60-GHz Broadband LNA with Weak Interstage Coupling

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Abstract— **57-64**GHz **is an unlicensed frequency band that can be used for short range gigabit communication systems. A critical component that controls the receiver performance is the low noise amplifier (LNA). On top of the common specifications for an LNA such as: noise figure and linearity, a strict demand for a gain flatness is required by this application. This demand arises from the need to support advance modulation schemes such as OFDM.**

In this paper a weak interstage coupling approach is suggested to solve the demand for gain flatness. Interstage coupling is identified as one of the mechanisms responsible for limiting the bandwidth. Weak coupling via a transformer with $k \approx 0.5$ **helps to increase the bandwidth without trading-off too much gain. The LNA is based on 3 balanced common source stages, in, which the** 3^{rd} **stage is needed to drive a** 50Ω **load only for measurements. Simulation of the amplifier, designed in a** $0.13\mu m$ **CMOS technology predicts less than** $1dB$ **ripple in the gain and a noise figure better than** $4dB$.

I. Introduction

The unlicensed frequency band that stretches from 57 to 64 GHz is only suitable, due to the strong atmospheric absorbtion, for a short range communication. The mere advantage of this frequency is that a "Ultra Wide Band" (UWB) signals (e.g., gigabit communication) can be used without the limitations of UWB systems, where the quality factor is low. For example for a 5GBit signal the quality factor is

$$Q = \frac{Frequency}{Bandwidth} = \frac{60G}{5G} = 12, \quad (1)$$

which can be considered to be a narrow band system. Another advantage is the natural immunity to interferers, due to the strong medium attenuation.

The sensitivity of a transceiver (i.e., maximum communication range) is mainly dependent upon the LNA's performance. Furthermore, the gain flatness over the band plays a significant role both for sensitivity and for channel capacity. Utilizing the wide band advantage impose a gain flatness specification that can vary according to the modulation scheme. A common scheme is the Orthogonal Frequency Division Multiplexing (OFDM), which is capable in handling non line of sight scenario. In order to enable the use of an OFDM scheme a gain flatness specification of a less than 1dB ripple is set.

Prior works done in 60GHz, are generally confined to two main methods. The first approach is the common gate (CG) topology (see Fig. 1). This method utilizes the advantage of an easy input matching and has been demonstrated both in SiGe [1], [2] and CMOS [3]. However, a good noise matching in the CG is difficult to achieve and one ends in trading off the input matching for a noise matching, furthermore the interstage matching is done using a narrow band LC network, which does not answer the gain flatness specification.

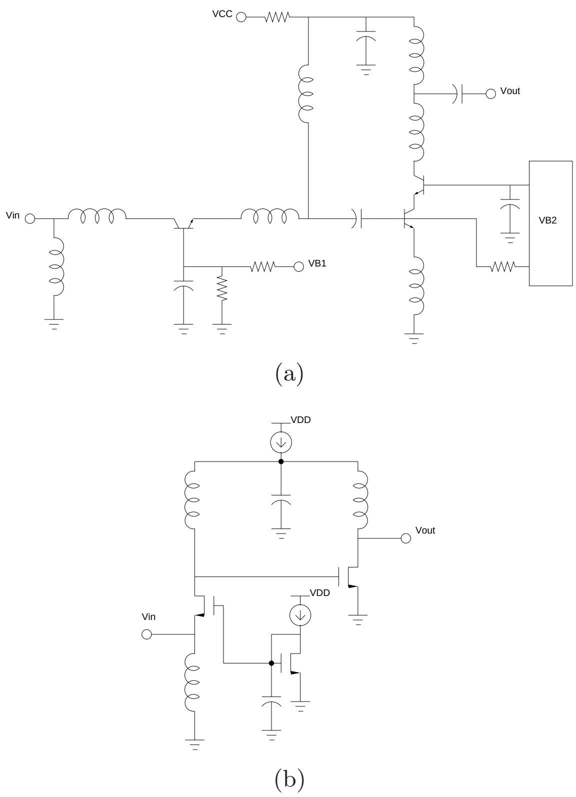

Fig. 1. CG LNA implementation.

The second method that does satisfy the gain flatness is the distributed amplifier [4] (see Fig 2). However, it generally exhibits a relatively high current consumption and noise figure.

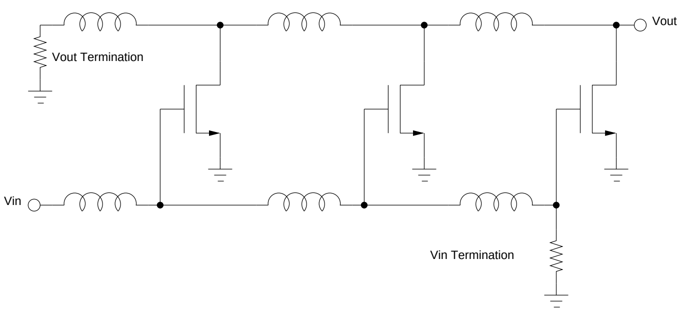

Fig. 2. Distributed LNA implementation.

