Proposed 240GHz Calibration-Free Low-Loss Passive Phase Shifter in 90nm SiGe 9HP

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Introduction

Modern radar and communications benefit from operating at mmWave frequencies (30-300GHz) due to broader bandwidth, high data transfer rates, reduced congestion, and higher radar resolution it offers compared to lower frequencies. However, the performance of Radio Frequency Integrated Circuits (RFICs) is more limited–and path loss becomes more significant–as the frequency of operation increases.

This phase shifter is a component of a proposed RFIC transceiver module which has 4 on-chip antennas (*Fig. 2*). Multiple transceiver modules will be packaged together in what is called a 'phased array' (*Fig. 1*), which mitigates the previous drawbacks of high frequency operation, increasing directivity and gain through the superposition of individual radio waves from individual elements. The phase shifters are individually controlled to change the direction and shape of the radiation pattern produced (beamforming).

The miniaturization of antennas at mmWave frequencies allows for a higher density of integrated antennas. Narrower fixed antenna array element spacing (λ/2 ≈ 0.625mm @ 240GHz) requires lower power consumption (to reduce heat density) and more compact ICs per element.

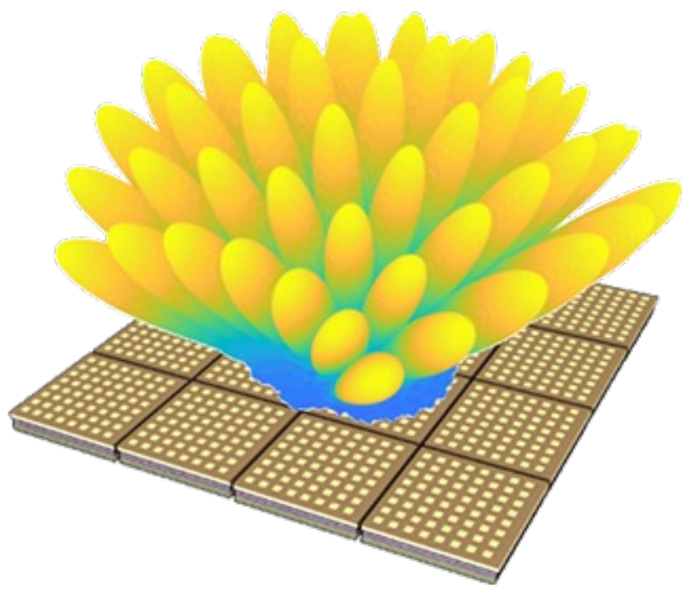

Fig. 1: Illustration of radiation pattern over antenna array [3]

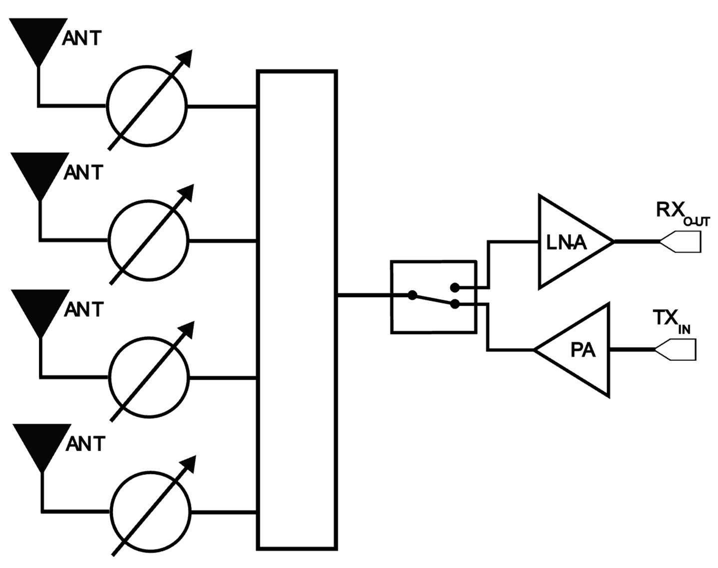

Fig. 2: Example of a generic transceiver design with a phase shifter per each element

Objectives

The objective of this research is to improve upon a previously published design [1] and achieve comparable or better performance at a higher frequency of operation and with a smaller chip size. The phase shifter must also achieve a 5-bit resolution (11.25°-step, 32-state) over 360° of phase.

