16-52 GHz 5G Transmit and Receive 64-Element Phased-Arrays With 50-51.7 dBm Peak EIRP and Multi-Gb/s 64-QAM Operation

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***Abstract* — This paper presents multi-band Tx and Rx phased arrays designed to support the 5G New Radio FR2. The 64-element arrays are built using 16×1 linear arrays each having four 4×1 beamformer chips on a low-cost printed-circuit board (PCB). The arrays demonstrate +/- 60^o scanning capability in the azimuth-plane with sidelobe levels <-10 dB. The 64-element Tx array achieves an EIRP of 50-51.7 dBm at P_{sat} operation and 47.6-49 dBm at P_{1dB} operation at 24.5-48 GHz. 64-QAM single-carrier (SC) 400 MHz waveforms are transmitted achieving <3% EVM_{rms} with 39-40 dBm average EIRP and with 2.4 Gb/s data rate. The Rx phased-array demonstrates a system NF of 5.3-6.9 dB at 16-50 GHz. To the author's knowledge, this work achieves the highest bandwidth phased-array systems suitable for multi-band 5G operation.**

***Keywords* — wideband, beamforming, data link, error vector magnitude (EVM), fifth-generation (5G), flip-chip, multi-band, EIRP, mm-wave, multiple-input multiple-output (MIMO), phased-array, printed circuit board (PCB) antenna, quadrature amplitude modulation (QAM), transmitter, SiGe.**

I. Introduction

The inevitable growth of mobile users and the proliferation of data-intensive applications are creating unprecedented challenges. And to answer this growth, the development of mm-wave communication systems is accelerating and is driven by the high data rate demands. 5G networks are being deployed worldwide and several bands have been allocated in the 5G new radio frequency range 2 (NR FR2) which spans 24.25-52.5 GHz (Fig. 1). Therefore, mm-wave ultra-wideband communication systems are essential to address the challenges of widespread spectrum coverage with a low-cost multi-band solution [1]–[4].

This paper presents 16-52 GHz scalable transmit (Tx) and receive (Rx) multi-band phased-arrays based on 4×1 beamformers chips. A wideband tapered slot Vivaldi antenna design and a 64-element phased array system implementation are presented. Far-field pattern with +/- 60^o scanning range is demonstrated, with 15-50 GHz effective isotropic radiated power (EIRP) and 400 MHz 64-QAM EVM measurements.

5G NR Frequency Range 2 Bands

NR Band	UL and DL FR (GHz)
n257	26.5– 29.5
n258	24.25 – 27.5
n259	39.5 – 43.5
n260	37 – 40
n261	27.5 – 28.35

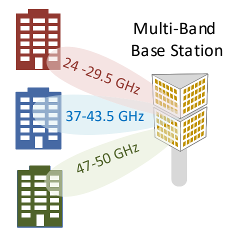

Fig. 1. Multi-band base-station and 5G NR FR2 operating bands [8].

II. Multi-Band 64-Element Phased-Arrays

A. Wideband Beamformer Chips

Wideband Tx and Rx 4×1 beamformer chips are used to build the 64-element phased-arrays. An RF beamforming architecture is employed to minimize the system complexity and power consumption. These chips have been presented before in [5] and [6].

The beamformer chips are fabricated in the Tower-Semi 5^{th} generation SiGe BiCMOS process with an f_t/f_{max} of 272/305 GHz referenced to the top metal [7]. The Rx beamformer has 23 dB peak electronic gain with a 15-57 GHz 3-dB bandwidth, a midband NF of 4.9-6.2 dB and an IP1dB of -26 to -28 dBm. The Tx beamformer IC has a peak gain of 28 dB including the 6 dB division loss and a 15-52 GHz 3-dB bandwidth. The output P_{1dB} per channel is 12–14.8 dBm at 16-52 GHz with a power consumption od 250 mW.

The chips are controlled using a serial peripheral interface (SPI) for gain, phase, and bias current settings. The Rx beamformer chip operates from a 2 V supply and the Tx beamformer chip from a 3 V for the power amplifiers and 2 V for the rest of the chip.

