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MICROSTRIP PATCH ANTENNA BANDWIDTH ENHANCEMENT USING METASURFACE

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Abstract
This study explores the use of a "Metasurface" to enhance the bandwidth of a microstrip patch antenna. The metasurface is strategically placed in relation to the antenna to allow for the overlapping of resonances, resulting in a wider bandwidth. The metasurface is designed to create new resonances within the antenna. The proposed antenna achieves a bandwidth of 5.1 GHz to 8.0 GHz, which is suitable for WiFi standards 5 and 6. The study employs Ansys HFSS software to obtain numerical outcomes. Additionally, a prototype is created and measurements of S11, Smith chart, and gain are obtained. The findings from both the experiments and calculations demonstrate good agreement.

Keywords: Patch Antenna, Metasurface, Bandwidth Enhancement.

I. Introduction
Microstrip patch antennas are widely used in modern wireless communication systems due to their compact size, low profile, and ease of integration with other components. However, their limited bandwidth is a major challenge for designers to achieve efficient communication systems.To overcome this limitation, metasurfaces have emerged as a promising solution. Metasurfaces are artificial structures composed of subwavelength periodic elements that manipulate electromagnetic waves through their subwavelength geometry and arrangement. By designing the metasurface elements appropriately, it is possible to tailor the surface wave propagation and reflection properties, which can lead to bandwidth enhancement and improved radiation characteristics.In this approach, a metasurface is placed on top of the microstrip patch antenna, and it modifies the electromagnetic wave's propagation characteristics,resulting in a broader bandwidth. The metasurface can be designed to introduce additional phase shifts, reflection, and refraction to the wave, which can enhance the antenna's performance.This technique has shown great potential in achieving broadband operation for microstrip patch antennas, which can enable various applications in modern communication systems, such as 5G, Wi-Fi, and satellite communication. Moreover, the use of metasurfaces can also improve the antenna's radiation efficiency, gain, and directivity.Overall, the use of metasurfaces has opened up new possibilities for enhancing the bandwidth of microstrip patch antennas and improving the performance of wireless communication systems.

II. Literature Review
In [11], a double-layered meta-surface coupled with a broadband antenna design is suggested. It consists of two metallic layers printed on two dielectric layers, creating a meta-surface with a 4 x 4 array of square cells on each metallic layer. This design allows the antenna to operate in two modes with resonant frequencies close to each other, resulting in a broader bandwidth. The antenna has a maximum realized gain of 11 and an impedance bandwidth of approximately 43% (-10 dB) between 4 and 6 GHz. The total size of the antenna is 65 x 65 mm2 with a thickness of 5.0 mm.In [12], a fractal meta-surface coupled with an antenna is proposed to increase bandwidth. The antenna patch has a circular design with six double rings, four rectangular slots, and an FR4 substrate with a thickness of 1.6 mm. The antenna has a gain of about 3.6 dB and 90% efficiency, with a size of 40 x 40 mm. The final bandwidth achieved is 2.3 - 4.0 GHz.In [13], a hybrid meta-surface (HMS) is suggested to create a network of broadband antennas. The antenna consists of a ground plane with an H-shaped coupling

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slot and a 4 x 4 matrix of square and metallic patches. The total size of the array is 95 x 95 mm2 with an F4BTM substrate (εr = 3.38, loss tangent of 0.0027) and a thickness of 4.08 mm. The measured impedance bandwidth is 28% (4.41 - 5.85 GHz) with a gain of 8.4 dBi in the operational band. In [14], a meta-surface and a microstrip antenna are coupled to create an antenna for satellite communications. The meta-surface consists of an array of 2 x 2 elements of parasitic square crossed gaps between four-unit cells. The bandwidth achieved is 39.25% (4.28 - 6.37 GHz) with a gain of 6.8 dBi. The total size of the antenna is 36 x 36 mm2 on an FR4 substrate with a thickness of 3.5 mm.In [15], a low-profile microstrip antenna coupled with a meta-surface as a ground plane is proposed. The meta-surface has periodic diamond-shaped unit cells. The antenna has a total size of 55 x 55 mm2 and a thickness of 0.5 mm. It has an impedance bandwidth of 1.83%, radiation efficiency of 83% in the measurement, and a maximum gain of 4.6 dBi.In [16], a low-profile microstrip antenna coupled with a meta-surface as the ground plane is suggested. The meta-surface has periodic diamond-shaped unit cells. The antenna has a size of 55 x 55 mm2 and a thickness of 0.5 mm. It has an 83% radiation efficiency, a 1.83% impedance bandwidth, and a maximum gain of 4.6 dBi.In our work, we propose using a patch antenna coupled to a circular meta-surface to increase bandwidth. The final volume of the antenna is approximately 3.82 cm3. To achieve the widest possible bandwidth, we rotate the meta-surface with respect to the antenna. The antenna is suitable for WiFi 5 and 6 applications. The final fractional bandwidth achieved is 45.4% with a peak gain of 3.8 dBi. Table I compares the results of the cited works in terms of bandwidth, gain, and antenna size.

