Characterization of Microstrip Patch Array Antenna at 28 GHz

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***Abstract*— A Microstrip patch array antenna is presented and resonates at 28 GHz. It is a well-known antenna because of its easiness to manufacture with a high gain, easy on the pocketbook, as well as it has a simple structure. The substrate is based on the Rogers Duroid RT5880 with dielectric constant εr 2.2 and the height of copper Hc 0.254 mm. In fact, the Computer Simulation Technology Microwave Studio 2015 software has been used as a technique for simulating in this project. The design of the 28GHz antenna is done according to the specification of ETSI. By selecting optimum parameters of proposed, the measured return loss of proposed antenna during design frequency (28 GHz) is -52.522 dB at 28.08GHz. In addition, the value gained is high, which is 21.1 dBi and the achieved bandwidth is 1120 MHz. Hence, the target of the antenna is for the KA-Band communication which can work on 5G communication.**

***Index Terms*—Microstrip; Patch Array; Antenna; KA Band; 5G.**

I. Introduction

The 5G frequency spectrum is started from 10 GHz to 86 GHz [1]. In this paper, the operating frequency is at 28 GHz, therefore the design of the antenna only focus on the operating frequency. The emerging of 5G technology is demanding antennas with features previously unseen on a user terminal, such as the beamforming capability of the radiation pattern to perform spatial scanning [2,3]. This requirement raises numerous design challenges to achieve a reasonable trade-off between technological design issues and commercial criteria - low cost, small size, radiation efficiency, antenna gain, broadband performance, and much more.

The reason of why the Microstrip Array Antenna is at 28-GHz is significant. This is because of the famous microstrip patch's basic features which are low cost, easy to manufacture and it has a simple structure. Next, the array design permits the antenna to achieve tremendous expansion.

Furthermore, the design and the development of 28GHz of Microstrip Array antenna is based on the ETSI specification and Table 1 shows the table for the specification [4]. This antenna operates at 28 GHz. Other than that, the antenna's design is developed from a single patch to 32-Element patch array antenna. The material that has been used for this design is Rogers Duroid RT5880 the dielectric constant which is εr 2.2, and the height of the dielectric constant is 0.254 mm. There are some advantages of the patch which are low profile design, feed line and matching network can be fabricated simultaneously, light weight and comfortable, low fabrication loss and countless more.

Table 1
ETSI Specification for The Design [4]

Parameters	Specification (28 GHz)
Return loss (dB)	<-10
Gain (dBi)	>22
Front to back lobe ratio(dB)	>25
Side lobe ratio (dB)	17 at 15˚
Bandwidth	1 GHz

II. Antenna Design

A. Single Patch Design

The dimension of proposed antenna are as follows: the length of the patch *Lp*= 3.47 mm, the width of the patch *Wp*= 4.42 mm, the thickness of the copper *hcopper*= 0.017 mm, and the width of the insert *wg*= 0.4 mm. According to Balanis' book entitled '*Antenna Theory: Analysis and Design'* [5], the calculations of the dimension of a single patch are presented in Equation (1).

Calculation of the patch Width, *Wp*:

$$W_p = \frac{c}{2\,fr\sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{1}$$

Substitute c= 3 x 10^8, fr =28 GHz and εr= 2.2 and then W=4.42 mm.

Calculation of the actual length of antenna, *L*:

$$L = L_{eff} - 2\Delta L \tag{5}$$

Substitute $Leff$=3.73 mm, ΔL=0.13 mm and then L= 3.47 mm

Figure 1 illustrates the front and the back of the single patch antenna. All parameters are calculated manually by using the formulas given in Antenna theory book (3rd edition) by Balanis [5].

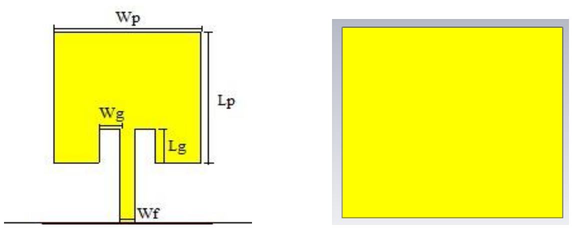


Figure 1: The front view of and back view of single patch antenna

On the other hand, the initial value for the single patch antenna is presented in Table 2. The initial value will undergo parametric study. *Wp* is the width of the patch, *Wf* is the width of the feed line, followed by *Wg* is the width of the gap, and finally, *Ws* is the width of the substrate. In addition, the *L* stands for the length and it follows the same meaning with the width.

