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Technologies for D band links with beam steering functionality

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Abstract—**The architecture of a D-band transceiver with beam-steering functionality is proposed and enabling technologies needed for implementation of the transceiver are studied. Viability of high frequency printed circuit board technology and 55 nm SiGe BiCMOS process for implementation of the D-band transceiver is demonstrated.**

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

I. Introduction

One of the main challenges in 5G and beyond 5G mobile networks is increasing mobile backhaul and front haul capacity for the explosive growth of data traffic. Hundred Gbit/s requested in future communication networks demands the use of large bandwidths, which are available only in the high millimeter-wave and sub-terahertz regions [1], [2]. Free spectrum in D-band (130 to 175 GHz) offering a vast bandwidth is considered as a strong candidate for 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. The reconfigurability of a network when each node can be reached by different paths can be exploited to prevent 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 [4]. Due to the short wavelength in D-band, the beam steering functionality can be built with a very compact size and a 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 desired in urban environment.

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

II. D-Band Radio Constraints

A. Regulation

Anly four fragments of the D-band spectrum will be available for fixed wireless communications according to the ECC Recommendations: 130-134 GHz, 141-148.5 GHz, 151.5-164 GHz and 167-174.8 GHz [3]. Other portions of the D-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], [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 up to 300 meters with the required availability for up to 60 mm/h rain rate.

III. Architecture Selection

A proposed D-band transceiver with beam steering functionality is shown in Fig. 1. The system employs separate transmitting and receiving antenna arrays 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 beam steering algorithms. To compensate the phase shifter losses on the system output power and noise figure, the phase shifters in the transmitter and receiver chains are placed

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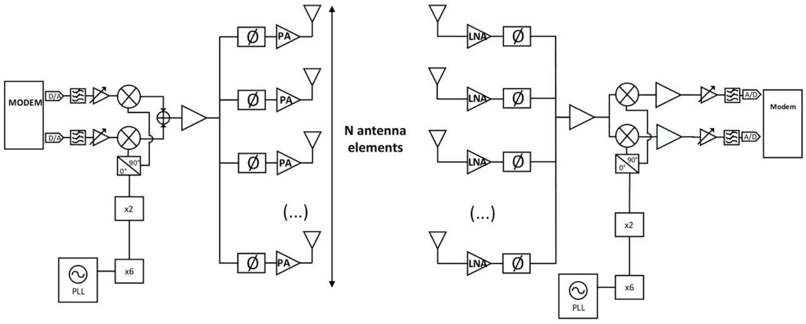

Fig. 1. Architecture of the D-band phased array transceiver.

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 enables to achieve the desired 100 Gbit/s capacity in the case of usage of 2-GHz channels, 256-QAM modulation in combination with 4x4 MIMO [4].

The D-band antenna array with integrated MMIC chips is shown in Fig. 2. The antenna elements are arranged into a half-wavelength (1.0 mm) grid. Each four-channel MMIC chip feeds four antenna elements. The channel of the chip includes a phase shifter and a power amplifier at the transmitter and LNA and a power amplifier at the receiver. The chips have size 1.5 × 1.5 mm^2 to fit into the array spacing. All RF, DC and control interconnects should fit into the spacing between the chips.

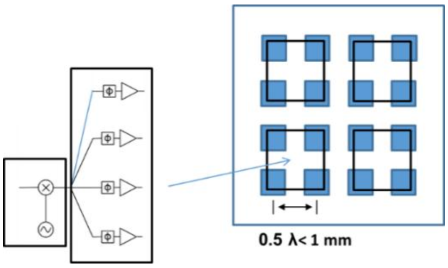

Fig. 2. 16 element D-band phased antenna array (filled squares) with four 4-channel MMIC chips (squares).

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 suited for integration of complex functions. Nevertheless, 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

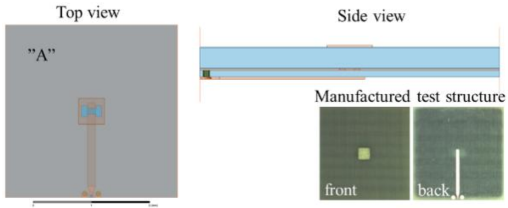

Fig. 3. Patch antenna for D-band phased array. Simulation model and photograph of the manufactured antenna.

