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Reconfigurable Reflectarray Unit Cell using Vanadium Dioxide

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***Abstract*— This paper describes the design of a reflectarray unit cell element using vanadium dioxide (VO_2). Two halves of a quarter wavelength copper patch are joined using a VO_2 thin film. The VO_2 serves as the switching mechanism for the unit cell allowing dual state reconfigurability when thermally actuated. When heated, the resistivity of the material significantly decreases changing the properties from dielectric to conductor. Traditional methods of reflectarray reconfiguration such as the addition of diodes, MEMS switches and ferroelectric materials typically exhibit high losses. Alternatively, this element achieves 181° of phase shift while maintaining a maximum loss of 0.44 dB at 35 GHz making it an extremely appealing option for reconfigurable reflectarray design.**

Keywords—Reflectarray; Vanadium Dioxide; Millimeter Wave.

I. Introduction

Reflectarray antennas combine the advantages of both phased array antennas and parabolic reflectors while eliminating their complexities and short comings. Parabolic reflectors while wideband and high gain, lack beam steering capabilities. Phased array antennas excel when considering beam-scanning but require complex feeding networks introducing undesirable losses, complexity, and costs [1]. Alternatively, reflectarrays are an effective low loss, high gain method of beam scanning.

Reflectarray antennas are constructed using a series of radiating elements designed with specific phase requirements to construct a culminated beam when illuminated by a feed source. Such phase requirements are a function of the spatial length from the feed to the element, designed to delay the incident wave [2]. Various element designs have been explored to produce the optimal phase response, the most common of which are microstrip elements with various shapes, sizes and tuning parameters. Such elements allow for simple, low-cost fabrication while achieving full phase range. With the demand for effective wireless systems rapidly increasing, reconfigurable reflectarrays have become more appealing. Several reconfigurable reflectarrays have been proposed using methods such as electronic reconfiguration and ferroelectric materials [3, 4]. However, at higher frequencies such methods introduce high losses. This paper proposes the use of vanadium dioxide (VO_2) as tuning mechanism for a dual state reconfigurable reflectarray to minimize intrinsic structure losses.

The properties of VO_2 make it a unique candidate for the construction of a dual state reflectarray unit cell. VO_2 is a phase change material that undergoes a reversible insulator to metal transition at 68°C [5]. For reflectarray applications, this change can be utilized to dynamically alter the shape of a metallic unit cell tuning the phase response.

II. Element Design

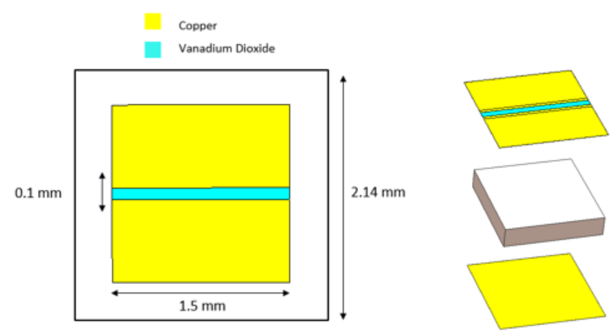

Fig. 1. Reflectarray unit cell element using VO_2 and copper.

The proposed unit cell is designed at 35 GHz as shown in Fig. 1. The unit cell consist of a 500 µm thick λ/4 copper patch loaded with a 0.1 mm slit. This slit contains a 100 nm thick VO_2 strip underneath to act as the switching mechanism for the unit cell. The VO_2 extends 5 µm underneath both sides of the patch to avoid misalignment during fabrication. The copper and VO_2 lie on top of a 430 µm sapphire substrate (ε_r=9.4) and a 1 µm copper ground plane underneath.

In the cool state, the gap in the patch is large therefore minimizing the capacitance between the two halves of the patch. This results in unit cell functionality similar to two separate patches where the electric field of each of the halves is highest at the edges. When heat is applied, the VO_2 resistivity decreases dramatically, changing the electrical properties from dielectric to conductor. As a result, the resonant frequency of the unit cell is shifted creating a phase response. In this state, the VO_2 acts as an electrical bridge between the two halves of the patch changing the behavior to that of a typical patch antenna maximizing the electric fields along the outer edge of patch as shown in Fig. 2. The electrical properties of the VO_2 are determined by the deposition parameters. Slight variations in the deposition environment can significantly affect the film conductivity. A parametric study varying the VO_2 conductivity was done which determined 1000 S/m to be the minimum conductivity necessary for optimal element functionality. When simulated, the VO_2 was modeled with a conductivity of 6.152×10^{5} S/m when in the heated state. When cooled the dielectric permittivity was considered (ε_r=154.3 ε_i=-156.7) [6].

