High Linearity Phased Array Receiver System for 5G/6G Application

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***Abstract*—This paper presents a 16-element linear array with Vivaldi antennas to showcase system-level application in ultra-wideband system in next generation communication system. The array is implemented with a high-linearity 8-channel phased-array receiver operating at 3-28 GHz, designed for multi-band base station applications using a 90 nm SiGe BiCMOS process. Over-the-air (OTA) testing reveals up to $\pm 50^\circ$ beam scanning capability while maintaining high linearity with 64-QAM modulated signals. These results highlight the potential of the proposed receiver for future multiband 6G FR3 systems.**

***Index Terms*—Beamformer, phased array, receiver, SiGe BiCMOS, sixth-generation (6G) communications, ultra-wideband.**

I. Introduction

6G base station systems must support multiple frequency bands, including C, X, Ku, and K bands. Unlike traditional single-band systems, wideband systems experience varying space loss and beamwidth characteristics, significantly impacting communication quality. Phased arrays offer an effective solution by dynamically shaping beams to ensure compliance with FCC standards. Various beamformers and phased arrays have been developed for single-band operations, such as 28 GHz [1], [2], 39 GHz [3] and 60 GHz [4] systems for 5G FR-2 applications, as well as X, Ku, K, and Ka bands [5] for satellite systems. More recently, dual-band systems have been introduced to cover 28 GHz and 39 GHz bands [6]. However, meeting the stringent 6G FR-3 requirements demands wider bandwidths and enhanced linearity.

This report presents an ultra-wideband phased array design, addressing key challenges in system integration, including the wideband receiver chip, antenna, and power combining network. Array pattern measurements are conducted to evaluate scanning performance.

II. 16-Element Phased Array Receiver

A 16-element phased array is implemented to evaluate the proposed system performance (Fig. 1(a)). Two beamformer chips control the gain, with differential G-CPW interfacing the antennas and chips. V and H polarized outputs from both chips are combined via a 4:1 PCB Wilkinson network. For power management and control, LDOs and SPI buffers are integrated on an 8-layer Megtron 6 PCB ($\epsilon_r = 3.4$, Tanδ=0.004, thickness=0.8 mm.), ensuring high RF performance across the operating band. The total DC power consumption of the array, including LDO dissipation, is 3.75 W.

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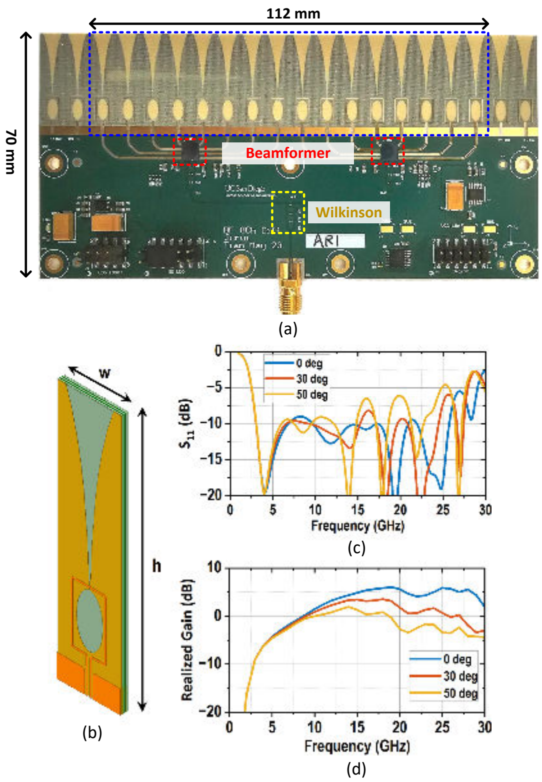

Fig. 1. (a) Photo of the 16-element linear phased array. Antenna element (b) structure, (c) simulated reflection coefficient, and (d) realized gain.

A. Beamformer

The beamformer chip features eight RF channels, each comprising an LNA chain, wideband vector modulator phase shifter (PS), and VGA. Two 4:1 Wilkinson networks is designed for dual-polarized operation. Fabricated with Tower Semiconductor's 5^{th} generation 90 nm SiGe BiCMOS process, the chip offers high RF performance.

