v. 2, n. 14, 2022

Journal of
Engineering
Research

A 2X1 MIMO ANTENNA FOR 5G MOBILE TERMINALS

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Abstract: A 2x1 MIMO antenna with inset line fed rectangular microstrip patch elements designed for 5G mobile terminals is presented. The geometry of the MIMO antenna presents a bend in the section of the line feed for its installation in mobile terminals, seizing an area of 17.35 mm x 7.38 mm. The performance parameters were obtained with the HFSS electromagnetic simulation software from ANSYS. The return loss response is equal to -20.75 dB at 27.89 GHz and achieves an operating bandwidth of 1.07 GHz, from 27.34 GHz to 28.41 GHz. Its maximum estimated gain is equal to 8.0 dB.
Keywords: Antenna, MIMO, 5G, mobile terminals.

INTRODUCTION

Fifth generation technology or 5G will provide unlimited access to information, as well as availability to share it anywhere, at any time, by any person or device, for the benefit of society, according to Ericsson (2014). The intelligent technologies of the Internet of Things (IoT) on a large scale will use 5G technology as a means of communication (González, 2016, Rappaport et al., 2013).

A large research effort is currently being carried out on the feasibility of millimeter wave bands (30 GHz - 300 GHz) for 5G cellular system applications, up to a peak speed of 20 Gbps (Yilmaz & Akan, 2015). Part of this initiative includes the analysis of the effect of the geometry of the buildings, both in the initial deployment and in the maintenance of RF coverage levels, which guarantee an appropriate reception power level. These levels vary over time due to variations in the environment, such as changes in the geometry of the buildings in the service area (Chávez & León, 2018). Millimeter waves suffer from some limitations, such as high atmospheric losses, free space propagation loss, and high manufacturing costs of communication terminals (Naqvi, 2018). Propagation losses are low in bands below millimeter waves, such as the 28 GHz band (Roh et al., 2014). The question arises, if it is possible to design an antenna with multiple input and multiple output operation (MIMO) for 5G mobile terminals with reduced manufacturing cost, bandwidth greater than 1 GHz, gain greater than or equal to 8 dB for increase the communication efficiency of the system and the appropriate radiation pattern to counteract atmospheric and free space losses. There are currently interesting proposals for MIMO antennas for the 28 GHz frequency band of 5G technology that meet some of the demands (Gohil, 2013).

(Koul, 2020) presents a folded rectangular microstrip antenna with inset feedline patch for the 28 GHz frequency. The antenna is printed on polycarbonate dielectric substrate with relative permittivity equal to 2.9, tangential loss of 0.01 and 0.5 mm of thickness. The estimated bandwidth is 1.9 GHz, from 27.4 GHz to 29.3 GHz.

(Rahayu, 2018) presents an 8-element MIMO antenna in a 2x4 configuration for 5G communication systems. The return loss reaches a minimum equal to -19 dB at 28 GHz. And the transmission coefficient between consecutive ports is less than -20 dB.

We proceed with the design of the antenna element based on mathematical models present in the electromagnetic literature and the optimization of the transmission coefficient between MIMO ports using electromagnetic simulation software. A bend is made in the feed line for its application in 5G terminals. With two rectangular patch elements, the 2x1 MIMO antenna is formed and its geometry is optimized for its MIMO operation.

THE ANTENNA ELEMENT DESIGN

The design of the patch antenna using mathematical equations is presented. The patch is printed on a Neltec NY9220 dielectric substrate with a dielectric constant of 2.2 (ε_r), a thickness of 0.508 mm (h), a loss tangent of 0.0009, and is initially designed for the 28 GHz frequency. The patch antenna has length L_p, width W_p. The width and length of the ground plane are W_g (=W+10h) and L_g (=Lp+2*Lf), respectively.

Figure 1 shows the geometry of the rectangular patch antenna. The width patch W_p is calculated with (Balanis, 2015):

$$W = \frac{\lambda_o}{2}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

where λ_o (λ_o=c/f) is the wavelength of the operating signal.

