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RESEARCH PAPER

Ultra-low noise active microstrip antenna

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An active receiving antenna for Radio Navigation and Radio Positioning applications in S-band frequency is designed and fabricated. In this active antenna, the amplifier is integrated with the radiator which is a rectangular patch antenna. This patch antenna is analyzed with full-wave momentum method. With the developed design routine, ultra-low noise active receiving antenna can be realized. The ADS software and its full-wave Momentum is used for simulation. The experimental results show good agreement with the simulation results.

Keywords: Microstrip antenna, Active antenna, S-band, ADS software

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I. INTRODUCTION

In recent years, active antennas have become an area of growing interest because they can reduce size, weight, and cost of the transmitter and receiver systems [1]. In an active antenna structure, a passive antenna is placed beside of the amplifier. If the antenna is to be used as a load to the amplifier, the antenna is a transmitter; and similarly, if it is used as an input to the amplifier, it will act as a receiver, respectively. The main considerations in the design of an active antenna include high gain and smooth frequency response in all its bandwidth, linear operation, small size, and low noise figure. Unfortunately, only a few papers have been published dealing with the active receiving microstrip antenna [2–4]. In our research, we design and fabricate an active receiving microstrip antenna, for Radio Navigation and Radio Positioning applications, in which the antenna is a rectangular patch. This structure offers a number of parameters for the optimization, and by properly choosing all of these parameters, low noise receiving antenna can be designed, operating with a minimum of matching circuits between passive antenna and transistor, and therefore reducing losses and overall noise figure.

II. THE PASSIVE ANTENNA DESIGN

Among different planar antennas such as dipoles, microstrip patches, bowties, or slot antennas, which can be used as a radiator in an active antenna, we choose microstrip patch because of its low profile, easy fabrication, and analysis and its compatibility with solid-state devices. The rectangular microstrip patch antenna, which is used as the input of the amplifier, is designed at a fundamental resonant frequency of 3 GHz, using the relations extracted from [5–8]. Also we select a center microstrip feed arrangement [9]. In order to obtain a well-matched broadband passive antenna, a matching network is designed at the input port of the patch antenna. Then the whole passive antenna is simulated and analyzed by momentum. The obtained input impedance will be considered as an input for the amplifier. The overall schematic of the designed patch antenna is shown in Fig. 1.

The used substrate is RO-4003 with relative permittivity of 3.38 and thickness of 20 mil. Basic parameters of this antenna include the length of patch (L_p), the width of patch (W_p), the notch width (g), the inset distance from the radiating edge (d), and width of feed line (w). Using classical formulas (1)–(10), we can calculate these parameters as shown in Table 1

The width of the antennas can be determined by

$$W_P = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}. \quad (1)$$

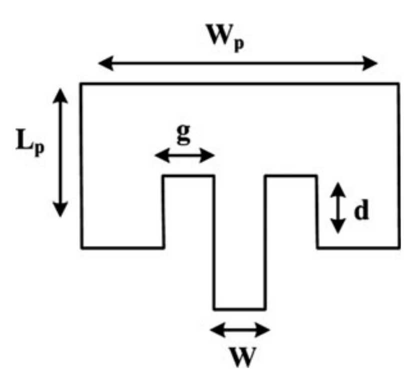

Fig. 1. Geometry of the employed microstrip patch.

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Table 1. The physical dimensions of microstrip patch antenna.

Parameters	Dimensions (mm)
Length of the patch (L_P)	26.95
Width of the patch (W_P)	33.1
Position of inset-fed point (d)	7.15
Width of the microstrip feed line (W)	1
Notch width (g)	1.5

The effective dielectric can be obtained by

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W_p}\right]^{-1/2}, \quad \text{for} \quad W_p/h > 1. \tag{2}$$

Normalized extension of the length, ΔL, is given by

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff} + 0.3)\left(\dfrac{W_p}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\dfrac{W_p}{h} + 0.8\right)}. \tag{3}$$

The actual length of the patch, L_p, can be expressed by

$$L_P = \frac{v_0}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L. \tag{4}$$

The notch width, g, can be obtained by using

$$f_r = \frac{v_0}{\sqrt{2\times\varepsilon_{reff}}}\frac{4.6\times 10^{-14}}{g} + \frac{f}{1.01}, \tag{5}$$

$$g = \frac{v_0}{\sqrt{2\times\varepsilon_{reff}}}\frac{4.65\times 10^{-12}}{f}. \tag{6}$$

