An Innovative Conformal Electronically Scanned Array Antenna for full 360° Steerability in the Ka-band

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***Abstract*— A novel approach to constructing an omnidirectional 5G/6G Ka-band Tx/Rx frontend module using an Active Electronically Steerable Array (AESA) will be presented. The 5G standard includes a number of mmWave frequency bands that provide the bandwidth for high data rates. However, up to now 5G still transmits primarily in the sub-6 GHz frequency range. Small cells like micro or pico cells operated in the mmWave range are capable to increase network capacity in densely populated areas. Efficient beam-based communications using directional antenna arrays can overcome the limitations imposed by propagation loss at high frequencies. These and a number of further requirements have been taken into account in the design of the antenna module presented here, making it a fundamental component for the cellular infra—structure of future 5G/6G mmWave networks. The dual-polarised module is using 2 x 96 elements to scan 360° in azimuth and ±45° in elevation. The operation frequency range is 24.25 GHz to 29.5 GHz, covering n258, n257, and n261 3GPP bands. Additionally, the module is capable to control up to four beams simultaneously.**

I. Introduction

5G mmWave communications technology is being implemented in many commercial mobile phones today. Communication in the mmWave frequency bands of the 5G and 6G standards promises to meet the need for increased mobile bandwidth, high reliability and low latency data transmission [1][2], which is increasingly demanded by autonomous driving, robotics and telemedicine applications, among others. On the downside, mmWave frequency bands suffer from high propagating losses. Small cells and beam-based communications with an AESA are the answer to this challenge. The proposed front-end module concept provides an excellent solution for a compact 5G base station unit to be used, for example, in street lamps or in an indoor environment such as an exhibition centre or airport. Rather than combining a number of planar arrays, the antenna array in this concept is wrapped around a cylinder to provide omnidirectional coverage. A subset of the radiating elements is used to form the active antenna aperture for one beam.

II. Frontend Module Concept

The omnidirectional RF front-end module covers the frequency band from 24.25 GHz to 29.5 GHz and supports both horizontal and vertical polarised RF signals. Up to four antenna beams can be controlled via a serial interface. 12 V and 10 A are required for power supply. The frontend module “5G CAN” is shown inFigure 1.

Figure 1: Omnidirectional mmWave 5G frontend module "5G CAN".

Today, many front-end modules are designed in tile architecture [3]. However, this design is based on a modified brick concept [4] where the PCBs are perpendicular to the antenna aperture. For the omnidirectional module, this architecture has several advantages, as explained below. The radiating elements are open-ended waveguides formed from two halves milled from aluminium and the via fence in the PCB sandwiched between the two metal plates. Each of the radiators is used for both polarisations, vertical and horizontal. The antenna aperture is the perimeter of a stack of five aluminium discs and four disc-shaped circuit boards. The organisation of the functional blocks on the different PCBs of the antenna module is shown in the block diagram in Figure 2.

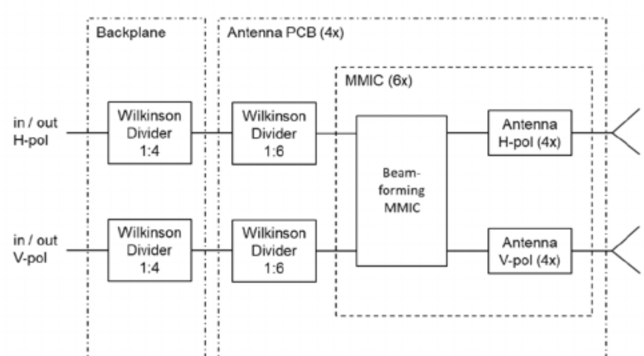

Figure 2: Schematic of the mmWave 5G/6G frontend module

The two bidirectional RF signals (input and output of horizontal and vertical polarisation) are distributed via the vertical backplane PCB to the four antenna PCBs to six beamforming MMICs. On the antenna PCB the signals for horizontal and vertical polarisation are routed separately on top and bottom layer to ensure good decoupling.

Each beamforming MMIC provides four horizontal and four vertical polarized output signals which can be controlled in amplitude and phase. The antenna element for the vertical polarisation is the end of a Substrate Integrated Waveguide (SIW) in the printed circuit board, while for the horizontal polarisation the open ended waveguide is used, fed by a stripline to waveguide transition in the same printed circuit board. Each RF board is sandwiched between two metal discs. The antenna array is designed in a sparse configuration for compactness. This means that only half of the grid positions are used in an alternating pattern. On the cylinder jacket, this is achieved by rotating the antenna board in the next layer by 7.5° (see Figure 3).

