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A mmWave rod antenna array compatible with a PCB prototyping technology

A. N. Lyubchak [1, 2]✉, A. N. Prikhodko [1, 2], V. S. Andreev [1, 2], A. S. Shurakov [1, 2, 3], G. N. Goltsman [1, 2]

[1] National Research University Higher School of Economics, Moscow, Russia;

[2] Moscow Pedagogical State University, Moscow, Russia;

[3] National University of Science and Technology MISiS, Moscow, Russia

✉ anlyubchak@miem.hse.ru

Abstract. A mmWave communication is becoming a reality. Nowadays, 5G networks are at the stage of commercial implementation while numerous studies around the world are devoted to investigating practical issues of switching to the 6G standard. Next generation communication systems should rely on highly directive transceivers, which potentially suffer from a micromobility issue. In this paper, we report on the design of a mmWave rod antenna array compatible with a PCB prototyping technology. The array makes use of a dielectric multimode interference power splitter integrated with four weakly coupled dielectric rod antennas at its output. It is cheap to fabricate and has a half-power beamwidth of 11° with a corresponding side lobe level of -11 dB at 135 GHz. Thus, the proposed design seems suitable for prototyping mmWave transceivers within lab studies of a micromobility issue in 6G networks. The design is adaptable for high permittivity PCB laminates and, therefore, is potentially compatible with Si platform. All together suggests efficient operation of dielectric rod antenna arrays in the mmWave band and beyond.

Keywords: millimeter waves, dielectric rod antenna, multimode interference power splitter, antenna array, PCB laminate, direct machining

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Решетка штыревых антенн миллиметрового диапазона совместимая с технологией прототипирования печатных плат

А. Н. Любчак [1, 2]✉, А. Н. Приходько [1, 2], В. С. Андреев [1, 2], А. С. Шураков [1, 2, 3], Г. Н. Гольцман [1, 2]

[1] Национальный исследовательский университет «Высшая школа экономики», Москва, Россия;

[2] Московский педагогический государственный университет, Москва, Россия;

[3] Национальный университет науки и технологий «МИСиС», Москва, Россия

✉ anlyubchak@miem.hse.ru

Аннотация. В настоящее время сети связи 5G находятся на стадии коммерческого внедрения, а научные исследования во всем мире направлены на изучение практических аспектов перехода на стандарт 6G. Системы связи следующего поколения должны иметь в своем составе узконаправленные приемопередатчики, которые потенциально подвержены негативному влиянию микромобильности. В данной статье мы сообщаем о разработке решетки штыревых антенн миллиметрового диапазона, совместимой с технологией прототипирования печатных плат. Ключевую роль в устройстве решетки играет делитель мощности на основе многомодовой интерференции, интегрированный по выходу с четырьмя слабосвязанными диэлектрическими штыревыми антеннами. Геометрия решетки проста в изготовлении и обеспечивает ширину пучка 11° с уровнем боковых лепестков -11 дБ на частоте 135 ГГц. Таким образом, предлагаемая конструкция хорошо подходит для создания прототипов приемопередатчиков миллиметрового диапазона в рамках лабораторных исследований эффекта микромобильности в сетях 6G. Конструкция может быть также адаптирована к использованию ламинатов для печатных плат с высокой диэлектрической проницаемостью и, следовательно, потенциально совместима с кремниевой платформой. Все вышесказанное позволяет сделать вывод об эффективности использования решеток диэлектрических штыревых антенн как в миллиметровом волновом диапазоне, так и за его пределами.

Ключевые слова: миллиметровые волны, диэлектрическая штыревая антенна, делитель мощности на основе многомодовой интерференции, антенная решетка, ламинат для печатной платы, механическая обработка

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Introduction

Nowadays, millimeter waves (mmWaves) attract close attention of both the scientific community and the communication industry. The society needs for fast and reliable data transfer eminently grew in the coronavirus pandemic era. A mmWave communication is becoming a reality. 5G networks are at the stage of commercial implementation while numerous studies around the world are devoted to investigating practical issues of switching to the 6G standard. Next generation communication systems should rely on transceivers equipped with high directivity antennas [1] causing potential loss of connection upon slight displacement of a mobile device. This is referred to as a micromobility issue and is of high practical importance [2].

Conventional way to implement a high directivity input optics of a receiver/transmitter is to use an antenna array. Since there is a variety of antenna array technologies, the choice is always a trade-off between performance of the array and its fabrication complexity. In this paper, we report on the design of a mmWave rod antenna array compatible with a PCB prototyping technology. The design is inspired by that of a W-band fully dielectric rod antenna array with integrated power divider [3], but it relies on a low-cost PCB laminate (FSD255G series, 1 mm thick [4]). Fabrication details and outcome of performance tests are provided further in the text.

