Microstrip Antenna Design for 3.1-4.2 GHz Frequency Band Applied to 5G Mobile Devices

S. Ricardo Meneses G., Rita T. Rodríguez M.

***Abstract*—Actually Internet of Things (IoT) applications, from driverless cars, mobile devices, smart homes and smart cities are highly requested by the costumers, obliging telecommunication businesses operators established in countries to provide shortly this significant and inevitable technological leap forward. 5G is the technology that will enable these smart mobile devices to be well connected. These devices are becoming smaller, therefore and because to the high degree of miniaturization and an efficient wireless link, small antennas, which satisfies gain, resonance frequency, wideband, impedance, and low cost are demanded, which dimensions are enough small for be assembled into these kinds of mobile devices. This work proposes a wide bandwidth ranging from 3.1 GHz – 4.2 GHz Slotted Planar Microstrip Patch Antenna, applied to first trials and introduction of 5G services, describing the design, simulation, implementation, measurement and experimental results.**

***Index Terms*—5G Band, Microstrip Antenna, Radiation Pattern, Resonance Frequency, S_{11} Parameter.**

I. INTRODUCTION

The main challenges in transforming the cellular network to be an efficient platform for a vast and diverse set of applications and services, Massive Internet of Things, Enhanced Mobile Broadband, Mission Critical Services, as shown in Fig. 1, have been faced and undertaken by the Next Generation Mobile Networks (NGMN), 5G networks, which has been defined as slice for massive Machine-Type Communications (mMTC) to provide wireless connectivity to tens of billions of machine-type terminals and trillions of connections and provides an affordable solution. 5G networks must be scalable and efficient, matching the appropriate radio frequency (RF) and physical layer protocols, based on the unique requirements of different applications, in this sense, 5G radios will need to be broadband, multi-mode, highly efficient (“green”), and highly integrated [1,2].

The International Telecommunication Union (ITU) coordinates, in order to reach the diverse goals 5G NR (New Radio), is set to achieve [3,4] the spectrum needs to be divided in the following new manner, as shown in Fig. 2.

Below 6 GHz, called sub- 6 GHz consists of Low Band (sub 1 GHz), Mid Band (1 to 6 GHz). The following band is the 5G enhanced Mobile Broadband, eMMB, operating at 2.5 GHz, which composed by 4G LTE Pro (B41) and the 5G Band operating at 3.5 GHz (B42/B43) [5-7].

Above 6 GHz we have the centimeter wave (cmWave) and millimeter wave (mmWave) bands starting at 28 GHz and 39 GHz, respectively [8].

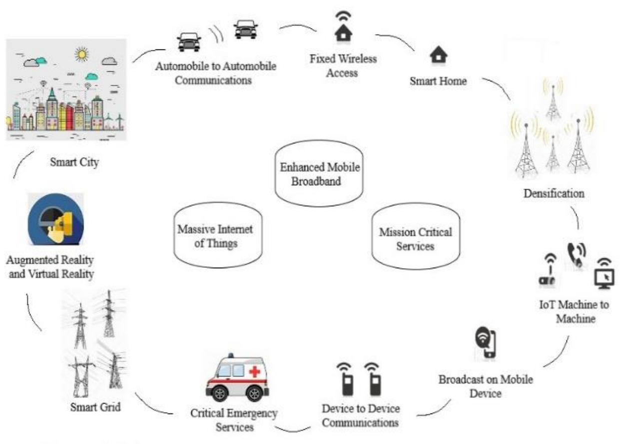

Fig. 1. shows 5G network applications and services.

Fig. 2. 5G frequency bands classification [4].

On the other hand, due to its favorable properties, such as radio wave propagation and available bandwidth, frequency below 6 GHz is less complex in development of infrastructure, deployment and future network enhancements, therefore, the band 3100-4200 MHz is being considered for first trials and introduction of 5G services in a number of countries and regions in the world, in this way, a microstrip patch antenna modified with a slotted planar structure is the baseline of this work focused to cover 3.1-4.2 GHz frequency band.

To determine the performance of design parameter, as impedance, resonance frequency, radiation pattern, wideband, etc., CST software (Computer Simulation Technology) and experimental equipment as anechoic chamber and vectorial network analyzer has been used.

