Chapter

Co-Design Block PA (Power Amplifier)-Antenna for 5G Application at 28 GHz Frequency Band

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Abstract

This subject addresses the issue related to Transmitters for the new communication standard, namely 5G. Indeed to respond to the problems of radio coverage, the speed of services as well as the rise in user demand, transmitters must have ideal characteristics to be able to meet these requirements. This chapter proposes in order to answer such a problem a block made up of a linear array of antennas has 4 elements and a transistor amplifier operating at the 28 GHz frequency band. The Design of the Block is done first by the design of the antenna then the design of the amplifier and finally the junction of the two devices with a matching network to therefore form the block of transmitters Speaking of the design of the antenna, the prepared antenna is a patch antenna with a patch shape excluding the classic shapes which is printed on a Rogers-Duriod 5880 substrate so the thickness is 0.127 mm, the linear antenna array proposed has a gain greater than 15 dB and a Good Bandwidth, the transistor amplifier is in turn printed on the same substrate has the same thickness to minimize the losses during the junction of this one with the antenna, this amplifier offers a higher gain than device 15 dB and therefore the Bandwidth is greater than 2 GHz, each transmitter has an input and output reflection coefficient of less than −10 db. The simulation of each transmitter is made with the CST-microwave software for the Antenna and the ADS (Advanced Design System) software for the amplifier and the Block PA-Antenna. It is important to note that the Block output impedance is 50 ohms making our device more practical and easily commercial.

Keywords: 5G, Antenna, PA (Power Amplifier)

1. Introduction

In recent years, wireless communication systems have had a significant impact on the daily life of human beings, therefore nowadays more and more users are connecting their devices to existing networks causing a constant increase in data traffic and the need for high speed networks will continue to increase over the years [1–3]. To cope with this rise the new 5G communication systems would have to dramatically improve the communication capacity by exploiting enormous unlicensed bandwidth in particular, in the millimeter waveband. It should also be prepared to provide and support very high data rates which in turn therefore requires the design of antennas and amplifiers satisfying the expected data rate [4–6]. Research in 5G Millimeter Band wireless communication shows that as mobile industries developed to use the millimeter wave spectrum, carriers are likely to use the 28, 38 and 73GHz bands which will become available in future technologies [7]. The requirements imposed by 5G technology on the antennas are: light-weight antenna, low profile, low cost mass production, ease of installation, Despite its narrow band the microstrip patch antenna may prove to be an ideal candidate to meet these requirements and the design of a microwave amplifier becomes very interesting in view of the operation of 5G technology in millimeter band. This chapter proposes the design of a microstrip patch antenna and an amplifier for 5G application then a PA-Antenna Unit operating in the 28 GHz band. In the following lines we will respectively present the architecture of our Co-Design then the mathematical model of the antenna and the amplifier as well as their modeling then the interpretation and analysis of the results and finally the conclusion.

2. PA-antenna Co-design architecture

The principle of the Co-Design of a PA-Antenna block is based on the fact that the junction of the antenna and the amplifier must be done with as little loss as possible, which is why it is very objective for us to work on each one. Equipment with a reference impedance which will facilitate the junction of the two because the option of designing a matching network no longer becomes a necessity. So let us say the stages of Co-design illustrated in the figure below (**Figure 1**).

In the chain of transmission of wireless communication systems, the proposed Co-Design Block is of capital importance because the amplifier will have the role of taking a weak signal as input and producing a high intensity signal at the output.

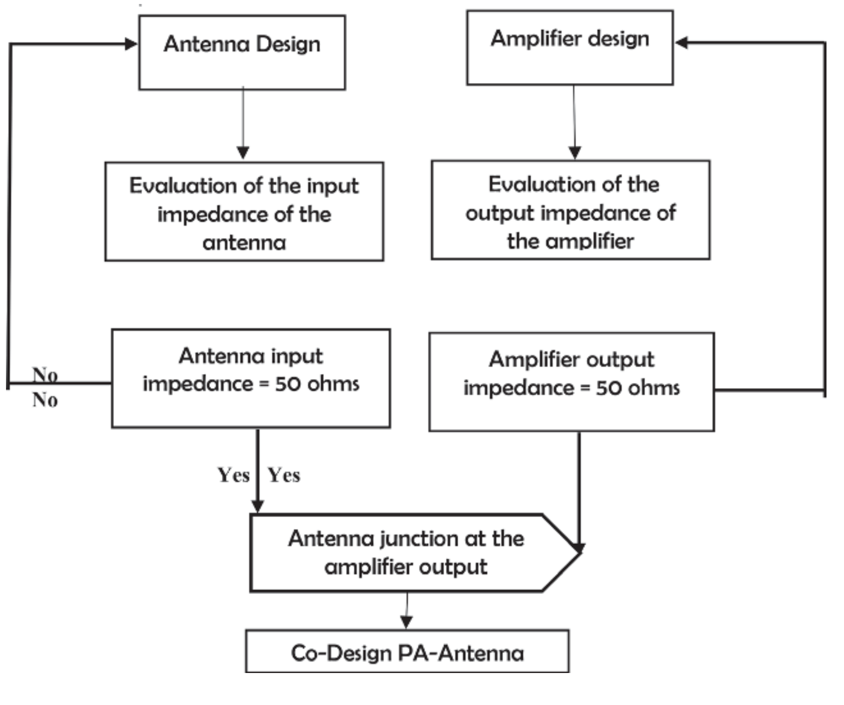

Figure 1.
PA-antenna block Co-design principle.

This signal will be recovered at the output by the antenna and radiates by it in the free space.

3. Mathematical model and modeling of the antenna and the amplifier

3.1 Mathematical model of the antenna

In this section we will notify the different formulas used to obtain the dimensions of the rectangular patch:

3.1.1 The width of the W_P *patch is expressed as follows*

$$W_P = \frac{C}{2f_0}\sqrt{\frac{\varepsilon_r + 1}{2}} \tag{1}$$

where C is the speed and ε_r the dielectric constant of the substrate.

3.1.2 The length of the patch is expressed by the formula

$$L_p = \frac{C}{2f_0\sqrt{\varepsilon_{reff}}} - 2\Delta_L \tag{2}$$

where the effective dielectric constant is expressed by the formula

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \times \left[\frac{1}{\sqrt{1 + \frac{12h}{W_p}}}\right] \tag{3}$$

Where h is the height of the dielectric substrate, the extension of length Δ_L is expressed by the following formula:

$$\Delta_L = 0.412h\left[\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W_p}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W_p}{h} + 0.813\right)}\right] \tag{4}$$

3.1.3 Dimension of the ground plan

The dimensions of the ground plane are expressed by the following formulas:

$$W_g = W_p + 6h \tag{5}$$

$$L_g = L_p + 6h \tag{6}$$

W_g: Ground plane width in mm, L_g: Ground plane length in mm.

The feeding technique used for our antennas is the microstrip feeding technique because of its ease of manufacture and its better reliability according to [8].

3.1.4 Adaptation technique

The choice of the feeding technique chosen therefore imposes a choice of adaptation technique in our work we have chosen the insed feed adaptation technique. This technique involves inserting notches to bring the impedance of the antenna down to that of the power line [9]. Each notch is equivalent to a parallel admittance Y with a conductance G and a subceptance B. The following formulas on the conductance of a slot, the mutual conductance and the resistance of the antenna are expressed as follows

$$G_1 = \frac{1}{120\pi^2}\int\left[\frac{\sin\left(\frac{K_0 W_p}{2}\cos\theta\right)}{\cos\theta}\right]^2 \sin^3\theta d\theta \tag{7}$$

The mutual conductance is expressed as follows:

$$G_2 = \frac{1}{120\pi^2}\int\left[\frac{\sin\left(\frac{K_0 W_p}{2}\cos\theta\right)}{\cos\theta}\right]^2 \times j_0(K_0 L_P \sin\theta)\sin^3\theta d\theta \tag{8}$$

Where j_0: represents the Bessel function of order 0. The resistance of the antenna is

$$R_{in} = \frac{1}{G_1 + G_2} \tag{9}$$

After having developed all the theoretical analysis which allows us to find, using mathematical formulas, the various parameters important for the design of the antenna, we will now proceed to the modeling of the antenna.

