A Tooth-shaped Microstrip Antenna for IEEE 802.11ax Wi-Fi applications

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***Abstract*—Microstrip antennas are widely used in WiFi applications. Due to some IEEE standards, it is not sufficient for those antennas to operate only at some frequencies but some bands. Hence, in this paper, a microstrip antenna design is employed based on a previous design. The previous design is matched at 2.4 and 5 GHz bands but does not conform to the IEEE 802.11ax Europe standards. At this point, the design is modified to encompass the frequency ranges of 2.4-2.485 GHz and 5.150-5.875 GHz with enhanced bandwidths. Also, the maximum gain of the higher band is improved by 2.65 dBi, and the physical size of the design is reduced by 35%.**

***Index Terms*—WiFi antenna, 802.11ax, patch, microstrip, dual-band.**

I. Introduction

In telecommunications, antennas are one of the most critical components, and a well-designed antenna significantly reduces the overall system requirements and enhances the overall performance [1]. In addition, among various types of antennas, microstrip or patch antennas come to the forefront due to their high performance, wide application areas and simple fabrication.

In literature, it is noted that microstrip antennas are used in a wide range of applications such as satellite communications [2], radio frequency identification (RFID) [3], wearable devices [4], and array or single design for wireless fidelity (WiFi) [5]. WiFi antennas are generally designed to operate at 2.4 GHz Industrial, Scientific and Medical (ISM) and 5 GHz Super High Frequency (SHF) bands. Although all those antennas are of type microstrip, they differ in their design. They can adopt different feeding techniques, e.g., proximity feed, co-axial feed, aperture feed, and inset feed [6]. Moreover, a patch can have various shapes such as circle, rectangle, triangle, and a fractal shape [7]–[10]. Furthermore, a patch antenna can be lonely used, or a group of them can be combined to constitute an array [11].

There are various types of WiFi antennas differing in those manners. In [12], a dual-band Sierpienski fractal shaped patch antenna is proposed. This antenna surpasses its 3x3 MIMO patch and dipole antenna array counterparts with a gain of 6.21 dBi, and demonstrates wideband characteristics with an upper bandwidth of 4.3-6.2 GHz [12]. Whereas [12] employs the Sierpienski method to operate at two different frequencies, [13] makes use of a way simpler method, the asymmetric slit method. It achieves $|S_{11}|$ values of -10.15 and -37.315 dB at 2.4 and 5 GHz, respectively. In [14], a slot antenna is suggested for WiFi applications, and differently, it is designed with a squared arch structure to tune and control the radiation pattern of the antenna more effectively. Apart from the studies explained so far, [15] simulates different slot shapes introduced on a bowtie antenna and obtains a good matching around 2.4 and 5 GHz with the help of circular slots.

This paper proposes a microstrip antenna with a symmetrical tooth-shaped patch. It is a dual-band antenna operating at 2.4 GHz Industrial, Scientific and Medical band (ISM) and 5 GHz bands, which conforms to IEEE 802.11ax standards. The bandwidths are 0.45 and 0.68 GHz, respectively, and both comprise the bands of 2.4-2.485 GHz and 5.150-5.875 GHz used in Europe. In Table I, it can be said that the proposed design is superior to other ones in conforming to 802.11ax Europe standards and having a higher radiation efficiency. Also, the overall size is smaller than the original design.

This paper consists of four sections. Section I is Introduction, followed by Section II, which is Antenna Design. Then, simulation results are discussed in Section III, named Results and Discussion. Finally, the critical points are summed up and put forward in Section IV as a conclusion.

II. Antenna Design

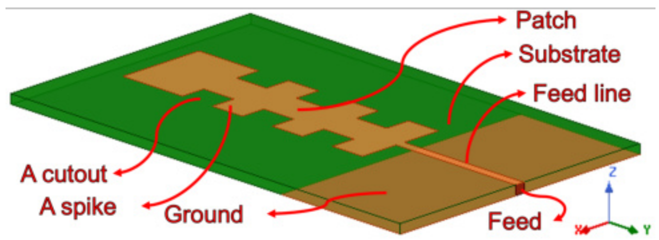
The author was expected to make a WiFi antenna design complying with IEEE 802.11ax standards. Although its higher band does not entirely comply with 802.11ax, the author starts with [22]. Numerically, the design is matched between the frequencies of 2.31-2.69 and 5.23-5.64 GHz. Hence, the main goal is to change the latter to 5.150-5.875 GHz.

