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A scalable photomixing array for increased emitted power

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***Abstract*—The goal of this work is to increase the power emitted at E-band by a photomixing antenna array on PCB technology. The antenna architecture has been tailored to obtain a scalable design and a high radiation efficiency, while featuring a relative bandwidth larger than 10%. Our first prototype, with a 3-dB gain bandwidth of 12 GHz and one active photodiode, has been used in a wireless link. This preliminary demonstration has yielded a 2.15 Gb/s error-free data rate transmission for a 25 cm distance.**

I. INTRODUCTION

Millimeter and sub-millimeter wave photonic-based transceivers feature promising characteristics to meet the increasing demand for high data rates in wireless communications. Their main advantages are a large bandwidth, seamless integration with deployed optical fiber networks, and re-use of well-established photonic technologies [1], [2]. These features have played a key role in the growth of photonic-enabled technologies in the sub-Terahertz range. In addition, the integration of photodiodes with antenna arrays can offer attractive characteristics at the system level, such as photonic-enabled 2D beam steering for applications where auto-alignment and/or tracking are required. However, the main drawback of photonic generation at these wavelengths is the relatively low level of emitted power, typically ranging from a few hundreds of micro-watts to a few milliwatts. In this paper, we propose a proof of concept solution to increase the radiated power by employing two Uni-Travelling-Carrier Photodiodes (UTC-PD) integrated with an antenna array at E-band.

II. ANTENNA DESIGN

Fig. 1 shows the geometry of the proposed antenna, with center design frequency equal to 82 GHz. It consists of a 4-columns array, where each of the two UTC-PD feeds two columns. The array elements have been manufactured using PCB technology on a grounded Duroid 5880 substrate (thickness 127 µm, $\varepsilon_r = 2.2$, $\tan\delta=0.003$), suitable for high frequency applications. This planar design is scalable and advantageous in terms of integration with respect to classical sub-millimeter wave antennas, such as substrate lenses [3] and feed horns [4].

A. Array Column

Each column consists of a series fed stub array. In this particular case, a microstrip line is periodically loaded with groups of $\lambda/4$ stubs that progressively radiate the input power. Each group includes 4 stubs: two towards the right and two towards the left. This configuration allows one to reduce the antenna size and to increase the radiation efficiency, while maintaining good radiation pattern performance. The 4 stubs are also equispaced to minimize the reflected power. The width of the stub controls the amount of power radiated, whereas the periodic spacing of the groups controls the pointing direction of the radiated beam. Although a similar configuration can be found in [5], here, it has been modified to obtain a compact design and to yield low S_{11} values at the frequency of broadside emission. We have selected broadside-directed emission at the central frequency to minimize the beam squint with frequency, which is a desirable characteristic to test the system in a wireless communication link. However, off-broadside designs can be accomplished by changing the periodicity of the 4-stubs groups for applications such as imaging or radar, where scanning a wide area is usually an attractive feature.

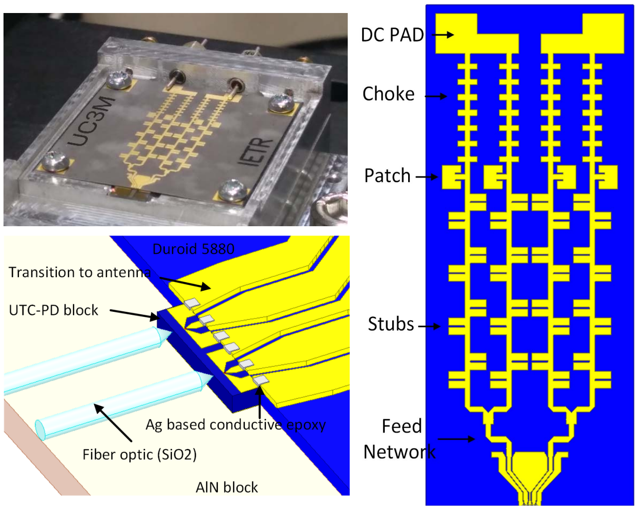

Fig. 1. Top left: Fabricated antenna prototype with housing and photodiode chip assembled. Bottom left: Detail of the feed structure of the antenna. Right: Front-view of the designed antenna layout.

Finally, the loaded microstrip line is terminated with a patch that truncates the stub array and radiates the remaining power. In addition, after the patch, an RF choke is placed to isolate the antenna from the pads used to bias and monitor the current of the photodiodes. The choke features an RF isolation better than 40 dB for the whole operating frequency range of the array.

The above-described column is then used to obtain the final planar array comprised of 4 columns. First, the column is duplicated to get a 2×1 array. Second, this 2×1 array is mirrored. Each 2×1 array is then excited by a photodiode in phase opposition, which leads to a significant reduction of the cross-polarization levels. The final structure consists of an approximately square array that produces nearly symmetrical patterns with a directivity between 18.5-20.0 dB, side-lobe level < -9 dB and a FWHM $< 13^{\circ}$ in the 77−86 GHz frequency range (see top of Fig. 2).