3.1.5 Antenna modeling

The previous section allowed us to show how to obtain the different antenna dimensions of a rectangular patch antenna. **Table 1** below illustrates these dimensions.

When modeling the antenna several initiatives were taken first with the proposal of several antenna shapes departing from the known classical shape. The **Figures 2** and **3** below represent the different forms of modeled antennas.

The Other forms of antennas modeled in terms of contribution are illustrated below.

Dimension	Value (mm)
W_p	4.23
L_p	3.52
W_g	11.84
L_g	10.3
W_f	0.3912
L_f	1.95
Fi	0.93
gap	0.26

Table 1.
Antenna dimension.

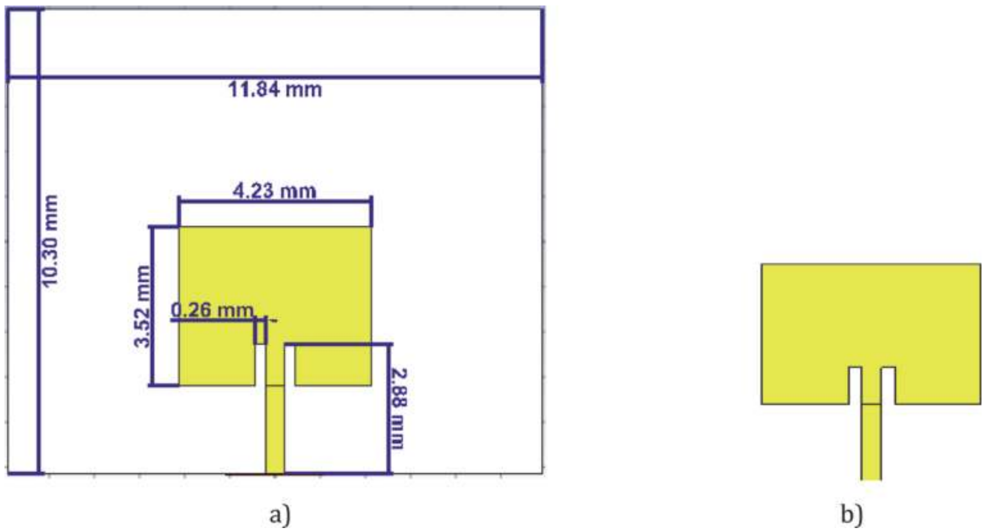

Figure 2.
Rectangular patch modeled: a) with dimension, b) without dimension.

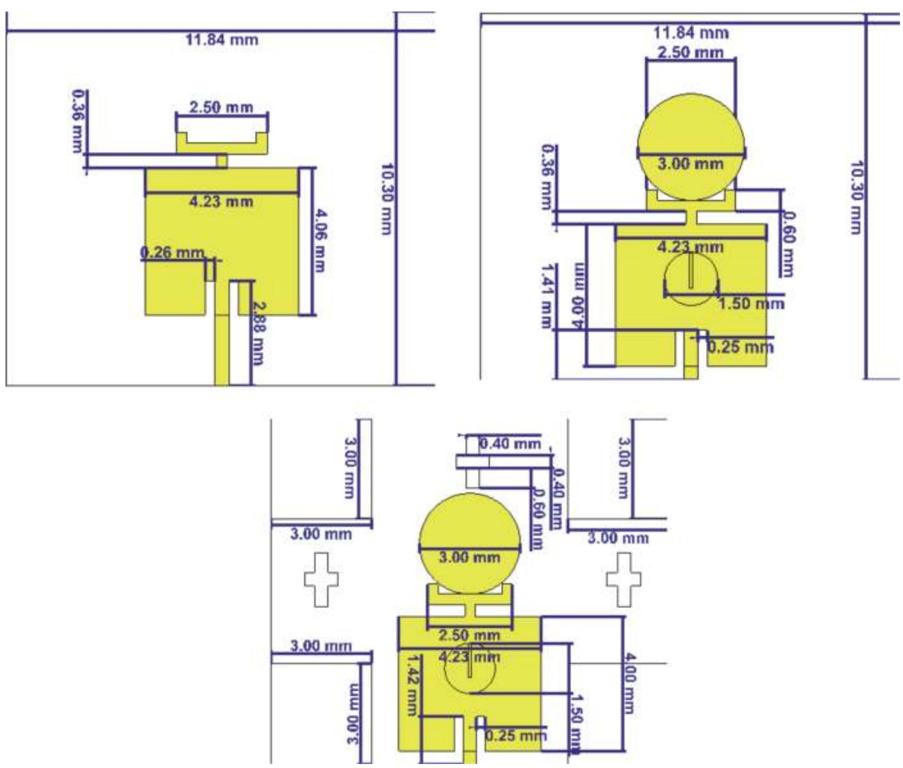

Figure 3.
Proposed patch antenna shape.

3.2 Mathematical model of the amplifier

An Amplifier is an electronic device whose role is to increase the power of a signal introduced at its input. To simplify our study we will admit that our amplifier is a quadrupole whose matrix is [S] and connected to a voltage source E with an internal impedance and it is loaded by an impedance (**Figure 4**).

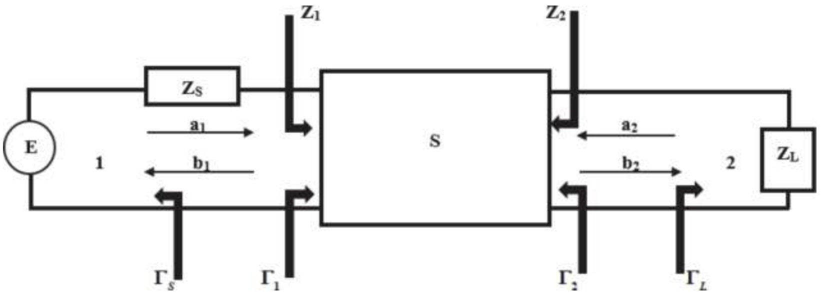

Figure 4.
Distribution waves and reflection coefficients at the entry and exit of the quadrupole.

The matrix [S] of distribution of this linear quadrupole is such that [9]:

$$[b] = [S][a] \Rightarrow \begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{11}S_{12} \\ S_{21}S_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

$$\begin{cases} b_1 = S_{11}a_1 + S_{12}a_2 \\ b_2 = S_{21}a_1 + S_{22}a_2 \end{cases} \tag{10}$$

$\mathbf{Z_2}$**:** is the output impedance of the quadrupole fed by the Zs impedance source.
$\mathbf{a_1}$: is the incident wave at port 1;
$\mathbf{b_1}$: is the wave reflected at the access;
$\mathbf{a_2}$: is the incident wave at port 2;
$\mathbf{b_2}$: is the wave reflected at port 2.

When making the amplifier, we try to have maximum gain. In other words, it is necessary to perform the adaptation at the input of the transistor and the source simultaneously with the adaptation between the transistor output and the load.

3.2.1 Presentation du transistor

The transistor amplifier are very recurrent microwave amplifiers their characteristics depend on the properties of the Transistor for the design in our work we looked at the FET transistor sp_aiiAF035P1_00–19941209 manufactured by Alpha Industries so we will first illustrate the characteristics of our transistor namely the input and output reflection coefficients S_{11}, S_{22} the transmission coefficient S_{21} which represents the transmission from the input to the output or the own gain of the transistor and of the future amplifier S_{12}, represents the isolation or the reverse transmission from the output to the input the drain source voltage Vds = 5 V and the current Ids = 70 mA. We will therefore present and illustrate the S-parameters listed below in **Figure 5**.