As shown in Fig. 1(a), the studied antenna consists of a patch, feed line, substrate and ground plane. It has three cutouts and three spikes at each side of the patch such that one unit of spike or cutouts is one-eighth of P_y. A feed line connects the feed to the patch without any inset distance.

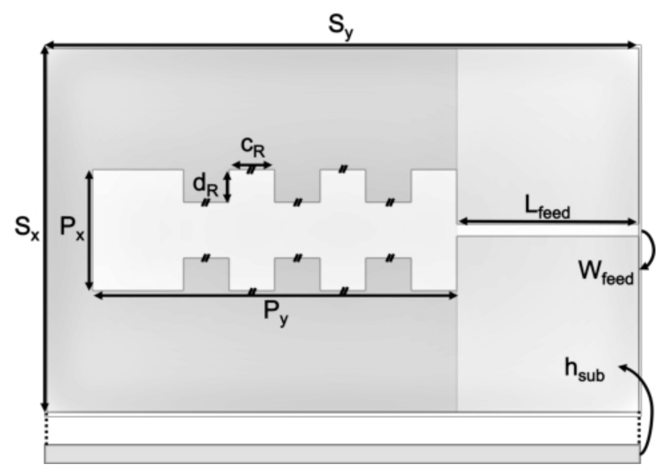
Below the patch and feed line, we have 1 mm thick FR4 as a substrate. Its relative permittivity (ϵ_r) and mass density (ρ) is 4.5 and 1000 kg/m^3, respectively. At the very bottom, there lies a ground plane only under the part of the substrate with a feed line. The reason for having a small ground is that the ground acts as a reflector, and its absence allows the radiation to be omnidirectional. The dimension labels and corresponding "starting" values can be seen in Fig. 1(b) and the column [22] of Table III, respectively. All parametric simulations are done in Ansys HFSS [23].

TABLE I
COMPARISON OF SOME PROPERTIES BETWEEN WIFI ANTENNAS IN THE LITERATURE AND THE PROPOSED DESIGN

Ref	**Size** (mm^3)	**Standard**	$B_{2.4}$	$f_r^{2.4}$	B_5	f_r^5	**Substrate**	$e_r^{2.4}$	e_r^5
[16]	25 × 20 × 1.6	802.11ax	2.33-2.5	2.44	4.89-5.08	5	Flame Retardant 4	N/A	N/A
[12]	75 × 75 × 1.8	802.11n	2.19-2.82	2.46	4.28-6.30	5.38	$\epsilon_r = 2.5$	N/A	N/A
[13]	42.03 × 27.13 × 0.035	802.11n	-	2.4	4.95-5.12	5.02	Rogers RO4533	N/A	N/A
[14]	90 × 80 × 39.5	802.11n	2.27-2.88	2.48	4.41-6	N/A	Rogers RO4533	0.8-1	0.7-0.9
[15]	31 × 30	802.11n & 802.16	2.17-2.82	2.34	5.15-5.28	5.21	-	high e_{rad}	
[17]	33 × 17.6 × 0.78	802.11n & 802.16e	2.03-2.51	2.32	4.93-6.54	5.10, 5.85, 6.39	RT/Duriod 5880	N/A	N/A
[18]	21.5 × 15 × 1.6	802.11(n or ax)	2.38-2.52	2.45	5.41-6	5.62	FR4	0.72	0.75
[19]	40 × 40 × 1.6	802.11n	N/A	2.45	N/A	5.2	FR4	N/A	N/A
[20]	40 × 35 × 1.6	802.11ax/WiMAX	1.96-4.33	2.4	5.05-7.23	5.4	FR4	N/A	N/A
[21]	25 × 25 × 0.8	WLAN/WiMAX	2.14-2.85	2.7	5.02-6.09	5.2	FR4	N/A	N/A
[22]	75 × 30 × 1	802.11ax	2.31-2.69	2.49	5.23-5.64	5.41	FR4	N/A	N/A
$[22]_{Kati}$	48.75 × 30 × 1	802.11ax (Europe)	2.20-2.65	2.44	5.20-5.88	5.5	FR4	0.955	0.916



(a) Dimetric view



(b) Dimension labels

Fig. 1: The final design of the proposed antenna from different views.

