

Comparison between Rectangular and Circular Microstrip Patch Antenna at 28 GHz

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Abstract: This study compares two types of microstrip patch antennas—rectangular and circular—that are designed to work at 28 GHz, an important frequency used in 5G networks. The goal is to see how each shape performs when it comes to things like signal return (S11), bandwidth, gain, directivity, and how efficiently they radiate energy. Both antennas were built and tested using the same materials and thickness, so the comparison is fair. The results show that while both types work well at 28 GHz, the rectangular antenna slightly outperforms the circular one in terms of signal strength and bandwidth, which is great for situations where strong signals and wide coverage are needed. However, the circular antenna has its strengths too—it has a more even radiation pattern and takes up less space, which makes it a good fit for small, compact devices. Overall, the study helps engineers choose the right antenna shape depending on what their device or system needs.

Keywords: Antenna Design, Fifth generation, Antenna gain, Microstrip patch antenna, VSWR, s-parameter

I Introduction

Wireless communication is quickly advancing, especially with the arrival of 5G technology. This progress has created a need for powerful antennas that can work well at very high frequencies, like the 28 GHz band. This frequency is important for 5G because it allows for faster data speeds and lower delay times. However, building antennas that function effectively at such high frequencies can be tricky due to challenges with size, efficiency, and how they send out signals.

Microstrip patch antennas (MPAs) are becoming a favorite for 5G because they are thin, easy to make, and work well with electronic circuits. The two most common shapes for these antennas are rectangular and circular. Each has its benefits: rectangular antennas usually connect better with circuits and can handle a wider range of frequencies, while circular antennas are valued for their even signal patterns and smaller size.

This study looks at how rectangular and circular MPAs perform when both are made to work at 28 GHz. To keep things fair, both designs use the same material and thickness. Their performance is measured by looking at how well they send and receive signals, how wide a range of frequencies they support, how strong their signal is, and how efficient they are overall.

The purpose of this research is to highlight the pros and

cons of each antenna shape. This helps engineers choose the best design depending on their specific needs for a 5G project—whether they need strong signal coverage or a compact device. Knowing these differences is key to making sure antennas work their best in today's high-speed communication systems.

1.1 Feeding Techniques in Microstrip Patch Antennas

Microstrip patch antennas can be fed using different methods, each with pros and cons:

Coaxial Feed: Simple but can cause higher signal loss.

Microstrip Line Feed: Easy to integrate with good matching, but may lead to interference.

Aperture-Coupled Feed: Offers better signal matching and lower losses.

Proximity-Coupled Feed: No direct contact; gives low loss and minimal interference

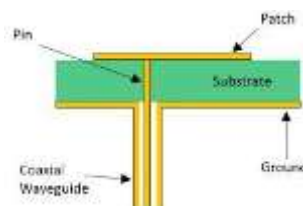


Figure 1.1 coaxial feed

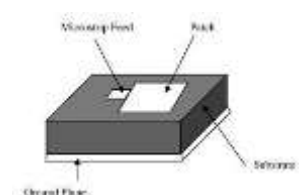


Figure 1.2 line feed

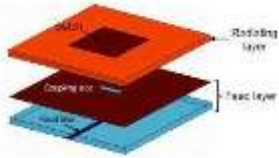


Figure 1.3 aperture coupled feed

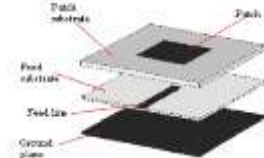


Figure 1.4 proximity coupled feed

2 RECTANGULAR AND CIRCULAR PATCH ANTENNA USING LINE FEED

2.1 Rectangular Patch Using Line Feed

Rectangular patch antennas are widely used in communication systems because they're flat, lightweight, and easy to integrate with circuits. They have a metal patch on top of a grounded layer, with a feed line connected at a specific spot called the feed point.

When using an inset line feed, the line connects a bit inside the patch rather than at the edge. This "inset distance" can be adjusted to improve how the antenna transfers energy and radiates signals.

