

A Comparative Study of a Wideband Active Integrated Antenna Design for WLAN Applications

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Abstract– In this paper, we are presenting a design of an active integrated antenna (AIA) that serves in WLAN applications. An AIA typically consists of an active device and a radiated element. In this context, the active device can be either one port semiconductor and/or two port semiconductor. In this work, we have chosen the two port semiconductors (transistors) because these devices give a better performance in the case of power and low noise amplifiers. Hence, we are investigating the quality and the performance of the active integrated antenna with various types of transistors in the purpose to select the most adequate device. The AIA with the best type of transistor will be compared with a passive antenna where the reflection coefficient and the bandwidth are the key parameters of this analysis.

Keywords - Active integrated antenna, WLAN applications, Transistors, Reflection coefficient and Bandwidth.

I. INTRODUCTION

The huge growth and improvement in the use of wireless communications technology increases the call for extremely efficient compact devices such as the active integrated antennas. In this sense, due to the rapid development in the wireless communications and the augmented requirement for high data rate, the wireless local area networks (WLANs) play a vital role for short distance communications and also users can access internet in their portable devices by using 3G/4G through the WLAN. Many standards have been created by the IEEE to define the frequency band of different applications. In the case of WLAN, the IEEE 802.11b, 802.11g and 802.11a are defined. Indeed, the IEEE 802.11b and 802.11g standards utilize the 2.4 ISM band. This band is licensed, so the WLAN equipment will suffer interferences from cordless phones, microwave ovens, Bluetooth devices and other applications that use the same band. Thus, the 802.11a standard uses the 5 GHz band which is cleaner to support high speed WLAN [1].

The active integrated antennas (AIAs) have been a growing area of research in recent years since the innovation in solid state devices and that could be used in WLAN applications. These antennas offer the functions of radiation and power generations. So, when an active device is integrated with a microstrip antenna for the purpose of amplifying an inserted power, it is classified as an amplifier-type active microstrip antenna. This amplifier antenna increase the antenna gain, the absolute output radiated power and improve the receiver sensitivity by decreased Noise Figure (NF) [2], [3].

Besides, the active amplifier antenna can be viewed as a combination between two major components: an active device such as a diode (Gunn, IMPATT, Schottky and Varactor) and/or a transistor (BJT, MESFET, and HEMT) and a radiated element that could be a microstrip patch. The two components will be integrated directly in the same substrate. In fact, patch antennas have been chosen here because they are very attractive and widely used in the area of wireless communications, both for civilian and military purposes. These antennas provide an effective solution to

several fundamental problems such as noise matching, power saving and size reduction. The success of such antennas is mainly due to their low cost, low profile, good conformability on curved surfaces and reduced space occupancy [4], [5].

In addition, the central idea here is to realize a wideband active integrated antenna for WLAN applications. Also, this paper is designed to present a comparative study between an active integrated patch antenna and a passive patch antenna in the purpose to highlight the performance parameters. The proposed investigation is presented to study the performance of AIA with various types of inserted active device that can be a BJT, HBT, MESFET or HEMT where the reflection coefficient, the bandwidth are simulated and calculated.

II. ANTENNAS GEOMETRY

Both antennas have been designed to fit in WLAN applications. The next is a summary of the details of both antennas designs.

2.1. Active integrated antenna

The active integrated antenna, as shown in figure 1, has been designed at the frequency of 5.2 GHz. In the proposed antenna, we have followed the mathematical approach of the transmission line model (TLM) where the important parameters are the resonant frequency (f_c), the dielectric constant (ϵ_r) and the height of the substrate (h).

As a result, the designed antenna (AIA) consists of a passive patch antenna with dimensions W_p and L_p , a transistor and a feed port that are connected using three identical microstrip transmission lines (W_c and L_c). Indeed, the first terminal of the transistor is related to the feed line, the second terminal is linked to the ground plane and the third terminal is connected to the radiating element through a microstrip line.

In the design of this antenna, since a suitable and similar substrate must be chosen in order to provide a general platform for the shapes to be simulated, the chosen substrate is FR-4 which has a dielectric constant (ϵ_r) of 4.32, a dielectric loss tangent ($\tan\delta$) of 0.018 and the substrate height (h) is 1.6 mm. The antenna was designed and simulated using Advanced Design System (ADS) tools software. Figure 1 shows the geometry of the designed AIA with the dimensions: $L_c = 20.10$ mm, $W_c = 3.33$ mm, $L_p = 13.31$ mm and $W_p = 17.67$ mm.

