A New Metasurface Structure for Bandwidth Improvement of Antenna Array

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Abstract **─** In this paper, the design of an antenna array with enhanced bandwidth is presented. The antenna array includes 16 elements (4 x 4) based on RT5880 with height of 1.575 mm, dielectric constant of 2.2 and loss tangent of 0.0009 and it is yielded at the central frequency of 5.8 GHz for Wireless Local Area Network (WLAN) applications. In addition, in order to enhance bandwidth for antenna, the paper proposes a new metasurface. The metasurface, which is a lattice of 3 x 3 cells, is printed on a substrate of FR4 (h = 1.6 mm, ε_r = 4.4, and tanδ = 0.02) and it acts as an artificial magnetic conductor reflector. The final prototype with an overall dimension of 123 x 120 x 3.315 mm^3 was fabricated and measured. The antenna witnesses an impedance bandwidth of 5.1-7.5 GHz at -10 dB (41%) and a peak gain of 17.65 dBi for measurement. The simulation results are confirmed by measurement ones to verify the performance of the proposed antenna.

Index Terms **─** Array antenna, bandwidth enhancement, metasurface.

I. INTRODUCTION

The antenna plays an important role in wireless systems and a good design of the antenna can satisfy system requirements and improve overall system performance. However, due to limitation of space for antenna in modern communication systems, microstrip antennas [1] are preferred thanks to their advantages such as small size, low cost and profile, easy fabrication and integration. Besides the above advantages, there are some limitations in microstrip antennas that narrow bandwidth, low gain and efficiency are their main drawbacks.

Moreover, Wireless Local Area Network (WLAN) is one of the most popular applications in the wireless communication field. In these applications, antennas with high gain are always required in order to satisfy the demand for long distance communication. Therefore, the improvement for parameters including gain and bandwidth of WLAN antenna is very necessary.

Besides, metasurface can be considered a new version of metamaterial [2]. Compared to metamaterial, metasurface has some advantages including less losses, planar structure and easy for fabrication while they consist of the same characteristics. Currently, thanks to its flexible features is listed in [3], metasurface is becoming more and more popular in a lot of different applications such as cloak [4], imaging [5], absorber [6], beamforming [7] and so on [7] - [8]. For antenna, using metasurface can divide into two types: the first type, the antennas are placed above metasurface [10]. In this case, metasurface includes a metallic lattice and it acts as an artificial reflector. Meanwhile, for the second type, the antennas are located under metasurface [11]. The operation principle of these two types is found in [12]. Recently, many papers have been published to improve performance for antennas [13]–[16]. In [13], a broadband multi-feed tightly coupled patch array antenna is proposed with the bandwidth percentage of 41.3%; however, the peak gain of antenna is only 11.2 dBi. In [14], although a substrate-integrated-waveguide antenna array is designed at frequency of 28 GHz, the bandwidth percentage is only 8.2%. In addition, the peak gain of the fabricated antenna is 13.97 dBi. In other paper [15], a wideband tightly-coupled compact array of dipole antennas arranged in triangular lattice has achieved the bandwidth percentage at -5 dB of 96.3%, but the peak gain is only 16.4 dBi. With paper [16], a hybrid array antenna for millmeter-wave applications at frequency of 30 GHz; however, the percentage of bandwidth is only 13.3%.

For the above reason, an antenna array of 4 x 4 with enhanced bandwidth by using metasurface is presented in this paper. Metasurface composes a new metamaterial structure arranged into a lattice of 3 x 3 based on a substrate layer of FR4. The dimension of the proposed antenna is 120 x 123 x 3.315 mm^3 with a 10dB impedance bandwidth of 41% (respect to the frequency of 5.8 GHz) and a peak gain of 17.65 dBi for measurement. In addition, the antenna remains a high radiation efficiency of 71% at the central frequency. The antenna has been modeled numerically by the software of Computer Simulation Technology Microwave Studio (CST MS) and verified through measurement results to confirm the performance of the proposed antenna.

