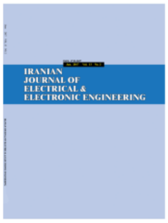
IUST
Iran University of
Science and Technology

Iranian Journal of Electrical and Electronic Engineering

Journal Homepage: ijeee.iust.ac.ir

Research Paper


IRANIAN
JOURNAL OF
ELECTRICAL &
ELECTRONIC ENGINEERING

Phase-Only Synthesis of Antenna Arrays Using Nonuniform Phased Sampling Method

M. Khalaj-Amirhosseini*(C.A.)

Abstract: Nonuniform Phased Sampling method is proposed to phase-only synthesize the power pattern of both linear and planar antenna arrays. This method modifies the conventional sampling method which is used for amplitude-phase synthesis. This method is based on assigning suitable phases to the sampling points of radiation pattern in order to reach desired amplitude of currents. Some examples are given to verify the effectiveness of the proposed method for both pencil-beam and shaped beam patterns.

Keywords: Antenna Array Synthesis, Nonuniform Phased Sampling Method, Phase-Only Synthesis.

1 Introduction

SYNTHESIS of antenna arrays is usually done by changing both amplitude and phase of their antenna currents [1-4]. This conventional approach for array synthesis is called amplitude-phase synthesis. However, in some arrays such as reflectarray antennas having either pencil beams or contoured beam, only the phase of the unit cells is under our control [5-8]. In these antennas, the amplitude of unit cells are specified by the key parameter F/D [5-8]. Moreover, changing the phase of antennas of an array is more practical and easier than changing their amplitudes. Hence, we have to synthesize many linear and planar arrays by changing only the phase of their antennas. This approach for array synthesis is called phase-only synthesis [9-19].

Almost all proposed methods for phase-only synthesis are based on optimization methods in two main categories; local search algorithms; like alternating projections method [9, 13], and the evolutionary algorithms; like genetic algorithm (GA) [12], particle swarm optimization [10, 11], and semidefinite relaxation technique [14-15]. In [16], a scaling factor is introduced in an iterative optimization approach. In [17], a least-square error is minimized by applying gradient-descent optimization. Besides, autocorrelation matching method (AMM) was introduced to phase-only synthesis of linear arrays in [18, 19].

In this paper, a different method is proposed for phase-only synthesis of both linear and planar antenna arrays. This method is called Nonuniform Phased Sampling (NPS) method. The proposed NPS method is a modification of the well-known sampling (or Woodward-Lawson) method. In the conventional sampling method, the phases of the radiation pattern at the sampling points are uniform. However, in the proposed nonuniform sampling method the phases of the radiation pattern at the sampling points are nonuniform. The nonuniform phase distribution of the sampling points is assigned so that the amplitude distribution of the antenna currents approaches the presumed one. Then, the phases of the antenna currents are determined from both the amplitude and assigned phases of the sampled points of the radiation pattern.

The NPS method introduced in this paper for phase-only synthesis of linear arrays is completely different from the AMM method presented in [18-19]. However, it is shown that the results of these two methods are comparable and almost similar. In the AMM method, the amplitude-phase synthesis must be done at first. However, in the introduced NPS method this requirement is not needed.

The paper is organized as follows. In Section 2, the uniform phased sampling method is reviewed. In Section 3, nonuniform phased sampling method is introduced. Some examples for both linear and planar

---

Iranian Journal of Electrical and Electronic Engineering, 2021.
Paper first received 01 June 2020, revised 09 August 2020, and accepted 18 August 2020.
* The author is with the School of Electrical Engineering, Iran University of Science and Technology, Tehran, Iran.
E-mail: khalaja@iust.ac.ir.
Corresponding Author: M. Khalaj-Amirhosseini.
https://doi.org/10.22068/IJEEE.17.2.1896

arrays are presented in Section 4 to verify the performance of the proposed NPS method as a new phase-only synthesis method.

2 Uniform Phased Sampling Method

A linear antenna array comprises N identical antennas of uniform inter-distances d on the z axis. The excitation current of the nth antenna is $I_n = |I_n|\exp(j\varphi_n)$. The radiation pattern of linear arrays is written as follows.

$$F(\psi)=\sum_{n=0}^{N-1} I_n \exp(jn\psi) \tag{1}$$

where $\psi = kd\cos(\theta)$ is a real variable in which $k = 2\pi/\lambda$ and λ is the wavelength in the free space.

A planar antenna array may be comprised of $M\times N$ antennas on the xy plane. are d_x and d_y in x and y directions, respectively. The excitation current of the mnth antenna is $I_{mn} = A_{mn}\exp(j\varphi_{mn})$ for $0 \le m \le M-1$ and $0 \le n \le N-1$. The radiation pattern of planar arrays is written as follows.

$$F(\psi_x,\psi_y)=\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} I_{mn}\exp\left(j(m\psi_x+n\psi_y)\right) \tag{2}$$

where ψ_x and ψ_y are real variables defined as $\psi_x = 2\pi\frac{d_x}{\lambda}\sin\theta\cos\varphi$ and $\psi_y = 2\pi\frac{d_y}{\lambda}\sin\theta\sin\varphi$.

