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Design and Simulation of a Microstrip Leaky-Wave Antenna with the Substrate of the Metamaterial

Mohammad Amin Semsar [1], Ali Hashemi [2]
1-Ms of Telecommunications ⁄ Islamic Azad University ⁄Majlesi branch, Isfahan, Iran.
Email: amin.semsar@gmail.com
2- Assistant Professor/ Department of Electrical and Computer Engineering, Faculty of Mohajer,
Isfahan Branch, Technical and Vocational University, Isfahan, Iran.
Corresponding Author: Mohammad Amin Semsar

***ABSTRACT**: Microstrip leaky-wave antenna is a group of microstrip antennas that are small in size, easy to build and easy to install. The characteristic feature of the leakage antennas is to change the angle of the antenna by changing the frequency. This feature will increase the antenna's spatial scan and scan a wider range. In this paper, we try to increase spatial scanning using the substrate of the metamaterial, in addition to minimizing the dimensions of the antenna. Antenna design is carried out using the transmission line method. The proposed antenna is simulated by the HFSS software. The simulation results indicate that the proposed antenna can scan the space between the angles of -20 ° to 35 ° in the frequency range of 3.7 to 5.2 GHz, and the number of 8 via has been removed from the prototype. The spatial scanning of the negative angles and the reduction of the number of electrical connections of the upper and lower layer of the microspheres are the advantages of the proposed antenna.*

Keywords: *Leaky-wave antenna, Metamaterial, Space Scan, Antenna radiation pattern, Transmission line method*

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I. INTRODUCTION

Microstrip antennas have been used by many researchers for their simplicity of analysis, ease of construction, easy installation, and proper radiation characteristics [1].The versatility with the installation location, the simplicity and cost-effectiveness of using the PCB, small, mechanical strength, and radiation pattern compatible with the intended application are considered as the main advantages of these antennas [1]. Leaky-wave antennas are a special type of antennas in which there is a scrolling wave. In the structure of these antennas there are discontinuities in which the radiation is carried out. An important feature of these antennas is to scan the space by changing the frequency so that it changes by changing the frequency to the original pattern. But leakage antennas also have some disadvantages, including scanning angle limitation or narrowing of part of space, such as negative angles, dimension enlargement, or increase in the number of array elements, and the complexity of the construction due to the increase in the number of Via. Via[1] is an electrical connection between the top layer and the microstrip substrate. The plurality of these connections causes the complexity of the construction and diversion of antenna specifications from the desired values. Metamaterials are materials with permeability (ε) and permeability (μ). The idea of a material with negative electromagnetic characteristics was first introduced in 1967 [2]. The classification of materials in terms of electromagnetic characteristics is shown in Fig. 1. [3]

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[1] Vertical Interconnect Access

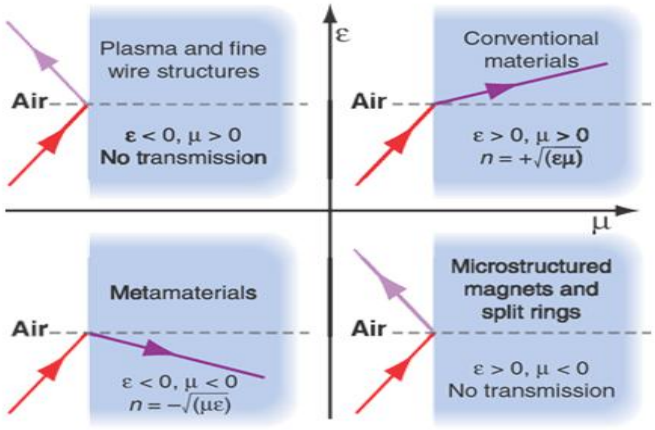


Fig. 1. Material classification based on permeability and permeability coefficients