We can calculate the value of Z_o as

$$Z_o = R_{in}\cos\left(\frac{\pi}{L_P}d\right), \tag{7}$$

where d is the inset distance from the radiating edge, and R_{in} is the resonant input resistance when the patch is fed at a radiating edge. J_o, is the Bessel function of the first kind of order zero. We can calculate R_{in} as

$$R_{in} = \frac{1}{2(G_1 + G_2)}, \tag{8}$$

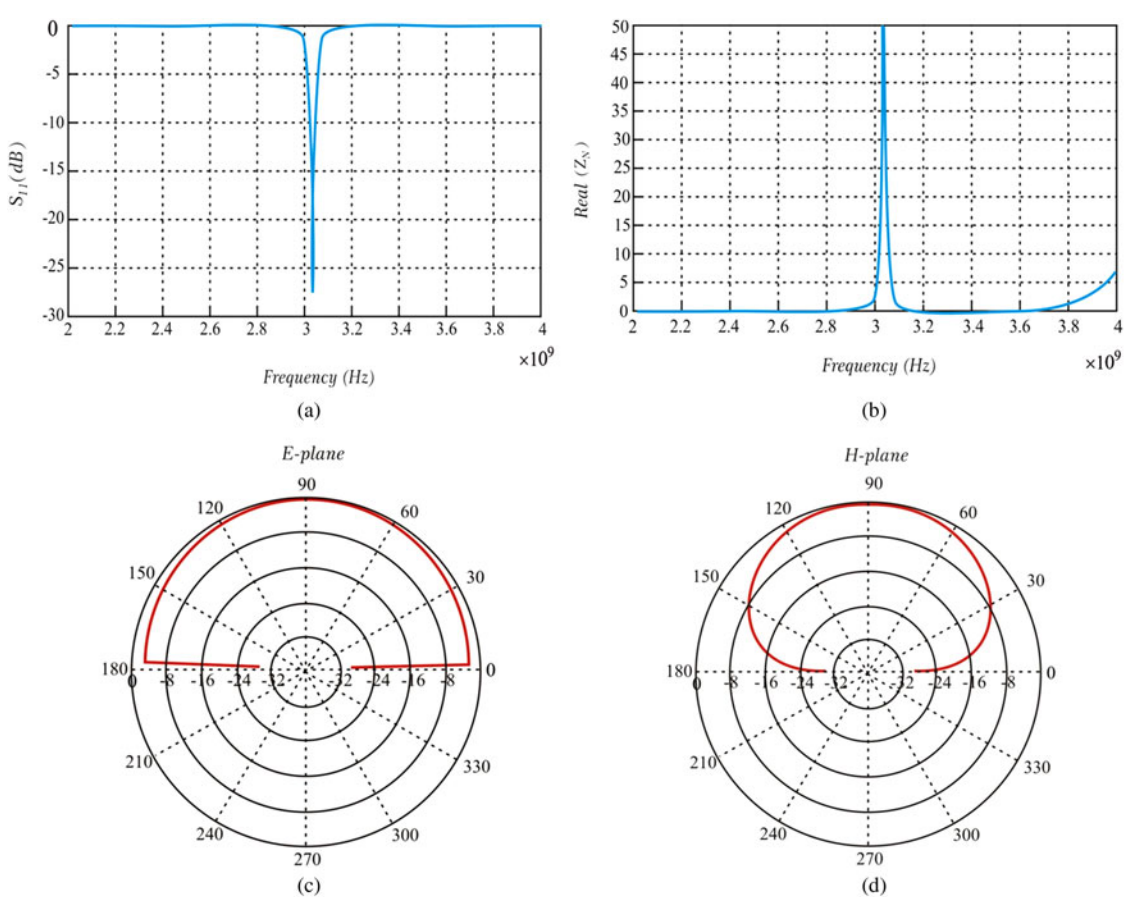

Fig. 2. The simulation results. (a) S_{11} parameter of the passive antenna, (b) real part of the input impedance, (c) E-plane pattern of the passive antenna, (d) H-plane pattern of the passive antenna.

