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4-Antenna array for MIMO operation in the 5G mobile device

4-antenowy układ do pracy MIMO w urządzeniu mobilnym 5G

***Abstract**. As a very promising choice for wireless communication, multiple-input multiple-output (MIMO) technology has the potential to alleviate traffic capacity limitations in high-speed broadband wireless network access. The MIMO system uses multiple antennas at the sending and receiving ends to increase the performance and efficiency of wireless communication systems. This study presents a 4-antenna array for multi-input multi-output (MIMO) functioning in smartphones running in the 2.3-GHz band (2160–2440 MHz). The antenna array is made up of a ground plane at the bottom of the FR-4 dielectric substrate and four patch antennas of a specific size placed in the top layer. Every antenna in the suggested array is coaxially fed, has a characteristic impedance of 50 ohms, and has the identical dimensions—13 x 9 mm2 (0.100λ × 0.069 λ), where λ is the wavelength at 2.3 GHz). To obtain the appropriate resonance frequency, four inverted L-strips are applied in the ground plane. The simulation results were produced using CST software. This antenna is built, and typically, experimental results such as the S-parameter and radiation pattern are reported, with good agreement between simulation and actual results. The manufactured four-antenna arrays have a 10 dB return loss in the long-term evolution (LTE) range of 2.16 GHz to 2.44 GHz. The simulated envelope correlation coefficient (ECC) was below 0.005.*

***Streszczenie.** Jako bardzo obiecujący wybór w komunikacji bezprzewodowej, technologia MIMO (multiput input multiple-output) może potencjalnie złagodzić ograniczenia przepustowości ruchu w szybkich szerokopasmowych sieciach bezprzewodowych. System MIMO wykorzystuje wiele anten na końcach wysyłających i odbierających, aby zwiększyć wydajność i efektywność systemów komunikacji bezprzewodowej. W pracy przedstawiono układ 4-antenowy typu multi-input multi-output (MIMO) funkcjonujący w smartfonach pracujących w paśmie 2,3 GHz (2160–2440 MHz). Układ antenowy składa się z płaszczyzny uziemienia znajdującej się na spodzie podłoża dielektrycznego FR-4 oraz czterech anten krosowych o określonym rozmiarze umieszczonych w warstwie wierzchniej. Każda antena w sugerowanym układzie jest zasilana koncentrycznie, ma impedancję charakterystyczną 50 omów i identyczne wymiary — 13 x 9 mm2 (0,100 λ × 0,069 λ), gdzie λ to długość fali przy 2,3 GHz). Aby uzyskać odpowiednią częstotliwość rezonansową, w płaszczyźnie masy zastosowano cztery paski w kształcie odwróconej litery L. Wyniki symulacji uzyskano przy użyciu oprogramowania CST. Antena jest zbudowana i zazwyczaj podawane są wyniki eksperymentów, takie jak parametr S i charakterystyka promieniowania, z dobrą zgodnością między wynikami symulacji i rzeczywistymi. Wyprodukowane układy czterech anten charakteryzują się stratą odbicia na poziomie 10 dB w zakresie długoterminowej ewolucji (LTE) od 2,16 GHz do 2,44 GHz. Symulowany współczynnik korelacji obwiedni (ECC) był poniżej 0,005.*

Keywords: 5G,Microstrip technology, Mobile antennas, Multi-input multi-output (MIMO)
Słowa kluczowe: 5G, Technologia mikropaskowa, Anteny mobilne, Wiele wejść, wiele wyjść (MIMO)