Metamaterial leaky wave antennas are an improved type of leaky wave antennas. Metamaterial causes scan more space and shrink the volume of the antennas. In Metamaterial leaky wave, it is not necessarily used with metamaterial materials, but they are simulated by creating predecessor and capacitive structures in the appropriate places of metamaterial behavior and its advantages in improving the antenna performance [4]. In reference [5], a leaky wave antenna is designed and analyzed in large scale which contains a network sheet being placed on a conductive sheet. The opening of this antenna has dimensions of 18 in 24 inches and works at frequencies between 7 to 13 GHz. This antenna has a narrow radiation that scans the angle between 20° to 60° in H-plane and within this bandwidth, bandwidth radiation remains almost constant in H sheet. In frequencies between 7 to 10 GHz side beam drops about 29 dB, or more than the main beam, and at frequencies between 10 to 13 GHz this value is about 23 dB. As it is clear, this antenna needs to have huge frequency change in the input, making the impedance adaptation difficult in order to scan a limited angle range. In addition, constructing it with such a bandwidth may arise certain problems. In reference [6] a leaky wave antenna with elliptical polarization is introduced. This antenna is a flat antenna, which is made through making alternate holes on the sidewall of a rectangular waveguide. Such an antenna has a narrow radiation width, and is capable of scanning the space approximately between 30° to 60°. Reference [7] introduces an antenna that is created by inserting a network of conductive wires into a nonconductive material. Through this, the relative permittivity of this artificially created material is less than 1. This antenna which operates in the X frequency range varies between 17° to 47°. The changing substitute frequency of this angle is 8.6 up to 11.5 GHz. And in this frequency range the radiation angle varies from 5.6° up to 4.8°. In [8], an antenna has been introduced, which has a different structure from mentioned leaky wave antennas so far. In this antenna a nonconductive substrate is used on which a magnetic corrugated material is placed. The radiation angle of this antenna changes with both frequency and the changes of the intensity of static magnetic field, which is induced in the antenna. In [9], a nonconductive antenna has been introduced whose surface is covered with conductor strips arrayed in a special order. The antenna is power-supplied from the middle and is able to yield a rectangular-shaped radiation. In [10], a simple type of leaky-waveguide antenna is presented in which the leak occurs from side walls. This antenna is made of nonconductive and conductive strips that are used to create the radiation in the side wall so that the necessary discontinuity for radiation in the structure will be obtained. This antenna is placed in the category of alternative structure of leaky wave antennas, but its structure is different from the conventional alternative antennas. The antenna in [11] is similar to a wave guide with an open port. It is supplied by a probe in the middle which is able to move. Also, both ends of the antenna as wave guide are connected to the load. The change can be detected in the radiation angle as the frequency changes so that when it varies from 40 to 60 GHz, the antenna is capable of scanning angles from 30° to 57°. This is, then, not satisfactory since it does not scan negative angles and it is just able to scan a limited positive angle range. The reference antenna in [12] is designed for mobile systems. In contrast with most of the introduced antennas so far, it uses micro strip instead of waveguide system and the radiation occurs from the holes on a grounded plate. In reference [13] a metamaterial array leaky-wave antenna with two-dimensional structure is presented. The analysis of this antenna is possible through transmission line. Antenna [14] uses conductive strips in the nonconductive substrate to create the metamaterial structure and by making different arrays of holes on its conductive surface, two leaky-waves antennas are placed close together. This increases the efficiency and orientation of the antenna.

In this paper, an antenna will be provided that pattern begins to scan space from negative angles and uses the metamaterial structure to increase the frequency of this scan continuously to positive angles. The zero angle is the line perpendicular to the antenna board. Also in design will try to get the number of via in the antenna structure to its lowest level, making it easier to build.In the following, the transmission line method is described for the antenna design. By optimizing the proposed structure, it attempts to reduce the complexity of the antenna while improving antenna specifications. The structure is simulated using the full-wave HFSS software and its results will be reviewed. In the final section of the paper, the results of simulation of the proposed antenna are compared with the results presented for the antennas introduced in the articles and authoritative references.