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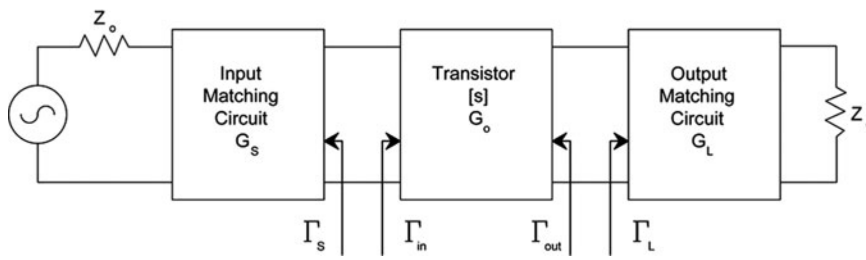

Fig. 3. The general transistor amplifier circuit.

where G_1 is the conductance of a single slot and can be obtained by

$$G_1 = \frac{1}{120\,\pi^2}\int_0^{\pi}\left[\frac{\sin\left(\frac{k_0\,W_p}{2}\cos\theta\right)}{\cos\theta}\right]^2 \sin^3\theta d\theta \qquad (9)$$

and, G_{12}, is the mutual conductance and can be calculated using

$$G_{12} = \frac{1}{120\,\pi^2}\int_{0\pi}^{\pi}\left[\frac{\sin\left(\frac{k_0\,W_p}{2}\cos\theta\right)}{\cos\theta}\right]^2 J_0\left(k_0\,L_p\sin\theta\right) \times \sin^3\theta d\theta. \qquad (10)$$

The simulation results of the designed patch are given in Fig. 2. As shown in this figure, the antenna has a good matching performance. The *E*- and *H*-plane patterns of the antenna are shown in Figs 2(c) and 2(d), which shows a wide beam pattern, which is desirable for many applications such as navigation systems.

III. AMPLIFIER DESIGN

The next stage is the amplifier design. The low noise amplifier (LNA), as one of the most important blocks in a receiving system, governs receiving sensitivity of the entire system. The first stage is amplifier selection. Most of the radio frequency (RF) and microwave LNAs are designed in CMOS, BiCMOS, GaAs FET, and p-HEMT technologies, and are used in a variety of applications. The area of application is an essential factor in the amplifier section design of an active antenna. For example, for transmitter applications, the design goals are to achieve higher gain and more bandwidth. For receiving applications, having a good noise figure is a design goal. This is a criterion for transistor selection, so that for transmitter antenna, HBT transistors are preferred because of their high gain, whereas for reception application, HEMT transistors are good choices because of their low noise. The second stage designs an appropriate bias network. Bias point is selected depending on the application such as low-power consumption, low noise, linearity, etc. After that we should check the stability situation of the

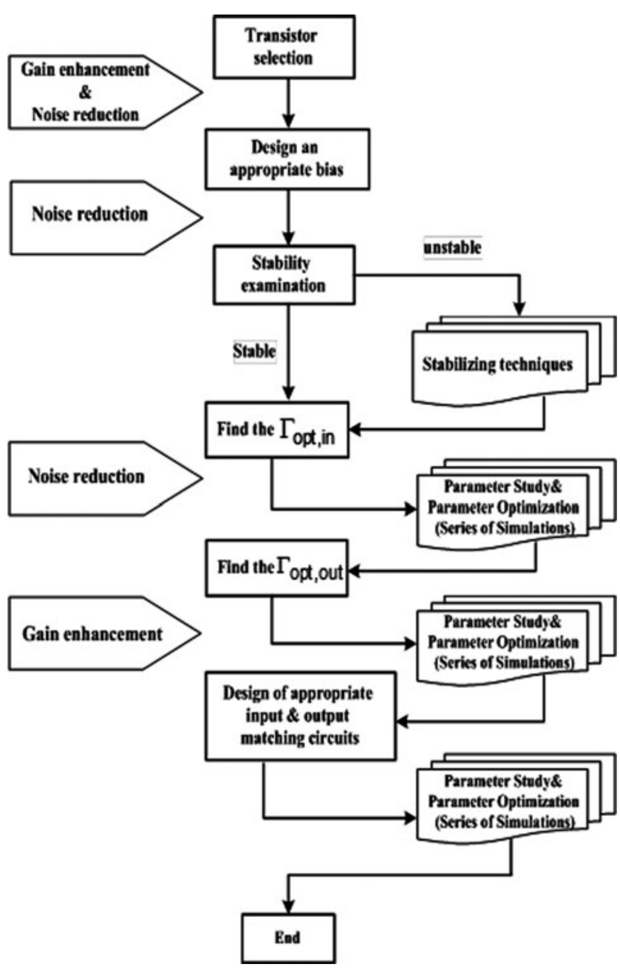

Fig. 4. Amplifier design flow diagram.