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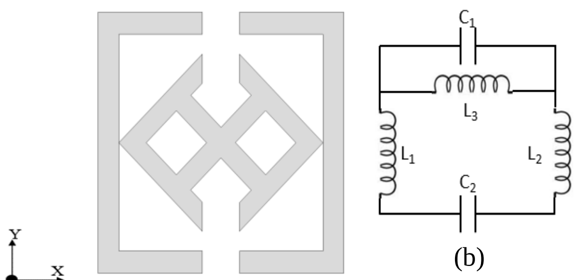
II. ANTENNA DESIGN AND CHARACTERISTICS

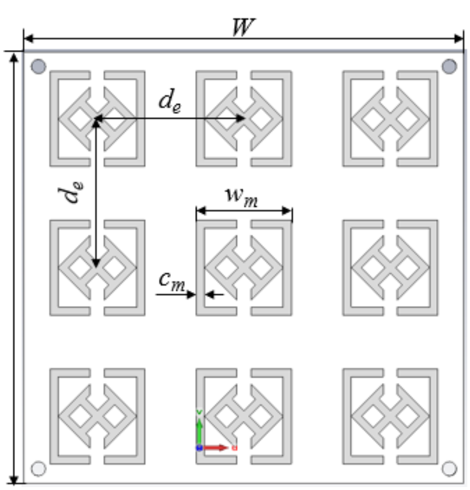
A. The proposed metasurface

First of all, the model of a cell in the proposed metasurface and its equivalent circuit are shown in Fig 1. The proposed model includes a square and a quadrangle, in which the square is outside and the quadrangle is inside. Moreover, to make parasitic capacitors, these shapes are truncated in the middle while the microstrip lines are placed inside of the quadrangle to make inductors. Meanwhile, the proposed metasurface is a lattice of 3 x 3 cells as illustrated in Fig. 2 (a). The metasurface is located on a FR4 substrate with parameters: h = 1.6 mm, ε_r = 4.4, and tanδ = 0.02. The total size of the metasurface is 123 x 120 x 3.315 mm^3 whereas the one of cell is 26.5 x 26.5 x 0.035 mm^3 (0.035 is the thickness of copper layer). The distance between cells is 41 mm. Table 1 shows some parameters of the proposed metasurface whereas the reflection phase of the metasurface is given in Fig. 2 (b). It is observed that the reflection phase is 0^o at the central frequency of 5.8 GHz.

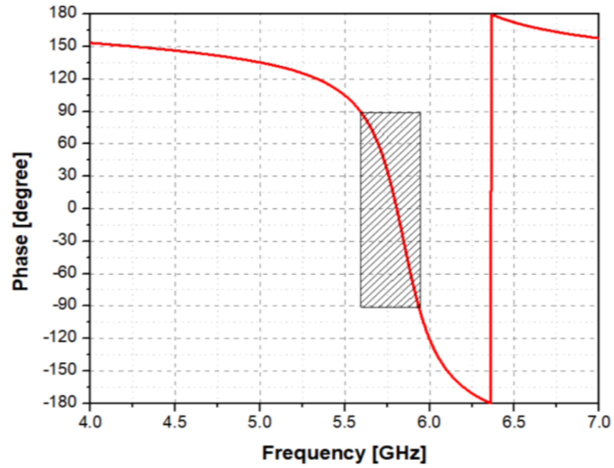


(a) (b)

Fig. 1. The model of the proposed metasurface (a); equivalent circuit (b) (dark colour for metal and light colour for substrate).



(a)



(b)

Fig. 2. Geometry of the proposed metasurface (a); the reflection phase (b).

