A D-band 1-channel Beamforming Transmitter Integrated Circuits for 6G mobile communication

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***Abstract*— This paper presents the measurement results of a D-band 1-channel beamforming transmitter integrated circuit, a fundamental component for multi-channel beamforming arrays in 6G mobile communication systems. The transmitter IC was designed using a 40nm CMOS process. The fabricated RFIC demonstrates a gain of 5.8 dB, a 3-dB bandwidth spanning 12 GHz, and includes 6-bit gain control and 9-bit phase control capabilities for up to 12 dB and 360-degree phase variation. The power consumption is measured as 125 mW, and it demonstrates a saturation power of 0 dBm.**

Keywords—6G, Sub-THz, CMOS, beamforming IC

I. INTRODUCTION

The next-generation 6G mobile communication will enable applications like autonomous driving, VR, holograms, remote surgery, and more that need very high data rates. To achieve this, wireless transceiver frequencies in the sub-THz range are being explored[1]. However, sub-THz frequency signals are significantly attenuated by the atmosphere. Also, it is hard to amplify and produce enough power for these signals because of the transistor limitations and the parasitic effects[2].

To overcome these problems, beamforming arrays with multiple antennas are implemented in the wireless system. By increasing the count of transmitter channels and antenna elements to N, a potential enhancement of the Effective Isotropic Radiated Power (EIRP) by a factor of 20logN can be achieved, contributing to the mitigation of challenges present within this frequency range. Due to its high integration capability, the CMOS process is advantageous for constructing the fundamental units of complex multi-channel beamforming systems.

The structure of a 4-channel TX integrated circuit is presented in Fig. 1, comprising an up-mixer, a power divider, a common amplifier, a variable gain phase shifter, and a power amplifier. In the sub-THz frequency range, achieving significant gain is hindered by the low transconductance of transistors. Moreover, when considering the combined effect of the insertion loss of the Wilkinson divider and its 6 dB dividing factor, and the insertion loss caused by the I/Q generator , driving the power amplifier with sufficient input power becomes challenging. As a result, the inclusion of a common amplifier within the shared section is necessary.

The 1-channel beamforming transmitter, composed of gain and phase control blocks along with a power amplifier is the fundamental unit for developing multi-channel chips such as 4-channel, 8-channel, and 16-channel TX with gain and phase control capabilities.

II. 1 CH TX INTEGRATED CIRCUIT

The beamforming IC is designed to control gain and phase in each channel for beam shaping and channel mismatch calibration. Unlike traditional designs using separate gain and phase control blocks, the fabricated 1-channel transmitter chip employs a variable gain phase shifter, unifying both controls within in a single block [3-4]. Single-ended input signals are fed into the differential I/Q generator, producing quadrature signals I+, I-, Q+, and Q-. Current-steering DACs regulate the tail current of the vector summation circuit through the gain and phase control bits. The gain-controlled sub-amplifiers determine both the gain and phase of the modulated differential output signal. A balun converts the phase shifter's differential output to single-ended, followed by amplification using a Gmax core-based power amplifier, resulting in the final output signal [5-6].

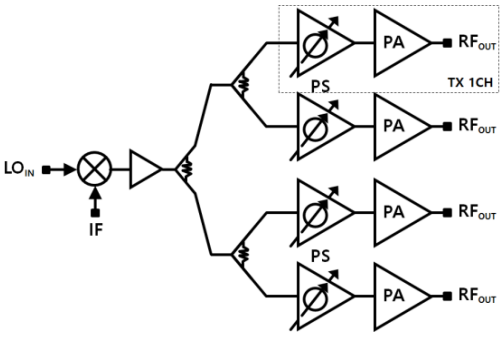


Fig. 1. Block diagram of 4 channel TX IC and 1-channel part

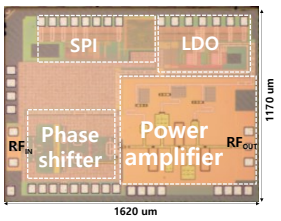


Fig. 2. Chip micrograph of 1-channel integrated circuit

Fig. 3. Measurement PCB module

III. MEASUREMENT SETUP

To facilitate measurement, the chip is mounted on an FR4-based DC bias board using epoxy. Bias and power supply lines are interconnected via bonding wire. To mitigate the impact

