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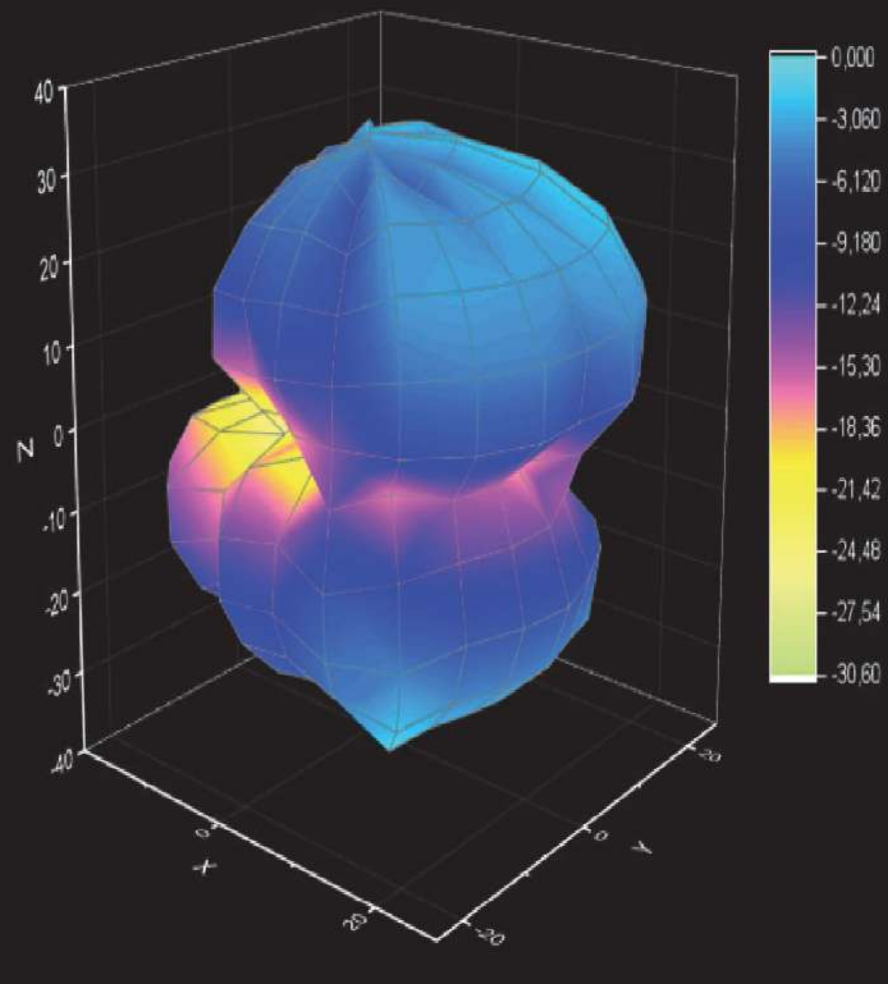


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# Bandwidth Enhancement of Array Microstrip Antenna Using Spiral Stub For 5G Communication System

***Abstract**. This paper proposes a new design of a 2x2 microstrip array antenna with spiral stub for a 5G communication system at the resonant frequency of 3.5 GHz. Spiral stub is useful for increasing the bandwidth value of the proposed antenna. The spiral stub is designed using a microstrip line with an impedance of 70.7 ohms. This study proposes three antenna models by adjusting the number and dimensions of the spiral stubs. From the simulation results using EM Simulation, the optimal bandwidth is obtained when the number of spiral stubs (n) = 3 with dimensions of spiral stub $W_{stub}$ =18.5 mm and $L_s$ = 8 mm . The bandwidth of the proposed antenna is 0.8 GHz or an increase until 88.88% compared with array 2x2 without spiral stubs. Furthermore, the gain of the proposed antenna is 10.67 dB at the resonant frequency of 3.5 GHz. This research is very useful for increasing bandwidth for the purposes of 5G communication systems.*

***Streszczenie.** W artykule zaproponowano nowy projekt anteny mikropaskowej 2x2 ze spiralnym odgałęzieniem dla systemu komunikacji 5G na częstotliwości rezonansowej 3,5 GHz. Spiralny odcinek jest przydatny do zwiększania wartości szerokości pasma proponowanej anteny. Spiralny króciec został zaprojektowany z wykorzystaniem linii mikropaskowej o impedancji 70,7 omów. W niniejszym opracowaniu zaproponowano trzy modele anten, dostosowując liczbę i wymiary końcówek spiralnych. Z wyników symulacji z wykorzystaniem symulacji EM optymalną szerokość pasma uzyskuje się, gdy liczba króćców spiralnych (n) = 3 o wymiarach króćca spiralnego Wstub =18,5 mm i Ls = 8 mm . Przepustowość proponowanej anteny wynosi 0,8 GHz lub jest wyższa o 88,88% w porównaniu z macierzą 2x2 bez spiralnych odgałęzień. Ponadto zysk proponowanej anteny wynosi 10,67 dB przy częstotliwości rezonansowej 3,5 GHz. Badania te są bardzo przydatne do zwiększania przepustowości na potrzeby systemów komunikacji 5G.* (***Poprawa przepustowości anteny mikropaskowej za pomocą spiralnego złącza dla systemu) komunikacji 5G***)

**Keywords:** antenna, array, bandwidth, microstrip, spiral stub, 5G Communcation System
**Słowa kluczowe:** antena szerokopasmowa, przepustowość, 5G.

## Introduction

The fifth generation communication system (5G) was introduced in 2017 and has advantages such as high data transfer data rates and wide bandwidth [1]. Based on the regulations set by [2] the frequency used for the fifth generation communication system is divided into several bands, namely for high band 28 GHz, mid band 15 GHz and low band 3.5 GHz (3.4 – 3.6 GHz). In a wireless communication system, an antenna is needed as a sender and receiver of signals that will be converted into electrical waves so that they can be used for voice and data communication purposes [3]. One of the antennas that has been widely developed for the purposes of wireless communication systems is the microstrip antenna [4]. Microstrip antennas have the advantages of compact design, low costs and can work at high frequencies [5]. However, microstrip antennas have several disadvantages, including narrow bandwidth, low gain and directivity [6]. The compact dimension is one of the advantages of the microstrip antenna so that it is suitable for use as a receiving antenna in a wireless communication system, but to maintain stable connectivity between the transmitter and receiver, an antenna with high gain and wide bandwidth is needed.