II. ANTENNA DESIGN WITH TRANSMISSION LINE METHOD

Different methods are used to design and model microstrip antennas [1]. In this paper, the transmission line method for antenna design is used. In this method, the antenna array is modeled as a transmission line composed of a number of inactive / passive elements (inductor and capacitor). The equivalent circuit of one of the elements of this array is shown in Fig. 2.

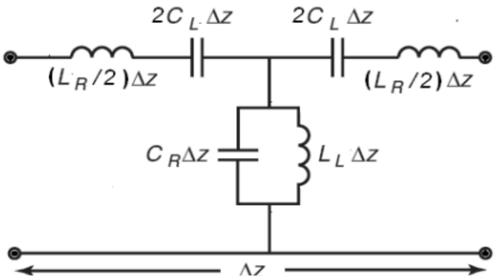


Fig. 2. Antenna Transmission Line Model

Each series inductor can be modeled with a segment of a typical transmission line of λg / 4. But this will prolong the structure of the microstrip antenna. To solve this problem, the equivalent circuit T and its transmission line model are used. Fig. 3 shows the equivalent circuit T and the model of the inductor transmission line.[15]

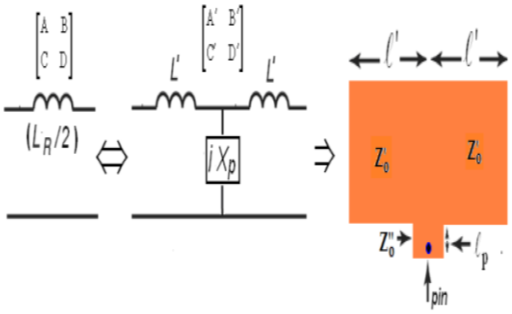


Fig. 3. The equivalent circuit of an inductor and its implementation in the microstrip line

Because of the similarity, to implement a serial capacitor in a microscope line, instead of using the transmission line model, use an interdigital technique and create a capacitor by creating a narrow gap in the transmission line [15].

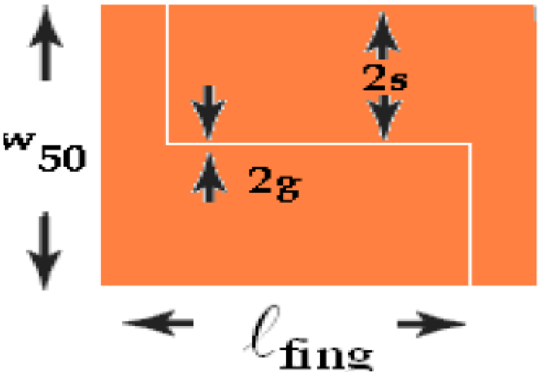


Fig. 4. Implementation of a capacitor in the transmission line using an interdigital technique

As shown in Fig. 5, the implementation of a parallel inductor is carried out by a short-circuit socket. To shorten the end of the socket use a via to connect the patch to the microstrip ground plane [15].

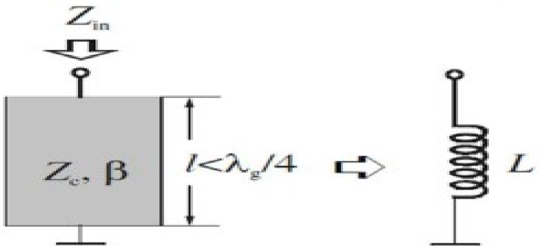


Fig. 5. The parallel inductor model in the microstrip line

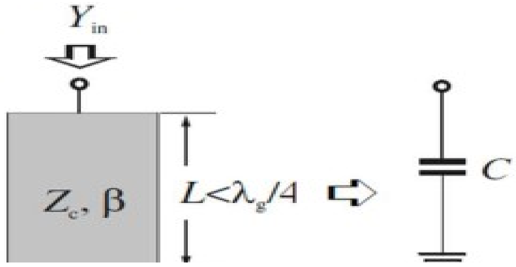


Fig. 6. Parallel capacitor model in microstrip line

A parallel capacitor is also implemented by a short-circuit coupler, as shown in Fig. 6. [15]

Fig. 7 shows the model of the transmission line equivalent to the circuit of Fig. 2. This line has 3 numbers and its dimensions are calculated and determined according to the values of the circuit elements and the frequency of work [15].