An efficient amplitude-phases method to synthesize linear and planar arrays is the sampling (or Woodward-Lawson) method [1-4]. In the sampling method, the excitation currents of linear and planar arrays are obtained from the samples of their radiation patterns $F(\psi)$ and $F(\psi_x, \psi_y)$, respectively, as follows [1-4].

$$I_n=\sum_{p=-(N-1)/2}^{(N-1)/2}F(\psi_p)\exp\left(-jn'\psi_p\right) \tag{3}$$

$$I_{mn}=\sum_{p=-(M-1)/2}^{(M-1)/2}\sum_{q=-(N-1)/2}^{(N-1)/2}F(\psi_p,\psi_q)\exp\left(-j(m'\psi_p+n'\psi_q)\right) \tag{4}$$

In (3) and (4), ψ_p and (ψ_p, ψ_q) are the sampling points for linear and planar arrays, respectively, where $\psi_p=\frac{2\pi}{N}p$ and $\psi_q=\frac{2\pi}{N}q$. Also, $m' = m-0.5(M-1)$, $n' = n-0.5(N-1)$ for $m = 0, 1, \ldots M-1$ and $n = 0, 1, \ldots, N-1$.

In conventional sampling method, the value of radiation patterns at sampling points, $F(\psi_p)$ or $F(\psi_p, \psi_q)$, are considered real. In fact, all sampling values $F(\psi_p)$ or $F(\psi_p, \psi_q)$ are considered to have the same phase like zero. Hence, one may call the conventional sampling method as Uniform Phased Sampling (UPS) method. This well-known method yields us excitation currents that may have undesirable amplitudes.

3 Nonuniform Phased Sampling Method

Here, we modify the conventional or uniform phased sampling method in order to control the amplitudes of the excitation currents. For this purpose, we propose nonuniform phased sampling (NPS) method. In this proposed method, we assign nonuniform phases to the radiation patterns of linear and planar arrays at the sampling points, as follows.

$$F(\psi_p)=|F(\psi_p)|\exp(j\varphi_p) \tag{5}$$

$$F(\psi_p,\psi_q)=|F(\psi_p,\psi_q)|\exp(j\varphi_{pq}) \tag{6}$$

In (5) and (6), φ_p and φ_{pq} are the phases assigned to the sampling points ψ_p and (ψ_p, ψ_q), respectively. These phases should be chosen so that the amplitudes of the excitation currents $|I_n|$ and $|I_{mn}|$ approach as much as possible to the desired amplitudes A_n and A_{mn}, respectively. This aim can be achieved by some suitable methods among them optimization. One can define the following error functions for the optimization methods for the linear and planar array, respectively.

$$\text{error}(|I_n|)=\sqrt{\frac{1}{N}\sum_{n=0}^{N-1}\left(|I_n|-A_n\right)^2} \tag{7}$$

$$\text{error}(|I_{mn}|)=\sqrt{\frac{1}{MN}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}\left(|I_{mn}|-A_{mn}\right)^2} \tag{8}$$

Minimizing these error functions makes amplitudes of the excitation currents $|I_n|$ and $|I_{mn}|$ equal to optimized amplitudes $\tilde{A}_n$ and $\tilde{A}_{mn}$ which are close to the desired amplitudes A_n and A_{mn}, respectively. We call these amplitudes as approximately desired amplitudes.

Successive using (5) and (6), Eqs. (3), (4), (7), and (8) yields the optimum values of φ_p and φ_{pq}. Finally, the excitation currents of the antennas are obtained by (3) and (4).

It is worth mentioning that to make the error functions defined in (7) and (8) more effective, it had better multiply the amplitudes of the excitation currents $|I_n|$ and $|I_{mn}|$ by an appropriate constant so that the following energy equivalence to be hold.

$$\sum_{n=0}^{N-1}|I_n|^2=\sum_{n=0}^{N-1}A_n^2 \tag{9}$$

$$\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}|I_{mn}|^2=\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}A_{mn}^2 \tag{10}$$

Holding the energy equivalence must be done in each step of the optimization before evaluating error functions.

To summarize, the following steps must be done for NPS phase-only synthesis of linear arrays:

1. Assign phases φ_p to the sampling points of desired radiation pattern $|F(\psi_p)|$ as indicated in (5).
2. Find the excitation currents I_n, considering the amplitude and (assigned) phases of the radiation

pattern $F(\psi_p)$, through (3).
3. Find the difference between the amplitude of the currents $|I_n|$ and the desired amplitudes A_n, through (7). Before this, the energy equivalence must be done as indicated in (9).
4. Go to step 2 and repeat steps 2, 3, and 4 until the error in (7) reaches a value as small as possible.
5. The phases of the excitation currents found in step 3, are the same phases φ_n we are looking for them.

The same procedure can be done for phase-only synthesis of planar arrays.

4 Examples and Discussion

To verify the proposed NPS method, several examples are presented in three different groups, i.e., pencil, flat-topped, and cosecant beams. The desired amplitudes A_n is presumed as symmetric linear variation with respect to n. The characteristic of the desired amplitude excitations is Amplitude Dynamic Range (ADR) which is defined as the maximum amplitude to minimum one. The initial values of phases of φ_p and φ_{pq} in the optimization process are produced by a random generator of $[-\pi, \pi]$. The initial values of phases φ_p should be regenerated several times to find the best solution which has the least error functions (7) or (8) among all solutions. The values of N and M are considered constant as 21 and therefore the sample points would be at multiples of $2\pi/21 = 0.299$.

4.1 Pencil-Beam Patterns

Two linear arrays with $N = 21$ antennas are designed to have pencil-beam patterns of Chebyshev and Taylor of $\bar{n} = 4$ types with sidelobe level of SLL = –20 dB. The amplitude dynamic range is considered ADR = 2.5.