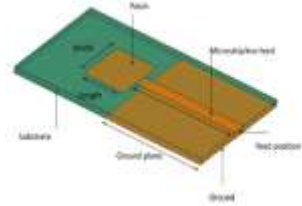


FIGURE 2.1: Structure of a Rectangular Patch

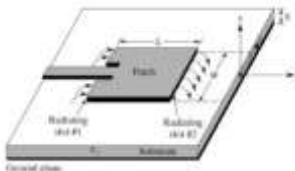


FIGURE 2.2: A Rectangular patch using Line feed (Inset)

The inset line feed is a popular method for feeding rectangular patch antennas because it offers key benefits:

Better signal matching: Adjusting the inset helps match the antenna's input to the feed line, improving energy flow and reducing signal loss.

Wider bandwidth: It allows the antenna to work across more frequencies than edge or corner feeds.

Less unwanted radiation: Placing the feed line inside the patch helps cut down interference.

2.2 DESIGN PARAMETERS OF ANTENNA

Frequency of operation (fo): The antenna has been designed at 28 GHz.

Dielectric constant of the substrate (er): Dielectric constants one of the most important parameters in the Microstrip antenna and substrate is used.

One of the most used materials is Rogers, Rogers/RT5880 is well suited for high frequencies/broadband application. Its permittivity is 2.2.

Height of dielectric substrate (h): Antennas used in phones are expected to be light in weight and small in size, which restricts their height.

By substituting $C = 3 \times 10^8 \text{ m/s}$ $Ct = 2.2$ and $f_0 = 28 \text{ GHz}$ the values of antenna dimensions can easily be determined. The following equations are used in designing the patch antennas.

- **Calculation of the width (W):**

$$W = \frac{C}{2 \times f_0 \sqrt{\frac{\epsilon_r + 1}{2}}}$$

- **Calculation of effective dielectric constant (e_{reff}):**

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2 \times \sqrt{\frac{1 + 12h}{W}}}$$

- **Calculation of extension length (ΔL):**

$$\Delta L = \frac{0.412 \times \left(\frac{W}{h} + 0.264\right) \times (\epsilon_{reff} + 0.3)}{(\epsilon_{reff} - 0.258) \times \left(\frac{W}{h} + 0.8\right)}$$

- **Calculation of effective length (L_{eff}):**

$$L_{eff} = \frac{C}{2f_0 \sqrt{\epsilon_{reff}}}$$

- **Calculation of actual length of patch (L):**

$$L = L_{eff} - 2\Delta L$$

- **Length & width of Substrate:**

$$L_S = L + 6h$$

$$W_S = W + 6h$$

$$H = \frac{0.0606 \lambda}{\sqrt{\epsilon_r}}$$

Calculation of Length of the Microstrip Transmission Line:

$$T_L = \frac{\lambda}{4} \sqrt{\epsilon_r}$$

3 CALCULATIONS FOR RECTANGULAR PATCH ANTENNA USING LINE FEED

3.1 S-PARAMETER (S11)

S-parameters show how signals move between different ports in a system. For example, S21 is power from Port 1 to Port 2, and S12 is the reverse. S11 and S22 represent how much power is reflected back at each port. In simple terms, they help us understand signal flow, reflection, and transmission between components—especially in systems like radios and antennas. These values change with frequency.

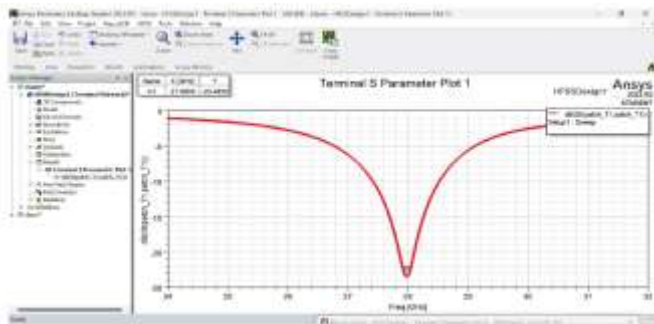


FIGURE 3.1: S-Parameter plot

3.2 VOLTAGE STANDING WAVE RATIO(VSWR)

VSWR, also called SWR, shows how well an antenna is matched to its feed line. The values range from 1 to infinity, where a value below 2 is generally considered a good match. If VSWR goes above 2 at a specific frequency, it usually means the antenna isn't well-matched.