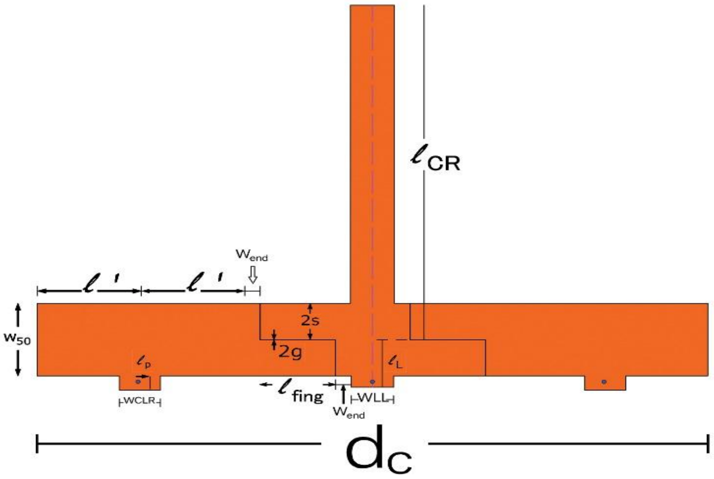
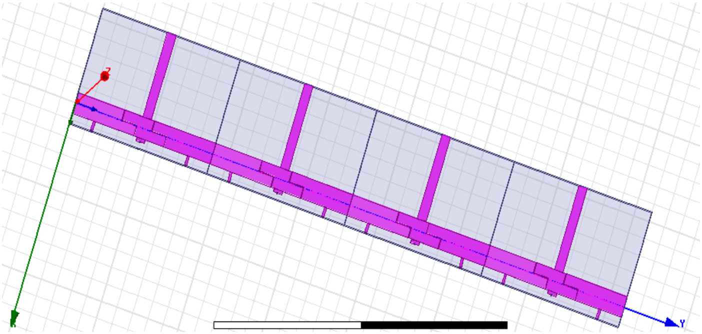


Fig. 7. Microstrip line model of circuit figure (2)

The proposed antenna in this paper is an array leaky wave antenna with a substrate of metamaterial. The array is composed of four identical elements, each of which is the metal patch of Fig. 7. Figure 8 shows the proposed antenna structure.



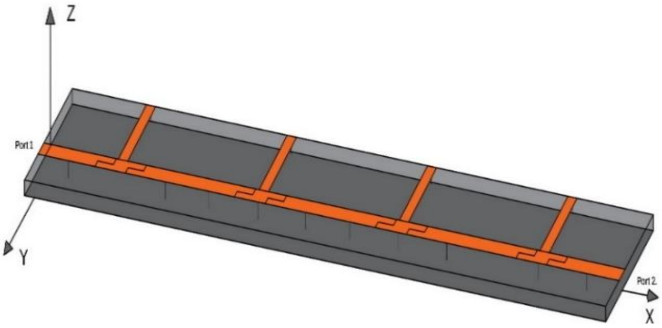


Fig. 8. Structure designed for antenna

As you can see, the proposed structure has 12 via. The high number of via will make the antenna complicated and difficult. In order to reduce the number of via and reduce manufacturing problems, the design of the antenna as shown in Fig. 9 is changed.

