Academic Science

International Journal of Electronics, Electrical and Computational System
IJEECS
ISSN 2348-117X
Volume 6, Issue 7
July 2017

Sideband Suppression of Time Modulated Linear Array using Fit Simulation Method

Ruchi[1], Banani Basu[2]

Dept. of Electronics and Communication Engineering, Thapar University, Patiala, India[1].

Dept. of Electronics and Telecommunication Engineering, National Institute of Technology, Silchar, India[2],

Abstract- *A time modulated linear antenna array consisting of 16 elements very thin wired dipole antennas is simulated using the CST Microwave Studio. The proposed technique utilizes on-off RF switches and operated at 3GHz central frequency and time switched at 1MHz pulse repetition frequency. Particle Swarm Optimization based technique is used to obtain the optimum time pulses applied to individual element to reduce the side band radiation while constraining the radiation pattern at central frequency below a fixed sidelobe level (SLL) for a given first null beam width (FNBW). Simulated results are in good agreement with those obtained using analytical approaches. Reduction of radiated power at sideband frequencies increases the gain of the proposed array.*

Key Words: **Antenna arrays, Particle Swarm Optimization, time modulation, Sideband radiations**

1. INTRODUCTION

THE realization of ultra-low sidelobe levels (SLLs) in the far-field pattern of an antenna array has posed long-term challenges to antenna designers. Conventional excitations with tapered amplitude distributions are very difficult to achieve ultra-low SLLs in practical arrays, due to various errors such as systematic errors and random errors [1]. Kummer *et al.* proposed a time modulation method and realized a nearly ultra-low SLL for an eight-element slotted waveguide linear array [2]. Bickmore presented the general principle for the analysis of the time-domain antenna system in [3]. As compared to conventional antenna arrays, the time modulated antenna arrays introduce a fourth dimension -time- into the design, and the time parameter used to taper the distribution can be easily, rapidly and accurately adjusted. Consequently, TMAAs have more flexibility for the design. However, the major disadvantage of time modulated arrays is that there are many sideband signals spaced at multiples of the modulation frequency, which causes loss of electromagnetic energy. In most of the applications, sideband signals are not desirable and should be suppressed to improve the efficiency of the antenna array. Different stochastic optimization algorithms are proposed to suppress the sideband radiation while synthesizing desired patterns is reported in [4-8]. Existing literatures presents various innovative approaches for synthesis TMAA using simple genetic algorithm (GA) in [4], particle swarm optimization (PSO) in [5], multi-objective optimization approach in [6] and differential evolution (DE) algorithm in [7-8].

In this communication, a method based on the PSO algorithm is proposed to reduce the sideband radiation losses while SLL is suppressed significantly at the centre frequency in a time modulated linear antenna array. The “switch-on instant” and the “switch-on time duration” of each element are optimized for synthesis of radiation pattern with fixed maximum SLL and FNBW at centre frequency and sideband radiation is minimized to increase the antenna gain simultaneously. The article simulates 16 elements time modulated linear dipole antenna array using the CST Microwave Studio at 3GHz central frequency where time modulation frequency is set at 1MHz. The radiation patterns obtained over the frequencies of interest are in good agreement with the existing closed form expression available in [9] validates the effectiveness of the proposed CST microwave studio approach.

Academic Science

2. THEORY

Let us consider an *N*-element linear array of equally spaced parallel dipoles with element spacing d. The corresponding array factor is given by [1]

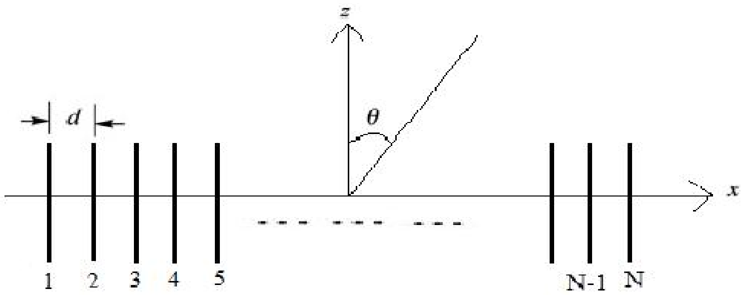


Fig.1 Geometry of an equally spaced N-element linear array

$$F(\theta,t) = e^{j2\pi f_0 t}\sum_{n=0}^{N-1} I_n(t)e^{jnu} \quad (1)$$

where f_0 is the central frequency, $u = \frac{2\pi}{\lambda_0} d\cos\theta$, λ_0 is the corresponding wavelength, θ is the angle measured from the axis of the array. Moreover the time modulated excitation for n-th element is given by