Building upon a previous design for a 140GHz phase shifter designed using 45RFSOI (45nm transistor width) technology [1], this design instead uses GlobalFoundries' SiGe BiCMOS 9HP 90nm technology due to the higher f_t/f_{max} (current gain/oscillation gain) of 310/370GHz [2] which would increase the speed of operation and decrease the overall size of the RFIC. 9HP technology possibly also has a smaller *insertion loss* (a source of signal power loss) per transistor compared to 45RFSOI [1].

Methodology/Analysis

The phase shifter functions by manipulating the transmission line length the signal propagates through. Each unit cell has a T-line length corresponding to a phase difference of 45° between the signal entering the unit cell and exiting it. There are two additional unit cells that, when active, change the phase by 11.25° and 22.5°, respectively (*Fig. 3*). In this design, the CMOS transistors in the 3-bit shifter are replaced with BJT transistors, one reason is a novel topology described in [2] may result in improved insertion loss.

The design is simulated using the *Cadence Virtuoso* program suite, which models approximate expected behavior of RFIC chips with a respective transistor technology.

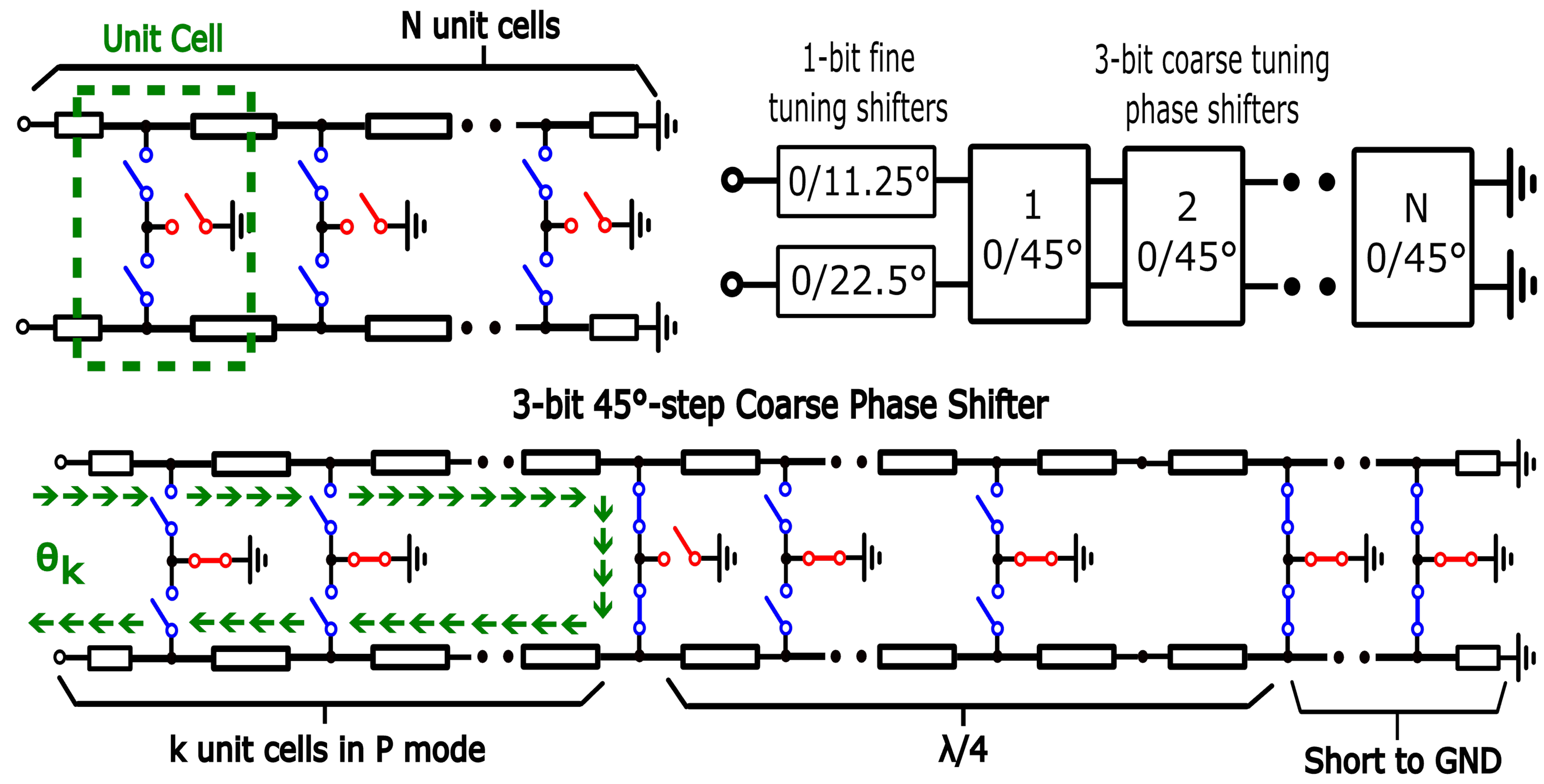

Fig. 3: Phase Shifter Design

The simulated phase state results were uniform across the full 360° range with low rms phase error of ~1.7°. (Fig. 4). The simulated insertion loss had poor uniformity across the coarse 45° phase states (Fig. 5), likely a consequence of directly substituting the previous CMOS transistors [1] with BJT transistors in this design. However, the 11.25°/22.5° phase shifters demonstrated an insertion loss of only ~-0.5dB and was uniform across all phase states.