Figs. 1 and 2, show the resultant patterns obtained by amplitude-phase (UPS) and phase-only (NPS) methods. It is seen that satisfactory patterns have been obtained because the resulted SLLs are not larger than -20 dB. Besides, the Taylor pattern has been synthesized better than the Chebyshev one. This may be due to smoother behavior of Taylor pattern and its excitation currents in amplitude-phase synthesis.

Fig. 3 illustrates the amplitude of currents for amplitude-phase and NPS methods, both desired amplitudes A_n and approximately desired amplitudes $\tilde{A}_n$. The value of error defined in (7) amounts to 0.0755 and 0.0433 for Chebyshev and Taylor patterns, respectively. Fig. 4 illustrates the nonuniform phases assigned to the sampling points. Finally, Fig. 5 shows the required phases of the phase-only synthesized currents obtained by NPS method. All the required phases for amplitude-phase synthesis are zero.

Now, a linear arrays with $N = 31$ antennas are designed to have a pencil-beam pattern of Chebyshev type with sidelobe level of SLL = –20 dB and having a deep null about ψ = 2.5. The excitations of such array factor could be found as explained in [3] by setting the

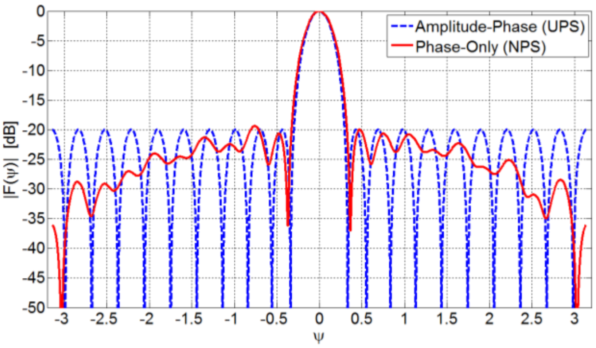


Fig. 1 Amplitude-phase and phase-only synthesized Chebyshev pencil-beam patterns of SLL = –20 dB and ADR = 2.5.

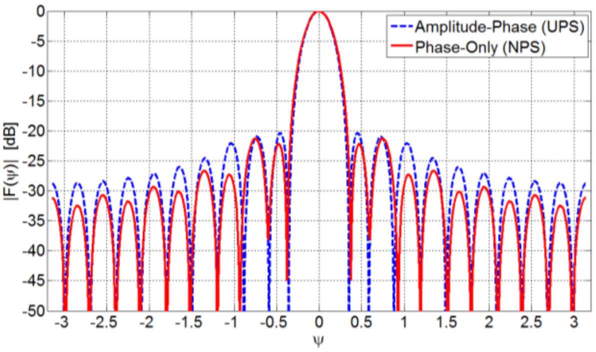


Fig. 2 Amplitude-phase and phase-only synthesized Taylor pencil-beam patterns of SLL = –20 dB, n-bar = 4 and ADR = 2.5.

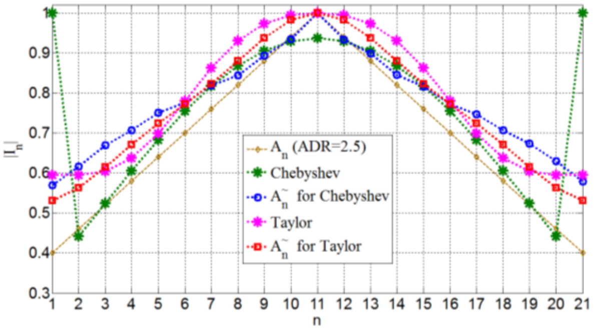


Fig. 3 Amplitude of the currents for both amplitude-phase and phase-only (NPS) pencil-beam patterns of Chebyshev and Taylor types.

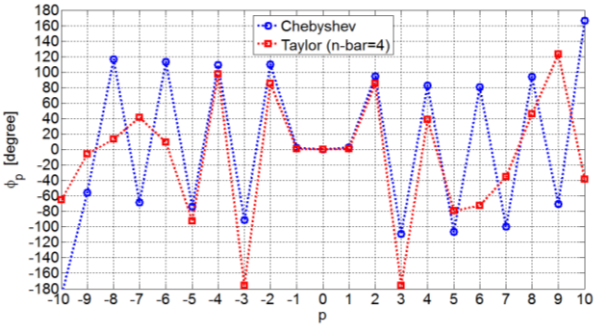


Fig. 4 Nonuniform phases at sampling points for the pencil-beam patterns of Chebyshev and Taylor types.

sixth sidelobe to be –40 dB.

The amplitude dynamic range is considered ADR = 2.5 and the value of error amounts to 0.0831. Fig. 6 compares the resultant pattern obtained by phase-only (NPS) method with the desired one. It is seen that a deep null has been created around $\psi = 2.5$ while SLL is somewhat larger than –20 dB. In this example, both amplitude-phase and phase-only patterns have complex currents. Figs. 7 and 8 show the amplitude and phase of these currents, respectively.

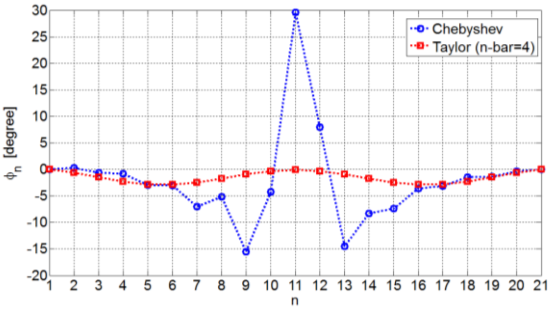


Fig. 5 Required phases of the phase-only synthesized currents for pencil-beam patterns of Chebyshev and Taylor types.

