# Active Phased Array Antenna With Parallel Feeder Excitation At 3.7 Ghz

*Yuri PALANIZA* [1], *Anatoliy MARTSENIUK* [1], *Volodymyr YASKIV* [1]
[1]Radio Engineering Systems Department, Faculty of Applied Information Technologies and Electrical Engineering,
Ternopil Ivan Puluj National Technical University, 56, Ruska Street, Ternopil, Ukraine

palanizayb@tntu.edu.ua, anatoliymartsenyuk@gmail.com, yaskiv@yahoo.com

DOI: 10.15598/aeee.v22i2.5290

Article history: Received Jun 22, 2023; Revised May 06, 2024; Accepted May 27, 2024; Published Jun 30, 2024.


***Abstract.*** *The article discusses the electromagnetic radiation level reducing in 5G telecommunication systems used in modern campuses of medical clinics, in order to ensure the correct operation of a number of medical devices and systems. The use of a phased antenna array (PAA) with beam scanning technique as part of a medical telecommunication system is proposed. A simulation of the proposed rectangular phased antenna array in the form of 0.5∗λ spaced 7x7 elements matrix was carried out. Matrix elements are constructed in the form the printed circuit board. Dipole-folded antenna element is used to increase the manufacturability of the system. Moreover, the receiving side is made in the form of three separate space sparse receivers site, but not in the form of a single one. The simulation was carried out by means of the Matlab IDE Phased Array System Toolbox. The proposed approaches made it possible to reduce the level of electromagnetic radiation in the 5G telecommunication system in two ways: by reducing the overall level of radiation compared to an omnidirectional emitter and by using the beam scanning technique of the proposed receiver structure.*

## Keywords

***3.7 GHz, Active phased array antenna, Electromagnetic Interference, Matlab IDE, medical data transmission, space sparse receiver site.***

## 1. Introduction

Today, there is a significant increase in electromagnetic pollution of the environment, due to the widespread use of modern devices and systems, the operation of which is accompanied by the appearance of high-level electromagnetic interference (EMI). First of all, these are means and devices of high-frequency power electronics and power engineering, modern communication and telecommunication systems, transport, information technologies, consumer electronics, etc. In addition, widely spreading and democratization is determining cause of high level of electromagnetic pollution of the environment. EMI spreads conductively and by radiation both, which has a complex synergistic negative impact on living nature [1,2], and also leads to unpredictable global emergency situations in various technical systems. One of the most important problems of modern times is the minimization of the negative impact of electromagnetic radiation on living nature and the system of ensuring a full-fledged human life, as well as on the functioning of technological means of its life support particularly in medical field [3,4].

## 2. Subject problem statement

There is a problem of personal remote access to patients in order to obtain and collect biomedical information for processing in a specialized center. In addition, there is often a need to obtain such information over a long period of time, with the patient's mobility, physical exertion, etc. Therefore, acceptable methods of information transmission in telemedicine cannot always be implemented. In this case, the use of active phased antenna arrays allows access to surveillance objects. It is proposed to use them in telecommunication systems of the 5G range in modern campuses of medical clinics. In particular, the 5G n77 3.7 GHz band is proposed to be used (according to a recent Opensignal report). However, in urban environment [5], especially on the territory of a medical campus, a significant negative factor is the level of electromagnetic interference, which can negatively affect the operation of sensitive medical devices/equipment. The proposed use of an active phased antenna array allows to partially minimize these negative factors using beam scanning technology. It is possible to improve the efficiency of its operation and reduce the level of radiated EMI by:

- achieving of the aim with minimal power energy (increasing the efficiency of the system as a whole);
- use of the high-efficiency devices and power supply systems with a minimum level of EMI, a high level of output voltages quality and dynamic characteristics;
- Increasing Signal-to-Noise Ratio [6];
- installation of additional means of reducing the level of EMI (filters, screens, circuit decoupling, snubber circuits);
- special approaches to constructivist design.

