Bandwidth Enhancement of the Rectangular Patch Antenna Using Artificial Dielectric and Proximity Coupled Line Feed

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ABSTRACT
A rectangular patch antenna is a compact antenna. It is appropriate to a modern mobile communication application. The main drawback of the rectangular patch antenna is the bandwidth. It restricts the antenna's application. The natural dielectric replaces the artificial dielectric to enhance the bandwidth. A stripline feed of the rectangular patch antenna is replaced by a proximity coupled line feed. The method is predicted to enhance more than 10% of the antenna bandwidth with natural dielectric. Furthermore, the antenna with and without modification is referred to as an artificial and conventional antenna. The artificial antenna performances are simulated. The performances of the artificial antenna are compared to a conventional antenna. The result shows that the method can enhance the conventional antenna bandwidth by 13.82%. In addition, the method has reduced the size of the conventional antenna to 14.12% smaller. The method can be used as a solution for the miniaturization of a patch antenna size.

Keywords: *Bandwidth enhancement, rectangular patch antenna, a natural dielectric, an artificial dielectric, proximity coupled line feed.*

1. INTRODUCTION

The antenna is an essential device in developing wireless communication systems. Currently, devices that are supported by wireless communication systems are commonly used for daily needs. In this case, the antenna becomes something that needs to be considered because it is compact and portable.

Microstrip antenna is a popular antenna used considering that this type of antenna has advantages, especially in light mass and high performance. Furthermore, its benefits show that the microstrip antenna is compact, which is very suitable for modern cellular communication applications.

However, the microstrip has drawbacks, i.e. in addition to radiating low electromagnetic wave power, microstrip antennas also have a narrow bandwidth. The condition has limited the applications. The need for greater bandwidth and smaller antenna sizes has pushed wireless communication systems to higher frequency band levels in the mm-wave region [1]. Some literature from researchers regarding microstrip antenna modifications can increase bandwidth.

There are several known methods to improve antenna performance, especially in terms of bandwidth. The increase in bandwidth is carried out by using the proximity coupled feeding technique [2] [3], and the use of an integrated impedance matching network [4]. This type of proximity coupled feeding is a solution to increase bandwidth, with other advantages having a wider bandwidth and smaller dimensions than conventional antennas [1].

Another method to increase the bandwidth is the use of artificial dielectric. In this case, the artificial dielectric is used to replace a natural dielectric. Artificial dielectric materials are makeable from natural dielectric material by an electromagnetic process. The electromagnetism process can be carried out by adding conductors to natural dielectric materials, either by implanting (some copper wires) or laminated (thin copper strips) [5]. The technique can change the antenna performance.

In this paper, a compact microstrip antenna is designed at a frequency of 1.8 GHz. The antenna is constructed from a rectangular patch. Collaboration between artificial dielectric and a proximity coupled line feed is carried out to enhance the antenna's bandwidth. Using proximity coupled line feed placed at the bottom of the rectangular patch can increase the magnetic field. It results in a conduction current. It works at a different resonant frequency but close to the resonant frequency generated by the rectangular patch. The method has increased the antenna bandwidth.

1.1 Related Work

In this section, some literature on the artificial dielectric in microstrip antenna are explored. A simple artificial dielectric made from Styrofoam was proposed in 2018 [6]. In the literature, researchers designed a circular patch microstrip antenna using modified Styrofoam material. Some thin wires are implanted to a Styrofoam as the host material. Researchers designed two antennas, namely a modified antenna with 82 thin wires and 110 thin wires with a diameter of 0.5mm. Embedding wire decreased the resonant frequency of 38.95% and 48.09% for the antennas with 82 and 110 conductor wires, respectively.

The thin wires have increased the relative effective permittivity of the host material by 167% and 270% for the antennas with 82 and 110 thin wires, respectively. Based on the results, the researchers stated that implanting the thin wires into Styrofoam can reduce the resonant frequency of circular patch microstrip antennas. The thin wires have increased the permittivity of the host material. In addition, high relative permittivity helps reduce the dimensions of conventional circular patch microstrip antennas [6].

In [7], the researcher stated that using artificial dielectric between the patch and the ground plane can determine the performance of circular patch microstrip antennas. In the research, FR4-Epoxy material was used as the host dielectric. FR4-Epoxy was modified by inserting some thin wires. It is referred to as ADM. The researcher also designed a conventional circular patch antenna as a comparison, in which the dielectric substrate was not modified.