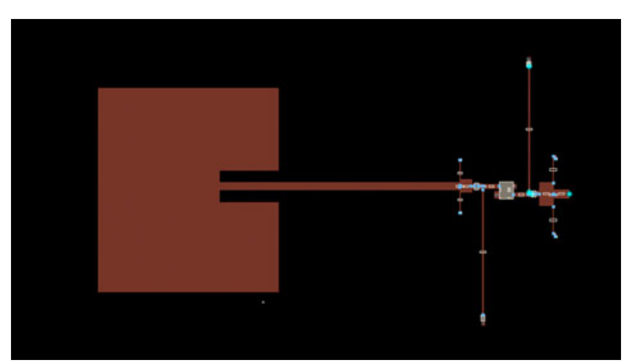

Fig. 5. Final layout of receiving active antenna.

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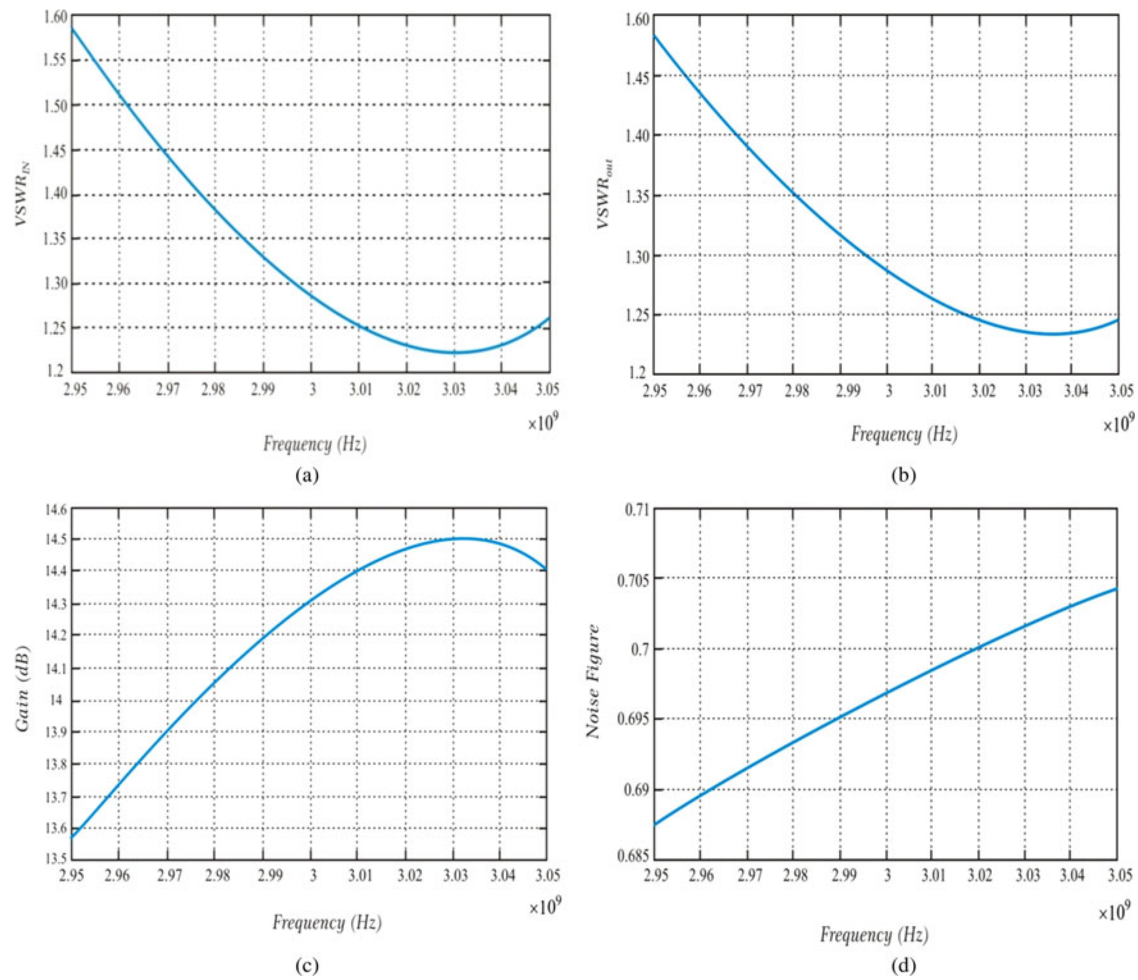

