Beam-Steering Antenna Technique Using Operational Amplifiers for Sub-6 GHz

Received 27 May 2024, accepted 15 June 2024, date of publication 18 June 2024, date of current version 26 June 2024.
Digital Object Identifier 10.1109/ACCESS.2024.3416311

RESEARCH ARTICLE

Beam-Steering Antenna Technique Using Operational Amplifiers for Sub-6 GHz

LIDA KOUHALVANDI[1], (Senior Member, IEEE), AND LADISLAU MATEKOVITS[2,3,4], (Senior Member, IEEE)
[1]Department of Electrical and Electronics Engineering, Doğuş University, 34775 İstanbul, Turkey
[2]Department of Electronics and Telecommunications, Politecnico di Torino, 10129 Turin, Italy
[3]Department of Measurements and Optical Electronics, Politehnica University Timisoara, 300006 Timişoara, Romania
[4]Istituto di Elettronica e di Ingegneria dell'Informazione e delle Telecomunicazioni, National Research Council, 10129 Turin, Italy
Corresponding author: Ladislau Matekovits (ladislau.matekovits@polito.it)

ABSTRACT A methodology for beam-steering using operational amplifiers (Op-amps) is presented. Continuous steering is required in various advanced applications and its implementation necessitates additional efforts since singularly control of the feeding of the radiators is mandatory for both phase and amplitude. The present work proposes a technique for generating the required sequence of the feeding signal using two Op-amps for each input port. It leads to generating incremental phases with sequential Op-amps without any limitation in the value of the phase differences, controlled by the bias voltage applied to the Op-amps, hence giving rise to a continuous beam-steering capability. The study case consists of a four-stage oscillator designed for creating a sequence of signals with progressive phase shifts between consecutive outputs. The general scheme allows continuous control of the phase differences here applied for generating a uniform, i.e., constant signal magnitude, feeding sequence. This set of signals is then used to feed a four-element microstrip array operating at 1.2 GHz. The effectiveness of the method is validated by numerical simulation of the array performances. Additionally, the low power consumption of active Op-amps, easy implementation, and high sensitivity are characteristics of the presented paradigm.

INDEX TERMS Active devices, beam-steering, operational amplifier (Op-amp), oscillator, phase manipulation.

I. INTRODUCTION

In radio and radar systems, beam-steering refers to altering the direction of the main lobe of a radiation pattern. This can be obtained by changing the relative phases of the single radiators with respect to a reference one [1], [2], [3], [4]. The beam-steering techniques result in reducing the interference and enhancing the gain and directivity of the antennas [5], [6], [7]. Recently, various innovative methods have been proposed to achieve beam-steering and in the following, a short review of some of them is reported.

In [4], a passive system for discrete and continuous beam steering with planar dielectric phase transformers is presented. A procedure based on the use of two perforated dielectric structures collocated in the near-field region of an antenna having a fixed beam is discussed in [8]. In other studies, [9], [10], a frequency-diverse array is detailed; its working principle is based on the range- and angle-dependent directional modulation. An optically controlled system is described in [11] that is investigating the fast-switching approach for orbital angular momentum. In [12], a beam-steering control method is described leading to the design speedy maneuvering platform for synthetic aperture radar imaging and to reduce Doppler bandwidth. Scarborough et al. [13] present a method for reducing the computational domain of traveling-wave modulated structures for beam-steering and amplification.

Although there are various modi operandi targeting beam-steering, the most challenging problem of generating a continuous phase control is still not fully solved. The present dissemination aims to contribute to this open question. To the best of the authors' knowledge, a beam-steering methodology

The associate editor coordinating the review of this manuscript and approving it for publication was Zaharias D. Zaharis.

with active Op-amps leading to generate various phases with no limitation to 2^N radiating elements is proposed for the very first time. In this method, an arbitrary number stage oscillator structure with two amplifiers in each stage is generated for producing various sequentially incremental phases. The achieved phases are inserted into the far-filed analysis of a microstrip array working at 1.2 GHz. The simulation environments for generating phases with Op-amps and for performing the far-filed analysis are LTSpice and Microwave Studio (Dassault Systèmes), sequentially. Even if the case study considers a 2^2 configuration, the presented method can be applied to an arbitrary number of radiators.

The paper is organized as follows: Sec. II, presents the proposed methodology for generating the progressive phase shift between consecutive output ports of the active circuit. These phases represent the input for the array elements to realize the required beam-steering. Section III is devoted to providing the numerical validation of the proposed method, while Sec. IV concludes the discussion.

