Quality of 5G communication with Antenna beams

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***Abstract*— In this paper, an intuitive approach to assessing advantages of beamforming in 5G wireless communication is proposed as a novel try and practical demonstration of importance of alignment between the transmitter's and receiver's beams working in millimeter-wave frequency bands. The effects of the misalignment and alignment between beams need to be checked for, which was conducted with a horn antenna and the 4 × 4 Butler matrix RF-to-RF wireless connectivity between the horn and the microstrip line beamformer, concerning the changing angle of the beam from the Butler matrix, was tested, showing over 12 dB enhancement in received power. This direct electromagnetic link test was accompanied by examining 64-QAM constellations for beam-angle change.**

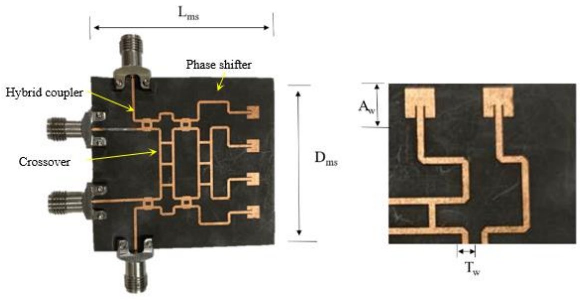
***Keywords*— millimeter-wave antenna; 5G antenna; beamforming antenna; Butler matrix; 64-QAM.**

I. Introduction

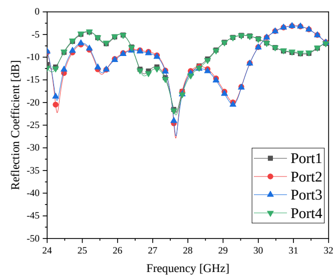
The 5th generation (5G) mobile communication is featured by technological fascination such as several Gbps data transfer-rate, low latency and low interference [1–3]. In order to realize the wireless connectivity for 5G, antennas operable in millimeter-wave frequency bands are needed. Making use of millimeter-wave antennas, the wide-bandwidth and narrow beamwidth would be accomplished by designing them to be arrays whose footprint is relatively small for even the commercial wireless phone. The beamwidth becomes narrow and pointy to have higher directionality in the far-field pattern. This is so-called beamforming. In this paper, a new way that 5G wireless system developers can obtain intuitions on the quality and effects of beamforming functions is suggested. This tried-and-true verification approach comprises the design of beamforming antennas and two experimental setups. Firstly, to give the capability of beamforming and beam-tilting to the wireless connectivity tests, the 4 × 4 Butler matrix was designed and manufactured. Secondly, a measurement setup was devised to check RF-to-RF sensing between the horn and the microstrip Butler matrix. By changing the angle of the beam from the Butler matrix, the transmission coefficient of the beam from the horn to the RX beamforming antenna was recorded for beam misalignment and alignment. Thirdly, a setup was formed to watch 64-QAM diagrams. According to the change in the angle of the beam, 64-QAM constellations were plotted. Notwithstanding, the beam alignment led to clear pictures of I/Q symbol spots. The tests revealed that beam alignment increases the received power by over 12 dB from the beam misalignment in the RF-to-RF connection .

II. Design of the Butler Matrix Antennas Beamforming AUT

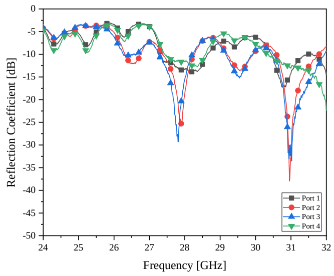
Figure 1a is the photograph of the prototype of the microstrip-line Butler matrix antenna looking similar to the one in [4]. This beamforming antenna has four input ports and four radiating elements at the output ports made on RT5880 as the substrate with thickness of 0.25 mm. The geometrical parameters noted in Figure 1a are mentioned in the followings as Table II.1.



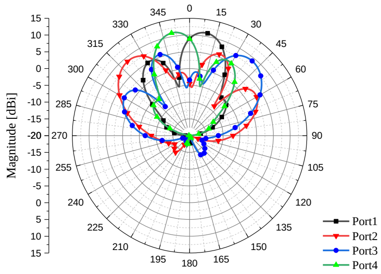
(a)



(b)



(c)



(d)

Figure 1 The microstrip-line Butler matrix (a) prototype; (b) port reflection coefficients (c) port reflection coefficients (d) beam-patterns

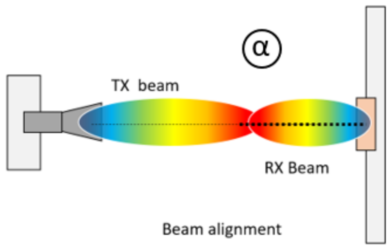
Table II.1 The physical dimensions of the microstrip-line Butler matrix.

