

# **A Wideband Variable Gain Amplifier Design for 60GHz Millimeter-wave Receiver\***

Yue Wu, ZhiquanLi<sup>+</sup>, Qin Li, Zhigong Wang

Institute of RF- & OE-ICs, Southeast University, Nanjing, 210096

<sup>+</sup>Corresponding author: [zhiquanli@seu.edu.cn](mailto:zhiquanli@seu.edu.cn)

**Abstract:** This paper presents a wideband variable gain amplifier (VGA) applied to 60GHz millimeter-wave receiver with an operating frequency from DC to 1.08GHz and variable gain range from 0dB to 60dB. The entire VGA consists of an 8dB fixed gain stage, a 0~48dB coarse gain control stage, a 0~12dB fine gain control stage and an output buffer stage. Both the coarse gain control stage and the fine gain control stage adopt open loop amplifier with local feedback. The feedback capacitors are added to compensate the bandwidth of the circuit. The VGA circuit is designed in TSMC 65nm CMOS process. The post simulation results show that: the operating current of the entire VGA with testing buffer is 20mA. The 3dB bandwidth is larger than 1.4GHz. The  $OP_{1dB}$  at 0dB gain is 0 dBm. The whole chip area is  $1.5 \times 0.6 \text{mm}^2$ .

**Key words:** Variable gain amplifier • Wideband • Feedback.

## **1. Introduction**

With the development of multimedia applications, wireless communications require increasing transmission rate and signal bandwidth, demanding the study of 60GHz wireless communications. Since 2000, many countries opened near 60GHz continuous spectrum resources for high-speed wireless communications research and applications. Continuous 5~7GHz of unlicensed spectrum resources greatly stimulated the research and open process of 60GHz wireless communications<sup>[1-2]</sup>.

RF signals received from the antenna have large amplitude variation. In order to make these different signal amplitudes get the correct demodulation, RF

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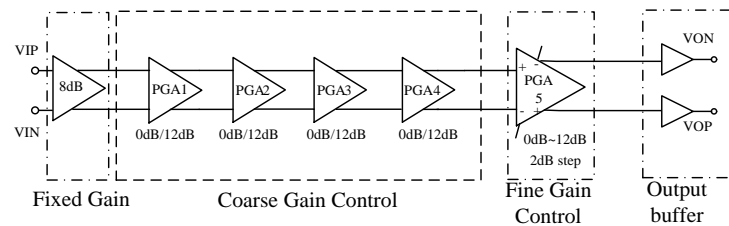
\*Project supported by the National High Technology Research and Development Program (No. 2011AA010202).

receiver chips usually use a variable gain amplifier (VGA) to achieve gain controlling, the control signals of VGA are from the baseband digital signal processor. The VGA is required to adjust the amplitude of the received signal depending on the signal level so as to keep almost constant signal level at the ADC input<sup>[3]</sup>.

This paper presents a wideband VGA with an operating frequency from DC to 1.08GHz, variable gain range from 0dB to 60dB, 2dB gain step, 50 ohms output resistance. The total current consumption is 20 mA.

## 2. VGA Structure

Fig.1 shows the block diagram of the whole VGA. The VGA includes an 8dB fixed gain stage, a 0~48dB coarse gain control stage, a 0~12 dB fine gain control stage, and an output buffer stage. The 0~48dB coarse gain control stage consists of 4 amplifiers, each providing 0dB/12dB gain. The fine gain control stage achieves a gain range of 0~12dB with 2dB gain step. The output buffer provides a 50Ω output resistance to drive the input impedance of high speed ADC. Each stage of the VGA system is AC coupled.

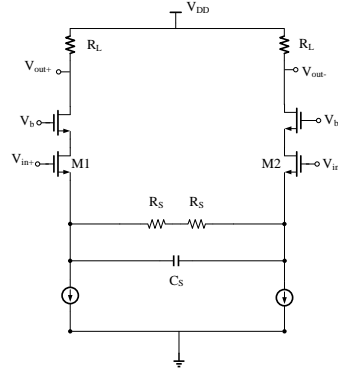


**Fig.1** Block diagram of the proposed VGA

## 3. Circuit Design

### 3.1 8dB Fixed Gain Stage

The schematic of the 8dB fixed gain stage is shown in Fig.2.



**Fig.2**Schematic of the 8dB fixed gain stage

The main purpose of the 8dB fixed gain stage is to compensate the gain loss of the output buffer. The topology of the 8dB fixed gain stage is a cascode amplifier with source degeneration. The feedback resistor  $R_S$  can improve the linearity and the feedback capacitor can increase the bandwidth. But pay attention that a too large  $C_S$  could make the circuit unstable.

### 3.2 Amplifier Design for Coarse Gain Control Stage

Four same amplifiers are cascaded to form the coarse gain control stage. The topology of the amplifiers is shown as Fig.3. The amplifiers use open loop structure with local feedback<sup>[4]</sup>. Compared to the closed loop structure with operational amplifier, Open-loop amplifiers are suitable for low power and broadband applications<sup>[5]</sup>. The input stage of the circuit is a transconductance amplifier which converts the input voltage into small signal current. The small signal current is copied by the current mirror and converted to voltage by the output stage. For this circuit different gain can be achieved by changing  $R_S$  ( $R_{S1}$  in parallel with  $R_{S2}$ ) or  $R_L$ .