Fabrication and Evaluation Details

Referring to Fig. 1, *a*, the proposed antenna array is fully dielectric and makes use of a multimode interference (MMI) power splitter integrated with four weakly coupled dielectric rod antennas (DRAs) at its output. Dimensions of the antenna array key elements are summarized in Table 1. It is worth mentioning that the chosen PCB laminate is intrinsically fibrous, and, therefore, the fabricated array structure has no sharp edges along perimeter which complicates inspection of its actual linear dimensions. The geometry is implemented with the aid of a MITS Eleven Lab PCB prototyping machine [5], metallization on both sides of the PCB laminate is removed via wet etching. The array is designed for operation at 135 GHz, where it has a half-power beamwidth (*HPBW*) of 11° and a side lobe level (*SLL*) of -11 dB. It is also well matched with a feeding WR6.5 rectangular waveguide: we measure return loss (*RL*) of 17.5 dB at 135 GHz.

As shown in figure 1b, during the beam profile measurements, we used a membrane-integrated planar Schottky diode (PSD) [6] as a core of direct-detection receiver (Rx). The PSD WR6.5 input was loaded by the proposed DRA array. Transmitter (Tx) made use of a backward wave oscillator (BWO) providing CW AM signal over the frequency range of 126.5–145.5 GHz. Tx was equipped with input optics identical to that of Rx. The measurements were conducted at the Tx-to-Rx distance of 35 cm, which approaches a Fraunhofer distance (D_F) defined by equation 1 for chosen geometry of the DRA array. Despite noticeable absorption loss in the array elements, we observed peak value of a signal-to-noise ratio (*SNR*) of ~ 670 during all the measurements. This *SNR* value was achieved for the Rx time constant of 100 ms. Given that power at the array input can be increased from 1.5 to 120 mW if BWO is replaced by a commercially available solid state mmWave source, insertion loss of the array is acceptable from a practical point of view. Outcome of the beam profile measurements is provided in Fig. 2.

$$D_F = 2D^2\lambda^{-1}, \tag{1}$$

where D is the largest dimension of the DRA array aperture and λ is the free space wavelength.

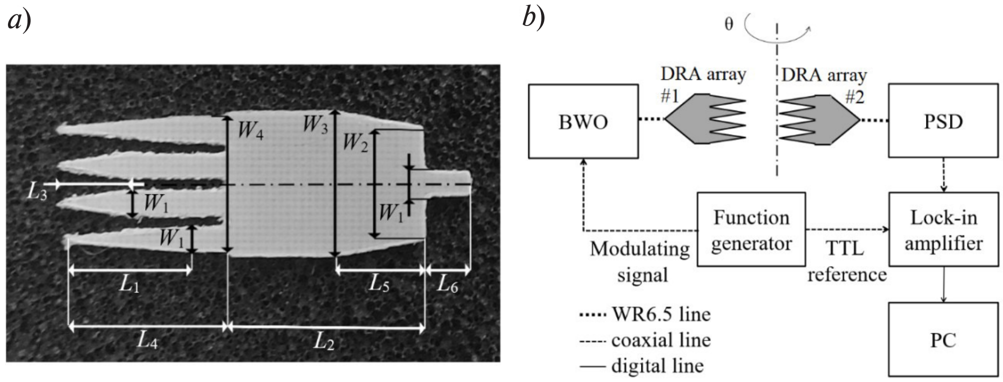

Fig. 1. Geometry of the proposed DRA array in H-plane (*a*); (*b*) diagram of the experimental setup for measuring the beam profiles in H- and E-planes (*b*)

Table 1

Dimensions of the antenna array key elements

Geometric parameter	Nominal value	Measured value	
		DRA array #1	DRA array #2
L_1	7.72 mm	7.44±0.36 mm	7.65±0.14 mm
L_2	11.74 mm	11.73±0.14 mm	11.73±0.14 mm
L_3	4.15 mm	4.15±0.14 mm	4.14±0.14 mm
L_4	10.80 mm	10.65±0.21 mm	10.58±0.22 mm
L_5	5.35 mm	5.36±0.14 mm	5.29±0.14 mm
L_6	2.86 mm	2.86±0.14 mm	2.86±0.14 mm
W_1	1.29 mm	1.29±0.14 mm	1.28±0.14 mm
W_2	6.86 mm	6.79±0.14 mm	6.79±0.14 mm
W_3	8.75 mm	8.79±0.14 mm	8.80±0.14 mm
W_4	8.14 mm	8.15±0.14 mm	8.15±0.14 mm