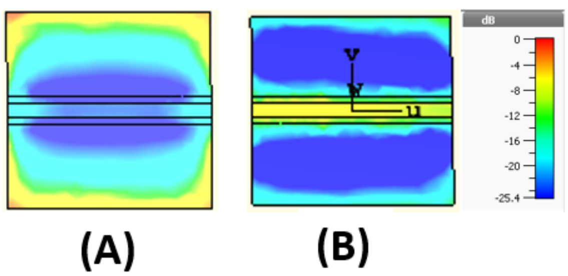

Fig 2. Maximum electric field distribution at 35 GHz for the on configuration (A) and off configuration (B)

III. Results

The unit cell was simulated using CST Microwave studio Frequency domain solver. Simulations were completed in an infinite array environment using a Floquet port assuming infinite periodic boundary conditions. Significant studies were done to optimize the unit cell including tuning the length of the cooper patches as well as the gap size.

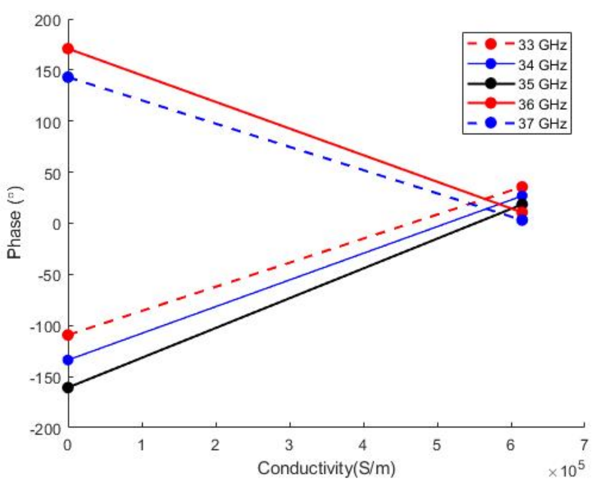

Fig. 3. Unit cell phase response 33-37 GHz

The optimized unit cell resulted in a phase change at 35 GHz of 181° and a loss of -0.13 dB in the cool state and -0.44 dB when the unit cell is heated. The phase of the unit cell provides an interesting perspective into potential reconfiguration capabilities shown in Fig. 3. This is attributed to the change in the direction of the phase curve across the frequency band. From 33-35 GHz an increase in conductivity results in a positively slopped phase curve. While at 36 and 37 GHz the phase transition is negative. This is due to the change in resonance between states. Utilizing this behavior can allow for unique reflectarray operation theoretically designing one array with customizable phase capabilities at different frequencies. The reflection loss of the reflectarray element remains below 1 dB for both the off and on states as shown in Fig.4. At the center frequency, the loss in the cool state is 0.13 dB while when heated the element loss is 0.44 dB.

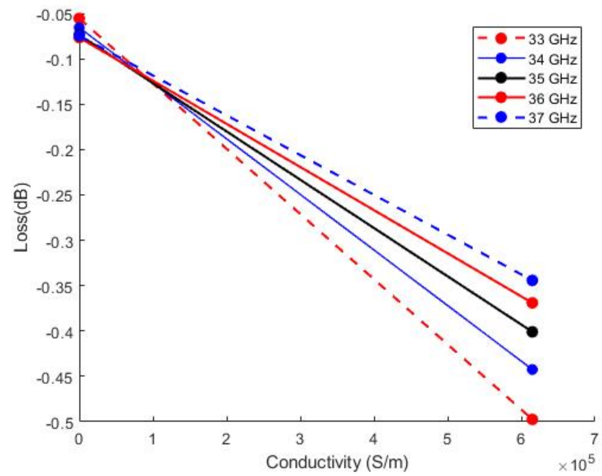

Fig. 4. Unit cell loss from 33-37 GHz

IV. Conclusion

This paper presents the design of a reconfigurable Ka band reflectarray unit cell using VO_2. The VO_2 film is used to tune the design such that a maximum phase change of 181° and a maximum loss of 0.4 dB is achievable. The unit cell is designed by strategically tuning the patch size and slit demesions to achieve optimal functionally. Further work is being performed to extend the design to be utilized in the construction of a finite dual state reconfigurable reflectarray capable of beam scanning.

V. References

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