Parameter	Value
L_{ms}	49 mm
D_{ms}	51.92 mm
A_w	3.48 mm
T_w	0.7 mm
Antenna gap	8.1 mm

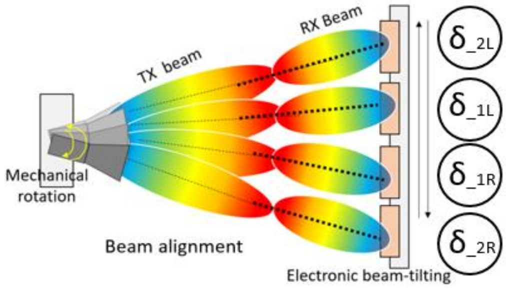
They present the impedance matching at 28 GHz as the 5G mobile frequency. The beamforming and beam-steering functions are observed in Figure 1 from EM simulation and measurement. Once fabricated, the surface of the thin substrate tends to be bent and a little deformed due to the weight of the connectors, which causes differences, i.e., unwanted back radiation and a shift in the angles of the beams from the EM simulated data. The beams range from −30° to 30°, which is adopted to the change in the beam direction for RF-to-RF link tests and I/Q digital wireless evaluation.

III. RF-TO-ROF TEST AND 64-QAM INVESTIGATION

As for a TX and an RX in 5G/6G mobile communication, there are four possible scenarios of beam pointing as in the following figure. Various situations of antenna positioning and beam pointing between the horn(TX) and the beamformer(RX) are represented by Figure 2. The strongest RF link is expected in Figure 2a as the in-line beam alignment (α). As the location of the RX changes, the beam tilted by the RX catches the beam by the rotated TX horn, which means beam alignment, and results in much improved connectivity as in Figure 2d, denoted as δ_2R, δ_1R, δ_1LR and δ_2L.



(a)

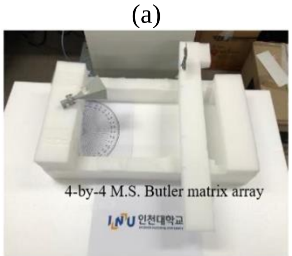


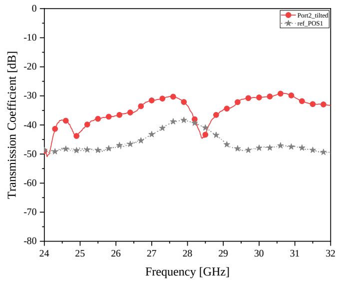
(b)

Figure 2. Directions of beams from the TX and RX antennas (a) in-line beam alignment; (b) beam alignment by cooperative TX and RX antennas.

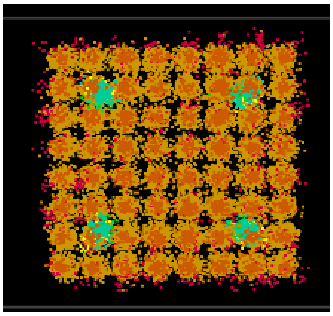
The microstrip-line Butler matrix antenna is substituted for the boresight antenna with a fixed beam. In addition, as case δ_2L, the −30° tilted beam is radiated to the TX horn antenna as in Figure 2, and S_{21} becomes −30 dB in Figure 7b where RF power transfer of the beamformers' beam in red is stronger than that of the non-tilting beam in gray. The increment in RF-to-RF connectivity is led to enhancement in wireless communication.

(a)





(b)

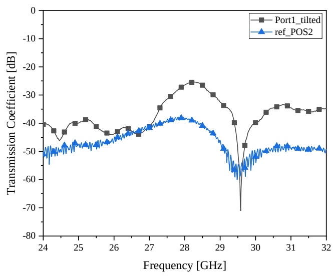


(c)

Figure 3. Beam alignment with higher tilting angle (a) in-line beam alignment (b) Transmissivity (c) 64-QAM

Figure 3 shows quite blurry constellations. It is inferred that the sidelobe of the RX antenna causes that. This will be mitigated by the reduced side lobe of next beam-angle.

(a)



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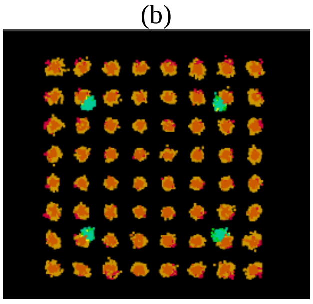

(c)

Figure 4. Beam alignment with lower tilting angle (a) in-line beam alignment (b) Transmissivity (c) 64-QAM

Transmissivity in Figure 4 is better than that in Figure 3, which leads to very clear constellations. The lower tilting-angle tends to have a lower side-lobe level which turns out to be a higher quality of communication.

IV. Conclusion

An intuitive method was suggested as a novel and practical attempt to interpret the characteristics of the beamforming antenna being forwarded to the performances of the system. Specifically, the beam-tilting and steering abilities of the TX and RX antennas are dealt with. For a horn antenna such as the TX, microstrip-line Butler matrix was built as the RX. The VNA as the RF-to-RF test setup and TRX7200 as the 64-QAM measurement apparatus were employed to measure the received power and constellations as the product of TX-to-RX electromagnetic connectivity via the beamforming antennas.

Acknowledgment *(Heading 5)*

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