Table 2
Design Parameters Single Patch

Parameters	*H*	*Hc*	*Lf*	*Lp*	*Ls*	*Wf*	*Wg*	*Wp*	*Ws*
Value(mm)	0.254	0.017	1.7	3.47	4.37	0.44	0.5	4.42	5.76

B. 2-Element Patch Of Array Antenna

After all parameter studies, the single antenna patch has achieved the best condition of all specifications. Next, the array antenna design is constructed. In this design, the distance between two patches are also being set up which is the wavelength (λ) and the feed of the antenna is being designed by using a calculator known as EMTALK as shown in Figure 2.

$$\lambda = 10.714 \text{ mm}$$

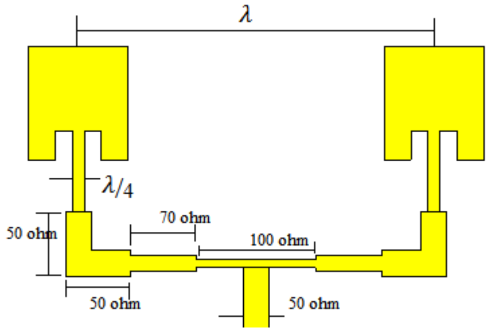


Figure 2: The front view of 2x1 patch antenna

The λ/4 is also known as the quarter-wave transformer. The quarter-wave transformer is a simple and useful method to match the real load of impedance to a different source of impedance, and frequently being used in antennas [4]. An additional feature of the quarter-wave transformer is that it can be extended to multi-section designs for broader bandwidth. Unfortunately, the impedance is valid at the resonant frequency and another technique can be used for broad banding.

The single section of the quarter-wave transformer has an equal length with the quarter-wave in microstrip and its characteristic of impedance is Z_1, should be given by:

$$Z_1 = \sqrt{Z_0 Z_{in}} \tag{8}$$

Where Z_0 the characteristic impedance of the 50 ohm is line and Z_{in}, is the input impedance of the rectangular patch

The width *W2* of the quarter-wave transformer can be located by an equation *Wd*, to calculate the value of Z_1, from an equation of the Z_1.

$$\frac{W1}{h} = \begin{cases} \dfrac{8C^A}{e^{2A}-2} \; for \dfrac{W1}{h} < 2 \\ \dfrac{2}{\pi}\left[B-1-\ln(2B-1)+\dfrac{\varepsilon_e}{\varepsilon_r}\left\{\ln(B+1)+0.39-\dfrac{0.61}{\varepsilon_r}\right\}\right] for \dfrac{W1}{h} > 2 \end{cases} \tag{9}$$

$$A = \frac{Z_0}{60}\frac{\sqrt{\varepsilon_r+1}}{\sqrt{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23+\frac{0.11}{\varepsilon_r}\right) \tag{10}$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \tag{11}$$

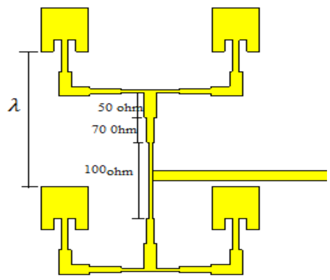
Table 3 elucidates the design of feed antenna from 2-Element up to 32-Element. Except for the length feed of 100 ohm. This is because the length feed is needed to be measured by using a pick point in CST and separated by a spacing element, therefore the length feed is designed. Each of the patch antenna is separated by 10.7143 mm.

Table 3
Design of feed antenna

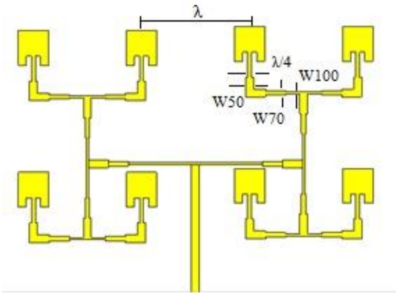
Design of feed	Width of feed (mm)	Length of feed (mm)
50 ohm	0.7826	1.9581
70 ohm	0.4569	1.9873
100 ohm	0.2276	2.0201

C. 4-Element,8-Element and 16-Element Patch Of Array Antenna

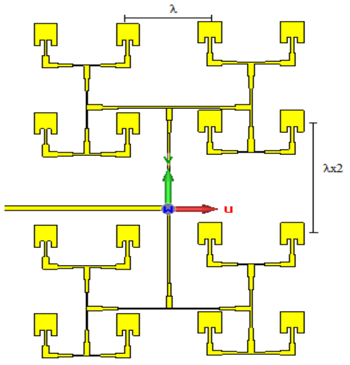
Figure 3 depicts the front view 4-Element, 8-Element and 16-Element patch array antenna. The antenna has been evolving into 4-Element, 8-Element and 16-Element that is because we want to achieve the better return loss and to have higher gain. The feed parameter is still using the same value except for the feed for the 2-Elements and another 2-Elements. It is because they use the separation between the element more than the first one as shown in Figure 3.



