Active Integrated Antenna (AIA) system for wireless communication

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Abstract- In this paper, an active integrated antenna (AIA) system is proposed for mobile and wireless communication devices. The AIA system consists of a microstrip patch antenna and a low noise amplifier (LNA), which are integrated together with a matching circuit and printed on an FR4 PCB circuit board. The system is designed, analyzed, and optimized by targeting to satisfy the design specifications for both the microstrip antenna and the LNA in terms of the industrial parameters.

The proposed AIA include two major components: the microstrip patch antenna and the low-noise amplifier. In the II[nd] section, a microstrip patch antenna is analyzed and designed according to requirements. It requires small size, reduced loss. In the III[rd] Section, the LNA (Low-noise Amplifier) is designed and tuned to enhance the signal, reduce power consumption as well as minimize the noise. In the IV[th] Sections AIA is designed and in V[th] section discussed the conclusions.

I. Introduction

From a systems standpoint, antennas have historically been viewed as static and passive devices with time-constant characteristics. Once an antenna design is finalized, its operational characteristics remain unchanged during system use. While the method of antenna operation is evolving, its role in communication systems still remains the same. The task that an antenna must perform is fundamentally that of a radiator and thus the metrics by which antennas operate and are measured are still intact. Gain, bandwidth, polarization, antenna feature size, etc.are still the realizable quantities of interest. But now the introduction of dynamic radiating structures has given the antenna designer an additional degree of freedom to meet these design goals.

The high demands for wireless communications systems in compatibility and efficiency have been greatly leading to rapid development and growth in the microwave and monolithic microwave integrated circuit technologies. The active integrated antenna (AIA), as an advanced solution to various existing problems in wireless communications, such as noise matching, power saving and size reduction, has been a growing area of research in recent years.

From a microwave engineer's point of view, an AIA can be regarded as an active microwave circuit, in which the output or input port is free space instead of a conventional 50Ω transmission line. Microstrip patch antennas are extensively used in commercial and military communication systems. Advantages of using microstrip patch antennas over conventional antennas are their light weight, low profile and volume, and low cost of fabrication [4]. However, in comparison to other types of microwave antennas, their disadvantages include narrow bandwidth, relatively high loss, low gain, only radiate in half space, and narrow design tolerance.

The low noise amplifier is an important building block in wireless receivers. It essentially determines the receiver's performance. The LNA design is full of tradeoffs between optimum gain, optimum input matching, low power consumption, lowest noise figure and high linearity [5].

II. Microstrip Patch Design

In order to improve the NF while maintaining a good gain, conjugate matching is no longer used at the input port of the transistor. Instead, transistor is tested to see which impedance gives a better NF and a high enough gain. Then the antenna is designed to have such output impedance. And it is connected directly to the transistor. In this case, the microstrip patch antenna combines the function of a regular antenna and a matching network.

The design procedure evolves from the analysis of the geometry. The ACMSA has been analyzed with different models such as transmission line model, modal expansion model, intergral equation model etc.., Of these transmission line model provides us with better intuition as to which dimension affects which parameter, but is inaccurate and the other two are more accurate and mathematically rigorous but provide us with very little design intuition

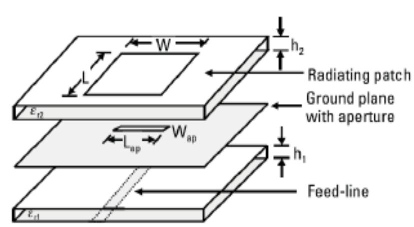

Fig.1 An exploded view of a simple aperture coupled microstrip patch antenna

The patch on the topmost substrate is the radiating element and the slot in the ground plane couples the energy from the microstrip feed line (beneath the bottom most substrate) to the patch.

In this designs air/foam(permittivity=1/1.07) has been used as antenna substrate with a thickness of 17mm. \FR4 material(permittivity=4.4 and thickness=1.58mm loss tangent=0.0023) is used for feed line substrate and material with permittivity=2.5, thickness=1.58mm and loss tangent=0.0023 is used for the radome substrate of the antenna.

