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Design of Trapezoidal Patch with Multi-Slot Antenna for Wireless Communication Applications

***Abstract**. This research presents a low-cost FR4 trapezoidal patch antenna design with multi-slot techniques combined with a microstrip feed for wireless communication applications at operating frequencies 2.45GHz ISM band. Initially, this research aimed to demonstrate the design and fabrication of a trapezoidal patch antenna with a radiating patch size of 47×25 mm. After that, the multi-slot technique is applied to reduce the patch size to 35×25 mm., as well as improve the bandwidth. The simulation results show that the antenna designed and presented in this research can support all of ISM bandwidth at the operating frequency of 2.45GHz., that is, it covers from 2.3957GHz to 2.5014GHz and has an antenna's gain of 4.67 dB. The prototype antenna was built with FR-4 for measurements at a -10 dB bandwidth impedance of 2.3859GHz to 2.5020GHz, and a gain of 4.35 dB. The measurement results of the prototype antennas are consistent with the simulation results.*

***Streszczenie.** Niniejsze badanie przedstawia niedrogą konstrukcję trapezoidalnej anteny krosowej FR4 z technikami wieloszczelinowymi w połączeniu z zasilaniem mikropaskowym do aplikacji komunikacji bezprzewodowej na częstotliwościach roboczych w paśmie ISM 2,45 GHz. Początkowo badania te miały na celu zademonstrowanie projektu i wykonania trapezowej anteny łatowej o promieniującym rozmiarze łaty 47 × 25 mm. Następnie stosowana jest technika wieloszczelinowa w celu zmniejszenia rozmiaru łatki do 35×25 mm., a także poprawy przepustowości. Wyniki symulacji pokazują, że zaprojektowana i zaprezentowana w badaniach antena może obsłużyć całe pasmo ISM przy częstotliwości roboczej 2,45 GHz, czyli obejmuje zakres od 2,3957 GHz do 2,5014 GHz i ma zysk anteny 4,67 dB. Prototypowa antena została zbudowana z FR-4 do pomiarów przy impedancji pasma -10 dB od 2,3859 GHz do 2,5020 GHz i wzmocnieniu 4,35 dB. Wyniki pomiarów prototypowych anten są zgodne z wynikami symulacji. (**Projekt patcha trapezowego z anteną wieloszczelinową do zastosowań w komunikacji bezprzewodowej**)*

Keywords: trapezoidal patch antenna, multi-slot technique.
Słowa kluczowe: antena wieloszczelinowa, trapezoidalny patchwork

Introduction

Over the years, various technologies have developed a lot, and communication technology is considered one of necessery and very important technogies in our daily lives, especially wireless communication technology. Wireless communication technology is now used in both multi-media and data communications, and one of the most important sub-system equipments in wireless communication technology is the antenna. Since the antenna itself is so flexible and complex that it can be designed to suit the purpose of the wide variety of components that will be assembled into the antenna. Therefore, using a properly sized antenna can reduce the problem of antenna installation for different applications. Basic antennas which are easy to design and build for various applications include monopole antennas, dipole antennas, and microstrip patch antennas [1-11]. The microstrip patch antenna is one of the very popular compact antennas with a continuous improvement for modern wireless communication systems. In addition, many new techniques and materials were developed for compact patch antenna design. [1,7-11]

The main focus of this paper is to study the capabilities of trapezoidal patch antennas combined with multi-slot techniques built using low-cost FR4 materials. In the antenna design process, multi-slot techniques are used to improve various aspects of antenna performance such as operation bandwidth, and gain, and they help to improve the size of the antenna's radiation layer while maintaining important properties of the antenna [6].

In this article, the antenna design started from the values obtained by designing a basic rectangular patch antenna in combination with a microstrip feeder. Then, the rectangular patch antenna turned into a trapezoidal patch antenna as a base antenna before improving by including a multi-slot into the patch. The results from the simulation software for comparison with conventional antenna measurements fabricated with FR-4 material demonstrate important antenna properties such as antenna bandwidth, radiation pattern, and antenna gain.

