12:24} and PUCA {1:12:23} configurations as $r_1 = 1.7\lambda_0$ and $r_2 = 2.0\lambda_0$, respectively and additionally for PUCA {6:12:18} and PUCA {1:6:12:18} the outermost ring radius is taken as $r_3 = 2.5\lambda_0$.

2.2 Time Modulation

In classical theory, array patterns may be synthesized by using the array factors given between equations (1) - (4). The parameters used in classical theory to synthesize process are usually the complex excitation, element positions and indirectly array geometries. Besides these parameters, if corresponding array elements are periodically switched by some high speed RF on-off switches, an additional parameter which depends on time emerges in array factor and hence the time concept may be used as a design parameter. This process which is periodic in time may be modelled mathematically as periodic rectangular pulse train thus this periodic pulse train may be expanded in Complex Fourier Series and the emerged additional radiation in harmonic frequencies are called the sidebands.

If the on-off switching sequence is taken as:

$$f_n(t) = \begin{cases} 1, & 0 \le t \le \tau_n \\ 0, & \tau_n < t \le T_P \end{cases} \tag{5}$$

where τ_n and T_p represent the switch-on time and switching period, respectively, the complex Fourier coefficients may be defined as:

$$C_n^0 = \frac{1}{T_P} \int_{t_0}^{t_0+T_P} f_n(t) \exp\{-jw_P mt\} \tag{6}$$

where

$$f_n(t) = \sum_{m=-\infty}^{\infty} C_n^m \exp\{jw_P mt\}. \tag{7}$$

If the equation (5) is considered, these coefficients may be written as $C_n^0 = \tau_n/T_P$ for central operating frequency and:

$$C_n^m = \frac{\tau_n \sin(\pi m\, \tau_n/T_P)}{\pi m \tau_n} \exp\{-j\pi m\, \tau_n/T_P\} \tag{8}$$

for sidebands. Hence the equation (8) and equation (9) becomes coefficients for the array factors given in equation (1) – (4). Here it must be noted that this situation is only valid for the case that, under the far field approximation where the wavefront is assumed to be planar, the carrier frequency is much bigger than the switching frequency

3. Results and Discussion

In this section a comparison of geometry types is conducted in terms of interference suppression and dissipated average sideband power. The suppression of 30 degree elevation and 0 degree azimuth angle ($(\theta, \varphi) = (40°, 0°)$) is constructed as the interference suppression scenario. For this reference scenario the switching sequences are calculated with the aid of “DE/best/1/bin” algorithm scheme which is a type of differential evolution algorithm (DE). The mutation factor, crossover factor and population size are selected as 0.6, 0.9 and 40, respectively, as the algorithm parameters. Since interference suppression-sideband power comparison is conducted in this study, the sideband level is not taken into account although it is an important parameter that affects the array performance; hence in accordance with the selected scenario, the cost function is constructed based on the instantaneous value of desired angle