The above results showed that the circular patch microstrip antenna made of ADM with 82 and 110 wires experienced a reduction in the resonant frequency of 16.3% and 24.8%, respectively, of the resonant frequency of a conventional microstrip antenna. Meanwhile, the 10dB bandwidth of circular patch microstrip antennas made of ADM is 43.4% narrower than conventional circular patch microstrip antennas. Then, the gain value of circular patch microstrip antenna with ADM is relatively higher, namely 5.54 dBi and 6.1dBi for each antenna with 82 and 110 wires, compared to conventional circular patch microstrip antenna with 5.24dBi gain [7].

In the following literature, a study was conducted to determine the effect of using artificial dielectric materials on the resonant frequency of square patch antennas. In this research, a conventional square patch antenna was modified, in which foam as the dielectric material was inserted in a cylindrical conductor in parallel with the direction of wave propagation. The experiment resulted in a decrease in the resonant frequency. The conventional square patch antenna with a resonant frequency of 850MHz decreases to 600 MHz when the foam is inserted in the conductor [8].

In the fourth literature, researchers designed a circular patch microstrip antenna. In the experiment, artificial dielectric material was implemented as a substitute for conventional dielectric material. The artificial dielectric material was obtained by inserting a cylindrical conductor on the FR4-Epoxy used as the host material, based on the TM_{11} resonance mode. The conventional circular microstrip patch antenna resonates at a frequency of 2.4 GHz. However, its resonant frequency decreases to 1.648 GHz when the material changes to the artificial dielectric material. Researchers also stated that it resulted in an effective increase in the permittivity of the artificial dielectric material by about 212.2% [9].

In [10], a study was conducted on the effect of applying artificial dielectric materials on the performance of microstrip antennas. The designed microstrip antenna resonates at a frequency of 2.4GHz. There are 3 ways of sequential modification, starting from adjusting the variation of the thickness of the substrate from 1.6 mm to 11.2 mm, then inserting a cylindrical conductor in the substrate with varying amounts from 4 to 12, and adjusting the diameter variation of the cylindrical conductor from 1 mm to 1.5 mm.

Based on the simulations that have been carried out, the results show that the antenna output is quite good when using a substrate with a thickness of 6.4 mm. Therefore, the thickness is used as a reference for simulations with subsequent modifications. Then with the modification of inserting the conductor, optimal results are obtained when the substrate is inserted as many as 4 cylindrical conductors. The thickness of the substrate is 6.4 mm and the number of cylindrical conductors as much as 4 pieces are used as a reference to see the effect of modifying the diameter of the conductor. The most optimal results are obtained when the diameter of the conductor is 1.2 mm. This study shows that the material modifications made affect all antenna parameters, such as changes in frequency, bandwidth, the direction of the radiation pattern, VSWR value, and S_{11} [10].

2. RESEARCH METHODS

Quantitative research methods used in this study are empirical research with a simulation approach. The two designed rectangular microstrip patch antennas consist of different dielectric materials. One antenna substrate is made of natural acrylic dielectric material, while the other antenna substrate uses artificial acrylic dielectric material.

The first thing before doing the simulation is to design the two microstrip antennas. Then calculate the dimensions in the form of area and length of each antenna element starting from the patch, feedline, and ground plane. Moreover, the substrate area follows the area of the ground plane. To calculate the dimensions of the antenna is necessary to know the working frequency and the characteristics of the material.