Table 1: Optimized parameters of the proposed metasurface (mm)

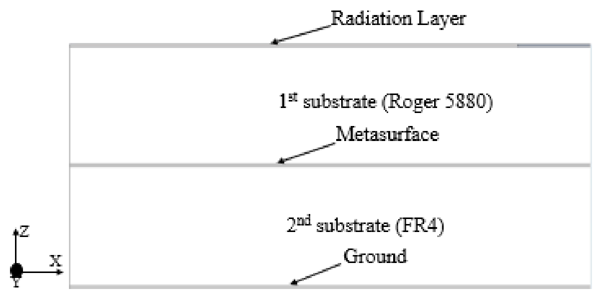
W	L	d_e	w_m	c_m	r	w_c
123	120	41	26.5	4.5	11	4

B. Antenna geometry

Figure 3 depicts the geometry of the proposed antenna array. The antenna consists of 16 microstrip elements (4 x 4), a feeding network, two dielectric layers, the ground plane and a connector of 50 Ohm. The elements, feeding network and the cells of the metasurface are printed on the top side of the first and the second substrate, respectively. Each single element is composed of a truncated corner square patch with the size of w_c while the distance between elements is about 30.5 mm. The two selected dielectric substrates in this paper are Roger RT/Duroid^{TM} 5880 substrate (h = 1.575 mm, ε_r = 2.2, and tanδ = 0.0009) and FR4 (h = 1.6 mm, ε_r = 4.4, and tanδ = 0.02). The feeding network includes 14 equal power dividers to distribute power to elements. The dimension of array is 120 x 123 x 3.315 mm^3. The antenna is implemented for WLAN applications at the frequency of 5.8 GHz. Table 2 shows some parameters of the proposed antenna.

Table 2: The parameters of the proposed antenna (mm)

W	L	d	w_p	l_p	w_s	l_s
123	120	30.5	19	13	0.5	2.75
l_{s1}	w_{s1}	w_c	w_f			
4	0.6	5.2	1.45			



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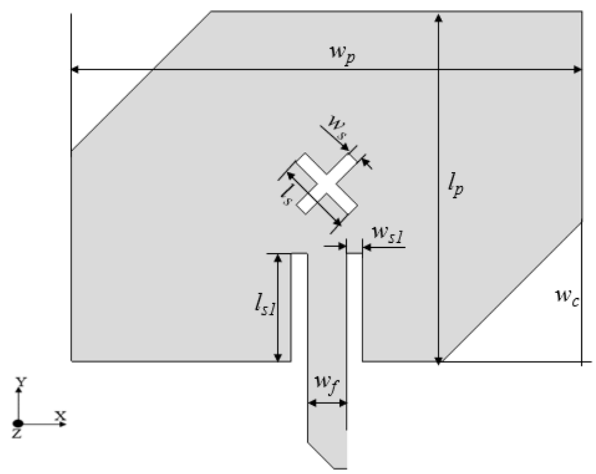
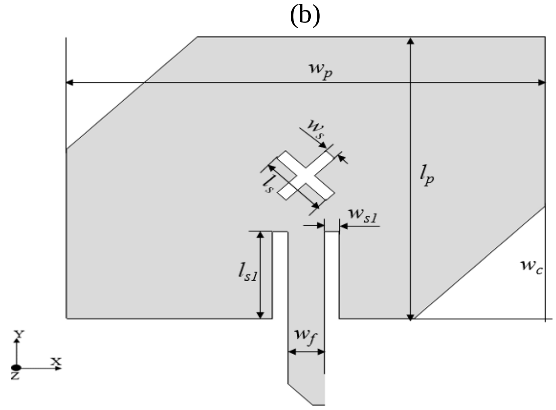


(b)



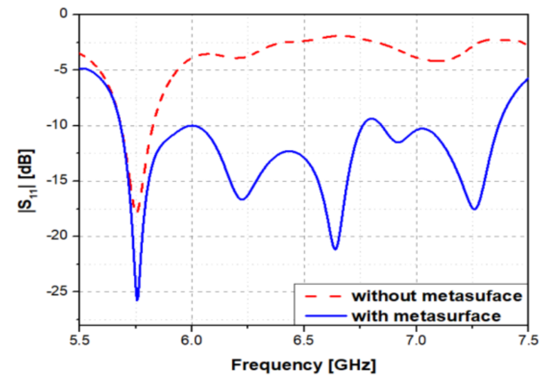
(c)

Fig. 3. The model of the proposed antenna: side view (a); the model of array (b); the geometry of an element (c).