Fig. 6. Results of active antenna simulation. (a) $VSWR_{IN}$, (b) $VSWR_{OUT}$, (c) $S(2,1)$, (d) noise figure.

transistor. The stability of an amplifier is a very important consideration in the design and it can be determined from the *S*-parameters, the matching networks, and the terminations. In the circuit Fig. 3 oscillations are possible when either the input or the output presents a negative resistance. This occurs when $|\Gamma_{IN}| > 1$ and $|\Gamma_{OUT}| > 1$. The reason is that Γ_{IN} and Γ_{OUT} depend on the source- and load-matching networks, while, the stability of the amplifier depends on Γ_S and Γ_L as presented by the matching networks. Alternatively, it can be shown that the amplifier will be unconditionally stable if the following necessary and sufficient conditions are met.

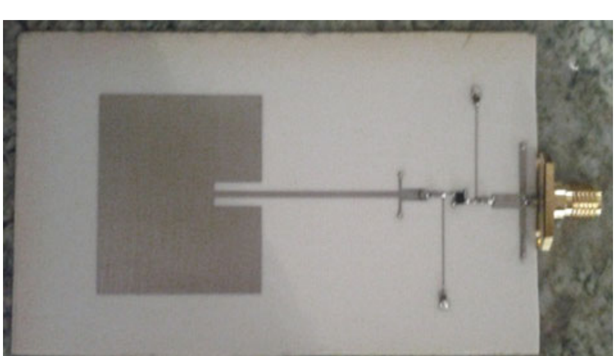

Fig. 7. The proposed antenna.

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

and

$$|\Delta| < 1.$$

If transistor is unstable at the desired frequency, then proper techniques are applied to make it stable. After this stage, we must design the proper matching networks, and optimize them. Different techniques are applied to optimize different parameters, such as noise figure, gain, and power dissipation. Two parameters cannot be optimized simultaneously. Various stages of the amplifier design for the active antenna are shown in the flow diagram of Fig. 4. The active device in this circuit is ATF-34143, whose small signal-scattering parameters are extracted from its datasheet. The calculated stability factor shows that this transistor is unconditionally stable at the desired frequency band. This active antenna needs two matching network, which are designed using simultaneous conjugate match condition. Also we assume that the source and load impedances are equal to 50 Ω. Using the appropriate design of the active elements, the passive part interconnections, and overall circuit layout, the structure shown in Fig. 5 is achieved.