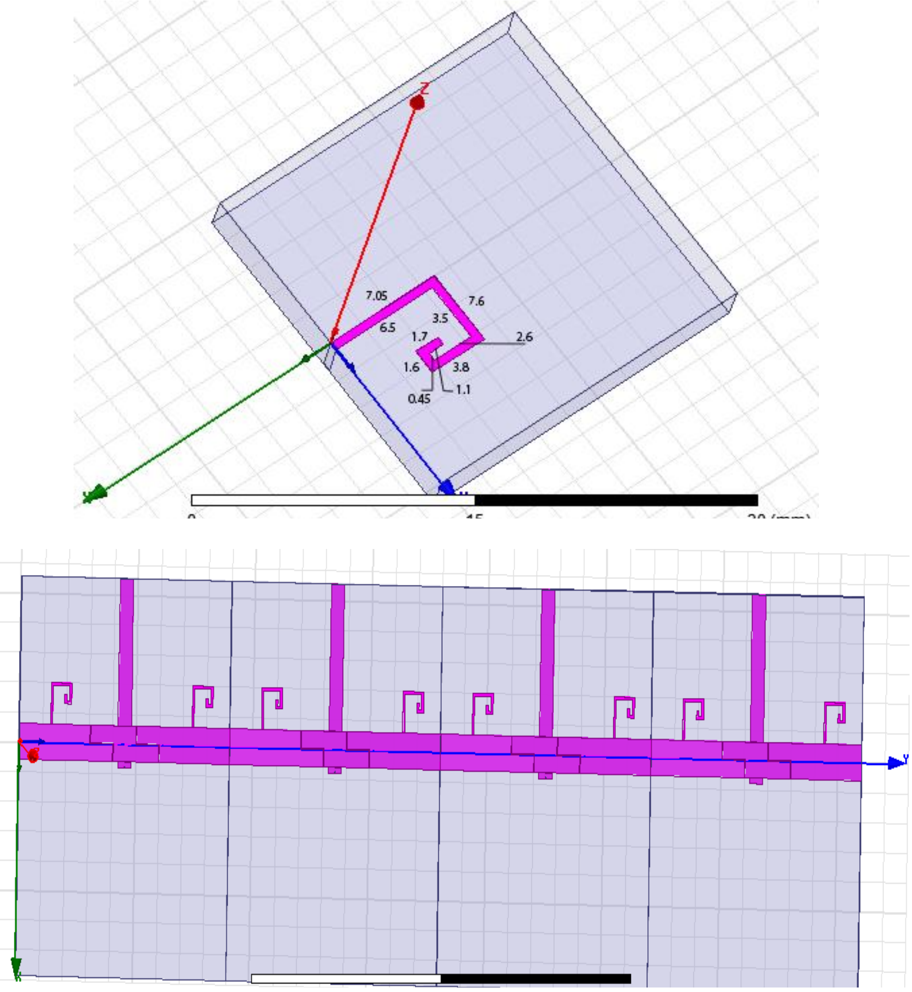


Fig. 9. Designed antenna modified structure

To fix the defects introduced, use from inductors made of microstrip helix line instead of inductors made of microstrip lines with short-cut ends. Because there is no precise analytical formula for making the helix succession with the desired value; the procedure is such that initially a spiral with a length close to the length of the inductor created with a short-term microstrip line is considered, Then, by changing the length and thickness of the helical arms, simulation is done in the HFSS software to create the desired value of the predecessor [15]. The helix patch will act like an inductor and will mount on the initial structure, which will reduce the required number of via per in each element of the array to 1. As a result, the number of via in the entire structure of the antenna is 4, which naturally reduces the construction problems.

