18. *Zelkin E.G., Kravchenko V.F., Gusevskiy V.I.* Konstruktivnye metody approksimatsii v teorii antenn [Constructive methods of approximation in antenna theory]. Moscow: SAYNS-PRESS, 2005, 512 p.
19. *Rafael A. Penchel, José R. Bergmann, Fernando J. S. Moreira.* Shaping Single Offset Reflector Antennas Using Local Axis-Displaced Confocal Quadrics, *Hindawi Publishing Corporation International Journal of Antennas and Propagation,* 2016, pp. 1-9. DOI: 10.1155/2016/4715681.
20. *Venetskiy A.S., Kaloshin V.A.* Fazovoe, luchevoe i amplitudnoe raspredelenie polya v osesimmetrichnoy dvukhzerkal'noy teleskopicheskoy sisteme pri smeshchenii obluchatelya iz fokusa [Phase, radial and amplitude distribution of the field in an axisymmetric two-reflector telescopic system when the irradiator is displaced from focus], *Reports of the VI All-Russia conference «Radar and radio communication»*. Moscow, 2012, Vol. 2, pp. 250-254.
21. *Semenov B.V., Chernykh N.I., Pleshchev V.M.* New method of reflector surface shaping to produce a prescribed contour beam, *Ural mathematical journal,* 2017, Vol. 3, No. 2, pp. 143-151. DOI: 10.15826/umj.2017.2.015.
22. *Zanin K.M.* Kriteriy effektivnosti primeneniya antenn s konturnymi diagrammami napravlennosti v sostave bortovykh kompleksov sistem sputnikovoy svyazi [The Criterion of the Efficiency of Use of Antennas with Contour Beams in Satellite Communication Systems], *Sistemy upravleniya, svyazi i bezopasnosti* [*Systems of Control, Communication and Security*], 2024, No. 2, pp. 1-13. DOI: 10.24412/2410-9916-2024-2-001-013.
23. *Poulton G.T., Hay S.G.* Shaped reflector synthesis by successive projections, *IEEE Antennas and propagation Society International Symposium*, 1992 Digest, pp. 363-366. DOI: 10.1109/APS.1992.221924.
24. *Shishlov A.V.* Zerkal'nye antenny s konturnymi diagrammami napravlennosti – effektivnost' i predel'nye vozmozhnosti [Reflector antennas with contoured beams: efficiency and limiting capability], *Radiotekhnika* [Radio engineering], 2006, No. 4, pp. 45-50.

Статью рекомендовал к опубликованию д.т.н., профессор К.Е. Румянцев.

**Занин Константин Михайлович** – Ростовский-на-Дону научно-исследовательский институт радиосвязи; e-mail: konstantinzanin@rambler.ru; г. Ростов-на-Дону, Россия; тел.: +78632018463; аспирант; руководитель группы.

**Габриэльян Дмитрий Давидович** – e-mail: d.gabrielijan2011@yandex.ru; тел.: +78632508985; д.т.н.; профессор; зам. начальника НТК.

**Кузнецов Юрий Викторович** – тел.: +78632018463; e-mail: kuznetsov_yu_v@list.ru; руководитель группы.

**Мищенко Сергей Евгеньевич** – e-mail: mihome@yandex.ru; тел.: +78633067810; д.т.н.; профессор; в.н.с.

**Zanin Konstantin Mikhailovich** – Rostov-on-Don Research Institute of Radio Communication; e-mail: konstantinzanin@rambler.ru; Rostov-on-Don, Russia; phone: +78632018463; postgraduate student; head of group.

**Gabrielyan Dmitry Davidovich** – e-mail: d.gabrielijan2011@yandex.ru; phone: +78632508985; dr. of eng. sc.; professor; deputy Head of the Scientific and Technical complex.

**Kuznetsov Yury Viktorovich** – e-mail: kuznetsov_yu_v@list.ru; phone: +78632018463; head of group.

**Mishenko Sergey Evgenievich** – e-mail: mihome@yandex.ru; phone: +78633067810; dr. of eng. sc.; professor; lead research scientist.