Besides, in the recommended AIA, the transistor can be relied to the design by its characteristics scattering parameters (S-parameters) taken from the datasheet of

fabrication with different biased voltages. So, the design and analysis approach presented here is entirely S-parameters depend. In the following section, we will describe the chosen transistors, their scattering parameters that provide the necessary values to perform the analysis as stability and maximum gain at the frequency of 5.2 GHz.

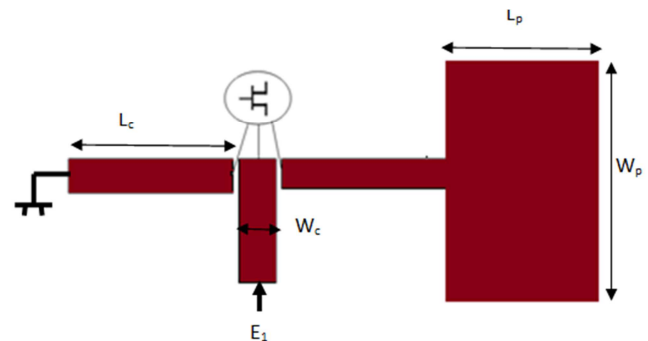


Figure 1. The designed active patch antenna with an active device.

2.2. Passive patch antenna

This antenna is build using a standard FR-4 substrate (dielectric constant $\epsilon_r=4.32$) with a thickness of 1.6 mm. The patch antenna consists of a rectangular radiator connected to a transmission line with the main length of $3 L_c + L'$ as shown in figure 2. In fact, this design has been extracted from the active integrated antenna presented earlier to compare them in terms of reflection coefficient and bandwidth improvement using the same substrate dimensions. The dimensions of the passive antenna are the same aforementioned parameters L_c , W_c , L_p and W_p with the addition of the length $L' = 6.6$ mm and the width $W' = 0.218$ mm. The main goal of the passive antenna is to resonate with a reflection coefficient below -10 dB.

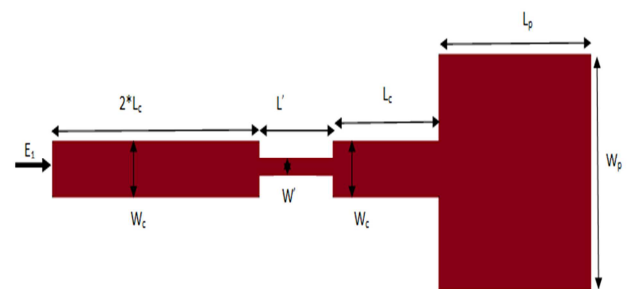


Figure 2. The design of the passive patch antenna.

III. CHOICE OF ACTIVE DEVICES: TRANSISTORS

Since the invention of transistors, the study of the AIA has received much more attention and become emerged technologies that can be used in military and commercial

purposes. In this context, the integration of the transistors has been investigated. Indeed, the transistor is defined as two port semiconductor device that can be categorized as either a junction transistor or a field effect transistor.

On the first hand, the junction transistors can be a bipolar junction transistor (BJT) or a heterojunction bipolar junction (HBT) that uses single or compound semiconductors. These devices operate in the frequency range of 2-10 GHz and known as current controlled devices. On the other hand, the field effect transistors (FETs) are a voltage controlled devices and that can be used till the frequency of 60 GHz and more. These FETs can take many forms such as the metal semiconductor FET (MESFET), the high electron mobility transistor (HEMT) and more [6]. In this sense, the use of transistors here has been related to its frequency range at fixed biased voltages that could be inserted in the design of the antenna and characterized by their characteristic S-parameters taken from their datasheets of fabrication. In this paper, we present four types of transistors:

- BJT (HXTR4101, S-Parameters: $V_C=15$ V, $I_C=30$ mA, $t_a=25$ deg).
- GaAs HBT (NE52418, $V_{CE}=2.0$ V, $I_C=3$ mA).
- GaAs MESFET (NEC- NE72218, $V_{DS}=3$ V, $I_D=30$ mA).
- Pseudomorphic HEMT (ATF-36077, $V_{DS}=1.5$ V, $I_D=10$ mA).