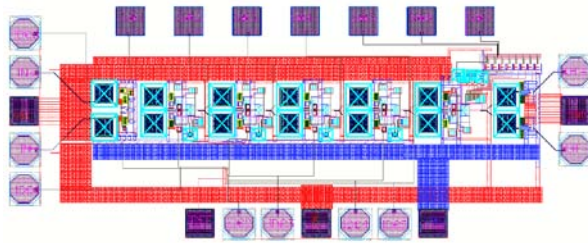


### 3.3 Amplifier Design for FineGain Control Stage

### 3.3 Output Buffer

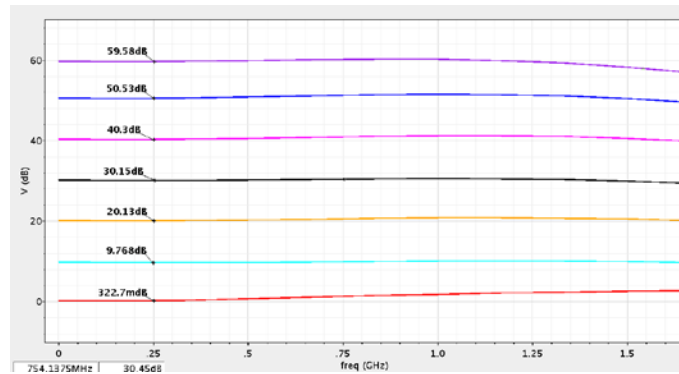
## 4. LAYOUT AND SIMULATION RESULTS

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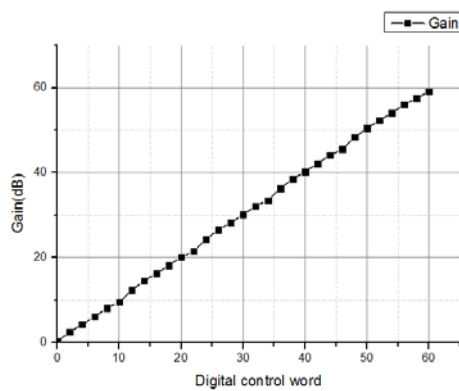
**Fig.5**Layout of variable gain amplifier

Using Cadence Spectre simulation tools, the post simulation is run under TT corner, temperature 27°C. The post simulation result shows that the working current of VGA is 20mA. The amplitude frequency characteristic curves at 7 different gain steps are shown as Fig.6. The bandwidth of VGA is up to 1.4GHz.



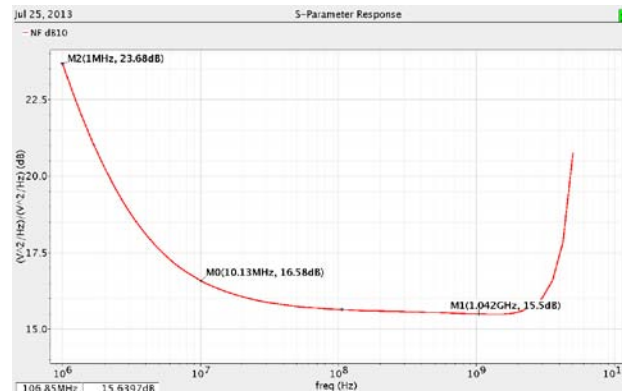
**Fig.6** Post simulation results of amplitude frequency characteristic curve of VGA

Fig.7 shows the overall VGA gain at different digital control words for 250MHz signal.



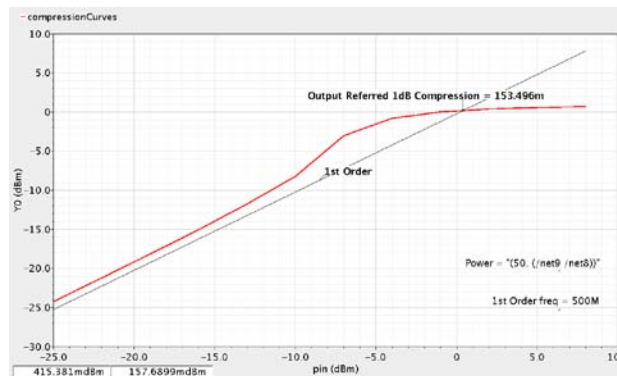
**Fig.7** Post simulation results of gain at different control word of VGA

Post simulation of noise figure at 60dB gain is shown as Fig.8. The NF is large at frequencies below 10MHz due to flicker noise. The NF is below 16.6dB at frequencies from 10MHz to 1.08GHz.



**Fig.8** Post simulation of noise figure at 60dB gain

The post-simulation result of output 1dB compression point at 0dB gain is shown as Fig.9. The output 1dB compression point at 0dB gain is 0dBm.



**Fig.9**Post simulation result of output 1dB compression point at 0dB gain

Table 1 is the summary of the post simulation results of the proposed VGA.

**Table 1**Summary of the VGA post-simulation results

Technology	65nm CMOS
Supply Voltage	1.2V
Gain Range	0-60dB
Gain step	1.4-2.86dB
OP <sub>1dB</sub>	0dBm@0dB gain
NF	16.6dB@60dB gain
Current dissipation	20mA

## 5. Summary

A wideband variable gain amplifier for 60GHz millimeter-wave receiver has been implemented in 65nm CMOS technology. The whole VGA circuit consumes 20mA current under 1.2V supply voltage. Simulation results show that the bandwidth can be up to 1.4GHz and the variable gain range is from 0dB to 60dB with 2dB step. The noise figure is below 18.8dB from 10MHz to 1.08GHz at 60dB gain. The output 1dB compression point is 0dBm at 0dB gain.

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