The structure of the article is organized into five topics. The first part is an introduction to the antenna technology and the approach to this research. The next part is the process of designing the structure and dimensions of the preliminary rectangular patch antenna and the modification of the original antenna to the trapezoidal patch antenna. Then, the utilization of multi-slot techniques will be applied to compact the size of radiating layers, which will be demonstrated through the simulation results. The results of the measurements obtained from the prototype antenna fabricated with FR-4 materials are then compared with the simulation results. Finally, the last section discusses the results of the research in the summary section.

Antenna Design

Rectangular patch antennas are generally chosen for their application because their simple shapes can facilitate the manufacture of antennas in combination with FR-4 based materials.

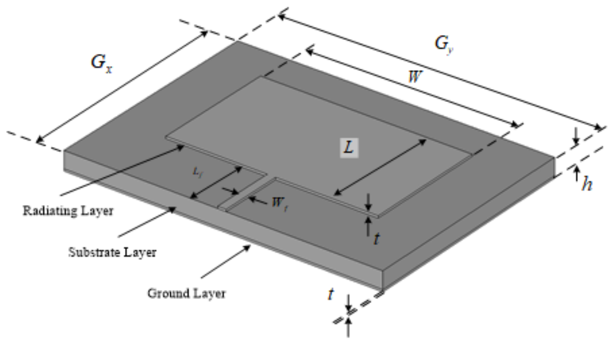

Fig. 1. Regular rectangular patch antenna with microstrip feed.

Fig.1 shows the parameters of the dimension's properties of a regular rectangular patch antenna with a micro-strip feed technique, where W and L are the parameters of width and the length for the regular rectangular patch antenna, respectively.

The overall dimensions of both the FR-4 substrate layer and the ground plane of the antenna are equal to G_x and G_y for the width and length, respectively. The thickness of the FR-4 substrate is h and t is the copper thickness layer used as radiation and ground plane. The micro-strip feed was connected from the center of the lower edge of the patch to the bottom line of the substrate with a width (W_f) that was calculated to provide good impedance matching [12,13].

The top copper layer will be a rectangular patch antenna, designed as described in [13] using (1) – (4).

$$W = \frac{c}{2 f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (1)$$

$$L = \frac{c}{2 f_r \sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (2)$$

Where

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (3)$$

$$\Delta L = 0.412h\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{w}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{w}{h} + 0.8\right)} \quad (4)$$

The calculated dimension parameters of the basic rectangular patch antenna at the operating frequency (f_r) are equal to 2.45GHz, then the thickness of dielectric layers (h) is 1.6 mm. and the dielectric constant or relative permittivity (ε_r) is 4.3. Therefore, the rectangular patch sizes are used for modeling by the simulation software [14]. The result of each dimension of a model after the optimized result from the simulation is shown in Table 1.

Table 1. Regular rectangular patch antenna parameters

Name of Parameter	Value (millimeter(s))	Name of Parameter	Value (millimeter(s))
G_x	55.00	G_y	65.00
W	52.00	L	45.00
t	0.035	h	1.60
L_f	5.00	W_f	2.80

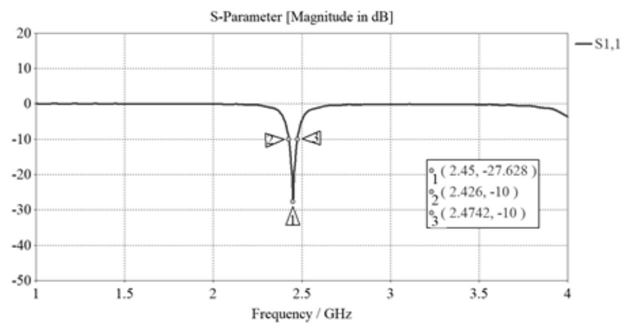

Fig. 2. S11 from simulation results of regular rectangular patch antenna

Based on simulation results, the designed antenna operates at a 2.45 GHz center frequency with a fractional bandwidth for a return loss of -10dB of 2.4260-2.4742GHz, as reported in Fig. 2.

