Signal Conditioning ASIC for the Detection of Combustible Gases

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Abstract

In this paper, the signal conditioning ASIC has been designed for transferring the information regarding gas concentration from the hazardous environment of coal mines to the control room. The ASIC is designed to avoid danger in the hazardous working environment with features like high operating temperature, faster response, high sensitivity, and low power consumption. For the desired application, the different modules for ASIC including Low Noise Amplifier (LNA), Voltage Controlled Oscillator (VCO), and Zero Crossing Detector integrated with a buffer are designed based on 180nm CMOS technology node using SCL pdk files on Cadence Virtuoso tool. The overall power consumption of the designed ASIC is 3.92mW with a gain of ~15 and a frequency range of 10KHz to 200KHz for 0.1% gas concentration for a sensor with the operating temperature of ~150^{o}C. The final output of the ASIC is 0V to 1.8V of the square wave which can be further transmitted to the control room.

Keywords: Low Noise Amplifier, Zero Crossing Detector, ASIC, Voltage Controlled Oscillator

1 Introduction

Combustible gases are a major concern with residential, commercial premises and gas-powered measures to avoid danger associated with it. Generally, various sensors are utilized for the monitoring of inflammable and poisonous gases. Specially, in a tricky environment like coal mines where it is very harmful for human beings to crave up the rocks which naturally emits toxic gases and chemicals. Such a system required continuous monitoring. For such a working environment, sensors are required with features like high operating temperature, faster response, high sensitivity, and low power consumption [1]. Several MEMS technology-based sensors are reported [2] for this type of environment, but still, where continuous monitoring is required for hazardous gases it is usually recommendable to have sensor platform integrated with a signal-processing unit. That system must be capable of amplify as well as modify low level signals from the sensors and transmitting these signals to a remote-control station.

The need for such sensors triggers interest of various research groups in monitoring system design. Earlier, many sensors specific CMOS based system with high operating temperature and low power consumption are reported. Graf et.al reported gas sensor system integrated with linearizing output voltage circuit [3]. Carbon monoxide detection sensor system associated with an oscillator circuit for voltage to frequency conversion which provides an improved resolution has also been reported [4].

This work is mainly focused to design a cost-effective ASIC, that will take input from a combustible gas sensor in the premise and convert it to a signal that can be transmitted to a remote location for further analysis. This system can be used to monitor combustible gases to avoid fire accidents providing safety features etc. This ASIC is designed to exhibit high sensitivity for primarily butane, iso-butane, propane, methane which are major constituents of combustible gases. This has been achieved all the way through the combination of sensor harvest with a Low Noise Amplifier (LNA) incorporated with a Voltage Controlled

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Oscillator (VCO). The 180 nm CMOS technology has been used to design this ASIC. The frequency signal from Voltage Controlled Oscillator (VCO) about the gas leakage can be transmitted to the remote control station. The output of Voltage Controlled Oscillator (VCO) is converted to a square wave using zero crossing detector modulated through output buffer to industrially accessible transceivers.

2 Design and Simulation of Different Modules in Signal Conditioning ASIC

The Signal Conditioning ASIC design is based on a Hybrid gas sensor which is used for sensing and further the information is transmitted through the GSM module as shown in Fig.1. To obtain the change in gas concentration of 0.1% with a voltage range of 40mV to 100mV, a standard IC chip with a constant current source is implemented so that the gas sensor can be driven. The schematic of the ASIC is consisting of a Low Noise Amplifier (LNA) which is used to amplify the output of gas sensor through a level shifter and provides a control voltage range of 0.4V to 1.4V to the Voltage Controlled Oscillator. Further, this Voltage Controlled Oscillator (VCO) is used to convert voltage range into a suitable frequency range required for signal transmission. The output of Voltage Controlled Oscillator (VCO) is modulated to a square wave of desirable range through a Zero Crossing Detector integrated with an output buffer for the ease of further processing of the signal. Thus, in this complete study, the design and implementation of these above mentioned modules with their results are discussed.