II. PROPOSED METHODOLOGY IN A NUTSHELL

This section is devoted to presenting the proposed method for generating the continuous phases required for the beam-steering of a linear array. The wording "beam-steering" refers to the possibility of the antenna changing the direction of the main beam; i.e., to generate the highest power density in a given direction in the space. Phased array antenna [4] are a classical example. The steering is obtained by proper selection of the phases of the single radiators; usually, one of them is considered as a reference. However, the overall radiation pattern, including the angular displacement of the main beam, also depends on the distance between the radiators, which in the simplest case is considered equal. A constant phase difference $\Delta\phi$ between consecutive radiators corresponds to a linear phase error. Figure 1 presents the phase front of the radiated fields by the different radiators for a uniform, equispaced array with constant phase shifts between them. In such a situation, according to the Fourier theory, the results will be a shift in space of the initial pattern of the array, i.e., that obtained for $\Delta\phi = 0$. Depending on the amount of steering, the beam will also suffer some distortions; a non-symmetric pattern with respect to the main direction and a reduction of the gain are the most imminent manifestations.

From an application point of view, considering 2^N radiators can be useful since equal length beam forming network (BFN) will ensure the same phase for each radiator using a single source. In such case, each arm can be equipped with a single phase shifter, that is individually controlled to impose the required phase for the considered radiator. The effect of the BFN is strongly reduced. However, this solution presents a limitation on the number of radiators. The proposed solution described below overcomes this problem.

The method proposed here consists of generating the single phases using a sequence of cascaded Operational amplifiers (Op-amps). A feed-back circuit applied to each Op-amp will give rise to oscillators that are cascaded in such a way as to obtain a progressive summation of the single phases of the different Op-amp outputs. The general structure of the oscillator is presented in Fig. 3. In the electronic field, the oscillators refer to the designs for generating the output signal with constant amplitudes and include both active and passive elements. The main objective of the oscillators is to convert DC voltage into a periodic AC signal.

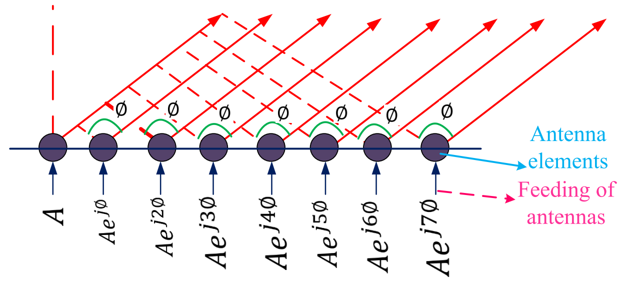

FIGURE 1. The concept of beam-steering: different elements are fed by different phase signals. The representation refers to an equi-spaced array configuration with a uniform (constant amplitude *A*) feeding signal with a progressive phase between consecutive radiators (Φ).

Applying Op-amps theory, the gain of the oscillator for a frequency dependent feedback, can be expressed as (1):

$$\mathrm{A_f(s)} = \frac{\mathrm{A(s)}}{1 - \mathrm{B_f(s)A(s)}} \tag{1}$$

For sustained oscillations, at the resonant angular frequency $\omega = \omega_0$ the "Barkhausen criteria" must be satisfied [14]. Equation (2) expresses the condition to fulfil this criteria where $\Phi(\omega_0)$ is the phase of $\mathrm{B_f}(\omega_0)\mathrm{A}(\omega_0)$.

$$\left|\mathrm{B_f}(\omega_0)\mathrm{A}(\omega_0)\right| e^{j\Phi(\omega_0)} = 1 \tag{2}$$

Figure 2 reports the concept of the methodology for generating non-limited phases by using active Op-amps. For generating N phases such as $\Phi_n = n\Phi(\omega_0), n \in (0, \cdots, N-1\}$, N stage oscillators is required. The proposed method is quite general since the number of back-to-back Op-amps can be increased without any limitation according to the number of radiators.

In the present investigation, identical 'LTC6269-10' (Linear Technology) Op-amps have been considered and the employed diodes behave as capacitors for feedback. This model of Op-amp is selected by considering the operational frequency band of the antenna, and by getting the help of Op-amps's data sheet [15].