The S-parameters of the transistor obtained are as follows: S_{11} = −1.067 dB, S_{22} = −0.219 dB, S_{21} = −11.164 dB, S_{12} = − 35.289 dB. We realize that the inherent gain of the transistor is very low, it is imperative for us to improve this gain as well as the characteristics of the amplifier in order to produce an amplifier that meets the constraints imposed by 5G technology.

3.2.2 Study of the stability of the transistor

Considering K as the stability factor, the expression of the stability factor is given by the following formula:

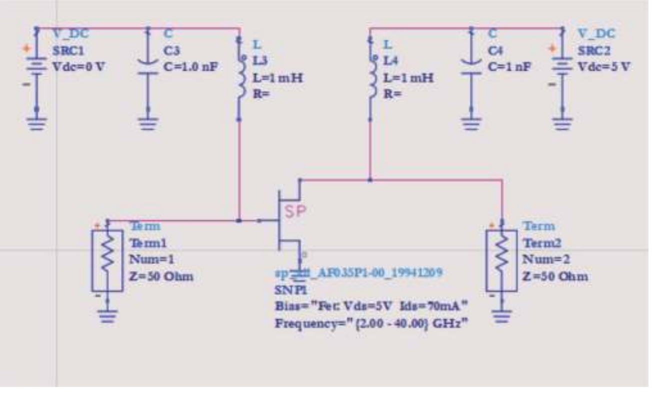

Figure 5.
Schematic of the transistor and simulation of S-parameters.

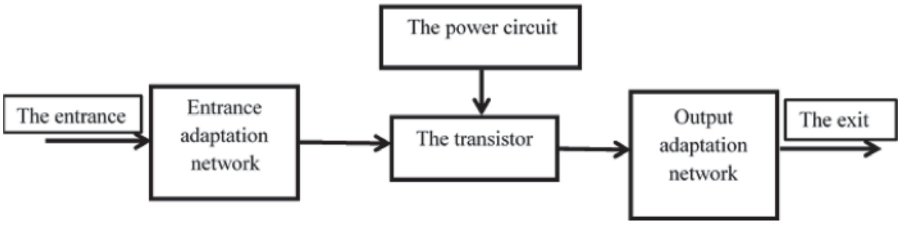

Figure 6.
Microwave amplifier.

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}S_{21}|} \tag{11}$$

and if $|\Delta| < 1$ and if $K > 1$ then the transistor is unconditionally stable [9] Δ: The determinant of the matrix S

$$\Delta = S_{11}S_{22} - S_{21}S_{12} \tag{12}$$

The Stability constant K of the transistor and mod_delta Δ are respectively 1.267 and 0.861 whose transistor is unconditionally stable.

3.2.3 Architecture of a microwave amplifier

The architecture of a Microwave Amplifier is shown as follows (**Figure 6**).

3.2.4 Modeling of the microwave amplifier

For the design of the amplifier, we will first start with impedance matching. The adaptation with Stub has been opted for by this document. The structure of the stub is shown in **Figure 7** below.

Figure 8 below shows the S-parameters of the Stub.

The validation of our Stub is confirmed by an impedance adaptation to 50 ohms at the input and at the output the table below summarizes the result obtained (**Table 2**).

The above table presents the results of synthesis of the S-parameters of the stub at the resonant frequency of the transistor. From these results, it can be seen that:

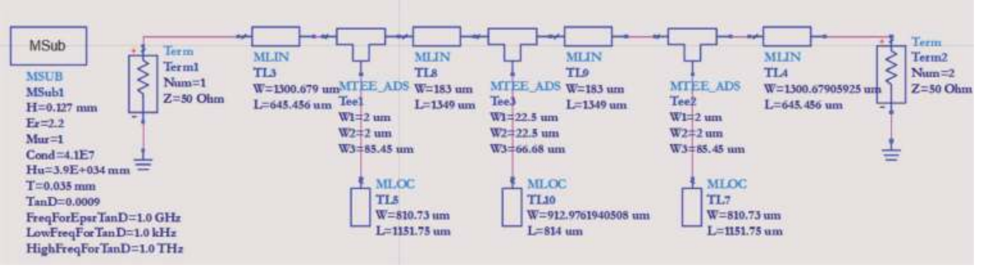

Figure 7.
Stub structure.

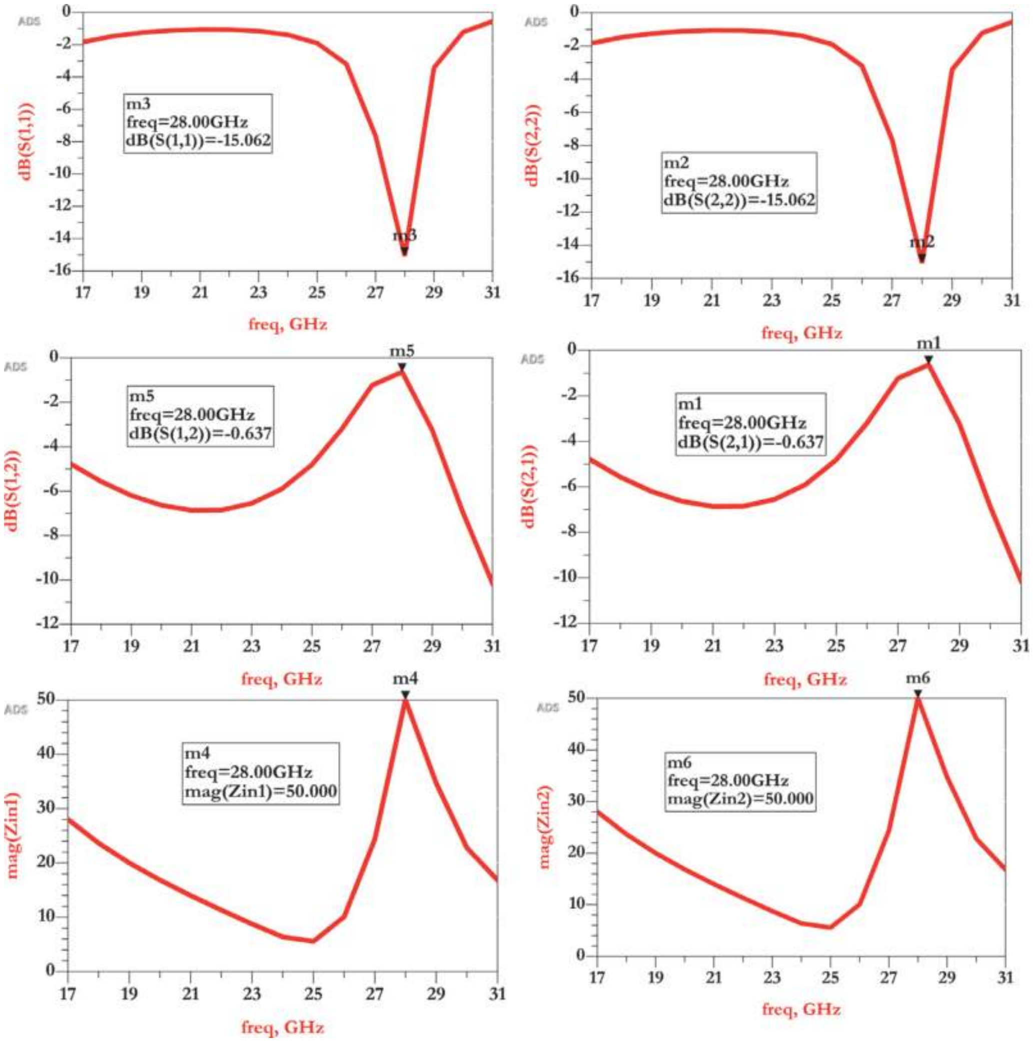

Figure 8.
Stub S-parameters.

Parameters	Value
S_{11} (dB)	−15.062
S_{22} (dB)	−15.062
S_{12} (dB)	−0.637
S_{21} (dB)	−0.637

Table 2.
Summary of the Sparameters of the stub.

