A Wideband Reconfigurable Reflectarray Using the Frequency Pulling Technique

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***Abstract*—In this work, we present an elegant, simple to fabricate and very cost effective technique for designing wide-band reconfigurable reflectarray antennas. First, we utilize our recently proposed frequency pulling technique (FPT) to increase the bandwidth of reflectarray antennas (RAs). Notably, based on FPT, a simple feeding network is properly designed and connected at the backplane of each RA's unit cell. In turn, we connect readily available diodes to this feeding network properly changing its electrical characteristics and applying the desired reconfigurability. To demonstrate our technique we utilize a traditional microstrip patch element. Specifically, we (a) apply our FPT method feeding each unit cell at two properly selected feed points and achieving a 28% fractional (gain) bandwidth, and (b) use a single diode to reconfigure the RA's beams between 30° and -30° in the $\phi = 0^\circ$ plane. Our designed RA shows great beam stability for both beam states within its entire 8.85 GHz to 11.75 GHz bandwidth of operation.**

I. Introduction

Reflectarray antennas (RAs) [1] have been used for decades in applications where high gain is required, such as satellite and long distance terrestrial communications. Notably, RAs demonstrate favorable performance as they combine the advantageous properties of parabolic reflectors (specifically, large apertures, high directivities) and phased arrays (specifically, low profile, phase shifting). However, there are several challenges that need to be overcome during the design of RAs (e.g., [2]) associated with their bandwidth and their reconfigurability.

Improving the performance of RAs is a topic that has received great attention in the last two decades. For example, in [3], an RA with improved bandwidth was demonstrated by using metallic blocks of variable length as unit cells. Additionally, in [4], a reconfigurable RA was presented by employing diode-loaded magneto-electric dipole elements. Although these works demonstrated RA performance with bandwidth greater than 32% in [3], and beam-reconfigurability with coverage up to 60° in [4], both of them suffered from increased profile and design complexity.

In this work, we address both challenges of bandwidth and reconfigurability. Notably, we very recently demonstrated that the frequency pulling technique (FPT) can be used effectively to improve the bandwidth of RAs while keeping the complexity and profile to a minimum level. Here, we expand on our previous work and we introduce a beam-reconfigurable RA based on the design shown in [5]. Namely, we first apply the FPT to a patch unit cell (UC) by feeding it at two appropriately chosen points increasing its fractional bandwidth two times compared to its traditional single-fed counterpart. Then, by strategically introducing a single diode, we are able to vary the electrical properties of our design, creating a phase shifting microstrip circuit that we use to switch between desired beams. Notably, as a proof-of-concept we introduce here an RA aperture that reconfigures its beam between -30° and 30° in the $\phi = 0^\circ$ plane.

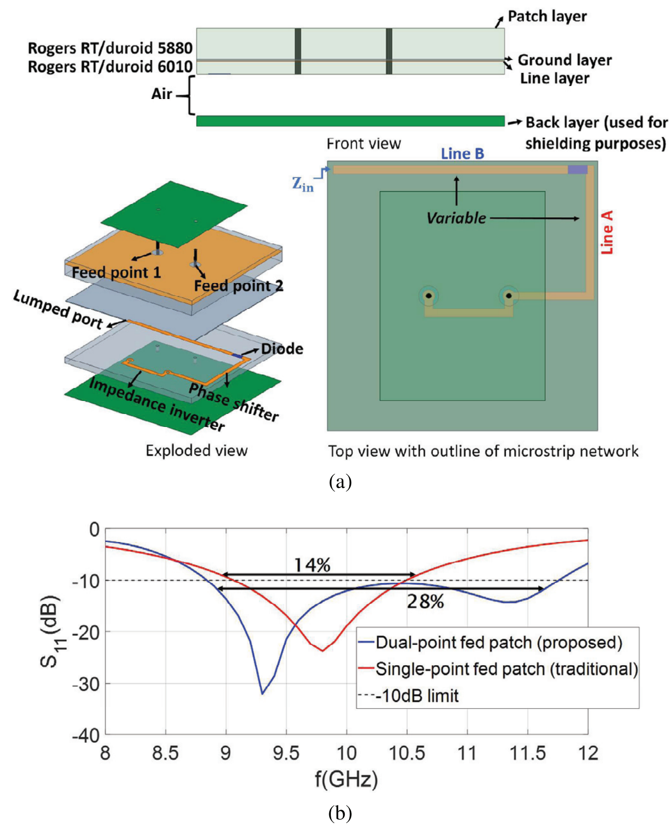

Fig. 1. (a) UC geometry: dimensions are not provided as they are almost identical to those in [5]. (b) Reflection coefficient (S_{11}) at the lumped port.

