A Polarization Insensitive and Angularly Stable Reconfigurable Unit Cell for Reconfigurable Intelligent Surfaces

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***Abstract*—A tunable unit cell is the building block of Reconfigurable Intelligent Surfaces (RIS). By controlling the reflection properties of individual unit cells, the propagation of the reflected electromagnetic (EM) wave can be manipulated in a programmable way. In this paper a new reconfigurable unit cell for RIS applications is proposed. The unit cell uses PIN diodes to switch between two reflection states which has a phase difference close to 180° over the frequency range of 7.25 to 8.5 GHz. The design is polarization insensitive, and the reflection responses are stable for oblique incidence of angle up to 45° for both TE and TM modes.**

I. Introduction

In recent years Reconfigurable Intelligent Surfaces (RIS) has become a research topic of significant focus because of its potential application in next generation of communication technologies [1], [2]. Numerous studies have explored the possibilities of application of RIS in different scenarios [3], [4].

The practical implementation of RIS involves an electronically controllable unit cell. The reconfigurability in such a unit cell is achieved by incorporating a varactor, a p-i-n diode, or other switching devices in the design [5], [6]. The capacitance of a reverse biased varactor can be tuned in a range by varying the applied voltage across it. Consequently a gradual variation in the reflection response can be achieved. On the other hand, p-i-n diodes have two switching states, ON and OFF, which result in distinct reflection states rather than a tuning range. In an RIS panel the unit cells are configured in a particular pattern depending on the position of receivers and transmitters to form a suitable scattering beam. The major challenges in designing unit cell for RIS are the bandwidth and oblique incidence response. The response of the unit cell, specially the phase, varies significantly with change in incidence angle. In practical use cases, the RIS should be able to handle incident waves from various directions, including wide angles of incidence with different polarizations. Thus, designing an RIS unit cell that has a wide operating bandwidth along with stable response with wide angle of incidence is of utmost importance.

In this paper, we present a reconfigurable unit cell for RIS. The p-i-n diode based unit cell can switch between two reflection states which has a phase difference $180 \pm 30°$ over frequencies 7.25 to 8.5 GHz. The unit cell is capable of working with any polarization and the reflection response maintains the phase difference of $180 \pm 30°$ for oblique incidence angle upto $45°$ for both TE and TM modes.

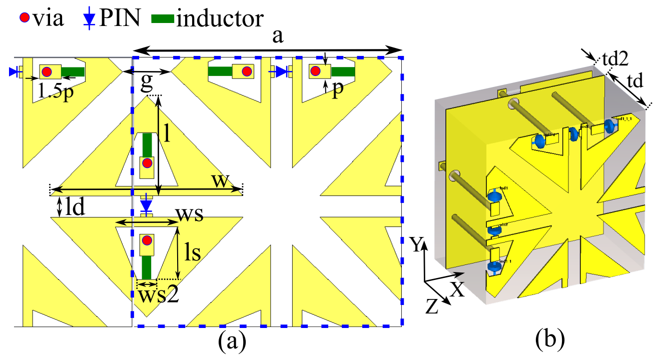

Fig. 1. The design of the switchable unit cell, (a) top view (unit cell is shown in blue dashed line) and (b) 3D view [Geometrical dimensions: *a* = 5.6 mm, *g* = 1 mm, *w* = 4.1 mm, *ld* = 0.45 mm, *ls* = 1.1 mm, *ws* = 1.2 mm, *ws2* = 0.45 mm, *p* = 0.3 mm, *via radius* = 0.1 mm, *length of RF choke* = 0.5 mm, *td* = 2.8 mm, *td2* = 0.762 mm].

II. Unit Cell Design

The primary objective of the unit cell design is to achieve a reflection phase switching of 180° for frequencies 7.25 - 8.5 GHz while maintaining a similar reflection magnitude in both the switching states. A dipole loaded with p-i-n diode is a good candidate for a switchable unit cell design. Fig. 1 (a) shows the proposed unit cell architecture in blue dashed line. The design has three layers with a dipole layer on the top, a ground plane in the middle, and a biasing layer on the bottom. The three layers are separated by Rogers AD 600 substrate with $\epsilon_r = 6.15$ and $tan\delta = 0.003$. A portion of the p-i-n diode loaded dipole extends to the next unit cell. The triangle shaped dipole arms are connected to vias though RF choke inductors highlighted in green colour in Fig. 1 (a). The bias voltage can be applied using the via, that connects to a bias line beneath the unit cell. The other via is connected to the RF ground plane in the middle which also acts as a DC ground. The dipoles are placed along both X as well as Y-axis to ensure a polarization insensitive nature.