Figure 3: Antenna module for mmWave 5G/6G with the control board on top.

In addition to their function as partial waveguides and shielding between the antenna PCBs, the metal disks also serve as heat sinks for the MMICs. Passive cooling of these heat sinks is provided by air circulation flowing from the centre of the stack around the outside. The two RF input signals of the module are distributed to the different RF PCBs via a backplane PCB. The backplane PCB is placed in the polygon cut-out in the centre of the module. A 90° SIW transition routes the signal from the backplane PCB to the different RF PCBs.

The DC supply and SPI control board is shown on top of the antenna stack in Figure 3. DC voltages are converted from 12V to approximately 2V for the internal chip power supply. A microcontroller is used for SPI control. The power supply and SPI signals are routed to the antenna board below via connectors, as shown in Figure 4. A similar connection is used to connect the stacked antenna boards.

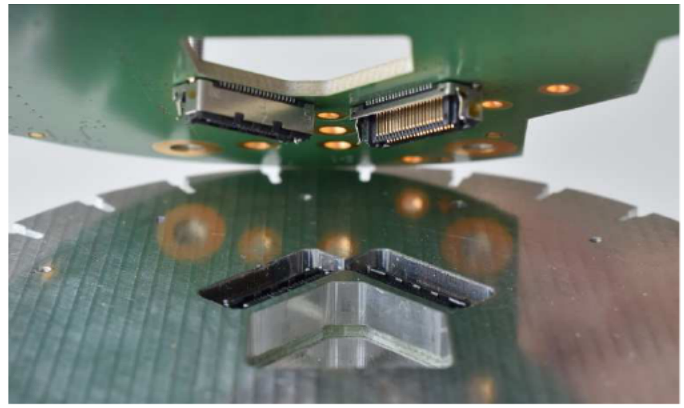

Figure 4: Connection of DC and SPI signals from the control board to the antenna board.

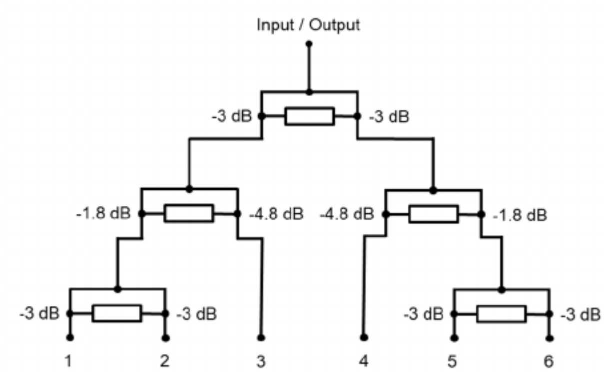

Figure 5: Circuit scheme of the 1:6 Wilkinson power divider / combiner.

In the block diagram of the antenna module (Figure 2) it can be seen that the signal for horizontal and vertical polarisation in transmit mode is distributed via a 1:4 Wilkinson divider [5] followed by a 1:6 Wilkinson divider network. In receive mode, the signal is summed in the opposite direction.

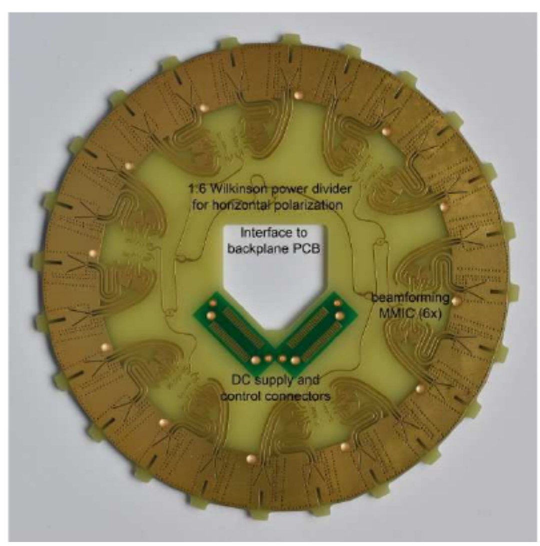

Figure 6: Component side of the antenna board with the footprint of six beamforming MMICs and the 1:6 power divider for horizontal polarisation.

Whereas the 1:4 divider on the backplane is a binary tree (two levels of 1:2 dividers), the 1:6 divider on the antenna board requires a more complex topology with unsymmetrical dividers in the second level, as shown in Figure 5. Note the extra loops in the microstrip line of the power divider. These are inserted to achieve equal transmission delay for all signal paths.