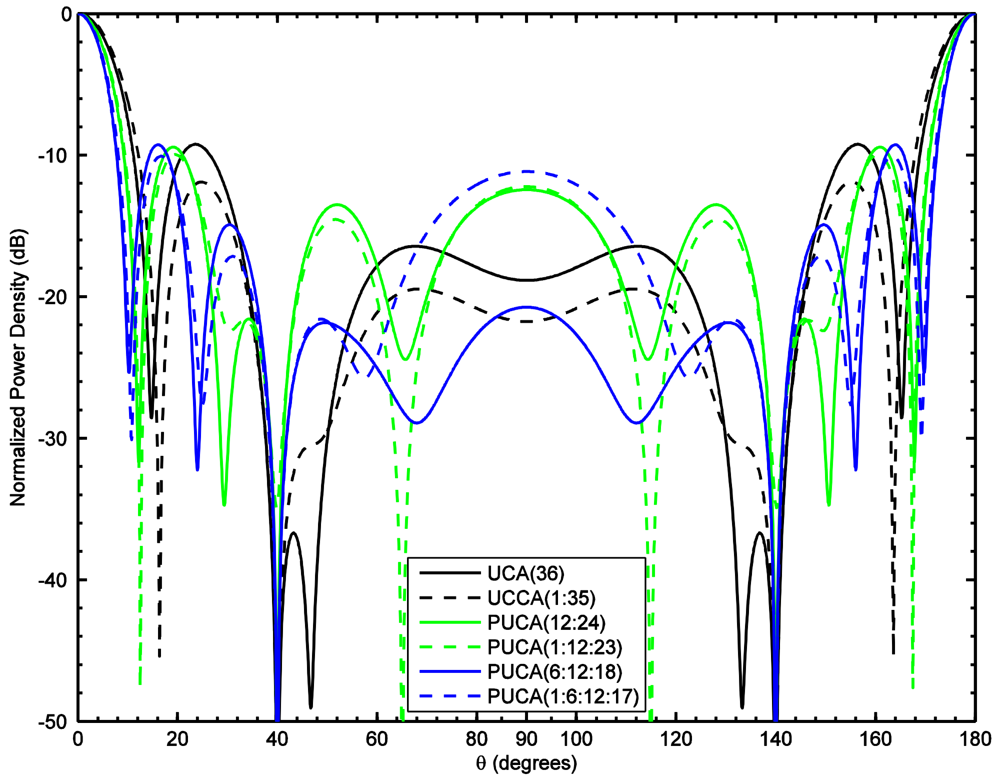


Figure 4. The radiation patterns of different array configurations for the reference scenario

The radiation diagrams obtained from 6 different array topologies are presented in Figure 4. As it can directly be observed in Figure 4 that the interference suppression process is achieved in all 6 different array geometries. The Interference suppression may be realized in all array types in a similar way however, these topologies distinguish from each other in terms of the power wasted in sidebands. This power which became calculable by the equations given in [12, 13] appears as a function of switching times. Since different time schemes may be found in order to produce similar array responses in the same scenario, which the array topology cannot be shown to be better in terms of sideband power with a single solution. In other words, for different solutions providing similar goals may have less sideband power compared to the others for different array geometries. A matter of fact, Figure 5 may be given as an example to this case. In Figure 5, the solutions with the least sideband level according to array type among 200 different solutions are presented. As it can be seen from Figure 5 that while UCA{36} have the least power loss with 27.72 % of total radiated power (this value is 30.57 % for UCCA{1:35}) for the first solution, UCCA{1:35} gives the best result of 25.62 % power loss in the second solution (this value is 34.18 % for UCA{36}) for similar array responses. Obtained least power loss percentages are presented in Table 1.

In accordance with this fact, making comparisons upon mean values instead of using the best solutions may provide more sensible results. The results obtained from the average of 200 independent experiments are presented in Figure 6. If Figure 6 is examined, in terms of power loss percentage for the reference scenario, while the UCCA{1:35}configuration exhibits the best performance with a minimal loss of 35.07 %, these results are calculated as 36.76 %, 39.32 %, 40.04 %, 41.49 % and 41.90 % for UCA{36}, PUCA{1:12:23}, PUCA{12:24}, PUCA{6:12:18} and PUCA{1:6:12:17}, respectively. Through these results it can be said that, while the UCCA{1:35} configuration provides the best performance, the PUCA{1:6:12:17} exhibits the worst in terms of the power loss wasted in sidebands.