A. Determination of the offset of the spike-cutout pattern

In [22], it is assumed that $c_R = b_R/8$ whereas three spikes and three cutouts, corresponding to a total length of $6b_R/8$, is introduced. This constitutes an excess of $2b_R/8$ in P_y, and this results in an ambiguity in the position of the spike-cutout pattern. Therefore, this excess is used as an offset to determine where to start this pattern with respect to the smaller edge of the patch on the -y side.

Employing $1 \times c_R$ and $2 \times c_R$ as an offset value, simulated $|S_{11}|$ plots can be seen in Fig. 2(a). The latter is selected for the next steps since the observed bands are much closer to the desired one.

B. Antenna Size Reduction

In the following step, the excessive difference between S_y (75 mm) and P_y (24 mm) is observed. This difference is considered as an opportunity to reduce the overall antenna size. At this point, S_y is set to $P_y + L_{feed} + c_R$, which is 42 mm. Simulation results demonstrate neither a deterioration in $|S_{11}|$ nor a shift in resonant frequency, as can be seen in Fig. 2(b). Thus, there is no inconvenience to set S_y to 42 mm in the manner of size reduction.

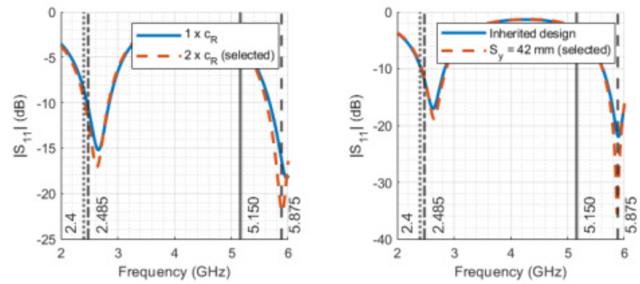
In [22], this design is reported to cover the required bands, containing the resonant frequencies. However, due to unknown reasons, maybe size reduction or mistakes originated from unreported design details, the antenna is resonant at comparatively higher frequencies in Fig. 2(b), which is where we left off, and it does not cover the requirements of the higher band. Hence, the author is required to find the remaining way of design from now on.

C. Tuning P_y

In [22], it is suggested to set d_R between 3.6 - 3.8mm for keeping the higher band as desired, but we arbitrarily select d_R to be 2.7 mm, and then tune P_y accordingly. The tuning in P_y can be seen in Fig. 2(c), keeping d_R to be 2.7 mm as constant. The frequency bands obtained can be seen in Table II. Note that the lower band is always covered, but P_y of 30.0 mm covers the most for the higher required band. Thus, this variation finalizes the design steps with a frequency band deficit of only 50 MHz. The final design parameter values are given in the third column of Table III.

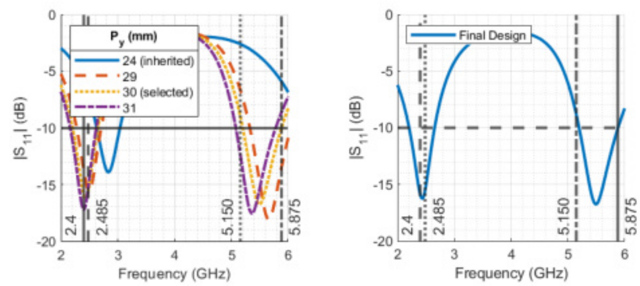
TABLE II
THE GOAL AND OBTAINED FREQUENCY BANDS BY VARYING P_y (UNITS: GHZ).

$P_y (mm)$	$f_{lower}^{2.4}$	$f_{higher}^{2.4}$	f_{lower}^{5}	f_{higher}^{5}
29.0	2.28	2.71	5.32	6.05
30.0	2.20	2.65	**5.20**	**5.88**
31.0	2.16	2.62	5.08	5.78
Goal	2.4	2.485	5.150	5.875



(a) Determination of the offset of the spike-cutout pattern

(b) Antenna Size Reduction



(c) Tuning P_y

(d) $|S_{11}|$ of the final design

Fig. 2: $|S_{11}|$ plots for each design step.

