Comparison of the Performance of Two Circular Patch Antennas Made from Taconic RF- 60A Substrate with and without Artificial Dielectric Using Simulation Approach

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ABSTRACT
This paper presents a comparison of the performance of two circular patch antennas. The antennas use a natural Taconic RF-60A with and without modification using laminating metal strips as the substrate, respectively. The first and the second antenna are referred to as a conventional patch antenna and an artificial patch antenna. Laminating metal strips at the natural substrate is predictable will change the antenna performances, such as a gain, a bandwidth, and a pattern. The comparison is conducted using an experimental simulation. The artificial patch antenna has some advantages using simulation optimization in such dimensions and antenna parameters. It has a bandwidth of 49.5 MHz or 21.42 % wider than the conventional patch antenna. A return loss at the centre frequency is 2.97 dB or 9.17 % higher than the conventional patch antenna, and a half-power beamwidth is 0.6° or 0.63 % wider than the conventional patch antenna. Although the artificial patch antenna has a gain of 0.68 dB or 13.47 % lower than the conventional patch antenna, to work at the same frequency of 1.8 GHz, the artificial substrate antenna requires an area of 40.67% smaller than the conventional substrate antenna. From these results, the artificial antenna has a good potential in miniaturizing the patch antenna device size.

Keywords: *Taconic RF-60A, Artificial dielectric, Miniaturization.*

1. INTRODUCTION

Microstrip antennas have advantages over other antennas such as light mass, low profile, and conformal [1]. However, the current wireless communication system requires an antenna with a smaller size than an ordinary microstrip antenna to be integrated with other small telecommunication devices [2]. Antenna dimensions can be affected by relative permittivity [3]. The higher the relative permittivity, the lower the operating frequency, so the antenna's dimensions become smaller [4]. Therefore, a dielectric substrate with a high permittivity is needed to have a microstrip antenna with small dimensions.

The relative permittivity of a substrate microstrip antenna can be increased by modifying the electromagnetic properties of the substrate artificially. The modified substrate is called an artificial dielectric material (ADM) [5]. This material is made by arranging small conductors on a substrate. Configuration of small conductors such as diameter, length, and distance between conductors on the substrate can affect the relative permittivity to be achieved [6]. Natural dielectric materials can be engineered by exploiting the nature of conductors and dielectric materials in response to an electric field [5]. As we know, the conductor and dielectric response to the external electric field.

The permittivity of the antenna can be increased by using some conductor strips inserted into a natural dielectric as an antenna substrate. Adriani et al. designed a microstrip antenna using an acrylic substrate material with modified permittivity by inserting four-conductor strips. The antenna is designed to have a square patch and operates at a frequency is 1.8 GHz. Based on the simulation, it was found that the use of artificial microstrip antennas can reduce the patch antenna dimensions by 9.72%, increase the bandwidth by 48.89% and widen the HPBW in the E-Plane and H-plane fields by 10.17% and 0.45%. However. there is a decrease in the gain of 0.18% from conventional microstrip antennas [7].

Risky Anisa et al. designed the antenna using the same material as Adriani, namely acrylic with modified permittivity by inserting 16 conductor strips. This antenna has a rectangular patch and operates at a frequency of 900 MHz. The result of this antenna design is that artificial microstrip antennas can increase the bandwidth by 68.64%. In addition, the gain also increased by 54.26% from conventional microstrip antennas [8]. Antenna design using the conductor strip insertion method is not optimal in reducing antenna dimensions.

Another method is to modify the permittivity of a dielectric substrate by passing small conducting wires through the substrate. Aditya et al. conducted a study using an artificial dielectric to reduce the resonant frequency of a circular patch microstrip antenna. The material used is FR-4 Epoxy. The antenna substrate is planted with thin wires in the TM_{11} wave mode configuration. As a result, the resonant frequency of the microstrip antenna can be artificially lowered to 1,648 GHz. Therefore, there is an effective increase in permittivity of the artificial dielectric material by about 212.2% [6].

Achmad Munir also performed the lowering of the resonant frequency. He lowered the resonant frequency of a microstrip antenna with a square patch with an operating frequency of 850 MHz. The cylindrical conductor is embedded in the foam used as the dielectric material using the TM_{01} configuration. As a result, the resonant frequency can be lowered to close to 600 MHz [9].

