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A Wideband Reconfigurable and Dual-Polarized Transmitarray Unit Cell

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***Abstract*—This work presents a wideband, reconfigurable transmitarray antenna (TA) unit cell (UC) design that supports dual-linear polarization. Namely, a novel TA UC is proposed, inspired by the magneto-electric dipole (MED) element, that achieves a 46% fractional bandwidth (BW). This UC utilizes a central via that is appropriately designed to allow the easy integration of the required PIN diodes, and enable 1-bit phase modulation (0° and 180°) between the transmitting and receiving elements. In addition, due to its design simplicity, our element is at least 4 times smaller compared to state-of-the-art MED elements. Notably, the small size and small number of vias of our element enable us to incorporate two orthogonal elements in a single TA UC so that two polarizations can be supported. The wideband performance of our proposed UC in the Ku band is demonstrated using simulation analysis in ANSYS HFSS.**

I. Introduction

Dual-polarized high gain antennas with beam-steering capabilities are essential components of communication systems used in applications, such as, satellite communications, imaging, remote sensing, etc. In the last decade, significant research effort has been put towards the design of wideband, reconfigurable, and dual-polarized space-fed high-gain antennas, such as, reflectarray and transmitarray antennas (RAs, TAs) [1] for beam-steering applications as a low-cost alternative to traditional phased arrays. For example, in [2], a wideband, dual-polarized TA based on the magneto-electric dipole (MED) was presented. However, a highly complex design with a meandered gamma probe is used in [2] to achieve dual-polarized performance, which makes it very challenging to convert this design into an electronically reconfigurable one. Moreover, a wideband and electronically reconfigurable MED-based TA was proposed in [3]. However, the lack of symmetry in this design and its complexity make the introduction of a second radiator that supports an orthogonal polarization impossible. Finally, an electronically reconfigurable and dual-polarized TA was proposed in [4], but it provided extremely narrowband performance due to its dipole elements. Therefore, there is an urgent need for transmitarray unit cell (UC) designs that can provide wideband, electronically reconfigurable, and dual-polarized performance.

To address this need, we propose here the first (to our knowledge) TA UC that satisfies all three criteria of wide bandwidth, dual-polarization, and reconfigurability. Notably, our design is inspired by the traditional MED antenna. A key element of our design is its central via and its implementation that enable us to achieve: (a) minimum insertion loss between the receiving and transmitting layer, (b) 1-bit electronic reconfigurability, by alternating the two opposite states of 0° and 180° with the use of the appropriate diodes, and (c) element miniaturization and dual-polarization, by orthogonally interleaving a pair of MEDs. Notably, our design requires only 6 vias and 4 narrow metallic strips, whereas state-of-the-art designs are four times larger and need at least four times the number of vias. For example, the MED element in [2] uses 26 vias without even providing reconfigurable operation.

II. Unit Cell Structure and Principle of Operation

The UC structure is inspired by the MED element (e.g., [5]) known for its broadband behavior. Notably, MEDs are complex and bulky antenna elements, as they consist of a combination of an electric and a magnetic dipole, respectively. Traditionally, the electric dipole element is formed using two metallic patches. In addition, the magnetic dipole element is, in the majority of the designs, a quarter wavelength transmission line, that is terminated on its one side and radiates through its open end from its other side. In our work, aiming for a dual-polarized MED element, properly designed for a TA environment, we introduce the novel miniaturized MED design shown in Fig. 1. Namely, the electric dipole of our proposed element is properly formed by the use of two narrow metallic strips, while the magnetic dipole is realized by only two vias. Notably, these two key modifications reduce the size of our element more than four times compared to traditional MED elements. In turn, to create the TA UC, two identical elements

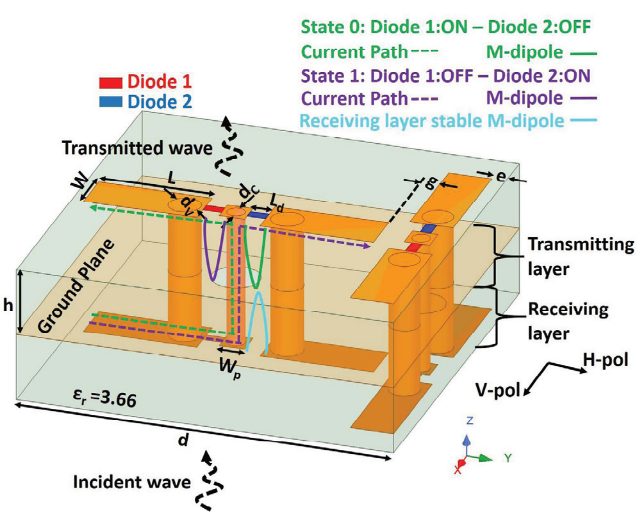

Fig. 1. UC structure (units in mm): d=10.65, h=2.6, L=3.25, d_V=0.9, d_C=0.5, L_d=0.5, e=0.4, g=0.5.