B. System Design and Integration

The phased-arrays employ the brick-array configuration based on linear arrays oriented perpendicular to the array face (Fig. 2). This architecture is compatible with wideband endfire antennas such as tapered-slot antennas but requires a number of independent RF boards.

The front and back views of the 64-element (16×4) phased-arrays are shown in Fig. 3. Each linear array employs 4 SiGe beamfomer chips with a wideband Wilkinson network [Fig. 3(a)]. The 4:1 Wilkinson network is laid out in a perfectly symmetrical design with the same length from the coaxial port to each of the 4 different chips. The 16×1 linear-array is surrounded with two dummy elements at both sides to improve the antenna performance at large scan angles. The array size is 50.8 mm×10 mm with a power consumption of 13.26 W in the Rx array and 17.6 W in the Tx array (at P_{1dB}).

C. Tapered-Slot Vivaldi Antenna Design

The Vivaldi antenna is designed on a low-cost Megtron-6 multi-layer PCB with a differential feed. The antenna grid is 2.54 mm×2.5 mm and selected to mitigate transverse-electric (TE1) parallel plate mode and operate up to 60 GHz.

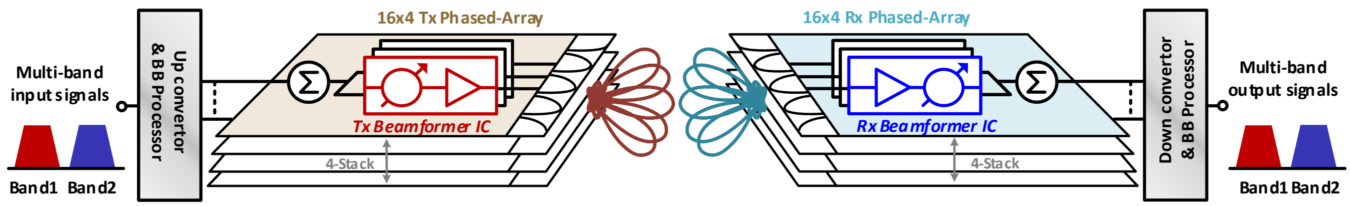

Fig. 2. Multi-band 16×4 Tx and Rx phased arrays based on the brick array configuration.

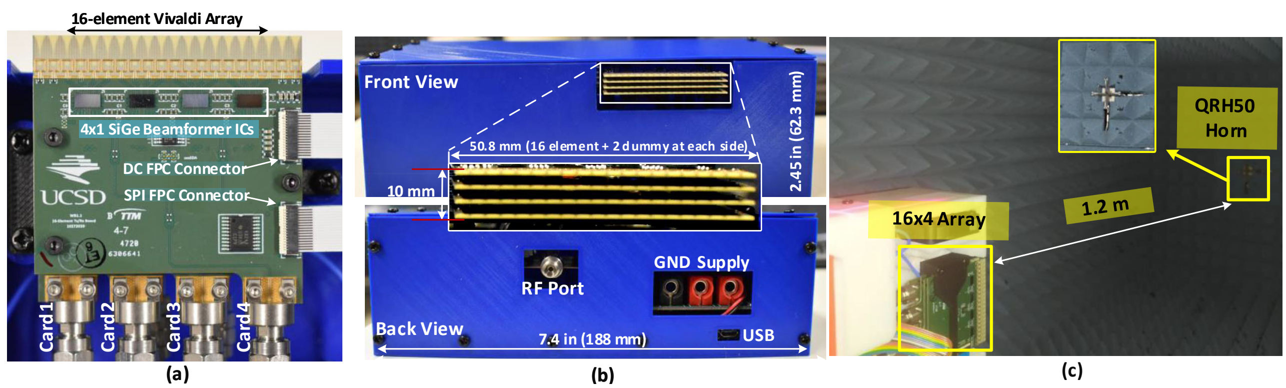

Fig. 3. (a) 16×1 linear phased-array with 4 SiGe beamformer chips. (b) Front and back view of the 16-52 GHz 64-element phased-array. (c) Photograph of the measurement setup.