In this a paper a new method based on weak interstage coupling is proposed. This approach satisfies the gain flatness specification without degrading the overall performance of the amplifier.

II. Weak Interstage Coupling

The LC network that is generally used to connect the two stages of the amplifier is narrow banded. An alternative interstage connection can be done using a transformer. Applying a simplified FET model, the obtained configuration is shown in Fig 3, where L_P

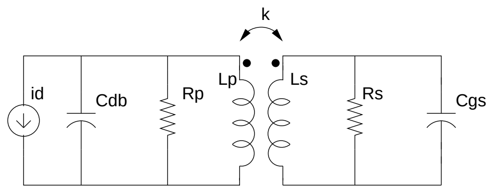

Fig. 3. Interstage connection using a transformer

and L_S represent the primary and the secondary inductors, respectively. R_P and R_S represent the equivalent inductor resistance. Such a configuration lends more flexibility to the designer. In this method one is trading off gain for a higher bandwidth by using weak coupling (i.e., low k), as can be seen in Fig. 4.

The same effect is achieved by reducing the quality factor of the drain inductor in a LC network connection, however, this method bears a penalty in the shape of noise performance degradation. Using a transformer allows to maintain noise performance. Furthermore, optimizing the inductance ratio $\frac{L_P}{L_S}$, reflect a higher load impedance to the output of the first stage and thus one obtains higher gain performance that compensates for the gain tradeoff.

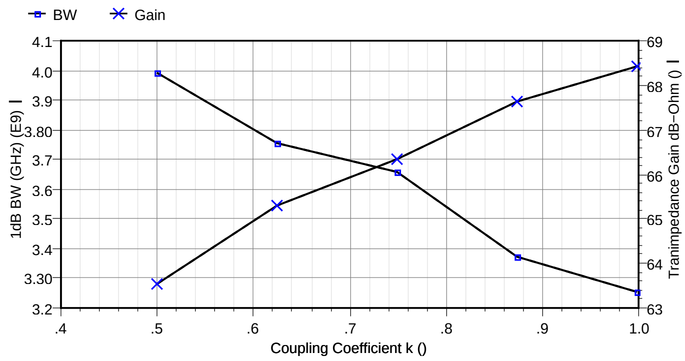

Fig. 4. The tradeoff between Gain and BW as function of the transformer coupling coefficient

III. LNA Topology

The amplifier suggested in this paper consists of three stages. The third stage is included for measurement purposes. In a full front-end configuration, the LNA will drive a relatively high input impedance of a mixer and therefore the third stage will not be required.

The topology chosen for each stage is the balanced Common Source (CS) amplifier, due to its better gain and noise performance alternatively to using a cascode topology, which in this frequency its input capacitance degrades the noise and gain performance. Another reason for using CS topology is low headroom of the supply voltage (1.2V). A difficulty of the CS is the input matching, both for noise and for gain. In order to solve this difficulty a source degeneration is applied by a transformer (see Fig. 5). In that way the negative feedback allows a good matching both for noise and gain. The value of the source inductor can be lower compared to a configuration, which uses just an inductor. Thus a higher gain is obtained.

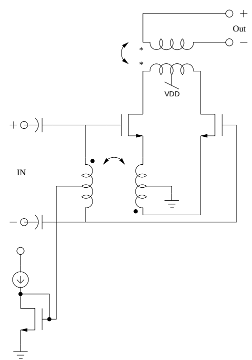

Fig. 5. The LNA input stage is matched using a source degeneration by transformer.

At 60GHz the return path of the current through the ground plain can not be determined accurately. A balance topology had been therefore used. In that way the ground is set accurately and also allows an dc feeding scheme. In Fig. 6 the degeneration transformer is shown.

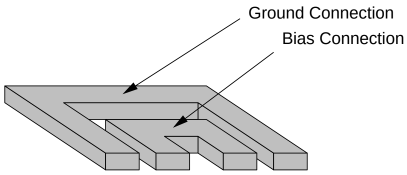

Fig. 6. Source-Gate feedback and degeneration transformer.

The full circuit schematic is seen in Fig. 7. As mentioned before the third stage is used for drive 50Ω load, and the drain-source feedback of the third stage is used to assure stability and for output matching. The value of k that was chosen for the interstage coupling is 0.5.

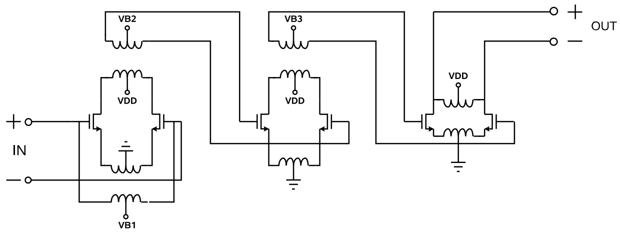

Fig. 7. Three stage LNA with al flat gain

IV. Simulation Results

The circuit has been implemented in $0.13\mu m$ CMOS technology and was simulated under a supply voltage of 1.2V. The simulations were done using Cadence and ADS software. The results are displayed in the following section.