The circuits in the blue boxes in Fig. 2, i.e., the second Op-amp at each stage, are used for high-frequencies that are keeping the clipping and oscillating [16]. As Eq. (3) presents, the R_f is the feedback resistor and the R_{in} is the input impedance of the amplifier. Hence for our proposed design, R_4 denotes to feedback resistor and R_3 affects the input resistor of the design. For this case, R_4 must be larger than R_3 as for Eq. (3).

$$V_{out} = -I_{in}R_f = -\left(\frac{R_f}{R_{in}}\right)V_{in} \tag{3}$$

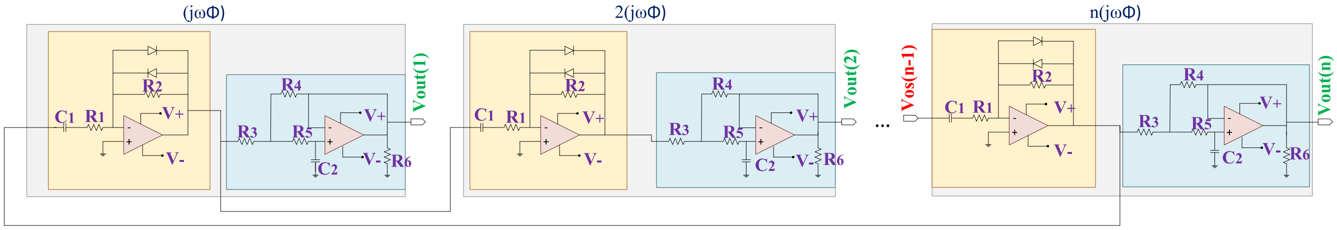

FIGURE 2. Proposed Op-amp based phase generation as a method for beam-steering.

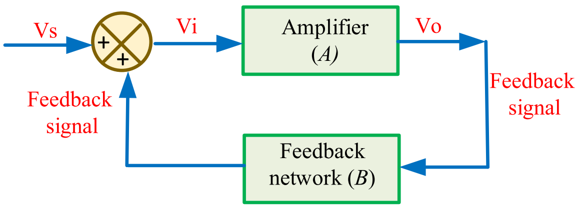

FIGURE 3. General concept of oscillator structure with a voltage gain of "A" and a positive feedback network with feedback gain of "B."

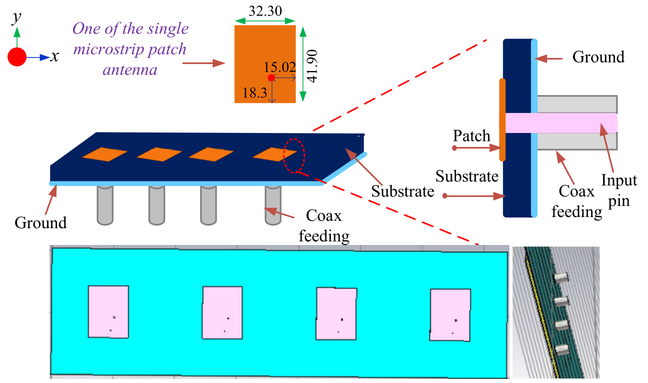

FIGURE 4. Four antenna arrays that are feeding by coax cable sketch (top), CAD model of the antenna with patches, and individual coaxial feedings (bottom).

In our design R_6 is the input impedance of the microstrip antenna, here considered equal to 50 Ω. However, a dispersive value, reporting the actual active impedance of the single patches can be incorporated into the model.

III. VALIDATION OF THE SUGGESTED PARADIGM

This section presents the practical simulation results of the proposed methodology leading to generating non-limited phases through Op-amp bases phase shifters. Successively, these values are considered in an electromagnetic analysis.

In this work, the design of beam steering at 1.2 GHz frequency is targeted. For this purpose, a 4-element antenna array working at 1.2 GHz has been designed (see Fig. 4 for the sketch and the Computer-Aided Design (CAD) model). It includes four square patch radiators, and each of them is fed individually by a coaxial cable. The considered substrate is characterized by the following specifications: $\tan\alpha = 0.044$, $\varepsilon_r = 1.3$, and a thickness of 0.17 mm.

Separately, a four-stage oscillator has been implemented. It provides the four incremental phases that have been considered in the analysis. For this case, four-stage amplifiers are sequentially connected; feedback that connects the output to the input is also present. In simple words, we use four-stage oscillators to generate $\Phi(\omega)$, $2\Phi(\omega)$, $3\Phi(\omega)$, and $4\Phi(\omega)$ phases, respectively. The overall structure is biased with two DC voltage sources namely: V+ and V−. For the determined design goals, i.e., having beam-forming at 1.2 GHz and generating four sequential phases, the optimal design parameters according to Eqs. (1-2) have been determined. Table 1 presents these optimal design parameters for generating four sequential phases at 1.2 GHz.

Regarding Eq. (3), we assume that R_4 and R_3 are 1.6 kΩ and 0.5 kΩ, respectively. Additionally, R_5 is determined to be 1 kΩ as it provides well-performance to the whole design in terms of sensitivity.

