

Metamaterial-based Reconfigurable 3.5 GHz Unit Cell with Pin Diode Switching

Dr.K Ramasamy

Department of ECE

KIT-Kalaignarkarunanidhi Institute of
Technology, Coimbatore, India
ramasamy10366@gmail.com

Dr.Sapna BA, M-IEEE

Department of ECE

PSG Institute of Technology and
Applied Research, Coimbatore, India
sapna79ece@gmail.com

P Kalaivani

Department of ECE

KIT-Kalaignarkarunanidhi Institute of
Technology, Coimbatore, India
pkalai.ece@gmail.com

Jeyadina M

Department of ECE

KIT-Kalaignarkarunanidhi Institute of
Technology, Coimbatore, India
kit27.eceb041@gmail.com

Loga brindha K

Department of ECE

KIT-Kalaignarkarunanidhi Institute of
Technology, Coimbatore, India
kit27.eceb053@gmail.com

Bharath R

Department of ECE

KIT-Kalaignarkarunanidhi Institute of
Technology, Coimbatore, India
kit27.eceb018@gmail.com

Abstract -- The development and analysis of a reconfigurable 3.5 GHz unit cell based on metamaterial using PIN diode switching are provided for possible use in 5G wireless communications. The proposed unit cell makes use of a PIN diode to enable reconfiguration of electromagnetic parameters by varying the current flow and resonances of the unit cell. Our proposed reconfigurable unit cell is made for operation around the 3.5 GHz frequency band of the 5G technology, with improved size and electromagnetic performance. The use of a switching PIN diode allows the unit cell to have different transmission and reflection responses when operating in ON and OFF modes. Various electromagnetic simulations are performed to study overall performance of the unit cell, in terms of parameters like S parameters, resonances, and effective metamaterial properties. It is found that the unit cell shows good switching behavior as well as performance around the desired frequency, validating the proposed concept.

Keywords— Metamaterial, Reconfigurable Unit Cell, PIN Diode Switching Mechanism, 3.5 GHz Frequency Range, 5G Communications, S-Parameters.

I-INTRODUCTION

The introduction of 5G mobile communications has led to the development of devices that need to be compact and adjustable electromagnetic devices that can work effectively in the 3.5 GHz frequency range. Out of various techniques available today, one technique that has attracted considerable attention is the metamaterial because of its ability to manipulate electromagnetic waves using artificial structures. Due to its uniqueness, the application of this technology has been seen in various wireless applications such as antennas, filters, absorbers, and frequency selective surfaces.

Recently, trends in the study of this phenomenon are connected with the integration of active switching devices [1] into metamaterial design, which provides the possibility to tune the frequency characteristics and controllable refractive index [2]. As for the choice of the devices, PIN diodes [3] are widely used due to their ability to provide rapid switching, low losses, and simple integration into microwave structures. Control of the biasing states of the diode allows varying the amount of the current passing through the structure and,

hence, the parameters of the structure's resonance behavior [4],[5], thus ensuring various operating frequencies of the structure. In the paper under discussion, a design of a frequency-tunable resonant unit cell [6] working at 3.5 GHz, intended for 5G [7] applications, is suggested. And also, there are various reconfigurable [8] techniques like negative metamaterial antenna [9], 1-bit transmission [10],[11] but here it includes outer rectangular resonator [12], inner ring-shaped resonator, and central diamond-shaped slit with PIN diode switches. Both two- and four-diode configurations are considered to explore the effect of the number of diodes on the resonance and EM behavior of the structure.

Moreover, a compact $9 \times 9 \text{ m}^2$ metamaterial unit cell on Rogers 5880RT substrate, which is designed for Sub-6 GHz 5G applications is of two circular split-ring resonators (CSRR), also a parallel rectangular copper elements and a tunable slotted strip line. Where this design leads to attain the resonance at 3.5 GHz and some properties like single/double-negative refractive index, also a negative permittivity, and near-zero permeability along two principal wave propagation axes. [13]. In a study on broadband frequency-reconfigurable metamaterial absorber incorporating a novel switchable ground plane (SGP) with double resistive square-ring resonators. It is observed that the SGP which is controlled via PIN diodes toggles between states. Over 90% absorption is attained from 3.5 – 11 GHz when the pin diodes are in ON state and it shifts to 1.7–5.2 [14]. For IoT applications a reconfigurable metamaterial multiband antenna is proposed using SRR, quasi-complementary CSRR and a PIN diode for frequency switching. It is observed that it resonates at 8 frequencies covering S, C, X, Ku, and K bands and this supports WLAN, Satellite, and radar communication with stable radiation, reasonable gain, and efficient multiband operation.[15].

