A 2.45 GHz Phased Array-Based Reader for Long-Range RFID Applications

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***Abstract*—This paper presents a 2.45 GHz phased array-based RFID reader to extend the range and coverage area of conventional RFID systems. The reader has three front-end boards, each comprised of a 4×4 Butler matrix that feeds into a 4-element linear patch antenna array. The excitations to the input ports are controlled by an RF switch and a Wi-Fi module connected to a microcontroller, allowing the beam to be steered at 12 angles. The simulated and fabricated front-end exhibits successful beam steering at 2.45 GHz with a maximum gain of 11.5 dBi, enabling >3.5 km range with 360° coverage.**

I. Introduction

With improved fabrication technologies and design methods, phased arrays have increasingly become an emerging solution to various wireless communication challenges in commercial applications. With their widespread usage in some of these commercial applications—including logistics, asset tracking, Internet-of-Things (IoT), and many more—RFID systems also benefit from the beam forming and beam steering capability of phased arrays.

2.45 GHz RFID systems have an advantage over Ultra High Frequency (UHF) RFID systems in that the size of the reader antennas and tags are smaller. These tags are more readily able to be applied to widespread applications. With smaller tag sizes and at higher frequencies, the challenge of coverage and range becomes a greater problem. Phased array-based solutions have been proposed to extend RFID readers' coverage at 2.45 GHz [1] and range at UHF [2]. However, neither of these solutions ensure 360° coverage for long-range applications. Other solutions to the coverage and range problem include incorporating more reader antennas and amplifiers, adding to engineering system complexities, or buying more RFID readers, adding to costs [3]. Tackling these challenges, this paper proposes a solution to improve the range and coverage area of conventional RFID systems through a compact phased array-based RFID reader at 2.45 GHz.

II. System Architecture

The proposed phased array-based RFID reader's architecture consists of a front-end and a back-end as shown in Figure 1. The front-end is comprised of three identical antenna arrays and passive feeding networks in the form of Butler matrices. These elements are fabricated on three separate boards and connected with mechanical hinges. The back-end is comprised of a Wi-Fi module, a microcontroller unit (MCU), and an RF switch for data processing and system control. The back-end board is also connected to the front-end boards with hinges. These hinges also serve as electrical connectors for the ground planes of all four boards. This mechanical fixture allows the reader to be compact and easy-to-deploy for any application. The 3D model of the system is shown in Figure 2.

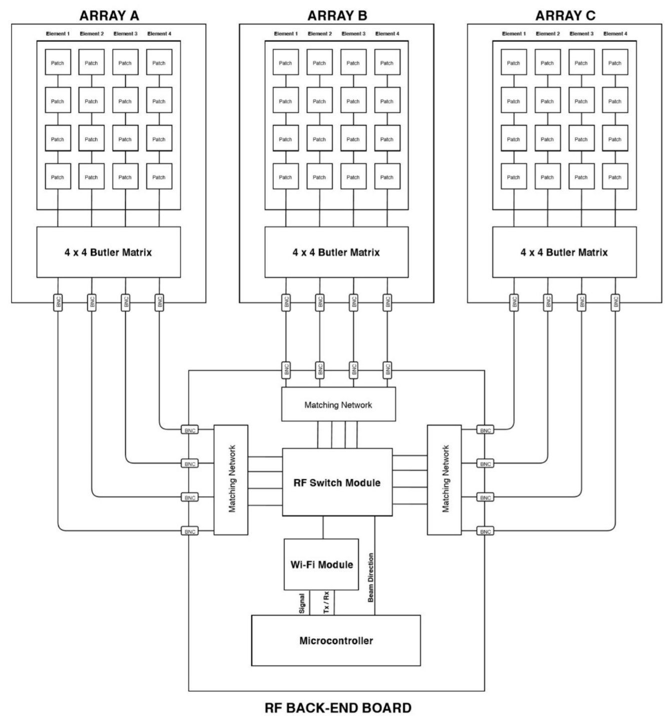

Fig. 1. Block diagram of the RFID reader's system architecture.

A. Front-End

Each front-end board has a linear array comprised of four series-fed patch antennas and a 4×4 Butler matrix optimized for 2.45 GHz. Each array element is inset-fed with the Butler matrix applying appropriate phase shifts to each input, allowing the radiated beam to be steered at four angles, $\pm 15^\circ$ and $\pm 45^\circ$ from the broadside. Since each board covers 120° of the azimuthal plane, the entire system enables a 360° coverage with 12 steering angles spaced 30° apart.