TABLE 1. Optimal values of proposed beam-steering through active Op-amps presented in Fig. 2.

parameter	value	parameter	value
R_1	22 (kΩ)	R_2	47 (kΩ)
R_3	0.5 (kΩ)	R_4	1.6 (kΩ)
R_5	1 (kΩ)	R_6	50 (kΩ)
C_1	100 (nF)	C_2	40 (nF)

In the "s" domain, $B_f(s)$ is defined as $\left(\frac{s + R_{in}C}{1 + sR_{in}C}\right)^4$ where R_{in} is the input impedance of each stage of oscillator. Indeed, $A_f(s)$ is also defined approximately by the $\frac{R_4}{R_3}$. For satisfying the condition in Eq. (2), C_2 is determined to be between 40 nF - 60 nF; here we prefer using the smallest value capacitor. Lastly, for having the oscillation the $R_2 = 2R_1$ constrain must be fulfilled.

After inserting the optimal design parameters, the whole Op-amp-based phase shifter has been simulated. Based on the simulation output, firstly T_1, T_2, T_3, and T_4 have been extracted that represent the time value at the maximum magnitude for first, second, third, and fourth stages. They are used to determine the phases associated with the delay of the signal. Figure 5 (top) presents the simulation results of the Op-amp-based phase shifter; output voltages, including the transient time, between 10 (ns) and 40 (ns) are reported. The plot illustrates the various output specifications namely as V_{out1}, V_{out2}, V_{out3}, and V_{out4}. For better visualization, Fig. 5 (bottom) shows in detail the magnified version of Fig. 5 (top) in the 30 ns to 33 ns interval. Continuously, Tab. 2 reports the time differences between the sequential outputs namely $T_2 - T_1$, $T_3 - T_2$, and $T_4 - T_3$ for four different DC

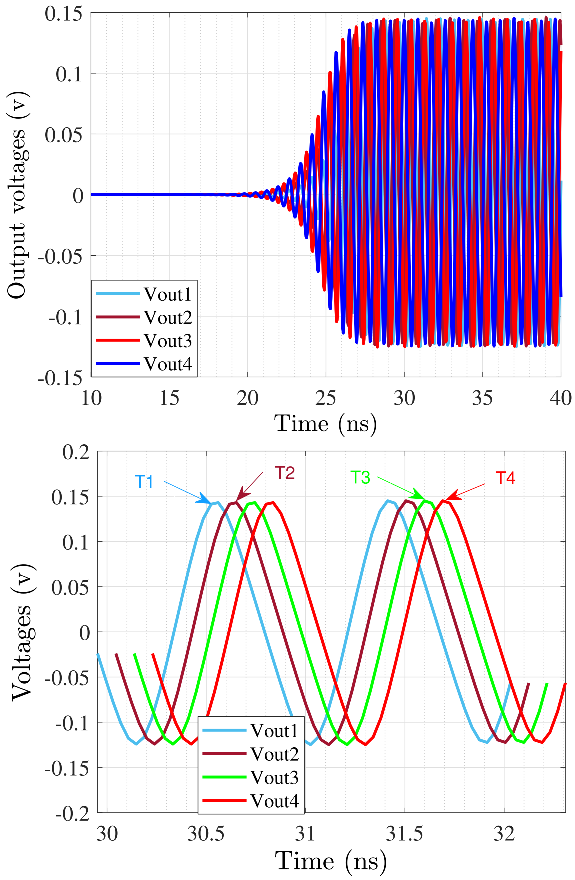

FIGURE 5. Performances of the proposed Op-amp based phase delay generation. (0-40 ns (top) and zoom for the 30 ns - 33 ns interval (bottom).

TABLE 2. Time delay of the different outputs for various values of the control voltages; units are (V) and (ns).

V+ Or -(V-)	$T_1 - T_2$	$T_3 - T_2$	$T_4 - T_3$
7.5	0.09	0.10	0.10
9	0.09	0.13	0.10
10	0.13	0.11	0.15
12	0.18	0.15	0.15

voltages as 7.5 V, 9 V, 10 V, and 12 V. As expected, the time variation between sequential outputs are approximately the same for all values of the control voltage.

After the determination of the time-variant, the phase variant is achieved from various DC voltage sources. For this case, equation $\Delta\Phi = 360f\Delta T$ (°) is used, where f indicates the frequency, and ΔT is the time variance (i.e., $T_n - T_{n-1}$). Table 3 presents the various achieved values for the first, second, third, and fourth phases, respectively, for various control voltages. These phases are set in the Microwave Studio (Dassault Systèmes) post-processor utility and used to excite the microstrip array elements under unitary amplitude conditions. The main lobe direction has been monitored. As expected, the phases for each voltage are increasing sequentially which results in incremental steering of the main lobe direction. Figure 6 presents the radiation pattern of the antenna in Fig. 4 for different control voltages present in Tab. 3.

