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Design a High-Gain Wideband Two-Stage Cascode Low Noise Amplifier with Chebeyshiv Filter matching Technique

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Abstract—

This Paper presents the design of 1.6GHz-10.6GHz ulta-wide band (UWB) low noise amplifier (LNA) using pHEMT GaAs Process. The matching network uses lossy matching made up of lumped element. Under the software Agilent's Advanced Design System (ADS) environment, the simulation results show a high gain ($S_{21} > 30dB$), fine flatness (<1dB), good noise characteristics (NF<2dB), and fine input/output return loss ($S_{11} < -10dB, s_{22} < -10dB$) in the frequency range of the design.

Keywords—LNA; UWB; feedback; matching; optimization;

I. Introduction

LNAs are one of the most important components in microwave/millimeter-wave transceiver systems. As the first stage of the whole receiver system, its main function is to amplify the input signal without distortion and deliver it to mixer to process. Its noise figure influences the whole system directly. Besides, to reduce the noise induced by mixer and other components, the gain of LNA must reach a high level. However, the gain cannot be too high to weaken the linearity of receiver. According to the demand of the satellite communication system, the LNA must accomplish impedance matching in wide band, supply enough flat gain degree, and induce noise as low as possible. As is mentioned by many papers [1-4], the input port of LNA should be matched as noise matching method. However, in practice, how to accomplish the impedance matching and noise matching in wide band LNA design is an essential problem that needs to be solved. The hard point is that it can hardly get two of them by the same time in such a wide band. Besides, other problems such as stabilization, negative DC bias and so on also cause many troubles for MMIC LNA. So far, the wide band LNAs have many structures such as feedback structure, filter impedance matching, cascade and distributed amplifier and so on[5, 6].

Low noise amplifier (LNA) is a vital component in microwave and millimeter-wave (MMW) applications, such as radio astronomy, and satellite communications. For the radio astronomy, a extremely sensitive receiver is demand, such as the Atacama large millimeter/submillimeter array (ALMA) [1]. In the radio astronomy applications, most of LNAs were designed using GaAs- or InP-based HEMT processes due to their low noise figure and high gain. The InP-based HEMTs have established excellent MMW characteristics as compared to the GaAs-based HEMTs. Due to cost consideration, the LNA in our work is implemented in GaAs pHEMT.

The design targets of the LNA are 20-dB gain and noise figure below 3.5 dB to make sure the total noise figure of the receiver is conquered by the LNA. This LNA needs cryogenic operation in the future, so the drain current is desired is lower than 10 mA per stage for low noise consideration. Compared with the beforehand reported LNAs of narrow bandwidth [7]-[9], our LNA shows 50% bandwidth. In addition, this LNA exhibits total power consumption lowers than 10 mW. The LC filter impedance matching method is applied to input and output ports on one GaAs substrate for higher integrating level. At last, an inductor is applied to the source of the transistor to accomplish the impedance matching and noise matching by the same time. The measurement result shows good performance on noise figure and VSWR.

II. Matching Technique

A Chebeysiv filter design procedure is developed based on the method of least squares, which incorporates source and load impedance matching leading to the drastic reduction of circuit size and complexity. General network topologies and filter characteristics may be considered for the filter design. Quite general desired design specifications and frequency responses may be realized by the design algorithm, such as spurious response elimination, multiband filter characteristics and realization of any frequency response, applications in general electronic circuits, and enhancement of some special effects. The filter design method may be applied for microwave circuits too. The method of least squares may potentially be used for the determination of optimum topology of filter configurations, which could be the subject of further investigations.

We consider the filter topology composed of the cascade connection of consecutive series and parallel circuit units as shown in Fig.1. The circuit unit next to the source or load may be selected as a series or shunt branch. Each series or shunt branch may be selected as a subset of the circuit unit shown in Fig.1.

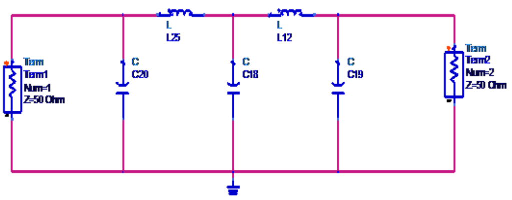

fig.1. Chebeyshive Filter Schematic Design

After the selection of initial values for circuit elements (L and C), design tool Agilent's ADS seek to determine their optimum values under some specified constraints. In case, the value of inductance (L) of an inductor decreases towards small values (namely zero), then the inductor is removed and shorted out. In case, the value of capacitance (C) of a capacitor increases towards large values (namely infinity), then the capacitor is removed and shorted out. On the other hand, if the value of L increases towards high values and that of C decreases towards zero, they are open circuited. However, the shorting out and open circuiting of L and C should not cause on interruption in the filter circuit. As a result, the proposed algorithm may simplify the filter circuit configuration. Consequently, the filter designer can select a large variety of circuit topologies for the realization of the desired filter specifications and can obtain the configuration that best fits the specified characteristics (and circuit requirements and constraints), through some experimentation and trial and error on the computer programs.