Using MagAmp power converters euchre a low level of EMI [7]. The external electromagnetic radiation test of the MagAmp power converter (24 V, 8 A) and its transistor counterpart (USA) was conducted within the framework of a joint NATO grant (IC S.NUKR.CLG 982639) with the Power Electronics Laboratory of the University of California (Irvine, USA). The level of EMI emitted by the MagAmp power converter in the frequency range from 42 MHz to 400 MHz is significantly lower than that of the transistor analog (so in the frequency range of 130-200 MHz - by 4-5 times) [7]. This made it possible to use the MagAmp power converters for computer facilities [8], microprocessor devices [9] and radar applications [10]. The use of the proposed synchronous rectification method in MagAmp power converters makes it possible to significantly increase the efficiency (up to 96%), which ensures a decrease of the EMI level [11].

## 3. Mathematical description of the main PAAs technical characteristics

Active phased antenna arrays are described [12] by the directional pattern, the width of its main lobe, the level of the side lobes, the magnitude gain coefficient (Ga), the coefficient of directional action, the reflection coefficients of the elements, the potential A and the specific spectral density of the noise power Q. For PPA, the potential is equal to:

$$A = G_a A_{\sum} = K_a P A_0 N_e, \tag{1}$$

where $c$ is the specific heat capacity in (J·kg$^{-1}$·K$^{-1}$), $m$ is mass in (kg) and $T$ is temperature in (K), $G_a$ is gain coefficient is the amplification factor of the active phased array antenna (numerically equal to the product of the useful effect factor by the directional effect factor), $P_0$ is radiation power of a single element, $N_e$ is the number of single elements, $A_{\sum}$ is the total potential of all single elements.

For the receiving PAA, the specific noise power spectral density is equal to:

$$Q = h_\omega / S_{eff}, \tag{2}$$

where $h_\omega$ is the noise power spectral density at the output of the PAA, $S_{eff}$ is the effective surface of the antenna.

The three-dimensional directivity diagram of the PAA $f(\theta, \phi)$ in the general case has the form:

$$f(\theta,\varphi) = \frac{1}{MN} \left| \frac{\sin\left[\frac{M\pi d_x \sin(\theta)\cos(\varphi)}{\lambda}\right]}{\sin\left[\frac{\pi d_x \sin(\theta)\cos(\varphi)}{\lambda}\right]} \right| \times \left| \frac{\sin\left[\frac{N\pi d_y \sin(\theta)\sin(\varphi)}{\lambda}\right]}{\sin\left[\frac{\pi d_y \sin(\theta)\sin(\varphi)}{\lambda}\right]} \right|, \tag{3}$$

where $M$ is the number of elements along the length of the antenna array, $N$ is the number of elements across the width of the antenna array, $d_x$ is distance between emitters in the azimuth plane, $d_y$ is distance between emitters in the angular plane, $\lambda$ is the working wavelength of radiation, $\theta$ is azimuth, $\varphi$ is seat angle.

The optimal choice [13] of the antenna array dimensions is chosen according to the analytical dependence in the form:

$$\begin{cases} d_x \leqslant \dfrac{\lambda}{1+\sin\left(\theta^x_{\max}\right)} \\ d_y \leqslant \dfrac{\lambda}{1+\sin\left(\theta^y_{\max}\right)} \end{cases}, \tag{4}$$

where $\theta^x_{\max}$, $\theta^y_{\max}$ are the maximum aperture angles of the directional diagram in the azimuth and elevation directions, respectively.