II. Proposed Work

This research work presents a discussion on the design and analysis of a reconfigurable metamaterial unit cell

From Fig.6 to Fig.9 depict the electric field distribution of the suggested metamaterial unit cell for both ON mode and OFF mode states of the both two and four-PIN-diode arrangements. It can be clearly seen that with the change of the ON/OFF states of the PIN diodes, there is a variation in the current distribution within the arrangement, and hence there is a corresponding variation in the electromagnetic field distribution in the resonator, resulting in variations in the resonant properties of the latter. With the additional two PIN diodes used in the four-PIN-diode structure, the number of current paths passing through the resonator increases, resulting in enhanced electromagnetic fields by means of increased electromagnetic field confinement. The effect is enhanced due to increased current density.

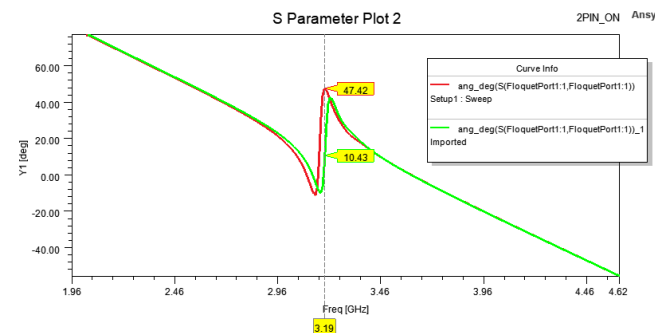


Fig.10 Phase shift of using 2 Pin diode

Fig. 10 illustrates the simulated phase variation of the proposed antenna using a two-pin diode configuration, with a significant phase transition observed around 3.19 GHz.

A phase response for the suggested metamaterial element was analyzed for both positions (ON/OFF) of two PIN diodes. Transition from one position to another implies that a new path is chosen for the current passage inside the resonator, which corresponds to a new phase value. As it can be seen from the results of the performed analysis, the phase difference between two positions is equal to 37.01° . The change of phase indicates that the presented structure possesses the feature of dynamic control of the electromagnetic response with electronics. The obtained results allow us to suggest that the designed element can be successfully used for phase-agile meta surfaces, beam-steering, and 5G communication.

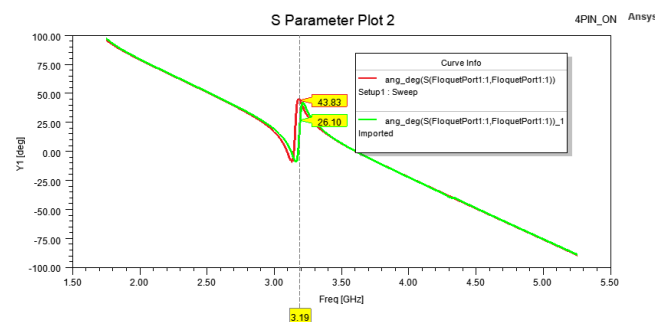


Fig.11 Phase shift of using 4 Pin diode

The graph in Figure 11 represents the output phase response for the unit cell developed using the 4-PIN-diode setup. As the diodes switch from the ON to the OFF states, the current density and electrical length of the resonator change, hence resulting in the phase shift in the transmitted signal. Simulation results confirm that there is a difference of phase value of 17.73° between the two ON/OFF diode setups.

However, if 2-PIN-diodes are used, then there will be a phase difference of 37.01° . The simulation results above clearly indicate that by increasing the number of diodes within the setup, the control of the field becomes much easier, hence leading to reconfigurations and phase modulations. In conclusion, it can be observed that the developed unit cell can offer phase modulation capability through electronic switching.

IV. CONCLUSION

For this study, the reconfigurable metamaterial unit cell at 3.5 GHz is introduced and designed using the two different PIN diode-based switching, such as the use of 2-PIN-diode and 4-PIN-diode. Simulation verified that there was indeed resonance at the intended frequency, along with the reconfiguration of the cell achieved by means of switching between PIN diodes. The simulation also provided the effects of switching by analyzing the electric field as well as S-parameters of the cell. From the simulation results, it could be clearly seen that the 4-PIN-diode cell performed better in terms of electromagnetic properties than the 2-PIN-diode one. Phase shifts of 37.01° and 17.73° were recorded for the two cells, respectively.

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