Introduction

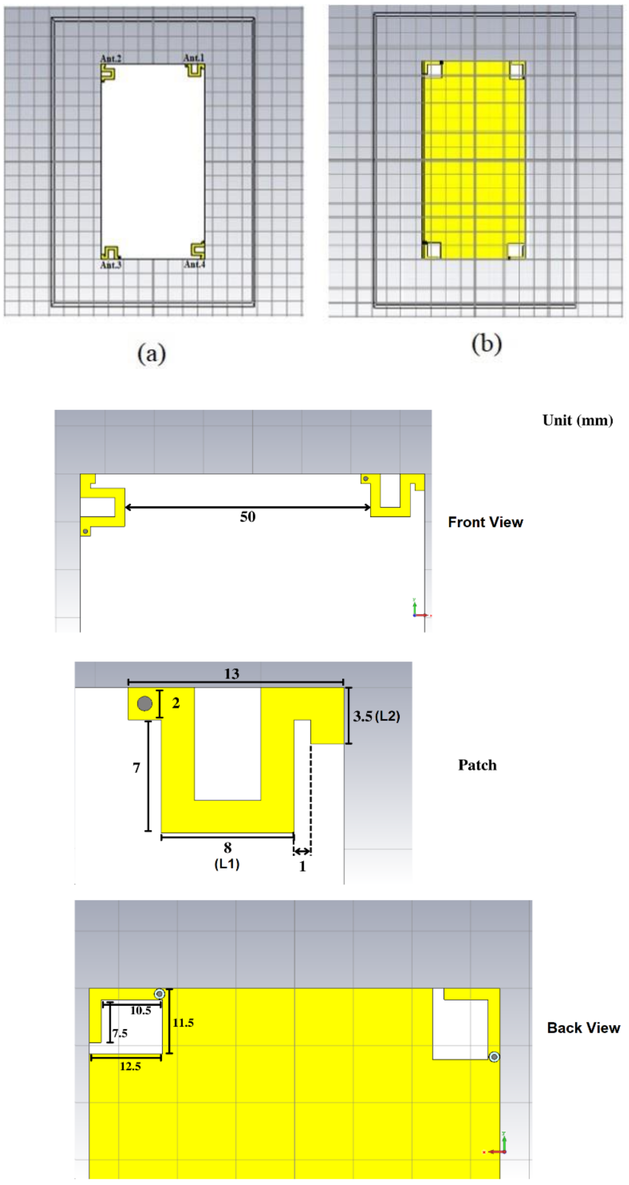
Fifth-generation (5G) mobile networks, which are a continuation of the previous generation [1], offer highly reliable communications and low latency, enabling a wide range of communication devices and enhancing mobile broadband. The 5G communication system aims to continuously improve the quality of the experience, provide high data speed for mobile users, and reduce energy consumption. 5G radio is a big step in mobile network capabilities. 5G will take traditional mobile broadband to the extreme in terms of speed, capacity, and availability of data. Additionally, 5G will enable services that include Internet of Things connectivity, industry, and important communications. Target set very high with data rates up to 20 Gbps and capacity expansion of up to 1000 times more with a flexible platform for very low latency device connectivity and very high reliability.

In MIMO, or Multiple Input Multiple Output technique, the output is multi antenna technology on the sender and receiver. The MIMO technique becomes one solution to more data transfer needs, is faster and bigger, and can handle multipath fading. MIMO technology can produce a more efficient frequency, namely by sending the same information from the two or more transmitters to receivers, which reduces the possibility of lost information compared to using a single transmitter.

The application of this communication technology requires telecommunications components that can support the technology. One of the supporting components of telecommunications is the antenna. There are various types of antennas, including the microstrip antenna. The microstrip antenna is one of the most popular antennas. This is because the microstrip antenna is very suitable for use in telecommunications equipment, easy to make, easy to install, and has a low cost. Multi-band 5G patch antenna was designed in [2]-[5] at the frequency of 28 and 38 GHz. [6] has proposed a 5G microstrip antenna on flexible substrates occupying 3.985 GHz. A compact dual-frequency of 38/60 GHz microstrip patch antenna with novel design was proposed in [7] for 5G mobile handsets to combine complicated radiation mechanisms for dual-band operation. A work in [8] presents a circular patch structure for 5G multiband antenna. Moreover, a patch antenna with a centre frequency of 30 GHz has been designed in [9]. [10] proposed an antenna which is utilised to operate at triple band: 2.4, 5.5 and 28 GHz with wide impedance bandwidth. In [11], the circular array microstrip patch antenna (MPA) was designed at a resonant frequency of 35 GHz for the 5G wireless communication. In [12]-[14], several surveys are presented on various antenna designs at different 5G frequency bands.