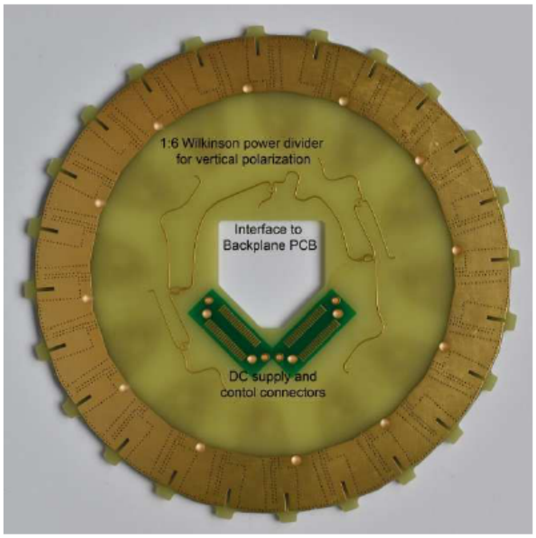

Figure 7: Bottom side of the antenna board with the 1:6 power divider for vertical polarisation.

Figure 6 and Figure 7 show both sides of the antenna board with the footprints of the six beamforming MMICs and the connectors for the DC and SPI signals. For better isolation, the Wilkinson power dividers for horizontal and vertical polarisation are on opposite sides of the board. The component side of the board (Figure 6) shows the microstrip to waveguide transitions for the horizontal polarisation of the 24 antenna elements in this layer.

The complete RF design of the module was performed using the 3D EM simulation software EMPIRE-XPU [6]. All the different building blocks (antenna, divider networks, RF transitions, backplane PCB, etc.) were designed independently in a first step. Step by step, more components were integrated and simulated (e.g. the beamforming MMIC with its eight corresponding antenna elements and the antenna feed network). Finally, the complete module, including all PCBs with components and antennas, was simulated together to ensure excellent RF performance. Thanks to efficient simulation techniques and software, the simulation of the entire module could be carried out in a few hours.

III. Module performance

The module achieves excellent performance over the entire frequency range from 24.25 GHz to 29.5 GHz. Omnidirectional coverage in azimuth is achieved with 96 antenna beams, 48 beams for vertical polarisation and 48 beams for horizontal polarisation.

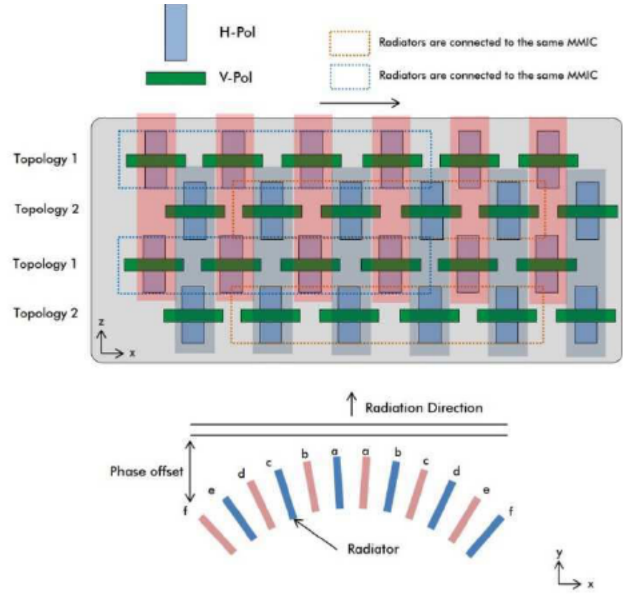

Figure 8: Antenna beam configuration.

Figure 8 depicts how each beam is realised by 4 x 6 antenna elements (using 4 antenna boards and 6 antenna elements per board). The resulting 3 dB beam width is approximately 8.5° in azimuth.