III. SIMULATION AND COMPARISON

In order to simulate the structures designed in the previous section, HFSS software was used. The substrate insulation was chosen from FR-4 with ε_r = 4.4 and 3.15 mm thickness due to its high mechanical strength. The microstrip line width is determined in such a way that the characteristic impedance of the antenna is 50 Ω. The operating frequency is considered to be 2.4 GHz. This frequency is used in mobile communication. Under these conditions, using the relations of the microspheres lines, the dimensions of the structure proposed in Fig. 8 in millimeters were determined as follows:

ℓ_P=2.8, WCLR=0.71, WLL=2.8, ℓ_{CR}=27.75, 2s=3.03, W_{50}=6.06, ℓ=4, d_C =45, 2g=4.14, ℓ_{fing}=5, W_{end}=1, ℓ_L =3.9

The thickness of the metal patch and Ground plane which is made of copper is 14 μm. In Fig. 10, the antenna parameter S_{11} is plotted in terms of frequency. As you can see, the frequency range for this antenna is 1.9 to 2.35 GHz. In order to determine the angle of the scan scanned by this antenna, in Fig. 11, the radiation pattern of the antenna is plotted in the aforementioned frequency range.

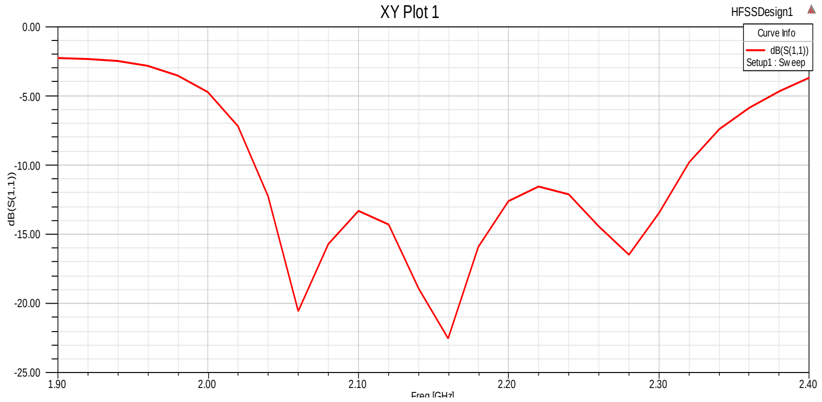


Fig. 10. Shows the proposed S_{11} antenna

As shown in Fig. 11, by varying the frequency of the antenna from 1.9 to 2.35 GHz, only 0 to 50˚ angles are scanned in space and unable to scan negative angles.