III. ANTENNA OTIMIZATION

As mentioned above, the goal of using metasurface in this paper is to enhance bandwidth by generating extra-resonances. Therefore, this section will concentrate to investigate the effect of metasurface to reflection coefficient. To clarity these mechanisms, some key parameters of the proposed antenna are studied and illustrated in Fig. 4.

Figure 4 (a) shows two values of reflection coefficient in two case with and without metasurface of the antenna array. It is observed that the presence of metasurface generated consecutive extra-resonances [17] and as a result, the bandwidth is significantly expanded. This can see that with the presence of metasurface, the number of resonances is four while this value is only one without metasurface. Therefore, the bandwidth percentages with and without metasurface are 29% and 2.5%, respectively.



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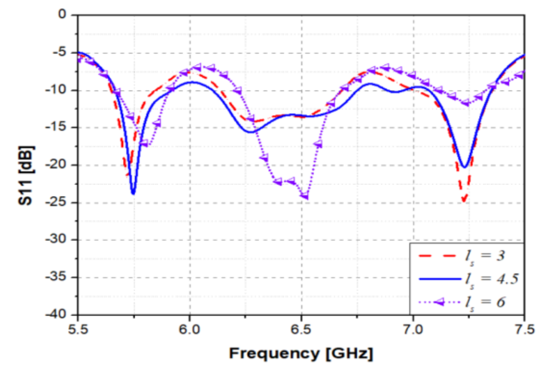

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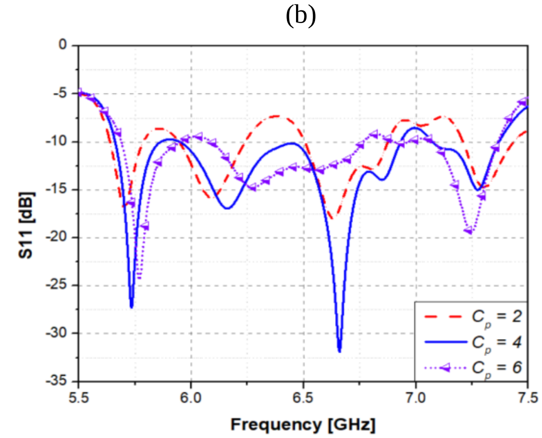


(c)

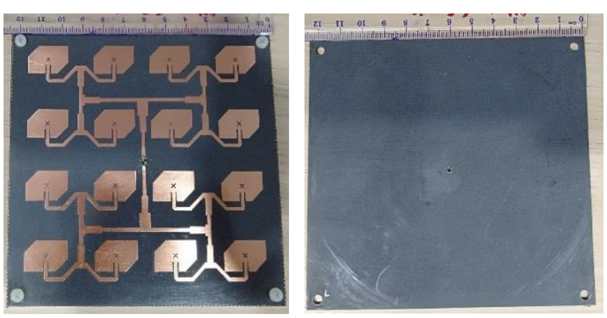
Fig. 4. The simulated result of reflection coefficient versus the change of parameters: (a) with and without metasurface; (b) different slot lengths; (c) cutting at four corners of patch with different dimensions.

Figure 4 (b) displays the simulated S11 for different slot length of the patch. There are many various types of impedance matching including microstrip line feed, probe feed, aperture-coupled feed, and proximity-coupled feed [18]. For microstrip line feed type, the principle for impedance matching is to find point where the impedance is 50 Ohm. Therefore, the reflection coefficient will achieve the best value when it finds the closest value to 50 Ohm. As shown in Fig. 4 (b), by increasing ls, the slot length (ls) from 3 to 4.5, there is an improvement in impedance matching whereas the slot length is 6, the impedance is not as good as the two above cases.