The effective dielectric constant is obtained with equation (2).

$$\varepsilon_{\varepsilon ff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{10h}{W}}}\right), \tag{2}$$

The incremental length (ΔL) for fringing fields can be calculated with equation (3).

$$\Delta L = 0.412h\left[\frac{\varepsilon_{eff}+0.3}{\varepsilon_{eff}-0.258}\right]\left[\frac{\frac{W}{h}+0.264}{\frac{W}{h}+0.813}\right] \tag{3}$$

For the dominant mode TM_{010} without fringing fields, considering the substrate wavelength (λ_g), the patch length (L) is equal to $\frac{\lambda_g}{2}$, where $\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}}$.

Considering the presence of the fringing fields, the patch length comes equal to:

$$L = \frac{\lambda_g}{2} - 2\Delta L \tag{4}$$

The patch effective length is calculated with equation (5).

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

The resonance frequency (f_r) of the antenna element is calculated using equation (6),

$$f_r = \frac{1}{2\sqrt{\mu_0\varepsilon_0}\,L_{eff}\sqrt{\varepsilon_{ef}}} \tag{6}$$

where μ_0 y ε_0 are the free space permeability ($4\pi \times 10^{-7}$ H/m) and permittivity (8.85×10^{-12} Farad/meter), respectively.

The patch antenna has an orthogonal radiation with respect to the ground plane. The radiated electric field pattern can be obtained using equations (7) to (9) (Balanis, 2015).

$$E_\varphi^t = +j\frac{k_0 h\, w\, E_0 e^{-jk_0 r}}{\pi r}\left\{\sin\theta\,\frac{\sin(X)}{X}\frac{\sin(Z)}{Z}\right\}\cdot$$

$$\cos\left(\frac{k_0 L_e}{2}\sin\theta\sin\varphi\right) \tag{7}$$

$$X = \frac{k_0 h}{2}\sin\theta\cos\varphi \tag{8}$$

$$Z = \frac{k_0 W}{2}\cos\theta \tag{9}$$

The line feed is characterized by a length (l_f), a width (w_f) and an impedance (z_f) and connect the patch to an SMA connector with impedance Z_2 (=50Ω). The patch impedance is calculated with equation (10) and the line feed impedance with equation (11).

$$Z_p = \frac{90\,\varepsilon_r^2}{\varepsilon_r-1}\left(\frac{L}{W}\right)^2 \tag{10}$$

$$Z_f = \sqrt{Z_p Z_2} \tag{11}$$

The line feed length (l_f) in millimeters estimated with equation (12) depends on the quarter wavelength transmission line ($\theta_{a,rad}$ (=λ/4)) according to equations (12) and (13),

$$l_f = \frac{\theta_{a,rad}}{k_o\sqrt{e}} \tag{12}$$

$$e = 0.5(\varepsilon_r+1) + \frac{0.5(\varepsilon_r-1)}{\sqrt{1+12\frac{h}{Wo}}} \tag{13}$$

where $W_o = W_d$.h, for which $W_d = W_{d1}$ si $W_{d1}<2$, if $W_d = W_{d2}$ if $W_{d1}\geq 2$. And,

$$W_{d1} = \frac{8e^A}{e^{2A}-2} \tag{14}$$

$$W_{d2} = \frac{2}{\pi}\left[B - 1 - \ln(2 * B - 1) + \frac{\frac{\varepsilon_r - 1}{2}}{\varepsilon_r} * \left(\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\right)\right] \quad (15)$$

with:

$$A = \frac{Zo}{60} * \sqrt{0.5 * (\varepsilon_r + 1)} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right) \quad (16)$$

$$B = 377 * \frac{pi}{2 * Zo * \sqrt{\varepsilon_r}} \quad (17)$$

With the above equations, the geometric parameters for the rectangular patch antenna at 28 GHz are presented in Table 1. The wavelength at the frequency of 28 GHz is equal to 10.71 mm, the effective dielectric constant ($\varepsilon_{\varepsilon ff}$) results equal to 1.98, the incremental length (ΔL) is 0.26 mm, the patch impedance (Z_p) and the line feed impedance (Z_f) are equal to 218.06Ω and 104.58Ω, respectively.

RECTANGULAR PATCH ANTENNA ELEMENT PERFORMANCE

The length of the line feed was optimized to get a compact antenna geometry and better adaptation of the patch impedance to that of the coaxial conductor SMA. Figure 2 shows the rectangular patch antenna with their all dimensions, top and back views.

The antenna has a dimension of 9.32mm x 7.30 mm and a thickness of 0.508 mm. The rectangular patch antenna is printed on a Neltec NY9220(IM) dielectric substrate with relative dielectric constant of 2.2 (ε_r), and the ground plane is printed on the back of the substrate.