УДК 621.396.674 DOI 10.18522/2311-3103-2024-4-181-188

**И.А. Алшимайсаве, Ю.В. Юханов**

# ОПТИМИЗАЦИЯ ВСЕНАПРАВЛЕННОЙ АНТЕННЫ 2 × 2 MIMO ДЛЯ ВНУТРЕННИХ ПРИЛОЖЕНИЙ 2G, 3G, 4G И 5G

*Из-за сосуществования нескольких типов сетей связи и растущей потребности в высокоскоростной передаче данных многочастотные и широкополосные системы связи приобрели популярность в качестве тем для изучения. Всенаправленные антенны могут обрабатывать больше отдельных диапазонов частот и полезны для различных устройств беспроводной связи благодаря* *своей диаграмме направленности, которая облегчает эффективную передачу и прием с мобильного устройства. Однако для систем мобильной связи, поддерживающих приложения 2G, 3G, 4G и будущих 5G, использование антенны с высокой пропускной способностью может иметь решающее значение. Поскольку 5G предлагает своей обширной базе пользователей более высокую скорость передачи данных, большую надежность и снижение энергопотребления, были опубликованы многочисленные исследования широкополосных антенн 5G. Благодаря своим многочисленным преимуществам, таким как более высокая пропускная способность канала, лучшая производительность передачи и приема сигнала, возможность размещать большие антенны в крошечных пространствах и многое другое, MIMO стала важнейшей технологией для 5G. Недавно для мобильных телефонов было предложено несколько различных типов антенн 5G MIMO. В этом исследовании предлагается внутренняя система связи GSM/3G/LTE/5G с использованием широкополосной MIMO-антенны 2 × 2. В антенне используются два антенных элемента, равномерно расположенных вокруг центра, для формирования всенаправленной диаграммы направленности. Одновременно достигаются превосходные свойства всенаправленного излучения и широкая полоса пропускания. Полоса импеданса (0,7–5,3) ГГц может быть достигнута с обратными потерями до -23 по результатам моделирования и усилением до 6,5 дБ. Для моделирования антенны используется ANSYS HFSS (High Frequency Structure Simulator) 2020.*

*Всенаправленная; MIMO-антенна; сверхширокополосная.*

**I.A. Alshimaysawe, Yu.V. Yukhanov**

## OPTIMIZATION OMNI-DIRECTIONAL 2 × 2 MIMO ANTENNA FOR INDOOR 2G, 3G, 4G, AND 5G APPLICATIONS

*Due to the cohabitation of multiple types of communication networks and the increasing need for high-speed data transmission, multi-frequency and broadband communication systems have gained popularity as study topics. Omnidirectional antennas can handle more individual frequency bands and are useful for a variety of wireless communications devices due to their radiation pattern, which facilitates effective transmission and reception from a mobile device. However, for mobile communication systems supporting 2G, 3G, 4G, and future 5G applications, the use of a high-bandwidth antenna may be crucial. Since 5G offers its vast user base higher data speed, greater dependability, and reduced power consumption, numerous studies on 5G broadband antennas have been published. Because of its many advantages, such as higher channel capacity, better signal transmission and reception performance, the ability to place big antennas in tiny spaces, and more, MIMO has emerged as a crucial technology for 5G. A number of different 5G MIMO antenna types have recently been suggested for cellphones. An indoor GSM/3G/LTE/5G communication system using a 2 × 2 wideband MIMO antenna is suggested in this study. The antenna uses two antenna elements evenly spaced around the centre to form an omnidirectional radiation pattern. Simultaneously, excellent omnidirectional emission properties and a broad bandwidth are obtained. An impedance bandwidth of (0.7-5.3) GHz can be accomplished with a return loss of up to -23 based on the simulation results, with a gain of up to 6.5 dB. ANSYS HFSS (High Frequency Structure Simulator) 2020 is used to simulate the antenna.*

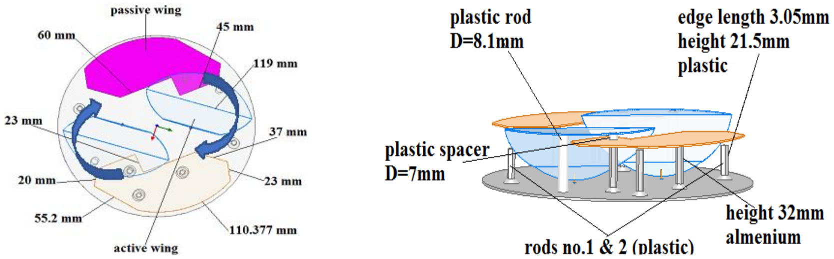
*Omni-directional; MIMO antenna; ultra-wideband.*