The simulated performance is shown in Fig. 4. The antenna has a very wide bandwidth of 15-60 GHz and can scan up to +/- 60^o with $|S_{11}|$ < -10 dB. The unit cell has a gain of -3.7 to 4.4 dB at 15-58 GHz including the differential feed ohmic loss.

III. Measurements

The 64-element phased arrays are tested inside an ETS-5700 anechoic chamber at a range of 1.2 m [Fig. 3(c)]. The phased arrays are calibrated by turning each channel individually and then measuring the far-field S_{21} in the nominal gain and phase state for each channel. After completing the characterization of the 64 channels, one channel is set as a reference and the gain and phase offsets are calibrated using the phase shifter and VGA control for each channel.

Fig. 5 presents the measured azimuth plane (E-plane) patterns at 20 and 40 GHz with uniform illumination for the 64-element Rx array. The array has 3-dB beamwidths at boresight of 18.5^o and 9^o at 20 and 40 GHz, respectively. The measured cross-pol. level is <-20 dB at 20-40 GHz at broadside and demonstrate good agreement with the simulated patterns. Fig. 6 presents the measured patterns as it scans in the azimuth plane at 50 GHz. The phased-array scans to +/-60^o with 3.9 dB loss and without grating lobes following a $\cos(\theta)^{1.3}$ rolloff. The Tx array has similar patterns and not shown for brevity.

The 64-element Rx array is tested using the Keysight N5245B PNA-X with noise figure option (S93029B) and the array G/T is measured as described in [9]. The array demonstrates a system NF of 5.3-6.9 dB and with a mean NF of 6.2 dB at 16-50 GHz.

EIRP measurements are conducted for the 64-element Tx phased-array using the Keysight E8257D signal generator and the Keysight 1913A power meter. With a uniform illumination, an EIRP of 45-49 dBm is measured at P_{1dB} operation and agrees with the simulated EIRP at 20-50 GHz. A peak EIRP of 46-51.7 dBm is measured at P_{sat} operation at 20-50 GHz.

The EVM performance of the 64-element Tx array is evaluated with 400 MSym/s single-carrier 64-QAM waveform filtered with a root-raised cosine pulse shaping filter with a roll-off factor α= 0.35 and has a PAPR of 7.7 dB. This measurement is conducted at 29 and at 38 GHz at broadside and with uniform illumination. The measured spectrum, constellation, and EVM values are presented in Fig. 8. An EVM value <3% with an average EIRP of 39-40 dBm is achieved at 28 and at 39 GHz.

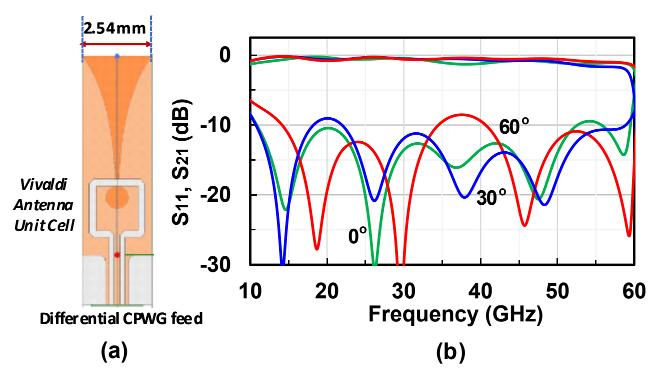

Fig. 4. (a) Vivaldi antenna unit-cell and (b) simulated E-plane transmission and reflected coefficients over different scan angles.