Using the 3D electromagnetic simulation Software HFSS from ANSYS, an estimation of the return loss response is obtained, and presented in figure 3. The minimum return loss results equal to -32 dB at frequency 28.05 GHz with a bandwidth of 1.33 GHz, from 27.37 GHz to 28.70 GHz.

DESIGN OF BENT PATCH ANTENNA TO MOBILE TERMINALS

The implementation of the rectangular patch antenna in a mobile communications terminal requires a bend in one edge of the antenna to improve its radiation pattern. The bend is chosen to be at the edge of the antenna feed line. The fold location and its length were optimized for maximum resonance at the 28 GHz frequency using Ansys HFSS electromagnetic simulation software.

A bending length in the ground plane equal to 0.292 mm was obtained, leaving the antenna with a height of 0.8 mm. Figure 4 shows the geometry of the folded rectangular antenna with direct microstrip feeding line in the patch. The dimensional parameters are in Table 2.

The patch antenna has an area of 64.03 mm2 (9.32 mm 6.87 mm), a height of 0.8 mm (L_{g2}+h) and a thickness of 0.508 mm.

The 3D electromagnetic simulation software provides the bent antenna return loss response, shown in Figure 5. The minimum return loss response is -16.27 dB at 27.95 GHz frequency, with a bandwidth of 1.08 GHz, from 27.39 GHz to 28.47 GHz.

2X1 MIMO ANTENNA FOR MOBILE TERMINALS

Two bent patch antennas conform the compact 2x1 antenna for MIMO operation in the 28 GHz frequency band. Figure 6 shows the geometry of the 2x1 MIMO antenna, with elements spaced (d_y) 3 quarters wavelength (8.03 mm).

Figure 7 shows the return loss for a half wavelength (λ/2) and 3 quarter wavelength (3λ/4) patch spacings. The return loss response, measured with the reflection coefficient (S_{11}), reaches a minimum equal to -15.52 dB for a λ/2 spacing, and -20.75 dB for 3λ/4 spacing.

Journal of Engineering Research ISSN 2764-1317 DOI 10.22533/at.ed.31721422060710

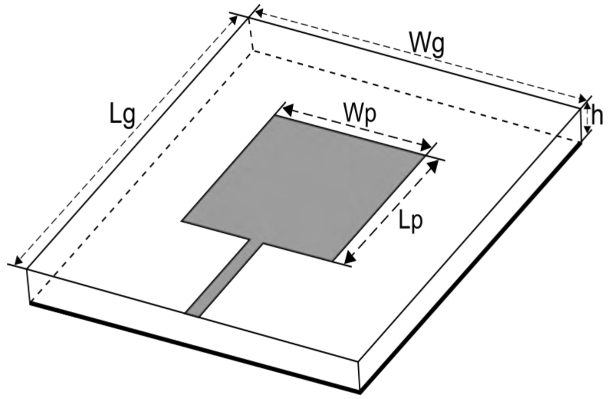

FIGURE 1. PATCH ANTENNA GEOMETRY

Parameters	Values
W_p	4.24 mm
L_p	3.28 mm
W_g	9.32 mm
L_g	7.38 mm
l_f	1 mm
W_f	0.41 mm