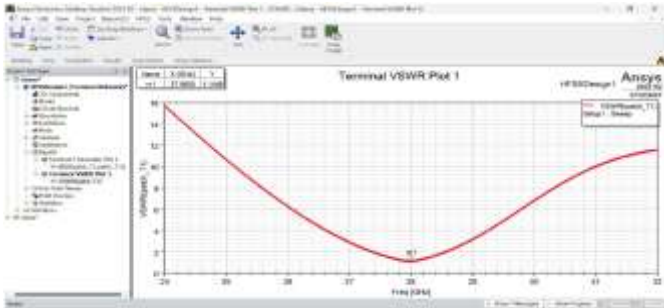


FIGURE 3.2: VSWR Plot

3.3 GAIN

Antenna gain is more useful than directivity because it also factors in any losses. It's calculated by multiplying directivity by efficiency. Basically, gain shows how much power is focused in the main direction the antenna

transmits. In this case, the antenna gain is 7.16 dB.

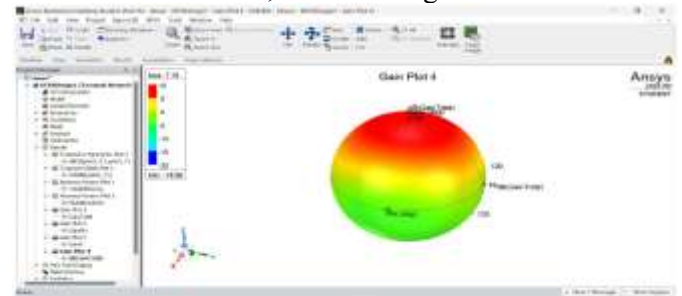


FIGURE 3.3: Gain

3.4 DIRECTIVITY

Directivity measures how focused an antenna's radiation is in a specific direction compared to its average radiation in all directions. It's basically the ratio of how strong the signal is in one direction versus the overall average. The average radiation intensity is the total radiated power of

the antenna averaged over all direction [i.e. $U_{avg} = \frac{P_r}{4\pi}$]

The directivity value of 5.3661 dB, we have been successfully determined from the simulation.

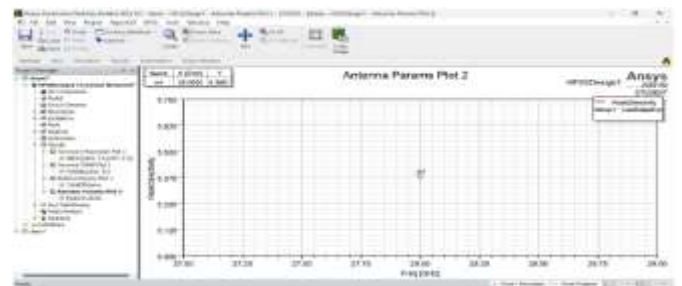


FIGURE 3.4: Directivity

3.5 TOTAL EFFICIENCY

A rectangular patch antenna's efficiency depends on how well it radiates power and how much is lost due to materials and design. Losses come from conductors, the dielectric, and radiation. With good design, it can reach about 70–80% efficiency, though actual results vary based on design and conditions.

It is known that, $Efficiency = \frac{Gain}{Directivity} \times 100\%$

Using these two parameters, it has been determined that the overall efficiency of the proposed antenna is 96.54 %.

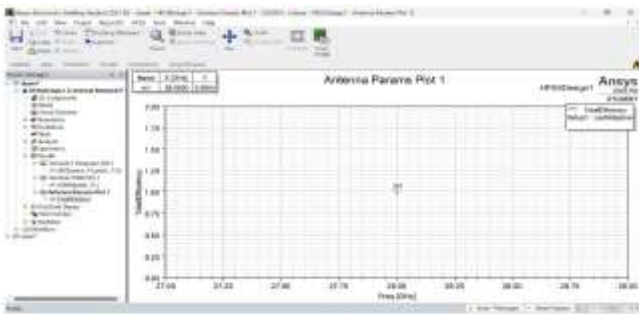


FIGURE 3.5: Total Efficiency

4 CIRCULAR PATCH USING LINE FEED

A circular patch antenna is a type of microstrip antenna that is widely used in various wireless communication applications. It consists of a circular metal patch that is printed on a substrate and is usually fed using a microstrip line.