$$I_n(t) = \beta_n U_n(t) \qquad n = 0,1,....N-1 \quad (2)$$

β_n is the static excitation of n-th element, the time switching function $U_n(t)$ for n-th element is given by

$$U_n(t) = \begin{cases} 1 & t_{0n} \le t \le t_{0n} + \tau_n \\ 0 & otherwise \end{cases} \quad (3)$$

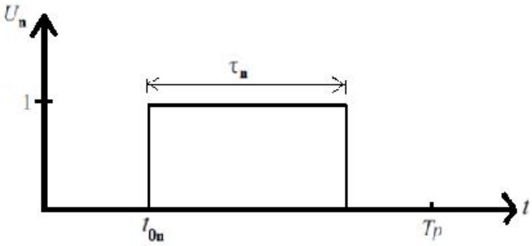


Fig.2. Time switching function

where t_{on} is the switch on time instance and τ_n is the duration of switch on time of n-th element. Due to the periodicity of $U_n(t)$, the space and frequency response of Eq.(1) can be obtained by decomposing it into Fourier series given in Eq.(4) . It is clear from the frequency bands that signal is not only radiated at the central frequency but also at the harmonics of the modulating frequency $m*f_p=m/Tp$ (m=0, ±1,±2,.....,±∞), where T_p is the total time modulation period.

$$F_m(\bar{\ }, t) = e^{j2®(f_0+mf_p)t} \sum_{n=0}^{N-1} ¥_{mn} e^{jnu} \tag{4}$$

Where

$$¥_{mn} = {}_n f_p{}^2{}_n \frac{\sin(m®f_p{}^2{}_n)}{m®f_p{}^2{}_n} e^{-jm®f_p(2t_{0n}+{}^2{}_n)} \tag{5}$$

At centre frequency f_0 (m=0) static excitation to individual element reduces to Eq.(6)

$$¥_{mn} = {}_n f_p{}^2{}_n \tag{6}$$

Thus the main beam at f_0 only depends on the duration of the switch-on time (τ_n). However for side band radiation due to the term $e^{-jm\pi fp}(2t_{on}+\tau_n)$ in Eq. (5) there exists some phase shifts between the elements.

Eberhart and Kennedy proposed an alternative solution to the complex non-linear optimization problem by emulating the collective behavior of bird flocks, particles, the boids method of Craig Reynolds and socio-cognition and called the new optimization technique as Particle Swarm Optimization (PSO).Global optimization algorithm PSO [10-13] is applied to minimize the sideband level as well as SLL at central frequency using the cost function given in Eq.(7)

$$Fitness = \begin{cases} (\mathrm{SLL_o} - \mathrm{SLL_d})^2_{f=f_0} + (\mathrm{SLL_o} - \mathrm{SLL_d})^2_{f=f_o+f_p} & \\ +(\mathrm{SLL_o} - \mathrm{SLL_d})^2_{f=f_0-f_p} & if \quad FNBW \le 20^0 \\ 1000 & otherwise \end{cases} \tag{7}$$

SLL_d is the desired SLL while SLL_o is the obtained SLL for the optimized set of values of t_{on} switch-on time instant and τ_n switch on time of individual element in each iteration.

3. RESULTS AND DISCUSSIONS

We consider a 16 elements linear array (shown in fig.3) of very thin wired half wavelength dipole antennas with λ/2 spacing between elements at 3GHz frequency. The total length of each dipole is 50mm with gap of 0.25 mm between two arms of dipole. The time modulated array is used to reduce the power losses associated to the sideband radiations while synthesizing fixed SLL target pattern at 3GHz frequency. The switch-on time instance (t_{on}) and the switch-on time duration (τ_n) of each element is optimized via PSO using the fitness function given in Eq. (7). Optimization is carried out to generate SLL^d=-25dB and SBL^d=-30dB with pulse repetition frequency prf =1MHz.