To decrease the substrate size for a more compact system, the front-end components were designed and fabricated on RO3006 substrate [4], which has a dielectric constant, ϵ_r, of

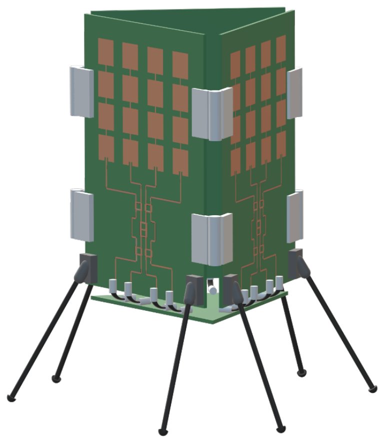

Fig. 2. Rendered 3D model of the system, showing the arrangement of the array panels and the back-end board.

6.15. Furthermore, to reduce conductor losses and increase radiation efficiency of the antennas, substrate and conductor thicknesses were chosen to be 1.52 mm and 17 μm, respectively. The overall substrate size is 22.9 cm $\times$ 30.5 cm. The fabricated front-end board is shown in Figure 3.

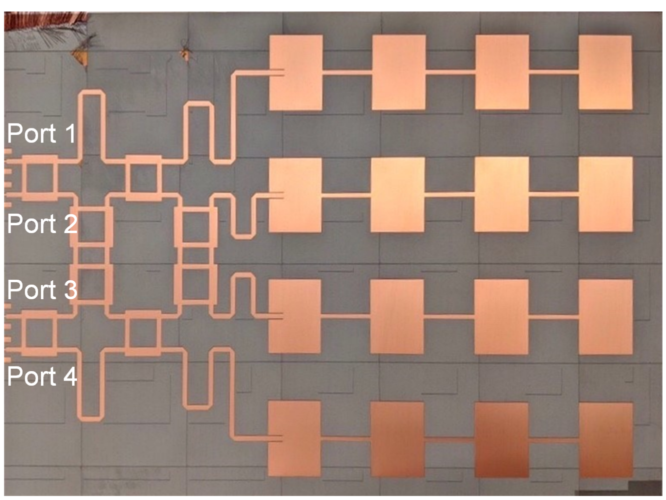

Fig. 3. Photograph of the manufactured front-end board with labeled input ports.

B. Back-End

The back-end utilizes a Wi-Fi module and single-pole, 12-throw RF switch, both connected to an MCU. The MCU is loaded with a beam steering and localization algorithm to identify and localize the tags by sweeping the azimuthal plane. The back-end board was designed and fabricated on 6.22 cm $\times$ 9.65 cm FR408 substrate.

III. Preliminary Results

A 3D EM model of the front-end was developed and simulated in ANSYS HFSS 19.2 for system characterization. Radiation patterns for the four steering angles are shown in Figure 4.

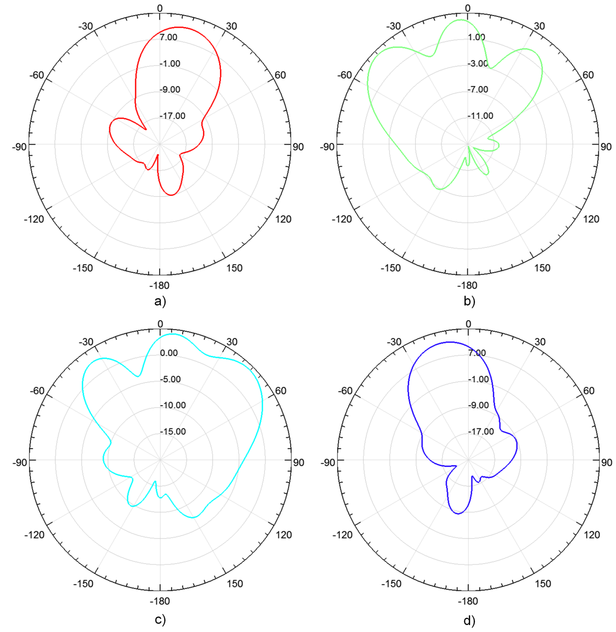

Fig. 4. Simulated radiation patterns of the array when a) Port 1 is excited (steered to 15°). b) Port 2 is excited (steered to -45°). c) Port 3 is excited (steered to 45°). d) Port 4 is excited (steered to -15°).

IV. Conclusion

In this work, a phased array-based RFID reader utilizing patch antenna arrays fed with Butler matrices has been demonstrated to improve the range and coverage of current RFID systems. The RFID reader was designed, simulated, and fabricated. Simulation results of the front-end ensure 360° coverage via beam steering with 11.5 dBi maximum gain, enabling a theoretical read range of >3.5 km. The next steps are assembling the system and conducting signal-to-noise ratio (SNR) measurements to empirically characterize the read range.

Acknowledgment

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