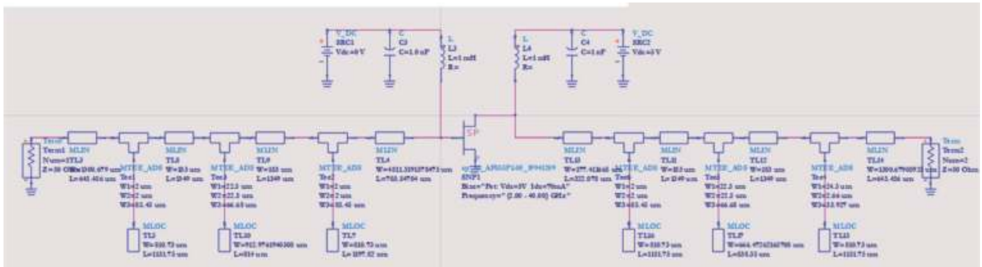

Figure 9.
Microwave amplifier without stage of transistor.

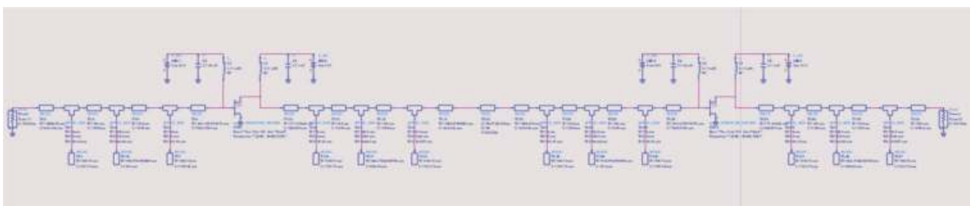

Figure 10.
Microwave amplifier with stage of transistor.

$S_{11} = S_{22}$, $S_{12} = S_{21}$ Hence, the matching of the impedance is good, because the waves leaving the source and passing through the line are not partly reflected when they arrive on the load.

The design of the transistor amplifier is shown in the **Figures 9** and **10** above.

4. Presentation of the results

4.1 Antenna case

The Antenna Parameters shown below are: Reflection Coefficient S_{11}, Voltage Standing Wave Ratio (VSWR), Antenna Gain in (dB), and Antenna Input Impedance in Ohms The S_{11} reflection coefficient is the parameter demonstrating whether the antenna adaptation is good or not, the criterion for defining good adaptation through this parameter is $S_{11} < -10$ dB. The **Figure 11** below illustrate the S_{11} parameter of the antennas.

The Voltage Standing Wave Ratio (VSWR) is the parameter demonstrating if the adaptation of the antenna is good the characteristic value is VSWR ≤ 2 the **Figure 12** illustrates the voltage standing wave ratio obtained by the antennas.

The gain of the antenna characterizes the capacity of the antenna to radiate the maximum power that is ingested at its input. The **Figure 13** illustrate the gain of antennas.

The input impedance of the antenna obviously shows whether we have suitably adapted the antenna or not, it is also clear that this is one of the conditions to be satisfied in order to be able to make our Co-Design Block PA-Antenna the **Figure 14** below illustrates the impedance of our antennas.

In the summary of the **Figures 2** and **3** presented above we have proposed 04 antenna shapes the first shape (**Figure 2**) is the classic rectangular patch template then the other shapes offered are patch templates excluding classic models (**Figure 3**). We can obviously note that the antennas have a good adaptation and an input impedance at 50 ohms but the gain proposed by these antennas are quite low because the strongest gain proposed here is 7.25 dB to improve these gains so we

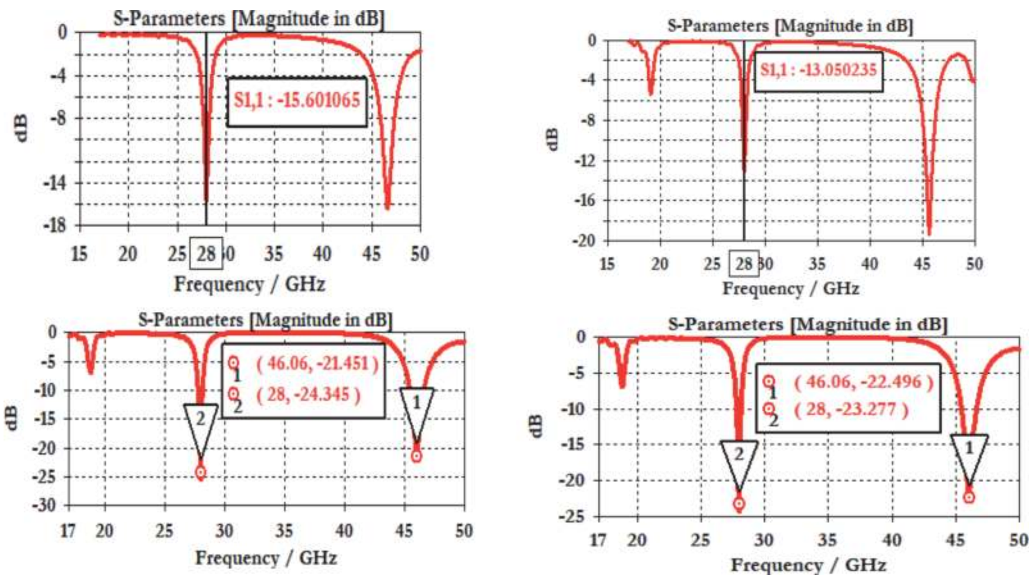

Figure 11.
Antennas parameter S_{11}.

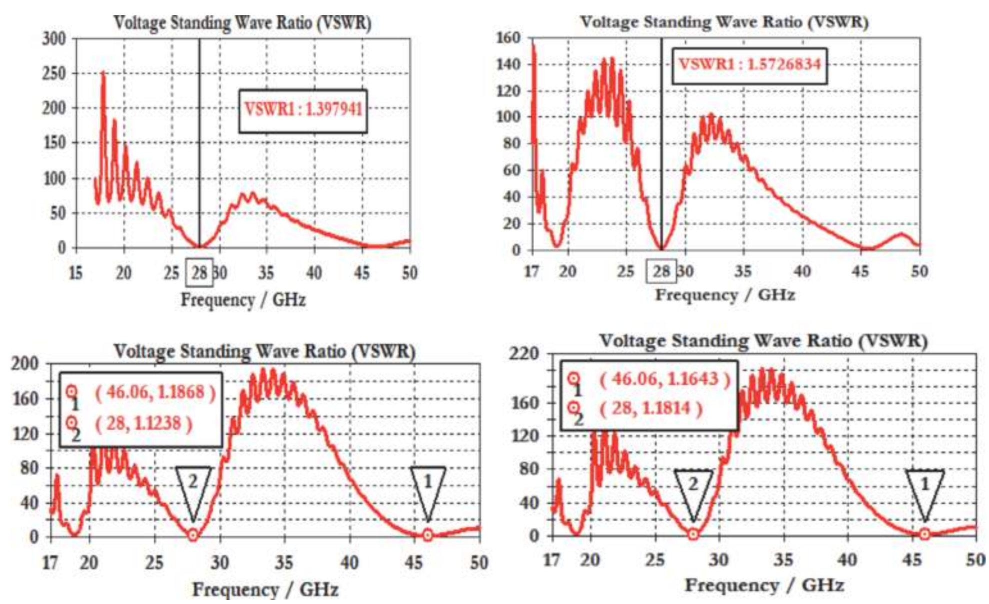

Figure 12.
Stationary wave ratio of antennas.

have model antenna arrays. An antenna array: is the combination of several antenna of the same type in order to form a single antenna the assembly of the different radiating elements must respect a certain distance between radiating element the standard pitch most used in most cases is not worth = 0.5λ for our work we will be interested in linear networks and we will model this one with 4 elements so the distance between will be worth 0.5λ **Figure 15** below presents the modeling of the two antenna arrays the step of value 0.5 λ is 5.36 mm. The **Figure 15** below illustrates the configuration of these antenna networks.