TABLE 3. Summary of the beam steering performances for different control voltages and associated phases applied to the individual radiators @ 1.2 GHz. The 1st radiator is considered as reference.

Voltages (V)	Φ_1	Φ_2	Φ_3	Φ_4	Lobe direction
7.5	0	39.86	86.54	130.30	19°
9	0	42.78	101.61	147.08	22°
10	0	56.68	106.52	173.18	25°
12	0	78.76	144.84	212.67	32°

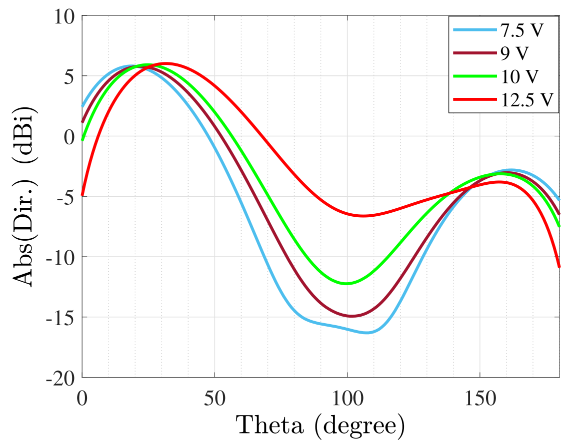

FIGURE 6. Directivity for various DC supply voltages.

In the proposed design, by altering the DC supply voltages the phases are also differing respectively. For instance, as Tab. 3 shows, when a DC supply voltage of 9 V is considered the circuit generates 0, 42.78°, 101.61°, and 147.08° phases, respectively. By augmenting the voltage (see row for 10 V in Tab. 3) the phases are altering and increasing: in particular 0, 56.68°, 106.52°, and 173.18° phases have been obtained. Additionally, Tab. 3 proves the accuracy of the method whereby by altering the phases, the main lobes are also controlled in a desired way. One can note, that as expected, the increasing tilt angle introduces a variation at side-lobe level as well. Controlling of such dependence can be incorporated in the generation of the phase values, and represent one of the future aspects. These increments result in the steering of the main lobe direction of the considered array. The corresponding steering angles are reported in the last column of Tab. 3. For the circuit designs including Op-amps, considering signal-to-noise ratio (SNR) specification plays an important role. The selected Op-amp (here, 'LTC6269-10') includes a FET-input operational amplifier with low input bias current and low input capacitance. Hence, it characterizes low input-referred current noise and voltage noise [15]. Figure 7 presents the overall SNR performance of four-stage amplifiers in which the SNR value varies between 64.7-71.8 dB for the voltages from 7.5-12 V.

Additionally to underline the novelty of the proposed method, Tab. 4 is provided. As it is clear, the presented method in this study is proposed for the very first time in the literature leading to the employ of active devices in the field of antenna technology and beam-steering methods.

TABLE 4. Summary of various reported beamforming techniques in the literature.

Ref.	Method	Goal(s)	Performance metrics
[17]	Design of linear antenna array with integrated butler matrix beamforming network	- Generating four beams in four different directions used for 5G applications	Steered in: 40°, 15°, +15°, and +45°
[18]	Design of whole array with adaptive digital beamforming	- Dividing whole arry into subarrays and multiple phase centers results in accurate estimation of angle of arrival for the signal source	Direction of arrival as: 29.82°, 30.59°, 31.99°
[19]	Presenting a steerable differential beamformer for linear acoustics vector sensor arrays	- Solving the problem of non-steerable beam patterns of linear arrays	Steering angle as: 0°, 30°, 60° and 90°
[20]	Presenting echo separation scheme with digital beamforming and bandpass filtering	- Resulting in high-efficiency echo separation for the spaceborne multiple-input and multiple-output (MIMO) synthetic aperture radar	Bore-sight angle as: 28°
[21]	Design of broadband 16-way two-dimensional Butler matrix-based beamforming network	- Enhancing in size and bandwidth	Phase difference fluctuation as: ±21°
[22]	Presenting the beampattern matching design technique	- Much faster compared to the well-known traditional semidefinite quadratic programming counterpart	Range of angle as: [90° ≈ 90°]
[23]	Presenting the harmonic-based MIMO transceiver based on the time-modulated array	- Linearly mapping the actual multipath channels between multiple users and the antenna elements	Angle of arrival as: 0°/30° for a special case and 4°/25° for a more general case
This work	**Generating diverse continuous phases via active Op-amps**	**- Controlling an arbitrary number of radiators; - Generating phases without limitation in the value of the phase differences; - Generating constant signal magnitude and feeding sequence**	**No limitation in phase differences and all phases are continuous**

