Double layer parasitic radiator for S-Band antennas to increase gain and bandwidth performances

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Abstract. In this paper, a parasitic radiator combination was developed to improve the gain performance and bandwidth of the S-Band frequency microstrip antenna. Previous studies focused on adding one side layer of the parasitic radiator and the same structure, so the idea emerged to develop a microstrip antenna by adding parasitic radiators from the two sides of the antenna radiator layer and the different structure of the parasitic structure. In this paper, the design of the parasitic radiator is added by combining the circular parasitic radiator patch on the upper layer of the antenna radiator and the square parasitic radiator patch on the bottom layer of the antenna radiator. This study uses a research and development approach through the calculation of parasitic radiator structure and setting the distance between layers. Next is the simulation design and fabrication of antenna samples to verify the test results. Simulation and measurement results show that by adding a parasitic combination of radiators with a distance of 0.36 \( \lambda_g \) at the top layer and 0.15 \( \lambda_g \) at the bottom layer of the antenna, a better gain and bandwidth performance improvement as compared to the addition of parasitic radiator designs in previous studies. This result confirms that the idea of adding a double layer parasitic radiator can be used to improve the performance of a microstrip antenna.

1. Introduction
The development of communication systems requires the design and development of antennas to improve the performance of the communication system, including the development of antennas for S-band frequencies that are widely used for cellular systems and radar surveillance. One type of antenna that is developed by many antenna researchers today is the microstrip antenna. The microstrip antenna is widely used because of its relatively small physical size, low profile and easy fabrication [1]. Besides the advantages, there are some disadvantages of microstrip antennas, which are narrow bandwidth and low gain [1-2], so antenna researchers try to develop solutions to increase antenna gain and bandwidth.

One solution to increase the bandwidth and gain of a microstrip antenna is to use a parasitic radiator. Compared to other techniques of increasing gain and bandwidth, the addition of the parasitic radiator to the microstrip antenna design resulted in significant improvement with a simple design process. The parasitic radiator method is the addition of material to the main antenna placed above or below the main antenna with a certain distance [3-4]. Some research results show that the addition of the parasitic radiator can increase the bandwidth and gain of the microstrip antenna. Parasitic additions can be done by the layer stacking method of the radiating element [4]. The proposed stacked synthesis uses the finite-difference-time-domain (FDTD) calculations. The result is a significant gain increase and wider bandwidth compare to without the stacking method [4]. The proposed compact stack-patch antenna
design was also obtained from the addition of low temperature co-fired ceramics (LTCC) substrate for ISM 2.4 GHz and 5.8 GHz frequencies and local multipoint distribution service (LMDS) 28 GHz. The result is a 7% bandwidth increase in return loss below -10dB [5].

Other research results propose the addition of a notch and parasitic radiator patch for WLAN applications [6]. Besides the addition of notches and parasitic layers, several studies have also focused on engineering the shape of the parasitic radiator structure [7-8] and parasitic radiator development on array structures and MIMO antennas [9-11]. The results of this study conclude that the addition of the parasitic radiator can increase antenna and bandwidth gain significantly. However, the research that has been carried out only focuses on the development and addition of parasitic radiators on one side of the layer, so it is interesting to see the phenomenon that is produced when adding two sides of the parasitic radiator layer. For this reason, we will observe the effect of adding double layer parasitic radiators to increase antenna gain and bandwidth performance. Besides observing the effect of adding double layer parasitic radiators, this study will also observe the effect of the magnitude of the gap between the parasitic radiator layer and the radiating element. Setting the air gap between these layers is able to provide an increase in gain and bandwidth [12].

2. Theoretical foundations

2.1. Microstrip antenna

In this study used a circular microstrip antenna as a sample to observe the effect of adding a double layer parasitic radiator as shown in figure 1. The equation for determining the radius of a circle patch (a) is as follows [2],

\[
a = \frac{F}{\left(1 + \frac{2h}{\pi \varepsilon_r F} \left[\ln \left(\frac{\pi F}{2h}\right) + 1.7726\right]\right)^{\frac{1}{2}}}
\]  

(1)

With \(F\) is a function of the logarithmic radiating element, obtained from the following equation,

\[
F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}}
\]  

(2)

Where \(f_r\) is resonance frequency and \(\varepsilon_r\) is substrate dielectric constant.