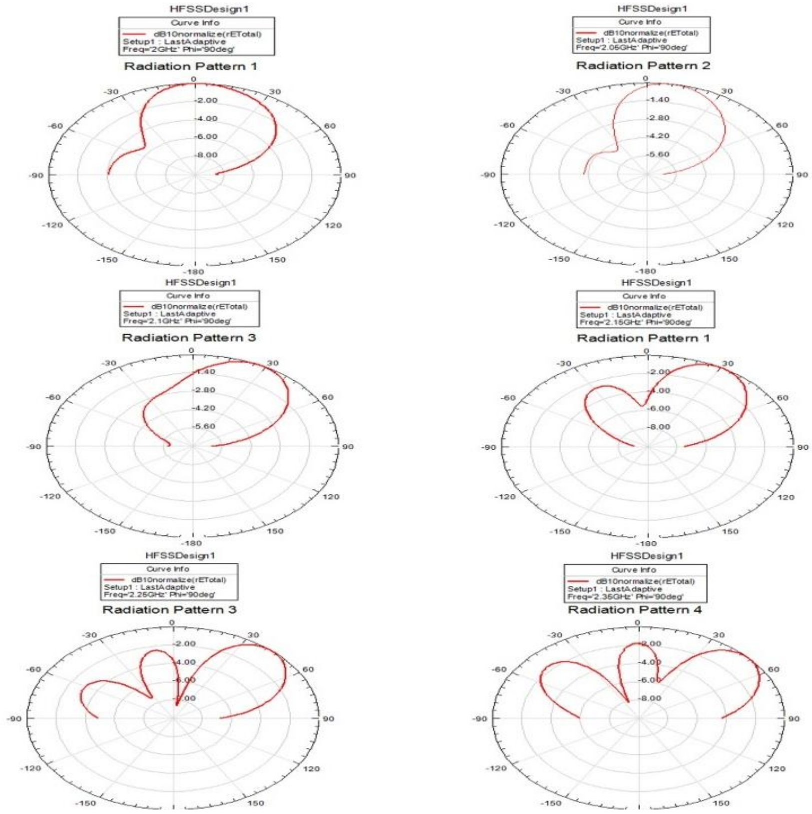


Fig. 11. Initial proposed antenna pattern

In Fig. 12, the antenna modified structure parameter S_{11} is plotted in terms of frequency. It is noticeable that the antenna's operating frequency is in the range of 3.7 to 5.2 GHz. This shifting of the frequency relative to Fig. 10 is due to the fact that the amount of inductor generated in the helix structure differs from that of the Initial structure.