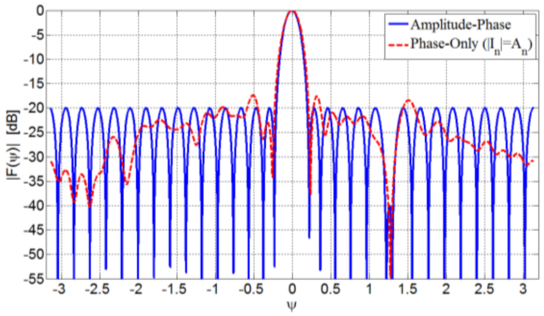


Fig. 6 Amplitude-phase and phase-only synthesized pencil-beam patterns having a deep null.

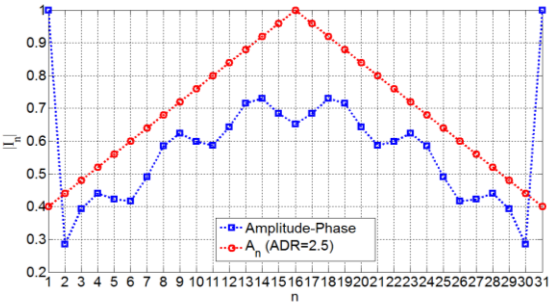


Fig. 7 Amplitude of the currents for both amplitude-phase and phase-only pencil-beam pattern having a deep null.

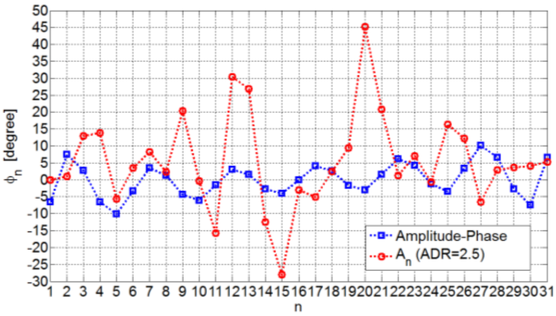


Fig. 8 Required phases of the currents for both amplitude-phase and phase-only pencil-beam pattern having a deep null.

4.2 Flat-Top Beam Pattern

A linear array with N = 21 antennas is designed to have a flat-top beam between $\psi = -0.898$ to $\psi = +0.898$ supposing $F(\pm 0.898) = 0.5F(0)$. The amplitude dynamic range is considered ADR = 2.5 and 5.

Figs. 9 and 10, show the resultant patterns obtained by amplitude-phase (UPS) and phase-only (NPS) methods for ADR = 2.5 and 5, respectively. In NPS method, the amplitudes of currents $|I_n|$ are considered equal to both desired amplitudes A_n or approximately desired amplitudes $\tilde{A}_n$. It is seen that satisfactory patterns have been obtained, specifically when $|I_n|$ are imposed to be equal to the desired amplitudes A_n. Besides, the case of ADR = 5 gives a more satisfactory pattern than the case of ADR = 2.5. It is worthy to mention that the synthesized patterns by both UPS and NPS are equal to the desired pattern at N sampling points ψ_p.

Fig. 11 compares the amplitude of currents for both

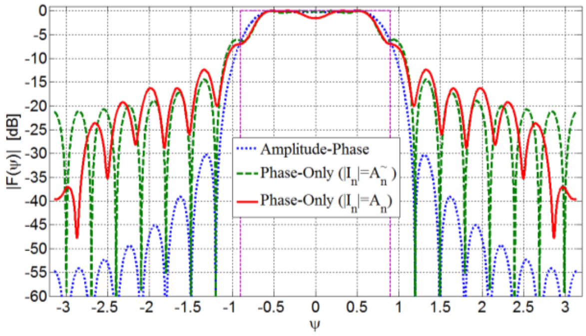


Fig. 9 Amplitude-phase (UPS) and phase-only (NPS) synthesized flat-top beam patterns for ADR = 2.5.

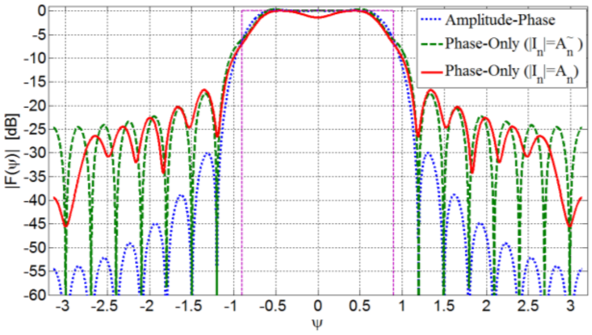


Fig. 10 Amplitude-phase (UPS) and phase-only (NPS) synthesized flat-top beam patterns for ADR = 5.

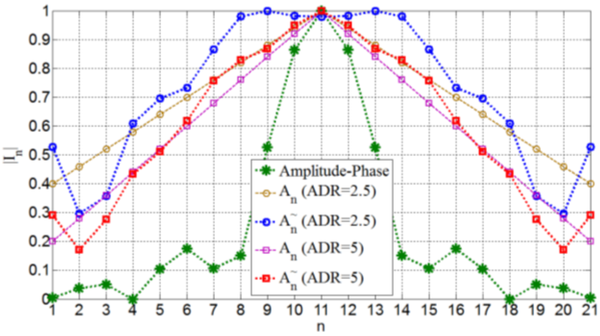


Fig. 11 Amplitude of the currents for both amplitude-phase and phase-only (NPS) flat-top beam patterns for ADR = 2.5 and 5.