A new MIMO 5G antenna configuration, with two different elements is proposed in [15], while [16] design a 4×4 subarray antenna for 5G MIMO. Both latter designed antennas occupied the frequency of 3.5 GHz. [17] presented a 4.8 GHz multiple-input-multiple-output (MIMO) antenna array with low-profile and flexible characteristics. A compact self-complementary two port multiple-input multiple-output (MIMO) 5G microstrip patch antenna in 64/71 GHz is presented in [18]. A MIMO array printed 5G patch antenna operated in 26 GHz was designed in [19]. [20]-[23] gave out an exhaustive review of MIMO antenna design with regard to mutual coupling reduction techniques and safer user applications.

5G Network implementation in Indonesia will occupy the frequency of 700 MHz and 2.3 GHz [24]. This study proposes a 4-antenna array operating in the 2.3-GHz band for the MIMO operation in the smartphone. The proposed array consists of two two-antenna arrays disposed, respectively, along two long side edges of the system ground plane. Each antenna has same dimensions and can fit in the narrow spacing between the display panel and the long side edges of the smartphone. The proposed array is also fabricated and tested.



(c)

Fig. 1. Geometry of the 4-Antenna Array for MIMO Operation in the 5G Mobile Operation (a) Overall Front View (b) Overall Back View (c) Detailed Design

Antenna Design

The antenna design uses the MIMO microstrip antenna model to produce the antenna with desired working frequency. The proposed MIMO antenna consists of four radiating elements or patches, four inverted L-strips, a groundplane, and also FR-4 (ε=4.3) substrate with a thickness of 1.6 mm.

The design of four radiating elements or patches (see Figure 1) has the shape of a winding line printed on the top of the FR-4 substrate. Meanwhile, a groundplane with four upside-down L-strips is printed on the back of the FR-4 substrate [25]. Patch antennas are placed at the ends of the ground and substrate antenna patch is placed on a 140x70 mm substrate. Then four reverse L-strips and a groundplane are placed behind the substrate.

Then the position of the antenna port and the position of the four inverted L-strips were changed, such that the antenna ports were placed at an angle of 90o with the next antenna ports which gave a mutual coupling that was smaller than the mutual coupling value before being modified. The modified antenna's mutual coupling becomes smaller because the polarizations between the antennas become perpendicular to each other so that the interference that occurs between the antennas becomes smaller.

The Table 1 shows the effect of modifying the antenna port position on the value of S_{11} and mutual coupling.

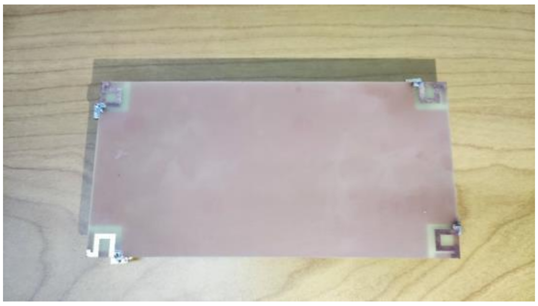
The proposed 4-Antenna Array is fabricated and measured. Figure 2 shows the photograph of the fabricated antenna.

Table 1. Antenna optimization

Dimension (mm)	L2 = 4	L2 = 3.5	L2 = 4 90^o Port Confi-guration	L2 = 3.5 90^o Port Confi-guration
S_{11} Port 1 (dB)	-15.409	-13.306	-21.064	-38.673
S_{11} Port 2 (dB)	-15.412	-14.296	-33.507	-25.926
S_{11} Port 3 (dB)	-15.415	-13.309	-20.027	-38.569
S_{11} Port 4 (dB)	-15.408	-14.293	-33.401	-25.965
Mutual Coupling 2,3 (dB)	-9.656	-9.754	-16.335	-16.391
Mutual Coupling 1,4 (dB)	-9.656	-9.754	-16.284	-16.391