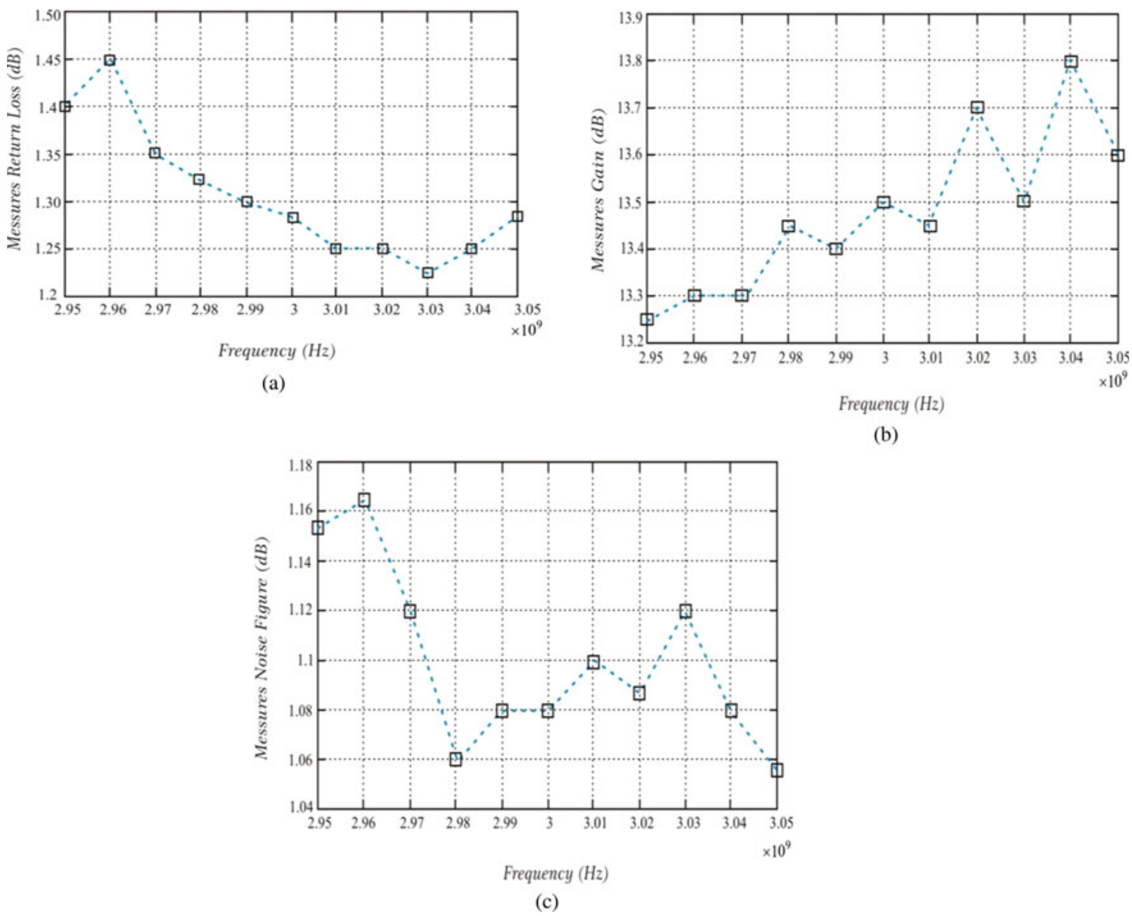

Fig. 8. The experimental results. (a) The measured return loss, (b) the measured gain, (c) the measured noise figure of the active antenna active antenna.

IV. SIMULATION RESULTS AND DISCUSSION

The antenna simulation is performed by ADS simulator. Figures 6(a) and 6(b) display the simulated $VSWR_{IN}$ $VSWR_{OUT}$ of the proposed active antenna, respectively. It is evident that the impedance matching is excellent in intermediate frequency. An active antenna gain >13 dB has been obtained across the bandwidth and is depicted in Fig. 6(c). The maximum gain of the proposed antenna is 14.5 dB at the frequency of 3.05 GHz by ADS simulator. Figure 6(d) shows the simulated noise figure of the antenna. It is seen

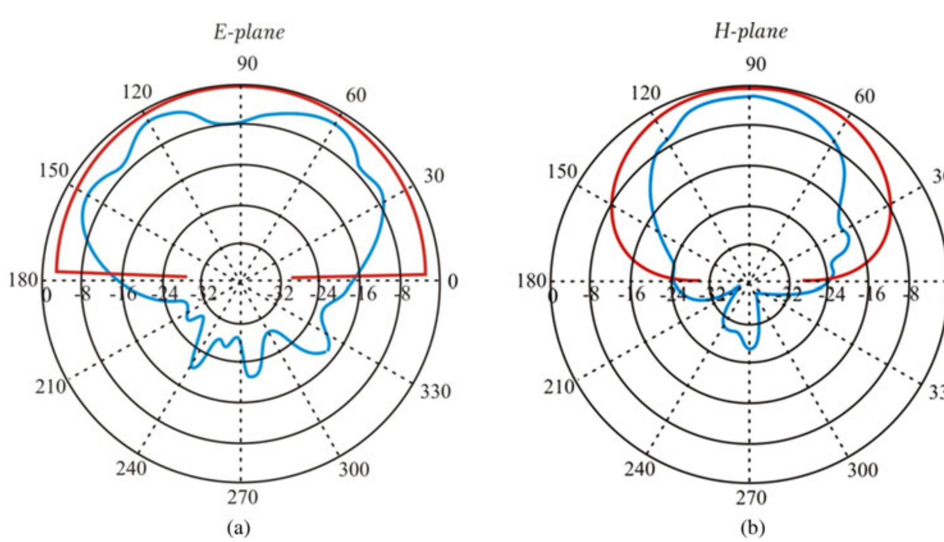

Fig. 9. Comparison between the simulation results with the experimental results. (a) The measured *E*-plane of the active antenna. (b) The measured *H*-plane of the active antenna.