TABLE 1. GEOMETRIC PARAMETERS OF THE PATCH ANTENNA ELEMENT

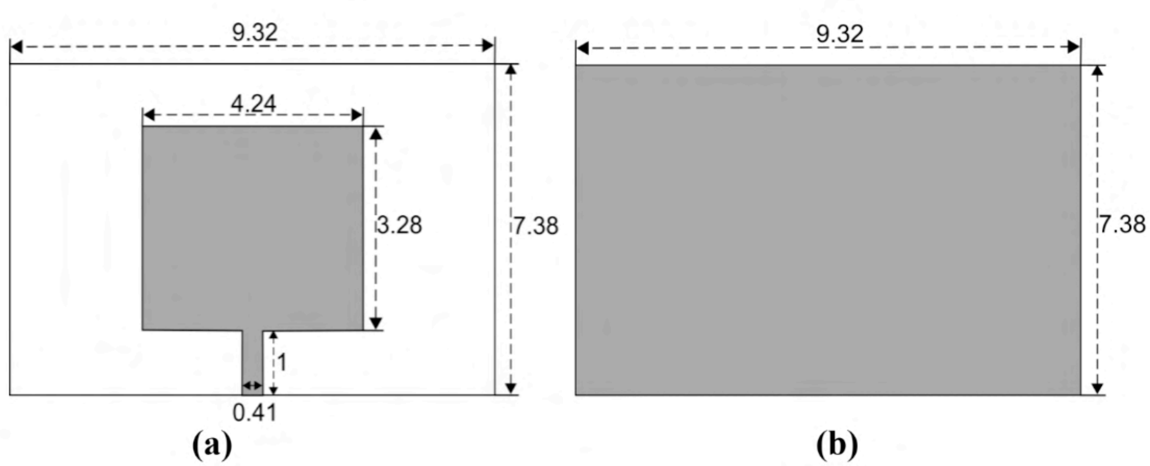

FIGURE 2: PATCH ANTENNA GEOMETRY a) TOP VIEWS AND b) BACK VIEWS. ALL UNITS IN MILLIMETERS

Journal of Engineering Research ISSN 2764-1317 DOI 10.22533/at.ed.31721422060710

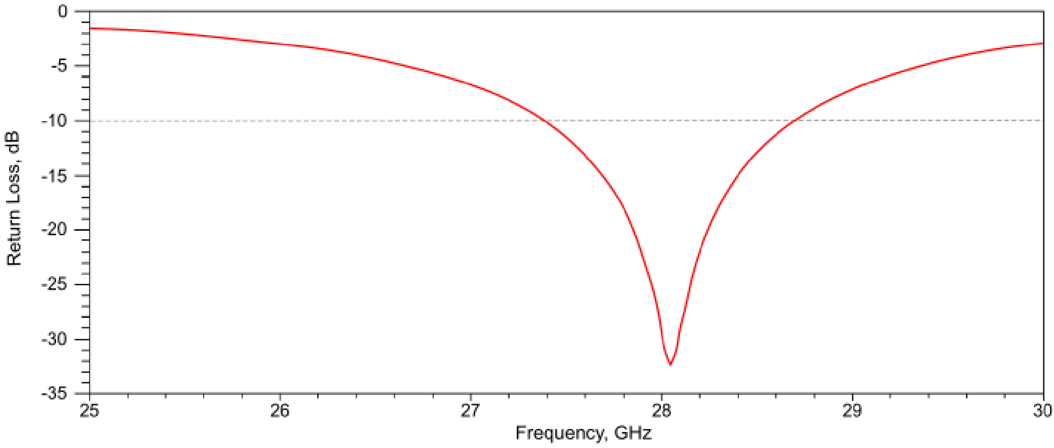

FIGURE 3: SIMULATED RETURN LOSS RESPONSE

Parameters	Values
W_p	4.24 mm
L_p	3.28 mm
W_{g1}	9.32 mm
L_{g1}	6.87 mm
W_{g2}	9.32 mm
L_{g2}	0.29 mm
l_f	1.6 mm
W_f	0.41 mm