The active PAA module in the time domain can be described by the following system of equations in the operator form:

$$\begin{cases} u_{in} = L_{in}(e, i_{in}) \\ u_{out} = L_{out}(i_{in}) \end{cases}, \begin{cases} i_{in} = F_{in}(u_{in}, u_{out}) \\ i_{out} = F_{out}(u_{in}, u_{out}) \end{cases}, \tag{5}$$

where $u_{in}$, $u_{out}$, $i_{in}$, $i_{out}$ are voltages and currents at the input and output of the antenna module, respectively, $e$ is normalized vector, $F_{in}$, $F_{out}$ are non-linear in the general case integrodifferential linearly independent operators describing the active element, $L_{in}$, $L_{out}$

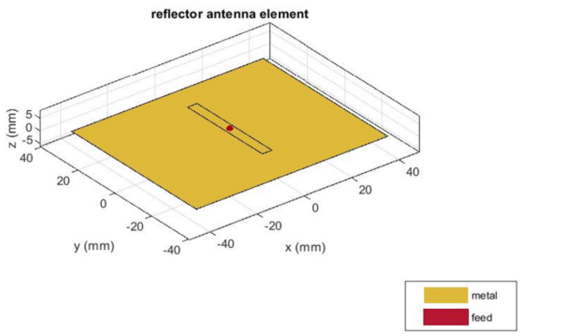



**Fig. 1:** Geometric dimensions of a single antenna element of the active phased array antenna.

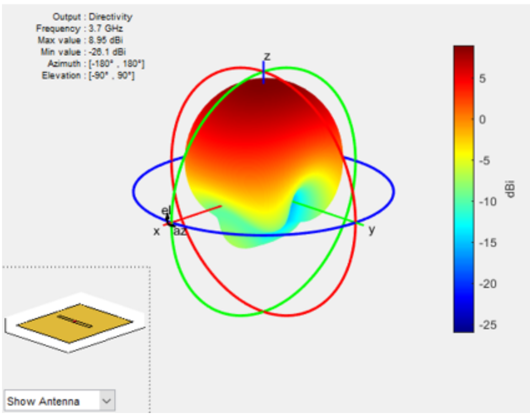
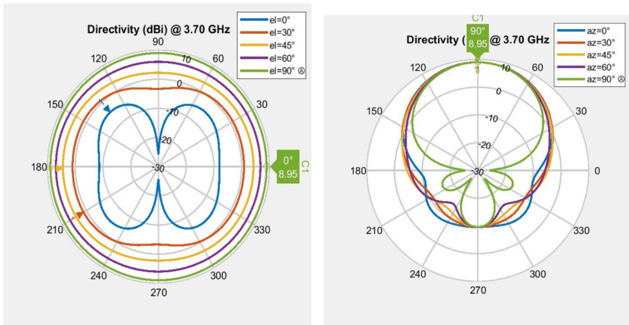



**Fig. 2:** Directivity diagram of a phased array antenna element plotted in 3-dimensional coordinates.




(a) (b)

**Fig. 3:** An azimuth (a) and elevation (b) cut of directivity at 0, 30 45, 60 and 90 degrees elevation/azimuth.

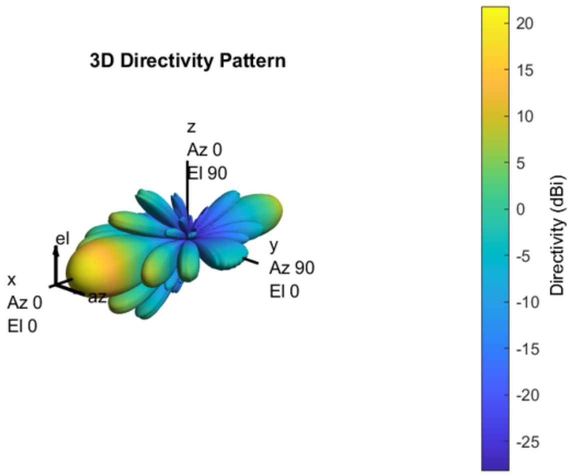



**Fig. 4:** Directivity diagram of a 7-by-7 phased array antenna in 3-dimensional coordinates.

are linear integrodifferential operators describing the input and output circuits of an active element (vacuum lamp, bipolar or field-effect transistor) and are determined by a system of equations in the form:

$$\begin{cases} L_{in} = \sum_{m=0}^{M} a_m^R \frac{d^m}{dt^m} + \sum_{n=0}^{N} b_b^R \int \int \cdots \int_{n=0}^{N} A_{e_n}(t)\, dt, \\ L_{out} = \sum_{m=0}^{M} a_m^F \frac{d^m}{dt^m} + \sum_{n=0}^{N} b_b^F \int \int \cdots \int_{n=0}^{N} A_{e_n}(t)\, dt, \end{cases} \tag{6}$$

where $R, F, n, m$ are dimensionality indices of the operator space, $a, b$ are weighting coefficients, $A_{e_n}(t)$ - excitation potential of n-th element.

# 4. Design of PAA and simulation results

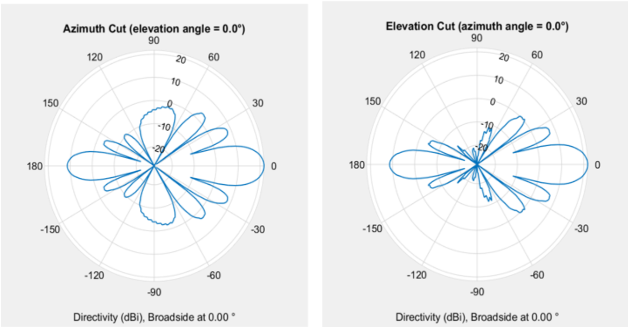
On the basis of input data, and theoretical analysis, the geometric dimensions of a single antenna element of the active phased array [14] antenna with parallel feeder excitation at 3.7 GHz were obtained, Fig. 1.

Using the Matlab Integrated Development Environment [15], the directivity diagram of a phased array antenna element in 3-dimensional coordinates [16] is built, Fig. 1,2.

An azimuth 3(a) and elevation 3(b) cut of directivity at 0, 30, 45, 60 and 90 degrees elevation/azimuth, assuming a 3,7 GHz operating frequency in 2-dimensional coordinates with few slices [20] is built, Fig. 3.

The Phased Array System Toolbox to design a PCB 7x7, 0,5$*\lambda$ spacing rectangular array from the antenna element is used. The main goal of Array dimensions selection is -3dB beamwidth lover then 15 degrees has been achieved. The array normal to radiate direction in the same-parallel direction to generate a maximum coverage region in the geographic azimuth is specified. Type of single antenna element: reflector-backed dipole antenna element.

The directivity diagram [17–19] of a phased array antenna in 3-dimensional coordinates is built, Fig. 4. An azimuth cut of directivity at 0 degrees elevation [20] of a 7-by-7 phased array antenna, assuming a 3,7




(a) (b)

**Fig. 5:** An azimuth (a) and elevation (b) cut of directivity diagram of a 7-by-7 phased array antenna in 2-dimensional coordinates.