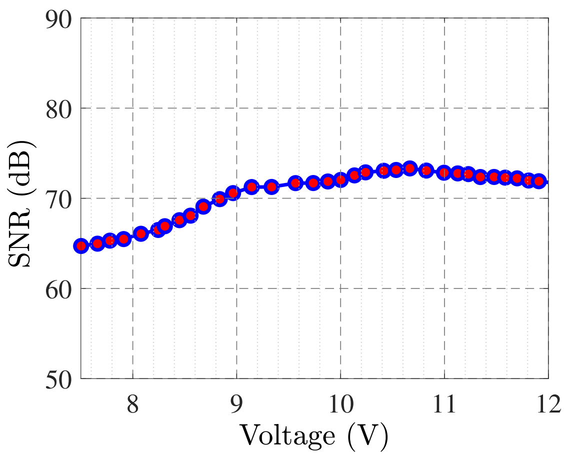

FIGURE 7. SNR value versus voltages.

IV. CONCLUSION

A method to generate continuous beam-steering for a linear array has been presented. For the very first time in the literature, this dissemination presents a novel concept in creating various continuous phases through active Op-amps. The design of the proposed active RF circuit incorporating an oscillator and clipping has been presented; it allows for generating various phases continuously. The paradigm permits sequential connection of a non-limited number of oscillator stages hence controlling an arbitrary number of radiators. Using Op-amps leads to having few external components with reduced design size. For validating the proposed procedure, a four-stage oscillator leading to generating four sequential phases has been presented and these phases are controlled by changing the DC supply voltage. The simulation results verify that the main lobe direction of the considered printed linear patch array is incrementally increasing for crescent DC supply voltage. The presented method in this study is suitable and adaptable to be implemented for all larger antenna arrays by designing a compatible Op-amp-based phase generator in terms of frequency and operational bandwidth. Additionally, by paying attention to the operated bandwidth, various strategies for enhancing the SNR value can be executed.

REFERENCES

[1] J. Kraus, *Antennas* (Electrical engineering series). New York, NY, USA: McGraw-Hill, 1988.

[2] K. Singh, M. U. Afzal, A. Lalbakhsh, and K. P. Esselle, "Reflecting phase-gradient metasurface for radar cross section reduction," in *Proc. IEEE Asia–Pacific Microw. Conf. (APMC)*, Nov. 2021, pp. 344–346.

[3] A. Goudarzi, M. M. Honari, and R. Mirzavand, "A millimeter-wave Fabry–Perot cavity antenna with unidirectional beam scanning capability for 5G applications," *IEEE Trans. Antennas Propag.*, vol. 70, no. 3, pp. 1787–1796, Mar. 2022.

[4] A. A. Baba, R. M. Hashmi, M. Attygalle, K. P. Esselle, and D. Borg, "Ultrawideband beam steering at mm-Wave frequency with planar dielectric phase transformers," *IEEE Trans. Antennas Propag.*, vol. 70, no. 3, pp. 1719–1728, Mar. 2022.

[5] J. Yu, W. Jiang, and S. Gong, "Low-RCS beam-steering antenna based on reconfigurable phase gradient metasurface," *IEEE Antennas Wireless Propag. Lett.*, vol. 18, pp. 2016–2020, 2019.

[6] M. U. Afzal, K. P. Esselle, and M. N. Y. Koli, "A beam-steering solution with highly transmitting hybrid metasurfaces and circularly polarized high-gain radial-line slot array antennas," *IEEE Trans. Antennas Propag.*, vol. 70, no. 1, pp. 365–377, Jan. 2022.

[7] F. Zhang, H. Gao, Z. Wang, and W. Fan, "An improved complex signal-based calibration method for beam-steering phased array," *IEEE Antennas Wireless Propag. Lett.*, vol. 20, pp. 2161–2165, 2021.

[8] T. Hayat, M. U. Afzal, F. Ahmed, S. Zhang, K. P. Esselle, and J. Vardaxoglou, "The use of a pair of 3D-printed near field superstructures to steer an antenna beam in elevation and azimuth," *IEEE Access*, vol. 9, pp. 153995–154010, 2021.

[9] W. Wang, "DM using FDA antenna for secure transmission," *IET Microwave, Antennas Propag.*, vol. 11, no. 3, pp. 336–345, Feb. 2017.