The reflection coefficients observed in each of the antenna networks below are illustrated in the **Figure 16** below.

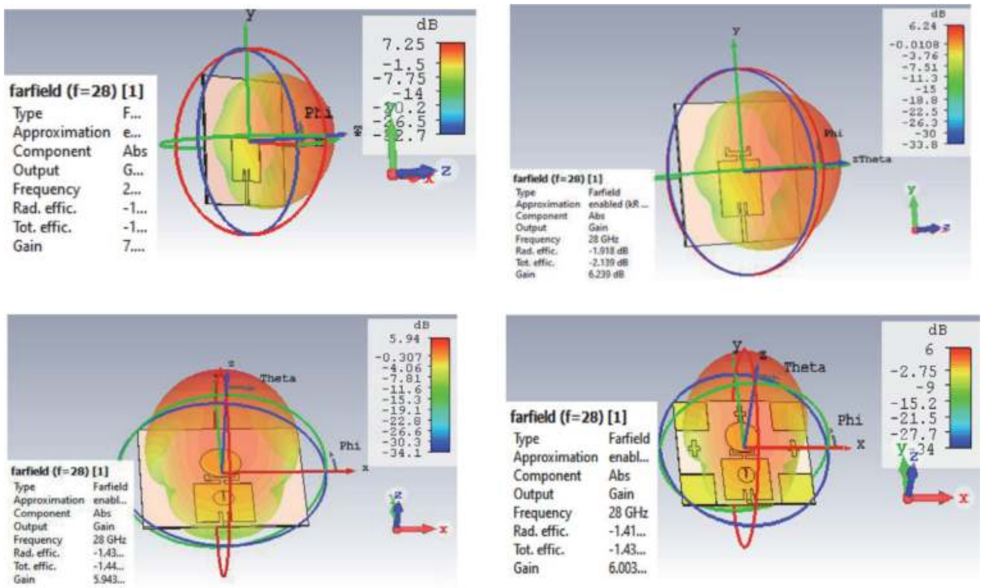

Figure 13.
Antennas gain.

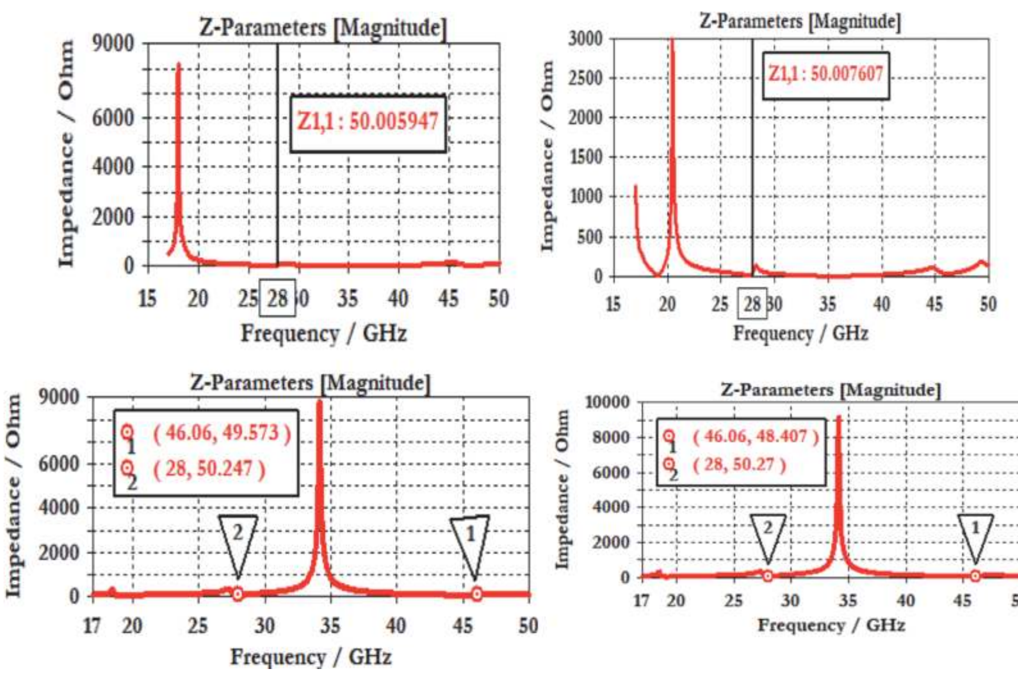

Figure 14.
Antenna input impedance.

Figure 17 shows the gains obtained by these different antennas network.

We are now going to explore the gain of the antenna arrays in the E plane in order to observe the side lobes generated; the **Figure 18** below illustrates it.

To confirm the validity of our results, the representation of the impedances of the antenna networks are illustrated in **Figure 19** below.

It is clear that the impedance presented by our input antenna arrays is 50 ohms at the resonant frequency. We will summarize our work on Antennas in the table below (**Table 3**).

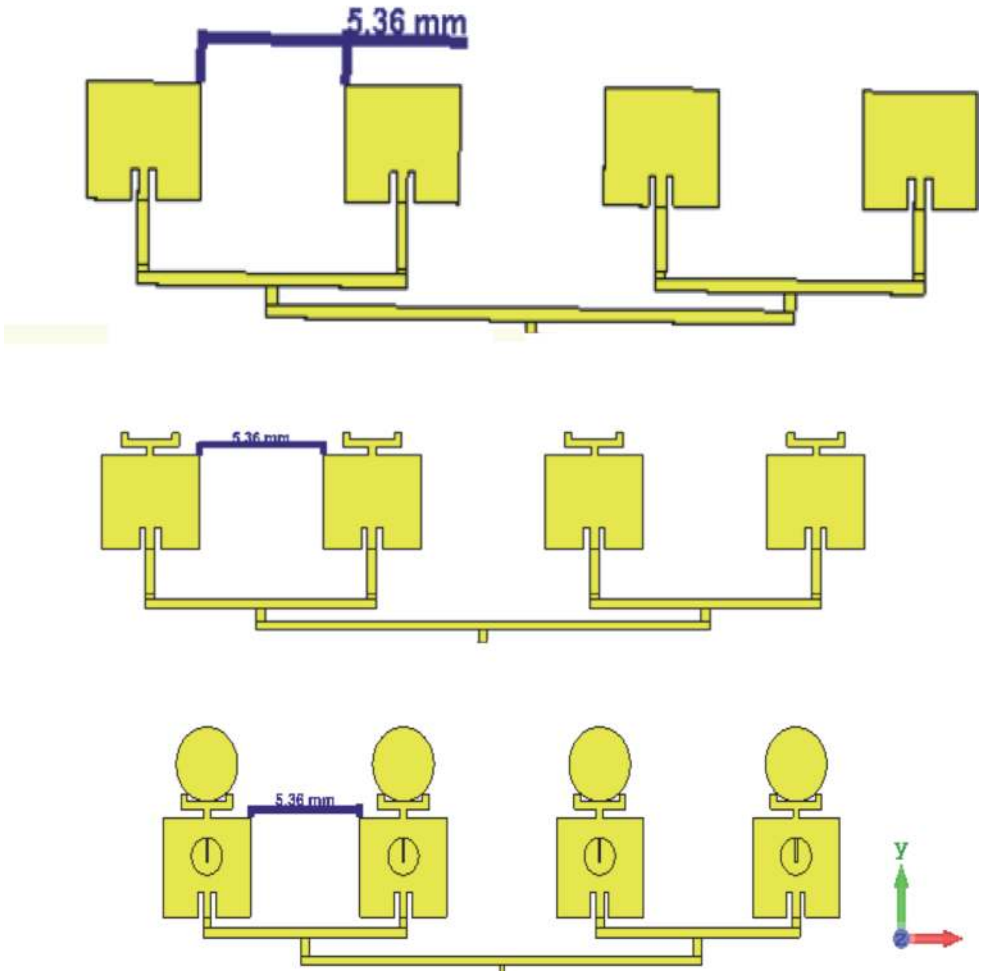

Figure 15.
Linear antenna arrays modeled with different shape.