Hepi Ludiyati et al. conducted another study that explores artificial dielectric. In the study, a circular patch antenna is designed using FR-4 Epoxy material. The antenna substrate is covered with 62 and 110 thin conductor wires. In the measurement results, the artificial dielectric material is proven to reduce the dimensions of the antenna by 16.3% and 24.8%, respectively, to increase the antenna's gain by 5.73% and 16.41%, respectively. However, unfortunately, the bandwidth reduces by 43.4% than the microstrip antenna with natural material [10].

Based on previous research, in addition to reducing the dimensions of the antenna, the use of artificial dielectrics can affect antenna performance such as bandwidth, gain, and antenna radiation pattern. In this paper, the effect of using an artificial dielectric on the performance of a microstrip antenna is analyzed. The analysis focuses on the antenna's performances, such as gain, return loss, and radiation pattern.

2. METHODOLOGY

This research applied a quantitative research method with a simulation approach. The antenna that was made has a circular patch and operates at a frequency of 1.8 GHz. The feeding technique used was proximity coupling. Two types of antennas were made of each material: conventional microstrip antennas (antenna with natural substrate material) as a comparison and artificial microstrip antenna as the primary antenna.

In designing the antenna, the conventional microstrip antenna dimension was calculated first, then simulation and optimization of the conventional microstrip antenna were carried out to view the antenna parameters. Meanwhile, an artificial microstrip antenna was made by planting or inserting conductor wires on the substrate. Then, simulation and optimization were carried out to see the parameters of the artificial microstrip antenna using the same software. The results of the conventional microstrip antenna and the artificial microstrip antenna were then compared. Parameters compared are dimension reduction, bandwidth, gain, and antenna radiation pattern.

Artificial dielectric was used to use a wire configuration in TM_{01} mode with a wire diameter of 1 mm, a wire length of 3.2 mm, and a line spacing of 2.8 mm between wires. The number of conductor wires used was 72 pieces with copper material. In addition to conductor wire, copper was also used as a material for patches, ground planes, and feedlines with a thickness of 0.035 mm.

The substrate material used was Taconic RF-60A. The following are the characteristics of the Taconic RF-60A material that will be used:

a. Relative permittivity (ε_r) : 6.15

b. Loss tangent : 0.0028

c. Total thickness (h) : 9.6 mm

d. Thickness per substrate : (0.8 x 4) mm

The design of the antenna can be seen in Figure 1. The antenna consists of 3 layers of substrate. In Figure 1, it can be seen that figure (a) is an antenna display on the use of three substrate layers with h, which is the total substrate height. At the very top of the antenna, there is a patch with a, which is the radius of the patch. Figure (b) is a view of the antenna on the use of two layers of substrate. Above the second layer of substrate, there is a feedline where W_f is the width of the feedline and L_f is the length of the feedline. Then in figure (c), it can be seen that the antenna displays on the use of a single layer substrate. There are conductor wires planted between the third layer substrate and the second layer substrate. Meanwhile, in figure (d) there is a ground plane where W_g is the width of the ground plane and L_g

is the length of the ground plane. Furthermore, figure (e) is a side view design of the antenna.