**I. Introduction.** Mobile base stations and antennas must adapt to support the new 5G frequency bands below 6 GHz, as well as 2G, 3G, and the current 4G (0.7-0.96 GHz and 1.7-2.7 GHz) as telecom service providers look to install 5G mobile systems around the world [1]. Compared to the present 4G system, fifth generation (5G) communication technology can offer a number of benefits, such as faster transfer rates and lower latency [2–4]. Research has demonstrated that in order to obtain greater transmission rates for 5G operations at frequencies lower than 6 GHz, a multiple-input multiple-output (MIMO) antenna system should be implemented [5–13]. A number of 5G MIMO smartphone antennas have recently been proposed [14–17]. In 2016, the European Commission (EC) revealed the bands between 3.4 and 3.8 GHz as part of its spectrum strategy for 5G testing. 2017 saw the official announcement by China's Ministry of Industry and Information Technology (MIIT) that the 3.4-3.6, 4.8-5, and 3.3-3.4 (indoor only) GHz bands would be reserved for 5G services [18]. For indoor base stations where there is limited space for placing antennas, a single antenna element covering the desired frequency bands is preferred over several antennas for different bands [1]. Many attempts have been made to use a single antenna covering the frequency bands of 0.7 to 0.96 GHz and from

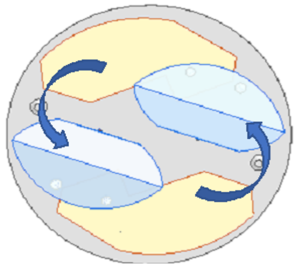
1.7 to 2.7 GHz to suit the needs of 2G, 3G, 4G, and 5G applications [1]. In [19], a wide-band multiple-input multiple-output (MIMO) antenna with dual-band (2.4 and 5 GHz) operation was proposed for premium indoor access points (IAPs), and its performance was compared with that of dipole and patch antennas. In [20], the explanation of a method for incorporating dual-band frequencies into a broad bandwidth single-layer board. In this study, two "L"-shaped and rectangular radiating elements are combined and implanted on a relatively compact single layer structure to construct a dual-band printed dipole antenna. Two IEEE WLAN standards can be completely supported by the printed dipole antenna, which operates in the frequency range of 2400–2500 MHz and 4900–5875 MHz. In [21], developed a brand-new, low-cross-polarization, wideband omni-directional antenna for indoor GSM1800/3G/LTE/5G communication systems. The printed log-periodical antenna elements of the suggested antenna are uniformly spaced around the centre to achieve the omni-directional radiation patterns. Additionally, a wide bandwidth and high omnidirectional radiation performance are realised concurrently between 1.7 and 3.8 GHz with a gain of around 1.5 dBi across the whole operating frequency thanks to the cooperation of the log-periodical antenna and annular parasitic patches. In [22], the proposed antenna is composed of three radiators above a ground plane, a coupling patch above the monopole with three shorting legs to increase the lowest operating frequencies, a monopole composed of three patches fed by a coaxial line and a top-loading disc on top of the coupling patch to further reduce the lowest operating frequencies. An enhanced impedance bandwidth of 9.23:1 was obtained with S11 -13.9 dB (for SWR 1.5) from 650 MHz to 6 GHz. In [23], an electrically compact upper-band Alford loop antenna and a lower-band omnidirectional loop antenna are combined on a single substrate to provide a small, horizontally polarised dual-band omnidirectional antenna, according to the technique presented. To reduce the gain variation in the azimuthal plane, a method for effectively extending the Alford loop's bandwidth was developed, the electrically small loop is fed by four symmetrical radial strips extended from a circular patch, for demonstration, the electrically small loop and Alford loop were created for the 2.4- and 5-GHz Wi-Fi bands. It covers the 2.4–2.5 GHz and 5.1–5.9 GHz Wi-Fi frequencies. In [1], the dual polarisation antenna consists of two orthogonal dipole antennas. Each dipole is composed of three different types of radiators are cat-ear-shaped arms for different bands, bowtie dipoles, and elliptical dipoles. Three broad bands, each with individually controlled fractional bandwidths of 31.3% (0.7-0.96 GHz), 55.3% (1.7-3 GHz), and 14% (3.3-3.8 GHz), are offered by the proposed antenna. In [24], three MED antennas were used in this submission to present a novel 3-D circular conformal MIMO antenna system. The single MED element was meticulously built with one main (lower-band) dipole and two auxiliary (upper-band) dipoles to achieve the dual band radiation. The MED element exhibits an impedance bandwidth of 54.2% (1.68 GHz-2.93 GHz) with a stable gain of 6.05±1.15dBi in the lower band and 9.2% (3.32 GHz-3.64 GHz) with 5.71±0.7dBi in the upper band, respectively. In this paper, an antenna designed in [25] is developed, operating at frequencies (698-960) MHz, (1710-2700) MHz and (2800-3800) MHz. Typical 2×2 MIMO antenna that are omnidirectional radiation pattern is developed by modification in the design Where work is done to change the location of two passive wings, Simulations are conducted for a number of designs, and the best results are obtained in two cases, the first case when change the angles through moving passive wings clockwise by 4 degrees, the results are better at first band (698-1) GHz, second bands (1.7-1.9, 2.4-3.1) GHz, and third band (3.4-3.8) GHz in S11, VSWR, gain, and efficiency, while the second case when change the angles through moving passive wings counter clockwise by 1 degree, the results are the best in the band (3.4-3.8) GHz and slightly lower in the band (698-0.9) GHz in terms of S11, VSWR, gain, and efficiency. The antenna must work in the whole WLAN frequency spectrum since the frequency covers both IEEE 802.11b/g and 802.11a/j, and because it has enough gain and beam coverage to apply to a premium access point. For mobile communication systems supporting 2G, 3G, 4G, and upcoming 5G applications, a broadband antenna can be useful. It is different from the previously listed antennas in that it has a large bandwidth, low return loss, and high gain, making it appropriate for usage in a variety of settings and with communication systems across all generations (2-5G).

