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Design and Simulation of Multi-Arc Spiral FSS for 5G Application

P .Kalaivani
Dept.of ECE
Kalaignarkarunanidhi Institute of Technology , Coimbatore, India
pkalai.ece@gmail.com

Dr.K .Ramasamy
Dept.of ECE
Kalaignarkarunanidhi Institute of Technology , Coimbatore, India
ramasamy10366@gmail.com

Dr.Sapna B A(*M-IEEE*)
Dept.of ECE
PSG Institude of Technology and Applied Research, Coimbatore, India
sapna_psmi@yahoo.co.in

Tharshini. M
Dept.of ECE
Kalaignarkarunanidhi Institute of Technology , Coimbatore, India
tharshinimuthu2607@gmail.com

Sri Jagannath. K
Dept.of ECE
Kalaignarkarunanidhi Institute of Technology , Coimbatore, India
srijagannath05042607@gmail.com

Udhai Subasree. P
Dept.of ECE
KIT-Kalaignarkarunanidhi Institute of Technology , Coimbatore, India
pichaiyaudhaisubasree @gmail.com

Abstract— The purpose of the research was to create a frequency selective surface (FSS) unit cell's design and measurement at a frequency of 3.5 GHz using FR4 types of materials. The influence of the angles, theta (θ) and phi (Φ), upon the performance of the unit cells has been studied in order to obtain an experience with both the resonance and frequency selectiveness behaviors of the unit cells. The performance of the entire group of unit cells within a 2 x 2 array was evaluated and the findings from the evaluation showed a gain in performance for the array in both passband dimensions and ability to filter out an undesired signal. The resultant of the simulation indicates that was a significant reduction in the amplitude of the signal from the undesired antenna, therefore, the developed rectangular FSS unit cell design should have good potential in future utilization for smart wireless data communication applications (less than 6 GHz). The rectangular structure that was constructed using an FR4 substrate is compact and provides a cost-effective means to construct the unit cells; therefore, this design is amenable to practical realization and implementation. The structures can also readily be scaled which opens a pathway for the construction of larger arrays that would provide for more advanced capabilities in terms of operational functionality that could be realized. In summary, the results demonstrate that the use of advanced communication technologies with respect to the connection of the unit cell to an FSS will provide a consistent frequency of resonance, exhibit stable angularity, and demonstrate excellent performance for any application requiring frequency selectivity, reduction in interference, and improvement of signal quality. Future work will include validation through experimentation and defining designs for multi-band frequency applications to further enhance the performance of the FSS to address their intended uses.

Keywords— Frequency Selective Surface, 5G communication, electromagnetic wave, Multi-Arc Spiral, Angular Stability.

I. INTRODUCTION

The innovative approaches related to the electro-magnetic protection, performance enhancement, and efficient electro-magnetic control of wireless and aerospace next-generation wireless communications and advanced radome and antenna systems have been explored using Frequency Selective Surfaces (FSS) [1]. The dual-stopband FSS structures will create better filtering and suppress unwanted frequencies more effectively than previously used methods [2]. Also, the ability to create tunable and active FSS configurations continues to develop, resulting in more flexibility and adaptability as the environment changes [3]. Miniaturized dual band FSS designs are already being investigated to reduce size and yet still have multipoint operations [4]. The new all-dielectric FSS configurations have been developed using FSS with no metal components to reduce losses, thereby increasing efficiency [5].

FSS structures that operate over many frequency ranges have been developed to provide greater bandwidth and more effective operation across the full frequency range [6]. dual-polarity advanced FSS designs have been made to work with today's advanced communication systems with greater signal handling and less variability in polarization matching losses [7]; FSS structures have also been studied for stealth and low observable applications, using FSS to reduce radar cross section while maintaining the ability to communicate [8]; Another critical element is to maintain a consistent performance level regardless of the angle of incidence, which can be achieved using high-selectivity FSS designs that are very stable at all angles for reliable performance in real-world environments [9]; The challenges of controlling beams and adapting to changing environments can be met using reconfigurable frequency selective surfaces (FSS) that can change the direction of the electromagnetic wave and increase coverage [10]; The need for multiple functionalities has created a demand for various types of FSS structures with dual-band and multi-band properties that provide multiple operating frequencies within the same structure, which will provide for improved performance and operational flexibility [11]. Also, band-pass FSS structures have been extensively studied for use in wireless communication systems. These systems provide a means of selectively passing or rejecting signals based on the desired frequency [12]. FSS have traditionally been designed as fixed-frequency devices, meaning they are not adaptable to meet the needs of a changing frequency. For this reason, tunable or reconfigurable FSS structures have been investigated for use with active devices, thereby providing a means of

dynamically controlling their operating frequencies [13]; One of the problems in multi-antenna systems is that mutual coupling between adjacent or closely spaced elements minimizes their effectiveness. One solution to this problem has been the use of compact electromagnetic (magnetic) absorbing FSS structures that provide improved isolation and overall system efficiency [14]. The electromagnetic and wireless systems have experienced rapid development in recent years. This paper discusses some of the challenges and creative solutions to these issues, as well as how they have influenced the design of efficient Frequency Selective Surface (FSS) structures which can be used for modern communication applications. Improving the performance of antennas has always been an important issue; using FSS structures to manipulate the propagation of electromagnetic waves has been an effective way to improve transmission properties (gain and directivity) of antennas [15]. They have provided a comprehensive basis for the development of advanced FSS technologies for high-performance, flexible, low-cost next generation communication systems.