TABLE 2. GEOMETRIC PARAMETERS OF THE BENT PATCH ANTENNA

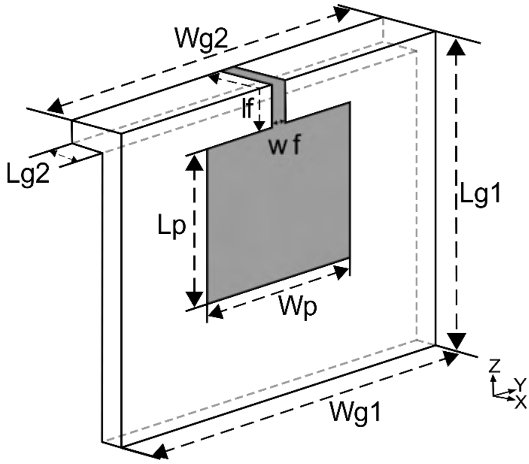

FIGURE 4: BENT ANTENNA GEOMETRY

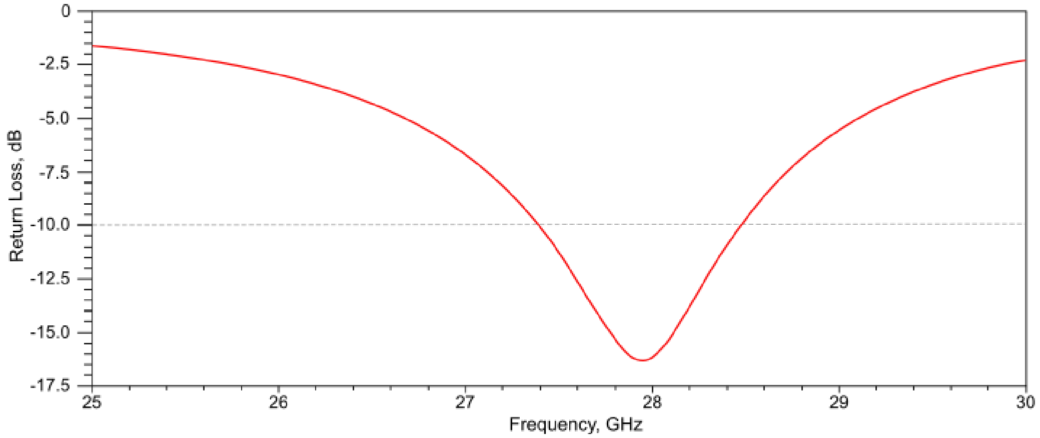

FIGURE 5: SIMULATED RETURN LOSS OF THE BENT PATCH ANTENNA

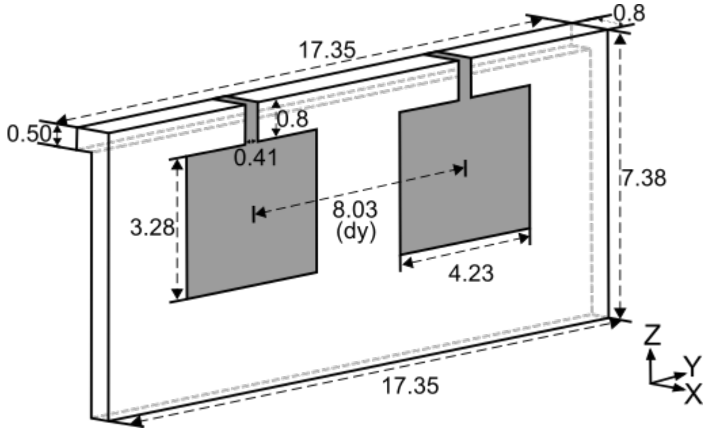

FIGURE 6: THE MIMO ANTENNA GEOMETRY. ALL UNITS IN MILLIMETERS.

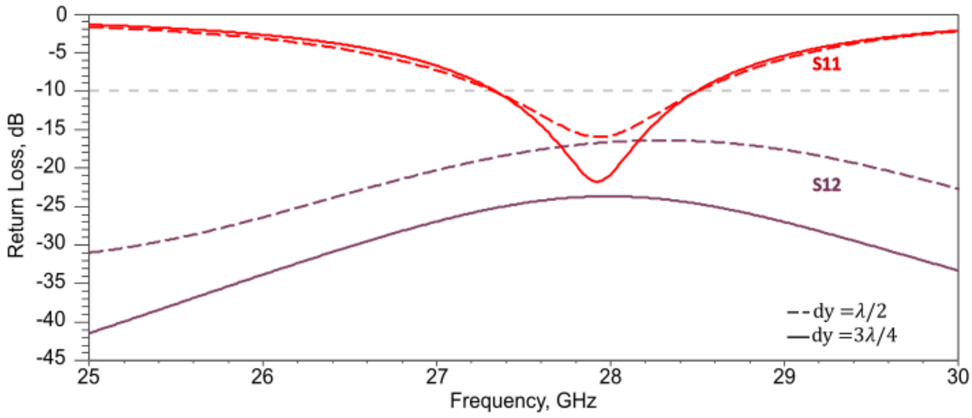

FIGURE 7: DISPERSION COEFFICIENT RESPONSES FOR SEPARATIONS BETWEEN ELEMENTS OF λ/2 AND 3λ/4.

If the elements are spaced half wavelength there is a strong electromagnetic coupling between elements, as the transmission coefficient (S_{12}) response is equal to -16.71 dB at 28 GHz, and greater than -15.98 dB at the operating bandwidth. The isolation between elements increases as the element spacing increases. The proposed MIMO antenna has elements spaced at 3/4 wavelength, and its transmission coefficient reaches a maximum equal to -24.72 dB at 28 GHz.