TABLE III
THE DIMENSIONS OF THE ACTUAL DESIGN IN [22] AND FINAL DESIGN PROPOSED BY THE AUTHOR

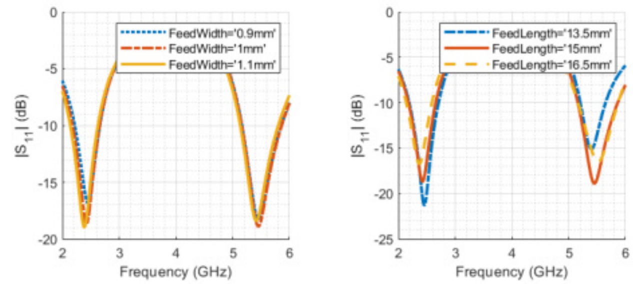
	[22]	This paper
Name of the dimension	Value (units: mm)	
Length of the substrate (S_y)	75	48.75
Width of the substrate (S_x)	30	30
Thickness of the substrate (h_{sub})	1	1
Length of the patch (P_y)	24	30
Width of the patch (P_x)	10	9.5
Feed length (L_{feed})	15	15
Feed width (W_{feed})	1	1
Ground length (G_y)	L_{feed}	L_{feed}
Ground width (G_x)	S_x	S_x
Depth of a cutout (d_R)	3.7	2.7
Length of a spike (c_R)	$S_x/8$	$S_x/8$

III. Results and Discussion

A. Parametric Sweep

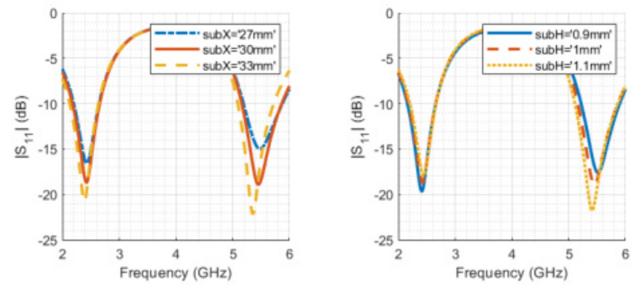
$|S_{11}|$ of the final design can be seen in Fig 2(d). As stated before, the designed antenna is a dual-band antenna. The minimum $|S_{11}|$ values of -16.2 and -16.7 dB are reached at 2.42 and 5.5 GHz, respectively. So, it operates in both 2.4 and 5 GHz (WiFi 6) bands but not 6 GHz band (WiFi 6E), as it is required in IEEE 802.11ax standards [24]. Numerically, the bandwidths of 2.20-2.65 GHz and 5.20-5.88 GHz are covered, and both comprise the corresponding 802.11ax bands for Europe, which are 2.4-2.485 GHz and 5.150-5.875 GHz [25].

2D polar plots can be seen in Fig. 4(a). In addition, 3D versions of them are presented in Fig. 4(b) and 4(c) for 2.42 and 5.5 GHz, with maximum gains of 1.7 and 4.0 dBi respectively. The previous design in [22] had maximum gains of 1.75 and 1.35 dBi at average band frequencies of 2.42 and 5.4 GHz. Therefore, the proposed design offers a higher maximum gain at the 5 GHz band, whereas the lower band gain is fixed.



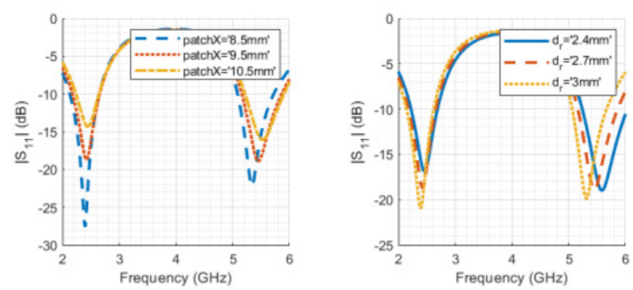
(a)

(b)



(c)

(d)



(e)

(f)

Fig. 3: $|S_{11}|$ plots when some design parameters are changed by ±10% such as (a) W_{feed}, (b) L_{feed} (c) S_x (d) h_{sub} (e) P_x (f) d_R

