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Increasing the Bandwidth of Reflectarray Antennas Using the Frequency Pulling Technique

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***Abstract*—In this work, a frequency pulling technique (FPT) is used to increase the bandwidth of traditional reflectarray antennas (RAs). Specifically, the bandwidth of a rectangular patch unit cell is doubled by simultaneously feeding it at two slightly asymmetric points. The required phase shift for each unit cell of our reflectarray is achieved using meandered microstrip lines below the patch elements. Our results illustrate that our proposed RA achieves a fractional gain bandwidth of 30%, which is approximately two times greater than the 16% fractional bandwidth of the traditional RA with single-point fed patches.**

I. Introduction

Reflectarray antennas (RAs) [1] provide a well-established alternative for high gain antenna applications. They are known for combining the advantages of reflectors (i.e., large apertures) with those of phased arrays (i.e., low-profile, beam-steering capabilities). However, the operation of RAs is limited by their inherently narrow bandwidth (BW) [2] due to: (a) the use of narrowband antenna elements, such as, patches, and (b) the differential spatial phase delay that occurs due to the different propagation paths that exist from the feed phase center to each RA unit cell (UC).

Significant research has been conducted during the last two decades towards addressing the BW challenges of RAs. For example, in [3], a wideband full-metal RA was demonstrated with the use of metal blocks of different heights. Also, in [4], a wideband RA was presented with the use of a magneto-electric dipoles. However, even though these designs provided RAs with higher fractional BWs (at least 32% and 38% BWs were achieved in [3] and [4], respectively), they exhibited significantly larger complexity and profile. Therefore, an important research question to investigate is: "Can we increase the bandwidth of traditional RAs, without increasing their design complexity and profile?"

Recently in [5], the novel technique of frequency pulling (FP) was introduced, which enables designers to increase the BW of radiators multiple times by using novel excitations. Here, our research followed the approach of [5], to increase the bandwidth of RAs. Specifically, we first applied the FP technique to a rectangular patch UC to double its bandwidth. Then, we designed an RA aperture based on our proposed UC to demonstrate its larger bandwidth compared to traditional RA designs.

II. Design Analysis and Results

A brief analysis of the FP technique is provided for completeness, while its detailed description is found in [5]. The equivalent circuit model of a patch antenna, fed by a microstrip line (or more generally by a single point), is a parallel RLC resonant circuit. A patch antenna, which is fed by N number of points, can be considered as a network that consists of N parallel RLC resonant circuits connected in series. The FP technique, [5], feeds an antenna at multiple points to increase its bandwidth. This is achieved by using traditional band-pass filter synthesis methods and appropriately selecting the lengths of the excitation lines for the feeding points of an antenna. In what follows, we first present our novel UC, where the FP method is applied. Then, we design an RA antenna based on our novel UC.

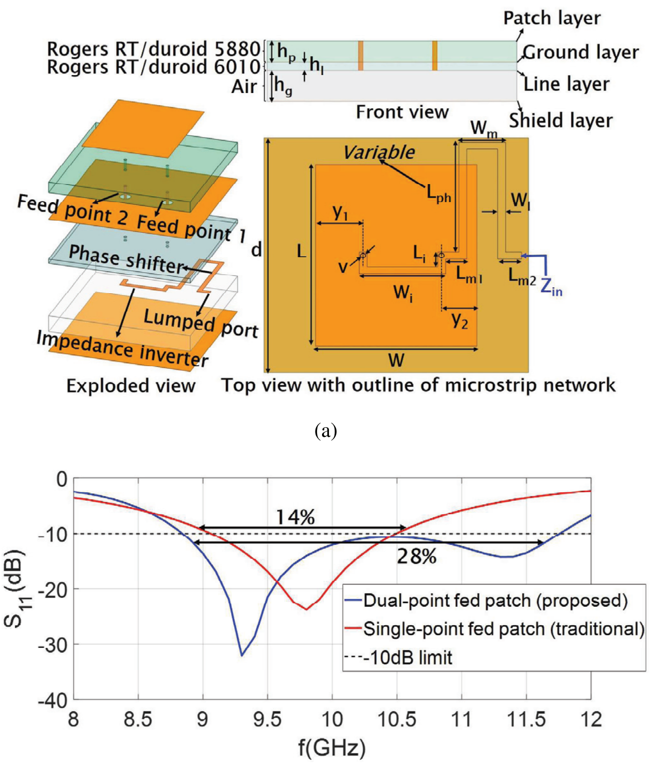

Fig. 1. (a) UC geometry: d=15, W=11.59, L=9.15, W_i=4.9, L_i=0.95 h_p=1.588, h_l=0.635, h_g=0.635, W_l=0.45, y_1=2.7, y_2=2.2, W_m=2.65, L_{m1}=1.2, L_{m2}=1.368, v=0.3 (units in mm). (b) Reflection coefficient (S_{11}) at the lumped port.