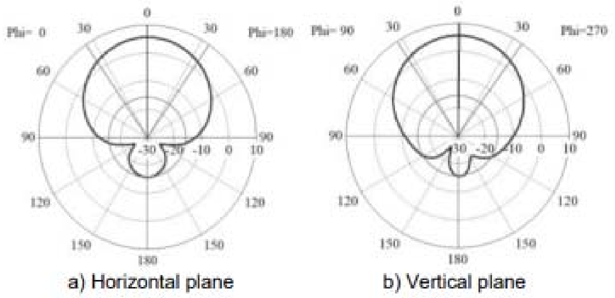

Fig. 3. 2D radiation pattern from the simulation result of the rectangular patch antenna

The simulation results in Fig. 3 present the 2D polar radiation patterns of the basic rectangular patch antenna. Both the antenna's ground and FR-4 substrate layers were on XY-plane. The simulation results show that the resultant value of the optimum gain of the antenna of about 5.56 dB with HPBW for the YZ plane (horizontal plane) was 68.8 degrees and 68.3 degrees for the XZ plane (vertical plane) in the Z-direction.

Trapezoidal Patch Antenna

A trapezoidal patch antenna based on a rectangular patch antenna by modifying the slope at both ends was proposed. The dimension values of the trapezoidal patch antenna are based on software simulation at a design frequency of 2.45GHz as shown in Fig. 4, and the obtained results for the various antenna sizes are shown in Table 2.

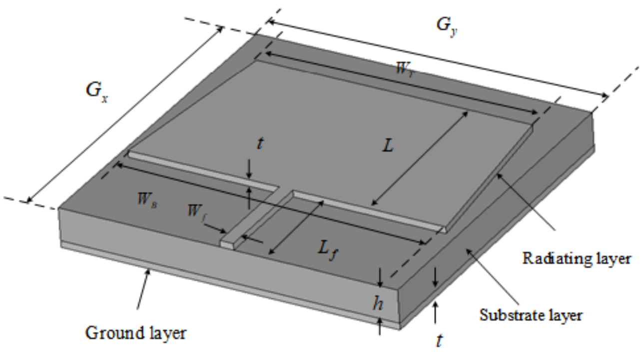

Fig. 4. A trapezoidal patch antenna model

Table 2. Trapezoidal patch antenna parameters

Name of Parameter	Value (millimeter(s))	Name of Parameter	Value (millimeter(s))
G_x	50.00	G_y	50.00
W_B	47.00	W_T	41.00
L	25.00	t	0.035
h	1.60	L_f	3.00
W_f	0.50		

Based on simulation results, the proposed trapezoidal patch antenna design at the resonance frequency of 2.458GHz with a fractional bandwidth of 2.4218GHz to 2.4955GHz as presented in Fig. 5.

To improve the dimension of the antenna patch, an advanced multi-slot technique was applied to the original trapezoidal patch antenna that was designed in the previous step. A multi-slot dimension and location can be designed using a simulation optimization process with the antenna final models and the dimensions were shown in Fig. 6 and Table 3, respectively.

