Conference materials
UDC 621.396.42
DOI: https://doi.org/10.18721/JPM.173.171

A mm-wave dielectric antenna with symmetric beam compatible with PCB machinery

M.I. Ershova [1] ✉, A.N. Prikhodko [1, 2, 4], A.S. Shurakov [1, 2, 3], G.N. Goltsman [1, 2, 4]

[1] Moscow Pedagogical State University, Moscow, Russia;
[2] National Research University Higher School of Economics, Moscow, Russia;
[3] National University of Science and Technology "MISIS", Moscow, Russia;
[4] Russian Quantum Center, Skolkovo, Moscow, Russia
✉ mi_ershova@student.mpgu.edu

Abstract. The current decade is associated with the start of active deployment and use of fifth generation networks, while the ongoing developments in the sixth generation communication technologies should be finalized in the upcoming decade. It is forecasted that sufficiently directive wireless transceivers will become integral parts of the next generation wireless communication systems. In this study, we report on the development of a low-cost millimeter wave dielectric antenna with nearly symmetric beam. The antenna makes use of a dual-stage dielectric multimode interference power divider terminated by 16 dielectric tapers with flare angles of 6–12°. It is designed for operation at frequencies of 50–77 GHz. The design is developed for fabrication by the means of printed circuit board prototyping machinery from high-permittivity laminates and, therefore, is compatible with the Si platform for solid-state electronics and integrated photonics. The fabricated antenna samples exhibit half-power beamwidths of 27° with corresponding side lobe levels of approximately −10 dB, as measured at 52 GHz.

Keywords: millimeter wave, dielectric rod antenna, antenna array, high-permittivity laminate, direct machining

Funding: This study was funded by the Russian Science Foundation grant number No. 21-72-10119, https://rscf.ru/project/21-72-10119/.

Citation: Ershova M.I., Prikhodko A.N., Shurakov A.S., Goltsman G.N., A mm-wave dielectric antenna with symmetric beam compatible with PCB machinery, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 17 (3.1) (2024) 349–353. DOI: https://doi.org/10.18721/JPM.173.171

Материалы конференции
УДК 621.396.42
DOI: https://doi.org/10.18721/JPM.173.171

Диэлектрическая антенна миллиметрового диапазона с симметричным пучком, совместимая с оборудованием для печатных плат

М.И. Ершова [1] ✉, А.Н. Приходько [1, 2, 4], А.С. Шураков [1, 2, 3], Г.Н. Гольцман [1, 2, 4]

[1] Московский педагогический государственный университет, Москва, Россия;
[2] Национальный исследовательский университет «Высшая школа экономики», Москва, Россия;
[3] Национальный университет науки и технологий «МИСиС», Москва, Россия;
[4] Российский квантовый центр, Сколково, Москва, Россия
✉ mi_ershova@student.mpgu.edu

Аннотация. Текущее десятилетие связано с началом активного развертывания и использования сетей пятого поколения, при этом текущие разработки в области коммуникационных технологий шестого поколения должны завершиться в ближайшее десятилетие. Прогнозируется, что достаточно направленные беспроводные приемопередатчики станут неотъемлемой частью систем беспроводной связи следующего поколения. В этом исследовании мы сообщаем о разработке диэлектрической антенны миллиметрового диапазона волн с почти симметричным пучком. В антенне использован двухкаскадный диэлектрический делитель мощности на основе многомодовой интерференции, оканчивающийся 16 диэлектрическими конусами с углами раствора 6–12°. Антенна предназначена для работы на частотах 50–77 ГГц. Конструкция разработана посредством прототипирования печатных плат из ламината с высокой диэлектрической проницаемостью и, следовательно, совместима с кремниевой платформой для твердотельной электроники и интегральной фотоники. Изготовленные образцы антенн имеют ширину пучка по полуспаду мощности 27° с соответствующими уровнями боковых лепестков примерно –10 дБ, измеренные на частоте 52 ГГц.

Ключевые слова: миллиметровые волны, диэлектрическая стержневая антенна, антенная решетка, ламинат с высокой диэлектрической проницаемостью, прямая механическая обработка

Финансирование: Исследование выполнено за счет гранта Российского научного фонда № 21-72-10119, https://rscf.ru/project/21-72-10119/.

Ссылка при цитировании: Ершова М.И., Приходько А.Н., Шураков А.С., Гольцман Г.Н. Диэлектрическая антенна миллиметрового диапазона с симметричным пучком, совместимая с оборудованием для печатных плат // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2024. Т. 17. № 3.1. С. 349–353. DOI: https://doi.org/10.18721/JPM.173.171

Introduction

Currently, science and technology are interested in the development of low-cost, efficient, and compact modules capable of transmitting and receiving of millimeter wave (mmWave) signals. Wireless channels of the fifth and sixth generation (5/6G) communication networks require sufficiently directive transceivers as their crucial elements [1]. Moreover, novel mmWave antenna solutions are in demand by such applications as radar systems or atmospheric monitoring within the context of meteorological and climatological remote sensing [2, 3], etc.

