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Design & Development of S-Band Ultra low Noise Amplifier

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***Abstract*-A highly stable wide band ultra Low Noise Amplifier with Minimum noise figure of 0.7dB & minimum gain of 44 dB has been developed & presented in this paper. Balanced amplifier configuration approach has been used in this discussed design to have stable noise figure over the wide bandwidth. The LNA Module has protection against overvoltage & reverse polarity. This paper gives complete design & measurement results of developed LNA.**

Keywords: LNA, Noise Figure, Gain, Balanced Amplifier

I. INTRODUCTION

The balanced amplifier approach was first reported by Engelbrecht and Kurokawa [1] as a way of providing a good input match when an amplifier was tuned for optimum noise performance in 1965, and in a subsequent paper by Kurokawa [2] discussed the theory of the balanced amplifier.

The ideal amplifier would have constant gain and good input matching over the desired frequency bandwidth. Conjugate matching will give maximum gain only over a relatively narrow bandwidth, while designing for less than maximum gain will improve the gain bandwidth, but the input and output ports of the amplifier will be poorly matched. Balanced amplifier configuration has trade off of this problem. Two amplifiers having 90° couplers at their input and output can provide good matching over an octave bandwidth, or more. The gain is equal to that of a single amplifier, but the design requires two transistors and twice the DC power.

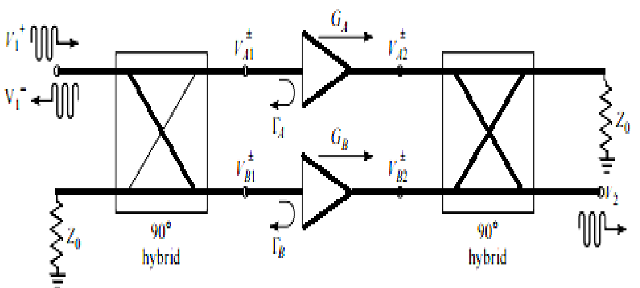

Fig 1 Balanced Amplifier using 90 ° hybrid couplers.

Fig 1 shows a Balanced Amplifier configuration [3] with a 90° coupler. A fairly flat gain response can be obtained if the amplifier is designed for less than maximum gain, but the input and output matching will be poor. The balanced amplifier circuit solves this problem by using two 90º couplers to cancel input and output reflections from two identical amplifiers. The first 90° hybrid coupler divides the input signal into two equal-amplitude components, with a 90° phase difference, which drives the two amplifiers. The second coupler recombines the amplifier outputs. Because of the phasing properties of the hybrid coupler, reflections from the amplifier inputs cancel at the input to the hybrid [4], resulting in an improved impedance match; a similar effect occurs at the output of the balanced amplifier. The gain bandwidth is not improved over that of the single amplifier sections. This circuit has advantage that individual amplifier stage can be optimized for gain flatness or noise figure, without concern for input and output matching. Reflections are absorbed in the coupler terminations, improves input/output matching, as well as the stability of the individual amplifiers. The circuit provides a graceful degradation of a 6 dB loss in gain if a single amplifier section fails. Bandwidth can be an octave or more, primarily limited by the bandwidth of the couplers.

Besides stability and gain, another important design consideration for a microwave amplifier is its noise figure. In receiver applications especially, it is often required to have a preamplifier with as low a noise figure as possible, since, the first stage of a receiver front end has the dominant effect on the noise performance of the overall system.

Generally it is not possible to obtain both minimum noise figure and maximum gain for an amplifier, so some sort of compromise must be made. This can be done by using constant-gain circles and circles of constant noise figure to select a usable trade-off between noise figure and gain. A white paper on practical design considerations for LNA designs by Tim Das gives good insight for practical designs [5]

II. DESIGN THEORY

The noise figure of a two-port amplifier can be expressed as [6]

$$F = F_{min} + \frac{R_N}{G_S}\left|Y_S - Y_{opt}\right|^2 \qquad (1)$$

Where the following definitions apply:

$Y_S = G_S + j\,B_S$ = source admittance presented to transistor.

Y_{OPT} = optimum source admittance that results in minimum noise figure.

F_{min} = minimum noise figure of transistor attained when $Y_S = Y_{opt}$.

R_N = equivalent noise resistance of transistor.