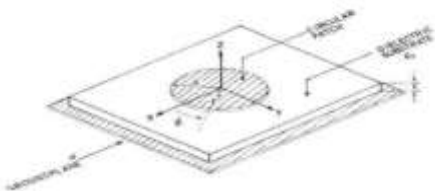


FIGURE 3.1: Structure of a Circular patch

To design a circular patch antenna with a microstrip line feed, you'll want to take the following steps:

1. **Find the Right Frequency:** First, determine the resonant frequency at which your antenna works best. This frequency depends on the patch's size and shape. You can figure it out using math formulas or simulation software.
2. **Pick the Material:** Next, choose a substrate, which is just the material on which your antenna is built. The substrate you choose, like FR4, Rogers, or Duroid, will influence how well your antenna performs.
3. **Set the Size:** After you have the frequency and substrate, calculate the exact dimensions for your circular patch. Again, you can do this with math or use simulation tools.
4. **Design the Feed:** Finally, design the microstrip line feed that connects power to the antenna. Its size and design depend on both the resonant frequency and the substrate.

In essence, by carefully choosing your resonant frequency, substrate, patch size, and feed design, you can create a functional and efficient circular patch antenna.

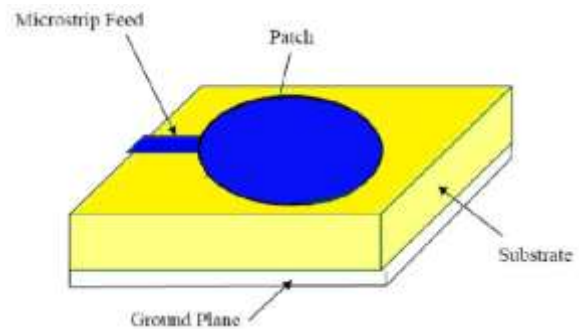


FIGURE 4.2: A Circular patch antenna using line feed

DESIGN PARAMETERS OF ANTENNA

$$f_r = 2.4 \text{ GHz}$$

$$h = 1.6 \text{ mm}$$

$$\epsilon_r = 4.4 \text{ (FR4)}$$

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\epsilon_r}}$$

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

CALCULATIONS FOR CIRCULAR PATCH ANTENNA USING LINE FEED

4.1 S-PARAMETER(S11)

S-parameters explain how signals move between ports in an electrical system. For example, S21 shows how much power moves from Port 1 to Port 2, and S12 shows the reverse.

For antennas, S11 measures how much power is reflected back instead of being transmitted. A good antenna has an S11 below -10 dB. The proposed antenna performs well, with an S11 of -20 dB at 28 GHz, meaning very little signal is wasted.

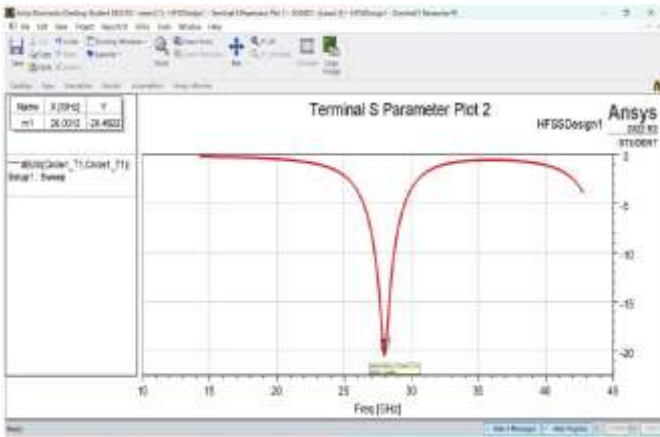


FIGURE 4.3: S-parameter

4.2 VOLTAGE STANDING WAVE RATIO (VSWR)

VSWR shows how well the antenna is matched to the cable feeding it. A lower VSWR means better matching. The ideal value is 1, and anything under 2 is generally good. If the VSWR goes above 2, it usually means the antenna isn't well-matched and may not work efficiently at that frequency

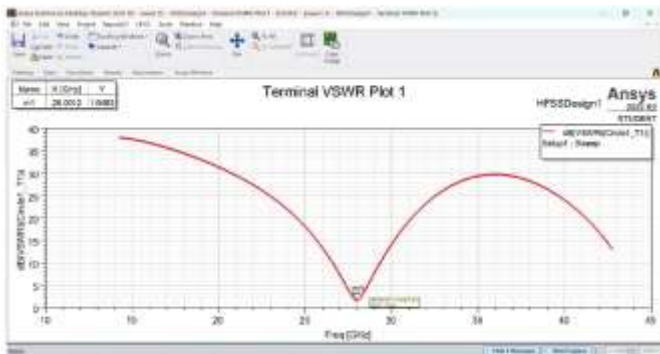


Figure 4.4:VSWR plot

4.3 GAIN

Antenna gain is more important than directivity because it also includes any power losses. It's calculated by multiplying directivity with efficiency. It shows how much power the antenna sends out in a specific direction. In terms of U the Antenna gain in a specified direction can be calculated as

$$G = \frac{U P_{in}}{4}$$

For microstrip circular patch antennas, the gain can reach 7.78 dB at 28 GHz, which means it effectively focuses the signal in one direction.