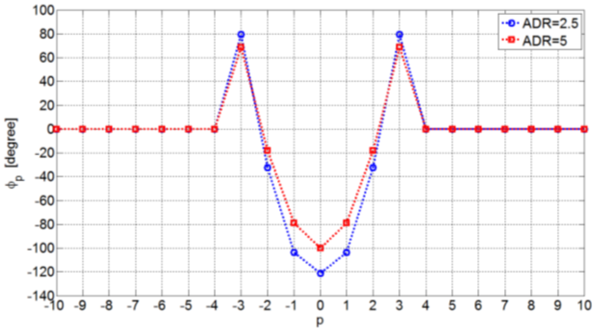


Fig. 12 Assigned phases at sampling points for the flat-top beam patterns.

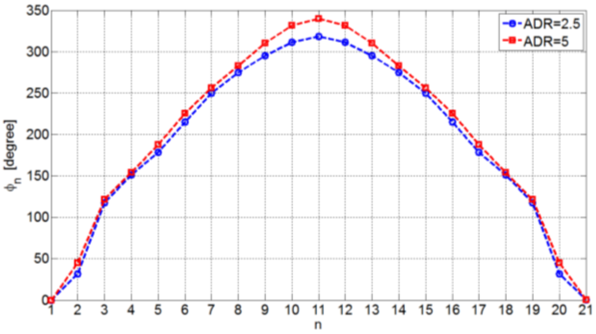


Fig. 13 Required phases of the phase-only synthesized currents for flat-top beam patterns.

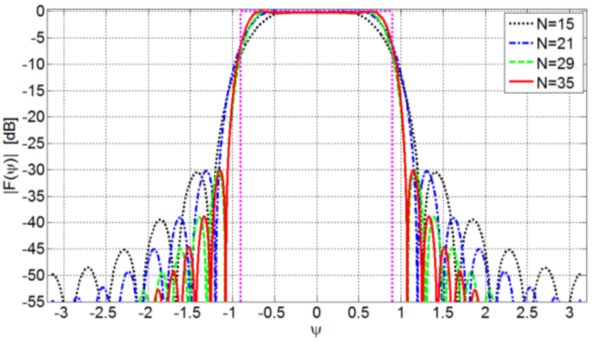


Fig. 14 Amplitude-phase (UPS) synthesized flat-top beam patterns for ADR = 5.

UPS and NPS methods. The value of error defined in (7) are equal to 0.0951 and 0.0575 for ADR = 2.5 and 5, respectively. Fig. 12 shows the assigned phases of the sampling points. Eventually, Fig. 13 shows the required phases of the phase-only synthesized currents obtained by NPS method. The required phases for amplitude-phase synthesis are either zero or 180°.

Here, the effect of the number of antennas is studied. For this purpose, desired flat-top beam is synthesized using four arrays having N = 15, 21, 29, and 35 antennas. Figs. 14 and 15, show the resultant patterns obtained by amplitude-phase (UPS) and phase-only (NPS) methods, respectively. ADR is considered to be equal to 5. To evaluate the similarity of synthesized patterns to the desired one, the following error is defined.

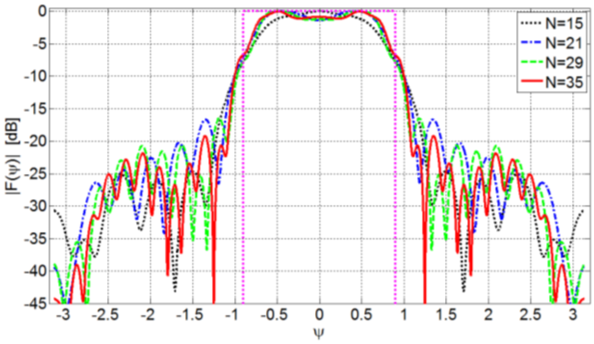


Fig. 15 Phase-only (NPS) synthesized flat-top beam patterns for ADR = 5.

Table 1 Errors defined in (7) and (11) for flat-top beam.

N	error($\lvert I_n\rvert$) (NPS)	error($\lvert F\rvert$) (NPS)	error($\lvert F\rvert$) (UPS)	$\frac{\text{error}(\lvert F \rvert)_{NPS}}{\text{error}(\lvert F \rvert)_{UPS}}$
15	0.0522	2.62	1.78	1.47
21	0.0575	2.33	1.43	1.63
29	0.0674	2.46	1.14	2.15
35	0.0621	2.33	1.03	2.27

$$\text{error}(|F|)=\sqrt{\frac{1}{2\pi}\int_{-\pi}^{\pi}\left(|\tilde{F}(\psi)|-|F(\psi)|\right)^2 d\psi} \tag{11}$$

where $\tilde{F}(\psi)$ and $F(\psi)$ are synthesized and desired patterns, respectively. Table 1, shows this error for four flat-top synthesized beams. As expected, the error of NPS method is larger than the error of UPS method. However, it is seen that from the last column of this table that as N increases the efficiency of NPS method decreases slowly with respect to UPS method.

4.3 Cosecant Pattern

A linear array with N = 21 antennas is designed to have a cosecant beam, i.e. $1/\psi$, between $\psi = 0.299$ to $\psi = +2.094$ supposing $F(0)=0.6F(0.299)$. The amplitude dynamic range is considered ADR=2.5 and 5.

Figs. 16 and 17, show the resultant patterns obtained by amplitude-phase (UPS) and phase-only (NPS) methods for ADR=2.5 and 5, respectively. It is seen that satisfactory patterns have been obtained, specifically when $|I_n|$ are imposed to be equal to the desired amplitudes A_n. Again, it is seen that as ADR increases from 2.5 to 5, the phase-only synthesized pattern tends the desired pattern further. Also, the synthesized patterns by both UPS and NPS are equal to the desired pattern at N sampling points ψ_p.