The development of microstrip antennas for fifth generation communication systems has been described in several previous studies [7-8]. The research proposed by [9] has succeeded in designing a circular single element microstrip antenna at a frequency of 3.5 GHz with a reflection coefficient value of -30 dB and a gain of 5.15 dBi, then previous research [10] proposed a rectangular microstrip antenna was developed at a frequency of 3.5 GHz using the defected ground structure method with reflection coefficients and gains of -17.43 dB and 6.6 dB, respectively. However, these two studies still produce low gain and narrow bandwidth, so optimization needs to be done. Several optimization methods to improve directivity and bandwidth have been described in previous studies, including arrays [11-12], parasitic [13], dual feed [14-15], proximity coupling [16-17] and coplanar waveguide [18-19] . In research conducted by [20] the array method was used to increase gain of the microstrip antenna at frequency of 3.5 GHz with gain of 7.3 dB while research conducted by [21] obtain gain of 12.6 until 13.6 dBi using the parasitic method. This research proposes a 2x2 element microstrip array antenna with spiral stub. The addition of spiral stub aims to increase the bandwidth of the proposed antenna. The spiral stub is designed using a microstrip line with an impedance of Z = 70.7 Ohm and number of stub (n) = 3. The main contribution in this research is to produce a microstrip antenna with high gain and wide bandwidth. From the simulation results, the bandwidth of proposed antenna increase until 88.88% with gain of 10.67 dB after using the spiral stub.

## Antenna Design

The initial stage of the research is to calculate the dimensions of a single element microstrip antenna that works at a frequency of 3.5 GHz. The shape of the microstrip antenna proposed in this study is a rectangular shape with length (L) and width (W). In addition, the microstrip antenna will be connected to a female SMA connector with an impedance of 50 Ohms using a microstrip transmission line. The function of the microstrip line is to match the impedance between the antenna and the connector. The antenna and connector must have the appropriate impedance to radiate electromagnetic waves at the proposed antenna. The dimensions of a rectangular microstrip antenna obtained using equations (1), (2), (3), (4) and (5) while for the microstrip line using equations (6) and (7) [22].

(1) $W = \frac{C}{2f\sqrt{\frac{\varepsilon r+1}{2}}}$

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

(3) $L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{reff}}}$

(4) $\varepsilon_{reff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}[1+12\frac{h}{W}]^{-\frac{1}{2}}$

(5) $\Delta_L = 0.412.h\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)}$

(6) $W_z = \frac{2h}{\pi}\{B-1-\ln(2B-1)+\frac{\varepsilon_r-1}{2\varepsilon_r}[\ln(B-1)+0.39-\frac{0.61}{\varepsilon_r}]\}.$

(7) $B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_{eff}}}.$

After performing calculations using equations (1), (2), (3), (4) (5), (6) and (7) the dimensions of W = 33.88 mm and L = 28.05 mm were obtained while the resonant frequency (f) of 3.5 GHz with dielectric constant (Ɛr) = 2.2 and the thickness of the substrate (h) = 1.575 mm according with specification of Duroid RT 5880. For the microstrip line dimensions, Wz = 4.6 mm is obtained while impedance of Z = 50 Ohm. The next step is to design a 2x2 element microstrip antenna array using microstrip lines with impedances of 50 Ohms, 70.7 Ohms and 100 Ohms. The patch of the antenna are separated from each other by the distance $d_a$ and $d_b$. The purpose of 2x2 array microstrip antenna is improve the gain and directivity of the proposed antenna. The design and structure of the 2x2 array microstrip antenna is shown in Figure 1 .

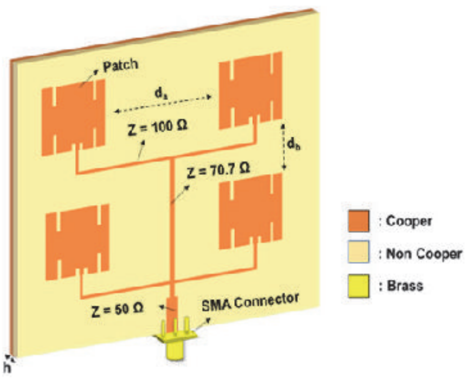


Fig.1. Structure of 2x2 Array Microstrip Antenna

Figure 1 shows the parameters while Figure 2 shows the structure of a 2x2 array microstrip antenna consisting of a patch antenna, microstrip line ($Z_1$ = 50, $Z_2$ = 70.7 and $Z_3$ = 100 Ohms), spiral stub and SMA connectors. The function of microstrip line with an impedance of 70.7 Ohm and 100 Ohm as an impedance matching to obtain a good reflection coefficient so that the antenna can work optimally [17]. Furthermore, a feed line with an impedance of 50 ohms is used as the main impedance which is directly connected to the SMA connector which also has an impedance of 50 Ohms.

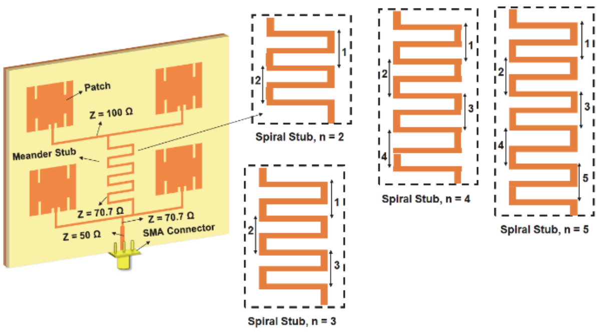


Fig.2. Structure of 2x2 Array Microstrip Antenna Using Spiral Stub with n = 2, 3, 4 and 5

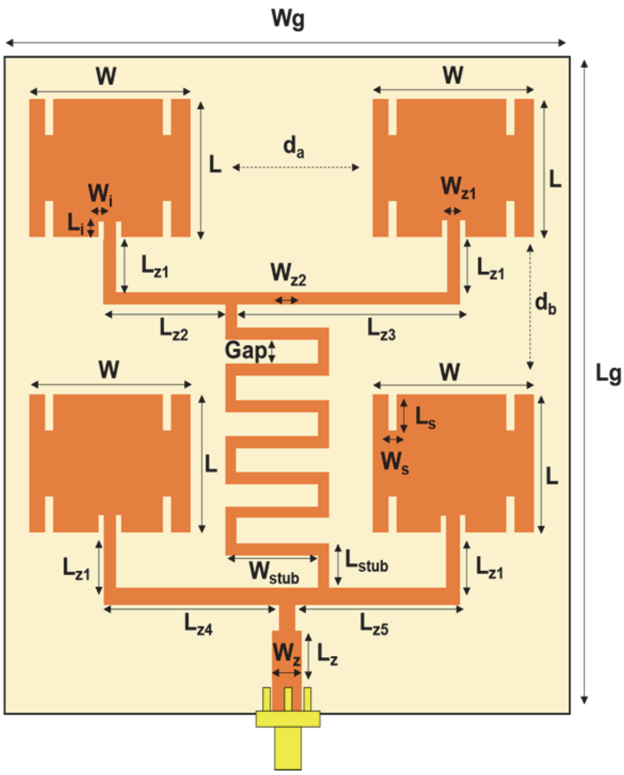


Fig.3. Dimension of 2x2 Array Microstrip Antenna Using Spiral Stub

The next step is to optimize the bandwidth of the 2x2 element antenna array using spiral stubs. Spiral stub aims to increase the bandwidth of the antenna. Spiral Stub is designed using microstrip line with impedance Z= 70.7 ohm which is placed between microstrip line with Z= 100 ohm and Z= 50 ohm. The dimension of a 2x2 element array antenna using a spiral stub is shown in Figure 3.

