

Reconfigurable Pixelated Unit Cell for Reflectarrays and Reconfigurable Intelligent Surfaces

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Abstract— Here we demonstrate a reconfigurable pixelated unit cell for reflectarray antennas and reconfigurable intelligent surfaces. This unit cell can be used to design a reconfigurable aperture with wide beam steering capability. The reconfigurability is based on the intelligent use of simple PIN diodes. The core of the design is based on a resonant structure with PIN diode integration. The reconfigurable surface can be physically scaled to support multiple frequency bands.

Index Terms — Reconfigurable pixelated unit cell, Reconfigurable intelligent surface, Reflectarray, Aperture antenna.

A. INTRODUCTION

Microstrip reflectarray has always been a topic of interest in antenna community. In comparison with conventional parabolic reflector, reflectarray has a low profile, light weight and a completely flat surface. It is also easy to fabricate using printed antenna technology. The reflectarray consists of periodic/non-periodic elements (cells) that are designed to collimate the main beam of the antenna by controlling the phase of the reflected wave at each unit cell. Due to the individually controlled phase of each element, one can also design the reflectarray to generate multi-beam or specially shaped beam [1-2]. The reconfigurable intelligent surfaces (RIS) design methodology is similar to that of a reflectarray design. The emerging and challenging applications of RIS extended the research and development of unit cell design.

The concept of pixelated cell configurations had been introduced in antenna community as a parasitic element working in conjunction with the antenna to improve its gain performance or add the reconfigurability to it [3]. The pixelated concept can be defined as follows: A metallic surface is discretized in sub-wavelength sections, known as pixels. Pixel can be defined as “on” (with metal) or “off” (no metal). Depending on the desired criteria, the “on” and “off” pattern will be optimized.

In this paper, we iterate the pixelated unit cell concept but with a reconfigurability option using Pin diode-based unit cell. The reconfigurable pixelated unit cell is a combination of pixelated metasurface design [4] and resonant structures [5]. The fundamental principle is the same as our previous work where a subwavelength resonant structures (pixels) with integrated Pin-Diode form a unit cell. By changing the state of the Pin diode in each pixel the unit cell reflected phase can be changed. Unlike the previous pixelated unit cell design this new unit cell is reconfigurable. This offers more flexibility in operation allowing each cell of a reflectarray or a RIS to be configured allowing for beam steer capabilities. We demonstrate this concept in this paper for a design centered around 11 GHz, however this can be scaled to other frequencies by properly changing the resonant pixel dimensions.

Simulation tools such as HFSS [6] are usually used to design a reflectarray antenna or reconfigurable intelligent surface (RIS) by first determining the desired direction of the main beam, the size of the antenna, and the number of elements (cells) to be utilized. Next the calculation of the required phase of the reflected input signal at every cell is determined. The selection and design of unit cells is considered the major task in the design. Once a proper unit cell design that can be adjusted to provide a wide range of phase variation, the radiation pattern can be easily computed [7].

B. RECONFIGURABLE PIXELATED UNIT CELL

Traditionally when designing a reflectarray or RIS a designer might choose between squares, terminated patches antennas, split rings, cross, etc. These elements/cells types are typically bandwidth limited and don't necessarily provide a smooth change in element reflected phase that theoretically should cover the entire phase range from 0° to 360°.

The proposed reconfigurable pixelated unit cell alleviates these difficulties. As an example, consider a unit cell with planar dimensions of 31.8 mm x 31.8 mm sitting on a 20 mil

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thick Rogers Duroid 5880 substrate. The substrate has a dielectric constant of 2.2 and a dissipation factor of 0.009. This unit cell contains 4x4 reconfigurable pixels, each is 7.95 mm x 7.95 mm as shown in Fig. 1. At the heart of each pixel is an RLC surface that simulates a Skyworks SMP1340-079LF PIN diode [8]. The on state the Pin diode is treated as a series resistance of value of 1.7 Ohms. While the off state the Pin diode is treated as a parallel combination of a 5 M Ohm resistance and a .21pF capacitance. The package inductance is ignored.

In the on state the pixel acts as a PEC square. This is a corollary to the PEC squares used in [7]. Due to the nature of the resonant structure the PEC effect generated by shorting out both of the arms is band limited. In the off state the pixel acts as an open circuit. This is a corollary to the lack of metallization presented as in [7].

The evaluation of each cell (4x4 pixels) performance is based on numerical simulation that utilizes periodic boundary conditions along with floquet ports to approximate an infinite array of a given unit cell while including the coupling effects. This approach also allows the incident wave to be scanned allowing for off normal incidence.

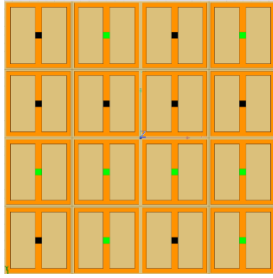


Figure 1: Reconfigurable pixelated unit cell.

Each unit cell can have 2^{16} or 65536 possible combinations of on/off states for the 16 Pin diodes. A random search in the solution space was employed to generate the reflected phase and their associated reflected magnitudes. A random number between 0 and 65535 is selected. It's then converted to a 16-bit binary number. Each position of the 16-bit number represents a position in the unit cell. The 4 most significant bits represent the top row of the unit cell from left to right. The 4 least significant bits represent the last row in the unit cell from left to right. For example, case 20725 becomes '0101000011110101'. The configuration is then implemented in HFSS and run over a frequency band centered at 11 GHz with normally incident wave. Figure 1 shows the configuration of a unit cell representing case 20725.

C. SAMPLE RESULTS

With this reconfigurable pixelated unit cell concept a phase range from 30° to 345° can be generated from different pixel unit cell designs where each is identified with a unique ID. An example is shown below in Fig. 2 for a reflectarray or RIS design centered at 11 GHz.

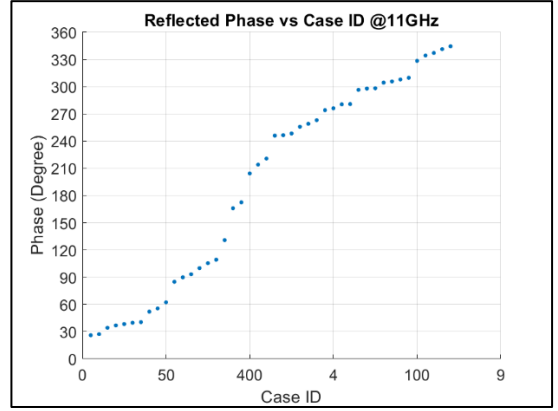


Figure 2: Reflected phase from 44-unit cell configurations.

D. CONCLUSIONS

Unlike traditional unit cells where a physical dimension is changed, such as lengths, rotations, gap, etc., the reconfigurable pixelated unit cell simplifies this by arbitrary turning pixels into a conducting or non-conducting state. The proposed reconfigurable pixelated unit cell proved to be a good candidate for providing a smooth and full phase range which can lead to broadband low loss reflectarray and RIS designs. The archiving of the reflected phase and amplitude data for unit cell configurations in a database allows a designer to go from a phase distribution to full model of a reflectarray or RIS design in a relatively short period of time. Scaling the pixels of a unit cell, or increasing the number of pixels in a unit cell allows for applications at different frequency bands.

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