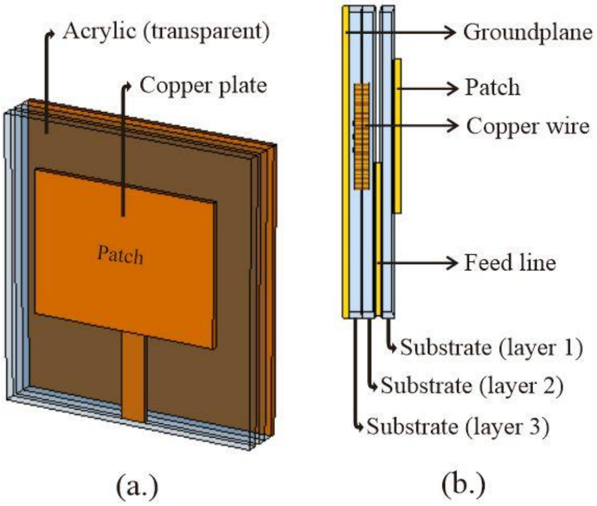

Figure 1 Microstrip antenna structure, (a.) Isometric view, (b.) Side view

The calculation of the antenna dimensions will be inputted into the simulator as a size parameter used to construct the antenna. A separate construction will be made between the conventional microstrip antenna and the artificial microstrip antenna. In this study, both antennas consist of 3 layers. In each layer, there is a dielectric material substrate. The upper part of layer 1 (top of the substrate) is a rectangular patch made of copper plate, while the lower part (bottom of the substrate) is directly in contact with the feed line and the upper substrate of layer 2. Then the lower part of the layer two substrates will be in contact with the upper part. Layer 3 substrate, and the bottom layer three, there is a ground plane. The difference between the two antennas lies in the dielectric material used. The acrylic dielectric material is modified using copper wire implanted in the middle of layer 2 and 3 substrates in the artificial microstrip antenna. The copper wire is embedded in the position of the strong electric field from the TM_{01} mode.

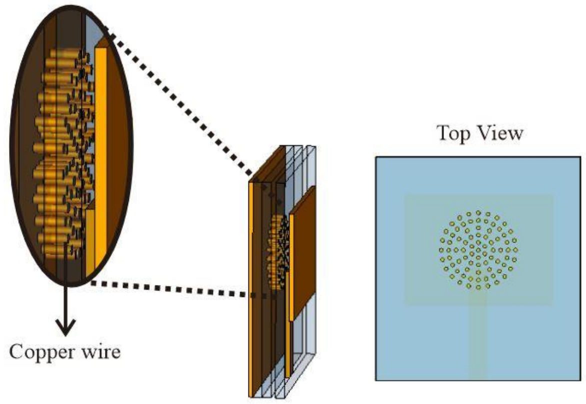

Figure 2 Artificial dielectric material details

Next, the antenna parameters are tested, it will be seen whether the parameters of the two simulated antennas are by the predetermined targets. If the target has not been achieved, it is necessary to re-optimize the antenna dimensions to obtain an antenna with specifications that reach the target. Meanwhile, if both have reached the target, the following data analysis will be carried out. First, the results of parameter testing of the two simulated antennas will be compared. After that, it will be analyzed in terms of dimensions and antenna parameters achieved, especially in bandwidth parameters.

3. RESULT AND ANALYSIS

A comparison study of the dimensions and parameters of conventional microstrip antennas with artificial microstrip antennas was conducted in this study. First, a dimensional comparison is performed using the surface area of each element. Then the compared antenna parameters are about the bandwidth, gain, and radiation pattern from the simulation results.

3.1 Antenna Dimensions

Table 1. Antenna dimension comparison

Antenna Type	Antenna Element Area Size (cm^2)		
	$W_f \times L_f$	$W_p \times L_p$	$W_g \times L_g$
Conventional Antenna	4.32	27.14	90.93
Artificial Antenna	5.98	24.76	78.09

Information:

W_f : Feed line width
L_f : Feed line length
W_p : Patch width
L_p : Patch length
W_g : Ground plane width
L_g : Ground plane length

Based on the results of the comparison, artificial microstrip antennas have smaller dimensions than conventional microstrip antennas. It can be seen in Table 1 that the ground plane area of the artificial microstrip antenna is 14.12% smaller than that of a conventional microstrip antenna. This is because embedding copper wire on the substrate causes an electromagnetic process to occur, thereby changing the permittivity value of the substrate. Changes in the permittivity of the material are proven by calculations using Equation (1). The permittivity value of the material is higher when the material is embedded with copper wire. Furthermore, a high permittivity value makes the antenna dimensions smaller. Therefore, the conventional microstrip antenna dimensions are reduced when the substrate is modified with copper wire.

$$\frac{Wp_{(c)}}{Wp_{(a)}} = \frac{\dfrac{c}{2.fr_{(c)}\cdot\sqrt{\frac{(\varepsilon r_{(c)}+1)}{2}}}}{\dfrac{c}{2.fr_{(a)}\cdot\sqrt{\frac{(\varepsilon r_{(c)}+1)}{2}}}} \quad (1)$$

Table 2. Material permittivity value

Antenna Type	ε_r Substrate
Conventional Antenna	3,4
Artificial Antenna	4,156

The new permittivity value of the artificial microstrip antenna is calculated using Equation 1. The permittivity value of the material increases by 0.756. It can be seen in Table 2.