**II. The proposed of antenna design.** The circular 2x2 MIMO antenna structure, as shown in figure 1, is designed for frequencies between 0.7 GHz and 5.3 GHz. The antenna consists of two active and two passive wings made of copper, four plastic rods and six aluminum rods. The antenna's ground is constructed of aluminum with dimensions of 213 mm, diameter, and 1.5 mm. As illustrated in figure referred to above, the antenna's size as simulated in ANSYS HFSS 2020.

In fig. 1(a) we have to change the location of two passive wings in [25] where moving passive wings clockwise by 4 degrees and the results obtained are better at first band (698-1) GHz, second bands (1.7-1.9, 2.4-3.1) GHz, and third band (3.4-3.8) GHz in S11, VSWR, gain, and efficiency, while in fig. 1(b) when moving passive wings in [25] where counter clockwise by 1 degree, the results obtained are the best in the band (3.4-3.8) GHz and slightly lower in the band (698-0.9) GHz in terms of S11, VSWR, gain, and efficiency.




(a) Rotate passive wings 4 degrees clockwise



(b) Rotate passive wings 1 degree counter clockwise

*Fig. 1. MIMO 2×2 antenna circular shape*

**III. Simulation results and discussions.** This suggesting antenna is created using ANSYS HFSS Version 2020 software. According to fig. 2–6, the lowest value for S11 is -23 in 1.9 GHz, the best value for VSWR is 1.12 in 1.9 GHz, and the maximum value for the Gain is 6.4 dB in 4 GHz. These results are obtained for the ultra-wide band (0.7–5.3 GHz) in the proposed antenna design shown in Figure 1(a), which illustrates how the antenna designed in [25] is modified by moving its passive wings clockwise by 4 degrees. The original antenna's characteristics are shown by red dashed curves, and the modifying antenna's characteristics are shown by solid green curves. The proposed antenna differs in that it can obtain better specifications at first range (698-1) GHz, S11 is -15, VSWR is 1.4, second range (1.7-1.9, 2.4-3.1) GHz, and third range (3.4-3.8) GHz, S11 is -12, VSWR is 1.6, gain is 6dB making it more efficient and suitable for use in 5G applications.