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Table 2. A comparison between this work and similar works.

Reference	Transistor type	Center frequency (GHz)	Gain (dB)	Noise frequency (dB)
[2]	HBT	5.8	8.3	1.4
[3]	PHEMT	5	10	1.22
This work	PHEMT	3	13.5	1.08

that there is a very low noise performance near the fundamental resonant frequency of 3 GHz; so this antenna can support many wireless services especially Radio navigation and Radio positioning.

V. EXPERIMENTAL RESULTS

A prototype antenna was fabricated and measured using an Agilent_8722ES Vector Network Analyzer. Figure 7 shows the fabricated active antenna. Note that the bias circuit is designed and fabricated separately to reduce the total size of the active antenna and additive noise. The experimental results are shown in Fig. 8. Figures 8(a) and 8(b) show the measured return loss and gain of the fabricated active antenna, respectively. Also, Fig. 8(c) shows the measured noise figure. The noise performance of the antenna is excellent which ensures a good sensitivity of the overall circuit. As seen in these figures, the measured gain varies from 13.25 to 13.6 dB and the measured noise figure varies from 1.05 to 1.15 dB; so they are nearly stable. As shown in Figs 9(a) and 9(b) the measured radiation patterns of *E*- and *H*-planes have good agreement with the simulation results. The slight difference between simulation and experimental results are to some extend because of the calibration errors. Table 2 compares the characteristics of the proposed antenna to the other active receiving antennas. It is seen that our proposed antenna has higher gain and better noise performance compared with the other active receiving antennas.

VI. CONCLUSION

In this paper, an active receiving microstrip patch antenna has been designed and fabricated for Radio navigation and Radio positioning applications. The implemented active antenna was investigated based on a comparison of the measured and simulated results. With the design proposed here, the transistor is operated near its noise minimum over the whole region of interest.

REFERENCES

[1] Chang, K.; York, R.A.; Hall, P.S.; Itoh, T.: Active integrated antennas. IEEE Trans. Microw. Theory Tech., **3** (2002), 937–944.

[2] Duerr, W.; Menzel, W.; scurmacher, H.: A low noise active receiving antenna using a SiGe HBT. IEEE Microw. Guid. Wave Lett., **3** (1997), 63–65.

[3] Peter, T.; Rahim, M.K.A.; Din, J.; Masri, T.: Active integrated antenna with low noise amplifier design at 5 GHz, in 2nd Eur. Conf. Antenna and Propagation (EUCAP), Edinburgh, 2007.

[4] Li, J.; Xing, L.; Xu, Q.; Ding, J.; Guo, C.: The solution and simulation for the stability of active receiving antennas, in Proc. Progress in Electromagnetics Research Symp., Xi'an, China, March 22, 2010.

[5] Bhartia, P.; Bahl, I.; Garg, R.; Ittipiboon, A.: Microstrip Antenna Design Handbook, Artch House, Boston, London, 2001.

[6] Balanis, C.A.: Antenna Theory: Analysis and Design, Wiley, New York, 2005.

[7] Basilio, L.I.; Khayat, M.A.; Williams, J.T.; Long, S.A.: The dependence of the input impedance on feed position of probe and microstrip line-fed patch antenna. IEEE Trans. Antenna Propag., **49** (2001), 45–47.

[8] Matin, M.A.; Sayeed, A.I.: A design rule for inset-fed rectangular microstrip patch antenna. WSEAS Trans. Commun., **1** (2010), 63–72.

[9] Abdipour, M.; Moradi, G.H.; Sarraf Shirazi, R.: A design procedure for active rectangular microstrip patch antenna. Int. J. Electron. Commun. Eng. Technol., **3** (2012), 123–129.

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