Technologies for D band links with beam steering functionality

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Abstract— **This paper presents a study of the D-band radio solutions, with beam-steering functionality, intended for use in the reconfigurable meshed networks. The regulation and radio network constraints defining the specifications of a D-band transceiver are reviewed. The architecture of the radio link is proposed and key enabling technologies needed to build the D-band transceiver with beam-steering functionality are presented.**

Keywords—*5G, mm-wave, D-band, radio link, beam steering*

I. INTRODUCTION

DATA rates in wireless communications have been increasing exponentially over the recent decades. For the upcoming decade, this trend seems to be unbroken. The requirement of hundred Gbit/s demands the use of large bandwidths, which are available only in the high millimeter-wave and sub-terahertz regions [1], [2]. The D-band, ranging from 130 to 170 GHz, offers a vast bandwidth and is being considered as a candidate for a new approach to high capacity backhaul networks for 5G and beyond [3]. Beam steering capability in the link provides multiple advantages. It simplifies installation and setup, provides flexibility and reconfigurability of the network that fiber cannot provide. If each node can be reached from any other node by at least two different paths, the capacity and/or availability requirements of each single radio connection can be relaxed [4]. Moreover, the reconfigurability of the network can be exploited to bypass failing links due to changes in urban environment (i.e.: trees growth or new building) or occasional obstructions (i.e.: transiting trunks or temporary installations), thus substantially increasing the network reliability. Due to the short wavelength in D-band the beam steering functionality can be built with a very compact size and form factor. For example, an antenna array with 1024 elements in D-band can fit within an area of only 35x35 mm^2 offering a solution with low visual impact desidered in urban environment.

In this paper, we present the key technologies allowing the realization of a D-band link with beam steering capability based on a phased antenna array.

II. D-BAND RADIO CONSTRAINTS

A. Regulation

According to the ECC Recommendation [3], four portions of the D-band spectrum will be available for fixed wireless communications: 130-134 GHz, 141-148.5 GHz, 151.5-164 GHz and 167-174.8 GHz. Other portions of the band are reserved for different services. Bands allocated for communications are subdivided into 250 MHz channels that can be freely aggregated up to 2 GHz, with 125 MHz guard bands for each portion of the available band.

B. Propagation conditions

For operation of the link, the equipment Gross System Gain (GSG) should at least match the maximum attenuation of a radio signal over the link under given conditions including attenuation due to gasses, fog and rain. Analysis on that is presented in [4] and [11]. It is demonstrated that, using components designed with 55 nm SiGe BiCMOS, a system using QPSK modulation in 2 GHz channel and an antenna array with 256 antenna elements can approach a GSG of 140dB, allowing a hop length of 300 meters with the required availability for up to 60 mm/h rain rate.

III. ARCHITECTURE SELECTION

A D-band phased array transceiver with the architecture shown in Fig. 1 is proposed in this work. The system employs separate transitting and receving antennas avoiding the use of a diplexer filter and enabling flexible duplexer operation. It consists of a direct-conversion transceiver, where phase shifting is performed directly at RF at each antenna element. This architecture simplifies the implementation of the RF front-end and of the beam steering algorithms. In order to minimize the effect of the phase shifter loss on the system output power and noise figure, the phase shifters in the transmitter and receiver

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This work has received funding from the European Union's H2020 research and innovation programme under grant agreement No 761390, acronym: DREAM.

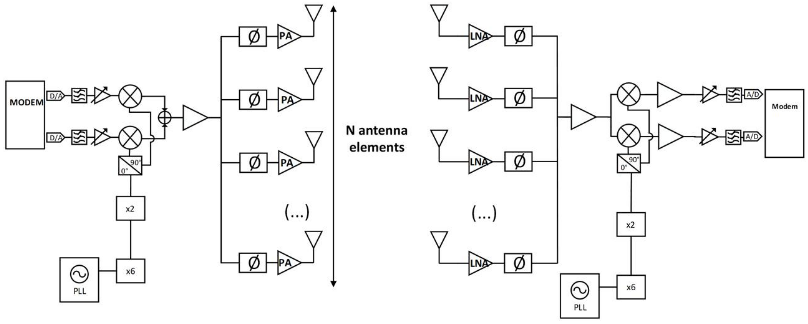

Fig. 1. Block diagram of the proposed architecture for the D-band phased array transceiver.

chains are placed before the PA and after the LNA, respectively. The transceiver feeds a matrix of NxN antenna elements, each connected to one PA/LNA. It is demonstrated that such a transceiver architecture, using 2-GHz channels and modulation orders up to 256-QAM in combination with MIMO 4x4, enables to achieve the desired 100 Gbit/s capacity [4].