Figure 8 shows the radiation patterns for a 3/4 wavelength element spacing. Figure 8a shows the radiation pattern in the XZ plane with a maximum gain equal to 8.0 dB in the direction θ=90°. Figure 8b shows the radiation pattern in the YZ plane with a maximum gain of -2.7 dB in the direction θ=0°.

RESULT ANALYSIS AND RECOMMENDATIONS

The 2x1 MIMO antenna for mobile terminals proposed in this work has a 3/4 wavelength spaced elements. The operating bandwidth of the MIMO antenna is equal to 1.07 GHz, exceeding the minimum required of 1 GHz for 5G applications. The isolation between MIMO elements is -24 dB, which indicates an increase of the efficiency of the MIMO antenna. The patch antenna has a dimension of 17.13 mm 7.38 mm, a height of 0.8 mm, and a thickness of 0.508 mm.

It is recommended that the appropriate installation of the MIMO patch antenna on a 5G mobile terminal be such that the longest antenna section, i.e., the width of 17.13 mm will be installed on the upper edge of the mobile terminal, as shown in Figure 9. Consequently, the direction of the radiation pattern main lobe shall be that of the positive X-axis of the XZ plane, that is, at the coordinate φ=0°, θ=90°.

Statistically speaking, people normally hold their mobile terminals at an angle of elevation between 30° and 50° with respect to the horizontal axis. Consequently, the main beam of the mobile terminal antenna will be linked to the antenna beam of the base station located by recommendation at 3 meters high (Koul et. al., 2020). In this way the operating efficiency of the 5G mobile terminal will be widely favored with a high-speed service, because in that direction the proposed MIMO antenna reaches the maximum gain equal to 8.0 dB.

CONCLUSIONS

The 2x1 MIMO antenna with rectangular patch elements has direct application in mobile terminals 5G at the frequency 28 GHz. The antenna is printed on Neltec NY9220 substrate of 0.508 mm thickness, relative permittivity equal to 2.2 and tangential loss of 0.0009. The geometry of the MIMO antenna presents a bend in the section of the power line for installation in mobile terminals, occupying an area of 17.35 mm x 7.38 mm, has a height of 0.8 mm and a thickness of 0.508 mm. The proper separation between elements, for maximum electromagnetic isolation is 3 quarters of the wavelength, i.e., equal to 8.036mm, for which the electromagnetic isolation reaches -24.72 dB at 27.89 GHz. Estimated return loss response of the bent MIMO antenna equals -20.75 dB at 27.89 GHz and achieves an operating bandwidth of 1.07 GHz from 27.34 GHz to 28.41 GHz. The maximum antenna gain is equal to 8.0 dB in the direction φ=0°, θ=90° in the XZ plane. The complete geometry of the folded 2x1 MIMO patch antenna with all its dimensions, radiation patterns and its location in a 5G mobile terminal is presented.

ACKNOWLEDGMENT

The authors are grateful for the support received from the research project SIP20221930 of IPN Mexico.