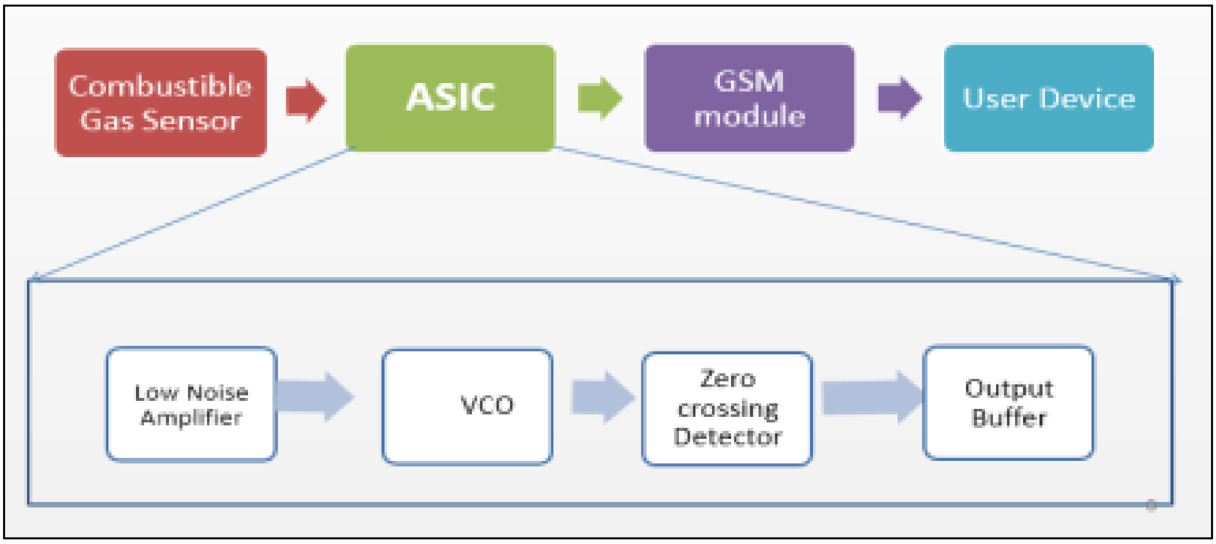

Fig.1: A complete block diagram of system hybrid with a gas sensor, signal conditioning ASIC and the GSM module for the transmission.

2.1 Low Noise Amplifier

This Low Noise Amplifier (LNA) is the combination of level shifter and a two stage non inverting amplifier. The output from the gas sensor is applied to a level shifter which provides a dc bias of 1.2V and the corresponding obtained signal is applied to a two stage non-inverting Amplifier as shown in Fig.2. This configuration has been selected for the better gain of ~15 along with appropriate input resistance and feedback [5-9]. To bring down the equivalent noise, the responses are registered to PMOS in the circuitry. The key element of the noise is flicker noise and it is underneath in the PMOS transistors. The open loop is applied through a feedback resistor to the closed loop configuration to obtain a gain of 15 as demonstrated in Fig.2. This design is simulated utilizing 180nm CMOS technology SCL pdk files using 1.8V power supply in Cadence Virtuoso tool [10,11]. The complete layout is shown in Fig. 3 [12]. The simulation results of the Low Noise amplifier is shown in Fig.4 and a gain of 14.9 is obtained. The noise voltage of 2-7$\mu V/Hz^{1/2}$ has been obtained for designed Low Noise Amplifier (LNA).