The paper is organized as follows: section II describes a brief antenna design basis and simulation results, section III discusses tests performed in the laboratory and experimental results, concluding the presently work with conclusions and references

Published on October 24, 2019.
Salvador Ricardo Meneses González, is with the Instituto Politécnico Nacional, Escuela Superior de Ingeniería Mecánica y Eléctrica, Unidad Zacatenco, 07738, Cd. de México, México. (e-mail: rmenesesg@ ipn.mx).
Rita Trinidad Rodríguez Márquez, she is with the Instituto Politécnico Nacional, Escuela Superior de Ingeniería Mecánica y Eléctrica, Unidad Zacatenco, 07738, Cd. de México, México. (e-mail: rtrodriguez@ ipn.mx).

DOI: http://dx.doi.org/10.24018/ejers.2019.4.10.1570

II. ANTENNA FOUNDATIONS

Since 5G technology is a future framework to support various applications, therefore, in view of the importance of their role, it must meet all necessary specifications, and one of them, it is the antenna radio mobile device. These kind of antennas should be safety, lightweight, extremely small, and robust structure, in this sense, there are complex factors involved that have to be considered when dealing with this issue, as miniaturization of the antenna's occupied volume/size, usually the given space within the radio device is limited, high efficiency, large bandwidth, radiation pattern, and interaction with the human body because the body directly degrades the performance of the antenna [9].

On the other hand, not all of them allow preserving the characteristics of the device in a frequency band broad enough, and some of them are complicated in terms of design, and have the disadvantage that bandwidth is limited [10], so, in order to enhance the antenna design antenna, many techniques are employed to design microstrip printed antennas with slotted structure, for example [11] comprises a tapered-shape slot and rectangular tuning stub, or with a rotated slot, and some modifications on the structure are applied, for instance, techniques based on coupled parasitic elements, employing slots and notches to redistribute current density, small coupling parasitic strips or resonators placed either on the same side or opposite side of the patch [12-13-14].

In this regard, initially, the antenna consists of a rectangular patch, which it is modificated, in order to establish the bandwidth and resonance frequency operation, adding slots; which shape and length of them and distance separation between them, offer design variables, used to tune performance antenna. On the other hand, the feeding structure, a simple line transmission, and the patch are etched on the same face of the substrate [15]. On the back side of the substrate, the ground surface consists of a U-shaped structure.

Let us remember that, thick substrates with low permittivity result in antenna designs with high efficiency and large bandwidths, thin substrates with high permittivity lead to small antennas but with a lower bandwidth and a high radiation loss [16]; during the simulation stage, we have made a tradeoff between substrate thickness and permittivity for the purpose to define the kind of material, and is in keeping to within our means in a cost-effective way, for that, we have used and built the prototype antenna on a FR-4 substrate which electric permittivity is $\varepsilon r = 4.4$, and a loss tangent $\delta = 0.0009$.

A. *Antenna Design*

Above mentioned, the width and the length of the patch determine the bandwidth and resonance frequency, but these values can be altered adding slots to the patch. The resonant frequency varies for different slot length and the bandwidth value can be varied for given slot width. In our case the vertical slots, act like a antenna array varying the central frequency and the horizontal slots varying the bandwidth of the patch, in the same way, a tradeoff between two parameters was made. On the other hand, the technique to feed the patch is by coaxial feed, that is, the outermost conductor is connected to the ground plane and inner conductor is connected to radiating patch. The feeding line length enables the match impedance antenna with SMA connector.

In such a way that the prototype antenna is designed to operate on 3.6 GHz, considering this frequency value the central frequency of the band to be covered (3.1-4.2 GHz), which wavelength is equal to $\lambda \approx 8$ cm, this one is based on two quarter wavelength vertical strips, $\lambda/4$, forming a two array elements, enclosed by two perpendicular horizontal strips, which length of each one is approximately a half of the vertical strip length, $\lambda/8$. As we know, the size of the microstrip antenna is directly proportional to the wavelength at the operating frequency.

The dimensions of the proposed antenna structure, front and back side are shown in Fig. 3, which have been determined using primarily the following expressions [17]:

Strip width, *W*:

$$W = \frac{1}{2f_r\sqrt{\varepsilon_0\mu_0}}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

Strip length, *L:*

$$L = \frac{1}{2f_r\sqrt{\varepsilon_r}\sqrt{\varepsilon_0\mu_0}} - 2\Delta L \tag{2}$$

Effective Permittivity:

$$\varepsilon_e = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+12\frac{h}{W}}}\right) \tag{3}$$

Resonance Frequency:

$$f_r = \frac{1}{2L_e\sqrt{\varepsilon_e}\sqrt{\mu_0\varepsilon_0}} \tag{4}$$

where:

f_r, resonance frequency
ε_r, relative permittivity
h, substrate thickness

The vertical length of the antenna is approximately equal to 20 mm, line feed length 24 mm and horizontal length is 12 mm, in a way that, enable fit inside the radio mobile device.