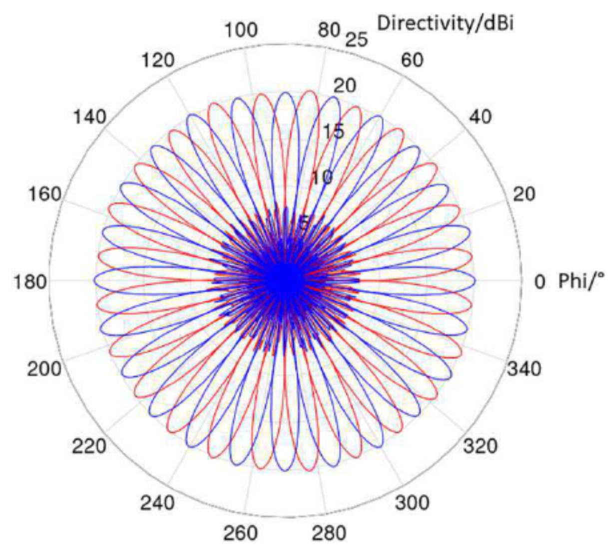

Figure 9: Azimuth scan performance for horizontal polarisation at 27 GHz

Figure 9 shows the simulated radiation pattern for the vertically polarised array (SIW) and Figure 10 for the horizontally polarised array (air waveguide) at 27 GHz. The achieved directivity is 20 dBi, resulting in an EIRP of 50 dBm at P1dB. The scan performance in elevation is ± 30° with a scan loss of less than 3 dB.

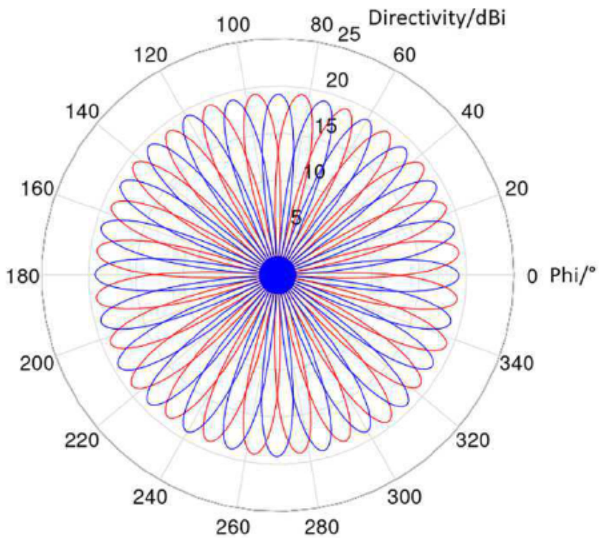

Figure 10: Azimuth scan performance for vertical polarisation at 27 GHz

The simulated 3D radiation pattern for one vertically scanned beam is illustrated in Figure 11. Up to four simultaneous beams are supported, each emanating from a quarter of the circular module. Figure 12 shows the simulated 3D radiation pattern for two simultaneous beams in vertical polarisation (SIW) at 26 GHz.

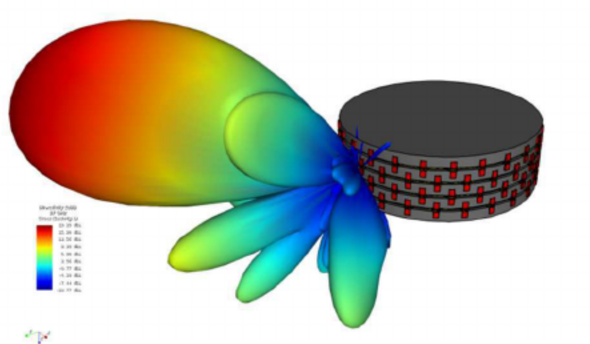

Figure 11: 3D radiation characteristic of one antenna beam scanned in vertical direction.

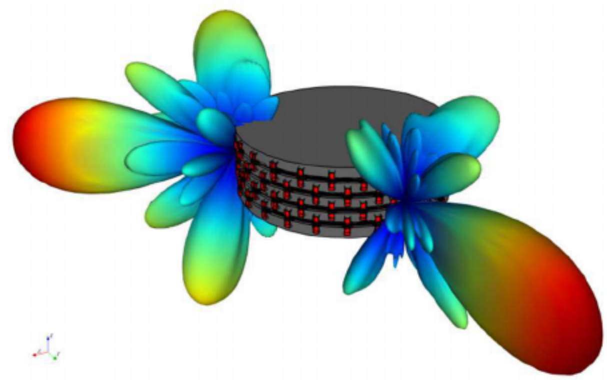

Figure 12: 3D radiation characteristic of two simultaneous antenna beams.

IV. Conclusion

The 5G CAN front-end module is a compact, flexible and scalable phased array front-end that can be used in many 5G/6G scenarios. The module described is intended to be used as a development platform for 5G/6G systems. It is available as an evaluation kit for 5G/6G research teams and other customers. The described module covers frequencies from 24.25 GHz to 29.5 GHz (e.g. n258, n257 and n261 3GPP band), together with omnidirectional coverage in azimuth and ± 30° scanning in elevation. The design can be easily scaled in size (diameter) to increase both EIRP and number of beams. Upscaling in frequency up to 39 GHz (5G mmWave band n260) is also possible.

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