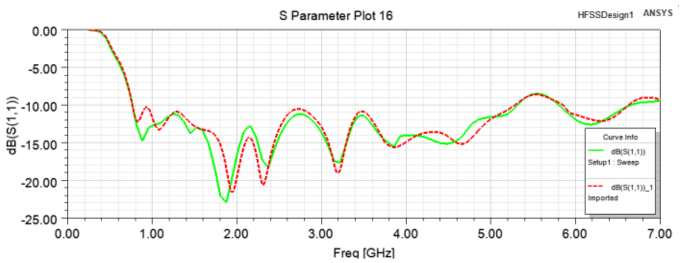



*Fig. 2. Return Loss (S11)*

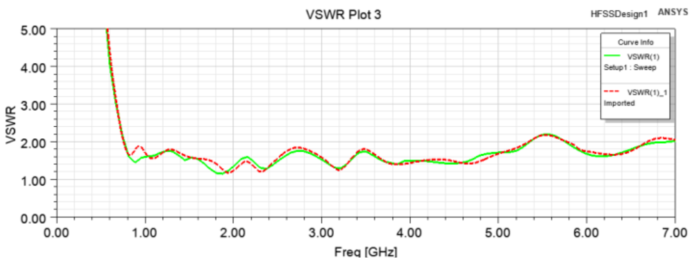



*Fig. 3 The VSWR Simulated Results*

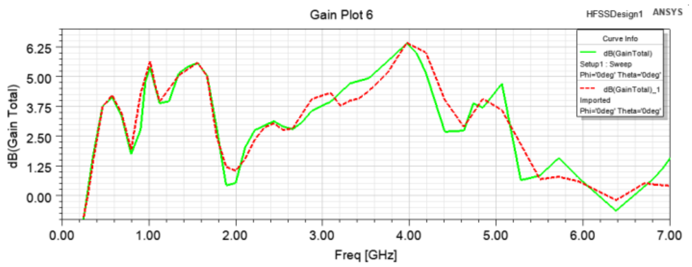



*Fig. 4. The Gain vs. Frequency*

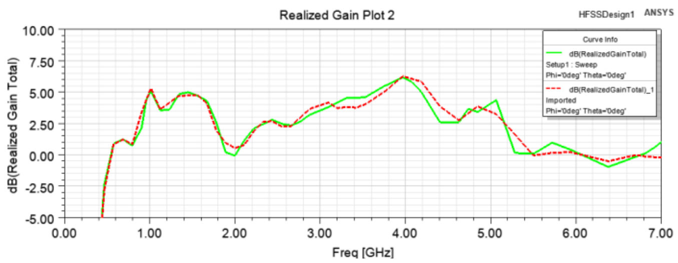



*Fig. 5. The Realized Gain vs. Frequency*

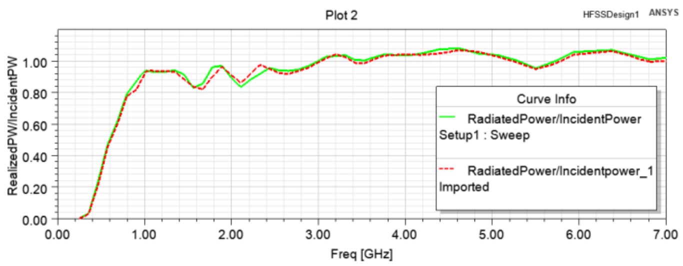



*Fig. 6. The Radiated Power / Incident Power vs. Frequency*

When modifying the antenna design [25] and studying several different cases, the best results are obtained through analysis by moving passive wings counter clockwise by 1 degree as in fig. 1(b), the results as shown in fig. 7-11 are -20 it's a minimum value for S11 in 1.9 GHz, 1.2 in 1.9 GHz it's the best value for VSWR, and 6.5 dB in 3.7 GHz represent the higher value of the Gain for the band (0.7–5.3 GHz), where (698-0.9) GHz with S11 is -12, VSWR is 1.6, gain is 5.4dB it is considered a little less compared to the antenna result referred to above, but with regard to the band (3.4-3.8) GHz with S11 is -13, VSWR is 1.5, gain is 6.4dB, the difference will be clearly for the better, which makes this design better for use, especially with fifth generation communications applications. Red dashed curves represent the characteristics of the original antenna and solid green curves represent the characteristics of the antenna after modifying the design.