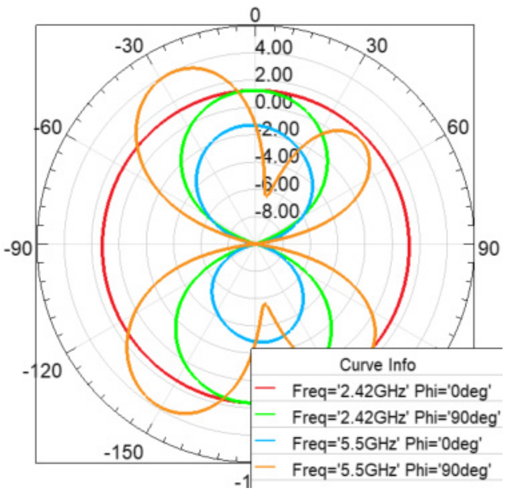
Also, although most of the radiation efficiency values for the antennas in literature are not provided, the final design has a radiation efficiency of 0.955 and 0.916 at 2.42 and 5.5 GHz, respectively. Those efficiencies are comparatively higher than the provided ones in Table I.

IV. Conclusion

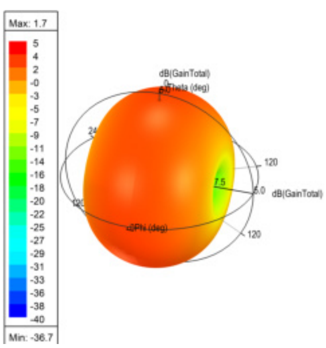
In this paper, a previously designed WiFi microstrip antenna is employed. Based on that design, the overall size is reduced by 35%. Then, the antenna is tuned to encompass the bands of 2.4 and 5 GHz, complying with IEEE 802.11ax standards for Europe (2.4-2.485 GHz, 5.150-5.875 GHz). In addition, its maximum gain in the higher band is improved by 2.65 dBi while keeping that of the lower band approximately the same. The antenna shows

TABLE IV
CHANGE IN THE RESONANT FREQUENCY AND $|S_{11}|$ VALUE AT RESONANT FREQUENCY WHEN DESIGN PARAMETERS ARE VARIED BY ±10%

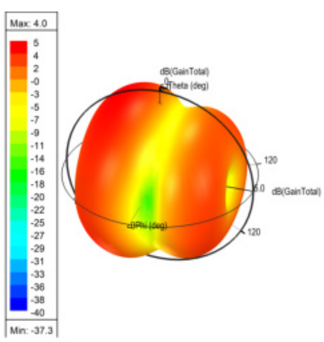
	Δf_r (GHz)		$\Delta\|S_{11}\|$ (dB)	
Variation \ Band	2.4	5	2.4	5
W_{feed} -= 1 mm	+0.02	-	1,90	-
W_{feed} += 1 mm	-0.04	-0.04	-0.30	+0.40
L_{feed} -= 1.5 mm	+0.03	-0.05	-2.50	+3.70
L_{feed} += 1.5 mm	-0.06	+0.07	+2	+2.30
S_x -= 3 mm	-	+0.03	+2.20	+3.90
S_x += 3 mm	-0.04	-0.09	-1.90	-3.30
h_{sub} -= 0.1 mm	-0.02	+0.07	-0.80	+1.20
h_{sub} += 0.1 mm	+0.01	-0.04	+0.80	-2.90
P_x -= 1 mm	-0.03	-0.11	-8.50	-3.30
P_x += 1 mm	+0.02	+0.08	+4.40	+2.70
d_r -= 0.3 mm	+0.03	+0.13	+1.90	-0.10
d_r += 0.3 mm	-0.02	-0.14	-2.10	-1.00
Nominal design	2.42	5.5	-18.70	-18.80



(a) 2D plots for $\phi = 0°$ and 90°.



(b) 3D polar plot at 2.42 GHz



(c) 3D polar plot at 5.5 GHz

Fig. 4: Simulated radiation patterns of the final design for both at 2.42 GHz and 5.5 GHz.

omnidirectional radiation characteristics, which is suitable for WiFi applications.

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