B. *Simulation*

Computer Simulation Technology software [18], CST, has been used to simulate the designed antenna, and let us remember that S_{11} parameter represents how much power is reflected and hence is known as the reflection coefficient, expressed in dB, it means the ratio of the values of reflected energy and transmitted energy (-10 dB), an important value that describes the performance antenna, this way, Fig. 4 shows the simulation result, Magnitude vs. Frequency graphic, S_{11} parameter. It is possible to observe that the obtained bandwidth is approximately equal to 3 GHz, starting from 1.2 GHz and ending at 4.3 GHz, nevertheless, there are some critic points around 1.9 GHz, where the magnitude is slightly lower than the -10 dB, (ten percent of the radiated energy is reflected from the antenna).

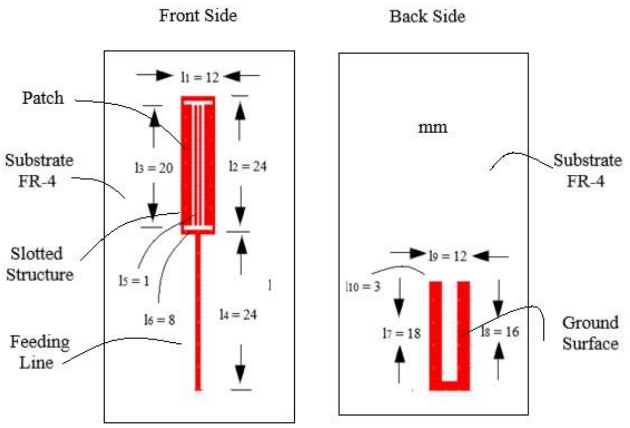

Fig. 3. Designed antenna structure.

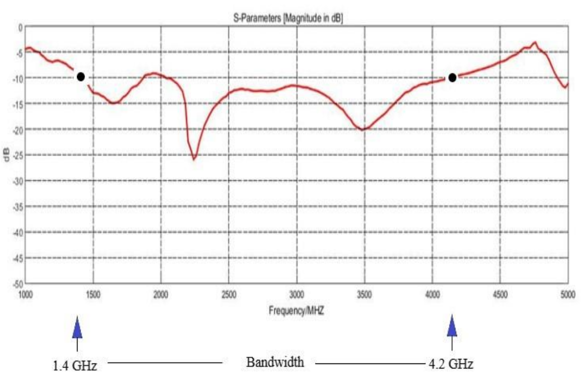

Fig. 4. S_{11} parameter simulation graphic.

Furthermore, it is possible to observe too, that, the better antenna efficiency is noted on the deepest points 2.3 GHz and 3.5 GHz frequency points, an important result, particularly in the first point mentioned, due to the Wireless Lan Application (Wi-Fi ISM) uses the 2400- 2483.5 GHz; so, in addition to cover 5G band, this prototype antenna covers this service to be used on radio mobile device.

The graphical representation of the spatial distribution of radiation from the designed antenna as a function of angle, that is, the radiation pattern, is shown in Fig. 5. The radiation pattern simulation graphic, vertical plane, E-Plane, |E| vs. θ, shows a quasi-omnidirectional performance. As we know, it is not possible to build an antenna that radiates coherently equally in all directions, a hypothetical isotropic antenna, this way, it is notorious that the energy declines from 30° up to 70°, and the minimum value is situated approximately in 55° direction, so this point can be considered as a semi-null, but still a radio mobile device situated in the mentioned point within of this coverage area, will still be connected to the network. Particularly about the obtained radiation pattern is an asset, due to a large geographic area can be covered.

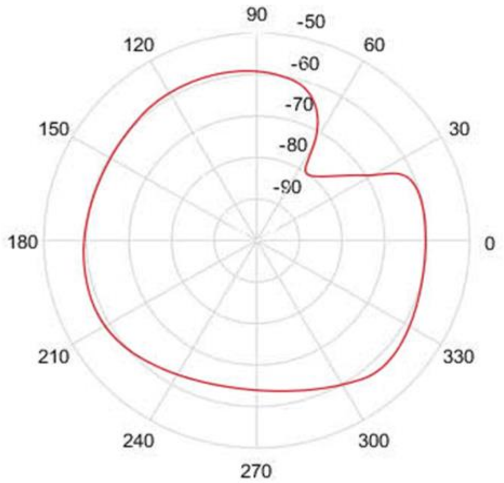

Fig. 5. Radiation pattern (Simulation)

III. Experimentation

The designed antenna is built and assembled, printed on the front side of the substrate, PCB (FR4), $\varepsilon_r = 4.4$, and the ground surface on the backside. Fig. 6 shows both sides of the prototype antenna.