3.2 Parameter Comparison

The comparison of the simulation results presented in Table 3 for the bandwidth parameter shows that the artificial microstrip antenna has a bandwidth value of 13.83% wider than the conventional microstrip antenna. It shows that the embedding of copper wire also affects the increase in antenna bandwidth.

Table 3. Antenna parameter comparison

Parameter	Antenna Type	
	Conventional Antenna	Artificial Antenna
Bandwidth (MHz)	151.9	172.9
Gain (dBi)	6.998	6.588
HPBW E-Plane (deg.)	85.5	82.3
HPBW H-Plane (deg.)	84.4	89.9

Figure 3 shows the s-parameter comparison of the simulation results of the two antennas. The microstrip antenna with artificial dielectric material where the s-parameter is blue has a wider bandwidth than the microstrip antenna with natural dielectric material (conventional) where the s-parameter is red.

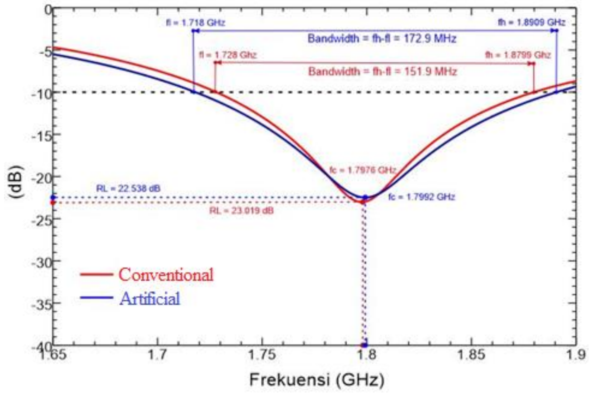

Figure 3 S-Parameter comparison

Figures 4 and 5 depict a 3-dimensional radiation pattern. From the figure, it can be seen the gain of conventional microstrip antennas and artificial microstrip antennas. The amount of gain is indicated by the color variations. The red color indicates the color variation with the highest gain value.

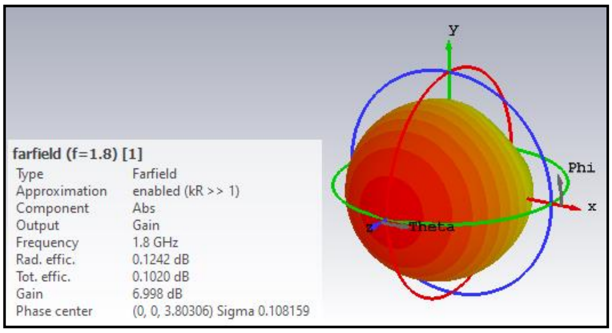

Figure 4 Gain of a conventional microstrip antenna

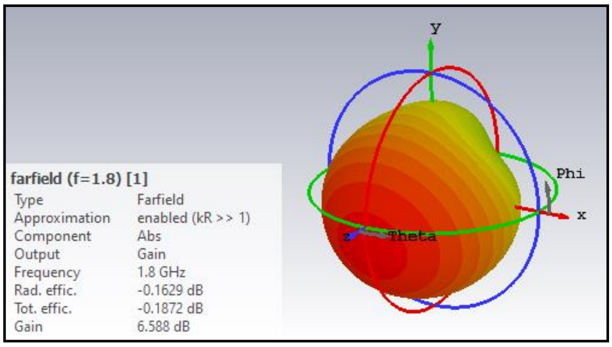

Figure 5 Gain of an artificial microstrip antenna

Although the bandwidth of conventional microstrip antennas is narrower than that of artificial microstrip antennas, the gain and return loss values of conventional microstrip antennas are greater than those of artificial microstrip antennas. Based on the simulation results shown in table 3, the microstrip antenna whose substrate was modified by embedding copper wire had a smaller gain value of 5.85% than the microstrip antenna whose substrate was not modified. That shows that the use of artificial dielectric materials can reduce the gain value.