Figure 2 shows the structure of a 2x2 element antenna array using a spiral stub with n = 3 elements. The overall dimensions of the proposed antenna are shown in Table 1. Furthermore, the proposed antenna uses slits with dimensions Ws = 1 mm and Ls = 1 mm. The purpose of adding slits is to control the resonant frequency and improve the reflection coefficient of the proposed antenna.

Table 1 shows that the stub designed using n = 3 elements with the gap of 5.5 mm. Further optimization is carried out by controlling the number of spiral stubs placed on the antenna. The purpose of this optimization is to obtain an increase in the bandwidth of the proposed antenna.

Table 1. The parameters of proposed antenna

| Parameter | Dimension [mm] | Parameter | Dimension |
|---|---|---|---|
| Wg | 120 | $W_{z1}$ | 2 |
| Lg | 100 | $W_{z2}$ | 3 |
| W | 35 | $L_{z1}$ | 13 |
| L | 28.3 | $L_{z2}$ | 29.5 |
| Wz | 5 | $L_{z3}$ | 48.5 |
| Lz | 48.5 | $L_{z4}$ | 37.5 |
| Ws | 1 | $L_{z4}$ | 39.5 |
| Ls | 6.6 | $d_a$ | 43 |
| Wi | 1 | $d_b$ | 27.4 |
| Li | 6 | h | 1.57 |
| $W_{stub}$ | 18.5 | $L_{stub}$ | 8 |

## Result and Discussion

Optimal bandwidth and gain are obtained by performing several iterations of the spiral stub configuration. In this study, iterations and parametric study were carried out by changing the number of spiral stubs (n) of the proposed antenna as shown in Table 2.

Table 2. Iteration Number of Spiral Stub

| Iteration | Number of Spiral Stub |
|---|---|
| 1 | 5 |
| 2 | 4 |
| 3 | 3 |
| 4 | 2 |

Table 2 shows the iteration process carried out by changing the number of spiral stubs (n) = 2, 3, 4 and 5. The simulation results of the iteration process are shown in the Figure 4, Figure 5 and Figure 6.

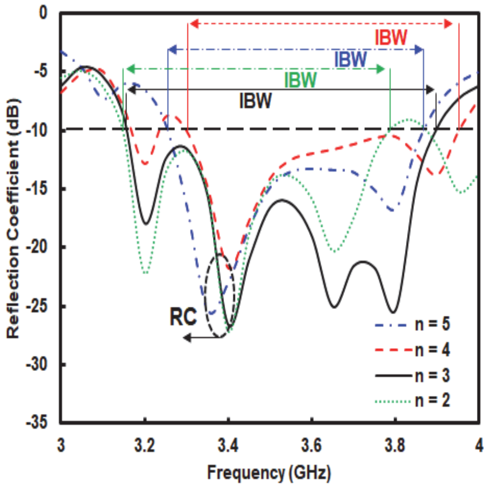


Fig.4. Simulation of Reflection Coefficient

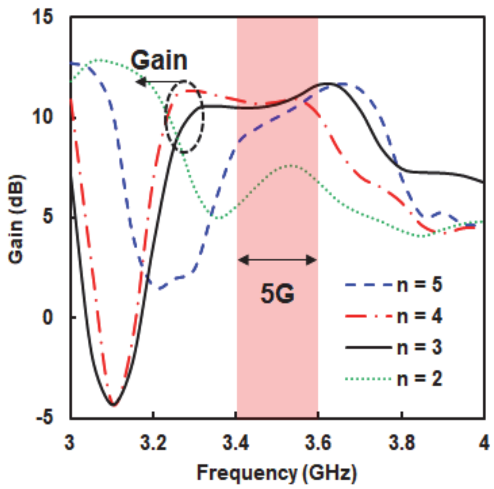


Fig.5. Simulation of Gain

Figure 4 and Figure 5 shows that the optimal bandwidth is obtained during the third iteration with the number of spirals n = 3 elements while at n = 5 elements, the bandwidth of the antenna is 600 MHz with a gain of 10.03 dB and at n = 4 elements, the bandwidth becomes narrower at 500 MHz but the gain increased to 10.76 dB. Furthermore, the fourth iteration with n = 2 elements produces a bandwidth of 650 MHz (3.15 3.8 GHz) while the gain is 7.45 dB. In the third iteration with n=3 elements, the most optimal bandwidth is 800 MHz (3.15 GHz – 3.95 GHz) with a gain of 10.67 dB at a resonant frequency of 3.5 GHz.

Furthermore, Figure 6 shows that the iteration processes have obtained impedance that are close to Z = 50 Ohms at a frequency of 3.5 GHz. This indicates that the antenna has resonated and in a match condition between the antenna and the transmission line. To control the resonant frequency of the antenna, iterations are carried out by controlling the Ws dimension as shown in Table 3.

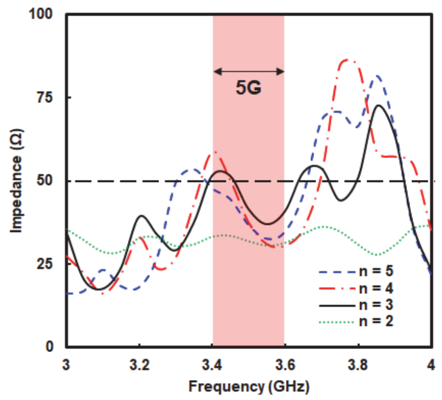


Fig.6. Simulation of Impedance

Table 3. Iteration Number of Spiral Stub

| Iteration | Dimension of Ws |
|---|---|
| 1 | 3 mm |
| 2 | 2 mm |
| 3 | 1 mm |

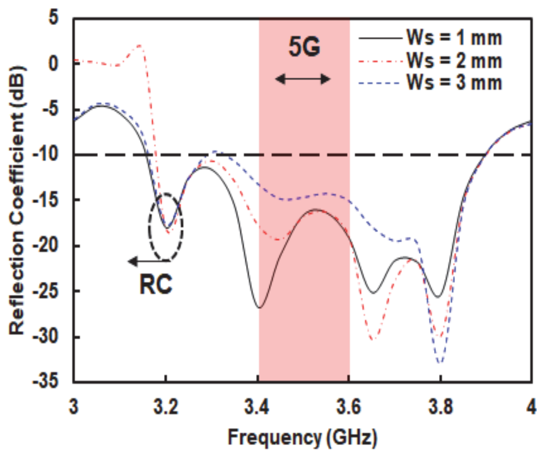


Fig.7. Simulation Result from iteration of Ws

Figure 7 shows the impact of the iteration process of Ws on the resonant frequency of the proposed antenna. Figure 7 shows the impact of the iteration process of Ws compared with the resonant frequency of proposed antenna. The bandwidth of the iteration results did not have a significant difference. However, the resonant frequency of the antenna has shifted, especially in the 3.4 - 3.6 GHz frequency range. In addition, the third iteration with Ws = 1 mm produces a optimal reflection coefficient ≤ -10 dB compared with second and third iterations.