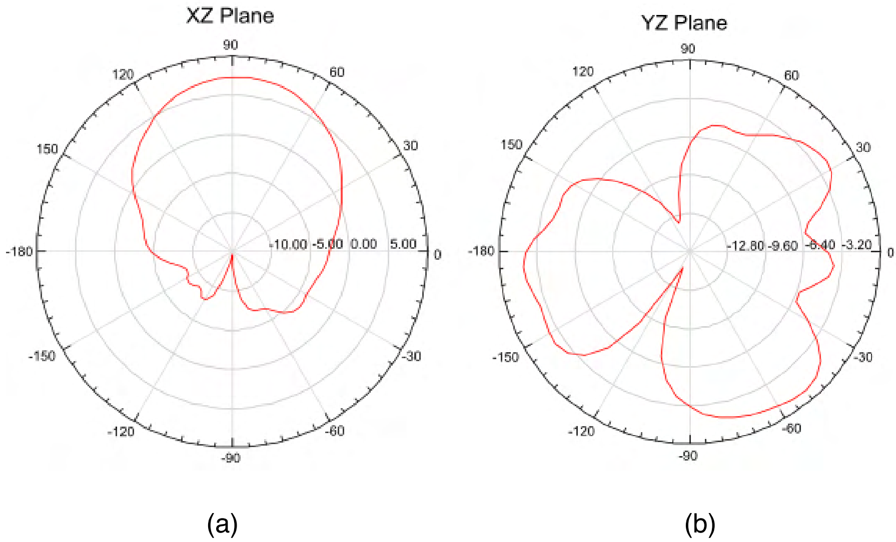

FIGURE 8: RADIATION PATTERNS IN (A) XZ PLANE AND (B) YZ PLANE

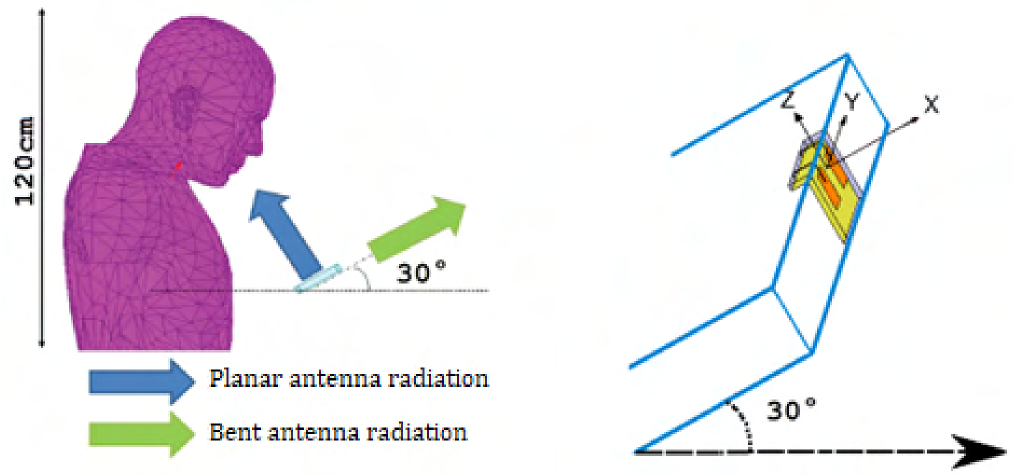

FIGURE 9: DIRECTION OF RADIATION AND INSTALLATION OF THE MIMO ANTENNA ON THE MOBILE TERMINAL

REFERENCES

Balanis, C. A. (2015). ***Antenna theory: analysis and design***. John wiley & sons.

Chávez Tigrero, M. I., & León Ortiz, D. E. (2018). ***Diseño e implementación de un método de Ray-Tracing para determinar la influencia de la geometría de edificios en un enlace de comunicaciones en la banda de 28 GHz*** (Bachelor's thesis, Espol).

Gohil, A., Modi, H., & Patel, S. K. (2013, March). ***5G technology of mobile communication: A survey***. In 2013 international conference on intelligent systems and signal processing (ISSP) (pp. 288-292). IEEE.

González, J., & Salamanca, O. (2016). ***El camino hacia la tecnología 5G. Télématique***, 15 (1), 27-47.
Koul, S. K., Karthikeya, G. S., Poddar, A. K., & Rohde, U. L. (2020). ***Compact Antenna Designs for Future mmWave 5G Smart Phones***. Microw. J, 63, 22-40.

Naqvi, A. H., & Lim, S. (2018). ***Review of recent phased arrays for millimeter-wave wireless communication. Sensors***, 18(10), 3194.

Rahayu, Y., Wijaya, J., & Syafitri, E. (2018). ***Characteristics MIMO 2x4 Antenna for 5G Communication System***. TELKOMNIKA (Telecommunication Computing Electronics and Control), 16(4), 1508-1514.

Rappaport, T. S., Sun, S., Mayzus, R., Zhao, H., Azar, Y., Wang, K., ... & Gutierrez, F. (2013). ***Millimeter wave mobile communications for 5G cellular: It will work!.*** IEEE access, 1, 335-349.

Roh, W., Seol, J. Y., Park, J., Lee, B., Lee, J., Kim, Y., ... & Aryanfar, F. (2014). ***Millimeter-wave beamforming as an enabling technology for 5G cellular communications: Theoretical feasibility and prototype results.*** IEEE communications magazine, 52(2), 106-113.

Yilmaz, T., & Akan, O. B. (2015). ***On the use of low terahertz band for 5G indoor mobile networks.*** Computers & Electrical Engineering, 48, 164-173.