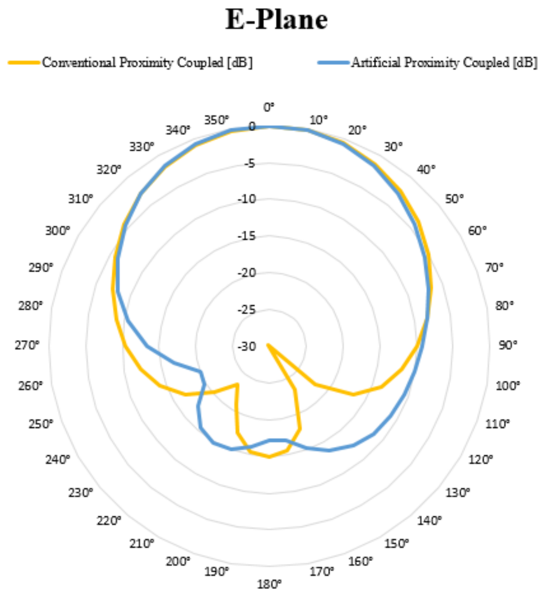

Figure 6 Comparison radiation pattern (E-Plane)

Figure 6 compares the radiation pattern of conventional proximity coupled microstrip antenna with artificial proximity coupled microstrip antenna in the E plane. Based on the simulation results shown in Table 3 and Figure 6, the artificial proximity coupled microstrip antenna has an HPBW value in the narrower E plane with a difference of 3.2 degrees.

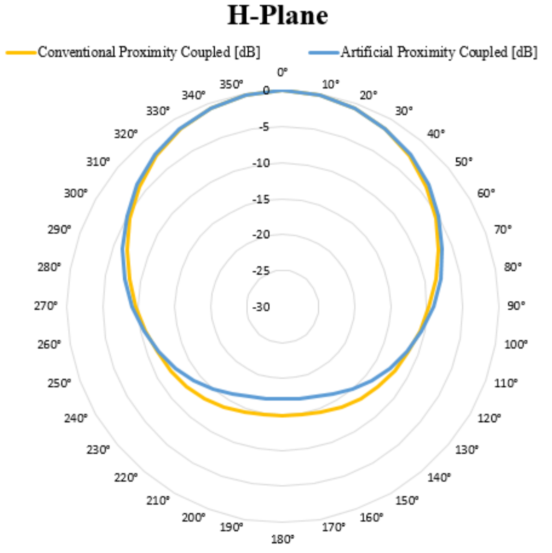

Figure 7 Comparison radiation pattern (H-Plane)

Figure 7 compares the radiation pattern of conventional proximity coupled microstrip antenna with artificial proximity coupled microstrip antenna in the H plane. Based on the simulation results shown in Table 3 and Figure 7, the artificial proximity coupled microstrip antenna has an HPBW value in the H plane, which is 5.5 degrees wider than the conventional proximity coupled microstrip antenna.

The HPBW value in the H plane is related to the antenna gain value, where the HPBW will narrow when the antenna gain is higher. Vice versa, the HPBW will be wider when the antenna gain value is lower. That can be observed through the simulation results shown in table 3, where when a conventional microstrip antenna has a gain of 6.998 dBi, the antenna has an HPBW value in the H plane of 84.4 degrees. While the artificial microstrip antenna with a lower gain of 6.588 dBi has a higher HPBW in the H plane, which is 89.9 degrees.

4. CONCLUSION

This study concludes that the use of artificial dielectric materials can change the performance of the antenna. Embedding wire can increase the antenna's bandwidth as indicated by an artificial microstrip antenna with proximity coupled feeding, which has a bandwidth value of 13.83% greater than a conventional microstrip antenna with the same type of feed. However, the gain from the increased bandwidth must be paid for by reducing the antenna gain value. As the antenna gain decreases, the HPBW in the H plane becomes wider. In addition, the use of artificial dielectric materials can be an effort to reduce the size of the antenna. From this research, it was found that the miniaturization of the antenna was 14.12%.

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AUTHORS' CONTRIBUTIONS

All authors contributed to this research starting by designing, experimenting, data analysis, and writing papers.

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