G_S = real part of source admittance, and the admittances are often expressed in terms of Reflection co efficient as follows

$$Y_S = \frac{1-\Gamma_S}{1+\Gamma_S}\left(\frac{1}{Z_0}\right) \qquad (2)$$

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$$Y_{opt} = \frac{1-\Gamma_{opt}}{1+\Gamma_{opt}} \left(\frac{1}{Z_0}\right) \quad (3)$$

Design of LNA proceeds with the specification of quantities F_{min}, Γ_{opt} and R_N for a given Transistor. Then Noise figure parameter N is computed [7].

$$N = \frac{F-F_{min}}{\frac{4R_N}{Z_0}} \left|1+\Gamma_{opt}\right|^2 \quad (4)$$

& the parameters for the Noise Figure circles are obtained as below:

$$R_F = \frac{\sqrt{N\left(N+1-\left|\Gamma_{opt}\right|^2\right)}}{N+1} \quad (5)$$

$$C_F = \frac{\Gamma_{opt}}{N+1} \quad (6)$$

The optimum solution is found in conjunction with the Constant gain circles on the Smith chart.

III. DESIGN APPROACH & METHOD

The design methodologies and strategies discussed broadly apply to amplifiers based on discrete devices like BJT/FET. To achieve ultra low noise, the input stage HEMT was matched at the impedance of minimum noise figure of HEMT. The output stage HBT was matched to 50 Ω for getting high gain & low VSWR. This provides compact, cheaper & highly stable design using the cascaded configuration of three MMICs (one HEMT & two HBT).

Fig 3 shows RF schematic of ultra low noise amplifier. In this low cost HEMT CGY2105XHV, with 0.25dB minimum noise figure, has been used in balanced configuration approach.

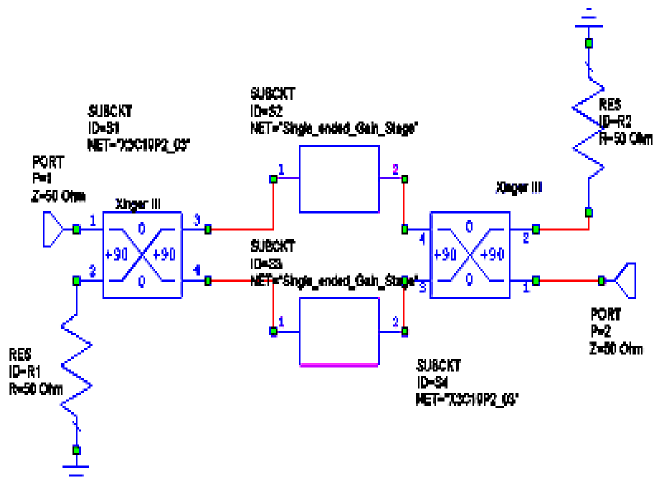

Fig.2 ADS Simulation for Balanced Configuration

HEMT gives 17.2 dB typical gain & 0.5 dB noise figure in this configuration. Subsequent amplification is being done by standard low cost Gali 5+ InGaP HBT Monolithic amplifier with same typical gain & 3.5dB noise figure.

ADS Simulation of LNA's shows Noise figure of 0.6 dB with 47.2 dB typical gain.

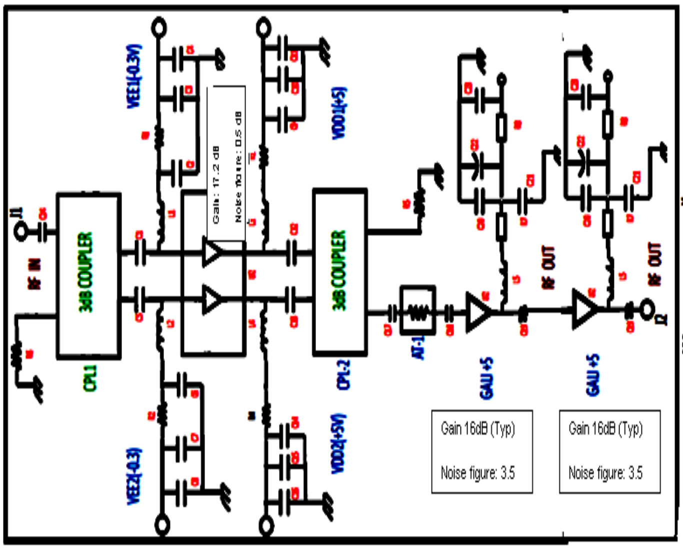

Fig.3 Schematic of ultra low noise amplifier module.

All MMIC's are configured for operation at +5 Volts & required negative voltage is also being generated internally in discussed design. For HEMT bias, sequencing has been implemented in design along with overvoltage protection. Frequency of hybrid used in present design limit the operational frequency from 2.3 to 2.7 GHz otherwise same can be used over bandwidth of DC to 4GHz. Fig 4 shows bias circuit for discussed LNA design.