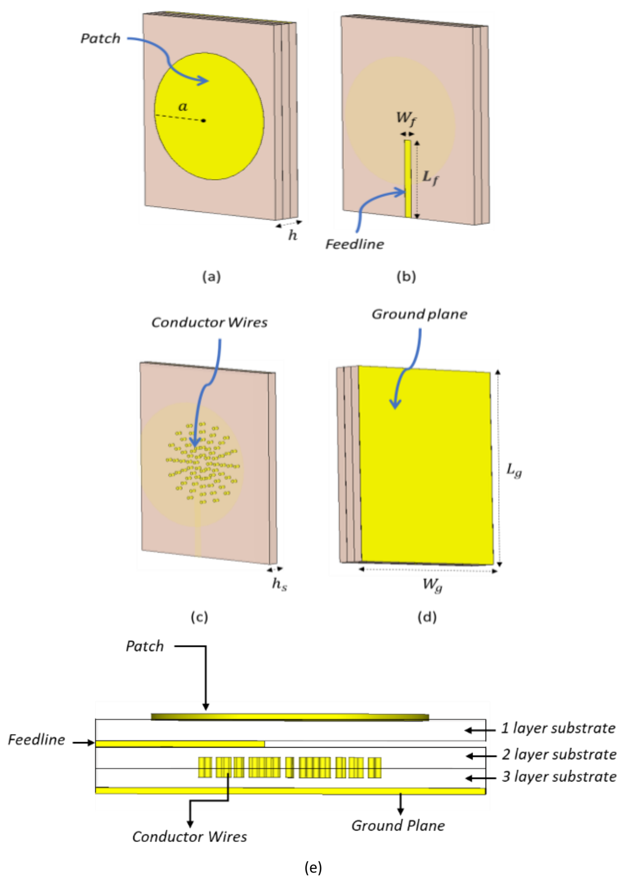


Figure 1 Circular microstrip antenna design with artificial dielectric

The dimensions of the designed antenna are obtained based on the results of calculations and antenna simulations. The size of the antenna dimensions based on the calculation is obtained through the following equation *[11]*.

a. Patch radius (a)

To calculate the patch radius, equation (1) is used as follows:

$$a = \frac{F}{\left\{1+\frac{2h}{\pi.\varepsilon_r.F}\left[ln\left(\frac{\pi.F}{2h}\right)+1{,}7726\right]\right\}^{1/2}} \qquad (1)$$

In the above equation, the variable h is the thickness of the substrate and ε_r is the relative permittivity of the antenna substrate material. The value of F or the logarithmic function of the radiating element is obtained from equation (2), where fr is the resonant frequency

$$F = \frac{8{,}791\times10^9}{fr\sqrt{\varepsilon_r}} \qquad (2)$$

b. Ground plane and substrate length (L_g)

The length of the ground plane and the substrate is calculated using equation (3) as follows:

$$L_g = 6h + a \qquad (3)$$

c. Ground plane and substrate width (W_g)

The width of the ground plane and the substrate is calculated based on equation (4) as follows:

$$W_g = 6h + \frac{\pi}{2}a \qquad (4)$$

d. Feedline Width (W_f)

The width of the feed channel in this antenna design is used in equation (5) as follows:

$$\frac{W_f}{h} = \frac{8e^A}{e^{2A}-2} \qquad (5)$$

With the value of A obtained from equation (6)

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon r+1}{2}} + \sqrt{\frac{\varepsilon r-1}{2}}\left(0{,}23 + \frac{0{,}11}{\varepsilon r}\right) \qquad (6)$$

e. Feedline Length (L_f)

The length of the feedline is calculated based on equation (7) as follows:

$$L_f = \frac{1}{4}\times\lambda_g \qquad (7)$$

With the value of the guided wavelength corresponding to the resonant frequency (λ_g) obtained from equation (8).

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon r}} \qquad (8)$$

Where the value of free space wavelength (λ_o) obtained from equation (9)

$$\lambda_o = \frac{c}{f} \qquad (9)$$

4. SIMULATION RESULTS

4.1. Antenna Dimensions

Table 1 is the antenna dimensions from the simulation and optimization results. Meanwhile, the shape of the artificial microstrip antenna in the simulation results can be seen in Figure 2.

Table 1. Antenna dimensions

Parameter	Description	Taconic RF-60A Conventional	Taconic RF-60A Artificial
L_f	Feedline length	27.5 mm	27.5 mm
W_f	Feedline width	3 mm	2.5 mm
L_g	Substrate length	70 mm	55 mm
W_g	Substrate width	48 mm	37 mm
a	Patch radius	16.7 mm	15.41 mm

Artificial microstrip antennas have smaller dimensions than conventional microstrip antennas. The artificial Taconic RF-60A microstrip patch antenna radius decreased by 7.72%, while the antenna substrate area decreased by 40.67%. The new relative permittivity of the artificial microstrip antenna can be found by using equation (10).

$$\frac{f_{rk}}{f_{ra}} = \frac{a_a\sqrt{\varepsilon_{ra}}}{a_k\sqrt{\varepsilon_{rk}}} \tag{10}$$

$$\frac{1{,}8\times 10^9}{1{,}8004\times 10^9} = \frac{15{,}41\sqrt{\varepsilon_{ra}}}{16{,}7\sqrt{6{,}15}}$$

$$\varepsilon_{ra} = 7.22$$

Description:

f_{rk} = Resonant frequency of conventional antenna
f_{ra} = Resonant frequency of artificial antenna
ε_{rk} = Relative permittivity of conventional antenna
ε_{ra} = Relative permittivity of artificial antenna
a_k = Conventional antenna radius
a_k = Artificial antenna radius

From the calculation, the relative permittivity of the artificial Taconic RF-60A microstrip antenna is 7.22. The relative permittivity has increased by 17.4% from the relative permittivity of conventional microstrip antennas. This proves that the use of artificial dielectrics can increase the relative permittivity value. In addition, the higher the permittivity value, the smaller the antenna dimensions will be.