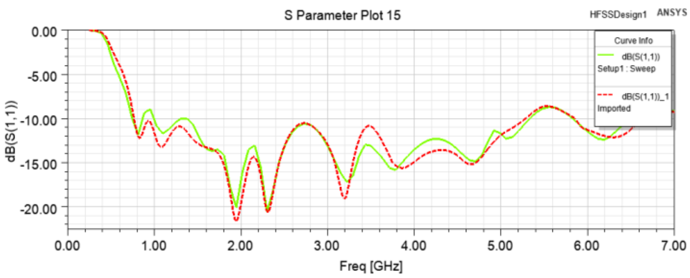



*Fig. 7. Return Loss (S11)*

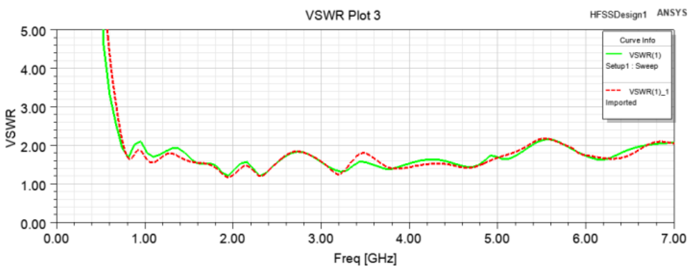



*Fig. 8. The VSWR Simulated Results*

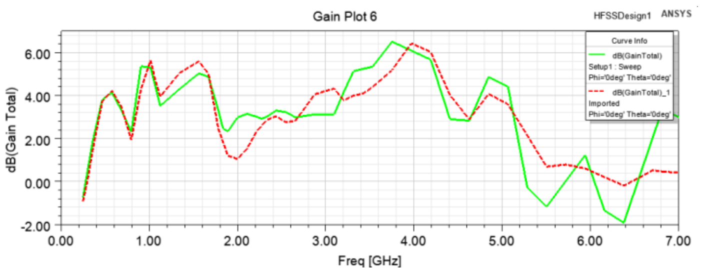



*Fig. 9. The Gain vs. Frequency*

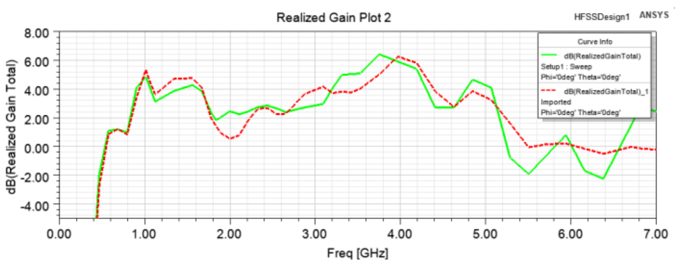



*Fig. 10. The Realized Gain vs. Frequency*

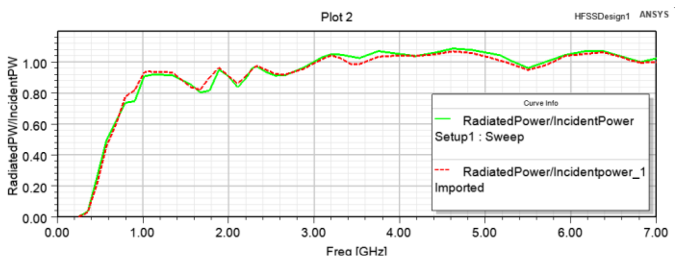



*Fig. 11. The Radiated Power / Incident Power vs. Frequency*

**Conclusions.** The rapid advancement of wireless technology and personal communications has led to a greater demand for antennas that can operate across a wide spectrum of frequencies. This makes them more appealing for a variety of applications and compatible with both present and future communication generations. This study describes the design of an omnidirectionally radiation-patterned wide-band MIMO antenna. The circular-shaped 2x2 MIMO antenna generated ultra-wide band frequencies (0.7-5.3GHz) with gain up to 6.5 dB and return losses approaching -23. It can be used for various applications across all mobile communication generations (2G, 3G, 4G, and 5G), all WLAN classes, and upcoming new applications.