The 3D view of the design is shown below followed by the layout of the design:

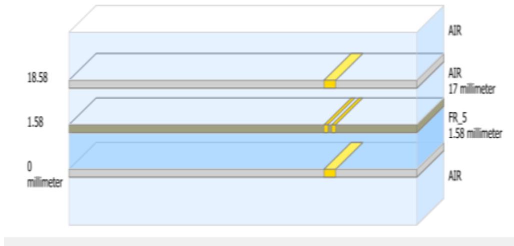

Fig.2 An exploded view of 3D View aperture coupled microstrip patch antenna layout in ADS

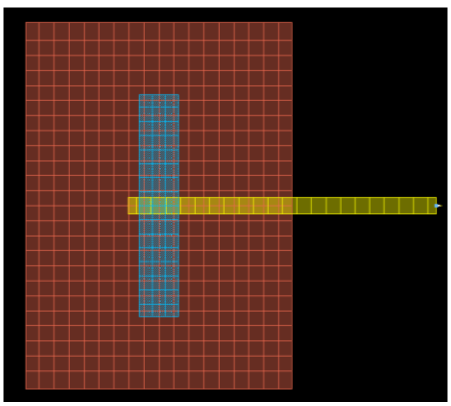

Fig.3 An exploded view of 2D View aperture coupled microstrip patch antenna layout in ADS.

Parameters:

Patch: Lp=48mm Wp=66mm patch substrate(radome):er=2.5 thickness=1.58mm loss tangent=0.0023,**Aperture:** La=40 Wa=7mm antenna substrate : er=1.07 thickness=17mm loss tangent=0.0009,**Feed line:** width=3mm stub length=5.5mm feed line substrate: er=4.4 thickness=1.58mm loss tangent=0.0009

Simulation results:

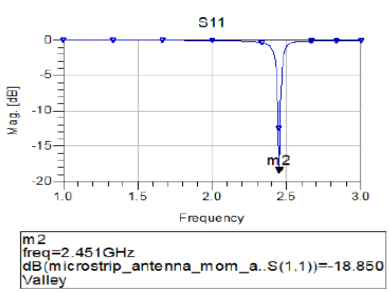

Figure 4: S_{11} of microstrip patch antenna

The simulation results of the radiation pattern at 2.4 GHz are shown below:

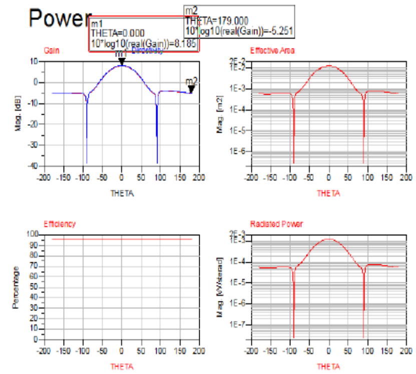

Figure 5: radiation patterns of microstrip patch antenna.

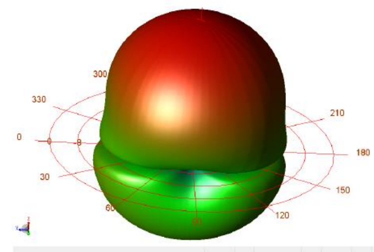

Figure 6: The 3D view of the radiation patter

III. LNA DESIGN

LNA is an electronic amplifier used to amplify very weak signals. It is usually located very close to the detection device to reduce losses in the feed line. The growing wireless communication market has generated increasing interest in RF technologies. New technologies are developed to increase higher data rates and capacity, and to reduce the power dissipation for longer operation time. Low-voltage and low-power RF circuit design becomes a necessary requirement [5]. A block diagram of a typical AIA receiver front-end is shown in Figure 7. The main function of the LNA is to provide high enough signal gain to overcome the noise of the subsequent stages while adding the minimum possible noise.