III. ANALYSIS AND DESIGN

Among different kinds of LNA structures, the cascade structure is one of the most famous for its outstanding character on gain and noise. The proposed schematic circuit is shown as Fig.2. In this cascade structure, the CS transistor M1 supplies enough gain for LNA, the CG one (M2) helps to reduce the Miller effect caused by M1 and improves the whole isolation character.

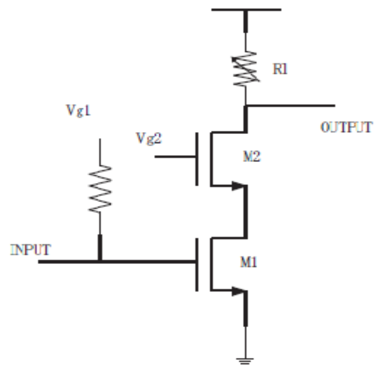

fig.2. Schematic of cascaded LNA

An important character of this structure is that it shows quite high output impedance comparing with CS LNA. As is known, the voltage gain of an amplifier, is presented as (1)

$$A_V = G_m R_{out} \quad (1)$$

In this equation, Gm is decided by M1, which should typically make compromise with bias current, component capacity and so on in design. So the best way to improve the voltage gain is to maximum the parameter ROUT .Comparing with CS structure, the CG transistor present higher output impedance. In cascade structure, if both transistors work at saturate region, we can calculate the voltage gain, which is shown as (2).

$$A_V = g_{m2} r_{o2} g_{m1} r_{o1} \quad (2)$$

It can be seen clearly that the voltage gain improves $g_{m2} r_{o2}$ times higher than CS structure. There is one point needs to be noticed that the gain bandwidth product remains unchanged, which means a lower working frequency for this LNA [8].

Another important point of LNA is stability problem. In proposed design, an inductive degeneration technology is usually applied. This structure introduces a small inductor at source to supply a negative feedback structure. This inductor not only plays a significant role on stabilizing the circuit, but also helps to accomplish the noise matching of input stage. An important index of this inductor is its quality factor Q. The noise resistor of the inductor's equivalent circuit affects the noise figure significantly.

The feedback circuit blocks low frequency and passes the high frequency signal reversely. The negative feedback structure supplies LNA sufficient Margin for stabilization and prevents the oscillation. For input noise matching and output impedance matching method, the LC passive integrated circuits are applied. How to feed DC voltage to the GaAs amplifier is always a big problem for MMIC design. Traditionally, some negative voltages are required to drive the transistor working at saturate region. However, by applying the self-bias structure to the circuit,

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there is only one voltage VCC is needed. This is a really convenience method for application. In this method, the DC voltage is added to CG by A resistor voltage divider circuit.

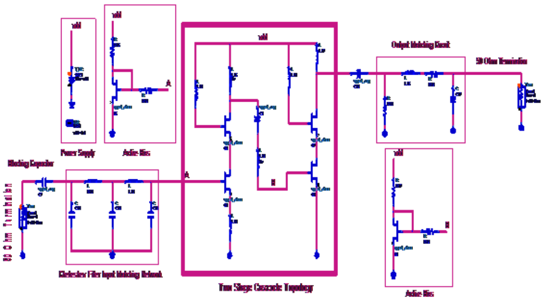

fig.3. Schematic Design of Two stage cascaded LNA

The proposed schematic circuit is shown in Fig.2. In order to achieve the low power consumption, the device size should be chosen as small as possible to ensure the lower drain current. The maximum available gain is about above 30 dB at 1.6GHz-10.6GHz, and the drain current is about 64 mA per stage. In the first stage of the LNA, two short circuited lines at the sources of the two sides of the transistor are added for source feedback which makes good noise performance while maintaining the input return loss good.

Fig. 2 is the schematic of this LNA. To achieve the flatness of the gain, the inter-stage matching is for gain and focused on the higher frequency. Due to the low gate bias and source feedback, the return loss and noise figure can be achieved simultaneously.

IV. SIMULATIONS AND MEASUREMENT

Fig 3 and fig 4 shows the simulation and measurement result of the gain, return loss of the proposed LNA. It can be seen in the simulation one that among the work band the highest gain can reach 33dB, which is quite a suitable value for the first stage of LNA to suppress the noise introduced by the second stage. The return losses of input and output ports reach a minimum value at 8GHz-6GHz. comparing with the simulated one; the measurement shows a little frequency deviation.