The goal of the design was to obtain a gain flatness of less the 1dB and as can be seen in Fig. 8.

A noise figure flatness is also required from the LNA. The variation over the frequency band is less than 0.5dB (seen in Fig. 9).

The input matching is very important since in high frequency > 40GHz, the use of bond wires is not possible and therefore the antenna will be connected directly to the die, which means that the matching must be done internally. The feedback around the input stage assures that the input matching of $S_{11} < -10$dB ,as can be seen in Fig. 10.

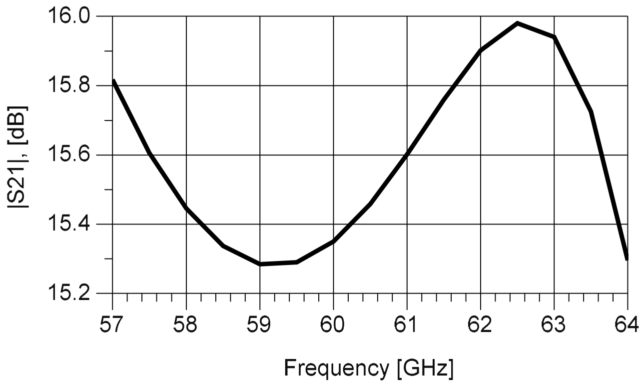

Fig. 8. Simulated Gain

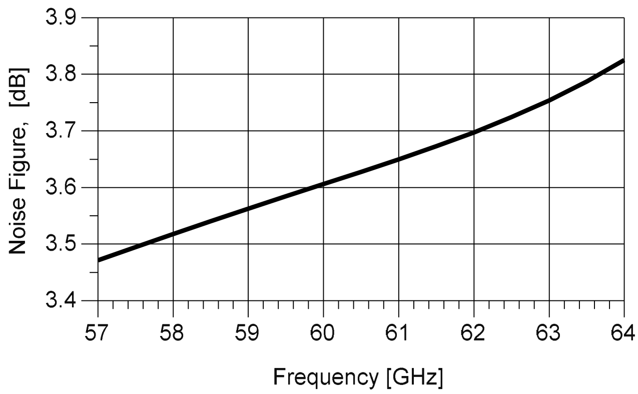

Fig. 9. Simulated Noise Figure

The output matching is as not good as the input (see Fig. 11), but this poses no reason for concern since the circuit is matched only measurement purposes. In the full front end configuration the amplifier will drive a mixer and will require a different type of matching.

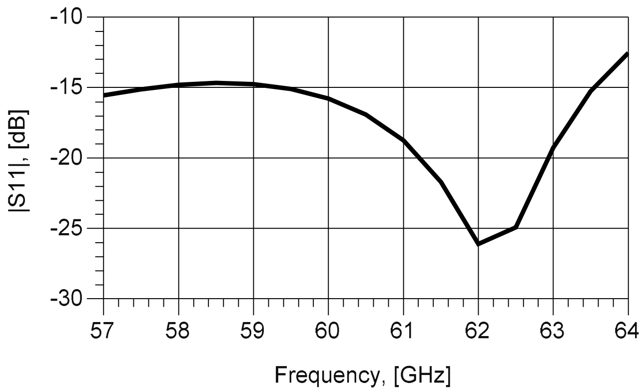

Fig. 10. Simulated Input Matching

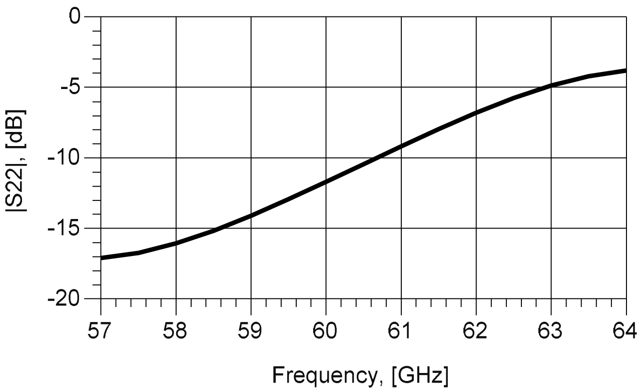

Fig. 11. Simulated Output Matching

V. Conclusions

The LNA has achieved the gain flatness that was required. The coupling coefficient of the interstage matching transformer can be optimized according to the flatness that is needed. In this method a simple CS stages are enough to supply the required gain. A further research should determine if this method would also apply to other topologies such as CG or cascode. The connection between the LNA and the mixer should also be studied and determine if the same method can be applied.

References

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