To achieve broadband impedance bandwidth, the cut at four corners of patch is implemented. Figure 4 (c) shows the effect of the cut at four corners of patch with different dimensions. Like as the effect of patch length, with increasing the cut dimension at four corners of patch (C_p), the impedance matching shifted toward the higher frequency. However, while the value of C_p is 4 and this is the best for impedance matching.

IV. RESULTS AND DISCUSSION

To confirm the performance of the proposed antenna, the prototype of the antenna was fabricated and shown in Fig. 5. The size of antenna is 123 x 120 x 3.315 mm^3. The antenna is fabricated on Roger5880 (h =1.575 mm, ε_r = 2.2, and tanδ = 0.0009) while metasurface is based on FR4 (h =1.6 mm, ε_r = 4.4, and tanδ = 0.02). Fig. 6 illustrates the simulated results of the proposed antenna. Observe Fig. 6 (a), we can see that the bandwidth of the proposed antenna at -10 dB covers from 5.68 to 7.36 GHz for simulation while this value is from 5.1 to 7.5 GHz for measurement and it corresponds to 29% and 41.3%, respectively. Here, there is a difference between simulation and measurement results. The reason of this tolerance can be contributed from the instability of the FR4 substrate, an undesired air between two substrate layers and the tolerance in fabrication. However, there is a similarity between the shape of measurement and simulation results and the operating frequency range is ensured. Therefore, this tolerance is acceptable.



(a)

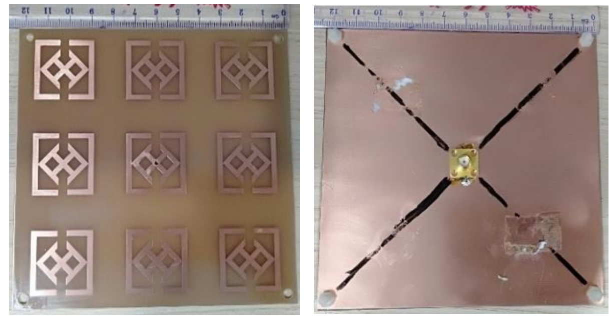


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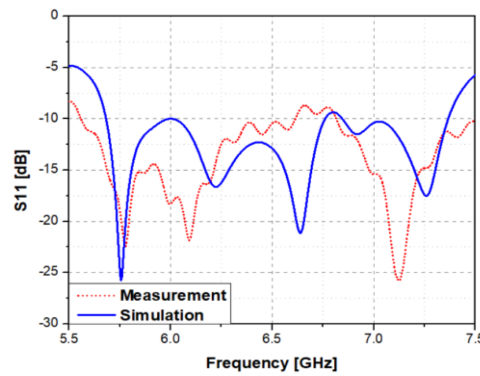
Fig. 5. The model of the fabricated antenna: (a) antenna array and (b) metasurface.



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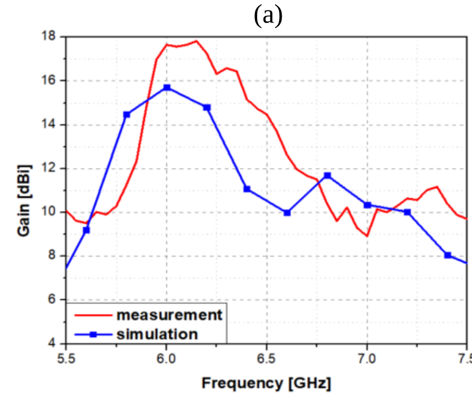
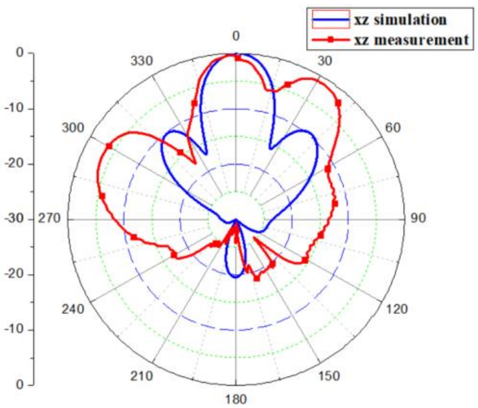