The transistor' performance analysis is based on the calculations of their stability factor and their maximum gain using their scattering parameters. In fact, the stability factor of an amplifier (K-factor), or its resistance to oscillate, is a very important parameter to be considered in the design. Using the stability factor, we can determine wherever the amplifier is unconditionally stable or unstable. The K-factor is expressed as below in equation (1). If this parameter is superior to 1 than the amplifier is stable, else if $K < 1$ than the device is unstable [7].

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

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

Another important parameter for the amplifier is the maximum unilateral transducer gain which is given by equation (2) in dB.

$$G_{max} = 10 \log \frac{|S_{21}|^2}{(1 - |S_{11}|^2)(1 - |S_{22}|^2)} \quad (2)$$

IV.RESULTS AND DISCUSSION

The simulations were carried out in ADS tools, which is commercial electromagnetic software. This software uses the

finite element method (FEM) and the method of moments (MoM) for simulations. Both antennas, passive and active, have been designed and simulated. The adopted frequency range of simulation is [3-6] GHz.

4.1.Study of the stability factor and the maximum gain of the transistors

Figure 3 presents the configuration to study the stability and the maximum gain of transistors. This structure consists of a Data term (S-param SNP1) which contains the scattering parameters of the transistor that has been taken from its datasheet. The scattering parameters used here have a start frequency at 2 GHz, a stop frequency at 18 GHz and step of 1 MHz. The circuitry is terminated with Term 1 and Term 2 of 50 Ohm. In the purpose to study the stability factor (K-factor) and the maximum gain of the transistors versus frequency, we are using the terms of the bloc S-parameters simulations where Stab fact1 (= stab-fact(S)) is taken to investigate the stability factor (K-factor) and Max-gain1 (= max-gain(S)) is used to analyze the maximum gain of the transistor.

Table 1 presents the stability factor and the maximum gain of various types of transistors that could be inserted in the design of AIA. As a consequence, based on the obtained results, it can be observed that the BJT and HEMT devices have a stability factor (K-factor) inferior to 1 which provides that these devices are unstable at 5.2 GHz.

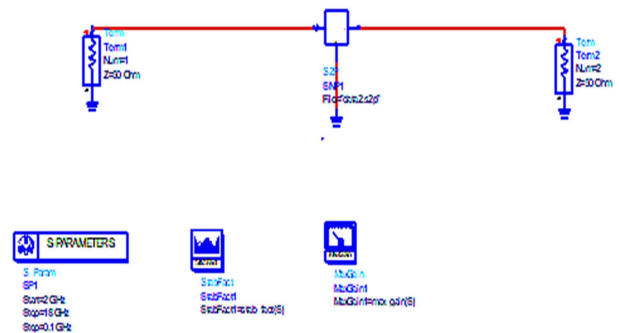


Figure 3. Simulated Circuitry to validate the stability and maximum gain of transistor.

Table 1. The stability factor and Maximum gain for various types of transistors at 5.2 GHz.

	K-factor	Max-gain
BJT	-0.342	-8.883
HBT	1.217	12.513
MESFET	1.082	11.998
HEMT	0.415	12.277

In contrast, for the MESFET and HBT devices, the K-factor is equal to 1.082 and 1.217, respectively. So, the MESFET and HBT represent the stable devices to be used in our design. In addition, by studying the calculated maximum gain, it can be concluded that the worst type of transistor is the bipolar junction transistor (BJT) because this transistor has a negative maximum gain. So, the best choice is the MESFET device.

4.2.Comparative study of the active integrated antennas' results

•Reflection coefficient

Figure 4 illustrates the reflection coefficient S11 on (dB) as a function of frequency of the AIA with different types of transistors. In this context, S11 parameter is the most commonly regarded parameter in the case of an antenna, which represents how much power is reflected from the antenna. If S11=0 dB, then all inserted power is reflected from the antenna and nothing is radiated. If S11=-10 dB, this indicates that if 3 dB is delivered to the antenna, then -7 dB is the reflected power which implies that this power is accepted by the antenna.