In this study, we report on the development of a low-cost mmWave integrated dielectric rod antenna (DRA) array. Our design makes use of a dual-stage dielectric multimode interference power divider (MMIPD) [4] terminated by a 4×4-element planar array of dielectric tapers [5] with flare angles of 6–12°. Such a design can be easy tuned for efficient operation at any desired frequency within 50–77 GHz. It is developed for fabrication by the printed circuit board (PCB) prototyping machinery from high-permittivity laminates and, therefore, is naturally compatible with solid-state electronics and integrated photonics based on Si platform. Results of the simulations and detailed performance analysis of the developed antenna structures are to be presented further in the text of the article.

Results and Discussion

Figure 1, *a* provides a photograph of the fabricated completely dielectric DRA arrays with flare angles α of 6° and 12°. The main dimensions of a dual-stage MMIPD and DRA arrays are presented in Table and shown in Figure 1, *b*. They are developed for operation at 52 GHz, and their MMIPDs are equipped with input taper interfaces for coupling with rectangular metallic waveguides of a constant waveform source and power detector during beam profile measurements. The DRA array samples are fabricated by the means of direct machining from a high-permittivity PCB laminate (FSD1020T series). This material possesses relative permittivity of 10.2 and a loss tangent of 0.002 at 10 GHz according to the specifications provided by the manufacturer, and its dielectric properties at 130–160 GHz are briefly reported in [6]. A similar type of one-dimensional antenna from another series of PCB laminates, along with a more detailed description of the technological process, is provided in [7]. The first and the second stages of the samples' MMIPDs are attached through dielectric holders made from a low-permittivity material by a 3-dimensional (3d) printing.

a) *b*)

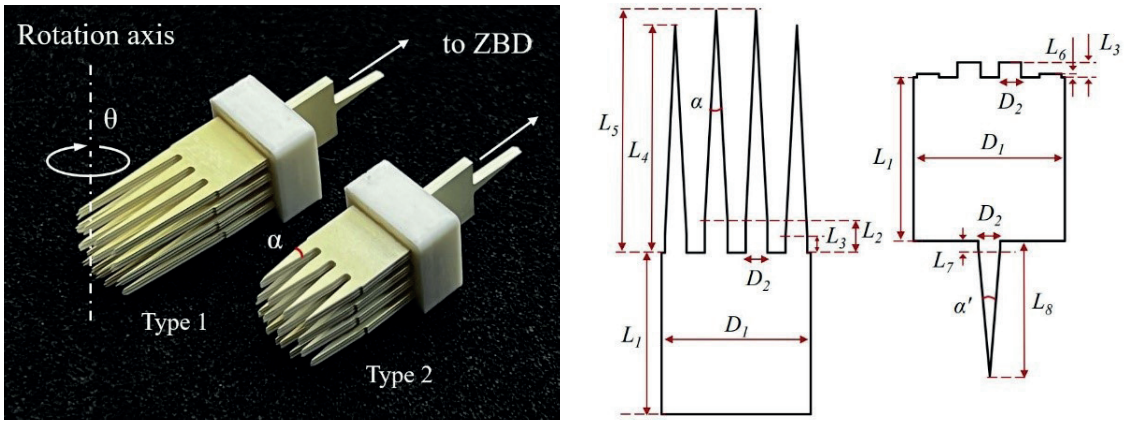

Fig. 1. Photograph of the fabricated DRA arrays (*a*); Geometry of the fabricated DRA arrays (*b*)

Table

Dimensions of the antenna array key elements

Array type	Geometric parameter											
	α, °	α', °	L_1, mm	L_2, mm	L_3, mm	L_4, mm	L_5, mm	L_6, mm	L_7, mm	L_8, mm	D_1, mm	D_2, mm
1	6	10	12	1.3	0.25	15.99	17.04	1.15	0.51	9.94	11.1	1.65
2	12	10	12	1.3	0.25	8.1	9.15	1.15	0.51	9.94	11.1	1.65

The fabricated DRA array samples are further experimentally studied. Experimental setup (Fig. 2, *a*) for the far-field radiation pattern measurements mainly makes use of a 50–77 GHz backward-wave oscillator (BWO) and a zero-biased Schottky diode detector (ZBD). The distance between Tx and Rx in the measurements significantly exceeds the Fraunhofer distance (DF). ZBD voltages are registered with aid of selective nanovoltmeter.

a) *b*)