REFERENCES


1. *Ahmed Alieldin, et al.,* A Triple-Band Dual-Polarized Indoor Base Station Antenna for 2G, 3G, 4G and Sub-6 GHz 5G Applications, *IEEE Access*, September 2018, Vol. 6, No. 2.
2. *Andrews J.G., et al.* What will 5G be?, *IEEE J. Sel. Areas Commun.*, Jun. 2014, Vol. 32, No. 6, pp. 1065-1082,.
3. Cho Y.S., Kim J., Yang W.Y., and Kang C.G. MIMO-OFDM wireless communications with MATHLAB. Wiley, New York, 2010.
4. *Anping Zhao, and Zhouyou Ren.* 'Size Reduction of Self-Isolated MIMO Antenna System for 5G Mobile Phone Applications. *IEEE Antennas and Wireless Propagation Letters*, November 2018.
5. *Ai-Hadi A.A., Iivonen J., Valkonen R., and Viikari V.* Eight-element antenna array for diversity and MIMO mobile terminal in LTE 3500 band, *Microwave and Optical Technol. Lett*., June 2014, Vol. 56, pp. 1323-1327.
6. *Wong K.- L., Lu J.Y., Chen L.Y., Li W.-Y., and Ban Y.L.* 8-antenna and 16-antenna arrays using the quad-antenna linear array as a building block for the 3.5GHz LTE MIMO operation in the smartphone, *Microwave and Optical Technol. Lett*., Jan. 2016, Vol. 58, pp. 174-181.
7. *Qin Z., Geyi W., Zhang M., and Wang J.* Printed eight-element MIMO system for compact and thin 5G mobile handset, *Electron. Lett.*, March 2016, Vol. 52, pp. 416-418.
8. *Ban Y.L., Li C., Sim C.Y.D., Wu G., and Wong K.-L.* 4G/5G multiple antennas for future multi-mode smartphone applications, *IEEE Access*, July 2016, Vol. 4, pp. 2981-2988.
9. *Li M.Y., Ban Y.L., Xu Z.Q., Wu G., Sim C., Kang K., and Yu Z.F.* Eight-port orthogonally dual-polarized antenna array for 5G smartphone applications, *IEEE Trans. Antennas Propag.*, Jun. 2016, Vol. 64, pp. 3820-3830.
10. *Wong K.-L., Tsai C.-Y., and Lu J.-Y.* Two asymmetrically mirrored gap-coupled loop antennas as a compact building block for eight antenna MIMO array in the future smartphone, *IEEE Trans. Antennas Propag.*, Apr. 2017, Vol. 65, pp. 1765-1778.
11. *Xu H., Zhou H., Gao S., Wang H., and Cheng Y.* Multimode decoupling technique with independent tuning characteristic for mobile terminals, *IEEE Trans. Antennas Propag.*, Dec. 2017, Vol. 65, pp. 6739-6751.
12. *Li Y., Sim C.-Y.-D., Luo Y. and Yang G.* 12-port 5G massive MIMO antenna array in sub-6GHz mobile handset for LTE bands 42/43/46 applications, *IEEE Access*, Feb. 2018, Vol. 6, pp. 344-354.
13. *Li Y., Sim C-Y.-D., Luo Y. and Yang G.* Multiband 10-antenna array for sub-6 GHz MIMO applications in 5-G smartphones, *IEEE Access*, June 2018, Vol. 6, pp. 28041-28253.
14. Ban Y.L., Chen Z.X., Chen Z., Kang K., and Li J.L.W. Decoupled closely spaced heptaband antenna array for wwan/lte smartphone applications, *IEEE Antennas Wirel. Propag. Lett*, 2014, Vol. 13, pp. 31-34.
15. *Li M.Y, Ban Y.L., Xu Z.Q., Wu G., Sim C.Y.D., Kang K., and Yu Z.F.* Eight-port orthogonally dual-polarized antenna array for 5g smartphone applications, *IEEE Trans. Antennas Propag*., Sept 2016, Vol. 64, No. 9, pp. 3820-3830.
16. *Ban Y.L., Li C., Sim C.Y.D., Wu G., and Wong K.L.* 4g/5g multiple antennas for future multi-mode smartphone applications, *IEEE Access*, 2016, Vol. 4, pp. 2981-2988.
17. *Li Y., Sim C.-Y.D., Luo Y., and Yang G.* 12-port 5G massive MIMO antenna array in sub-6GHz mobile handset for LTE bands 42/43/46 applications, *IEEE Access*, 2018, Vol. 6, pp. 344-354.
18. *Wu Q., Liang P., and Chen X.* A broadband ±45◦ dual-polarized multiple-input multiple-output antenna for 5G base stations with extra decoupling elements, *J. Commun. Inf. Netw.*, Mar. 2018, Vol. 3, No. 1, pp. 31-37.
19. *Insu Yeom, Young Bae Jung and Chang Won Jung*. Wide and Dual-Band MIMO Antenna with Omnidirectional and Directional Radiation Patterns for Indoor Access Points, Journal of Electromagnetic Engineering and Science, Jan. 2019, Vol. 19, No. 1, pp. 20-30.