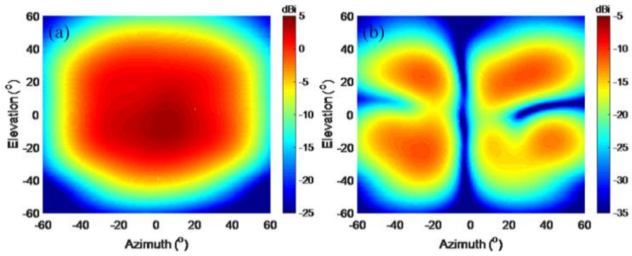

Fig. 4. Measured co- (a) and cross-polarized (b) radiation patterns (gain) at 150 GHz.

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 are presented for three cascaded D band amplifier shown in Figure 5.

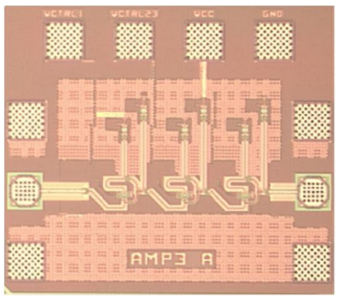

Fig. 5. Microphotograph of wideband, high-gain and compactness amplifier.

The amplifier is single-ended and matched to 50 Ohm. The maximum gain achieved is 25 dB at 150 GHz and a Small-Signal gain (SS-Gain) obtained is higher 18 dB over the full D-band (130 to 175 GHz). The output powers at 1 dB compression are -3 dBm and 2 dBm respectively (see Fig. 6).

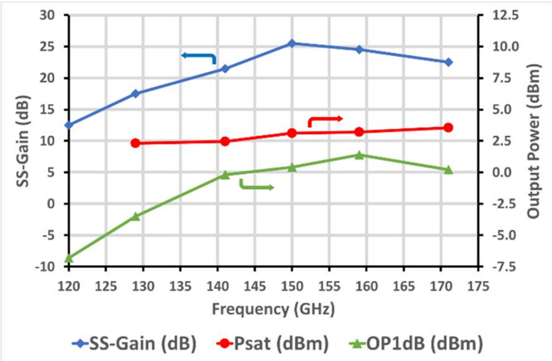

Fig. 6. Characteristics of the D band amplifier. The amplifier consumes 50mA at the nominal voltage supply (2.5 Volt).

The amplifier size (without probing pads) is 0.27 x 0.18 mm² or less than 0.05 mm².

C. Integration technology

High frequency PCB technology described above is used 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. The fabrication process allows fabrication of structures with parameters: line/gap width: 50/40 µm, minimum hole diameter for blind/thru via: 70/100 µm, and minimum pad diameter for blind/thru via: 190/250 µm. 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.

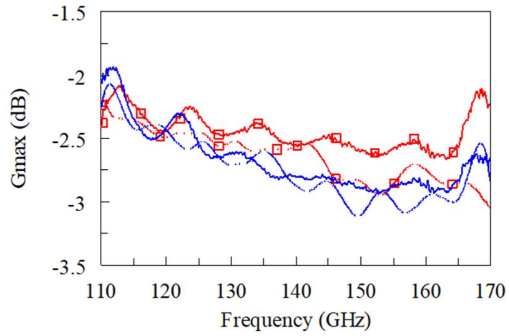

Fig. 7. Simulated (dashed line) and measured (solid line) attenuation for 10 mm long coplanar waveguide (without markers) and microstrip line (with "□"). Simulations are done using effective conductivity of 3×10^6 S/m for conductors.

A 60 um solder bumps are used in flip chip bonding process. They can be reliably bumped on the manufactured MMIC dies and provide enough clearance between the substrate-integrated antennas and MMICs. The MMICs are assembled on the PCB by using standard reflow processing.

V. Conclusions

Technologies for implementation of the D-band transceiver with beam steering are studied. The results show the viability of high frequency printed circuit board technology for D-band antennas and as an integration platform. The measurement results indicate losses of 2.6 dB/cm for microstrip line and 2.9 dB/cm for coplanar waveguide at 150 GHz. A maximum antenna gain of about 5 dBi is measured at 148 GHz. 55 nm SiGe BiCMOS process from STMicroelectronic is applicable for the design of the D-band transceiver MMICs

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