For optimization, the control parameters for PSO are set as suggested by the article [10-13] .The PSO uses swarm size of 30 and parameters w= 0.5, c_1 = 2.0, and c_2 = 2.0. Each run of the algorithm is executed for 500 iterations where dynamic range of search space is bounded within (0,1). PSO fulfils the synthesis constraints on SLL at the convergence.

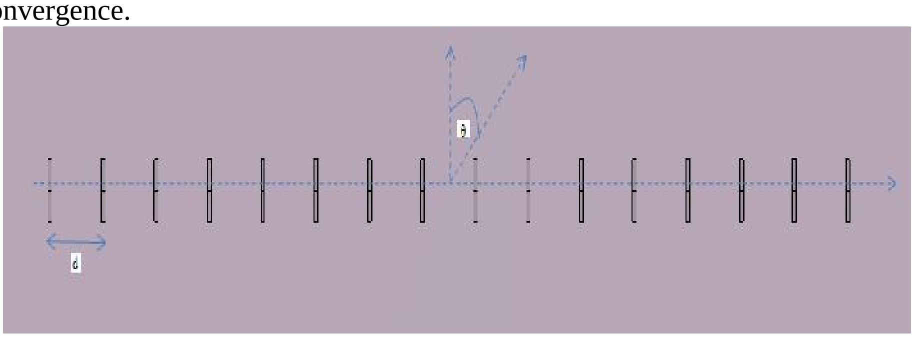


Fig.(3). Geometry of an equally spaced 16-element linear array of wired dipoles

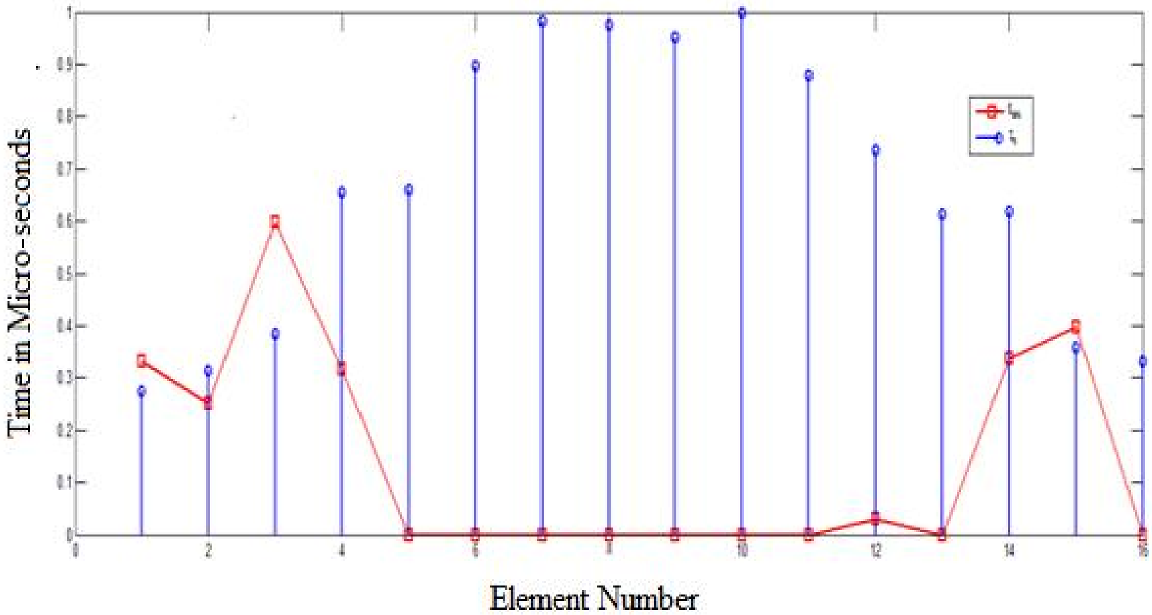
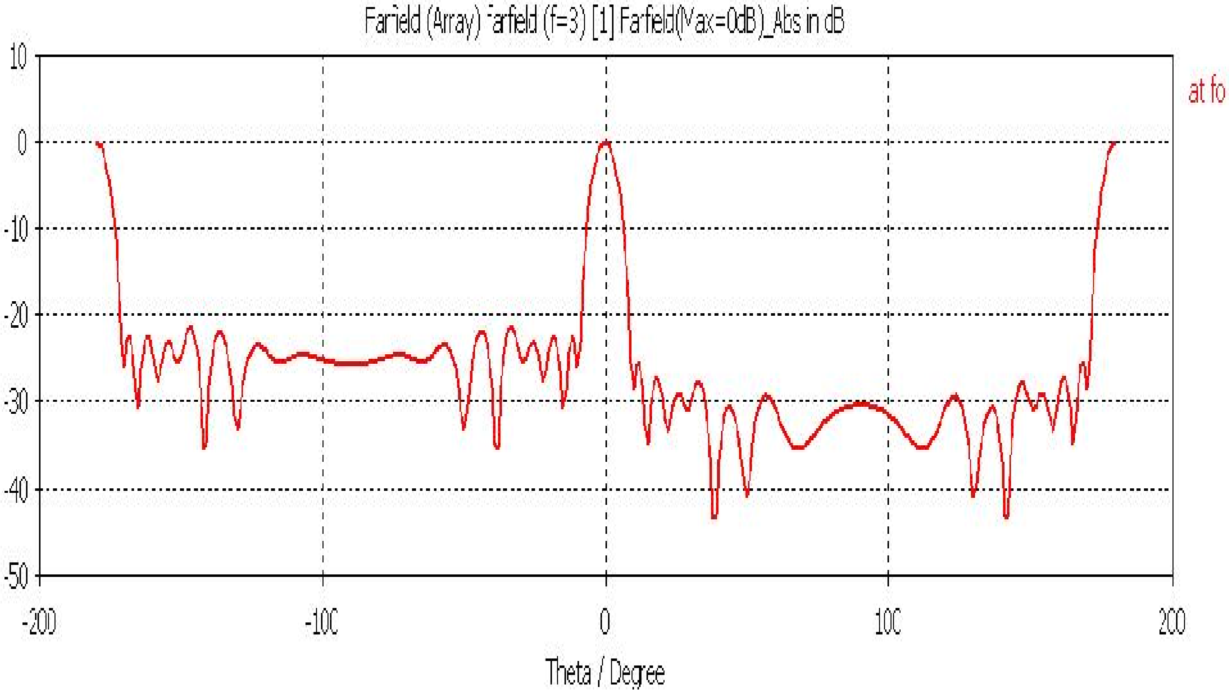


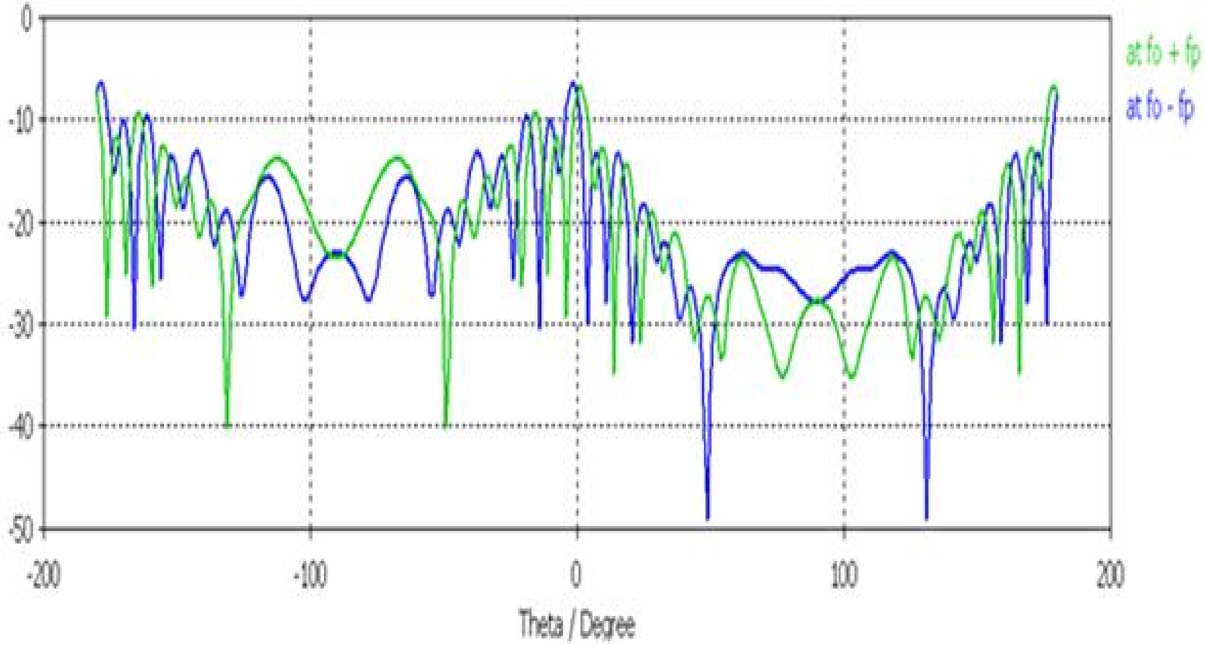
Fig.(4). Switch-on time instant (t_{on}) and switch-on time duration (τ_n)