Reference number	**Fractional bandwidth**	**Volume (cm^3)**	**Peak Gain (dBi)**
[11]	43 %	22.4	11.6
[12]	62 %	2.56	3.6
[13]	28 %	36.8	8.4
[14]	1.8 %	1.51	4.6
[15]	39 %	4.53	6.8
This work	45.4 %	3.82	3.8

Table I Comparison of recent articles published with bandwidth enhancement of microstrip patch antenna .

III. Proposed Work

The antenna design proposed in this section is characterized by its substrate thickness of h = 1.52 mm and a circular shape with a radius of R = 20 mm (at 4 points). The substrate is made of FR4 material, which is a common choice for antenna production due to its reasonable cost. The antenna patch itself is a square shape with dimensions of 21.6 mm x 21.6 mm, and it features four "L"-shaped slots with arm lengths of Ly = 8.55 mm and a slot width of Ws1 = 1.0 mm, as illustrated in Figure 1. The design of the patch is inspired by a previous study [20]. The physical characteristics of the proposed antenna are depicted in Figure 1.

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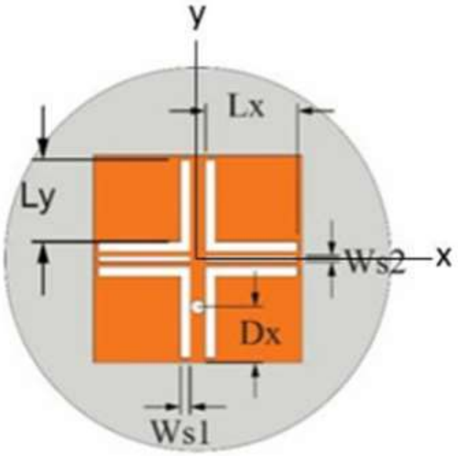

Figure 1

To enhance the bandwidth of the antenna, modifications have been made to the patch design based on the insights from Figures 2 and 3. Two additional slots, serving as capacitive and inductive elements, are inserted into the center of the antenna patch. These new elements are intended to improve the antenna's performance. As a result, the resonant frequency of the antenna's bandwidth of interest is adjusted. The antenna is fed using a 50 ohm coaxial cable connected to a SMA connector, which is positioned at a distance of Dx = 5.8 mm from the edge of the square patch.

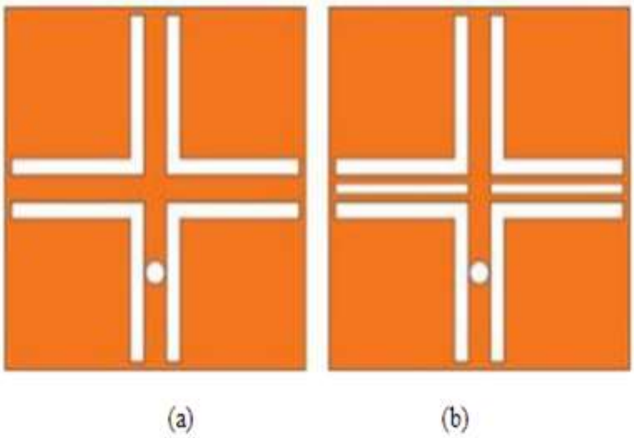

Figure 2. Microstrip patch antenna:(a)used in [20] and (b) suggested in this work.