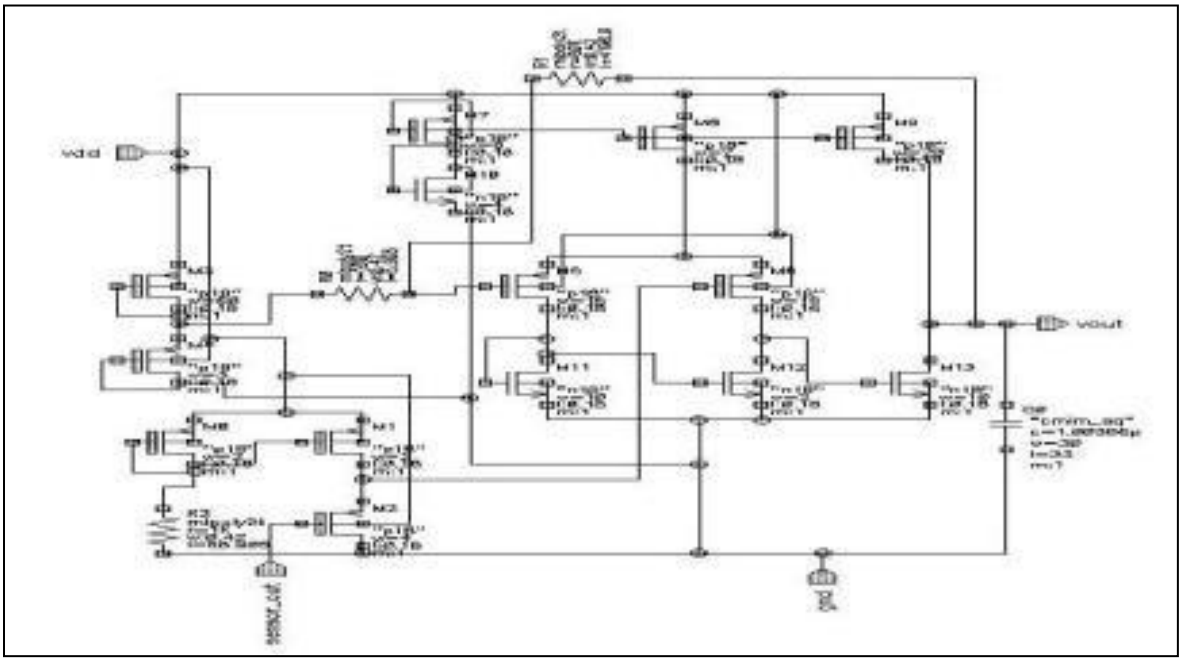

Fig. 2: Schematic of the level shifter integrated with low noise amplifier.

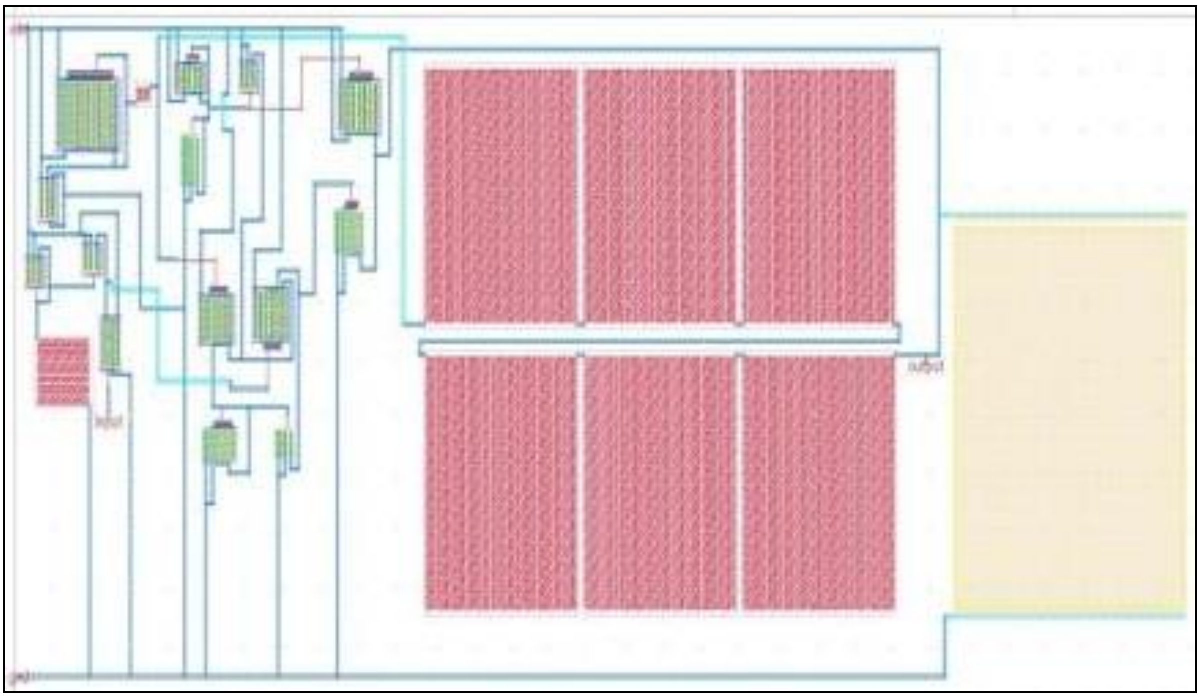

Fig. 3: Layout of the level shifter integrated with low noise amplifier.