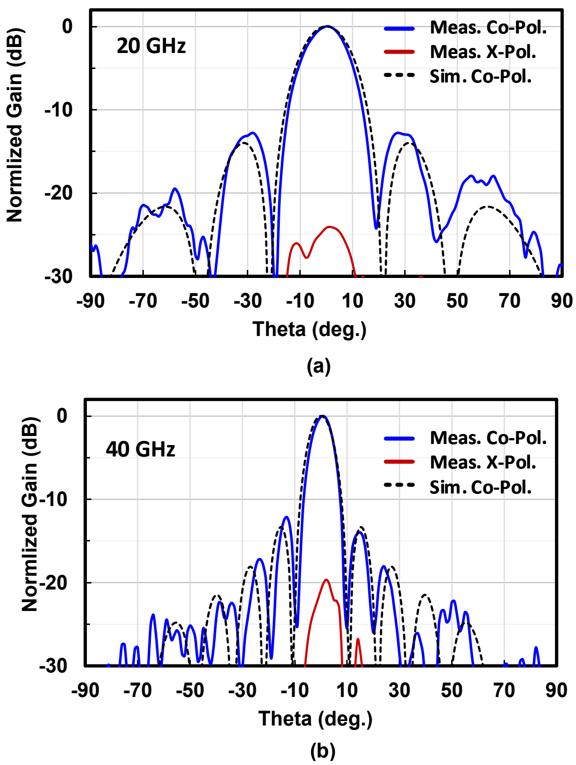

Fig. 5. Measured co-and x-pol pattern at (a) 20 GHz and (b) 40 GHz.

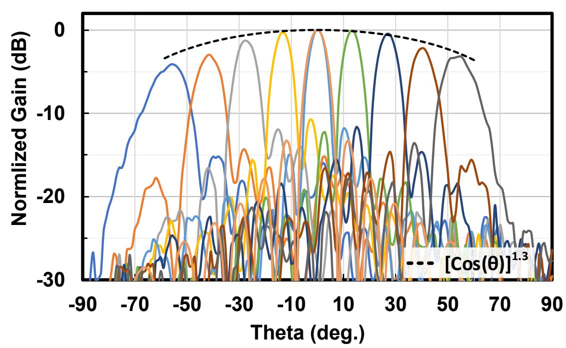

Fig. 6. Measured pattern at 50 GHz with +/- 60^o scan angles. Patterns at 20, 30 and 40 GHz also show similar scanning performance.

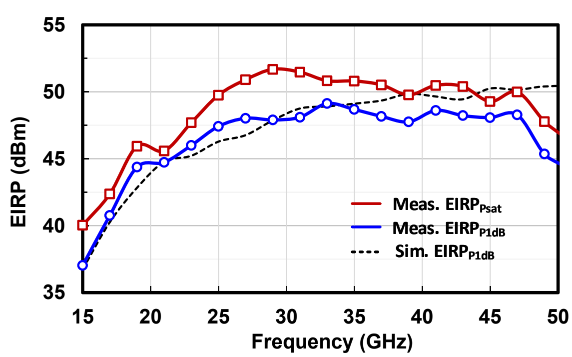

Fig. 7. Measured EIRP versus frequency of the 64-element Tx phased-array with P_{1dB} and P_{sat} operation.

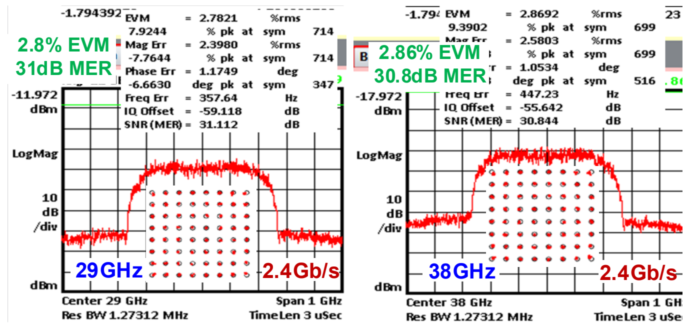

Fig. 8. Measured spectrum and constellation at 29 and at 38 GHz center frequency with 39-40 dBm EIRP and single-carrier 400 MHz 64-QAM waveform (2.4 Gb/s).

IV. Conclusion

This paper presented 16-52 GHz 64-element Tx and Rx phased-arrays. The arrays demonstrates ultra-wideband performance with +/-60^o beam steering capabilities, an EIRP of 45.9-51.7 dBm, and a system NF of 5.3-6.9 dB. 2.4 Gb/s 64-QAM data links are demonstrated at 29 and 38 GHz with an average EIRP of 39-40 dBm.

Acknowledgment

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