are placed above and below the ground plane. Also, our design uses a central via to achieve power transmission with minimum losses and 1-bit phase modulation between the transmitting (top) and receiving (bottom) layer of our TA. This via is carefully designed to go through a slot, etched at the ground plane of our TA, and properly connect the top and bottom MED elements to each other. Specifically, two PIN diodes are placed on the top layer of our UC connecting the via with the two arms of the dipole. At the bottom layer there are no diodes, and the central via is always connected to the one side of the dipole. Notably, by using this simple configuration, 1-bit phase modulation (0° and 180°) is achieved reversing the current direction every time the diodes are interchangeably activated. Specifically, as shown in Fig. 1, in state 0, a magnetic dipole is formed at the top layer between the central via and the via that connects the right arm of the MED element with the ground plane (see the green line in Fig. 1). Similarly, in state 1, an equivalent magnetic dipole is formed at the top layer between the central via and the via that connects the left arm of the MED element with the ground plane (see the purple line in Fig. 1). Notably, at the bottom layer the magnetic dipole is always formed between the central via and the via that connects the right arm of the MED element with the ground plane (see the cyan line in Fig. 1). Finally, since our proposed design is more than four times smaller compared to state-of-the-art MED elements, we can fit a pair of orthogonal radiators in a single UC thereby achieving dual polarization. The exact position of the two MED elements in respect to each other is thoroughly investigated through our simulation analysis, and it is appropriately chosen to maximize the BW of the UC. A complete analysis of the design parameters of our UC will be presented at the conference.

III. Unit Cell Performance

The electromagnetic performance of our proposed design is studied and validated using ANSYS HFSS. The magnitude and phase of the transmission coefficients S_{21} are shown in Fig. 2. The transmission coefficient S_{21} can be plotted for eight distinct cases, namely, cases H_{00}, V_{00}, H_{01}, V_{01}, H_{10}, V_{10}, H_{11}, V_{11}. The prime letter corresponds to the polarization component of S_{21} [horizontal (H) or vertical (V)] and the subscript numbers correspond to the states of the H- and V-polarized dipoles of the UC (00, 01, 10, 11). For clarity, the phase and magnitude of S_{21} are plotted in Fig. 2 for the extreme cases of H_{00}, V_{00}, H_{11}, V_{11}. The rest of the cases are omitted here, as they result in similar responses. The results in Fig. 2 show that a high transmission with a magnitude greater than -1.9 dB is achieved across a wide fractional BW of 46% that spans from 11.95 GHz to 19.12 GHz. Inside this frequency range, the phase difference between the two opposite states (state 0 and state 1) is $180°$ for both polarizations, validating the 1-bit phase control of our UC. Additionally, the phase response of the H-polarized component of S_{21} depends only on the state (state 0 or state 1) of the H-polarized MED, and is independent of the state of the V-polarized MED, and vice versa. A detailed analysis of the performance of our design will be presented at the conference and it is omitted here for brevity.

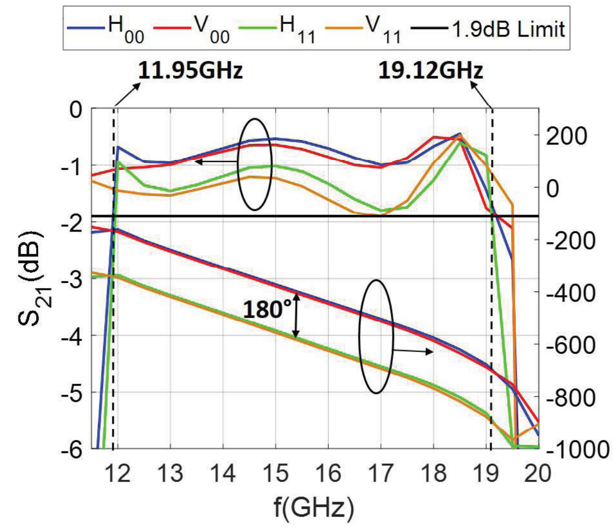

Fig. 2. UC response (magnitude and phase of S_{21}).

IV. Conclusion

In this paper, a wideband, reconfigurable, and dual-polarized TA UC was proposed. The essential component of this UC is a central via that is properly designed to provide a miniaturized MED element with dual-polarized performance. Notably, our design is four times smaller compared to state-of-the-art MED designs, and needs four times (or more) less number of vias than existing designs. To the best of our knowledge, this is the first time that a MED TA unit cell achieves all three properties of wideband, reconfigurable, and dual-polarized performance.

Acknowledgement

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