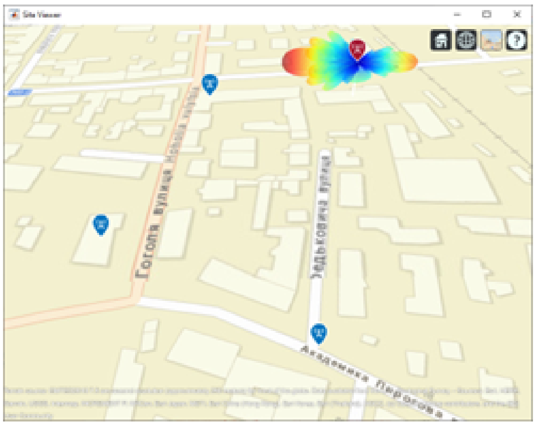


**Fig. 6:** Receivers allocation at 3 places.

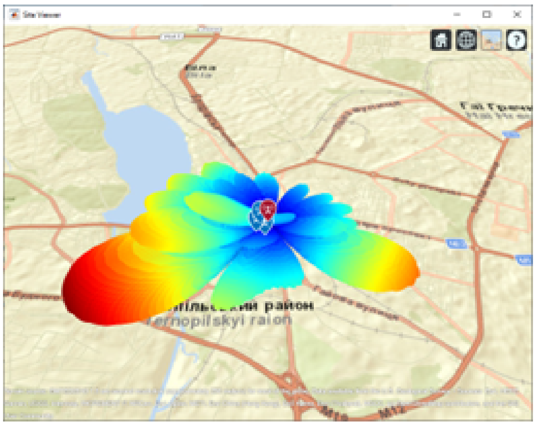


**Fig. 7:** Antenna beam scanning by applying a taper for an angle of -30 degrees in 3-dimensional coordinates.

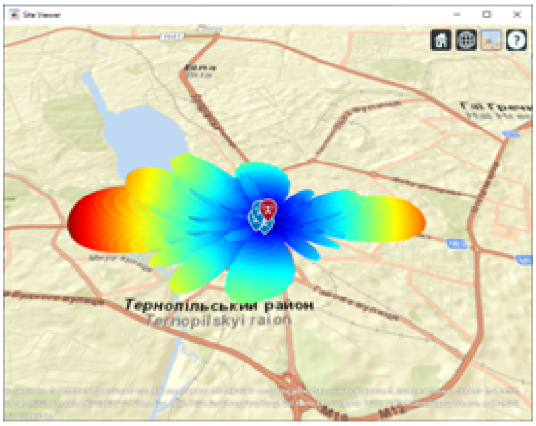



**Fig. 8:** Antenna beam scanning by applying a taper for an angle of 0 degrees in 3-dimensional coordinates.

GHz operating frequency in 2-dimensional coordinates is built, Fig. 5.

Modeling a hypothetical situation, let us place [15] a 0.1 Watt transmitter with an antenna on the top of the Ternopil Ivan Puluj National Technical University main building. The transmitter position height above the ground is 25 meters (which is equivalent to the 8-floor height building). With reference to the terrain, the phased antenna arrays pattern in 3-dimensional coordinates is built. Modeling a hypothetical situation, let us place [15] 3 space separated receiver parts of receiver site, Fig. 6.

Scan the antenna beam by applying a taper for an angle of -30 degrees, Fig. 7. Scan the antenna beam by applying a taper for an angle of 0 degrees, Fig. 8. Scan the antenna beam by applying a taper for an angle of +30 degrees, Fig. 9.

Let us project the directional pattern of the antenna onto the terrain surface. To perform a projection of 3D pattern phantom onto terrain surface and get a coverage map relative to the landscape, (an effect of buildings surfaces will be a subject of our further researches) built-it algorithm of a coverage() function of Matlab Antenna Toolbox is used. Scanning by the antenna beam by applying a taper for angles of -30, 0, +30 degrees is performed, Fig. 10, 11, 12.

The experiment results in the virtual environment are as follows (sensitivity of each receiver is -75 dB):

- strongSignal -65 dB;
- mediumSignal -70 dB;
- weakSignal -75 dB.

The obtained results of the experiment in a virtual environment confirm the phased antenna array design efficiency and the possibility of a real prototype manufacturing with minimal financial costs.

## 5. Conclusions

The proposed use of phased antenna array with beam scanning technique as part of 5G medical telecommunication system used in modern campuses of medical