Fig. 18 compares the amplitude of currents for both amplitude-phase and phase-only methods. The value of error defined in (7) are equal to 0.0698 and 0.0333 for ADR = 2.5 and 5, respectively. Fig. 19 illustrates the nonuniform phases of the sampling points. At last, Fig. 20 shows the required phases of the phase-only synthesized currents obtained by NPS method. This figure also shows the required phases for amplitude-phase synthesis. In fact, the currents of amplitude-phase

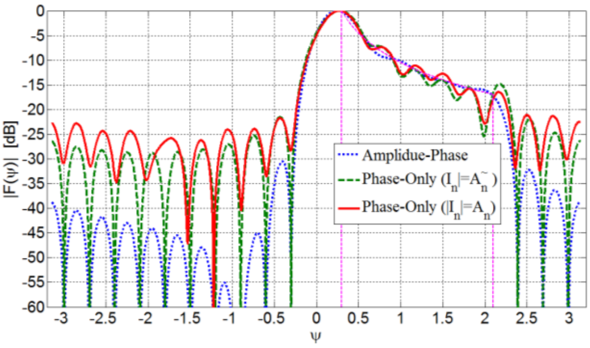


Fig. 16 Amplitude-phase (UPS) and phase-only (NPS) synthesized cosecant beam patterns for ADR = 2.5.

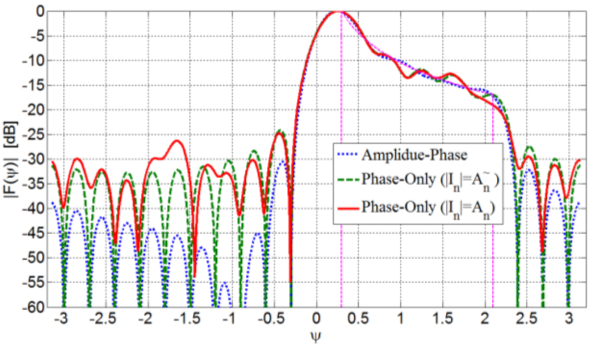


Fig. 17 Amplitude-phase (UPS) and phase-only (NPS) synthesized cosecant beam patterns for ADR = 5.

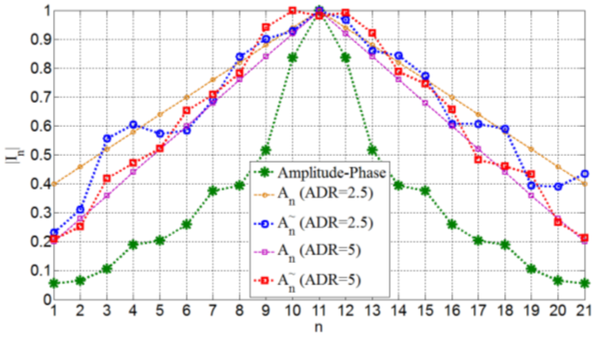


Fig. 18 Amplitude of the currents for both amplitude-phase and phase-only (NPS) cosecant beam patterns for ADR = 2.5 and 5.

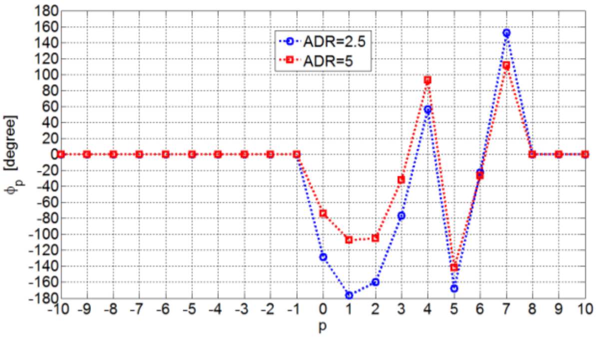


Fig. 19 Nonuniform phases at sampling points for the cosecant beam patterns.

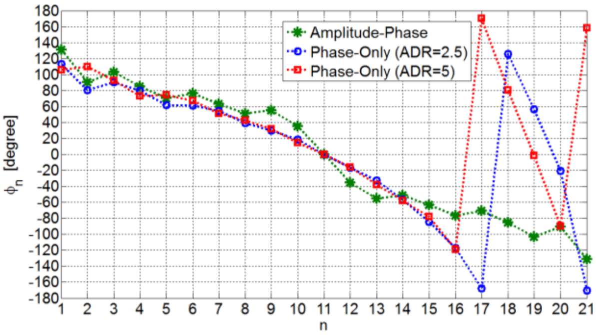


Fig. 20 Required phases of both amplitude-phase and phase-only synthesized currents for cosecant beam patterns.

synthesis are complex numbers, in this example.

It is notable that one can see the synthesized patterns by NPS method in Figs. 1, 2, 9, 10, 16, and 17 are comparable with those obtained by AMM method in [18]. This issue shows that both methods verify each other.

4.4 Two-dimensional Pencil-Beam Pattern

A planar array with $M\times N = 21\times 21$ antennas is designed to have a symmetric two-dimensional pencil-beam pattern of Taylor of $\bar{n} = 4$ with sidelobe level of SLL = –20 dB. The sidelobes are considered symmetric about the central axis of the $\psi_x - \psi_y$ plane. Hence, the amplitude-phase planar array should be synthesized by applying a suitable transformation [3-4] on the linear Taylor array, as shown in Fig. 21. Also, Fig. 22 shows the amplitude of the synthesized currents.

