A 60 GHz diversity LNA in 0.18µm SiGe

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Abstract

A combination low noise amplifier (LNA) and diversity switch (diversity LNA) is presented, allowing the switching between two spatially separated antennas to improve the received SNR in a multipath environment. This 60GHz diversity LNA has a simulated gain of 14.3dB and noise figure of 8.9dB. It is suitable for diversity of reception implementation for a complete system-on-chip (SOC) in the 60GHz band.

1. Introduction

To combat multipath, a diversity LNA has been designed to allow the switching between two antennas in a spatial switched diversity scheme. This diversity LNA has been implemented in Jazz Semiconductor's 0.18µm BiCMOS SiGe process.

The 60GHz band (57 GHz – 64 GHz) has recently attracted attention due to transistor scaling allowing low cost CMOS and SiGe BiCMOS circuits to perform sufficiently well in this unlicensed band [1-5].

Several usage models for this band have been suggested [6], of which, it is the short-range wireless personal area networks (WPAN) this work is targeting. In these short-range high-frequency indoor environments, multipath is viewed as one of the most predominant effects on the received signal.

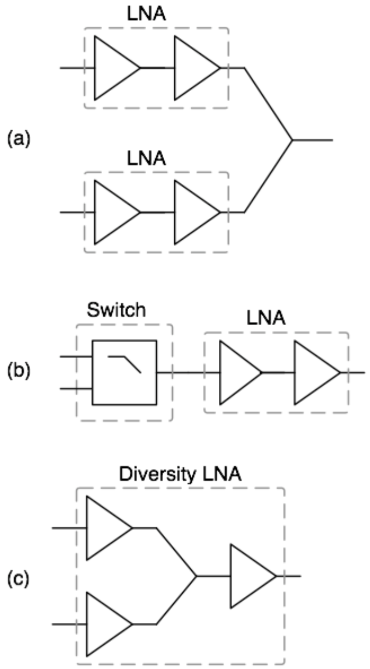

Figure 1. Three switched diversity options: (a) two parallel LNA's; (b) switch & LNA; (c) diversity LNA.

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2. Switched diversity at 60 GHz

Switched diversity is perhaps the simplest implementation of a spatial diversity scheme. It operates by constantly measuring the received signal strength and switching from the current antenna to another when the received signal strength gets too low e.g. in a deep fade. Using this scheme, SNR improvements of up to 6dB [7] are possible with just two antennas.

For a single chip diversity receiver in current consumer bands, such as those at 2.4 GHz and 900 MHz there are three main methods of implementing diversity switching between two antennas.

Fig 1(a) depicts the first solution. It uses two LNA's in parallel where one is connected to each of the antennas. In this case, antenna selection is performed by turning off the unused amplifier, so as to isolate the undesired antenna from the receive path.

Fig 1(b) depicts the second method which is to have a switch connected to both antennas and an LNA following. This solution would typically use less space than the first solution and therefore offer a more compact and cheaper layout. This solution however does introduce loss through the switch and hence increases the system noise figure.

Fig 1(c) shows the third solution which is a hybrid of the first two [8], where the switching can be done inside the LNA. The LNA would comprise of two or more stages with a copy of each of the first stages connected to each of the antennas and the then a second stage connected to both of the first stages. To switch between the two antennas, the unused antenna would have it's first-stage turned off.

At 60 GHz however, the relatively high parasitic capacitance of the active devices in the 0.18μm process mean the switch's (Fig. 1b) isolation is too low and insertion loss is too high. For example, while insertion loss can be an acceptable 0.5 dB at 900 MHz [9], at 20GHz this rises significantly up to 2dB [10] and is even worse at 60GHz. This limits us to the use of the first and third options with the third option becoming the most attractive due to its smaller footprint.

3. Diversity LNA

3.1. Circuit design

This diversity LNA is implemented as a two-stage amplifier. Each antenna is connected to their own first stage while the second stage is common. The switching is performed by turning the undesired's first stage bias voltage to 0V.

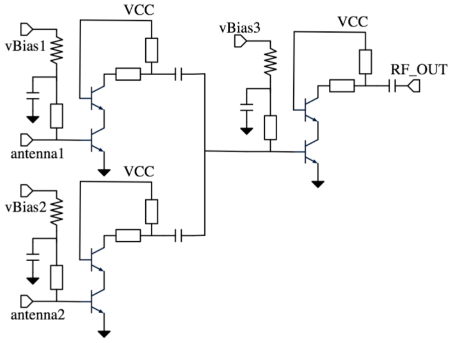

Figure 2. Diversity LNA schematic.

Each stage is implemented as a cascode of two SiGe bipolar transistors to improve the reverse isolation and ease the matching process. Matching is employed throughout the amplifier, at both the input and output of each stage. Due to the relatively high operating frequency compared the transistors unity gain cut-off frequency (f_T), the centre frequency of the matches needed to be somewhat higher (62 GHz) than the centre frequency (60.5 GHz) of the band to compensate for the decreasing gain. With this in mind, the transistors size, bias current and input match has been optimized to achieve the lowest noise figure (NF) overall.

For the input match of the first stage to 50Ω, techniques such as inductive emitter degeneration in [11] that optimally match the input for both return-loss and NF, could have been employed. While these techniques do improve the NF of the first stage, the already low-gain per stage is further decreased which actually reduces the cascaded NF of the 2-stage amplifier.

The inter-stage matching is also performed in a manner to optimise the gain of the entire amplifier. The input of the second stage is matched to the combined outputs of the first stage, where one stage is off and one is on. The output of the second stage was matched to 50Ω in this case. When integrated into a system, it would be conjugately matched to the input of the next stage.