Thus, to analyze the obtained results of the reflection coefficient, we divide the axe of S11 (dB) in two ranges: the first is above -10 dB and the other is below -10 dB. The results of figure 4 indicate that AIA with HBT device is the only antenna that has a reflection coefficient above -10 dB. Therefore, it can be predicted that the HBT device should not be used in the design of the active integrated antenna for WLAN applications at 5.2 GHz.

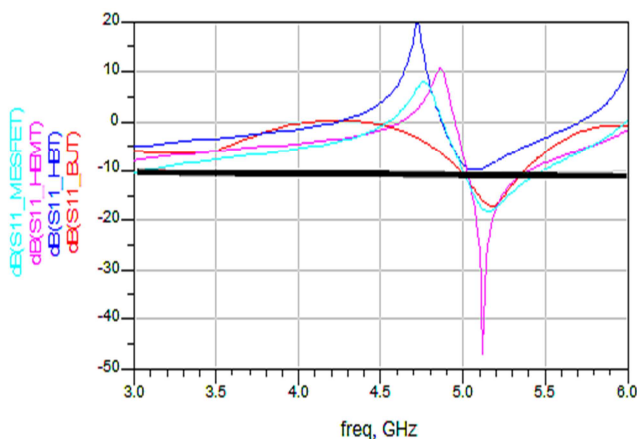


Figure 4. The reflection coefficient on (dB) of the active integrated antenna with various devices: BJT, HBT, HEMT and MESFET.

So, according to the simulated results, we are able to determine the reflection coefficient of the active integrated antenna with a specification of the exact value of reflection. It can be observed that S11 parameter of the AIA has the value of -16.998 dB, -9.880 dB, -18.322 dB and -47.159 dB where the active devices are BJT, HBT, MESFET and HEMT, respectively. Indeed, we can conclude that AIA with HEMT device has the best value of the reflection coefficient while AIA with HBT device has the worst value.

•Bandwidth

Another important parameter of an antenna is the bandwidth and its covers. There are many ways to calculate the bandwidth such as VSWR=2:1, S11< -10 dB and the maximum real impedance divided by the square root of two $[Z(\text{Re})/\sqrt{2}]$. Thus, we have chosen the way of S11< -10 dB. The equation (3) expresses the bandwidth as a function of the stop frequency (f_p), the start frequency (f_s) and the resonant frequency (f_c).

$$BW = \frac{f_p - f_s}{f_c} \quad (3)$$

Based on the reflection coefficient depicted in figure 4, we are able to calculate the bandwidth of the active integrated antenna with various types of transistors. Indeed, AIA with BJT device has a start frequency at 4.990 GHz and a stop frequency at 5.370 GHz which gives a bandwidth equal to 7.307%.

In addition, the bandwidth of the active integrated antenna with MESFET device has a start frequency at 5.010 GHz, a stop frequency at 5.480 GHz which gives the value of 9.03% while AIA with HEMT device has a start frequency at 5.030 GHz, a stop frequency at 5.380 GHz that provide a bandwidth equal to 6.73%. It can be concluded that AIA with MESFET device has the best bandwidth. Also, it should be noted that the bandwidth of the AIA with HBT device will not be taken into consideration because this antenna has a reflection coefficient value above -10 dB.

•Parametric study on length L_c of active antenna

In order to ensure the best choice of transmission line length (L_c) that connects the active device to the radiated element, a parametric study has been performed. The chosen lengths are L_1 , L_2 , L_3 and L_4 . The length $L_1=20.10$ mm is in the interval $[\lambda/4-\lambda/2]$ where λ has the value of 57.68 mm. The length L_2 is equal to $\lambda/2=28.84$ mm, L_3 is $\lambda/4=14.42$ mm and L_4 has the value of $\lambda/10=5.76$ mm. By observing the simulated reflection coefficient depicted in figure 5, it has been proved that we have made the best choice of $L_c (=L_1)$

which has a resonant frequency at 5.15 GHz the closest to the resonant frequency of WLAN applications (5.2 GHz).