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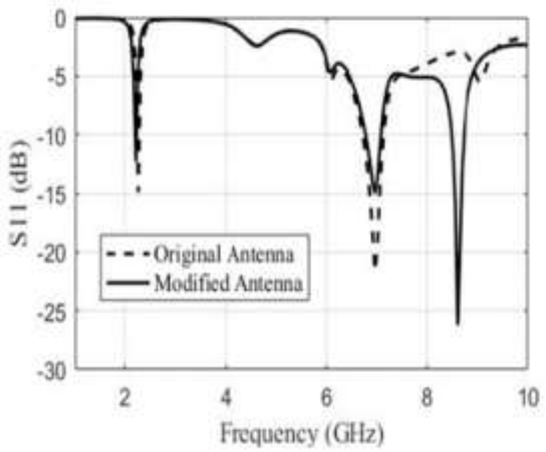

Figure 3. Comparison between the [S11] of the proposed antenna in [20] and our antenna.

The proposed metasurface is composed of unit cells that are uniformly distributed as per the area of metasurface across XY plane. The substrate used is made of FR4 with thickness of 1.524 mm, a radius of 20 mm and a relative permittivity of 4.4. the unit cell design is influenced by works [21-23], and includes a small circle cut with radius of R = 0.5 mm added to its rectangular shape . Fig.4 illustrates the periodic structure and unit cell of the proposed metasurface with measurements of 2.5 mm in width and 5.5 mm in length and rectangular cut of 0.5 mm width and 4 mm length in the middle of unit cell.

The proposed design eliminates the need for an air gap, as the metasurface directly touches the top of the microstrip antenna with its copper-free side.To characterize the proposed cell as a metamaterial in the desired frequency range, we adopt the approach described in [24], which uses an S-parameter retrieval method. The unit cell S-parameters are extracted using ANSYS HFSS, and the electrical permittivity, magnetic permeability, and refractive index are then calculated using equations from [24]. A Wave Port stimulation method is used, with an incident wave parallel to the surface resembling a semi-infinite waveguide to excite the structure. Fig. 6 depicts the retrieved material properties, including the retrieved index shown in Fig. 6(a), which supports the existence of a negative index band between 1 GHz and 9.5 GHz. The functional forms for the permittivity and permeability are determined using the impedance and index, as shown in Figs. 6(b) and (c), respectively.

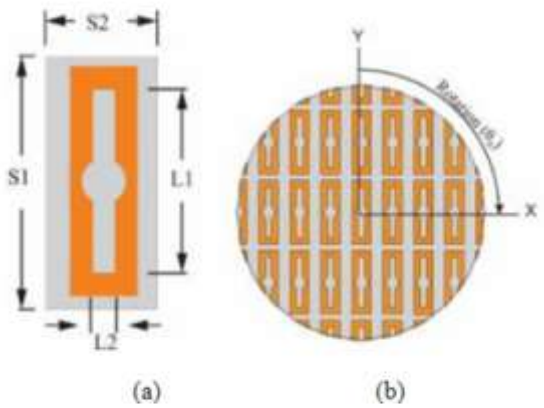

Figure 4. Geometry: (a) unit cell and (b) metasurface

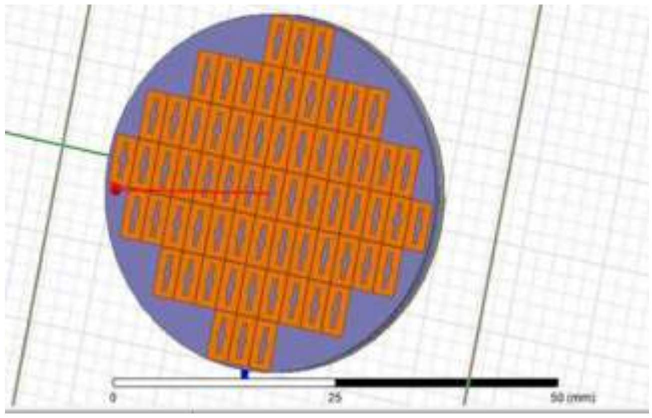

Figure. Metasurface design with total unit cells of 65.