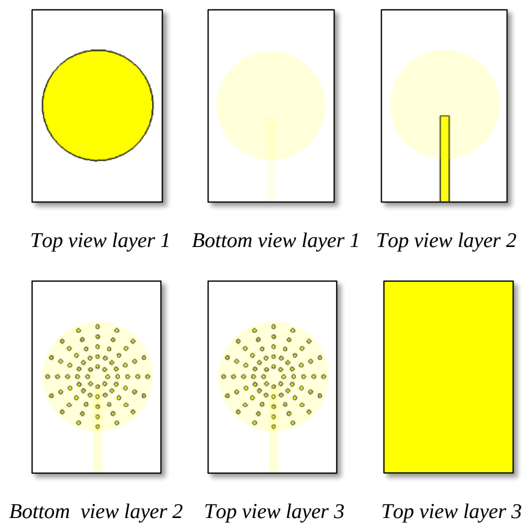


Figure 2 The simulated antenna shape and optimization of the artificial Taconic RF-60A microstrip.

4.2 S_{11} Parameter

The results of the S_{11} parameter simulation can be seen in Figure 3 and Figure 4. The Figure 3 and 4 are belonging to conventional microstrip antenna and artificial microstrip antenna, respectively. There is f_L which is the lower limit frequency, f_C is the center frequency, and f_U is the upper limit frequency. While R_L is the return loss and B_W is the bandwidth. In this study, bandwidth is a frequency area where the lower limit frequency and the upper limit frequency intersect with a value of S_{11} -10 dB. Based on the simulation results, the bandwidth of a conventional microstrip antenna is 231.6 MHz with a return loss of 32.49 dB at the center frequency. Meanwhile, the bandwidth produced by the artificial microstrip antenna is 281.2 MHz with a return loss of 35.47 dB at the center frequency. The artificial microstrip antenna has a bandwidth value of 21.42% and a return loss and 9.17 % greater than the conventional microstrip antenna.

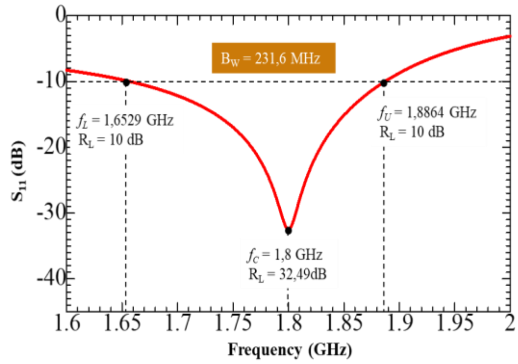


Figure 3 S_{11} parameters graph of conventional microstrip antenna

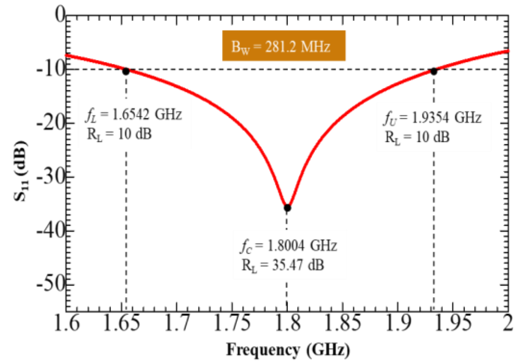


Figure 4 S_{11} parameters graph of artificial microstrip antenna

4.3. Gain

The results of the parameter simulation can be seen in Figure 5 and Figure 6. The figure 5 and 6 belong to conventional microstrip antenna and artificial microstrip antenna, respectively.