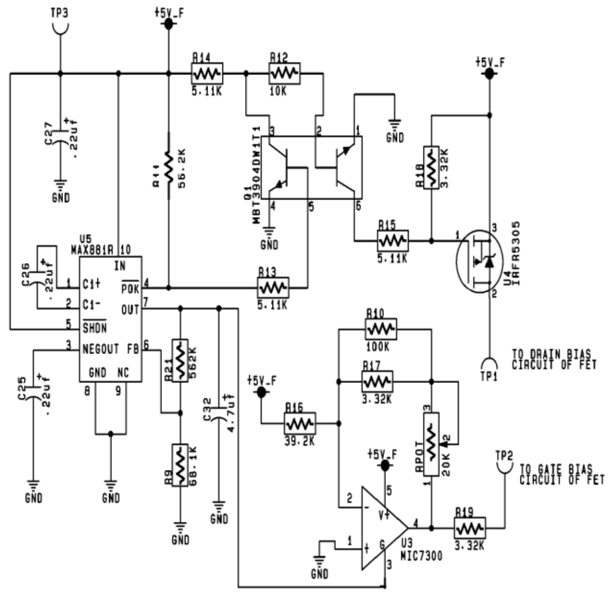

Fig.4 Bias circuit of LNA

PCB has been designed using Rogers Substrate RO4350, 20mil. Proper filtering has been done in power supply to avoid any noise introduction in circuit. Design & simulation tools like ADS, App-cad, Altium, Solid Works etc have been used in analysis/calculations & mechanical housing design for the developed LNA. Fig 5 shows developed LNA Module.

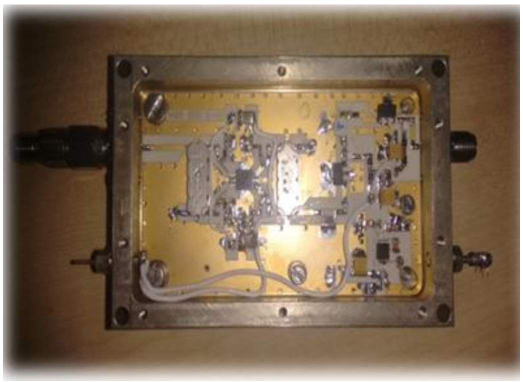

Fig. 5 Developed LNA module.

IV. EXPERIMENTATION & RESULTS

Measured results of Ultra Low Noise Amplifier shows 0.7 dB Noise figure with 46 dB gain. Developed LNA operates over the temperature (-30°C to +60 °C). The LNA module weighs less than 200 gm.

Measurement data in 2-3 GHz range is shown in Fig 6 & 7 respectively for noise figure & gain variation over frequency.

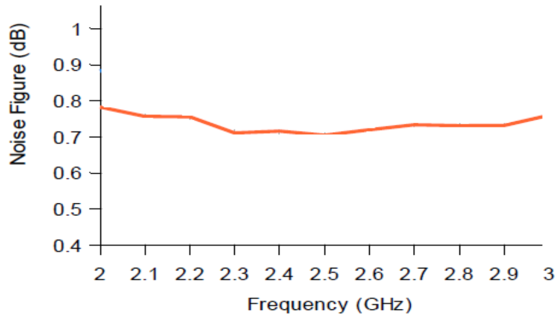

Fig.6 Noise Figure Vs Frequency

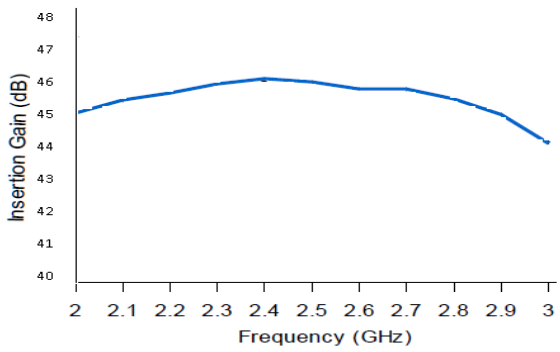

Fig.7 Gain Vs Frequency

V. CONCLUSION

Ultralow Noise Figure, compact size, high gain, wide band frequency of operation & stable behavior, make this design attractive for various applications. Developed module has been evaluated in system for SOTM (Satellite on the Move) application successfully in vehicle to receive satellite link at 2.56-2.59 GHz frequency

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