II. Proposed Work

A frequency selectivity surface (FSS) unit-cell has been created and evaluated for operation at 3.5 GHz. A major focus of the design was on the optimization of the electromagnetic response to provide a stable and reliable electromagnetic response at the design frequency. The proposed FSS is made up of several different arcs printed onto a single-sided insulated material (FR4), which reduces cost of production while maintaining a good level of performance electrically. The FSS unit-cell has been evaluated using simulations, which have shown that it provides a consistent resonating frequency and an effective frequency-selective surface for the use of wireless communication applications under sub-6 GHz. Fig 1. Shows the proposed unit cell structure designed for FSS.

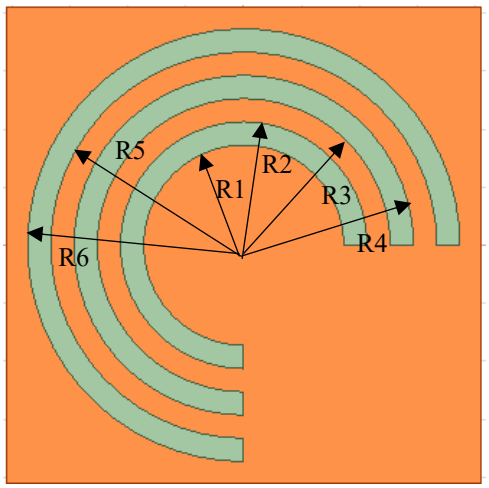

Fig. 1. FSS unit cell design

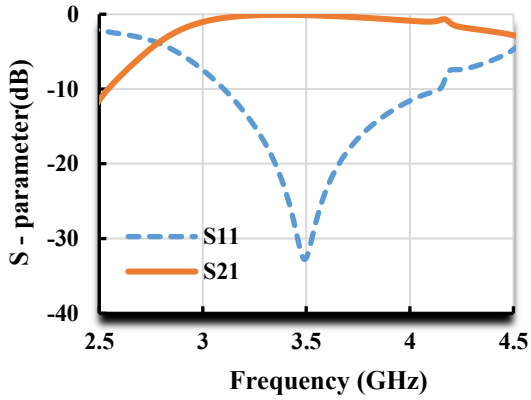

Fig. 2. Response of FSS unit cell

The angular component and radius parameters will influence on the control applied to the electromagnetic response. To adjust the interrelationship of the geometry (or shape) of each component, six radius variables; r1, r2, r3, r4, r5, r6 have been used. Each of the optimized parameters are defined as follows: r1 = 18.36 mm, r2 = 16.36 mm, r3 = 14.36 mm, r4 = 12.36 mm, r5 = 10.36 mm, r6=8.36mm, used to control the resonant characteristics of the device to operate correctly at a frequency of 3.5GHz. The validation of Fig. 2 was completed by analysing the varaiations of theta and phi angle, confirming that the device retains its performance characteristics when operated at 3.5GHz, even when subjected to varying incident angle conditions.

To investigate the effect of an array of unit cells on the overall structure's performance, a modified unit cell design was created into a 2×2 array configuration as shown in Fig. 3. The multiple unit cell components in the array's design will have their resonance characteristics preserved while enhancing the overall performance of the array in terms of both the frequency selectivity of the array, as well as enhancing the frequency bandwidth of the array. The simulation result shown in Fig. 4, demonstrate that 2×2 array has the stable operational characteristics, and the same resonance frequency of 3.5 GHz as the single unit cell. The evidence is clear that the overall frequency selectivity of the unit cell is retained in the array, while providing improved filtering of desired signals, as well as suppressing unwanted responses. This evidence additionally substantiates the scalability of the proposed design and illustrates the likelihood of practical application associated with current sub-6 GHz wireless communication systems. Furthermore, the small-scale FR4-based unit cells provide a low-cost manufacturing process, simple integration and applicability for also constructing small-scale arrays and therefore represent an appealing potential option for advanced frequency-selective surface applications requiring precise resonance and stable performance.

In reference to Table 1, the effective features of the Frequency Selective Surface unit cell as compared to other designs are evident. Improvements in all conditions have been demonstrated, as well as broader carrier frequency bandwidth and improved quality in terms of frequency selective filtering properties. The compact and scaleable physical design could quickly be incorporated into larger arrays to provide additional ability to control signals and eliminate unwanted responses in practical wireless communications systems.

IV Conclusion

A frequency selective Surface (FSS) unit cell has been designed and evaluated as part of this project to operate at 3.5 GHz which is a pertinent frequency for sub 6GHz wireless communication systems. The design has been evaluated with respect to its electromagnetic properties systematically to ensure that the unit cell has a stable resonance point and consistent frequency absolute behaviour at different structural parameters. The analysis results confirm that the proposed design operates reliably near the target frequency and demonstrates viable compactness and efficiency as an FSS. The proposed cell unit is capable of being part of bigger arrays due to its inherent scalability. Examples of these enlarged configurations will include 2×2 arrays. Being able to use these larger structures together will enhance their collective performance as well as improve their overall bandwidth and filtering capabilities. Because the unit's element is constructed from an FR4 substrate, it allows for relatively low-cost fabrication while allowing for practical use in today's communication networks. The inherent flexibility of the design will allow for future changes that allow for multi-band separation, thus permitting wider applications throughout the world and for future sub-6 GHz systems. Upcoming experiments will concentrate on the experimental validation and evaluation of a two-by-two FSS array's performance using actual operating conditions. The goal of these studies is to verify the results from simulations and show that the FSS can work successfully in the real world. The result of this research is to develop an FSS as a reliable and flexible component that can provide increased frequency selectivity, improved signal quality, and improved overall performance of future wireless communication systems. It can also aid the development of well-engineered FSS components for next-generation high-performance communication structures.

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