(a) 2x2 Patch



(b) 4x2 Patch



(c) 4x4 Patch

Figure 3: The front view 4-Element, 8-Element and 16-Element patch array antenna

The antenna array is to address the future need for lowered side lobe and deep, and null wide-band pattern. Therefore, the antenna radiation pattern of the array has a lot of side lobes. All the parameter of the antenna is still using the same parameters from 2x1 patch arrays.

Figure 3(b) shows the 4x2 patch array or 8-Element of array antenna use the same patch size like before, but the difference is only in the middle of the feed of 100 ohm that is connected to 50 ohm feed. The feed has been adjusted for a spacing between the 4-Element to the next 4-Element, which is 10.7143mm. For the left and right 4-Element patch have been designed and copied, hence the translating between the left and the right is approximately 10.7143. Therefore, the 100 ohm feed uses the pick point from both sides to measure the length and the design, and the value is 7.374 mm

Figure 3(c) illustrates the design of 4x4 patch array antenna by operating the same distance, the distance of λ between the patch is 10.7143 mm. The feed design is still using the same feed as before, except for the length of 100 ohm follows the distance measuring at 70 ohm when both 2x2 patch array antennas are designed.

The difference of each design is the length of the feed of 50 ohm and the feed of 100 ohm. The feed of 50 ohm is using the pick point until the end of the substrate. In contrast, for the feed of 100 ohm, the pick point is used by translating the 8-Element of 10.7143 mm and build the feed of 50 ohm and 70 ohm. Then, the 100 ohm is connected to the length of the pick point at 70 ohm feed, and the measurement is approximately 13.310030 mm

D. 32-Element Patch Of Array Antenna

Figure 4 illustrates the 32-Element patch array antenna design. This design is the decisive design to increase the directivity which is more than 22 dBi by following the specifications by ETSI. From the single design to the 32-Element patch design, the directivity of the antenna increased by half from the original directivity.

Each patch of the antenna separated by 10.7143 mm. Each patch feed is calculated by using emtalk.com calculator. Moreover, the length of 100 ohm is being used to connect the feed.

The distinctive of each design is that it differs in terms of the length of the feed. Which are 50 ohm and 100 ohm. The feed of 50 ohm is using the pick point up to the end of the substrate.

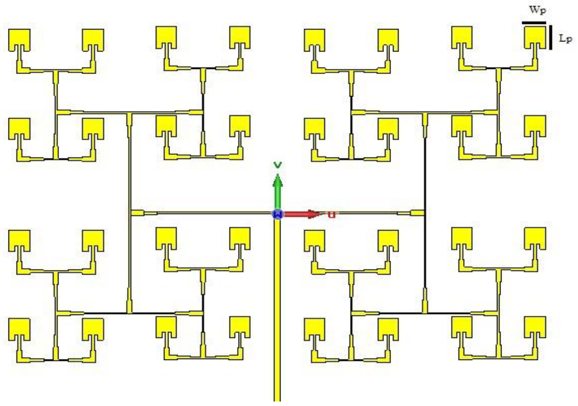


Figure 4 The front view of 4x8 patch array antenna

Additionally, for the feed of 100 ohm, the pick point is used by translating the 8-Element of 10.7143 mm and build the feed of 50 ohm and 70 ohm. Then, the 100 ohm is connected to the length of the pick point at 70 ohm feed, and the measurement is approximately 13.310030 mm.

III. Result And Discussion

A. Return loss and Bandwidth

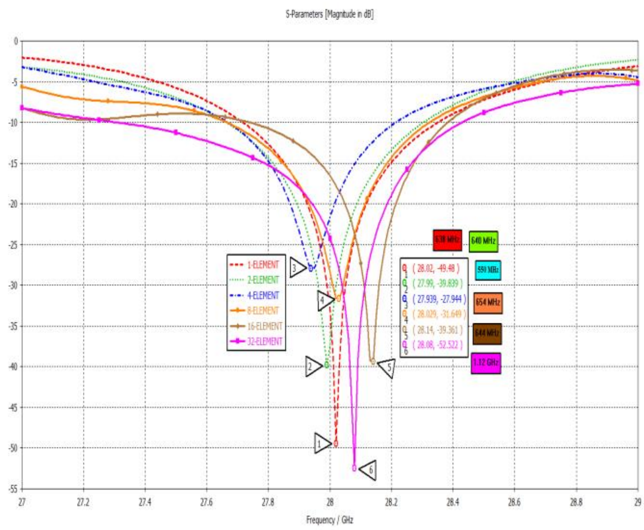


Figure 5: The Return loss for single patch until 32-Element patch array

i. Single Patch Design

Return loss for single patch design is -12.142 dB before the parametric study. The parametric study is several parametric studies had been done on the single patch antenna to show the effect of the design parameters on the antenna performance. The best performance of prototype antenna will choose to the next step of array designation.