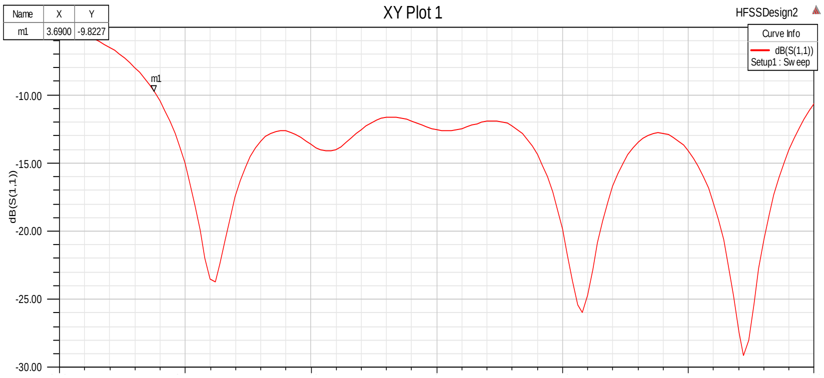


Fig. 12. S_{11} Modified Proposed Antenna

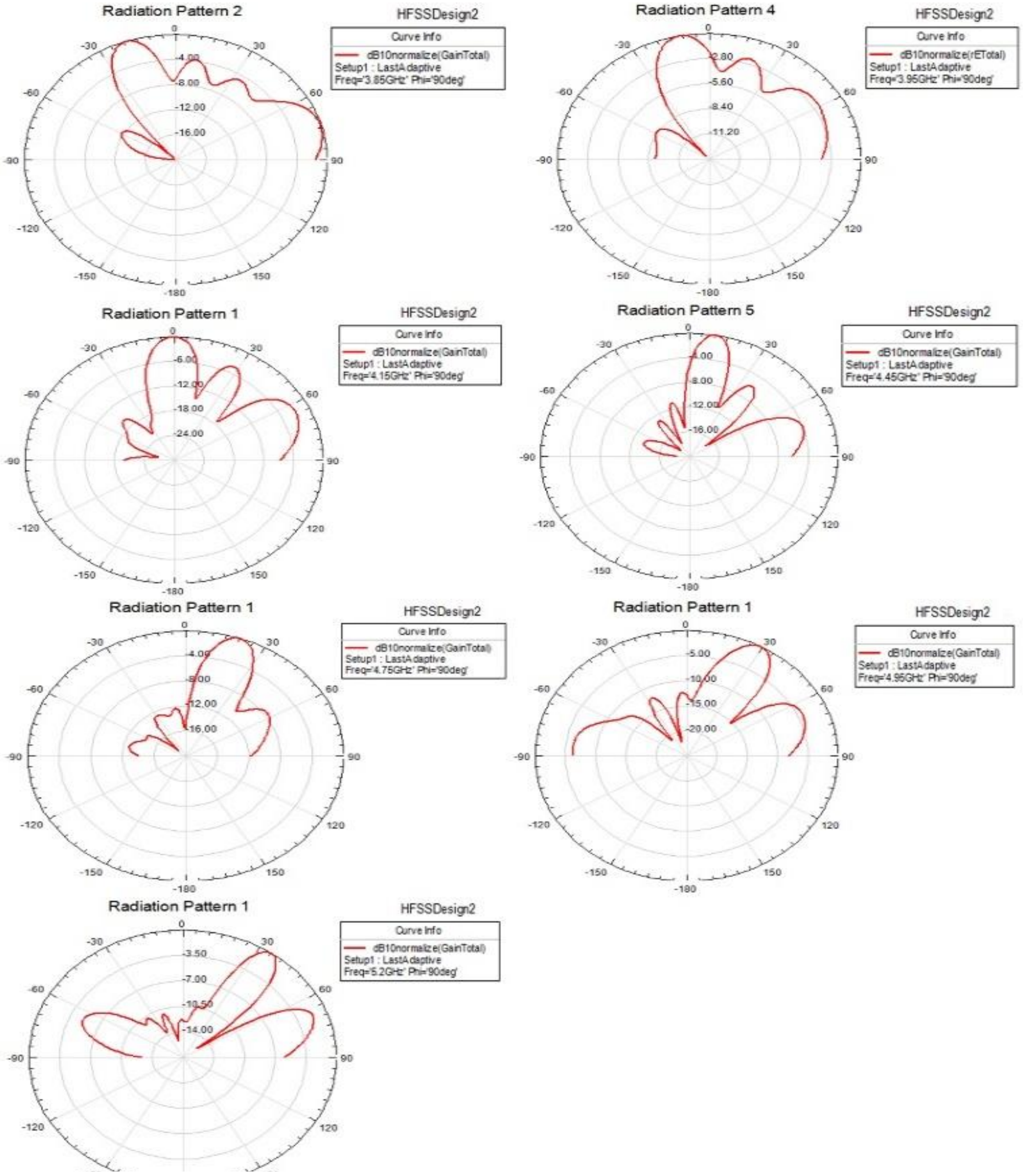


Fig. 13. Modified proposed antenna pattern

Figure 13 shows the radiation pattern of the proposed modified structure. As seen, in this antenna by changing the frequency, the scanned angle varies from -21˚ to + 35˚.

Table 1. Comparison of suggested antennas with valid references.

Description - Features	The complexity and size of the antenna	Frequency range required	Range of scanning angles	Least power Returning antenna
The initial proposed antenna structure	High	1.9 upto 2.4 GHz	0°upto 50°	-23 dB
The modified proposed antenna structure	low	3.7 upto 5.2 GHz	-21°upto 35°	-29 dB
Reference antenna [10]	Very high	5.7 upto 7.4 GHz	-21°upto 50°	-28 dB
Reference antenna [11]	Very high	8 upto 12.5 GHz	-60°upto 60°	-30 dB

Comparison of the structures proposed in this paper with the structures presented in the authoritative references [10 and 11] is presented in Table (1). The modified antenna structure in terms of return power is in the scope and size of the research. The proposed antennas are small in size in this two-dimensional article. While the antenna introduced in references [10] is two-dimensional and the antenna introduced in [11] is a two-story structure. So it has more volume and more complex construction. As presented in Table (1), the proposed structures are not able to scan all angles and are less capable of it, but instead have advantages such as smaller frequency range variations and simplicity of construction.

IV. CONCLUSION

In this paper, a metamaterial leaky wave antenna was introduced. The proposed structure is two-dimensional and has the ability to scan negative angles up to -20˚ at a frequency range of 3.7 to 5.2 GHz. The proposed structure was compared with the antennas introduced in the authoritative references. The comparison results indicate that, firstly, the frequency range needed to scan the space in the proposed antenna is smaller, and secondly, the proposed antenna is cheaper and simpler.

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