The Taylor pencil-beam pattern is phase-only synthesized using NPS method while the desired amplitudes of the currents are presumed as symmetric linear variation, as shown in Fig. 23. The amplitude dynamic range is equal to ADR = 2.5. Fig. 24 illustrates the approximately desired amplitudes synthesized by NPS method which is identical to desired amplitudes shown in Fig. 23. The difference between these two amplitudes is 0.0622 obtained by error defined in (8).

Fig. 25 shows the phase-only synthesized pattern obtained by NPS method. It is seen that the resultant pattern is semi-symmetric and has sidelobe level nearly –20 dB. Ultimately, Fig. 26 shows the required phases of the phase-only synthesized currents obtained by NPS method. The required phases for amplitude-phase synthesis are either zero or 180°.

5 Conclusion

Nonuniform Phased Sampling (NPS) was proposed for phase-only synthesis of power pattern of linear and planar antenna arrays. In this method the conventional sampling method was modified by assigning suitable phases to the sampling points. The effectiveness of the proposed procedure for pencil-beam, flat-top and cosecant patterns was verified. It was seen that as amplitude dynamic range (ADR) increases, the phase-only pattern tends the desired pattern further.

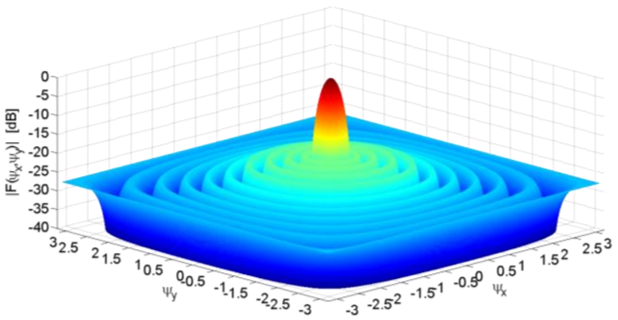


Fig. 21 Amplitude-phase synthesized pencil-beam pattern of Taylor type with nbar = 4 and SLL = –20 dB.

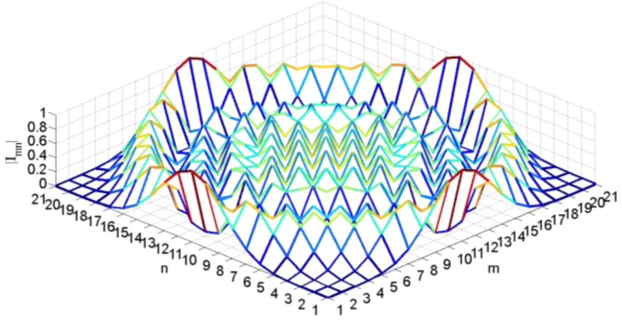


Fig. 22 Amplitude of the currents for amplitude-phase synthesized two-dimensional pencil-beam pattern.

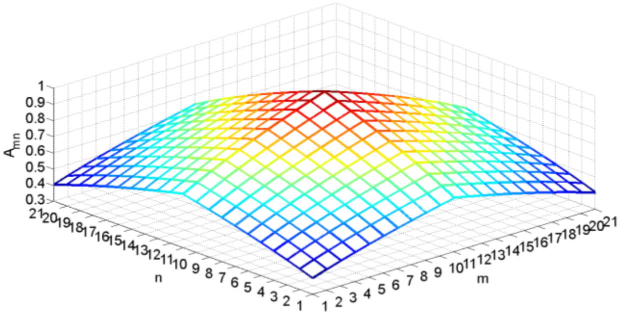


Fig. 23 Desired amplitudes of the currents presumed for phase-only synthesis.

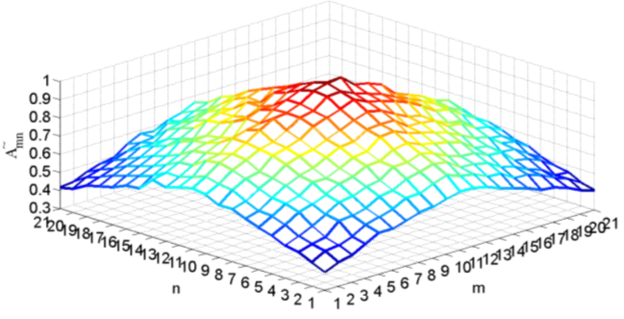


Fig. 24 Approximately desired amplitudes synthesized by NPS method.

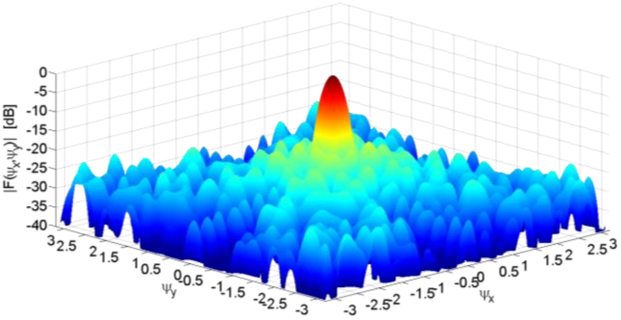


Fig. 25 Phase-only synthesized symmetric pencil-beam pattern for ADR = 2.5.