The optimized time sequence of switch-on time instant (t_{on}) and switch-on time duration (τ_n) for the desired fitness function is shown in the fig.(4).

The CST microwave studio simulated normalized radiation patterns at centre frequency f_0 and first side bands $f_0 \pm fp$ with the obtained optimized time sequence are shown in Fig. (5) (a), (b) and (c). Figure 5 (a) shows the normalized radiation pattern at centre frequency. The SLL achieved is -23.8dB at 3GHz. Figure 5 (b) is showing sideband levels of the designed TMLA.



(a)



(b)

Fig. (5). Simulated patterns with optimized time parameters. (a) Patterns at fo = 3GHz. (b) Patterns at fo ± fp.

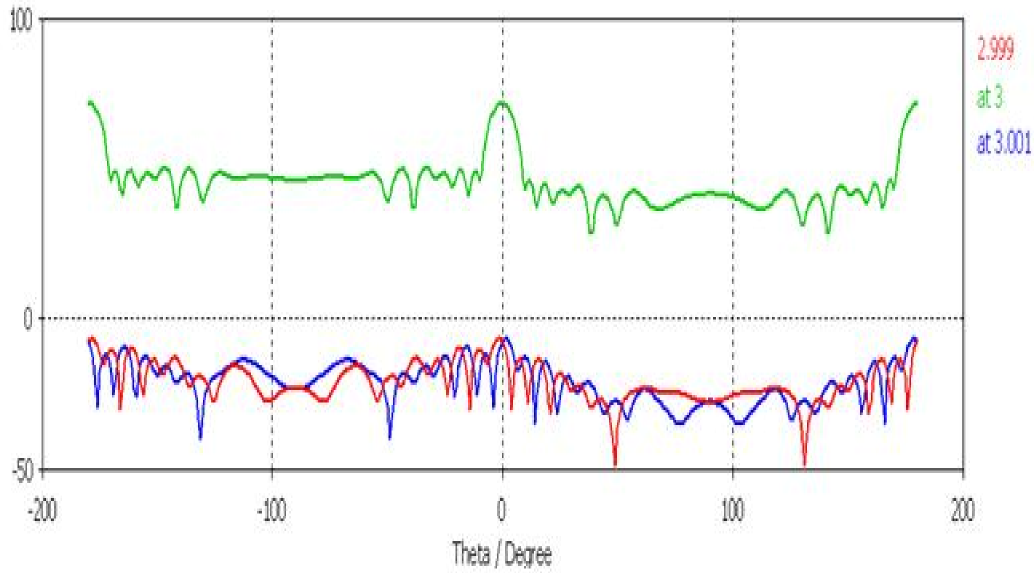


Fig. (6). Simulated patterns at f_o = 3GHz and at $f_o \pm f_p$

The maximum SBL at f_0+fp and f_0-fp is -31.72 dB and -29.59 dB respectively. Figure 6 is showing the combined pattern at centre and sideband frequencies from where it is clear that sideband level is approximately -5dB lower than that of the power pattern obtained at centre frequency.