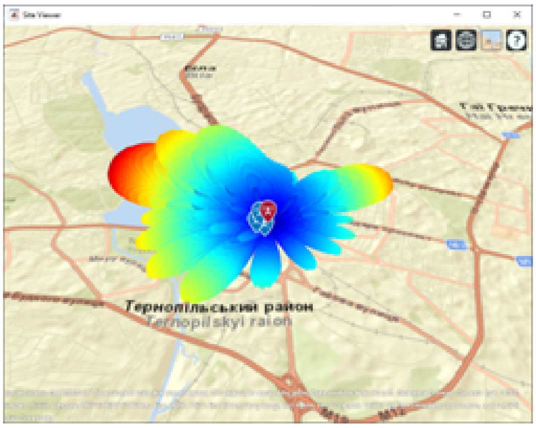



**Fig. 9:** Antenna beam scanning by applying a taper for an angle of +30 degrees in 3-dimensional coordinates.

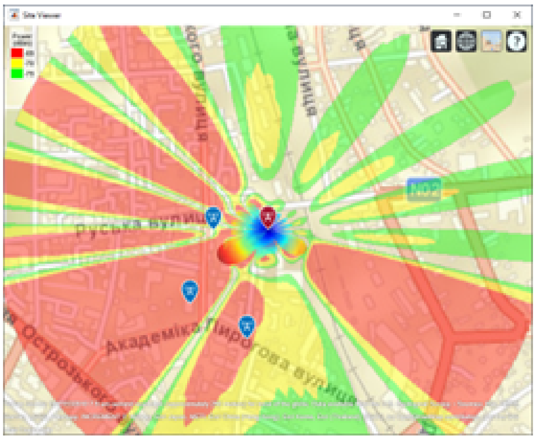


**Fig. 10:** Antenna beam scanning by applying a taper for an angle of -30 degrees (projection onto the terrain surface).

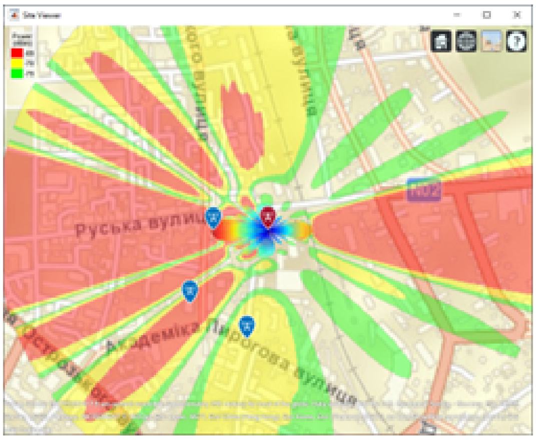


**Fig. 11:** Antenna beam scanning by applying a taper for an angle of 0 degrees (projection onto the terrain surface).

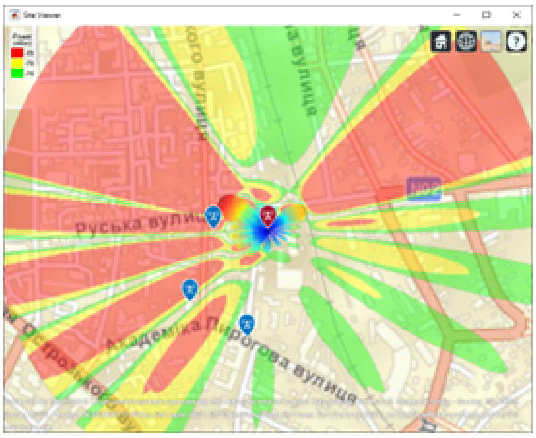


**Fig. 12:** Antenna beam scanning by applying a taper for an angle of +30 degrees (projection onto the terrain surface).

clinics has confirmed a reduction in the level of electromagnetic radiation. The simulation of the proposed rectangular phased antenna array in the form of a $0.5*\lambda$ matrix with an interval of 7x7 elements, which are made in the form of a printed circuit board, confirmed the improvement of signal transmission efficiency for the case when the receiving side is made in the form of three spatially separated receivers at receiver site, but not in the form of a single one. The conducted simulation made it possible to avoid the costs necessary for conducting full-scale experiments.

# Author Contributions

Both Yuri PALANIZA and Anatoliy MARTSENIUK performed the analytic calculations and the computer simulations. All authors contributed to the final version of the manuscript. Both Yuri PALANIZA and Volodymyr YASKIV supervised the project.