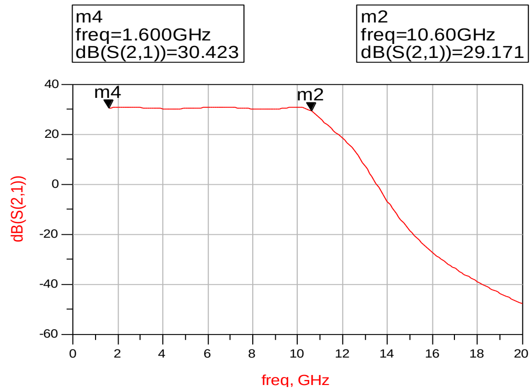

fig.4. Gain response of WLNA

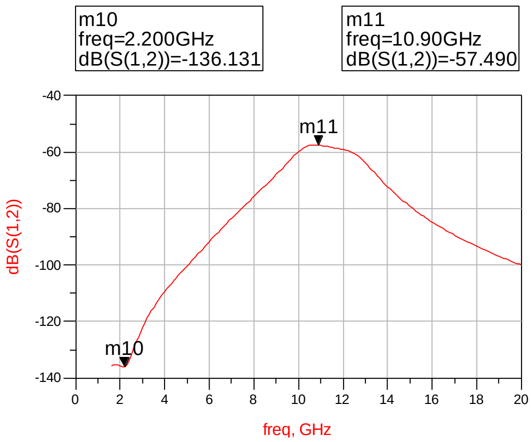

fig.5. Reverse Isolation

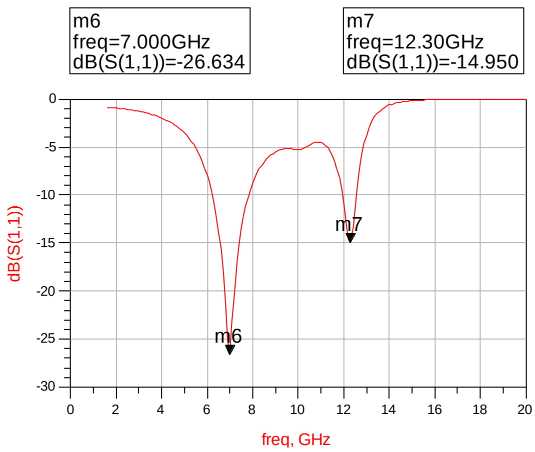

fig.6. Input Return Loss

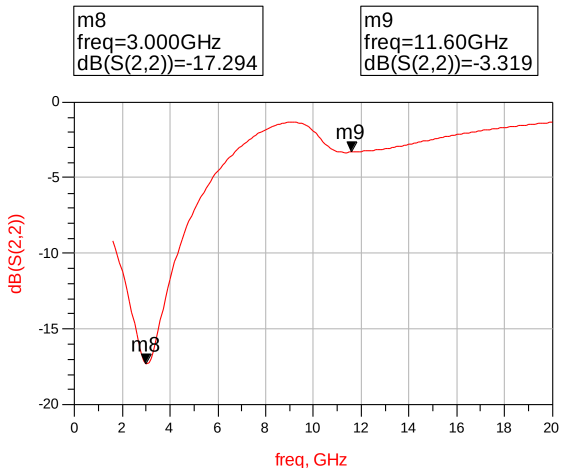

fig.7. Output Return Loss

As can be seen from the simulation figure, the noise reaches a minimum value at 2.2GHz with 0.813dB. The measurement shows that the noise figure is around 1dB at 2.5GHz

The whole LNA is unconditionally stable among the whole work band up to 40GHz, which proves the effectiveness of proposed structure. Fig.7 shows the simulated and measured noise figure of the LNA.

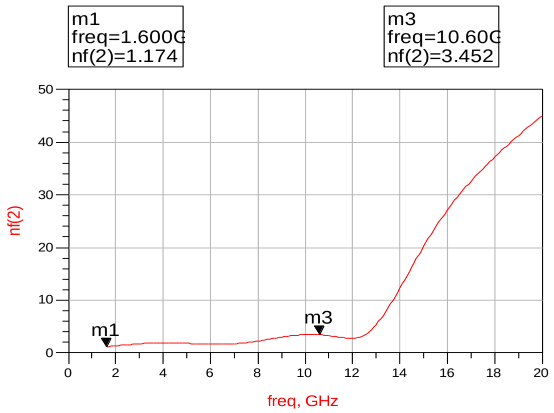

fig.8. Noise Figure

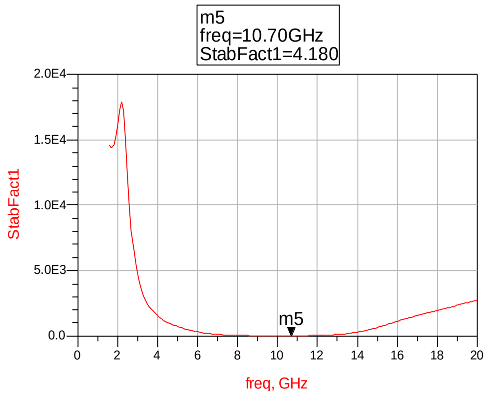

fig.9. Stability Factor

V. CONCLUSION

A Wide band LNA amplifier designed in pHEMT GaAs process has been demonstrated in this paper. Based on the simulation results, it can be seen that pHEMT GaAs is a suitable technology for high frequency applications. The low power consumption would make this LNA ideal for applications in portable electronics.

In this paper, we have proposed a 1.6GHz-10.6GHz two-stage Cascade WLNA using chebeyshive filter input matching technique. Good noise and gain performances were obtained. A noise figure of 0.8-2.7 dB and a power gain of 31 dB were achieved for the proposed LNA. Which shows the good linearity characteristics, was obtained.

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