[10] J. Ma, X. Song, Y. Yao, Z. Zheng, X. Gao, and S. Huang, "Secure transmission of radio orbital angular momentum beams based on the frequency diverse array," *IEEE Access*, vol. 9, pp. 108924–108931, 2021.
[11] X. Song, J. Ma, Y. Bai, Y. Yao, Z. Zheng, X. Gao, and S. Huang, "Optical-controlled fast switching of radio frequency orbital angular momentum beams with different mode and radiation direction," *J. Lightw. Technol.*, vol. 40, no. 3, pp. 640–646, Feb. 4, 2022.
[12] B. Bie, Y. Quan, K. Xu, A. Ren, G. Xiao, G.-C. Sun, and M. Xing, "High-speed maneuvering platform SAR imaging with optimal beam steering control," *IEEE Trans. Geosci. Remote Sens.*, vol. 60, pp. 1–12, 2022, Art. no. 5216012, doi: 10.1109/TGRS.2021.3121427.
[13] C. Scarborough, Z. Wu, and A. Grbic, "Efficient computation of spatially discrete traveling-wave modulated structures," *IEEE Trans. Antennas Propag.*, vol. 69, no. 12, pp. 8512–8525, Dec. 2021.
[14] L. von Wangenheim, "On the Barkhausen and Nyquist stability criteria," *Anal. Integr. Circuits Signal Process.*, vol. 66, no. 1, pp. 139–141, Jan. 2011.
[15] *Operational Amplifiers at Texas Instruments*. Accessed: Apr. 20, 2024. [Online]. Available: http://ti.com
[16] O. N. Pandey, *Operational Amplifier (OP-AMP)*. Cham, Switzerland: Springer, 2022, pp. 233–270.
[17] A. Karimbu Vallappil, M. Kamal A. Rahim, B. A. Khawaja, and M. Naeem Iqbal, "A miniaturized metamaterial-loaded switched-beam antenna array system with enhanced bandwidth for 5G applications," *IEEE Access*, vol. 12, pp. 6684–6697, 2024.
[18] R. Wang, Y. Deng, W. Wang, Q. Zhao, Y. Zhang, Z. Chen, J. Qiu, and S. Chang, "A novel adaptive digital beamforming method based on beam-space phase-center cross-correlation," *IEEE Trans. Geosci. Remote Sens.*, vol. 61, pp. 1–13, 2023, Art. no. 5212213, doi: 10.1109/TGRS.2023.3294289.
[19] F. Chen, K. Ma, Y. Mao, D. Yang, Y. Zhang, J. Shi, S. Mo, G. Chenyang, and S. Li, "A novel method to design steerable differential beamformer using linear acoustics vector sensor array," *IEEE/ACM Trans. Audio, Speech, Language Process.*, vol. 31, pp. 2836–2849, Sep. 2023.
[20] T. Wei, Y. Zhang, P. Lu, W. Wang, Q. Zhao, B. Li, and R. Wang, "An improved echo separation scheme with OFDM chirp waveforms for spaceborne MIMO SAR," *IEEE Geosci. Remote Sens. Lett.*, vol. 21, pp. 1–5, 2024.
[21] W. Li, J. Xu, R. Zhao, and W. Hong, "Compact broadband substrate-integrated coaxial line 2-D beamforming network and its multibeam array antenna applications," *IEEE Trans. Microw. Theory Techn.*, vol. 72, no. 1, pp. 1–13, Jul. 2023.
[22] E. Faghand, E. Mehrshahi, and S. Ali Ghorashi, "Complexity reduction in beamforming of uniform array antennas for MIMO radars," *IEEE Trans. Radar Syst.*, vol. 1, pp. 413–422, Aug. 2023.
[23] G. Ni, C. He, and R. Jin, "Harmonic-based MIMO transceiver with time-modulated arrays," *IEEE Trans. Antennas Propag.*, vol. 71, no. 9, pp. 7553–7565, Sep. 2023.