# References

[1] ZHANG, Y., N. WANG, L. HE, W. LI AND H. TAN. A potential saturation value of world population is near? *IEEE 13th International Conference on Signal Processing (ICSP)*, Chengdu, China, 2016, pp. 1781-1786, DOI: 10.1109/ICSP.2016.7878134.

[2] ROSSET, EDWARD. Aging process of population. *Elsevier*, 2017. ISBN: 9781483156668.

[3] LIN, J.C. Telecommunications health and safety: Public exposure to radio frequency, microwave, and millimeter-wave electromagnetic radiation. *In URSI Radio Science Bulletin*, vol. 2016, no. 356, pp. 49-51, March 2016, DOI: 10.23919/URSIRSB.2016.7909382.

[4] CHAN, S., M. ZENNARO, E. PIETROSEMOLI, M. RAINONE, I. OKTAVIANTI AND P. NOPPHAWAN. The Blindspot of Electromagnetic

**Tab. 1:** The results of the virtual experiment.

| Receiver # | Beam Scan Angle, degree | Signal strength, dB | Receiver's sensitivity - received power, dB |
|---|---|---|---|
| 1 | -30 | -84.64 | 9.64 |
| 2 | -30 | -60.70 | 14.29 |
| 3 | -30 | -87.07 | 12.07 |
| 1 | 0 | -57.76 | 17.23 |
| 2 | 0 | -75.28 | 0.28 |
| 3 | 0 | -90.21 | 15.21 |
| 1 | +30 | -72.60 | 2.39 |
| 2 | +30 | -97.16 | 22.16 |
| 3 | +30 | -104.19 | 22.16 |

Interference Affecting Sensitive Medical Devices at Hospitals and Healthcare Facilities. *10th Annual Computing and Communication Workshop and Conference (CCWC)*, Las Vegas, NV, USA, 2020, pp. 0449-0457, DOI: 10.1109/CCWC47524.2020.9031203.

[5] BALANIS, C.A. Antenna Theory. *Analysis and Design*, 3rd Ed., New York, Wiley, 2005.

[6] KHVOSTIVSKA, L., M. KHVOSTIVSKYI, I. DEDIV, V. YATSKIV, AND Y. PALANIZA. Method, Algorithm and Computer Tool for Synphase Detection of Radio Signals in Telecommunication Networks with Noises. *CEUR Workshop Proceedings*, 2023, 3468, pp. 173–180.

[7] YASKIV, V., A. ABRAMOVITZ AND K. SMEDLEY. MagAmp power converters with low level EMI. *XIIth International Conference "The Experience of Designing and Application of CAD Systems in Microelectronics (CADSM 2013) Lviv*, Polyana, Ukraine, 2013, P. 388-395.

[8] YASKIV, V. The new methods of switch mode power supply designing for computer facilities. *Proc. of the International Workshop on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS'2001)*, Resort Center FOROS, Foros, Crimea, Ukraine, Guly 1-4, 2001, p. 87-90. DOI: 10.1109/IDAACS.2001.941986.

[9] YASKIV, V., O. GURNIK, S. MOSKALYK, N. SHKLYARENKO. Power supply systems of microprocessor devices. *The Experience of Designing and Application of CAD Systems in Microelectronics: Proceedings of the VI-th International Conference CADSM 2001.* - Lviv: Publishing House of Lviv Politechnic National University, 2001, pp. 70-71, DOI: 10.1109/CADSM.2001.975745.

[10] YASKIV, V., O. SHABLIY, A. ALPATOV AND O. GURNIK. Development of switch power supplies for radar applications. *2001 CIE International Conference on Radar*. Beijing, China, 2001, P. 851-855. DOI: 10.1109/ICR.2001.984845.

[11] YASKIV, V., A. YASKIV, O. YURCHENKO. Synchronous rectification in high-frequency magamp power converters. *Conference Proceedings of International Conference "Advanced Computer Information Technologies"*, ACIT 2018, Ceske Budejovice, Czech Republic, June 1-3, 2018. p.128-131.