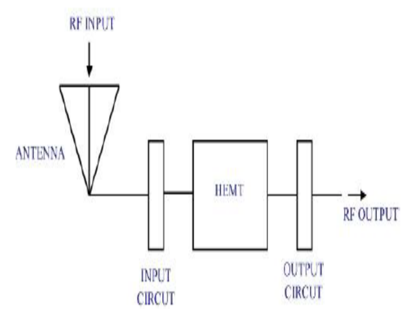

Figure 4.1: block diagram of an active integrated antenna amplifier receiver front end

Fig 7 A block diagram of a typical AIA receiver front-end

LNA Parameters:

III.(a) Noise Figure and Noise Temperature

The noise Figure of an amplifier can be defined as:

$$NF = \frac{S_{in}/N_{in}}{S_{out}/N_{out}}$$

The noise emitted by the amplifier is expressed by its Noise Temperature . The relationship between and NF is:

$$T_e = T_0 \times (NF - 1)$$

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \cdots + \frac{F_n - 1}{G_1 G_2 G_3 \ldots G_{n-1}}$$

III.(b)Gain: There are many different definitions of gain for an amplifier. Normally, for an LNA, Power Gain refers to the gain measured when the source and load are 50 Ohms.It is defined as follows:

$$Gain = 10 \log \left(\frac{P_{out}}{P_{in}} \right) dB$$

For a single stage LNA, its noise figure is expressed as:

$$NF = NF_{min} + 4R_n \frac{\left|\Gamma_s - \Gamma_{opt}\right|^2}{(1 - |\Gamma_s|^2)\left|1 - \Gamma_{opt}\right|^2}$$

III.(c)Linearity : 1 dB compression point and third-order intercept point are two important measures for weakly nonlinear systems and devices. In the design of LNA, the IP3 of the input LNA is normally chose to be a little higher, at least 20 dB higher than the input signal, to avoid much nonlinearity.

III. (1) LNA Design Consideration

Impedance matching

Unlike the conventional design, where an antenna and amplifier are separated by a standard 50 Ohms transmission line and interconnects, in the AIA approach, an antenna is directly attached to the input of amplifier circuit. One of the main challenges in realizing AIA design is the effective impedance match of antenna element and amplifier as their impedance mismatch significantly deteriorates the performance of integrated devices. Because of the importance of both gain impedance matching, which provides the maximum gain of AIA device, and noise figure minimum impedance matching, which minimizes the NF value, an amplifier must be designed according to the impedance characteristics of antenna element [12].

DC Bias

The bias network determines the amplifier performance over temperature as well as RF drive. The DC bias condition of the RF transistor is usually established independently of the RF design. Power efficiency, stability, noise, thermal runway, and ease to use are the main concerns when selecting a bias configuration.

The most common form of biasing in RF circuits is the current mirror. This basic stage is used everywhere and it acts like a current source. It takes a current as an input and this current is usually generated, along with all other references, by a circuit called a bandgap reference generator.

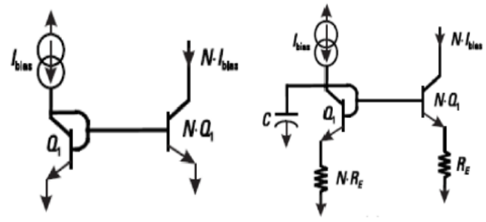

Fig 8. Current mirror circuit

In the current mirror shown in Figure 8, the bandgap reference generator produces current and forces this current through Q1. Scaling the second transistor allows the current to be multiplied up and used to bias working transistors.

In this LNA design, the transistor used is an NEC68030 NPN silicon transistor, with typical noise figure 1.76, gain 10.70, when Vce=6V, Ic=5mA. The amplifier is biased for class A operation, using current mirror method. The input and output of the transistor are conjugated matched to the source and load impedance, using microstrip stubs matching networks.

The bias circuit works by adjusting the gate voltage to maintain a particular value of drain current. Figure 9 shows the ADS schematic simulation of the LNA design with bias circuit.

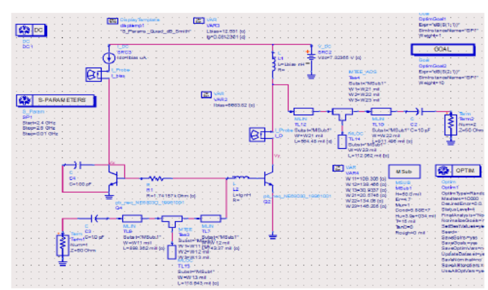

Fig 9. ADS schematic simulation of the LNA design with bias circuit.