Characteristic of proposed 4-antenna array

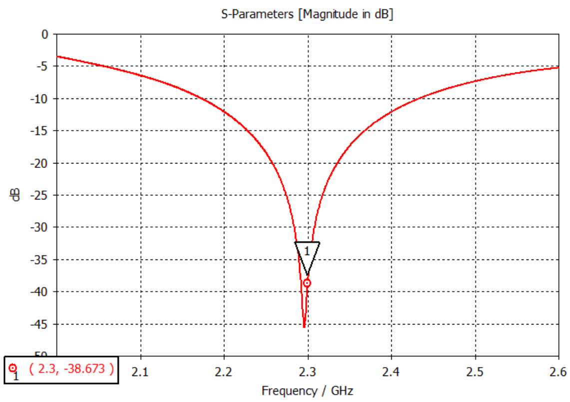
Figure 3 shows graph S_{11} of simulation results in CST Studio Suite 2019 software. All 5G antenna elements have shown good impedance matching of less than 10 dB between 2200-2400 MHz. The simulated three-dimensional radiation patterns for the antennas are presented in Figure 4. For brevity due to similar characteristic between antenna 1 and antenna 3 also between antenna 2 and antenna 4, only S_{11} graph of antenna 1 and S_{11} graph of antenna 2 are shown.



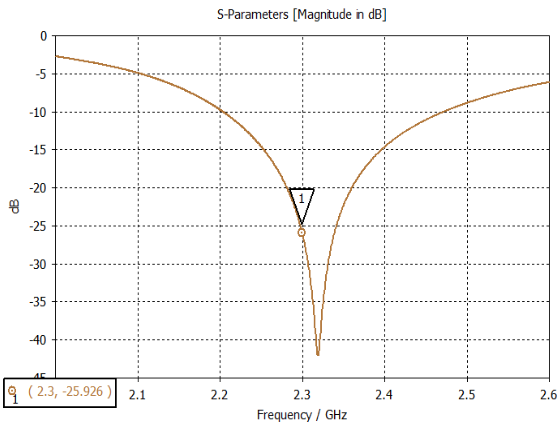
(a)

(b)

Fig. 2. Fabricated 4-Antenna Array for 5G MIMO Operation (a) front view (b) back view.

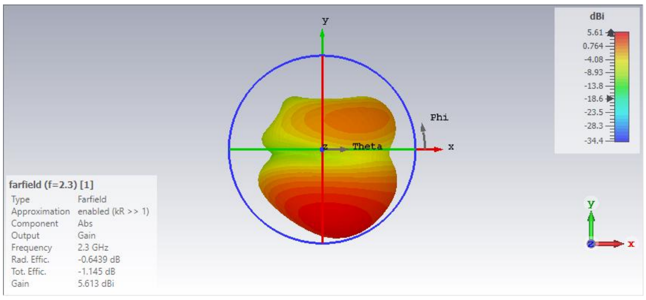


(a)

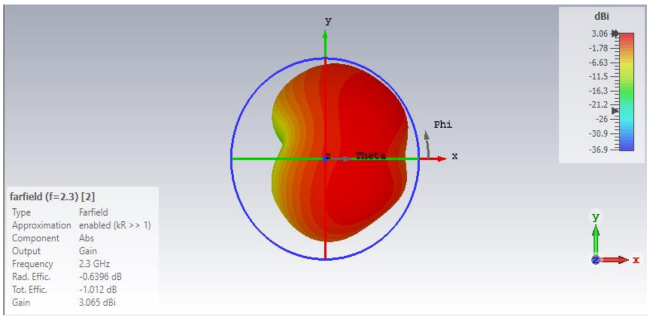


(b)

Fig. 3. S_{11} Simulation Results for each antenna port (a) port 1 (b) port 2



(a)



(b)

Fig. 4. Simulated three-dimensional radiation pattern for each antenna (a) antenna 1 (b) antenna 2.