The planned implementation of the D-band antenna array is shown in Fig. 2. The antenna elements are arranged into a half-wavelength (1.0 mm) grid and the four-channel MMIC core chips feed 4 antenna elements each. The core chips must fit into the array spacing, which sets a practical size limit of 1.5 × 1.5 mm^2 for the MMIC die. All RF, DC and control interconnects must fit into the spacing between the chips.

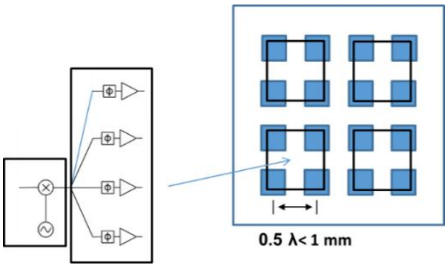

Fig. 2. Planned D-band phased antenna array (filled squares) geometry with 4-channel MMIC core chips (squares).

IV. TECHNOLOGY SELECTION

A. Antenna element

Suitable antenna-in-package technologies for D-band applications are, for example, low temperature co-fired ceramics (LTCC) [5]–[6], integrated passive devices (IPD) [7], and thin-film processing on alumina substrate [8]. In this work, we develop D-band patch antenna designs on cost-effective and low-loss multilayer build up which can be manufactured using standard printed circuit board (PCB) processing techniques. Astra® MT77 by Isola Group [9]–[10] was chosen as the substrate material because of its good dielectric properties, dielectric thickness availability and ease of processing. Laminate and pre-preg materials are available down to 0.063 mm thicknesses. The simulation model and photographs of the antenna are shown in Fig 3. The measured radiation patterns are presented in Fig. 4.

B. MMIC technology

Several technologies have been used to perform D-band functions, in particular the III-V technologies where the maximum oscillation frequency of devices can exceed 600 GHz [12]. However, this technology is not well suted for integration of complex functions. But the level of integration is the key factor for the phased array in D-band due to a limited space between the antenna elements. A 55-nm BiCMOS technology from STMicroelectronic has been selected for this work. The technology provides high performance devices (with transition frequencies above 300 GHz) in combination with high integration capability [13]. As demonstration of the technology, experimental results for a D-band high-gain amplifier are presented here.The amplifier is based on three cascaded single-ended amplifiers matched to 50 Ohm (see Fig. 5).

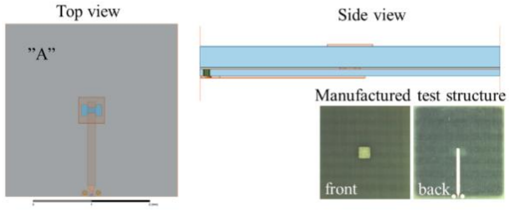

Fig. 3. Patch antenna for D-band phased array. Simulation model and photograph of the manufactured antenna.

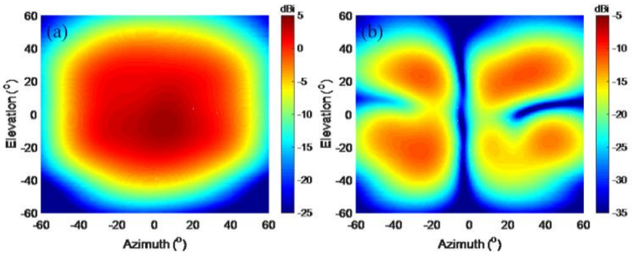

Fig. 4. Measured co- (a) and cross-polarised (b) radiation patterns (gain) at 150 GHz.