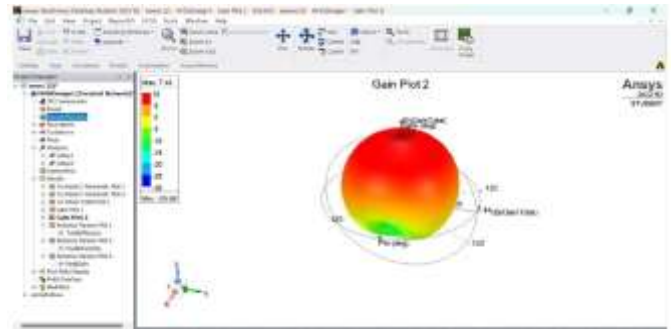


FIGURE 4.5: Gain Plot

4.4 DIRECTIVITY

Directivity shows how much stronger an antenna sends signals in one direction compared to all directions on average. The average is found by dividing the total radiated power by 4π [i.e., $U_{avg} = \frac{P_{total}}{4\pi}$], which is the area of a sphere in steradians.

The circular patch antenna has a directivity of 5.68 dB and achieves a bandwidth of 3.79%. The high return loss indicates good impedance matching between the patch and the feed, which means minimal signal is reflected back.

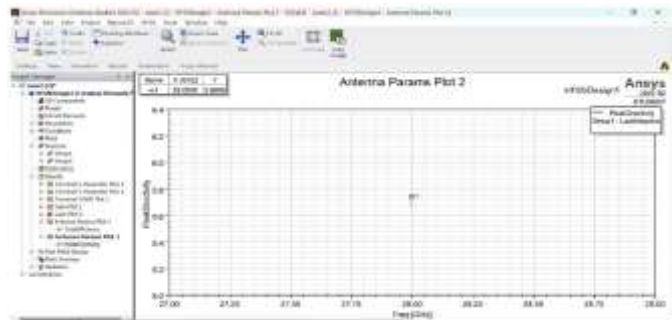


FIGURE 4.6: Directivity Plot

4.5 TOTAL EFFICIENCY

The overall efficiency of a circular patch antenna is influenced by things like the materials used, its size, the feed point, and how it radiates. If designed well, it can reach efficiency levels of 70–80%, and in some cases, even up to 90%.

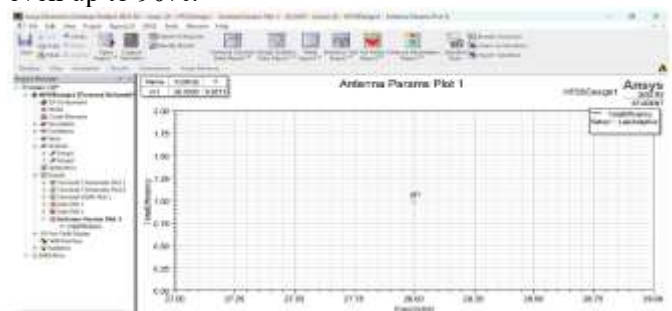


FIGURE 4.7: Total efficiency

Comparison table :

| SHAPE | RECTANGULAR | CIRCULAR |
|------------------|-------------|-----------|
| S-Parameter | -23.4830 | -20.4822 |
| VSWR | 1.1448 | 1.0483 |
| Directivity | 5.3661dB | 5.6806 dB |
| Total Efficiency | 96.54% | 97.11% |

II CONCLUSION

The rectangular patch antenna outperforms the circular one in terms of return loss, efficiency (96.54%), and bandwidth, making it ideal for applications requiring strong, focused signals and wide coverage. However, the circular patch provides slightly better gain and a more uniform radiation pattern, making it suitable for compact, omnidirectional devices. Ultimately, the better choice depends on the specific application requirements—performance vs. compactness.

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