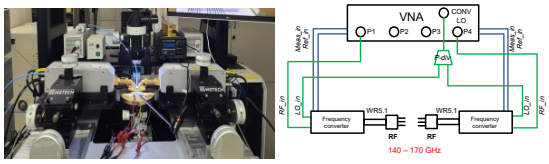
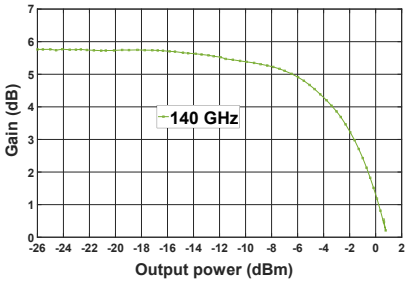
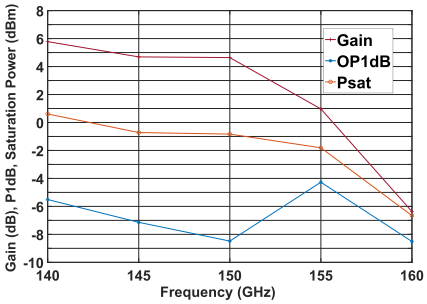


Fig. 4. Measurement setup with ZNA and frequency converters



(a)



(b)

of PCB line included inductance on circuit performance, SMD capacitors are placed between bias lines and ground as shown in Fig. 3. Additionally, the Raspberry Pi generates four signals — SCK, MOSI and SS— and reads the MISO signal from the chip. To facilitate bit control and communication with the chip, four pads on the fabricated chip are connected to Raspberry Pi. This enables the control of 7 bits for gain control and 9 bits for phase control.

Fig. 4. Shows the picture and diagram below depicts the measurement setup for the D-band transmitter integrated circuit. Measurements were carried out on wafer probing for the 140~160 GHz frequency band employing a ZNA and frequency converter. A 1-tone CW RF signal from port 1 of the ZNA enters the frequency converter as an LO signal and is up-converted to generate a D-band signal, which then enters the input of the DUT phase shifter. The signal output from the chip is analyzed to obtain the final measurement result. PM5 was used as a Power meter for ZNA's power calibration

IV. Meausrement Results

The 1-channel transmitter IC, manufactured using a 40nm CMOS process, occupies a 1620 x 1170 μm^2 area. At 1.1V supply voltage, it consumes 30mA for phase shifter and 83.4mA for power amplifier. Fig. 5 (a) shows the gain versus output power for a 140 GHz 1-tone CW signal, showing 5.8 dB gain and 0.7 dBm saturation power, and -5.9 dBm as P1dB. It has 12.2 GHz 3dB gain bandwidth as shown in Fig. 5 (b).

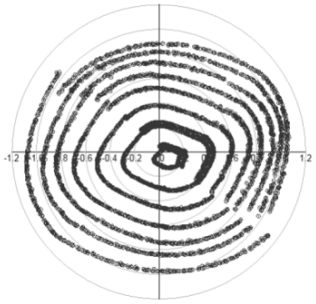


Fig. 6. Static vector constellation for 4352 state in total 65535 state at 142GHz

Fig. 6 shows the measurement results while varying gain and phase. The chip offers 7-bit gain control, 9-bit phase control, and a total of 16bits representing 65 535 state. The results, captured for 4352 chosen point at 142 GHz. The distortion in the gain-equivalent circle results from an impedance imbalance between the plus and minus nodes, which arises due to the balun at the output of the variable gain phase shifter. This distortion could potentially be improved by incorporating a differential buffer amplifier at the output of the phase shifter.

V. Conclusion

This paper discussed the composition and measurement of a D-band 1-channel beamforming transmitter integrated circuit using a CMOS process. Integration of a variable gain phase shifter enabling combined gain and phase control could make it smaller size and low power consumption.

The achieved power characteristics for the 140 to 160 GHz range will guide future research toward constructing multi-channel beamforming arrays for 6G mobile communication system.

Acknowledgment

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