The proposed technique guarantees satisfactory SB reduction besides the first harmonic. Moreover, it is seen that normalized static excitation amplitude on each element is same as switch-on time of the corresponding element.

Table 1 shows the simulated results in terms of desired and obtained values of SLL and relative level of sidebands respectively.

Table-1: Desired and Obtained Results for TMLA using CST microwave studio

Design Parameters	Side Lobe Level (dB)		FNBW (degrees)	
	Desired	Obtained	Desired	Obtained
f_o=3GHz	-25	-23.8	≤ 20°	19
f_o+f_p=3.001GHz	-30	-31.72	NA	
f_o-f_p=2.999GHz	-30	-29.59	NA	

The same observations were also obtained by analytical method using MatLab 7 simulation software, which validates the correctness of the CST microwave studio model in this study. However, there is little disagreement between some simulated relative levels of sideband beams and analytical data due to the mutual coupling effect and errors of amplitude and phase excitations. CST method provides an attractive tool for the analysis of the transient response of the time modulated arrays.

4. CONCLUSION

A time modulation approach with suitable Particle Swarm Optimization algorithm for the synthesis of low SLL time modulated linear array with suppressed sidebands has been proposed It is shown that, by means of a suitable Particle Swarm Optimization algorithm, the SLL and the sideband patterns of a time modulated antenna arrays can be significantly lowered by optimizing the “switch-on instants” & “on-time duration” time intervals of each element. The gain of the optimized array can be improved as a result of the sideband suppression. Experimental results were in reasonable agreement with the theoretical results and verified the proposed approach.

REFERENCES

[1] H. E. Schrank, “Low sidelobe phased array antennas,” *IEEE Antennas Propagat. Soc. Newslett.*, vol. 25, no. 2, pp. 4–9, Apr. 1983.

[2] W. H.Kummer,A. T. Villeneuve, T. S. Fong, and F. G. Terrio, “Ultra-low sidelobes from time-modulated arrays,” *IEEE Trans. Antennas Propagat.*, vol. AP-11, pp. 633–639, Nov. 1963.

[3] R. W. Bickmore, “Time versus space in antenna theory,” in *Microwave Scanning Antennas*, R. C. Hansen, Ed. New York: Academic, 1966, vol. III.

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

[5] L. Poli, P. Rocca, L. Manica, and A. Massa, “Handling sideband radiations in time modulated arrays through particle swarm optimization,” *IEEE Trans. Antennas Propag.*, vol. 58, no. 4, pp. 1408–1411, Apr. 2010.

[6] S. Pal, S. Das, and A. Basak, “Design of time-modulated linear arrays with a multi-objective optimization approach,” *Progr. Electromagn. Res. B*, vol. 23, pp. 83–107, 2010.

[7] Quanjiang Zhu, Shiwen Yang, Li Zheng, and Zaiping Nie, **“**Design Of A Low Sidelobe Time Modulated Linear Array With Uniform Amplitude And Sub-Sectional Optimized Time Steps”, IEEE Transactions On Antennas And Propagation, Vol. 60, No. 9, 4436-4439 ,September 2012.

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

[9] Balanis

[10] J. Kennedy and R. C. Eberhart, “Particle swarm optimization”, Proc.IEEE Int. Conf. Neural Networks, pp. 1942–1948, 1995.

[11] W. T. Li, X. W. Shi and Y. Q. Hei, “An Improved Particle Swarm Optimization Algorithm for Pattern Synthesis of Phased Arrays,” *Progress In Electromagnetics Research*, PIER 82, pp.319–332, 2008.

[12] Z. D. Zaharis, D. G. Kampitaki,P. I. Lazaridis, A. I. Papastergiou,A. T. Hatzigaidas and P. B. Gallion, "Improving the radiation characteristics of a base station antenna array using a particle swarm optimizer", Microwave Opt Technol Lett 49, pp.1690-1698, 2007.

[13] N. Jin and Y. Rahmat-Samii, “Advances in particle swarm optimization for antenna designs: Real-number, binary, single- objective and multiobjective implementations,” IEEE Trans. Antennas Propag., Vol. 55, no. 3, pp.556-567, 2007.