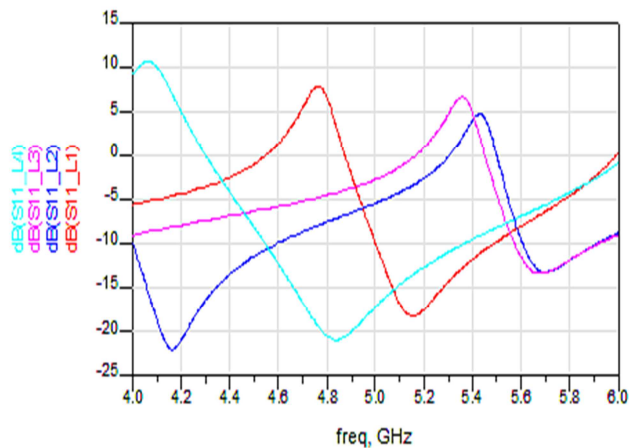
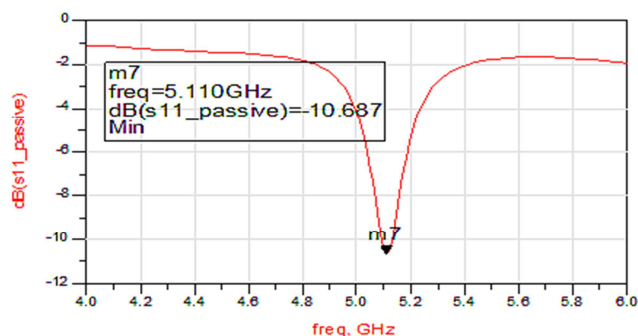


Figure 5. Simulated S_{11} of active integrated antenna with different length of transmission line.

4.3. Comparison between the active and passive patch antennas

• Reflection coefficient

By simulating the structures of figure 1 and figure 2, the reflection coefficient of the passive patch antenna has the value of -10.68 dB as seen in figure 6(a) while the value of reflection coefficient of the active patch antenna is -18.32 dB as illustrated in figure 6(b). Indeed, the passive patch antenna has a resonating frequency of 5.11 GHz while the active antenna resonates at the frequency of 5.15 GHz. Hence, it can be observed that AIA with MESFET device shows an improved result compared to the rectangular patch in term of the reflection coefficient.



(a)

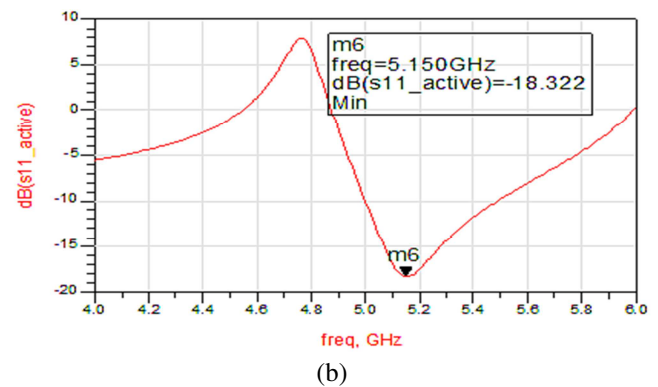


Figure 6. (a) Simulated S_{11} parameter of passive patch, (b) Simulated S_{11} parameter of active patch.

Furthermore, in the purpose to obtain the same reflection coefficient delivered by the active antenna, a parametric study has been performed by tuning the dimensions (W , L) of a rectangular passive antenna depicted in figure 7. Figure 8(a) illustrates the variation of the reflection coefficient versus the width W at a fixed frequency 5.2 GHz. It can be observed that S_{11} parameter has a minimum variation above the -10 dB which therefore will be neglected compared to varying the antenna length L .

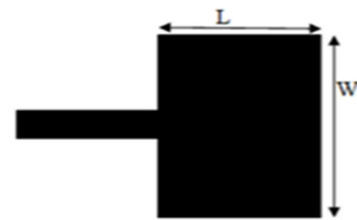


Figure 7. The proposed structure of passive antenna used in study of S_{11} .

Based on the results depicted in figure 6(b), the AIA's reflection coefficient is equal to -18.322 dB. In order to tend to the same value using a passive patch, a geometrical modification is the adequate solution specially by tuning the length L .