LIDA KOUHALVANDI (Senior Member, IEEE) received the B.Sc. degree in electronics engineering from Azad University, Tabriz, Iran, in 2011, the M.Sc. and Ph.D. (Hons.) degrees in electronics engineering from Istanbul Technical University, İstanbul, Turkey, in 2015 and 2021, respectively, and the Associate Professor degree, in February 2023. She joined the Department of Electrical and Electronics Engineering, Doğuş University, as an Assistant Professor, in October 2021. In recognition of her research, she received the Doctoral Fellowship with the Department of Electronics and Telecommunications, Politecnico di Torino, Turin, Italy, from 2019 to 2020, and also she joined Politecnico di Torino as a Research Fellowship, from February 2021 to July 2021 and from May 2022 to May 2023. Her research interests include radio frequency and analog engineering are power amplifiers, antenna, analog designs, and implantable medical devices. She also has experience in computer-aided designs and optimization algorithms through machine learning. She received the Best Presentation Award from the EExPolytech-2021: Electrical Engineering and Photonics Conference, in 2021. Additionally, her Ph.D. thesis was accepted for the presentation at Ph.D. Forum of the 2021 IEEE/ACM Design Automation Conference (DAC 2021) in San Francisco, CA, USA. She received the another Best Paper Award from the 30th IEEE Conference on Signal Processing and Communications Applications, in 2022. She received the 2022 Mojgan Daneshmand Grant from the IEEE Antennas and Propagation Society (AP-S), organized by the IEEE AP-S Young Professionals. Additionally, her Ph.D. thesis was awarded by Istanbul Technical University as an Outstanding Ph.D. Thesis and by Turkish Electronics Industrialists Association (TESID) as the Best Innovation and Creativity Ph.D. Thesis, in 2022.

LADISLAU MATEKOVITS (Senior Member, IEEE) received the degree in electronic engineering from Institutul Politehnic din Bucureşti, Bucharest, Romania, in 1992, and the Ph.D. degree (Dottorato di Ricerca) in electronic engineering from Politecnico di Torino, Turin, Italy, in 1995.

Since 1995, he has been with the Department of Electronics and Telecommunications, Politecnico di Torino, first as a Postdoctoral Fellowship and then as a Research Assistant. He joined the Department of Electronics and Telecommunications as an Assistant Professor, in 2002. In late 2005, he was a Visiting Scientist with the Antennas and Scattering Department, FGAN-FHR (now Fraunhofer Institute), Wachtberg, Germany. Since July 2009, he has been a Marie Curie Fellow with Macquarie University, Sydney, NSW, Australia, for two years, where he also held a visiting academic position, in 2013. He has been appointed as a Honorary Fellow, since 2014. He was appointed as a Senior Assistant Professor, in 2005, and as an Associate Professor, in 2014. In February 2017, he obtained a Full Professor qualification in Italy. Since 2020, he has been a Honorary Professor with Politehnica University Timisoara, Romania, and an Associate Researcher with Italian National Research Council. He was appointed as a member with the National Council for the Attestation of University Degrees, Diplomas, and Certificates (CNATDCU), Romania, from 2020 to 2024. His main research interests include numerical analysis of printed antennas and in particular development of new, numerically efficient full-wave techniques to analyze large arrays, optimization techniques, and active and passive metamaterials for cloaking applications. Material parameter retrieval of these structures by inverse methods and different optimization techniques have also been considered. In the last years, bio-electromagnetic aspects have also been contemplated, as for example design of implantable antennas or the development of nano-antennas for example for drug delivery applications. He has published more than 450 papers, including more than 125 journal contributions, and delivered seminars on these topics all around the world: Europe, USA (AFRL/MIT-Boston), Australia, China, and Russia. He has been invited to serve as a Research Grant Assessor for government funding calls (Romania, Italy, Croatia, and Kazakhstan) and as an International Expert in Ph.D. thesis evaluation by several universities from Australia, India, Pakistan, and Spain.

Prof. Matekovits has been a member of the Organizing Committee of the International Conference on Electromagnetics in Advanced Applications (ICEAA), Since 2010. He has been a member of the technical program committees of several conferences. He was a recipient of various awards in international conferences, including the 1998 URSI Young Scientist Award in Thessaloniki, Greece; the Barzilai Award 1998 (Young Scientist Award, granted every two years by Italian National Electromagnetic Group); and the Best AP2000 Oral Paper on Antennas, ESA-EUREL Millennium Conference on Antennas and Propagation in Davos, Switzerland. He was a recipient of the Motohisa Kanda Award 2018, for the most cited paper of IEEE Transactions on Electromagnetic Compatibility in the past five years, and more recently he has been awarded with the 2019 American Romanian Academy of Arts and Sciences (ARA) Medal of Excellence in Science and by the Ad Astra Award 2020, as a Senior Researcher, for excellence in research. He has been the Assistant Chairperson and the Publication Chairperson of European Microwave Week 2002 in Milan, Italy, and the General Chair of the 11th International Conference on Body Area Networks (BodyNets) 2016. He serves as an Associate Editor for IEEE Access, IEEE Antennas and Wireless Propagation Letters, and *IET Microwaves, Antennas and Propagation*. He is a reviewer of different journals.

Open Access funding provided by 'Politecnico di Torino' within the CRUI CARE Agreement