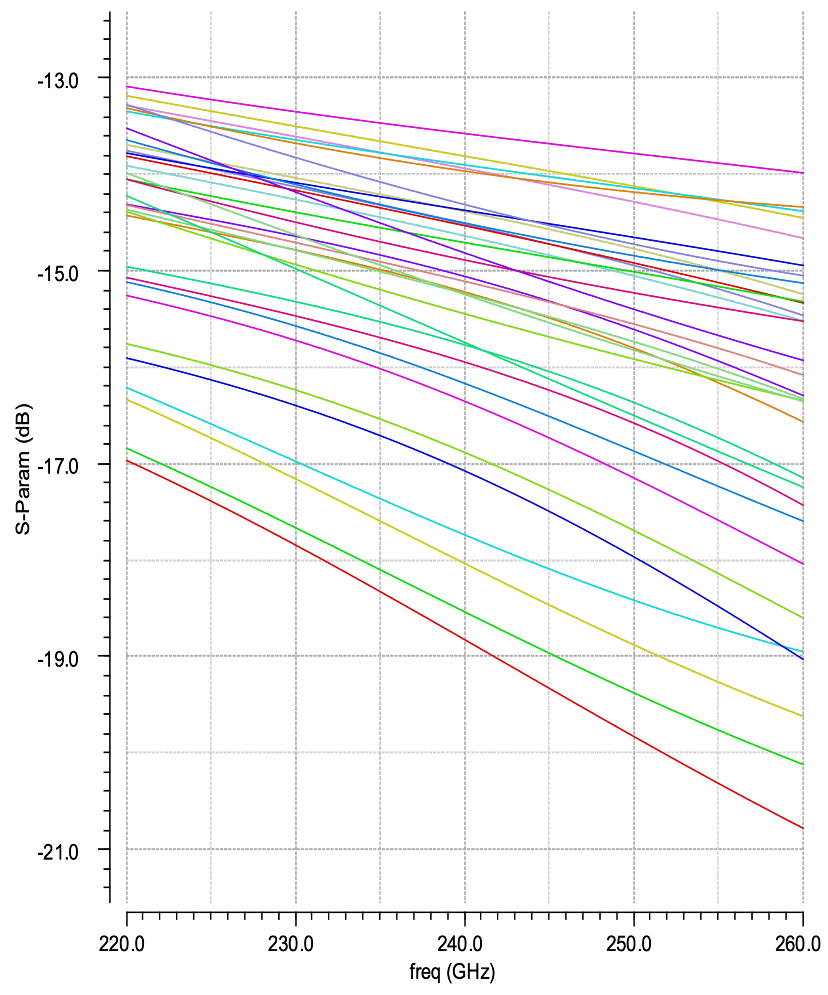

Fig. 4: Phase Shift States

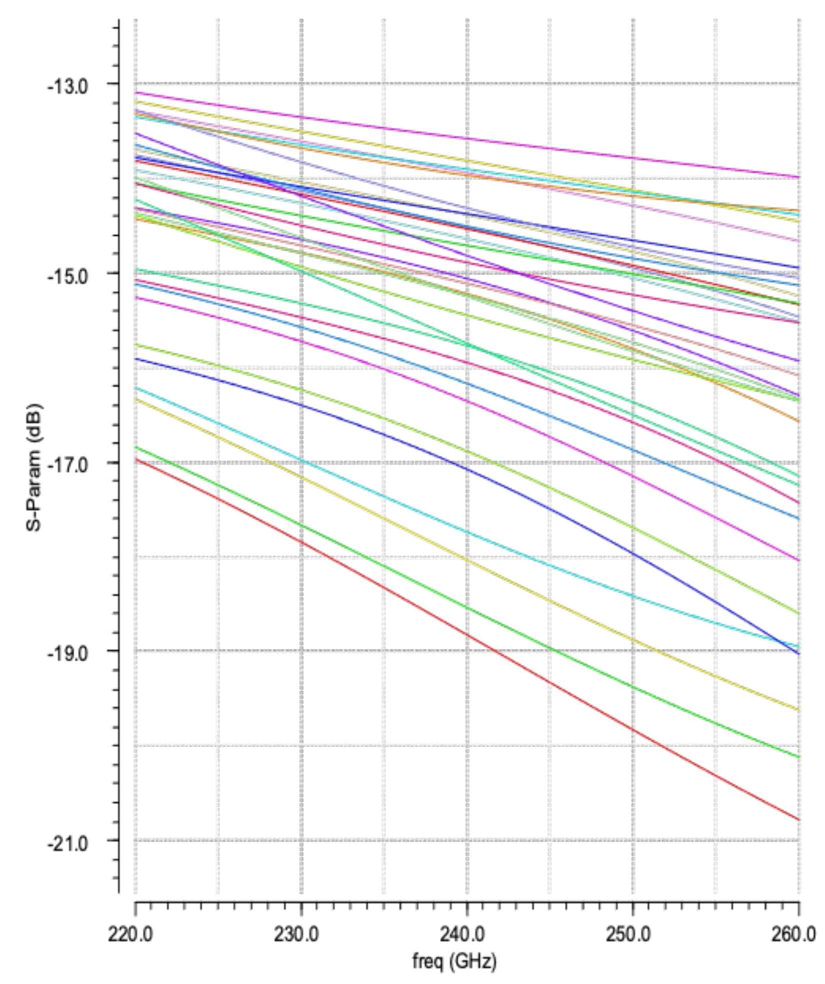

Fig. 5: S21 Insertion Loss

Future Objectives

240GHz Phase Shifter

- The 45° unit cells will be re-designed for use with BJT transistors to improve the insertion loss uniformity
- Complete phase shifter design, including layout

240GHz Transceiver with On-Chip Antenna

- Design other transceiver components, design on-chip antenna
- Integration of all components

Acknowledgements

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References

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[3] Darpa.mil, 2024. https://www.darpa.mil/program/millimeter-wave-digital-arrays (accessed Jul. 26, 2024)