20. *Tze-Meng O. and Geok T.K.* A dual-band omni-directional microstrip antenna, *Progress In Electromagnetics Research*, July. 2010, Vol. 106, pp. 363-376.
21. *Liangying Li, Wei Yan, Botao Feng and Li Deng.* A Wideband Omni-directional Antenna Based on Printed Log-Periodic Element, *IEEE 3rd International Conference on Electronic Information and Communication Technology*, November 2020, pp. 13-15.
22. *Lei Zhou, Yongchang Jiao, Yihong Qi*, *Zibin Weng, and Liang Lu.* Wideband Ceiling-Mount Omnidirectional Antenna for Indoor Distributed Antenna Systems, IEEE Antennas and Wireless Propagation Letters, April 2014, Vol. 13, pp. 836-839.
23. *Peng Fei Hu, Kwok Wa Leung, Yong Mei Pan, and Shao Yong Zheng.* Electrically Small, Planar, Horizontally Polarized Dual-band Omnidirectional Antenna and its Application in a MIMO System, *IEEE Transactions on Antennas and Propagation*, June 2021.
24. *Botao Feng, Kwok L. Chung, Jiexin Lai, and Qingsheng Zeng.* A Conformal Magneto-Electric Dipole Antenna with Wide H-Plane and Band-Notch Radiation Characteristics for MIMO Base-Station, *IEEE Access*, 2019.
25. *Alshimaysawe I.A*. Ultra wideband indoor omni-directional 2×2 MIMO antenna for 2G, 3G, 4G, and 5G applications, *Izvestiya SFedU. Engineering Sciences*, 2023, No. 3, pp. 266-275.

Статью рекомендовал к опубликованию д.т.н., профессор Б.Г. Коноплев.

**Алшимайсаве Ихсан Абдлкарем** – Южный федеральный университет; e-mail: alshimaysave@sfedu.ru; г. Таганрог, Россия; тел.: +79957566781; кафедра антенн и радиопередающих устройств; аспирант.

**Юханов Юрий Владимирович** – e-mail: yu_yukhanov@mail.ru; тел.: +78634371733; кафедра антенн и радиопередающих устройств; зав кафедрой; д.т.н.; профессор.

**Alshimaysawe Ikhsan Abdlkarem** – Southern Federal University; e-mail: alshimaysave@sfedu.ru; Taganrog, Russia; phone: +79957566781; the Department of Antennas and Radio Transmitting Devices; postgraduate student.

**Yukhanov Yuriy Vladimirovich** – e-mail: yu_yukhanov@mail.ru; phone: +78634371733; the Department of Antennas and Radio Transmitting Devices; head of Department; dr. of eng. sc.

УДК 621.396.67 DOI 10.18522/2311-3103-2024-4-188-196

**Во Ба Ау, И.Н. Бобков, Ю.В. Юханов**

## НИЗКОПРОФИЛЬНАЯ АНТЕННАЯ РЕШЕТКА СИЛЬНО СВЯЗАННЫХ ДИПОЛЕЙ КРУГОВОЙ ПОЛЯРИЗАЦИИ

*Рассмотрена конструкция низкопрофильной антенной решетки сильно связанных диполей круговой поляризации. Основной деталью конструкции являются два скрещенных диполя в печатном исполнении. Квадратурное возбуждение обеспечивается полосками в форме дуги окружности, соединяющими пары ортогонально расположенных плеч на верхнем и нижнем слое металлизации. Для обеспечения емкостной связи между элементами применяются металлические диски, гальванически соединенные с основанием при помощи металлических стержней. Для расширения полосы рабочих частот и улучшения характеристик излучения антенной решетки непосредственно над диполями расположен согласующий слой пластика Eccostock HiK. Представлены результаты численного исследования характеристик элементарной ячейки антенной решетки с периодическими граничными условиями на гранях в программном обеспечении ANSYS HFSS. Показана возможность работы в широкой полосе частот по заданному уровню согласования и коэффициента эллиптичности. Показана зависимость характеристик согласования и коэффициента эллиптичности от размеров полоска, обеспечивающего квадратурное питание плеч диполей. Расчетным путем установлено, что выбор радиуса полоска, обеспечивающего квадратурное возбуждение плеч диполей, представляет собой компромисс между широкой полосой рабочих частот и лучшим коэффициентом эллиптичности в центре диапазона. Показано, что использование расположенного непосредственно над слоем диполей согласующего слоя в решетках сильно связанных диполей круговой поляризации обеспечило согласование в широкой полосе частот при сохранении электри-*