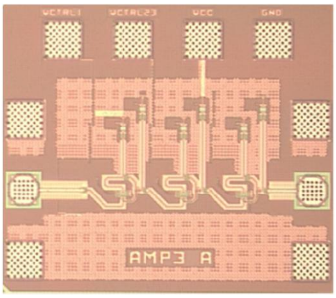

Fig. 5. Microphotograph of wideband, high-gain and compactness amplifier.

The amplifier achieves the maximum gain of 25 dB at 150 GHz and a Small-Signal gain (SS-Gain) > 18 dB over the full D-band (130 to 175 GHz) with an output power at 1 dB compression of

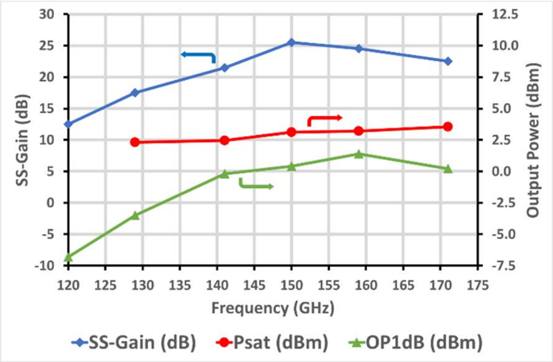

Fig. 6. SS-Gain and output power measurements of the amplifier versus input frequency. It consumes 50mA at the nominal voltage supply (2.5 Volt).

-3 dBm and 2 dBm respectively (see Fig. 6). It consumes 50 mA from a 2.5 V power supply. The size of the amplifier (without probing pads) is only 0.27 x 0.18 mm² or less than 0.05 mm².

C. *Integration technology*

State-of-the-art PCB technology described above was chosen as the integration platform in this work. The platform allows integration of the antenna array in a PCB substrate and flip chip bonding of the MMIC on the substrate. Required line widths and gaps down to 50 um are reached by using mSAP (semi-additive processing) on outer copper layers. HDI-anylayer (high density interconnect) construction technology is used to have minimum size (down to 80 um) laser vias between PCB metal layers. To evaluate the behavior of the platform in D-band, microstrip lines (MS) and grounded coplanar waveguides (GCPW) needed for the feed network of the antenna array are fabricated and tested. Results are shown in Fig. 7. The measured losses for the MS and GCPW are 2.6 dB/cm and 2.9 dB/cm at 150 GHz.

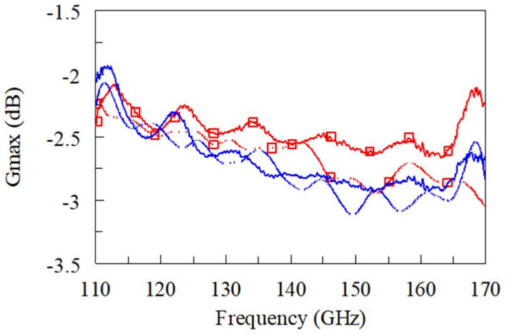

Fig. 7. Simulated (dashed line) and measured (solid line) attenuation for 10 mm long coplanar waveguide (without markers) and microstrip line (with "□"). Simulations are done using effective conductivity of 3×10^6 S/m for conductors.

A solder ball size of 60 um was chosen for the D-band application as they can be reliably bumped on the manufactured MMIC dies and provide enough clearance between the substrate-integrated antennas and MMICs. The solder bumped MMICs are assembled on the integration platform using standard reflow processing. A thin solder mask (<25 um) around the PCB contact pads prevents the solder from flowing along copper tracks.

V. CONCLUSIONS

The paper presents the studies of technologies needed to implement the base-line transceiver. D-band antennas and PCB substrate technology based on advanced substrate materials show promising performance for the integration with MMICs into scalable phased antenna arrays. MMIC design in D-band presents a big challenge due to the space constraints to fit in the antenna array and the limited transistor gain. However, realization of a very compact high-gain amplifier with good performances very closed to simulations demonstrates applicability of selected 55 nm SiGe BiCMOS process for the design of the D-band transmitter MMICs.

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