2.2. Microstrip feed line

The approach to calculating the width of a microstrip feed line is as follows [2]:

\[
u = \frac{W_s}{h} = \frac{8 \varepsilon A}{\varepsilon_r + 1}
\]  

(3)

Where \(A\) can be calculated by approach,

\[
A = \frac{Z_0}{100} \left[\frac{\varepsilon_r + 1}{2}\right]^{0.5} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1} \left[0.23 + \frac{0.11}{\varepsilon_r}\right]
\]  

(4)

Then calculate the length of the microstrip line as follows,

\[
L_F = \frac{1}{4} \lambda_g
\]  

(5)

Where \(\lambda_g\) can be determined from the following equation,

\[
\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}}
\]  

(6)

And \(\varepsilon_{eff}\) can be determined from the following equation.
2.3. Parasitic substrate
In some previous studies, the addition of the parasitic substrate can increase gain and antenna bandwidth. Setting the distance between the parasitic substrate and the radiating element ($\lambda_g$) can be calculated through the following approach [4].

$$\lambda_g = \frac{\lambda_0}{\varepsilon_{eff}}$$  \hspace{1cm} (8)

Where $\lambda_0$ is the wavelength of the microstrip antenna.

3. Design double layer parasitic radiator

3.1. Design of circular microstrip antenna
Before adding a double layer parasitic radiator, first design a circular microstrip patch antenna as the basis for development. The circular microstrip patch antenna is designed using CST Microwave Studio which works at a frequency 3 GHz (S-band antenna). The microstrip antenna designed has a width 39 mm and has length 42.5 mm, using FR4 as substrate material which has thickness 1.6 mm. Circular patch design that has a radius ($a$) 14.5 mm with thickness 0.035 mm. The antenna design as shown in figure 1.

![Figure 1. Design of circular microstrip antenna.](image)

3.2. Antenna design with double layer parasitic radiator
The first parasitic layer is designed using patch circles that work at a frequency of 3 GHz. This parasitic is designed with a width 39 mm and has length 42.5 mm, using FR4 substrate material with thickness 1.6 mm without ground. This first layer is placed at the top of the antenna element. While the second layer is placed at the bottom of the antenna element. The second parasitic layer design uses the same size as the first parasitic layer and the antenna element, but without using the radiating element and only using the ground side. To obtain the best performance, the best distance observation between the first layer and the second layer of the parasitic radiator was carried out in this study. The ideal distance is obtained by the equation (8) approach and is optimized through the expansion of the air gap of each layer against the microstrip antenna element. The observation results obtained the best distance for the first layer (top layer) is $0.36\lambda_g$ and the second layer (bottom layer) is $0.15\lambda_g$. The air gap distance between the two layers produces the best gain and bandwidth performance. The antenna design with the addition of a double parasitic layer as shown in figure 2 and figure 3.
4. Result and discussion
The results of this study were obtained by comparing gain and bandwidth performance of circular microstrip antenna conventional with circular microstrip antenna using a double layer parasitic substrate. The overall performance comparison between conventional antenna with antenna using a double layer parasitic substrate as shown in Table 1.

Table 1. Overall comparison circular microstrip antenna with double layer parasitic substrate.

| Antenna                     | Antenna Dimension | Antenna Parameters |
|-----------------------------|-------------------|--------------------|
|                            | Length x Width (mm) | Height (mm) | Return Loss (dB) | VSWR  | Bandwidth (MHz) | Gain (dB) |
| Conventional Antenna       | 39 x 42.5         | 1.6              | -21.7             | 1.17   | 89              | 4.07      |
| Antenna with Double Layer Parasitic | 39 x 42.5         | 34              | -18.8             | 1.24   | 120             | 6.68      |

Figure 2. Front view of microstrip antenna with addition double layer parasitic radiator.

Figure 3. Back View of Microstrip antenna with addition double layer parasitic radiator.
From table 1, it can be illustrated that the increase in gain and bandwidth performance is significant with the addition of the double later parasitic radiator. This increase is better than the results of the previous research on adding parasitic radiators which only increased by around 10% - 20%. Simulation and Comparison of radiation patterns far-fields between circular microstrip antenna conventional with a circular antenna with addition double layer parasitic substrate as shown in figure 4 and figure 5.

![Figure 4. Radiation pattern of far-field conventional circular microstrip.](image)

The simulation result of antenna microstrip conventional show the gain is 4.07 dB, the beamwidth is 93.3° and has a sidelobe level of -11.5 dB. While the circular antenna microstrip with the addition of a double layer parasitic radiator can provide antenna gain 6.68 dB, the beamwidth 69.3° and sidelobe level -15.6 dB. These results indicate that the addition of the double layer parasitic radiator can increase gain significantly and also improve the performance of beamwidth and sidelobe level.

![Figure 5. Radiation pattern of far-field circular microstrip with double layer parasitic.](image)

5. Conclusion
The addition of a double layer parasitic radiator has been shown to significantly increase antenna gain and bandwidth. The results of this study indicate that the addition of a double layer parasitic radiator can increase the gain by 64% and increase bandwidth by 35%. The results of this study also prove that
the addition of the double layer parasitic radiator can significantly improve the performance of the microstrip antenna radiation pattern.

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