(b)

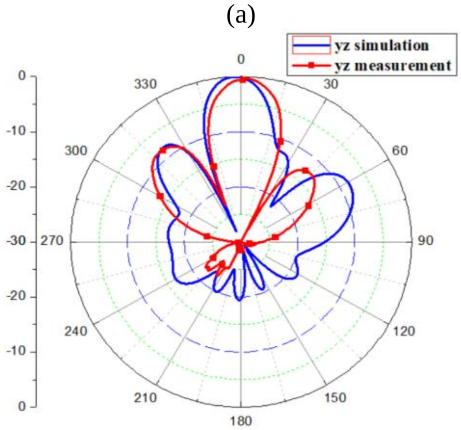
Fig. 6. The reflection coefficient (a); and gain of the proposed antenna (b).

Switch to Fig. 6 (b), we can see that the peak gain of antenna for measurement is 17.65 dBi at frequency of 6 GHz while this figure for simulation is 15.7 dBi. In this case, the measurement result is better that simulation one. This can be explained due to the effect of multipath signal. When there are many in-phased multipath signals, then the total signal is the sum of all signals. As a result, the measurement gain is better simulation one. Therefore, this difference is acceptable.

Figure 7 shows measured and simulated results in xz and yz planes. Observe Fig. 7, we can see that the measurement in yz plane is better and close to simulation result. Although there are differences between simulated and measured results in xz and yz planes, the direction of main lobe in two cases is not changed.



(a)



(b)

Fig. 7. The simulation and measurement results of radiation pattern: (a) xz plane and (b) yz plane.

Table 3: The comparison between the performance of the proposed antenna with recent antennas

References	[18]	[19]	[20]	[21]	**My work**
Number of elements	16	17	32	10	**16**
Frequency [GHz]	5.3	12	84.25	10	**5.8**
Bandwidth [%]	17	52.2	13.89	< 3	**41.3**
Efficiency [%]	x	64	82	x	**71**
Gain [dBi]	15	20.3	19.6	11.8	**17.65**
Size (λ)	2.33 x 2.33	1200 x 9200 x 440	x	2.5 x 1.06 x 0.027	**2.378 x 2.32 x 0.006**

Table 3 compares the performance of the proposed antenna with recent antennas. From Table 3, we can see that an antenna array including 16 elements is yielded at 5.3 GHz; however, the impedance bandwidth and gain are not high (17% and 15 dBi) [18]. Similarly, the percentage of bandwidth and gain in the antenna in [21] are not high (3% and 11.8 dBi) although antenna consists of 10 elements and is implemented at 10 GHz. In another proposal [19], although the antenna has a large bandwidth percentage and high gain (52.2% and 20.3 dBi) when the antenna is designed at 12 GHz (17 elements), the efficiency of antenna is not good (64%). In addition, an antenna of 32 elements operates at the center frequency of 84.25 GHz; however, the bandwidth percentage is only 13.89% [20].

V. CONCLUSION

A method for enhancing the bandwidth for antenna array by using metasurface is presented in this paper. The antenna comprises 16 elements placed RT5880 (h = 1.575 mm, εr = 2.2, and tanδ = 0.0009) and metasurface is implemented FR4 (h = 1.6 mm, εr = 4.4, and tanδ = 0.02). The final prototype with overall dimension of 123 x 120 x 3.315 mm3 accomplished a bandwidth percentage of 41% and a gain of 17.65 dBi (for measurement). Moreover, the efficiency of antenna achieves 71%. With benefits including simple configuration, ease for fabrication, integration and low cost, the proposed antenna can be widely used in WLAN applications.

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