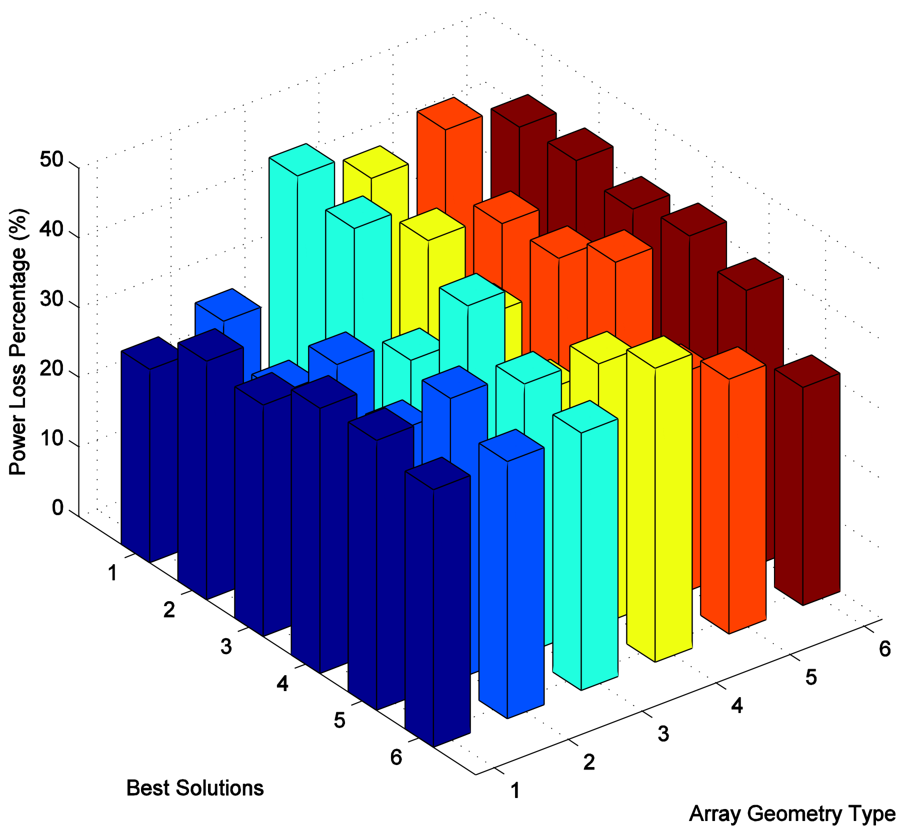


Figure 5. The best sideband loss percentages according to array type among 200 independent experiments; 1: UCA{36), 2: UCCA{1:35}), 3: PUCA{12:24}, 4: PUCA{1:12:23}, 5: PUCA{6:12:18}, 6: PUCA{1:6:12:17}

Table 1. The best sideband loss percentages obtained from the results of 200 independent experiments for different array configurations

Array Configuration	Sideband Power Loss (%)
UCA{36}	27.72
UCCA{1:35}	25.62
PUCA{12:24}	31.48
PUCA{1:12:23}	28.23
PUCA{6:12:18}	31.62
PUCA{1:6:12:17}	31.30