3.2. Active devices

Careful attention was placed on device selection so as to minimise the required input matching network that could achieve both a good S11 and noise match while still drawing a sufficient bias current to achieve an adequate compression point. Through this approach, a good NF and S11 were achieved with only an inductive stub on the input of each stage.

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Due to the high frequency of operation, the parasitics from even the smallest metal traces greatly impact the design. Because of this, extra attention was paid to the layout of each cascode and the required metal traces to connect to the matching networks in order to minimise parasitics. Prior to matching network synthesis, the transistor and interconnects were layed out. This layout then had the parasitic resistances and capacitances extracted and were back annotated into the schematic. It was this 'extracted' version of the cell that was used in the design process as was done in [12].

This methodology of moving parasitic extraction to earlier in the design cycle reduces the number of cycles and effort required – without such early extraction, matching networks would have to be re-designed and layout would have to be altered. As transistor operating frequencies increase and the parasitics associated with small interconnect play a larger role, it would seem prudent in future to take these into account when characterising devices and even in foundry models.

3.3. Passive devices

Due to the short wavelength of 60GHz on-chip of around 2.5 mm, we are able to use transmission lines as well as inductors and capacitors. For inductive elements, transmission lines are preferred as they generally have higher Q's and are easier to work with.

Several different types of transmission lines are realisable on a standard silicon process. These include microstrip and coplanar lines. Care must be taken when routing and meandering not to couple to nearby traces and devices. Not only is coupling generally undesired, it also changes the characteristic impedance of the line and therefore changes its effective length. When this occurs in a matching network the centre frequency of the match will shift.

Transmission line widths were chosen so as to maximise their inductive Q for the given lengths - which translates into having them as narrow as possible whilst still conforming to design rules and supplying sufficient current to the active devices.

Shielded microstrip lines, with a metal shield on each side from the bottom ground plane to the top signal line, overcome some of the problems associated with the implementation of standard microstrip lines. Shielded lines, by virtue of their shield, allow lines to be routed in almost any manner without a change in effective length or characteristic impedance – greatly improving the speed, ease and reliability of circuit layout. A cross-section of the shielded lines that were used is shown in Fig. 3.

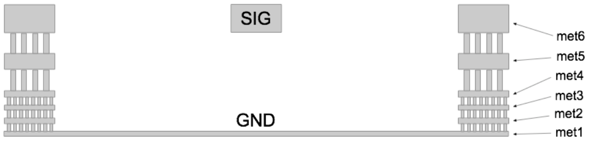

Figure 3. Cross-section of shielded microstrip transmission line.

4. Results

This LNA for diversity applications has been designed in 0.18 μm SiGe and the layout shown in Fig. 4 takes up only 0.32 mm^2 of area. Simulations were performed with one of the first stages turned off so as to be representative of actual use.

Table 1. Simulated performance of diversity LNA at 60GHz.

Gain (S21)	14.3 dB
NF	8.7 dB
P1dB (input referred)	-19.7 dBm
Input Match (S11)	-13.4 dB
Reverse Isolation (S12)	-61.2 dB
Supply Voltage	1.8 V
Power Dissipation	11.7 mW
Active Area	0.32 mm^2
Technology	0.18 μm SiGe
Isolation From Unused Antenna	34.3 dB

Fig. 6 below shows an input match of better than -10 dB and outlines how the output is matched slightly higher than the centre of the band to compensate for the decreasing gain.

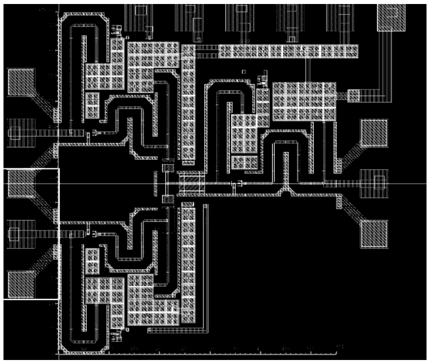

Figure 4. Diversity LNA layout.

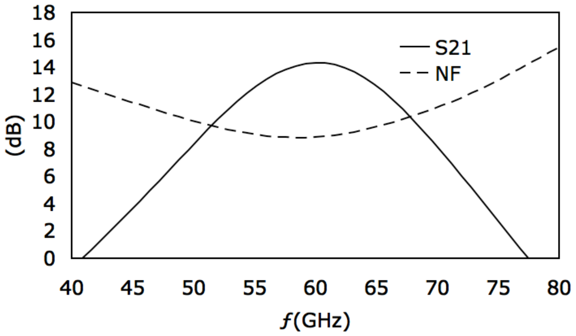

Figure 5. Gain and NF of Diversity LNA.

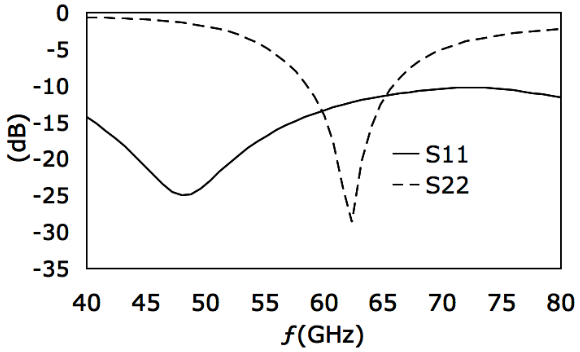

Figure 6. Input and output match of Diversity LNA.

5. Conclusion

To overcome the SNR problems associated with multipath, a diversity receiver scheme can be employed. Traditional MOS based switch's used at lower frequencies have low isolation and too high an insertion loss at 60GHz. To help mitigate to the effects of multipath, a diversity LNA with a simulated 14.3 dB of gain and a NF of 8.7 dB has been presented.

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