B. Photodiode Excitation and Feed network

The available chip contains two UTC photodiodes with a 500-µm pitch integrated with a 50-Ohm grounded coplanar waveguide (G-CPW) on InP. The photodiodes are mounted on an AlN block for mechanical support, handling and heat dissipation. Each photodiode is optically fed by a lensed fiber as shown in the bottom left-hand side of Fig. 1. The measured UTC-PD responsitivity is 0.17 mA/mW when illuminated with a 4 µm spot-size diameter fiber. The 3dB electrical bandwidth of the photodiodes is 110 GHz [6].

On the other hand, the antenna feed network comprises a tapered transition (see the bottom left in Fig. 1) to adapt the different widths of the 50 Ohm G-CPW lines on the InP and the Duroid 5880 substrates. After this transition it follows a section in which the two G-CPW separate to conform to the columns separation, a transition to microstrip line, and a symmetric corporate feed network. The transition and the feed network have been optimized to minimize the reflection coefficient, cross-talk between photodiodes and the radiation losses that could degrade the patterns. The S-parameters simulation results are shown in Fig. 2.

III. ANTENNA ASSEMBLY

The first assembly step is the pick and place of the UTC-PDs chip on an AlN block. Next, the AlN block and the PCB that includes the antenna are glued to the housing (metal block in the top left of Fig. 1). The AlN block is placed parallel to the PCB in such a way that the G-CPW of the chip is aligned with and at the same height as the PCB. Finally, the UTC-PD is bonded to the PCB using a silver-based conductive epoxy. This approach results in a thicker wire compared to wire bonding, thus reducing the resistive losses and the inductance of the wire, which leads to a better electrical connection. Moreover, as pointed out in [7], the use of epoxy allows one to have the photodiodes and the antenna structure on different substrates. This is an interesting feature, since it allows one to envisage the integration of mm-wave amplifiers after the UTC-PD to increase the emitted power.

IV. PRELIMINARY MEASUREMENTS

Power measurements of the fabricated prototype (see the top left of Fig. 1) with a single UTC-PD illuminated have shown a 12 GHz (from 73 to 85 GHz) 3-dB bandwidth of emitted power. The maximum output power was 120 µW for 45 mW input optical power and a -2.5 V bias voltage (9.8 mA photocurrent). Finally, a preliminary test of our prototype in a wireless communication link has yielded a 2.15 Gb/s error-free data rate at 25 cm distance, (7.0 mA photocurrent) using On-Off Keying modulation format and direct detection with a Schottky Barrier Diode (SBD). Fig. 3 shows the obtained eye-diagram.

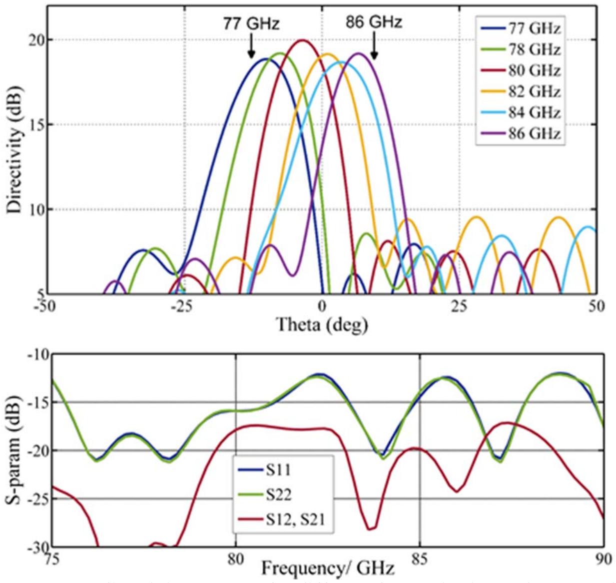

Fig. 2. Top: directivity patterns for different frequenies in H-plane (parallel to the columns). Bottom: magnitude of the reflection coefficients (S_{11}, S_{22}) and cross-talk (S_{12}, S_{21}) for the simulated structure, inlcudying the PCB, photodiode chip, AlN block and lensed fibers.

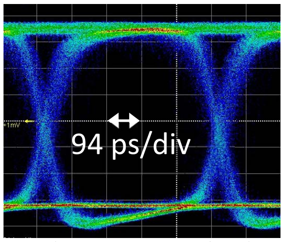

Fig. 3. Eye diagram at the SBD output for the 2.15 Gbps error-free transmission experiment.

V. SUMMARY

This abstract presents an antenna concept for a photonic transmitter on PCB technology compatible with arrays of photomixers. Although measurements are ongoing, initial tests in a wireless communications link have proven the validity of the prototype. We expect to increase the data rate of the link and the emitted power when both photodiodes are active.

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