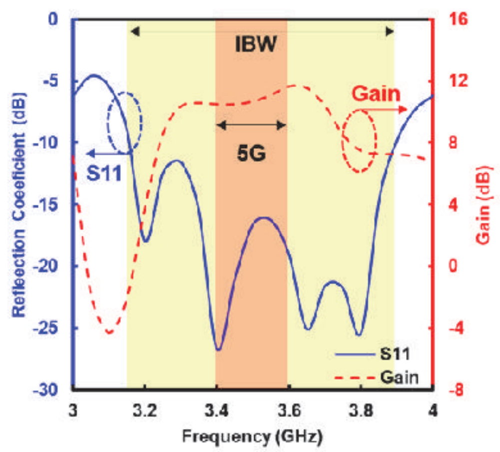


Fig.8. Simulation of Reflection Coefficient and Gain

Figure 8 shows the relationship between the reflection coefficient and the gain of the proposed antenna in a linear condition. The antenna produces a stable gain at a frequency of 3.4 - 3.6 GHz, which is 10 dB until 12 dB.

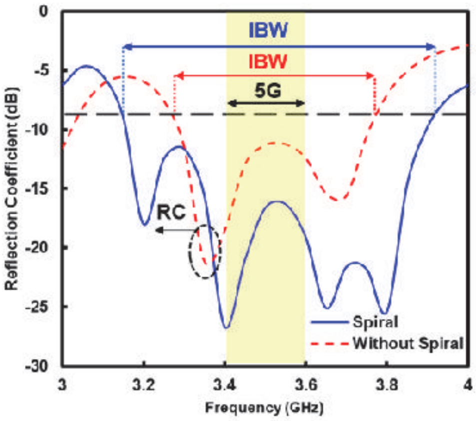


Fig.9. Comparison of Reflection Coeffficient

Figure 9. shows that the bandwidth of the proposed antenna has increased significantly after using spiral stubs up to 88.88% compared to array antennas without spiral stubs. The bandwidth of the 2x2 element array antenna before using the spiral stub was 450 MHz at a frequency of 3.3 – 3.75 GHz. After using the spiral stub, the bandwidth increases until 800 MHz with a frequency of 3.15 GHz – 3.95 GHz. Furthermore, the gain of the antenna with the spiral stub has decreased by 11.08 % compared to before using the spiral stub, this is due to a significant increase in bandwidth so that the gain of the antenna has decreased as shown in Figure 10. Generally, a wide bandwidth will reduce the gain of the antenna. Furthermore, to observe the directivity of the antenna, a simulation of the radiation pattern of the proposed antenna is carried out as shown in Figure 12. The addition of spiral stubs also affects the radiation pattern of the antenna compared to the previous design. Figure 13 shows that a microstrip antenna with a spiral stub has resonated at a frequency of 3.5 GHz with a current of 7.2 e+002 V/m.

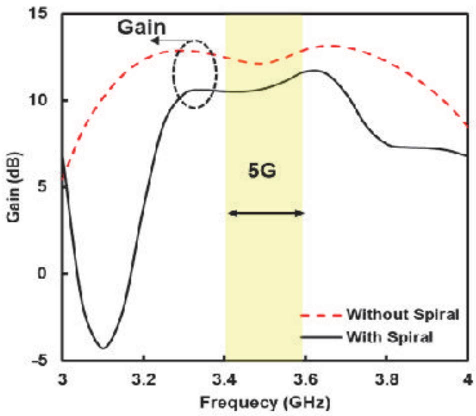


Fig.10. Comparison of Gain

Figure 11 shows that the impedance of the two proposed antennas has met the criteria, which is close to Z=50 Ohm. This indicates that the antenna has resonated and is in matched condition. Figure 11 shows that the spiral stub produces an antenna radiation pattern with two side lobe between main lobe while the antenna without spiral stub only has main lobe. The effect of adding spiral stubs produces produces radiation patterns with different diversity as indicated by the presence of two side lobes between the main lobes. This is due to a significant increase in bandwidth that affects the gain and directivity of the antenna. Generally, high gain antennas produce narrow bandwidth.

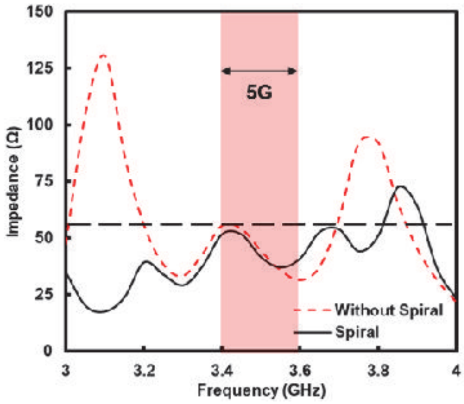


Fig.11. Comparison of Impedance

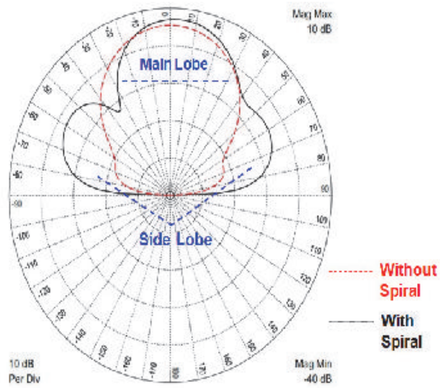


Fig.12. Comparison of Radiation Pattern

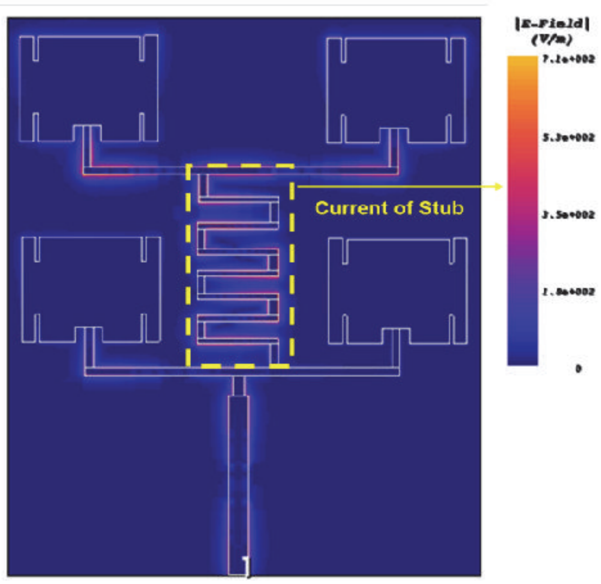


Fig.13. Current Distribution of Antena at Frequency of 3.5 GHz

Figure 13 shows the spiral stub has resonated at the indicated 3.5 GHz frequency, but the lower part of the patch antenna array has not resonated optimally, this is due to the wide bandwidth so that the antenna can resonate at different frequencies.