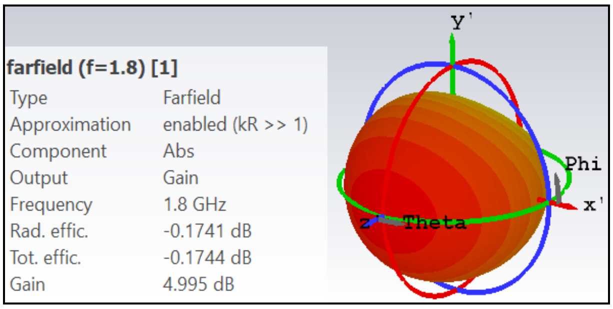


Figure 5 Gain of conventional microstrip antenna

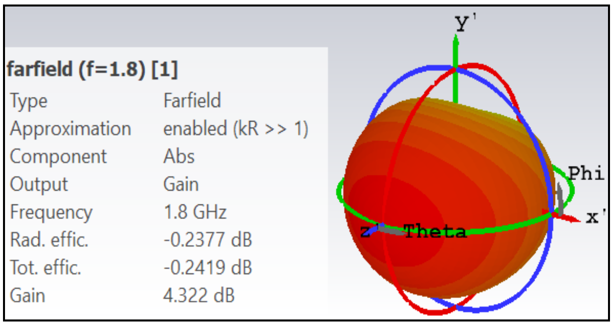


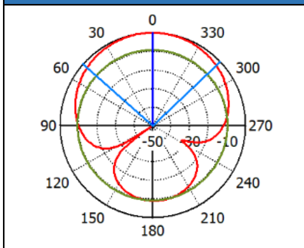
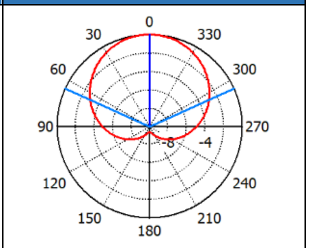
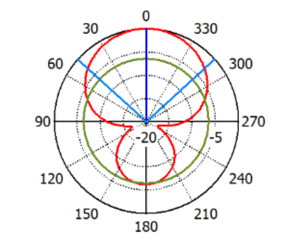
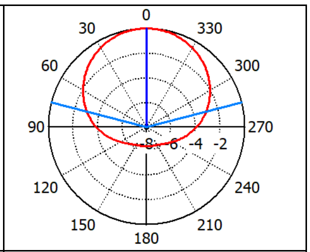
Figure 6 Gain of artificial microstrip antenna

In Figures 5 and 6, there is a color variation that shows the variation in the magnitude of the gain. The strongest gain magnitude is shown in red. The gain of a conventional microstrip antenna is 4.995 dBi, while the gain of an artificial microstrip antenna is 4.322 dBi. Based on this, the artificial antenna gains 13.47% less than the conventional microstrip antenna. This can occur due to the influence of the presence of wire embedded in the substrate. The embedded wires can withstand a lot of electric charges, so the antenna gain is small.

4.4. Radiation Pattern

Table 2 is a comparison table for the radiation pattern of artificial microstrip antennas with conventional microstrip antennas.

Table 2. Radiation pattern

E – Plane (Conventional)	H- Plane (Conventional)
	
• Main Lobe Magnitude = 0 dB • Main Lobe Direction = 0˚ • HPBW = 95.2˚	• Main Lobe Magnitude = 0 dB • Main Lobe Direction = 0˚ • HPBW = 131.6˚
E – Plane (Artificial)	**H- Plane (Artificial)**
	
• Main Lobe Magnitude = 0 dB • Main Lobe Direction = 0 ˚ • HPBW = 95.8˚	• Main Lobe Magnitude = 0 dB • Main Lobe Direction = 0 ˚ • HPBW = 151.4˚

The HPBW (Half-Power Beamwidth) value of the artificial microstrip antenna increased by 0.63% and 15.05% in the E-Plane and H-plane planes, respectively. The greater the HPBW value, the lower the gain value. This is because the gain is directly proportional to the directivity. The greater the value of HPBW, the value of directivity or directionality decreases, as well as the gain value.

5. CONCLUSION

In this study, a simulation approach has been demonstrated to compare the performance of two circular patch antennas made from Taconic RF- 60A substrate with and without artificial dielectric. The results showed an increase in bandwidth and HPBW on artificial microstrip antennas by 21.42% for bandwidth, 0.63% for HPBW on E-Plane, and 15.05% for HPBW in H-Plane. However, there was a decrease in gain by 13.47%. Taconic's RF-60A microstrip antenna was also proven to reduce the antenna substrate area by 40.67%.

AUTHORS' CONTRIBUTIONS

This paper presents research comparing conventional microstrip antennas and artificial microstrip antennas on Taconic RF-60A material. This material is rarely used. There has been no research on the effect of artificial dielectrics on this material before. This research also contributes to experiments using the number and size of conductor wires different from previous studies. The results of this study have good performance and quite a considerable antenna reduction.

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