II. Design Analysis and Results

To demonstrate our technique, we utilize a traditional microstrip patch unit cell structure (see Fig. 1 (a)) which we properly design following our FPT method. Notably, the

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principle of operation of our FPT method is omitted here for reasons of brevity, and it can be found in [6]. As it can be seen from Fig. 1 (a), our patch is connected to a microstrip circuit placed behind its ground plane through two appropriately chosen feeding vias (points). According to FPT, e.g., [6], a 90° section is introduced between the two feeding points. This results in the increased bandwidth of the UC. Notably, our UC is simulated using periodic boundary conditions and a lumped port excitation on ANSYS HFSS. The reflection coefficient is plotted in Fig. 1 (b) and validates the increased bandwidth of the dual-fed patch in comparison to the single-fed one (the two cases demonstrate fractional bandwidths of 28% and 14%, respectively).

To introduce the required phased variations across the RA aperture for reconfigurable beam operation, additional components are added in the microstrip network behind the first feeding point. First, two lines of variable length are included. Namely, line A is responsible for the required phase shifts for beam A (30° in the $\phi = 0^\circ$ plane), and line B is responsible for beam B (-30° in the $\phi = 0^\circ$ plane), respectively. Next, to achieve switching operation between beams A and B, we carefully place an active component (e.g., a diode) between lines A and B. The lines A and B as well as the diode are connected in-series as shown in Fig. 1 (a). The principle of operation of our proposed UC is the following. When the diode is OFF, the UC operates at state A, in which line A forms beam A. In contrast, when the diode is ON, the UC operates at state B, in which the in-series combination of lines A and B creates beam B. Fig. 2 shows the resulting characteristic curve of the reflected wave's phase as a function of the variable length of the phase shifting line (see detail in Fig. 1 (a)) at 9.5 GHz. Notably, the phase is wrapped to one full cycle of 2π. The first cycle (line varies from 1 mm to 7 mm) corresponds to line A (state A), while the second cycle (line varies from 7 mm to 13 mm) corresponds to the in-series combination of lines A and B (state B).

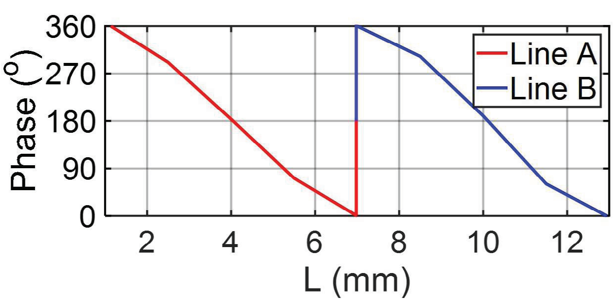

Fig. 2. Phase of the proposed unit cell's reflection coefficient vs. the length of its line at 9.5 GHz.

Last, to validate our concept, we design an RA aperture based on our proposed UC. The RA consists of 12×12 elements, where an $F/D = 0.9$ ratio is chosen to maximize aperture efficiency. The radiation patterns are evaluated using our in-house analytical code based on array theory in combination with the unit cell data provided by our ANSYS HFSS infinite array simulations. Fig. 3 indicatively shows the radiation pattern for both the ON and OFF states at the design frequency of 9.5 GHz, demonstrating the desired beam reconfigurability between 30° and -30° and validating our concept. Similar behavior is achieved for all other frequencies of our operational 8.85 GHz to 11.75 GHz bandwidth. The corresponding results are omitted here for reasons of brevity and will be presented at the time of the conference along with our measured results.

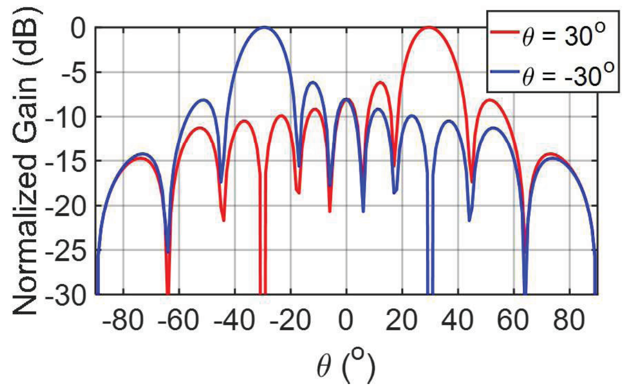

Fig. 3. Gain patterns for state A ($\theta = 30^\circ$) and B ($\theta = -30^\circ$) at 9.5 GHz.

III. Conclusion

In this work, beam reconfiguring capabilities were introduced for the first time in an RA designed following the FPT method. Specifically, utilizing our recently proposed FPT methodology and readily available diodes, we successfully demonstrated beam reconfigurability in a fractional (gain) bandwidth of 28%.

Acknowledgment

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