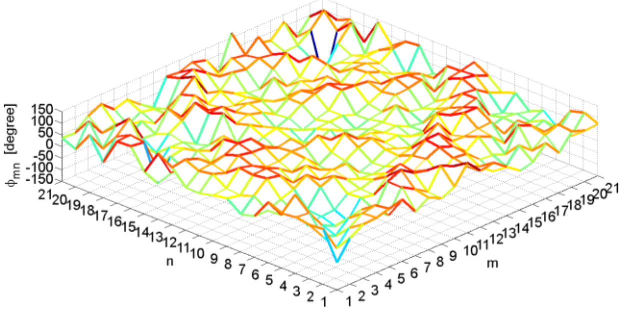


Fig. 26 Required phases of phase-only synthesized currents for two-dimensional pencil-beam pattern.

References

[1] R. C. Hansen, *Phased array antennas*. John Wiley & Sons Inc., New Jersey, USA, 2009.

[2] R. S. Elliott, “Beamwidth and directivity of large scanning array,” *Part II, Microwave Journal*, pp. 74–82, January 1964.

[3] M. Khalaj-Amirhosseini, “Synthesis of linear and planar arrays with sidelobes of individually arbitrary levels,” *International Journal of RF and Microwave Computer-Aided Engineering*, Vol. 29, No. 3, Mar. 2018.

[4] M. Khalaj-Amirhosseini, “Synthesis of planar arrays by applying transformations to linear arrays”, in *9th Internatioal Symposium on Telecommunications (IST 2018)*, pp. 39–44, Tehran, Iran, 17-19 Dec. 2018.

[5] J. Huang and J. A. Encinar, *Reflectarray antennas*. John Wiley & Sons Inc., New Jersey, USA, 2008.

[6] M. Zhou, O. Borries, and E. Jørgensen, “Design and optimization of a single-layer planar transmit-receive contoured beam reflectarray with enhanced performance,” *IEEE Transactions on Antennas and Propagation*, Vol. 63, No. 4, pp. 1247–1254, Apr. 2015.

[7] M. Khalaj-Amirhosseini, “Principles of ideal wideband reflectarray antennas,” *Progress in Electromagnetics Research*, Vol. 58, pp. 57–64, 2017.

[8] M. Khalaj-Amirhosseini and M. Nadi-Abiz, “Reducing the sidelobe level of reflectarray antennas using phase perturbation method,” *Iranian Journal of Electrical and Electronic Engineering*, Vol. 16, No. 2, pp. 153–157, Jun. 2020.

[9] O. M. Bucci, G. Mazzarella, and G. Panariello, "Reconfigurable arrays by phase-only control," *IEEE Transactions on Antennas and Propagation*, Vol. 39, No. 7, pp. 919–925, 1991.

[10] D. Gies and Y. Rahmat-Samii, "Particle swarm optimization for reconfigurable phase-differentiated array design", Mic*rowave and Optical Technology Letters*, Vol. 38, No. 3, pp. 168–175, 2003.

[11] P. Nayeri, F. Yang, and A. Elsherbeni, "Design of a single-feed reflectarray antennas with asymmetric multiple beams using the particle swarm optimization method," *IEEE Transactions on Antennas and Propagation*, Vol. 61, No. 9, pp. 4598–4605, 2013.

[12] S. Baskar, A. Alphones, and P. N. Suganthan, "Genetic algorithm-based design of a reconfigurable antenna array with discrete phase shifters," *Microwave and Optical Technology Letters*, Vol. 45, No. 6, pp. 461–465, 2005.

[13] R. Vescovo, "Reconfigurability and beam scanning with phase-only control for antenna arrays," *IEEE Transactions on Antennas and Propagation*, Vol. 56, No. 6, pp. 1555–1565, 2008.

[14] P. J. Kajenski, "Phase only antenna pattern notching via a semidefinite programming relaxation," *IEEE Transactions on Antennas and Propagation*, Vol. 60, No. 5, pp. 2562–2565, May 2012.

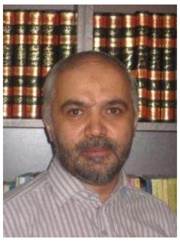
[15] B. Fuchs, "Application of convex relaxation to array synthesis problems", *IEEE Transactions on Antennas and Propagation*, Vol. 62, No. 2, pp. 634–640, Feb. 2014.

[16] J. Liang, X. Fan, W. Fan, D. Zhou, and J. Li, "Phase-only pattern synthesis for linear antenna arrays," *IEEE Transactions on Antennas and Wireless Propagation Letters*, Vol. 16, pp. 3232–3235, 2017.

[17] C. Lu, W. Sheng, Y. Han, and X. Ma, "Phase-only pattern synthesis based on gradient-descent optimization," *Journal of Systems Engineering and Electronics*, Vol. 27, No. 2, pp. 297–307, Apr. 2016.

[18] M. Khalaj-Amirhosseini, "Phase-only power pattern synthesis of linear arrays using autocorrelation matching method," *IEEE Transactions on Antennas and Wireless Propagation Letters*, Vol. 18, No. 7, pp. 1487–1491, Jul. 2019.

[19] M. Khalaj-Amirhosseini, "Phase-only synthesis of planar arrays using autocorrelation matching method," *International Journal of RF and Microwave Computer-Aided Engineering*, Vol. 30, No. 5, 2020.



M. Khalaj-Amirhosseini was born in Tehran, Iran in 1969. He received the B.Sc., M.Sc., and Ph.D. degrees in Electrical Engineering from the Iran University of Science and Technology (IUST), Tehran, in 1992, 1994, and 1998, respectively. He is currently a Professor with the School of Electrical Engineering, IUST. His current research interests include electromagnetics, microwaves, antennas, radio wave propagation, and electromagnetic compatibility.