As the figure shows, the 1dB compression point is about 1dbm, which is a satisfying result, indicates that the linearity of this LNA design is acceptable.

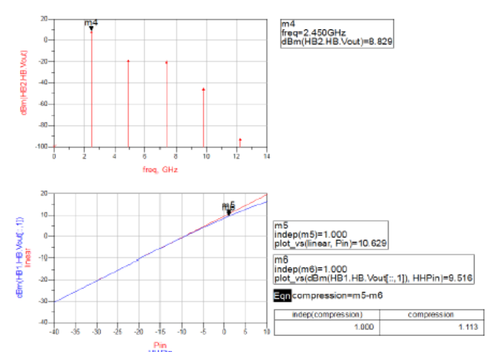

Figure 10. Linearity parameters of LNA

Parameter	Specification	Prediction	Unit
Frequency	2.4-2.5	2.4-2.5	GHz
Noise Figure	<2.7	2.6	dB
Gain	>9	9.6	dB
Power consumption	<50	50	mW
Source/load impedance	50	50	Ohms
1dB compression point	Not specified	8.829	dBm

Table(1):Summary of simulated LNA performance

IV. Design of AIA

Finally the designs of microstrip patch antenna and low-noise amplifier are combined together, tested and simulated using Agilent ADS. Figure (11) shows the schematic circuit of the complete AIA circuit, and Figure (12) display the layout design of the proposed AIA. Based on the simulation result shown in Figure (13)

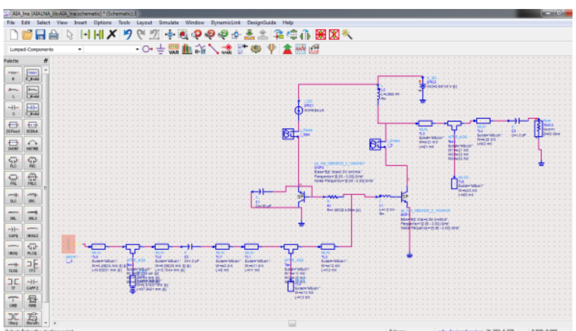

Figure 11: schematic circuit of the complete AIA design

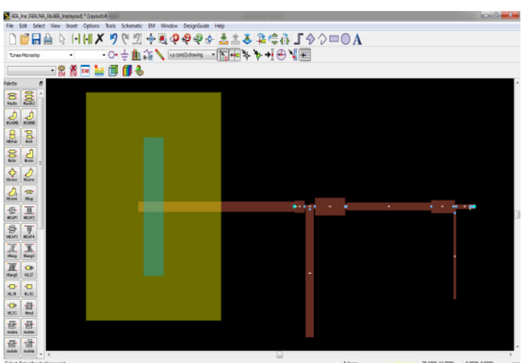

Figure 12: Layout design of the AIA

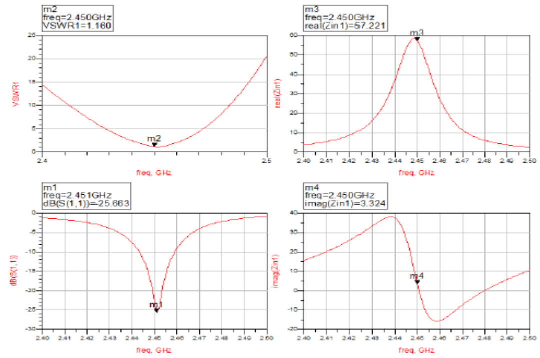

Figure 13: simulation result of the complete AIA design

V. CONCLUSION

In this paper, a design and simulation result of an active integrated antenna is presented. Compared to the conventional amplifying antenna, the new active integrated antenna leads to significant advantages such as compactness of the configuration, high power transmitting efficiency, and low noise. The antenna and the LNA performance match the specifications properly.

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