In order to get the S_{11} parameter in an experimental way, to this effect, specialized equipment has been used, a Vector Network Analyzer ZVB 40 calibrated in the band 500 MHz – 6 GHz, at short circuit, opened circuit and matching network. The magnitude vs. frequency achieved graphic, S_{11} parameter, is shown in Fig. 7, starting from 1 GHz and ending at 5 GHz, observing that the frequency center of this screen image is approximately equal to 2.5 GHz, in this respect the bandwidth of the designed antenna is approximately equal to 2.7 GHz (1.4 GHz – 4.2 GHz), enough to support data rate mobile devices, an appropriate band considered for first trials and introduction of 5G wireless mobile services, even for cover other technologies, 3G, 4G and Wlan for instance.

Mention should also be made of the very close resemblance between the simulation and experimental results (See Fig. 4 and Fig. 7).

With regard to technique to measure the radiation pattern, this one consists of install the prototype antenna, acting as receiver antenna, and a known second antenna (see blue flat antenna in Fig. 8 and Fig. 9), acting as a transmitter antenna [19], whose parameters are known, which transmits a known power value at certain frequency, both of them located front to front, line of sight, at certain known distance and height, into the anechoic chamber. The RF generator and the RF receiver are connected through cables to the transmitter and receiver antennas, respectively, which are measured previously in order to know and consider the overall transmission loss (cable loss).

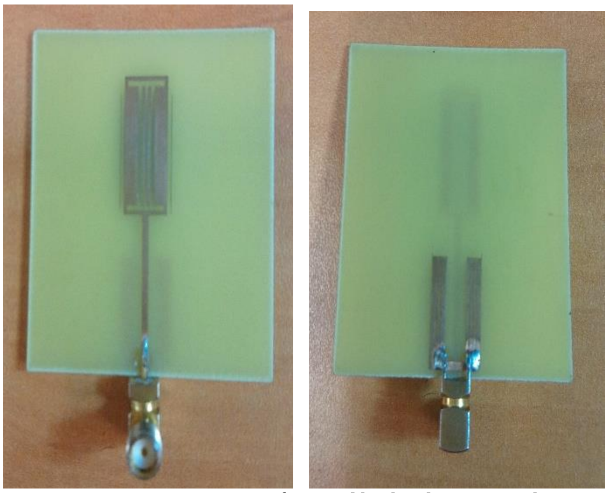

Fig. 6. Prototype antenna, front and back side respectively.

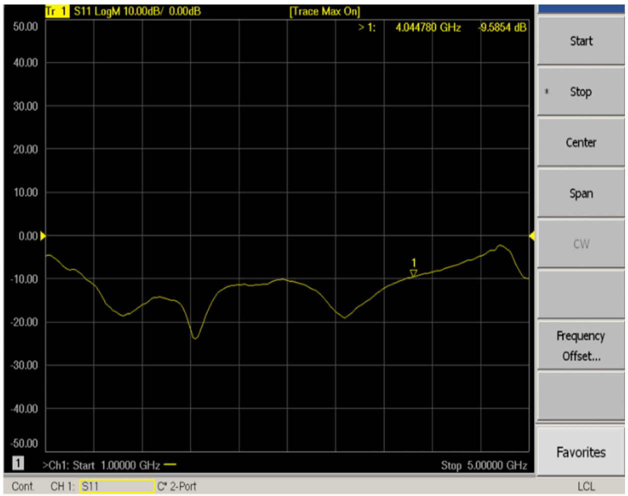

Fig. 7. S11 parameter measurement graphic.

Therefore, with earlier acquired data, the Friis Equation [20-21] is applied (4), obtaining a gain antenna value equal approximately to 2.3 dB. Fig. 8 shows measurement method configuration and Fig. 9 shows an aspect of the experimental antenna under test into the anechoic chamber.

$$P_{REC} = P_{TOTAL} G_{TX} G_{RX} \left(\frac{\lambda}{4\pi r}\right)^2 \quad (5)$$

where:

P_{TOTAL}, Transmmited power,
P_{REC}, Received power,
G_{TX}, Transmitter antenna gain
G_{RX}, Receiver antenna gain,
r, Separation distance between antennas.