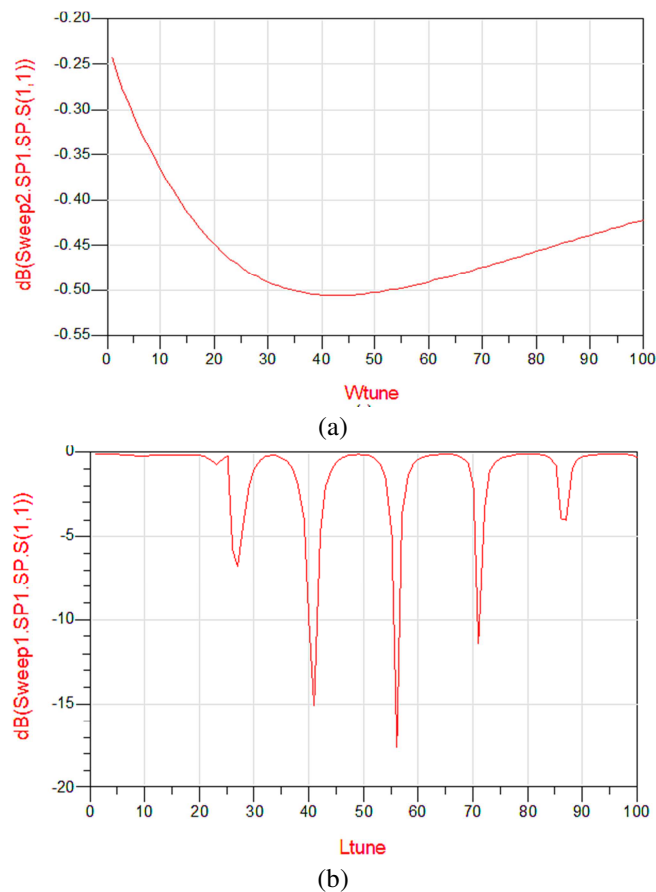


Figure 8. The variation of the reflection coefficient of the passive antenna: (a) versus the width, (b) versus the length.

As a result, the best value of a passive reflection coefficient ($S_{11} = -17.654$ dB) is obtained for the length L equal to 56 mm as demonstrated in figure 8(b). The reflection coefficient as a function of frequency as illustrated in figure 9 shows that at frequency of 5.2 GHz, we have obtained nearly the same reflection coefficient of the active integrated antenna.

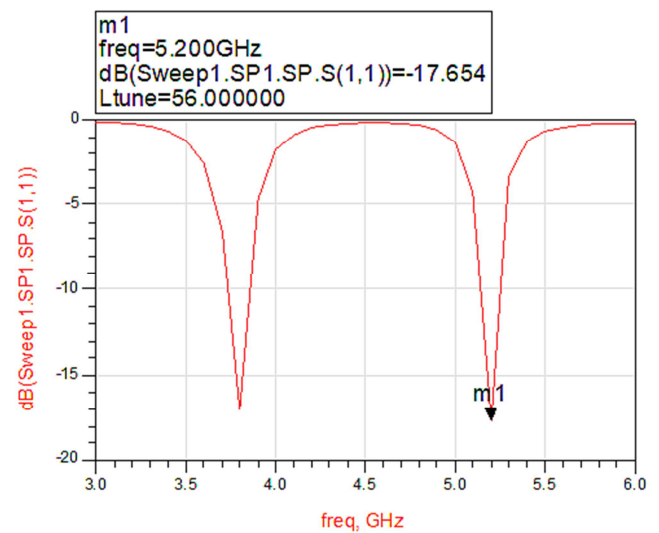


Figure 9. The reflection coefficient of the passive antenna at the length $L = 56$ mm.

The miniaturization is the main advantages of using AIAs compared to passive antennas, well the same desired performance is achieved by both antennas but the passive patch is very big to be integrated in nowadays devices. Indeed, table 2 shows the dimensions of both antenna categories.

Table 2: The dimensions of the passive and active antennas

	Passive antenna	Active antenna
W_p (mm)	17.08	17.08
L_p (mm)	56	12.76
S_{11} (dB)	-17.654	-18.322

•Bandwidth

Besides, the passive patch antenna of figure 2 has a start frequency at 5.09 GHz and a stop frequency at 5.13 GHz as shown in figure 10 (a) while the active patch antenna has a start frequency of 5.01 GHz and a stop frequency at 5.48 GHz.

By calculating the bandwidth, the passive and active antennas have the value of 0.77% and 9.04%, respectively. As it can be seen, to improve the performance of an antenna that is designed for WLAN applications in the term of the high reflection coefficient and wide bandwidth, the active integrated antenna with MESFET device is the most adequate solution which offers the desired performance.