The design parameter has been studied is the width of the patch, *Wp*. The purpose was to investigate the dependence the resonant frequency of the patch width. This was done by increasing the slot width from 3.60 mm to 4.50 mm and checked the resonant frequency. Figure 5 depicts the combined result from single to 32- Element patch antenna. Therefore, the best return loss for a single antenna parametric study is -49.48 dB with a bandwidth 630 MHz at *Wp* 3.21605 mm.

ii. 8-Element and 16-Element Patch Array Antenna

Figure 5 depicts the result for 8-Element and 16- element patch array antenna, the graph is falling at 28.029 GHz and 28.307 GHz with the return loss is -31.649 dB and -24.608 dB respectively. The bandwidth is around 654 Mhz and 644 MHz. The return loss is very good because it is still under the specification of ETSI.

iii. 32-Element Patch of Array Antenna

Figure 5 also shows the result for return loss for 32-Element patch array antenna which is -52.522 dB at 28.08 GHz, but the value is good because it is under -10 dB. So, the patch antenna still working good. The bandwidth of this design is 1.116 GHz.

Table 4
Summary for Return Loss and Bandwidth Result Parameter

Parameter and design	Return loss (dB)	Bandwidth (MHz)
Single patch	-44.464	630
2-Element patch array	-39.839	640
4-Element patch array	-27.944	550
8-Element patch array	- 31.649	654
16-Element patch array	-39.361	644
32-Element patch array	-52.522	1120

For the return loss and bandwidth for both design, as we can see from the Table 4, the single patch has the best result for parameters. But the 32-Element patch array also in a good condition by following the ETSI specification. The specification the return loss must be lower than -10 dB and the bandwidth already achieved the specification.

B. Directivity, Side lobes Ratio and Front to back lobes Ratio

Directivity is a fundamental of an antenna parameter. It is a measure how directional an antenna radiation pattern is. An antenna that radiates equally in all directions would have effectively zero directionality, and the directivity of this type of antenna would be 1 (or 0 dB).

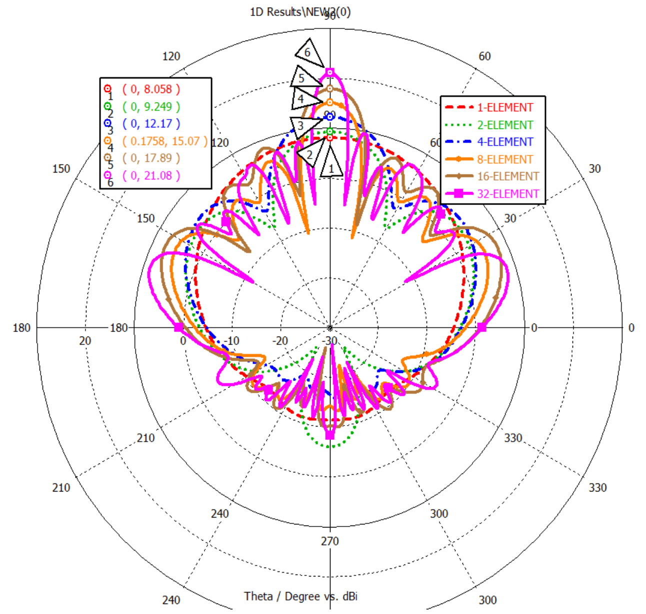
i. Single patch until 16-Element patch antenna.

Figure 6 shows all the Radiation pattern from a single patch to the 32-Element patch which shows from lower directivity until higher directivity. The value for a single patch is 8.058 dBi, which is really good for single patch have a high gain. Then the antenna became array to achieve the higher directivity 22 dBi.