**Conclusion**

This research proposes a new design of a 2x2 element microstrip array antenna with a wide bandwidth for 5G communication systems. The antenna has been designed and simulated at a frequency of 3.5 GHz with a bandwidth of 800 MHz or 24.28 % and gain of 10.67 dB. The addition of spiral stub with n = 3 succeeded in increasing the bandwidth of the antenna up to 88.88%. This research is useful for producing wide-bandwidth arrays antenna for 5G communication systems.

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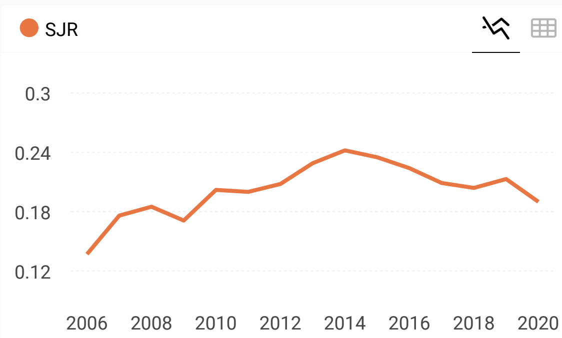



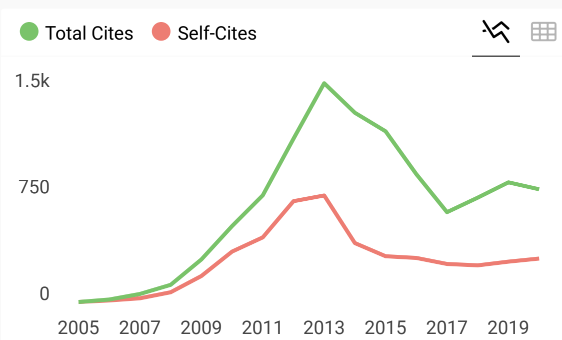


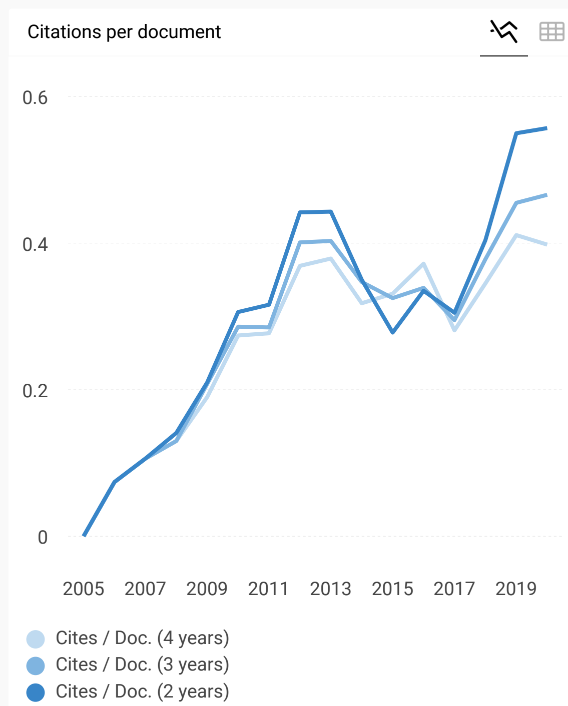


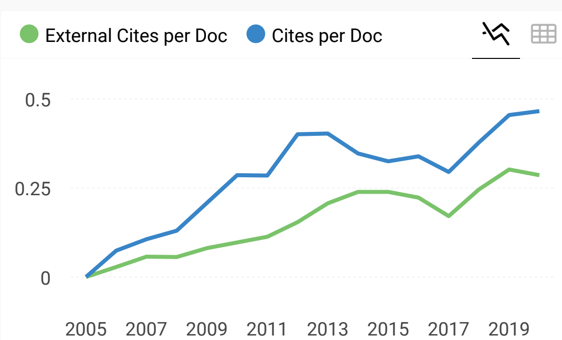


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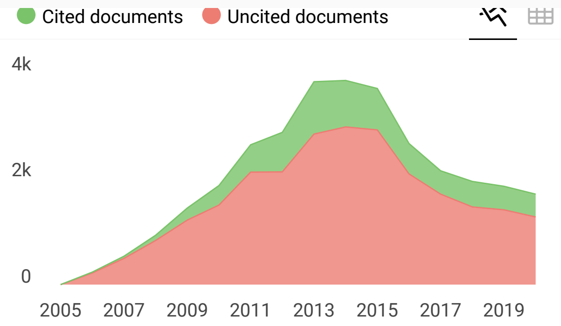



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# Bandwidth Enhancement of Array Microstrip Antenna Using Spiral Stub For 5G Communication System

***Abstract**. This paper proposes a new design of a 2x2 microstrip array antenna with spiral stub for a 5G communication system at the resonant frequency of 3.5 GHz. Spiral stub is useful for increasing the bandwidth value of the proposed antenna. The spiral stub is designed using a microstrip line with an impedance of 70.7 ohms. This study proposes three antenna models by adjusting the number and dimensions of the spiral stubs. From the simulation results using EM Simulation, the optimal bandwidth is obtained when the number of spiral stubs (n) = 3 with dimensions of spiral stub $W_{stub}$ =18.5 mm and $L_s$ = 8 mm . The bandwidth of the proposed antenna is 0.8 GHz or an increase until 88.88% compared with array 2x2 without spiral stubs. Furthermore, the gain of the proposed antenna is 10.67 dB at the resonant frequency of 3.5 GHz. This research is very useful for increasing bandwidth for the purposes of 5G communication systems.*

***Streszczenie.** W artykule zaproponowano nowy projekt anteny mikropaskowej 2x2 ze spiralnym odgałęzieniem dla systemu komunikacji 5G na częstotliwości rezonansowej 3,5 GHz. Spiralny odcinek jest przydatny do zwiększania wartości szerokości pasma proponowanej anteny. Spiralny króciec został zaprojektowany z wykorzystaniem linii mikropaskowej o impedancji 70,7 omów. W niniejszym opracowaniu zaproponowano trzy modele anten, dostosowując liczbę i wymiary końcówek spiralnych. Z wyników symulacji z wykorzystaniem symulacji EM optymalną szerokość pasma uzyskuje się, gdy liczba króćców spiralnych (n) = 3 o wymiarach króćca spiralnego Wstub =18,5 mm i Ls = 8 mm . Przepustowość proponowanej anteny wynosi 0,8 GHz lub jest wyższa o 88,88% w porównaniu z macierzą 2x2 bez spiralnych odgałęzień. Ponadto zysk proponowanej anteny wynosi 10,67 dB przy częstotliwości rezonansowej 3,5 GHz. Badania te są bardzo przydatne do zwiększania przepustowości na potrzeby systemów komunikacji 5G.* (***Poprawa przepustowości anteny mikropaskowej za pomocą spiralnego złącza dla systemu) komunikacji 5G***)

**Keywords:** antenna, array, bandwidth, microstrip, spiral stub, 5G Communcation System
**Słowa kluczowe:** antena szerokopasmowa, przepustowość, 5G.