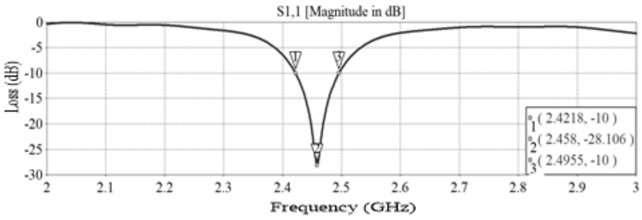

Fig. 5. S11 results for trapezoidal patch antenna

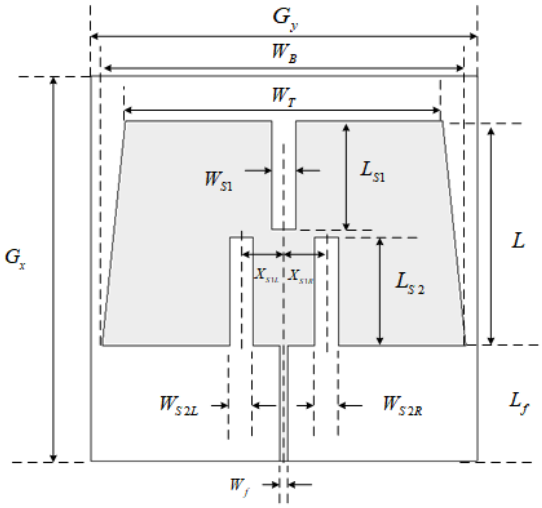

Fig. 6. Model of the trapezoidal patch with the multi-slot antenna

Table 3. Parameters of trapezoidal patch with multi-slot antenna

Name of Dimension's Parameter	Value (millimeter(s))	Name of Dimension's Parameter	Value (millimeter(s))
G_x	50.00	G_y	40.00
W_B	35.00	W_T	30.00
L	25.00	t	0.035
h	1.60	L_f	15.00
W_f	0.50	W_{S1}	5.00
W_{S2R} , W_{S2L}	4.00	L_{S1}	3.00
L_{S2}	3.00	X_{S1R} X_{S1L}	3.00
X_{S2}	3.00		

The total dimensions of the radiated layer after the addition of multi-slot were reduced by 25.53% and 26.82% (length W_B was reduced from 47 mm. to 35 mm., and W_T reduced from 41 mm. to 30 mm.)

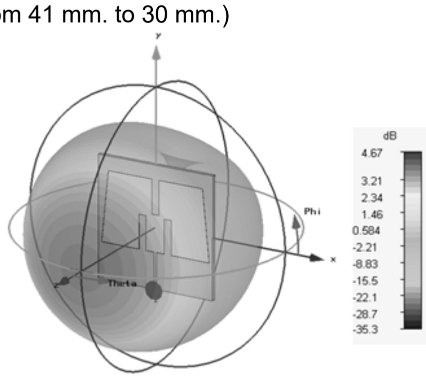

Fig. 7 3D radiation pattern from simulation of the trapezoidal patch with a multi-slot antenna

Fig. 7 and Fig. 8 present the simulation results of 3D and 2D radiation patterns of the trapezoidal patch antenna with a multi-slot using FR-4 material at 2.45GHz, respectively.

The 3D radiation patterns results of the simulation showed that the optimum gain of the antenna was 4.67dB. In addition, the antenna has a front lobe direction indicating HPBW equal to 93.5 degrees and 91.0 degrees for the vertical plane and horizontal plane, respectively.

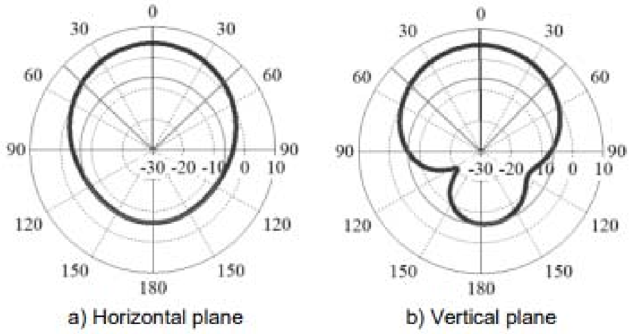

Fig. 8 2D radiation pattern from simulation of the trapezoidal patch with a multi-slot antenna

The finished prototype antenna was fabricated for measuring an antenna property as illustrated in Fig. 9.

