One of the promising approaches to managing the characteristics of THz rays is the use of Huygens' metasurfaces (HMSs) [7].

Cascade inductive and capacitive grids [8] HMSs implementation is most suitable in the millimeter and terahertz ranges, as it allows assembling HMS from several dielectric substrates bearing separate metal sheets with a pattern. Printed circuit board (PCB) and photolithography technologies can be used to make such layers. At frequencies up to 1 THz and above, photolithography provides sufficient accuracy.

We suggest adding extra layers to the observation to enhance the number of degrees of freedom. The efficiency of such a multi-layer structure can be increased by the proper selection of the transmission parameters of individual meta-atoms.

However, the technological challenge is to select suitable substrates and find the proper procedure for placing multilayer material without deformation and additional losses.

In this work, we synthesize and experimentally demonstrate a refractor made as a 5-layer Huygens metasurface in the transmission mode with an anomalous refraction of 55° at 0.166 THz, having a low level of undesirable scattering and achieving an experimentally measured transmission efficiency of 55%, parasitic diffraction losses of 25% and scattering losses of 20%. In addition, we present the technological steps that make it possible to produce such complex multilayer structures with low manufacturing deviations.

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DIGITAL PHASE SHIFTER ARRAYS FOR BEAMFORMING IN SUB-THZ COMMUNICATIONS

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With 5G communication networks being practically used, research on technological solutions for 6G networks is currently in focus of communication system developers. Intelligent reflective surface (IRS) [1] intended to upgrade capabilities of sub-THz channels, i.e., with carrier frequencies of 100–300 GHz, is among them. IRS is supposed to strengthen the received signal when line of sight of the transmitter is blocked and to mitigate multibeam interference. This is achieved by routing of propagating waves in IRS networks, where each IRS acts as a phase shifter array for beamforming in reflected light. Such an architecture is more efficient in terms of power consumption as compared to the multiple-input multiple-output wireless systems. It is also recently demonstrated that digital phase shifters with 2-bit resolution are promising for IRS up to a carrier frequency of 30 GHz [2,3].

In this paper, we report on the development of a 2-bit digital phase shifter array for beamforming in reflected light at 140 GHz. The array is planar. Each phase shifter in the array is presented by a patch antenna, whose ground plane metallization utilizes a cruciform slot. Distribution of currents along the slot is defined by the configuration of 5 diode switches integrated with it and determines the phase shift upon reflection of a sub-THz wave. In turn, the angle of reflection from the array is determined by the configuration of the phase shifters.

We use electromagnetic (EM) modeling to design the proposed phase shifter array. Both the Floquet port and incident wave analyses are conducted. The array geometry is implemented inside a region structure, whose faces are assigned as perfectly matched layers (or master/slave boundaries if the Floquet port is used). All the metallic surfaces are modeled as perfect conductors.

Subwavelength rectangular structures with predefined sheet impedances, Z, are used to model Schottky diode switches. At any given angular frequency, ω, $Z(R_j) \approx R_s + (R_j^{-1} + i\,\omega\,C_p)^{-1}$, where $R_j \approx 0\ \Omega$ and $R_j = R_{j0}$ for ON and OFF states of a diode switch, respectively. Quantities R_s, R_{j0} and C_p denote series resistance, nearly zero-bias resistance and parasitic capacitance of a Schottky diode, and i is the imaginary unit. For our Schottky diodes, we can reduce R_s down to a few ohms at the expense of increase in ideality factor by 30%, R_{j0} and C_p are typically equal to 0.45 MΩ and 10 fF.

The EM modeling yields linear dimensions of a phase shifter of $0.4\lambda_0 \times 0.4\lambda_0 \times 0.044\lambda_0$ (length × width × height) and width of a cruciform slot of $0.012\lambda_0$, where λ_0 is the free space wavelength. Array of rectangular patches is implemented on a $0.012\lambda_0$ thick quartz substrate facing incident EM radiation. Ground plane metallization of patch antennas is spaced by an air gap of $0.02\lambda_0$.

It is implemented on a back metallized quartz substrate with thickness of $0.012\lambda_0$. Diode switches are grouped, and only 2 traces are needed to turn them ON and OFF by DC biasing. Four-state beamforming is observed for such a phase shifter array of 16 elements. Parameters of reflected beams are studied for various R_s and C_p at 14 and 140 GHz.

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