In high-gain mode, channels achieve a 25–34 dB gain from 3–28 GHz, with a 9 dB gain peaking function to compensate for PCB routing losses. The measured noise figure (NF) ranges from 2–4.5 dB. The PS maintains precise phase control from 3–20 GHz, with RMS phase and gain errors below 2.8° and 1.5 dB, respectively. The VGA provides 20 dB gain tuning.

B. Antenna Element

An ultra-wideband Vivaldi antenna is used to cover the operating band of the beamformer chip (Fig. 1(b)). The element features a grid $w = 7\ mm$ (1/2 λ_0@21.4 GHz) and a

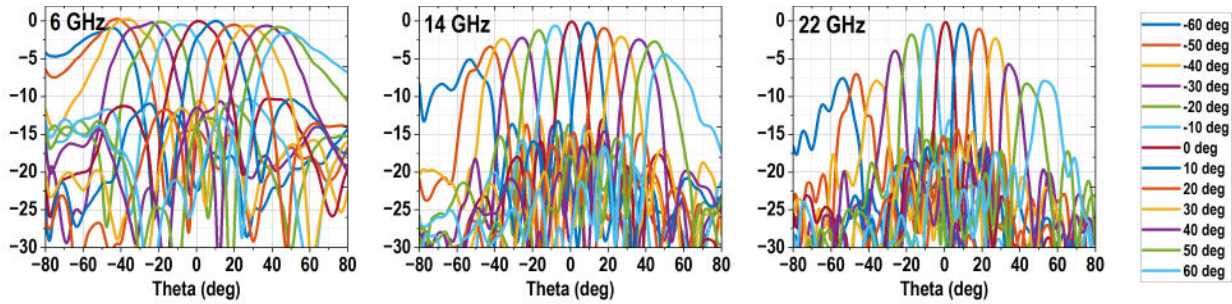

Fig. 2. Measured radiation pattern at 6 GHz, 14 GHz, and 22 GHz.

height $h = 26\ mm$. The radiating structure is placed on metal layer M2, optimized for impedance matching across a wide frequency range. The Vivaldi slot is fed by a microstrip line on M1, connected to differential G-CPW for efficient signal transmission.

C. Wilkinson Combiner

The 4:1 combining network consists of three ultra-wideband Wilkinson networks, designed in a three-stage configuration. It is optimized with two sections of 74 Ω transmission line and one section of 63 Ω transmission line. The 74 Ω transmission lines are referenced to M3 rather than M2 to comply with design rules. The isolation resistors are 0201 components, modeled in simulation for accurate performance prediction.

D. Array Pattern Measurement

Over-the-air (OTA) testing is performed in a 2.5 m far-field range using a Keysight N5245B PNA-X network analyzer. Two measurement setups cover 1–12 GHz and 6–26.5 GHz to encompass the full operational bandwidth. Array calibration is done at broadside with 1 GHz frequency steps for accurate measurements. Each element is tuned sequentially, and S21 is measured across all gain and phase states. After tuning, gains are equalized to the channel with minimum amplitude, and phases are equalized to channel 7, which is close to the center of the array.

The array pattern is measured with scan angles from -60° to 60° (Fig. 2). At 6 GHz, the array shows scanning up to 45°, with minimal gain degradation due to the broader element beamwidth at this lower frequency. At 22 GHz, a slight dip at 40° highlights these coupling effects.

III. Conclusion

This report presents the design of an ultra-wideband phased array and demonstrates how gain peaking effectively compensates for PCB losses, aiding in link budget design. The receive pattern is measured to validate the system performance in practical applications. This work shows that the proposed design is a strong candidate for 6G FR3 multi-band and multi-standard base station applications.

IV. Career Plan and Fellowship Impact

With the support of the MTT-S Fellowship, I attended IMS, where I witnessed how innovation drives product design in the largest microwave technology exhibition. This experience solidified my decision to pursue a career in industry, focusing on RFIC design and system integration to push the limits of wireless communication.

The fellowship provided invaluable resources, connections, and insights, bridging the gap between research and real-world applications. I am excited to apply my skills to develop high-performance RF solutions that drive technological advancements and benefit society.

Acknowledgments

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