III. Simulated Responses

The unit cell is simulated in CST Microwave Studio using periodic boundary conditions along X and Y axis. The p-i-n diode MADP-000907-14020P is embedded in the unit cell design using touchstone files from the manufacturer [7]. The p-i-n diode with 5 mA of forward current is taken as ON state and a reverse bias voltage of 0V is taken as OFF state. The RF

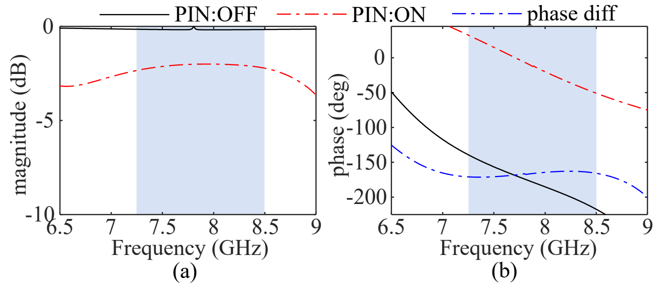

Fig. 2. The reflection coefficient of the unit cell in ON and OFF state (a) magnitude and (b) phase and phase difference between On and OFF state.

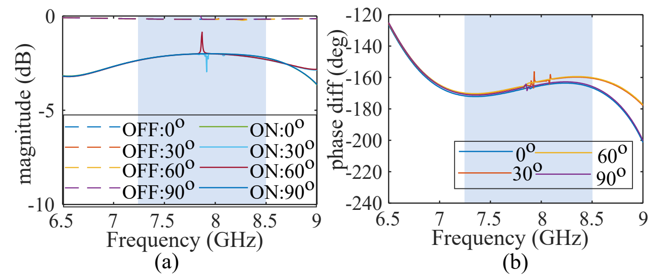

Fig. 3. Effect of polarization angle on reflection coefficient of the unit cell in ON and OFF states (a) magnitude and (b) phase difference between ON and OFF state.

choke is modelled as an inductor of $L = 9.5$ nH with parasitic capacitance $C = 0.04$ pF. The reflection coefficient of the unit cell considering normal incidence, in ON and OFF states are shown in Fig. 2. The magnitude of reflection coefficient in ON and OFF states has a difference of 3 dB, whereas the phase difference between the ON and OFF state reflection coefficients are within $180 \pm 30^\circ$ range in 7.25-8.5 GHz.

As the unit cell has an identical dipole structure with p-i-n diode along both X and Y axes, its response can be expected to be polarization insensitive. Fig. 3 shows the reflection coefficient for variation in polarization angle of the incident wave while keeping the incidence angle to be 0°. In 7.25-8.5 GHz frequency range the reflection coefficients have negligible variation with change in polarization angle. This confirms the polarization insensitive behaviour of the proposed unit cell topology.

The unit cell performance is also studied for higher angles of incidence. The reflection coefficient patterns of the unit cell for oblique incidence are shown in Fig. 4. It can be observed that the phase of the reflection coefficient varies with change in incidence angle. Moreover, the reflection phase in TE and TM modes varies differently. However, the phase differences are within $180 \pm 30^\circ$ for frequencies 7.25-8.5 GHz.

IV. Conclusion

A reconfigurable unit cell was designed that has the capability to switch the reflection phase in a frequency range of 7.25-8.5 GHz for a wide range of incidence angles in both TE and TM modes. The reflection phase switching of 180° can be used for generating reconfigurable scattering patterns. Thus the unit cell has the potential to be used as a building block for

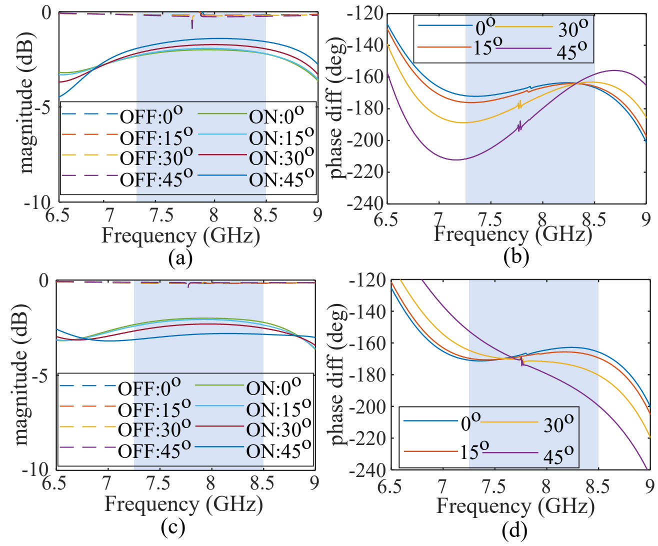

Fig. 4. Effect of incidence angle on reflection coefficient of the unit cell in ON and OFF states (a) magnitude in TE mode, (b) phase difference in TE mode, (c) magnitude in TM mode, and (d) phase difference in TM mode.

RIS panels where challenging operational requirements need to be met such as oblique incidence and different polarization states.

Acknowledgement

This work was supported in part by the UK Research and Innovation (UKRI) Horizon Europe Guarantee under the Project 10051462 (CONVERGE), and in part by a UK Government funded project (REASON) under the Future Open Networks Research Challenge (FONRC) sponsored by the Department of Science Innovation and Technology (DSIT).

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