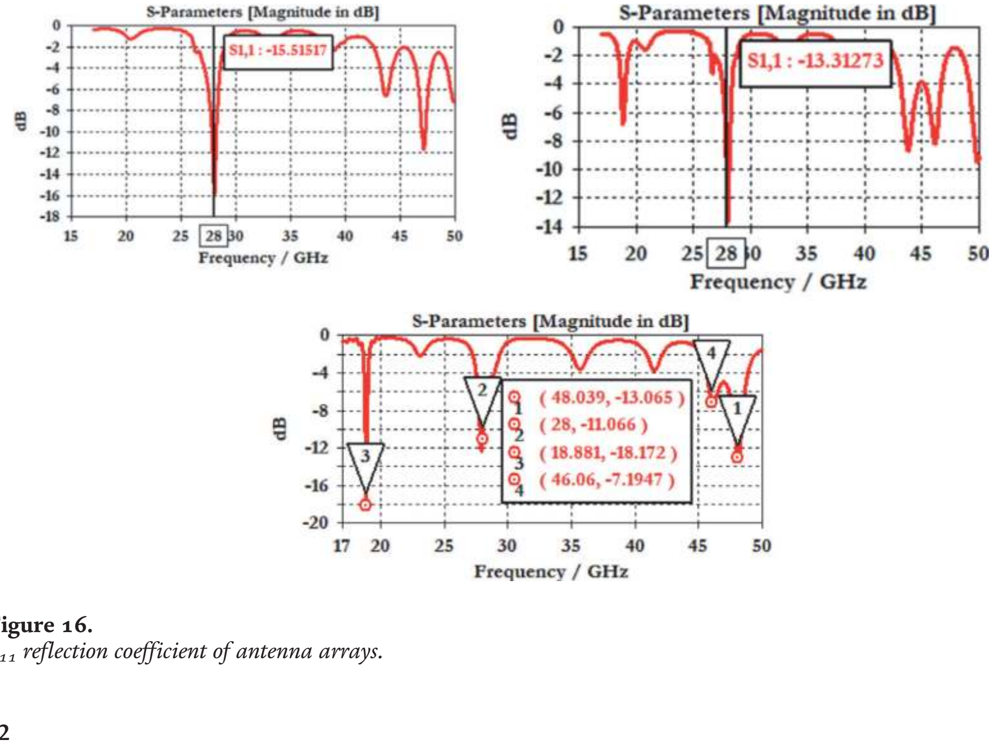

Figure 16.
S_{11} reflection coefficient of antenna arrays.

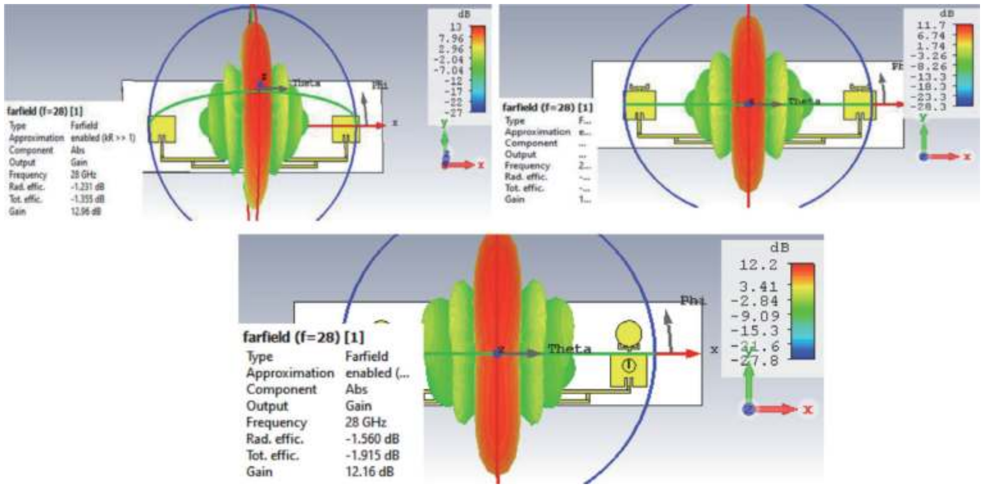

Figure 17.
Gain of different antenna network.

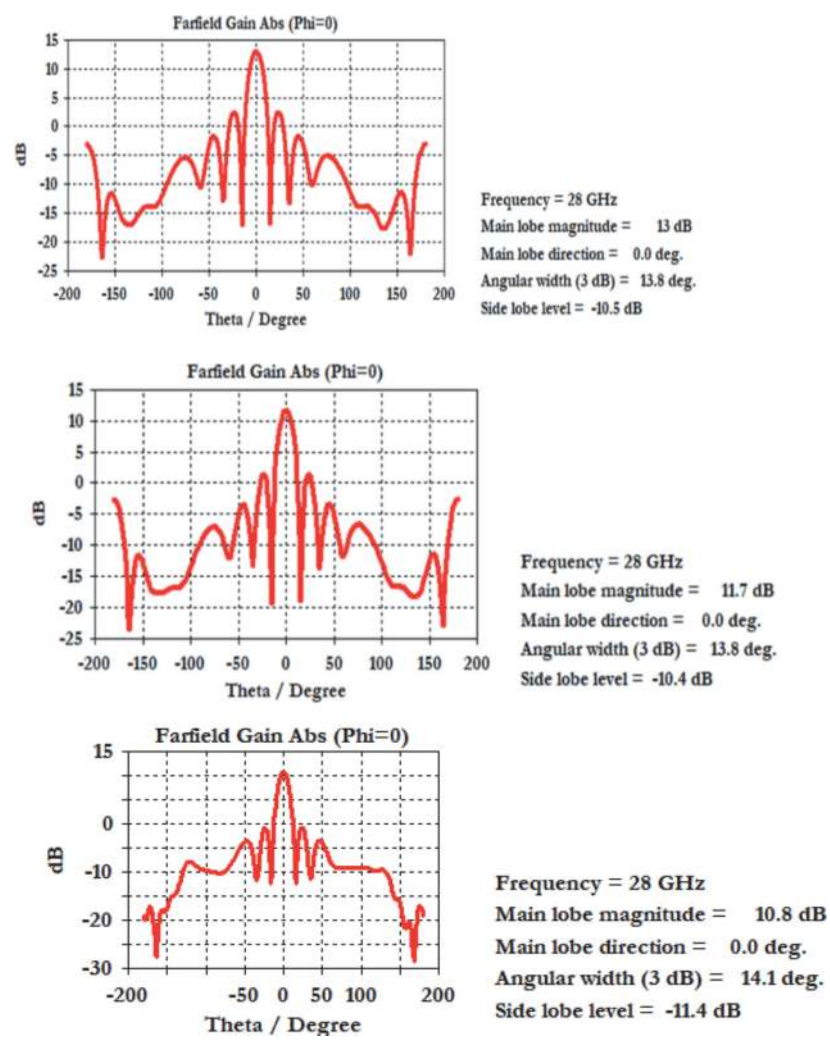

Figure 18.
Representation of gain in plan E of antenna network.