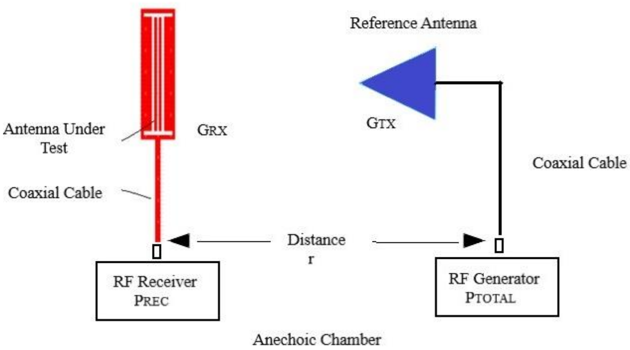

Fig. 8. Measuring technique configuration.

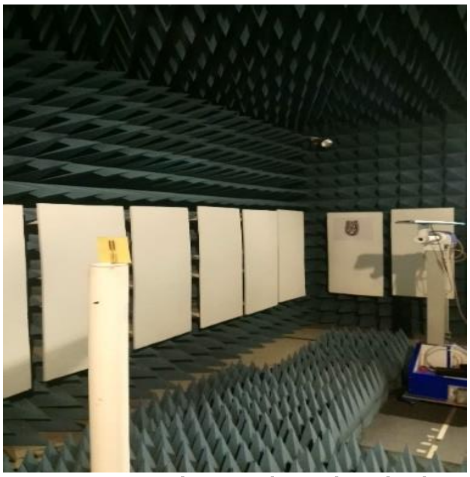

Fig. 9. Antenna under test in the anechoic chamber.

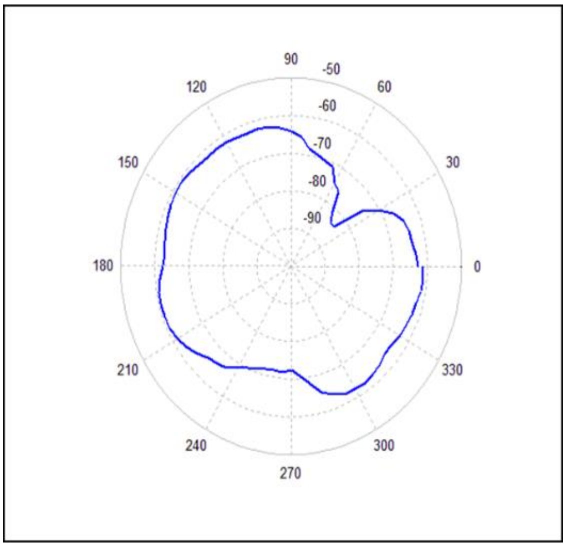

Fig. 10. Radiation pattern (experimental)

IV. Conclusion

In this paper, we presented a prototype microstrip patch antenna in order to be applied to forefront technology, 5G radio mobile devices (3100-4200 MHz). The designed antenna has been simulated, implemented and tested; parameters as resonance frequency, wideband have been verified and the radiation pattern shape has been obtained. The prototype antenna meets with small size requirement and easily and cheaply constructed.

The existence of a semi null around the 55° line is present in the radiation pattern, in this case the possible receivers situated along this direction will experience low received power values, even so, enough to recover the transmitted data.

There is a great similarity between the experimental and simulated results, and the minor differences is because to certain construction defects, for instance, bad soldier, low cost SMA connector, or not fit the exact dimensions, etc.

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Ricardo Meneses was born in Mexico City. He received the B.S, the M.S. and Ph.D. degrees in communications and electronic engineering from the Instituto Politécnico Nacional. Since 1987, he has been with different related telecom companies and is currently a Professor of the Escuela Superior de Ingeniería Mecánica y Eléctrica. He has been involved in electromagnetic problems, technology, antennas, and RF technology for wireless communications

Rita Rodríguez was born in Mexico City. She received the B.S.,the M.S. and Ph.D. degrees in electrical engineering, computer systems and information and communication technologies in education, respectively from the Instituto Politécnico Nacional. Since 1997, she has been with different related electrical companies and is currently a Professor of the Escuela Superior de Ingeniería Mecánica y Eléctrica. She has been involved in circuit theory problems.