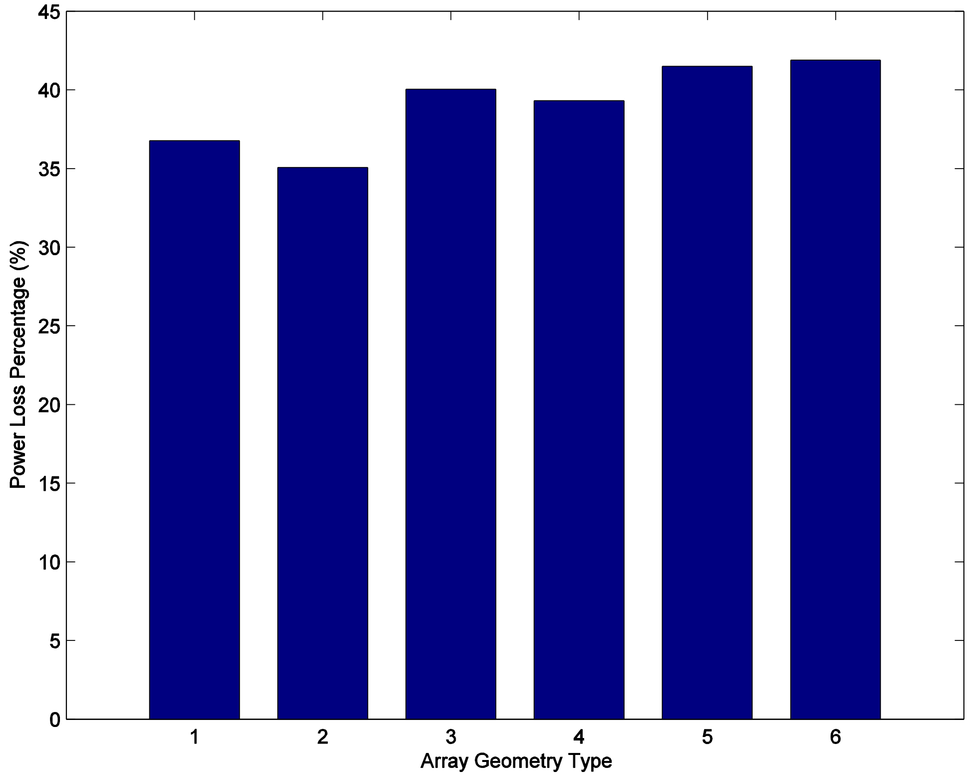


Figure 6. Average sideband loss percentages of 200 independent experiments; 1: UCA{36), 2: UCCA{1:35}) , 3: PUCA{12:24}, 4: PUCA{1:12:23}, 5: PUCA{6:12:18}, 6: PUCA{1:6:12:17}

Conclusions

In conclusion, in this study, a comparison of 6 different circular array geometry has been conducted in terms of total power wasted in harmonics over an example reference interference suppression problem and it is shown that since UCCA{1:35} configuration realizes the suppression process with less power loss, it is preferable over the other compared geometries. Considering the same performance criteria, the configuration preferability has been observed as UCA {36}, PUCA {1:12:23}, PUCA {12:24}, PUCA {6:12:18} and PUCA {1:6:12:17}, respectively.

References

[1] Tohme N, Paillot JM, Cordeau D, Cauet S, Mahe Y, Ribardiere P. A 2.4 GHz 1-dimensional array antenna driven by vector Modulators. IEEE MTT-S International Microwave Symposium Digest 2008;803-805.

[2] Balanis C A. Antenna Theory: Analysis and Design. 2nd ed. New York: Wiley; 1982.

[3] Shanks HE, Bickmore RW. Four-dimensional electromagnetic radiators. Canad. J. Phys. 1959;37:263.

[4] Kummer WH, Villeneuve AT, Fong TS, Terrio FG. Ultra-low sidelobes from time-modulated arrays. IEEE Trans. Antennas Propagat. 1963; AP-11(6):633-639.
[5] Yang S, Gan YB, Qing A. Sideband suppression in time-modulated linear arrays by the differential evolution algorithm. IEEE Antennas Wireless Propagat. Lett. 2002;1:173-175.
[6] Aksoy E, Afacan E. Thinned nonuniform amplitude time-modulated linear arrays. IEEE Antennas Wireless Propag. Lett. 2010;9:514-517.
[7] Poli L, Rocca P, Manica L, Massa A. Pattern synthesis in time modulated linear arrays through pulse shifting. IET Microw. Antennas Propag. 2010, 4(9): 1157-1164.
[8] Aksoy E, Afacan E. Sideband level suppression improvement via splitting pulses in time modulated arrays under static fundamental radiation. PIERS Proceedings, Suzhou, China, 2011;364-367.
[9] Poli L, Rocca P, Manica L, Massa A. Handling sideband radiations in time-modulated arrays through particle swarm optimization. IEEE Trans. Antennas Propagat. 2010;58(4):1408-1411.
[10] Bregains JC, Fondevila J, Franceschetti G, Ares F. Signal radiation and power losses of time-modulated arrays. IEEE Trans. Antennas Propagat. 2008; 56(6): 1799-1804.
[11] Poli L, Rocca P, Manica L, Massa A. Time modulated planar arrays - Analysis and optimisation of the sideband radiations. IET Microw. Antennas Propag. 2010;4(9):1165-1171.
[12] Aksoy E, Afacan E. Generalized representation of sideband radiation power calculation in arbitrarily distributed time-modulated planar and linear arrays," PIERS Proceedings, Suzhou, China, 2011;368-371.
[13] Aksoy E, Afacan E. Calculation of sideband power radiation in time-modulated arrays with asymmetrically positioned pulses. IEEE Antennas Wireless Propag. Lett. 2012;11:133-136.