## Introduction

The fifth generation communication system (5G) was introduced in 2017 and has advantages such as high data transfer data rates and wide bandwidth [1]. Based on the regulations set by [2] the frequency used for the fifth generation communication system is divided into several bands, namely for high band 28 GHz, mid band 15 GHz and low band 3.5 GHz (3.4 – 3.6 GHz). In a wireless communication system, an antenna is needed as a sender and receiver of signals that will be converted into electrical waves so that they can be used for voice and data communication purposes [3]. One of the antennas that has been widely developed for the purposes of wireless communication systems is the microstrip antenna [4]. Microstrip antennas have the advantages of compact design, low costs and can work at high frequencies [5]. However, microstrip antennas have several disadvantages, including narrow bandwidth, low gain and directivity [6]. The compact dimension is one of the advantages of the microstrip antenna so that it is suitable for use as a receiving antenna in a wireless communication system, but to maintain stable connectivity between the transmitter and receiver, an antenna with high gain and wide bandwidth is needed.

The development of microstrip antennas for fifth generation communication systems has been described in several previous studies [7-8]. The research proposed by [9] has succeeded in designing a circular single element microstrip antenna at a frequency of 3.5 GHz with a reflection coefficient value of -30 dB and a gain of 5.15 dBi, then previous research [10] proposed a rectangular microstrip antenna was developed at a frequency of 3.5 GHz using the defected ground structure method with reflection coefficients and gains of -17.43 dB and 6.6 dB, respectively. However, these two studies still produce low gain and narrow bandwidth, so optimization needs to be done. Several optimization methods to improve directivity and bandwidth have been described in previous studies, including arrays [11-12], parasitic [13], dual feed [14-15], proximity coupling [16-17] and coplanar waveguide [18-19] . In research conducted by [20] the array method was used to increase gain of the microstrip antenna at frequency of 3.5 GHz with gain of 7.3 dB while research conducted by [21] obtain gain of 12.6 until 13.6 dBi using the parasitic method. This research proposes a 2x2 element microstrip array antenna with spiral stub. The addition of spiral stub aims to increase the bandwidth of the proposed antenna. The spiral stub is designed using a microstrip line with an impedance of Z = 70.7 Ohm and number of stub (n) = 3. The main contribution in this research is to produce a microstrip antenna with high gain and wide bandwidth. From the simulation results, the bandwidth of proposed antenna increase until 88.88% with gain of 10.67 dB after using the spiral stub.

## Antenna Design

The initial stage of the research is to calculate the dimensions of a single element microstrip antenna that works at a frequency of 3.5 GHz. The shape of the microstrip antenna proposed in this study is a rectangular shape with length (L) and width (W). In addition, the microstrip antenna will be connected to a female SMA connector with an impedance of 50 Ohms using a microstrip transmission line. The function of the microstrip line is to match the impedance between the antenna and the connector. The antenna and connector must have the appropriate impedance to radiate electromagnetic waves at the proposed antenna. The dimensions of a rectangular microstrip antenna obtained using equations (1), (2), (3), (4) and (5) while for the microstrip line using equations (6) and (7) [22].

(1) $W = \frac{c}{2f\sqrt{\frac{\varepsilon r+1}{2}}}$

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

(3) $L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{reff}}}$

(4) $\varepsilon_{reff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}}$

(5) $\Delta_L = 0.412\, h\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)}$

(6) $W_z = \frac{2h}{\pi}\left\{B-1-\ln(2B-1)+\frac{\varepsilon_r-1}{2\varepsilon_r}\left[\ln(B-1)+0.39-\frac{0.61}{\varepsilon_r}\right]\right\}.$

(7) $B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_{eff}}}.$

After performing calculations using equations (1), (2), (3), (4) (5), (6) and (7) the dimensions of W = 33.88 mm and L = 28.05 mm were obtained while the resonant frequency (f) of 3.5 GHz with dielectric constant (Ɛr) = 2.2 and the thickness of the substrate (h) = 1.575 mm according with specification of Duroid RT 5880. For the microstrip line dimensions, Wz = 4.6 mm is obtained while impedance of Z = 50 Ohm. The next step is to design a 2x2 element microstrip antenna array using microstrip lines with impedances of 50 Ohms, 70.7 Ohms and 100 Ohms. The patch of the antenna are separated from each other by the distance $d_a$ and $d_b$. The purpose of 2x2 array microstrip antenna is improve the gain and directivity of the proposed antenna. The design and structure of the 2x2 array microstrip antenna is shown in Figure 1 .

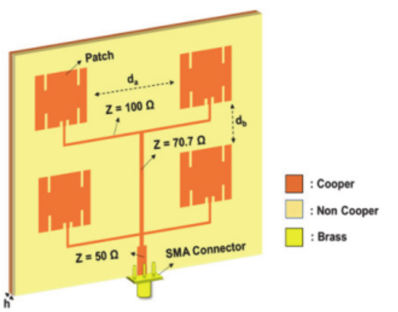


Fig.1. Structure of 2x2 Array Microstrip Antenna

Figure 1 shows the parameters while Figure 2 shows the structure of a 2x2 array microstrip antenna consisting of a patch antenna, microstrip line ($Z_1$ = 50, $Z_2$ = 70.7 and $Z_3$ = 100 Ohms), spiral stub and SMA connectors. The function of microstrip line with an impedance of 70.7 Ohm and 100 Ohm as an impedance matching to obtain a good reflection coefficient so that the antenna can work optimally [17]. Furthermore, a feed line with an impedance of 50 ohms is used as the main impedance which is directly connected to the SMA connector which also has an impedance of 50 Ohms.