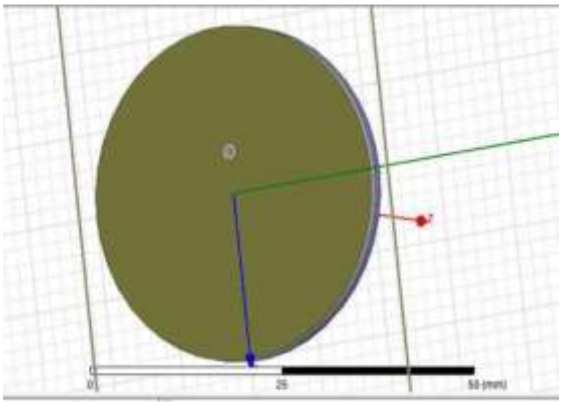

Figure. Bottom view for providing feed through coaxial cable of antenna.

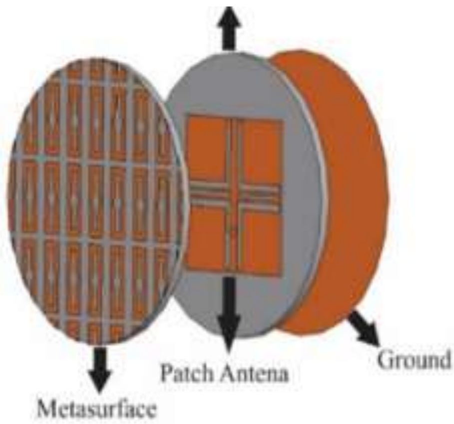

Figure 5. Proposed Structure

The real parts of the refractive index, permittivity, and permeability are all negative at every frequency of interest, leading to the observation that the unit surface meta-cell behaves as a DNG material or left-handed material.

IV. Results of numerical and experimental tests

In order to validate the new metasurface arrangement that can increase the bandwidth of a microstrip antenna, several simulation settings and measured (Agilent Vector Network Analyzer) findings will be compared in this section. The use of manufacturing dimensions was covered in Section 3.

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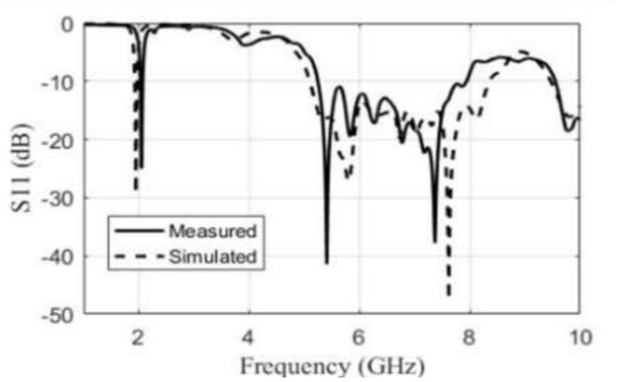

Figure 14. Comparison between simulated and measured results for metasurface at 60°

The outcomes of the 60° rotational metasurface (MS) linked antenna are compared in Fig. 14 using measured and simulated data (use 0° as the MS position in Fig. 4). It can be demonstrated that the simulated and measured results are in good agreement, despite the possibility of some differences between experimental and simulation results due to production tolerances and variations in the properties of the material used.

Figure 15 compares simulated and measured gain. As we can see, the outcomes demonstrate a high level of agreement. We made the observation while concentrating on the relevant frequency band. The WiFi 5 and 6 band operates in the frequency range of 5.1 GHz to 7.2 GHz. The dotted line represents the simulated gain, and the solid line represents the measured gain. HFSS was used to replicate the gain for Phi = 0 and Theta = 0. The measured mean gain is 2.74 dBi, compared to the mean gain that is simulated at 2.98 dBi. The gain was measured using an Agilent E5071C two ports network analyzer in conjunction with two calibrated SAS-571 double ridge guide horn antennas that were spaced 50 cm apart. S21 was measured. Then, we swapped out one of the antennas for our recommended antenna and repeated the measurement. We determined the gain of our antenna using the S21, the distance, and the known horn antenna gain.The difference between the gains from 6.6 GHz to 6.8 GHz, in our opinion, results from the tests not being conducted in an anechoic chamber.