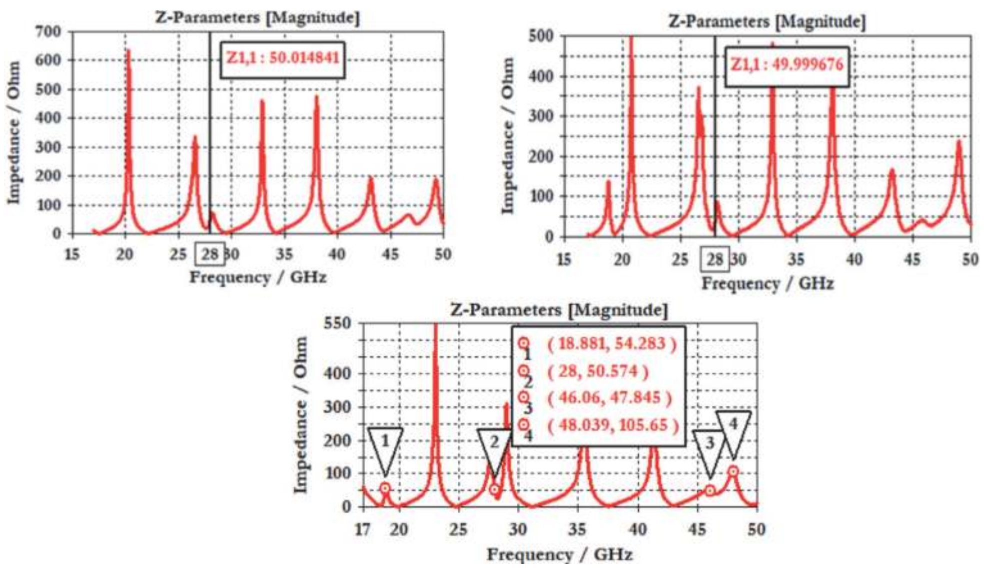

Figure 19.
Input impedance of antenna networks.

Antenna Parameters	Values	
S_{11} (dB)	−15.6	Single antenna with different shape offered
	−13.05	
	−24.345	
	−23.277	
	−15.515	Antenna has 4 elements with different proposed shape
	−13.31	
	−11.066	
Gain (dB)	7.25	Single antenna with different shape offered
	6.24	
	5.94	
	6	
	13	Antenna has 4 elements with different proposed shape
	11.7	
	12.16	
Bandwidth(MHz)	550	Single antenna with different shape offered
	361.3	
	416	
	473.88	
	504.59	Antenna has 4 elements with different proposed shape
	344.91	
	360.66	
Efficiency (%)	76.82	Single antenna with different shape offered
	64.313	
	71.9	
	72.15	

Antenna Parameters	Values	
	75.3	Antenna has 4 elements with different proposed shape
	69.81	
	63.99	
Impédance (ohms)	50 ohms	

Table 3.
Summary of antenna parameters.

4.1.1 Analysis of results and interpretation

The results obtained must be compared with those which have already been the subject of research and accepted in the scientific research community (**Table 4**).

Comparing our works to those listed, it is clear that our obtained gain is greater than the proposed works, the bandwidth obtained is better compared to the works [11, 18]. The reflection coefficients obtained are better compared to works [16, 15] but the bandwidth obtained in these works is better than ours. We can therefore deduce from these works that our antennas comply with and meet the requirements imposed by 5G technology.

4.2 Amplifier case

After modeling the amplifier, it is therefore important to observe the parameters obtained by the amplification after simulation. The S-parameters of the amplifier are summarized in **Figure 20** below.

Ref	S_{11} (dB)	Gain (dB)	VSWR	Bandwidth(GHz)	Efficiency (%)
[10]	−15.35	—	1.79	—	87.8
[11]	−20.35	6.21	1.02	0.4	65.6
[12]	−17.34	6.72	1.28	—	—
[13]	−23.67	6.7	—	1.15	81.2
[14]	−39.37	6.37	1.022	2.48	86.73
[15]	−39.7	5.23	—	4.1	—
[16]	−14.151	6.06	1.488	0.8	—
[17]	−22.2	6.85	1.34	—	—
[18]	−27.7	6.72	1.22	0.463	75.875
This Work	**−15.6**	**7.25**	**1.39**	**0.55**	**76.82**
	−13.05	**6.24**	**1.57**	**0.361**	**64.31**
	−24.345	**5.94**	**1.12**	**0.416**	**71.9**
	−23.277	**6**	**1.16**	**0.473**	**72.15**
	−15.515	**13**	**1.4**	**0.5**	**75.3**
	−13.31	**11.7**	**1.5**	**0.345**	**69.81**
	−11.066	**12.16**	**1.778**	**0.36**	**63.99**

Table 4.
Comparative analysis at the antenna level.

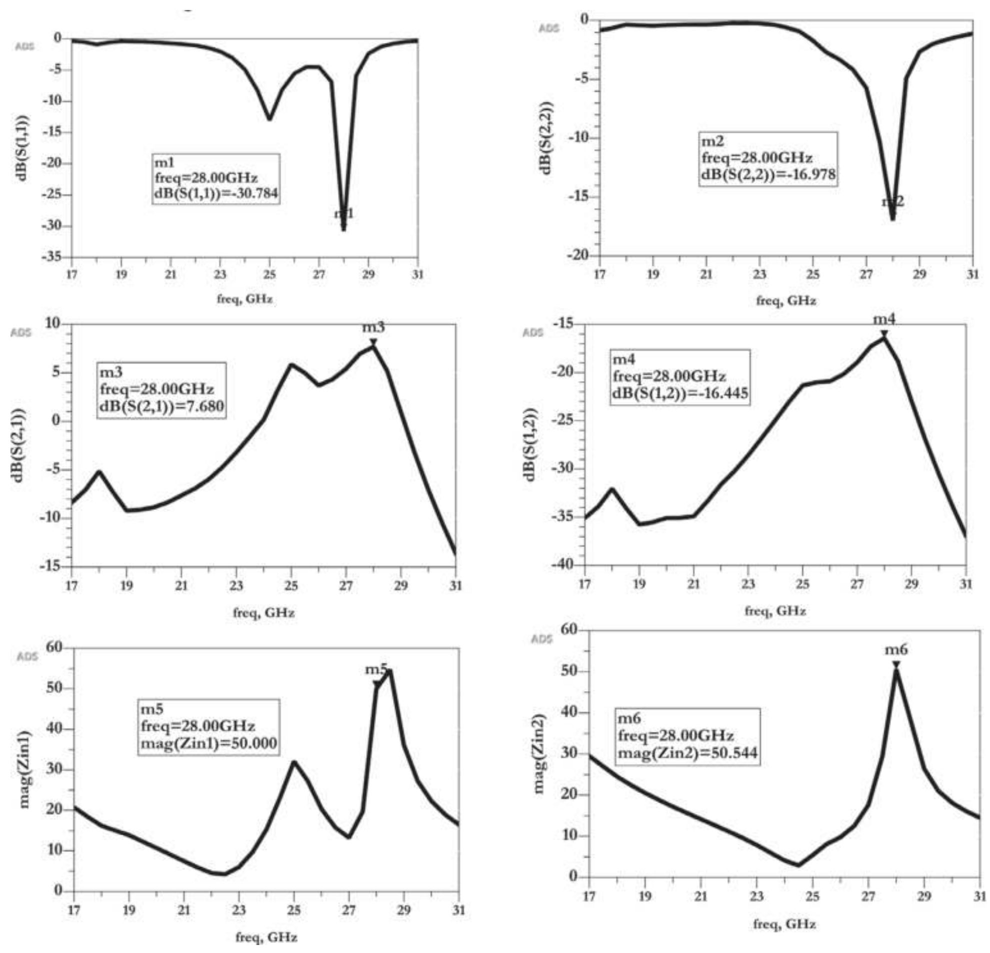

Figure 20.
S-parameters of the amplifier without stage transistor.

The S-Parameters of the amplifier with stage transistor are shown in **Figure 21** below.

As we notice in our figures above the amplifier presents 04 parameters namely S_{11}, S_{22}, S_{12}, S_{21} the parameters S_{11}, S_{22} respectively represent the reflection coefficients at the input and at the output of the amplifier and the parameter S_{12} represents isolation, the parameter S_{21} represents the amplifier transmission gain. The goal of making a transistor stage is therefore to improve the transmission gain of the amplifier. The **Table 5** below illustrates the characteristics of the amplifier.

The following table establishes a comparison between our work and the work carried out by [19] (**Table 6**).

Our results obtained in simulation are much better than that obtained in [19]. Our amplifier has a gain of 15 dB which shows that our amplifier meets the requirements imposed by 5G technology.