The geometry of our proposed UC is shown in Fig. 1(a). At the top layer, a patch element with two feed points is designed above the ground plane. Two metalized vias are used to connect the patch to a microstrip line network that is designed behind the ground plane of the patch. The microstrip line network consists of two components. The first component is a microstrip line that is placed between the two feed points of the patch, and it operates as an impedance inverter. Notably, the length of the line is defined based on the FP method; it is the one responsible for the bandwidth enhancement of the patch antenna. The second component is a microstrip line that is placed before the first feed point [see Fig. 1(a)] of the patch antenna. This line is responsible for introducing the required phase to the UC to synthesize an RA with a beam towards the desired direction. Finally, a conductive plate is placed below the microstrip line network to shield our design and suppress any occurring spurious radiation. Our UC is modeled using full-wave simulations in ANSYS HFSS.

To verify the increased bandwidth of our proposed design with two feed points (compared to a traditional patch antenna fed by a single point), we first use a lumped port excitation at the end of the feeding microstrip line, as shown in Fig. 1(a). Fig. 1(b) shows that our proposed design achieves a fractional bandwidth (FBW) of 28%, which is two times greater than the 14% FBW of the traditionally single-point fed patch element.

The next step is to examine if our UC can introduce the required phase variations needed by an RA aperture to collimate its beam towards a specific direction. To achieve this and provide the necessary phase in each of the RA elements, we introduce a microstrip line of variable length before the first feed point of our UC that acts as a delay line [2]. To model our design, we define periodic boundary conditions at the walls of our UC structure, and we excite it by a Floquet port. Fig. 2 shows the phase of our unit cell's reflection coefficient versus its delay line's length. It is seen that all the phase responses are almost linear, thereby confirming the increased bandwidth of our design. However, some non-linearities are observed and attributed to resonances of the delay line [6].

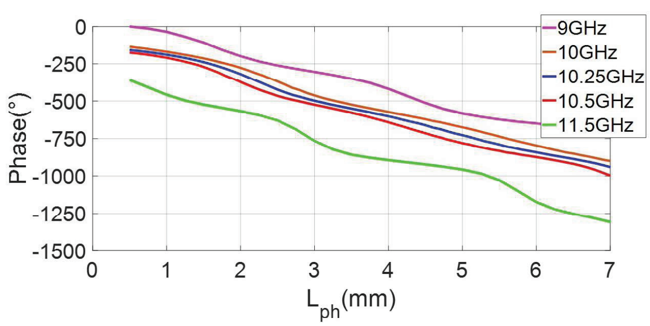

Fig. 2. Phase of the proposed unit cell's reflection coefficient vs. the length of its delay line for different frequencies.

The last step is to examine the performance of our RA with the proposed UC with two feed points. Utilizing the responses of Fig. 2, we design a 16×16 RA aperture to steer the beam 20° off broadside, where an $F/D = 0.9$ ratio is chosen for aperture efficiency maximization. To examine the BW performance of our proposed RA, we plot its realized gain-frequency response in Fig. 3, and compare it to the one of a traditional single-fed patch RA. As it is shown, our proposed design achieves a wide 3dB gain bandwidth of 30%, that is nearly double the 16% bandwidth of the traditional RA. The slight gain reduction at the higher frequencies of our operating band is attributed to phase errors, caused by the non-linearities of the phase response of Fig. 2 at those frequencies.

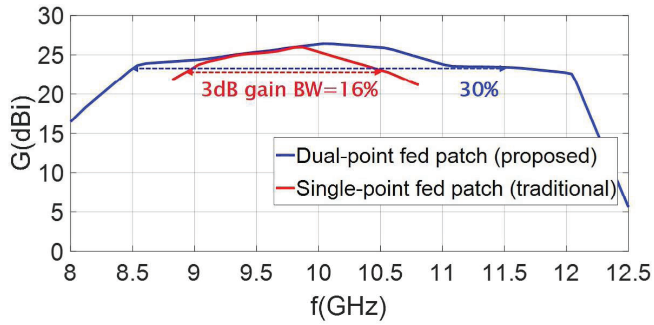

Fig. 3. Realized gain for the proposed dual-point fed patch-based and the traditional single-point fed patch-based RA, respectively.

III. Conclusion

In this work, the frequency pulling technique of [5] was applied to increase the bandwidth of traditional microstrip reflectarray antennas (RAs). Based on our results, the proposed RA achieved a fractional gain bandwidth of 30%, which is approximately two times larger than the 16% fractional bandwidth of the traditional RA. Also, this approach can be used to increase the bandwidth of other traditional RAs. A detailed theoretical analysis along with comparisons of simulated and measured results will be presented at the time of the conference.

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