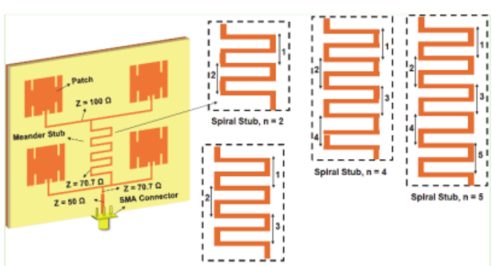


Fig.2. Structure of 2x2 Array Microstrip Antenna Using Spiral Stub with n = 2, 3, 4 and 5

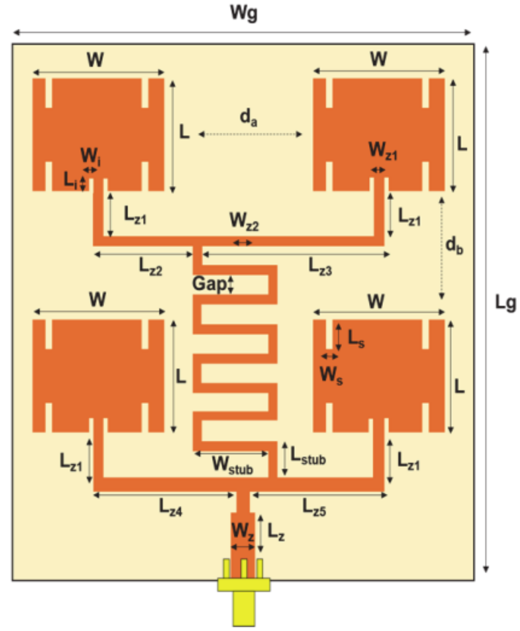


Fig.3. Dimension of 2x2 Array Microstrip Antenna Using Spiral Stub

The next step is to optimize the bandwidth of the 2x2 element antenna array using spiral stubs. Spiral stub aims to increase the bandwidth of the antenna. Spiral Stub is designed using microstrip line with impedance Z= 70.7 ohm which is placed between microstrip line with Z= 100 ohm and Z= 50 ohm. The dimension of a 2x2 element array antenna using a spiral stub is shown in Figure 3.

Figure 2 shows the structure of a 2x2 element antenna array using a spiral stub with n = 3 elements. The overall dimensions of the proposed antenna are shown in Table 1. Furthermore, the proposed antenna uses slits with dimensions Ws = 1 mm and Ls = 1 mm. The purpose of adding slits is to control the resonant frequency and improve the reflection coefficient of the proposed antenna.

Table 1 shows that the stub designed using n = 3 elements with the gap of 5.5 mm. Further optimization is carried out by controlling the number of spiral stubs placed on the antenna. The purpose of this optimization is to obtain an increase in the bandwidth of the proposed antenna.

Table 1. The parameters of proposed antenna

| Parameter | Dimension [mm] | Parameter | Dimension |
|---|---|---|---|
| Wg | 120 | $W_{z1}$ | 2 |
| Lg | 100 | $W_{z2}$ | 3 |
| W | 35 | $L_{z1}$ | 13 |
| L | 28.3 | $L_{z2}$ | 29.5 |
| Wz | 5 | $L_{z3}$ | 48.5 |
| Lz | 48.5 | $L_{z4}$ | 37.5 |
| Ws | 1 | $L_{z4}$ | 39.5 |
| Ls | 6.6 | $d_a$ | 43 |
| Wi | 1 | $d_b$ | 27.4 |
| Li | 6 | h | 1.57 |
| $W_{stub}$ | 18.5 | $L_{stub}$ | 8 |

**Result and Discussion**

Optimal bandwidth and gain are obtained by performing several iterations of the spiral stub configuration. In this study, iterations and parametric study were carried out by changing the number of spiral stubs (n) of the proposed antenna as shown in Table 2.

Table 2. Iteration Number of Spiral Stub

| Iteration | Number of Spiral Stub |
|---|---|
| 1 | 5 |
| 2 | 4 |
| 3 | 3 |
| 4 | 2 |

Table 2 shows the iteration process carried out by changing the number of spiral stubs (n) = 2, 3, 4 and 5. The simulation results of the iteration process are shown in the Figure 4, Figure 5 and Figure 6.

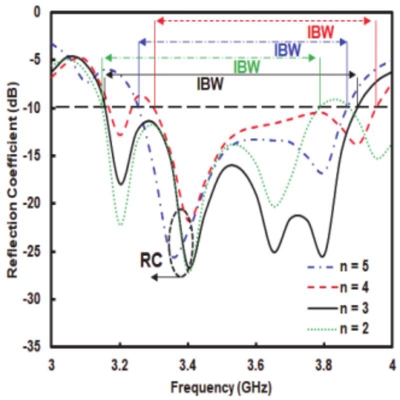


Fig.4. Simulation of Reflection Coefficient

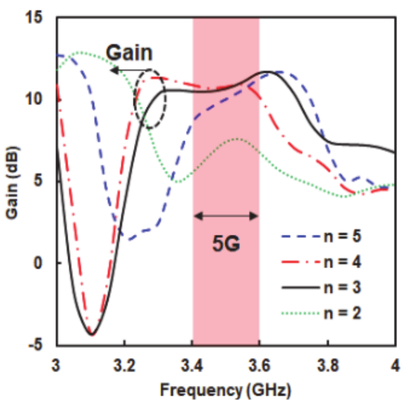


Fig.5. Simulation of Gain

Figure 4 and Figure 5 shows that the optimal bandwidth is obtained during the third iteration with the number of spirals n = 3 elements while at n = 5 elements, the bandwidth of the antenna is 600 MHz with a gain of 10.03 dB and at n = 4 elements, the bandwidth becomes narrower at 500 MHz but the gain increased to 10.76 dB. Furthermore, the fourth iteration with n = 2 elements produces a bandwidth of 650 MHz (3.15 3.8 GHz) while the gain is 7.45 dB. In the third iteration with n=3 elements the most optimal bandwidth is 800 MHz (3.15 GHz – 3.95 GHz) with a gain of 10.67 dB at a resonant frequency of 3.5 GHz.

Furthermore, Figure 6 shows that the iteration processes have obtained impedance that are close to Z = 50 Ohms at a frequency of 3.5 GHz. This indicates that the antenna has resonated and in a match condition between the antenna and the transmission line. To control the resonant frequency of the antenna, iterations are carried out by controlling the Ws dimension as shown in Table 3.