5. Co-design block PA-antenna

The Co-Design Block PA-Antenna can be done with the greatest serenity because the impedances of the two equipment's comply with the principles listed above. The figure below therefore illustrates the proposed PA-Antenna Co-Design (**Figure 22**).

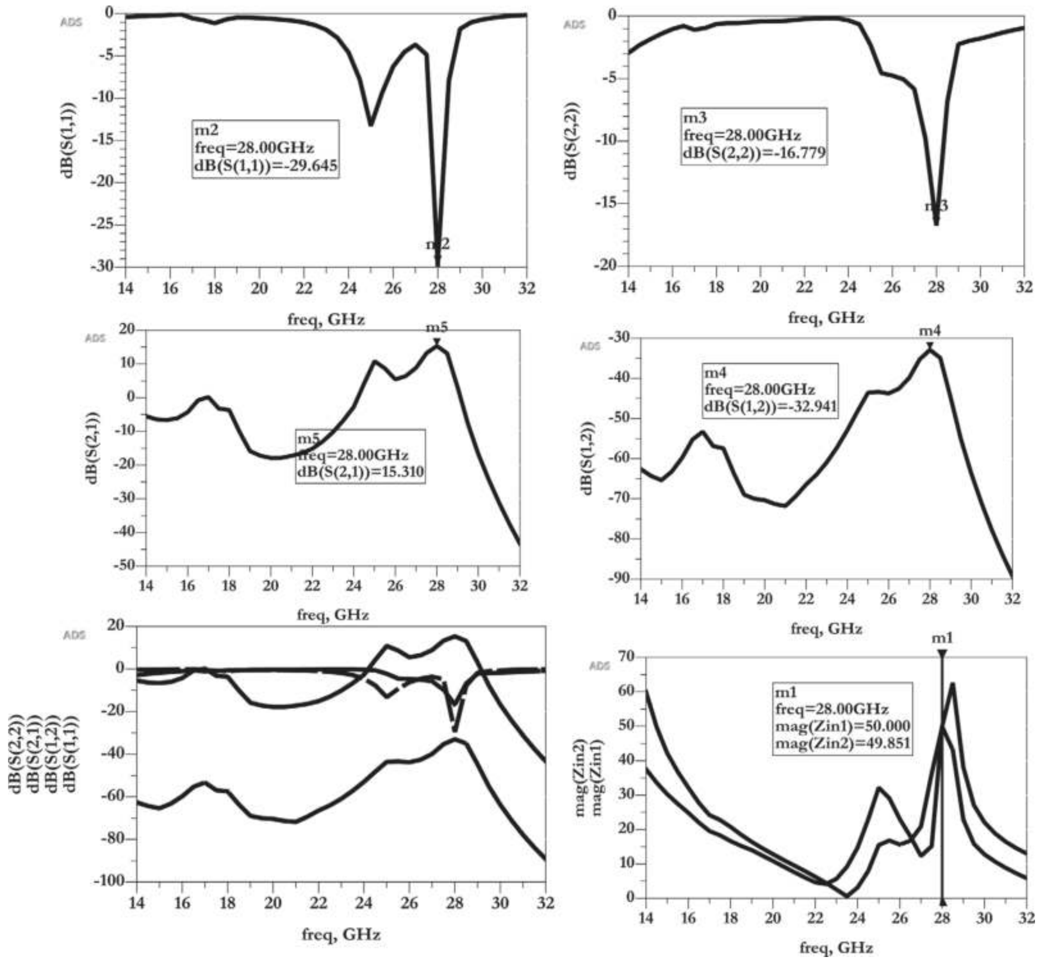

Figure 21.
S-parameters of amplifier with stage transistor.

Amplifier Parameters	Values	
	Amplifier without stages	Amplifier with stage
S_{11} (dB)	−30.784	−29.645
S_{22} (dB)	−16.978	−16.779
S_{12} (dB)	−16.445	−32.941
S_{21} (dB)	7.68	15.31
Impédance d’entrée ou de sortie	50 ohms	
Bandwidth (GHz)	Greater than 2GHz	

Table 5.
Summary of amplifier parameters.

The results obtained after simulation show us the following characteristics illustrated in the **Figure 23** below.

The S_{11} parameter clearly shows us that our Co-Design is functional and well suited to the resonant frequency. In this chapter we enumerate a method of designing a transmitter block namely the antenna and the amplifier it is important to note that the design of the block requires the partial design of each of the transmitters in

Parameters	This Work	[19]
Frequency (GHz)	**28**	28
S_{11} (dB)	**−29.645**	−13.124
S_{22} (dB)	**−16.779**	−15.455
S_{12} (dB)	**−32.941**	—
S_{21} (dB)	**15.31**	10.803
Application	**5G**	5G

Table 6.
Comparative analysis at the amplifier level.

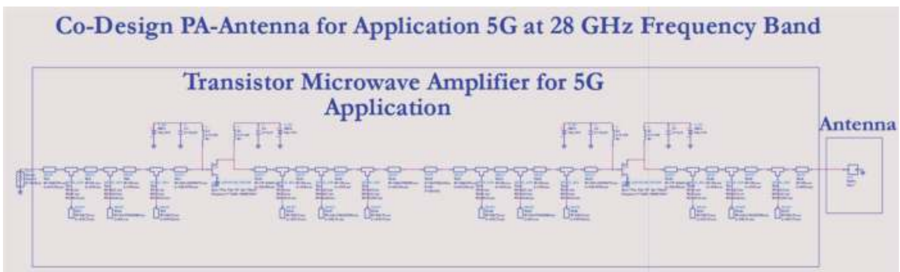

Figure 22.
Co-Design Block PA-Antenna.

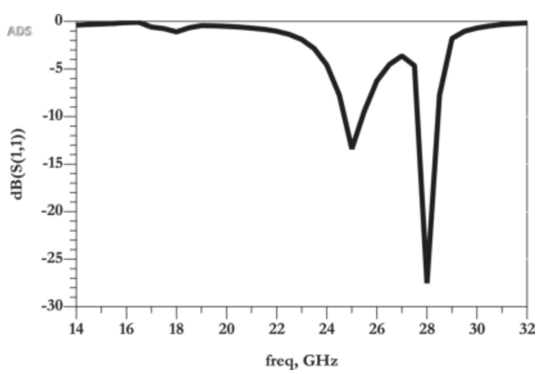

Figure 23.
Co-Design PA-Antenna Parameter S11.

order to consider the design of the block. The design of the block takes into account the impedance adaptation parameters this as well as in this chapter we have arranged such that the amplifier and the antenna present at input as at output an impedance of 50 ohms thus facilitating the junction of the two block the proof **Figure 23** illustrates clearly and clearly that the block is functioning correctly and the impedances of the various equipment are in conformity with the fixed reference impedance.

6. Conclusion

Having reached the end of this chapter, the objective of which is to propose a PA-Antenna Co-Design block for 5G applications, it is clear that the design of such a device requires fairly strict requirements and methodology. Therefore, we looked at the design on the one hand of the antenna and on the other hand of the amplifier by setting 50 ohms as the working impedance guaranteeing the adaptation of the impedance of the device. After design of the two equipment's separately. We therefore proposed and simulated said device. This has characteristics that meet the requirements imposed by 5G technology, which should be noted that the antennas and amplifier proposed in this chapter offer very good characteristics compared to some existing equipment and presented in this chapter. It is also necessary to note the double resonance of our antenna in the 46.06 GHz band and presenting in this one an impedance of 50 ohms and a good bandwidth.

Acknowledgements

All my thanks go to my teachers at the National Polytechnic School of Douala Cameroon for their teachings and advice. My thanks go to the Intech-Open author community who will shed some light on this work to make it even better.

Notes

In this chapter, it is clear that we have only had the possibility of simulating our project with the reference software, namely CST microwave and ADS. In this declaration we ask the community to offer us the possibility of being able to design our project indeed we are engineers in Telecommunications and the means to develop such technologies in our country Cameroon is extremely difficult so it will be a huge pleasure for us to have the chance to be able to realize our project thanks to your help.

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