The simulated three-dimensional radiation patterns for the antenna 1 and antenna 2 are presented in Figure 4, due to the similarity of characteristic for brevity. From Figure 4 it can be seen that the gain value obtained from the simulation results is different for antenna 1 (and antenna 3) compared to antenna 2 (and antenna 4). The gain obtained for antenna 1 (and antenna 3) is 5.613 dBi, while for antenna 2 (and antenna 4) the gain obtained is 3.065 dBi.

Due to enough distance among each elements, good isolation of less than 10 dB are also exhibited between any two antennas as shown in Figure 5.

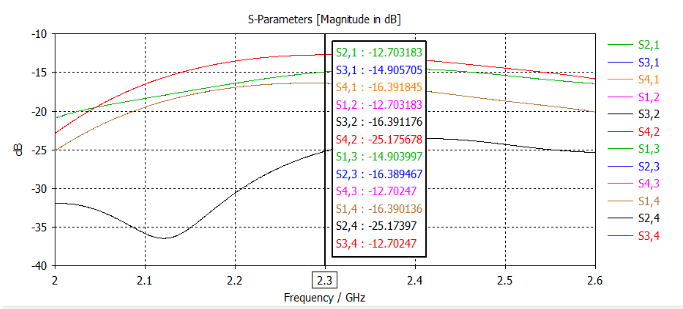


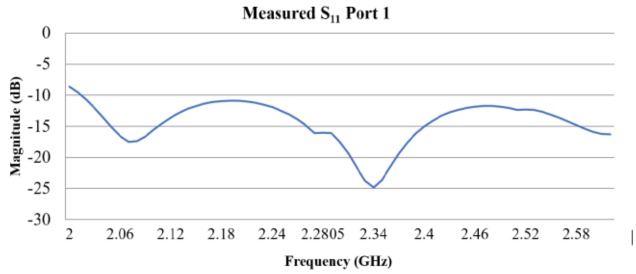
Fig. 5. Simulated S parameters for isolation between antennas.

In Figure 6 compared with Figure 3, there is a good agreement of S_{11} values between the simulation and measurement obtained. Slight differences or variations between the two results may be due to imperfect SMA connector assembly and fabrication tolerance.

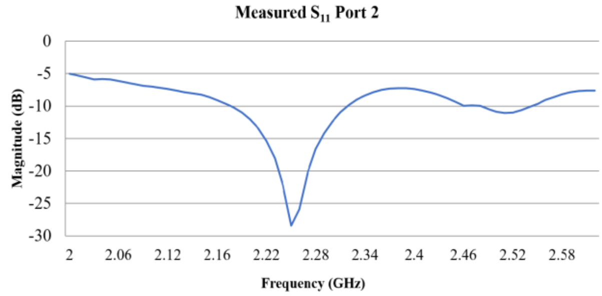
The antenna's bandwidth obtained from S_{11} measurement is 186 MHz for antenna 1, 152 MHz for antenna 2, 211.5 MHz for antenna 3, and 172 MHz for antenna 4.

Figure 7 shows the measured two-dimensional radiation patterns of Antenna 1 and Antenna 2 at 2300 MHz.

The correlation between signals received by the involved antenna at the same side of a wireless link is a crucial system-wide figure of merit for diversity and MIMO applications. The diversity capabilities of a multi-antenna system is typically assessed using the envelope correlation coefficient (ECC), where a low ECC value indicates greater isolation and a big diversity gain. To attain appropriate characteristics of variety for mobile terminal applications, the ECC value should generally be smaller than 0.5 [26]. The ECC value as shown in Figure 8 for the 5G MIMO antennas is less than 0.005 over the corresponding desired bands of interest.



(a)



(b)

Fig. 6. Measured S_{11} of (a) antenna 1 (port 1) and (b) antenna 2 (port 2).