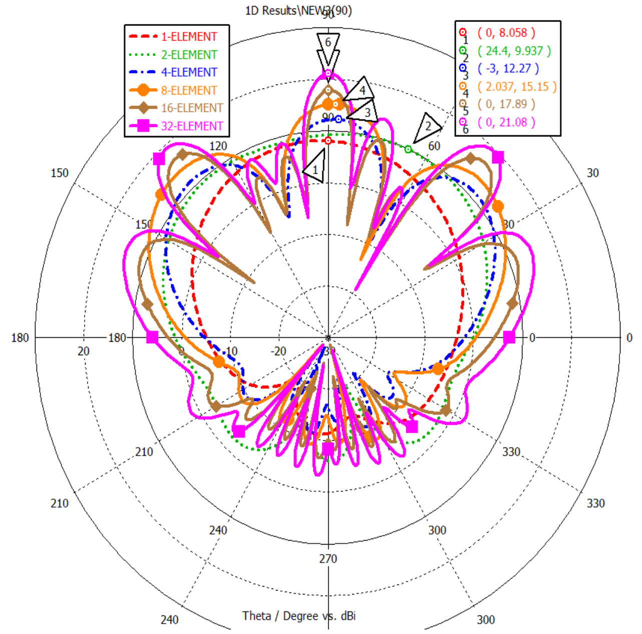
Next, the 2-Element antenna also shows in Figure 6, the gain in major lobe which is 9.93 dBi. Other than that, it can show the gain on side lobe, for our specification the side lobe ratio should be 17dB at 15 degree. The polar show the result is 9.4 dB. Last but not least is determined the front to back lobe ratio (dB), from the specification the ratio should be more than 25 dB.

The ratio has been analyzed which is 15 dB. The front to back ratio is smaller it maybe it is only on 2 -Element patch of antenna and to achieve the specification may be to level up the array.

Next, the 4-Element gives a higher result. The main lobe magnitude or directivity in this 4-element patch antenna is 12.17 dBi. The Main lobe direction is at 2.0 degree. This means that the antenna is best working at that position. The front back ratio for 2x2 array antenna is 22 dB. The side lobe ratio at 15 degree is 7.7 dB.



(a) H-field (0 degree)



b) E-field (90 degree)

Figure 6: Radiation pattern of single patch to 32-Element patch antenna

The Radiation pattern also affected by the feed design, size of 50 ohm, 70 ohm and 100 ohm all have a different dimension. If the feed is not matched, then it will give a bad result.

ii. 32-Element Patch of Array Antenna

The directivity shape for the 32-element antenna is totally different with the single patch design because in this array design the antenna has been matched with feed of 50 ohm, 70 ohm, and 100 ohm. Other than a match with the feed, the additional of the rectangular patch also made a lot of changes through the radiation pattern. The directivity for E-field and H-field have the same value on the 0 degree which is 21.1 dBi, all are shown in Figure 7.

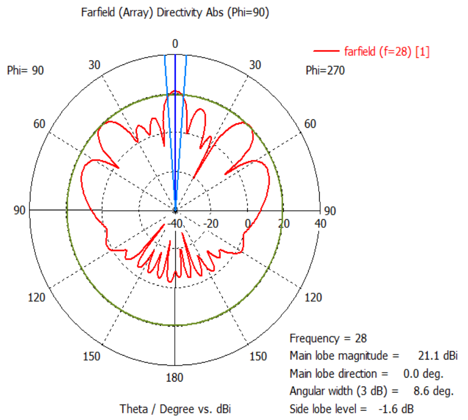


Figure 7: The Directivity (polar) for 32-Element patch array antenna

Table 5
Summary for Both Result Parameters

Design and parameters	Directivity (dBi)	Side lobes (dB)	Front to back lobe (dB)
Single patch	8.3	8.5	12
2-Element patch array	9.93	9.4	15
4-Element patch array	12.1	7.7	22
8-Element patch array	14.5	8.96	22
16-element patch array	17.4	9.2	24
32-element patch array	21.1	12	30

The main objective of the antenna design is to achieve the highest level of the directivity, side lobes, front to back lobes and have a good efficiency. From the first design, which is a single patch to the 32-Element patch antenna, there is an escalation in all parameters. In addition, the directivity has increased a lot from 8.3 dBi for a single patch to 21.1 dBi for 32-Element. The increasing of the directivity is coming from the addition of the patch. The higher the number of patches, the more increase on the directivity. Other than the directivity, the side lobes and the front to back lobes have also shown the increasing of the magnitude (dB). This is because of the radiating elements of the antenna are radiated in many directions.

IV. Conclusion

This research is present a design and development of 28GHz microstrip array antenna with microstrip feed line as the connector is achieved. The 32-element patch array antenna is chosen which gives a high gain of 21.1 dBi at 28 GHz, while single patch design only 8.9 dBi.

The front to the back lobe of the 32-element has achieved the ETSI specification. The antenna design also gives an effect to parameters. In the example, all the ETSI specification are evaluated. The design and development of this antenna is simulated and studied in this paper.

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