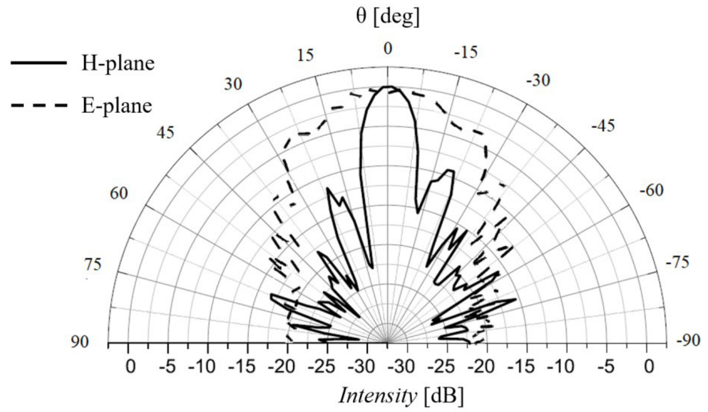

Fig. 2. Measured H- and E-plane beam profiles of the proposed DRA array

Fig. 3 provides frequency profiles of return losses measured for the DRA arrays #1 and #2. During the measurements, we used a solid state mmWave source providing up to 120 mW of output power over the frequency range from 132 to 162 GHz. The source and the array under study were connected through a waveguide directional coupler with a coupling factor of -15 dB and an isolation of 30 dB. For a given frequency of the source (Fss), the RL value was calculated with the aid of equation 2.

$$RL = 10\log_{10}\left(P_1 P_2^{-1}\right), \tag{2}$$

where P_1 and P_2 are the mmWave powers at the input and transmitted ports of the directional coupler, respectively. The power values were consequently measured by a precision waveguide power meter while the source was permanently connected to the coupled port of the directional coupler.

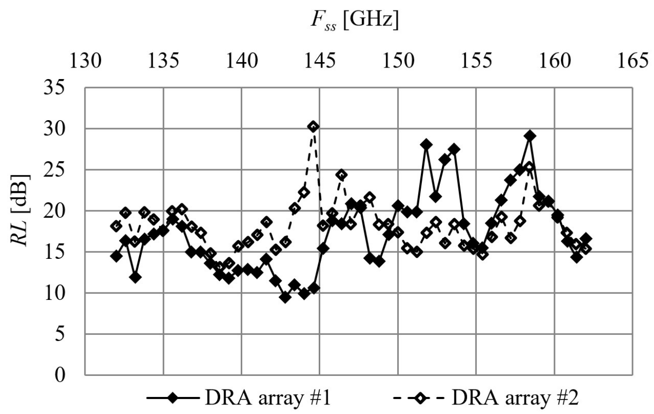

Fig. 3. Measured return losses of the DRA arrays

Both DRA arrays demonstrated decent match with a WR6.5 rectangular waveguide over the entire range of 132–162 GHz and at F_{SS} = 135 GHz specifically. Together with the beam profile frequency dependence [3], this suggests that the proposed design provides fractional input frequency bandwidth of at least 20%. Moreover, the design is adaptable for high permittivity laminates. Switching to a material with relative permittivity of 4.4 provides reduction in the array dimensions by ~ 50% [7]. Thus, we plan to further reduce aperture size of the array via switching to FSD1020T series laminate [8]. In addition to shortening a Fraunhofer distance, this aids to minimize propagation losses due to absorption in the array elements. Remaining compliant with a 2D PCB machinery, the design becomes even more attractive for implementation of highly directive mmWave transceivers as part of a lab measurement equipment.

Conclusion

In this paper, we propose design of a linear DRA array integrated with MMI power splitter developed for operation in the mmWave band. Low-cost PCB laminate and 2D CNC machining are used to implement the array geometry. The proposed design is evaluated via both the beam profile and return loss measurements conducted in the frequency range from 132 to 162 GHz. We measure the H-plane $HPBW = 11°$ with SLL = -11 dB and $RL \geq 17.5$ dB at 135 GHz. The design is adaptable for high permittivity PCB laminates and Si platform. In addition to shortening a Fraunhofer distance, switching to them aids to minimize propagation losses due to absorption in the array elements. All together suggests efficient operation of DRA arrays in the mmWave band and far beyond it.

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THE AUTHORS

LYUBCHAK Anastasia N.
anlyubchak@miem.hse.ru
ORCID: 0000-0002-4861-2466

PRIKHODKO Anatoliy N.
anprihodko@hse.ru
ORCID: 0000-0002-4859-8975

ANDREEV Vladislav S.
AndrejeffVS@yandex.ru
ORCID: 0000-0003-2604-5496

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

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

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