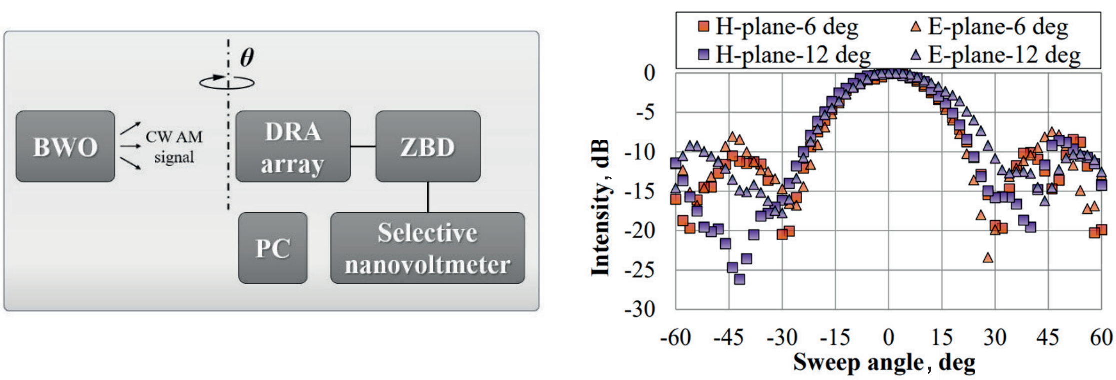

Fig. 2. Scheme of the experimental setup for measuring the beam profiles in H- and E-planes (*a*); H- and E-plane beam profiles of the fabricated samples measured at 52 GHz (*b*)

We use the 3D EM finite element method to simulate the beam profiles. Measured half-power beamwidths (*HPBW*) of 27° and side lobe levels (SLL) of −10 dB for both designs are qualitatively consistent with the calculated *HPBW* of 24° and SLL of −15 dB. Comparing the results of the manufactured dual-stage structure with the one-dimensional ones given in [7, 8], it is possible to identify an increase in the symmetry of the beam due to the cross-orientation of the power dividers.

The DRA gain weakly depends on the geometry of the flare angle. Thus, fabrication tolerance is relieved, and potential errors in fabrication of the most mechanically vulnerable elements, i.e., dielectric tapers, do not compromise performance of the integrated dielectric structure. In our study devices with 6−12° flare angles demonstrate decent performance at 52 GHz and can be tuned to any frequency within 50−77 GHz. Given that the proposed antenna design is naturally compatible with Si platform.

Conclusion

We propose the design of DRA arrays integrated with dual-stage MMIPD at the ends of which 16 tapered rod antennas are implemented. This work provides a detailed description of the fabrication and study of the main characteristics of the antennas. In direct machining, we use low-cost PCB laminate with high permittivity, so fabrication of DRA arrays becomes a simple and cheap process. As part of the study, radiation patterns of DRA arrays are measured at a carrier frequency of 52 GHz and show the half-power beamwidths of 27°, with corresponding side lobe levels of −10 dB for both designs. The corresponding calculated values of 24° and −15 dB are consistent with the experiment. Proposed DRA arrays are compatible with Si platform and can be used in solid-state electronics and integrated photonics in the millimeter wave range. The compact transceivers equipped with them can be used in 5/6G wireless communication modules, as well as in radar systems and atmospheric monitoring instruments due to their advantages.

REFERENCES

1. **Boulogeorgos A., Alexiou A., Merkle T., Schubert C., Elschner R., Katsiotis A., Rodrigues F.,** Terahertz Technologies to Deliver Optical Network Quality of Experience in Wireless Systems Beyond 5G. IEEE Communications Magazine. 56 (6) (2018) 144−151.

2. **Michler F., Scheiner B., Reissland T., Weigel R., Koelpin A.,** Micrometer Sensing With Microwaves: Precise Radar Systems for Innovative Measurement Applications. IEEE Journal of Microwaves. 1 (1) (2021) 202−217.

3. **Westwater E., Crewell S., Matzler C.,** A review of surface-based microwave and millimeter-wave radiometric remote sensing of the troposphere, September 2004URSI Radio Science Bulletin. 310 (2004) 59−80.

4. **Soldano L., Pennings E.,** Optical multi-mode interference devices based on self-imaging: principles and applications. Journal of Lightwave Technology. 13 (4) (1995) 615−627.

5. **Prikhodko A., Yaropolov T., Shurakov A., Gol'tsman G.,** Parametric model of a dielectric rod antenna array for terahertz applications. Proceedings of the 34th European Modeling & Simulation Symposium (EMSS 2022).

6. **Prikhodko A., Belikov I., Lvov A., Shurakov A., Gol'tsman G.,** Millimeter wave photonic crystal waveguides fabricated via direct machining, St. Petersburg Polytechnic University Journal. Physics and Mathematics. 15 (3.3) (2022).

7. **Lyubchak A., Prikhodko A., Andreev V., Shurakov A., Goltsman G.,** A mmWave rod antenna array compatible with a PCB prototyping technology, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 15 (3.3) (2022) 340−344.

8. **Shurakov A., Belikov I., Prikhodko A., Ershova M., Goltsman G.,** Superconducting Electronic−Photonic Platform for HEB-Based Terahertz Spectrometers. Appl. Sci. 13 (2023) 5892.

THE AUTHORS

ERSHOVA Margarita I.
mi_ershova@student.mpgu.edu
ORCID: 0009-0009-6785-4389

PRIKHODKO Anatoliy N.
anatprikh1995@yandex.ru
ORCID: 0000-0002-4859-8975

SHURAKOV Alexander S.
alexander@rplab.ru
ORCID: 0000-0002-4671-7731

GOLTSMAN Grigory N.
goltsman@rplab.ru
ORCID: 0000-0002-1960-9161

Received 04.07.2024. Approved after reviewing 08.08.2024. Accepted 08.08.2024.