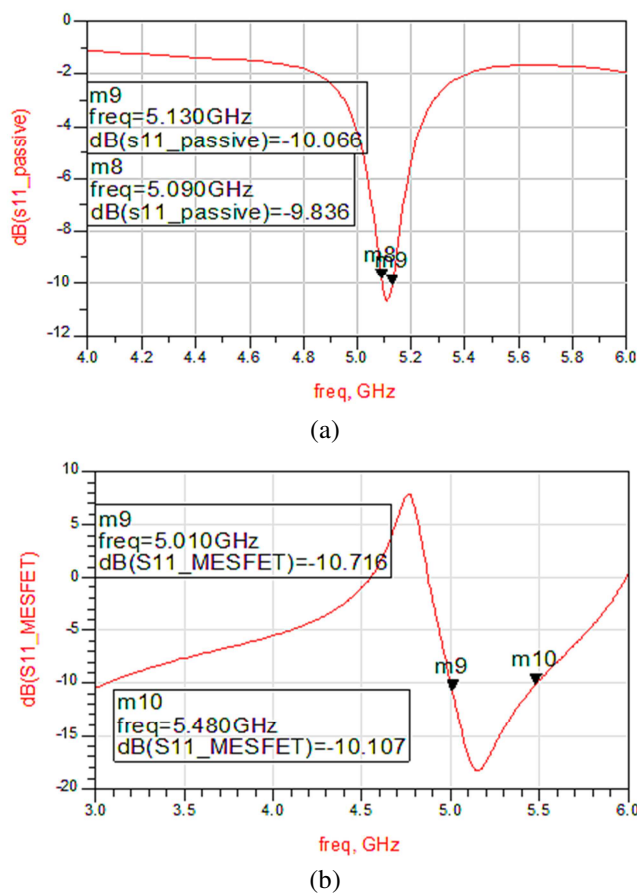


Figure 10. (a) The bandwidth of passive antenna, (b) The bandwidth of active integrated antenna with MESFET device.

V. CONCLUSION

In this paper, the simulation of the active integrated antenna with various inserted types of active devices was successfully designed and analyzed using ADS simulator. In addition, two patch antennas (passive and active) were

designed to operate for WLAN applications. The main concern was to study the comparison of the reflection coefficient and the bandwidth of both antennas. By observing the obtained results, it is very clear that the best device that should be used at high frequencies with AIA is the MESFET device. Also, it was observed that the design of the active integrated antenna with MESFET device gives an enhanced bandwidth more than 9% and a good reflection coefficient compared to the passive antenna.

REFERENCES

- [1] Adel Y.I. Ashyap, Waddah A. M. A, Abdirahman M. S, M. Z. M. Jenu, Z. Z. Abidin and S. H. Dahlan, *A comparison between rectangular and c-shape patch antenna for bandwidth improvement at 5.2 GHz for WLAN applications*, ARPN J. Eng. Appl. Sci. 11: 3923–3928, 2016.
- [2] K. Swamy and M. Veluri, *Active Integrated Antenna (AIA) system for wireless communication*, Int. J. Sci. Res. Publ. 3:1–5, 2013.
- [3] N. K. Singh, V. K. Singh, A. Singh, and B. Marsh, *Wide Band Open Spanner Patch Antenna for Wireless Local Area Network Application*, JoMET 1: 21–25, 2014.
- [4] Y. Qian, T. Itoh, and L. Fellow, *Progress in Active Integrated Antennas and Their Applications*, IEEE Trans. Microw. Theory Tech. 46: 1891–1900, 1998.
- [5] K. Chang, R. A. York, S. Member, P. S. Hall, and T. Itoh, *Active Integrated Antennas*, IEEE Trans. Microw. Theory Tech. 50: 937–944, 2002.
- [6] D. U. of M. at A. M. POZAR, *Microwave Engineering*, John Wiley and Sons, Inc., New York, pp.1-756, 2011.
- [7] P. Sharma and R. Prakashdwivedi, *Novel technique developed to design and simulate RF amplifier using GaAs MESFET in ADS tool*, Proc.- 5th Int. Conf. Comput. Intell. Commun. Network, Mathura, India, pp. 436–441, 2013.