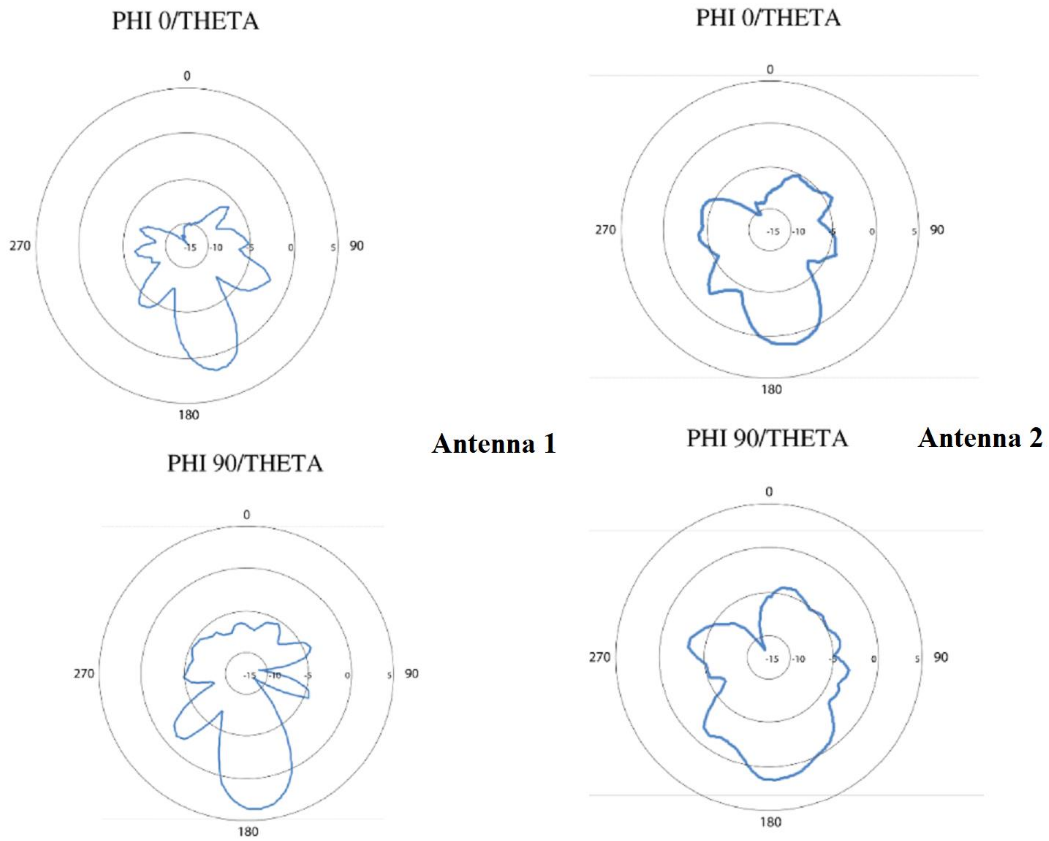


Fig. 7. Measured two-dimensional radiation pattern.

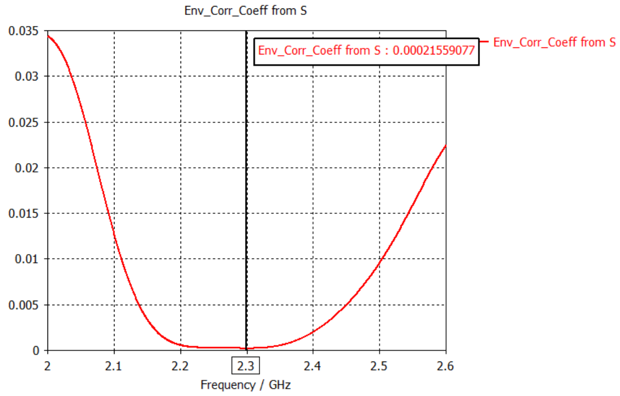


Fig. 8. Simulated ECC from CST.

Conclusion

A 2.3-GHz 4-antenna array in the smartphone has been proposed for MIMO application. The antenna prototype was fabricated and measured. Each antenna can cover the appropriate 2.3 GHz frequency band. Acceptable isolation of greater than 10 dB between antennas in the proposed array has also been achieved. Any two antennas in the proposed array demonstrate an ECC of less than 0.005. There is agreement between the measured and simulated results of the proposed 4-antenna array. The proposed 4-antenna array appears promising for smartphone applications in a 5G MIMO system.

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