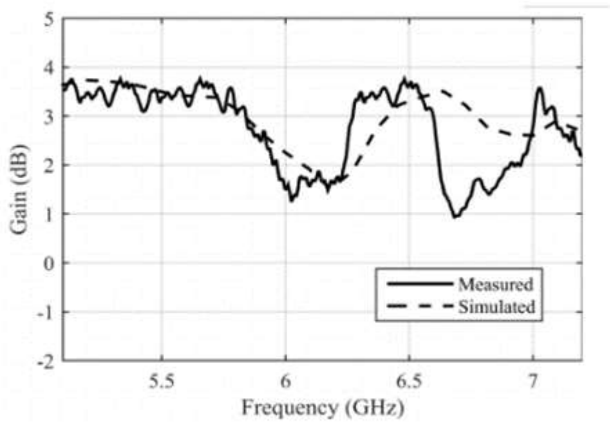

Figure 15**.** Comparison between simulated and measured gain for range from 5.1 GHz to 7.2 GHz.

Some important parameters were simulated to show how the MS increased the antenna's response. Among these factors was efficiency. Figure 16 shows how the efficiency changes as the degree of rotation changes. Efficiency increased everywhere when we rotated the MS.The average efficiency increased to 58% for 60° from 48% for 0°.

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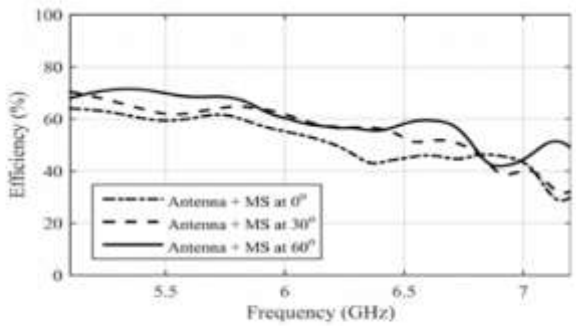

Figure 16. Comparison of the measured and simulated gain over the 5.1 to 7.2 GHz frequency range.

Another significant element is the radiation pattern, which is seen in Fig. 17. It is essential that only minimal alterations to the schematic occur over the whole band. We then draw the diagrams on the E and H planes for the frequency of 6.5 and 5.5 GHz. It is clear that neither the XZ plane nor the YZ plane exhibit major variations in the radiation patterns along the band. Additionally, we can observe that the antenna is not circularly polarised but lacks polarisation purity.

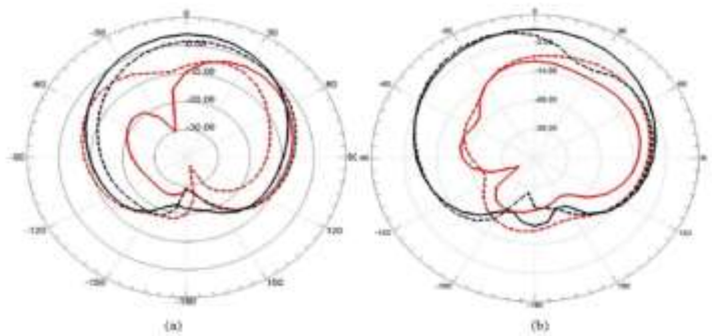

Figure 17. Co- (black line) and Cross-polarization radiation patterns: (a) XZ-plane and (b) YZ-plane, at frequencies of 6.5 GHz and 5.5 GHz, respectively

V. Conclusion

A research paper has shown that it is possible to increase the bandwidth of a microstrip patch antenna by coupling it with a metasurface. This approach also reduced the overall size of the antenna to 3.82 cubic centimeters. The optimal angle for obtaining the metasurface's largest fractional bandwidth was found to be 60 degrees, which required the antenna to be rotated. This new antenna can be used for Wi-Fi 5 and 6 applications and has a fractional bandwidth of 45.4% (covering frequencies between 5.1 and 8.0 GHz) and a peak gain of 3.8 dBi. To validate these findings, a square patch antenna was also constructed and compared to the simulated results. The measured outcomes demonstrated good agreement with the simulated results.

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