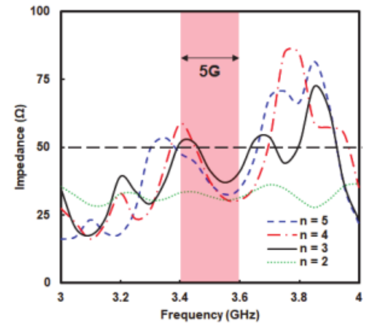


Fig.6. Simulation of Impedance

Table 3. Iteration Number of Spiral Stub

| Iteration | Dimension of Ws |
|---|---|
| 1 | 3 mm |
| 2 | 2 mm |
| 3 | 1 mm |

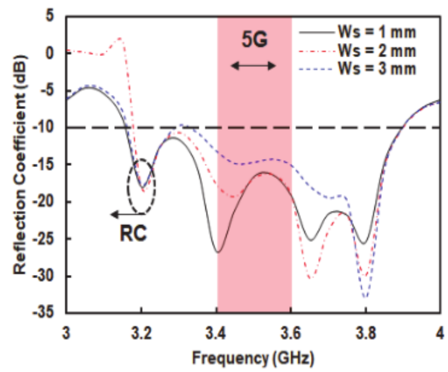


Fig.7. Simulation Result from iteration of Ws

Figure 7 shows the impact of the iteration process of Ws on the resonant frequency of the proposed antenna. Figure 7 shows the impact of the iteration process of Ws compared with the resonant frequency of proposed antenna. The bandwidth of the iteration results did not have a significant difference. However, the resonant frequency of the antenna has shifted, especially in the 3.4 - 3.6 GHz frequency range. In addition, the third iteration with Ws = 1 mm produces a optimal reflection coefficient ≤ -10 dB compared with second and third iterations.

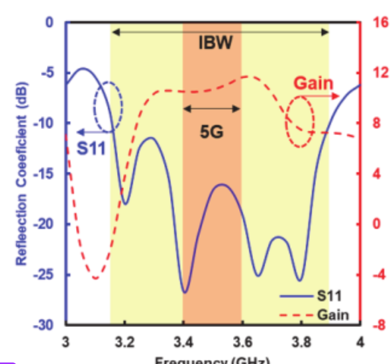


Fig.8. Simulation of Reflection Coefficient and Gain

Figure 8 shows the relationship between the reflection coefficient and the gain of the proposed antenna in a linear condition. The antenna produces a stable gain at a frequency of 3.4 - 3.6 GHz, which is 10 dB until 12 dB.

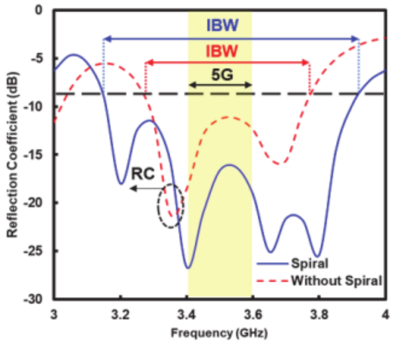


Fig.9. Comparison of Reflection Coeffficient

Figure 9. shows that the bandwidth of the proposed antenna has increased significantly after using spiral stubs up to 88.88% compared to array antennas without spiral stubs. The bandwidth of the 2x2 element array antenna before using the spiral stub was 450 MHz at a frequency of 3.3 – 3.75 GHz. After using the spiral stub, the bandwidth increases until 800 MHz with a frequency of 3.15 GHz – 3.95 GHz. Furthermore, the gain of the antenna with the spiral stub has decreased by 11.08 % compared to before using the spiral stub, this is due to a significant increase in bandwidth so that the gain of the antenna has decreased as shown in Figure 10. Generally, a wide bandwidth will reduce the gain of the antenna. Furthermore, to observe the directivity of the antenna, a simulation of the radiation pattern of the proposed antenna is carried out as shown in Figure 12. The addition of spiral stubs also affects the radiation pattern of the antenna compared to the previous design. Figure 13 shows that a microstrip antenna with a spiral stub has resonated at a frequency of 3.5 GHz with a current of 7.2 e+002 V/m.

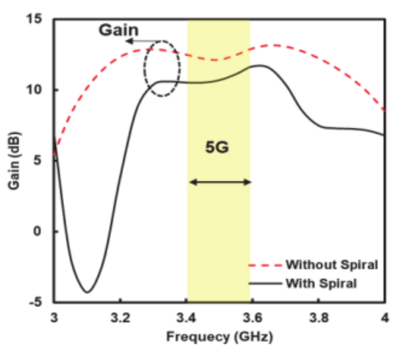


Fig.10. Comparison of Gain

Figure 11 shows that the impedance of the two proposed antennas has met the criteria, which is close to Z=50 Ohm. This indicates that the antenna has resonated and is in matched condition. Figure 11 shows that the spiral stub produces an antenna radiation pattern with two side lobe between main lobe while the antenna without spiral stub only has main lobe. The effect of adding spiral stubs produces produces radiation patterns with different diversity as indicated by the presence of two side lobes between the main lobes. This is due to a significant increase in bandwidth that affects the gain and directivity of the antenna. Generally, high gain antennas produce narrow bandwidth.

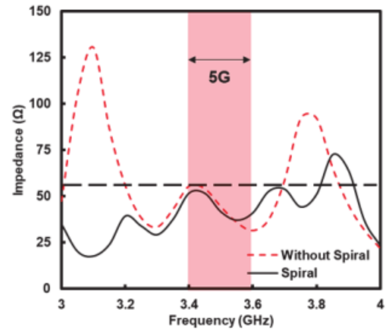


Fig.11. Comparison of Impedance

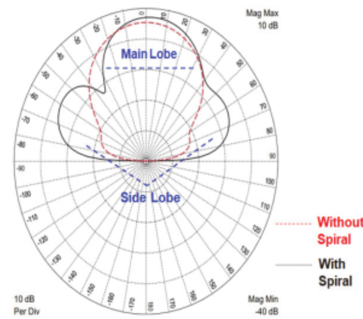


Fig.12. Comparison of Radiation Pattern

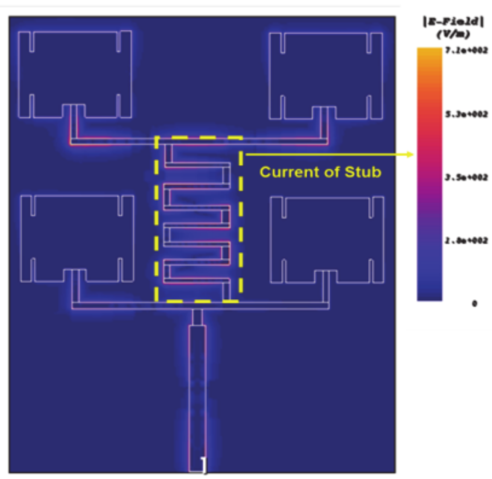


Fig.13. Current Distribution of Antena at Frequency of 3.5 GHz

Figure 13 shows the spiral stub has resonated at the indicated 3.5 GHz frequency, but the lower part of the patch antenna array has not resonated optimally, this is due to the wide bandwidth so that the antenna can resonate at different frequencies.

## Conclusion

This research proposes a new design of a 2x2 element microstrip array antenna with a wide bandwidth for 5G communication systems. The antenna has been designed and simulated at a frequency of 3.5 GHz with a bandwidth of 800 MHz or 24.28 % and gain of 10.67 dB. The addition of spiral stub with n = 3 succeeded in increasing the bandwidth of the antenna up to 88.88%. This research is useful for producing wide-bandwidth arrays antenna for 5G communication systems.

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