[12] MAILLOUX, R.J. *Phased array antenna handbook*, 2nd ed., Artech house, 2017.

[13] BALANIS, C.A. *Antenna Theory, Analysis and Design*, Chapter 2, sec 2.3-2.6, Wiley.

[14] NAKAMOTO, N., T. TAKAHASHI, Y. KONISHI AND I. CHIBA. Phase optimization for accurate beam forming of phased array with element field errors at every phase shift," *2013 IEEE International Symposium on Phased Array Systems and Technology*, Waltham, MA, USA, 2013, pp. 693-697, DOI: 10.1109/ARRAY.2013.673191.

[15] MAKAROV, S. N. *Antenna and Em Modeling in MATLAB*. Chapter 3, Sec 3.4 3.8., Wiley Inter-Science.

[16] VASILIADIS, T.G., A.G. DIMITRIOU AND G.D. SERGIADIS. A novel technique for the approximation of 3-D antenna radiation patterns. *In IEEE Transactions on Antennas and Propagation*, July 2005, vol. 53, no. 7, pp. 2212-2219. DOI: 10.1109/TAP.2005.850752.

[17] GAMPALA, G., AND C. J. REDDY. Advanced computational tools for phased array antenna applications. *2016 IEEE International Symposium on Phased Array Systems and Technology (PAST)*, Waltham, MA, USA, 2016, pp. 1-5, DOI: 10.1109/ARRAY.2016.7832612.

[18] ELHEFNAWY, M. AND W. ISMAIL. A Microstrip Antenna Array for Indoor Wireless Dynamic Environments. *IEEE Transactions on Antennas and Propagation*, vol. 57, no. 12, pp. 3998-4002, Dec. 2009, DOI: 10.1109/TAP.2009.2026712.

[19] JIHAO, L. Antenna on board package for 5G millimeter wave phased array antenna. *2020 21st International Conference on Electronic Packaging Technology (ICEPT)*, Guangzhou, China, 2020, pp. 1-5, DOI: 10.1109/ICEPT50128.2020.9202652.

[20] LEONOR N.R., R.F.S. CALDEIRINHA, M.G. SANCHEZ AND T.R. FERNANDES. A Three-Dimensional Directive Antenna Pattern Interpolation Method. *IEEE Antennas and Wireless Propagation Letters*, 2016, vol. 15, pp. 881-884, DOI: 10.1109/LAWP.2015.2478962.

## About Authors

**Yuri PALANIZA** Was born in Ternopil region, Ukraine in 1989. He received his Master's degree (2012), Ph.D. degree from Ternopil Ivan Puluj National Technical University (TNTU) in 2019. Current position is Senior Lecturer of Radio Engineering Systems Department (TNTU). His scientific interests are: embedded systems, artificial intelligence, expert systems, signal and image processing, wireless communication and remote monitoring.

**Anatoliy MARTSENIUK** Was born in Ternopil region, Ukraine in 1963. He received his Master's degree from Vinnytsia Polytechnic Institute in 1989. Current position is Senior Lecturer of Radio Engineering Systems Department (TNTU). His scientific interests are: wireless communication, power converters, radio- and electronic apparatus design.

**Volodymyr YASKIV** Was born in Ivano-Frankivsk region, Ukraine in 1964. He received his Master's degree from Lviv Politechnic Institute in 1986. Received Ph.D. degree in Electrical Engineering in MPEI in 1993. Received Doctor of Science Degree in Electrical Engineering in National Technical University Kharkiv Polytechnic Institute in 2021. Current position is Professor of Radio Engineering Systems Department, Head of the Power Electronics Laboratory (TNTU). His scientific interests are: switch mode power converters/inverters with high-frequency magnetic amplifiers, its parallel operation, high level of the load current, resonant converters, control theory.