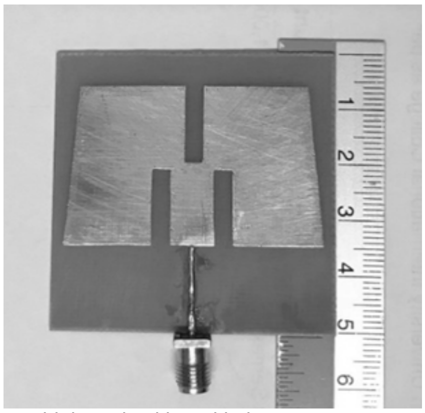

Fig. 9. Trapezoidal patch with multi-slot antenna prototype

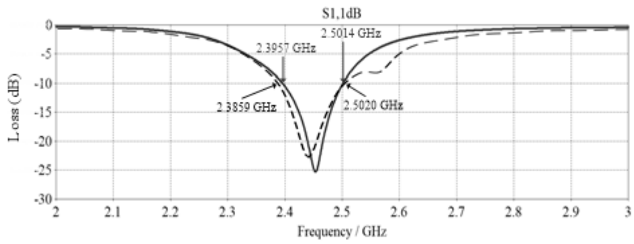

Fig. 10. S11 measurement and simulation results for trapezoidal patch antenna with multi-slot

In Fig. 10, the results of |S11| are compared between the simulated values and the results of measurement obtained from the prototype antenna. From the simulations, the bandwidth of the modified trapezoidal patch antenna with multi-slot is 2.3957GHz to 2.5014GHz, and from the prototype measurement results, the bandwidth starts from 2.3859GHz to 2.5020GHz. Both the simulation results and measurements of the S11 are reasonable and consistent.

A radiation pattern from the results of simulation and measurement of a trapezoidal patch with a multi-slot antenna is shown in Fig. 11. The trapezoidal patch with a multi-slot antenna provides a 4.67dB gain from simulation results, and the measurement result of the trapezoidal patch with a multi-slot prototype antenna is 4.35dB in the front direction. A comparison table that shows some literature work and the proposed antenna is shown in Table 4.

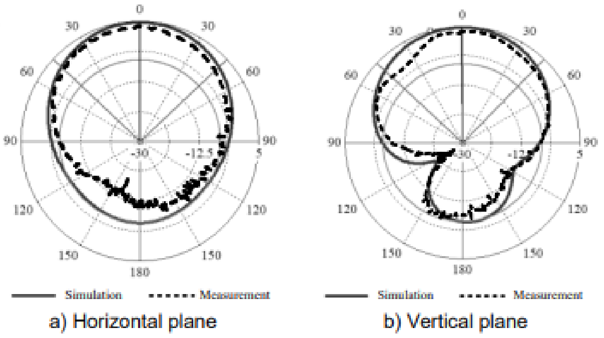

Fig. 11. 2D Radiation pattern for the trapezoidal patch with a multi-slot antenna from simulation and measurement

Table 4. Comparison size and gain to other related works

Reference	Substrate Dimension (mm.)	Patch Dimension (mm.)	Gain (dBi)
[8]	120x130	90x45	5.35
[9]	80x60	39x31	5.49
[10]	57x59	53x47	2.83
[11]	40x40	29x29	5.52
This Work	50x40	35x25	4.35

Conclusion

In this article, a trapezoidal patch antenna design along with a multi-slot technique for the 2.45 GHz ISM band was studied and designed with FR-4 material. The key characteristics of the antenna were studied the overall reduction of the antenna radiation layer by multi-slot techniques while maintaining the core characteristics of the antenna. The results of the simulation showed that the fractional bandwidth of the proposed antenna was 2.3957GHz to 2.5014GHz, compared to the 2.3859GHz to 2.5020GHz bandwidth of the results from the prototype of the trapezoidal patch with multi-slot antenna measurements. Otherwise, the simulation results showed that the antenna gave a 4.67dB gain, but the result of the prototype antenna measurement was 4.35 dB. However, from the measurement results, the antenna gain was only 6.85% different from the simulation results. This study found that trapezoidal patch antennas with a multi-slot technique can help improve the dimension of the antenna's radiated section that it can be applied to a variety of wireless communication applications because the size of the radiation layer is 25.53% smaller than the original size.

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