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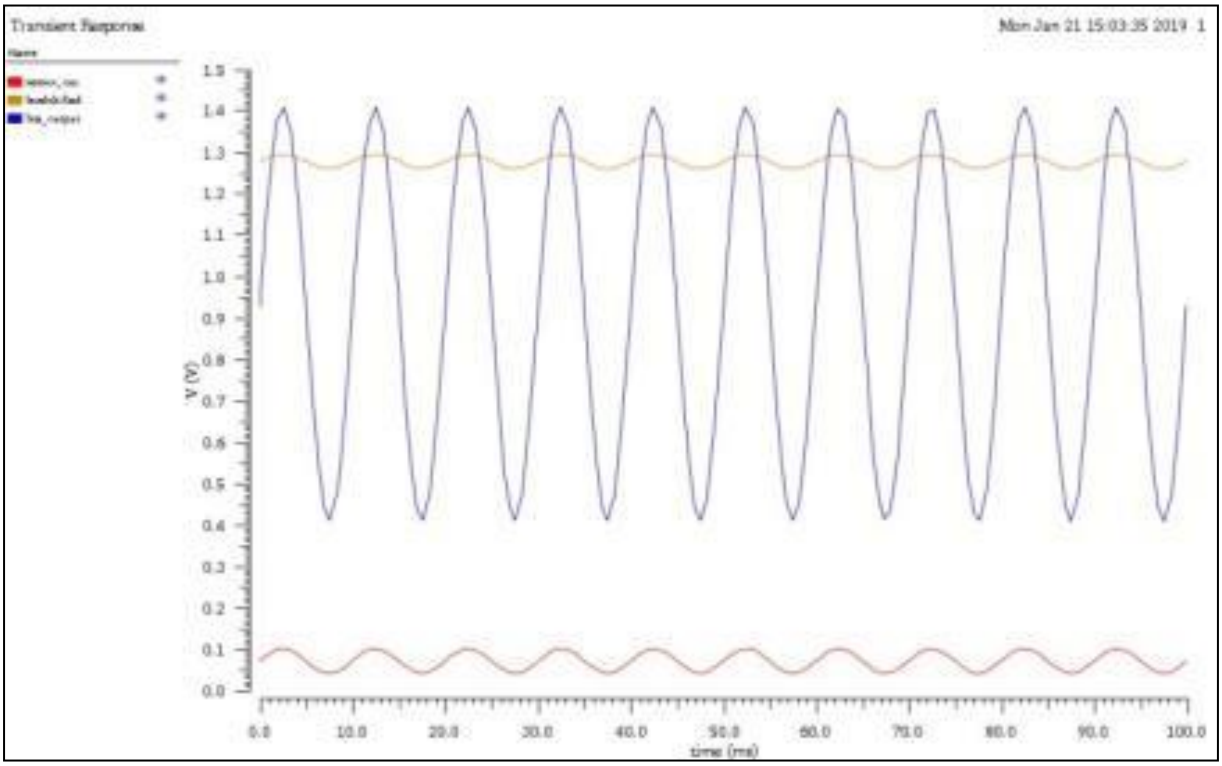

Fig. 4: Simulation results of the amplifier.

2.2 Voltage Controlled Oscillator

The output of amplifier is employed at the response of Voltage Controlled Oscillator (VCO) which act as a tuning voltage [13,14]. The schematic of VCO is designed considering important metrics such as: wide tuning range, low power consumption and tuning frequency ranging from 10KHz to 200KHz to meet up with desired resolution of detecting 0.1% concentration of gas [2,5,6]. The schematic and layout of designed VCO is shown in Fig. 5 & 6 respectively designed using 180nm CMOS technology SCL pdk files [10-12]. The extracted transient response for VCO is shown in Fig. 7 and the frequency sensitivity with control voltage is demonstrated in Fig. 8. The frequency sensitivity of 218 KHz /V has been obtained for the designed VCO.

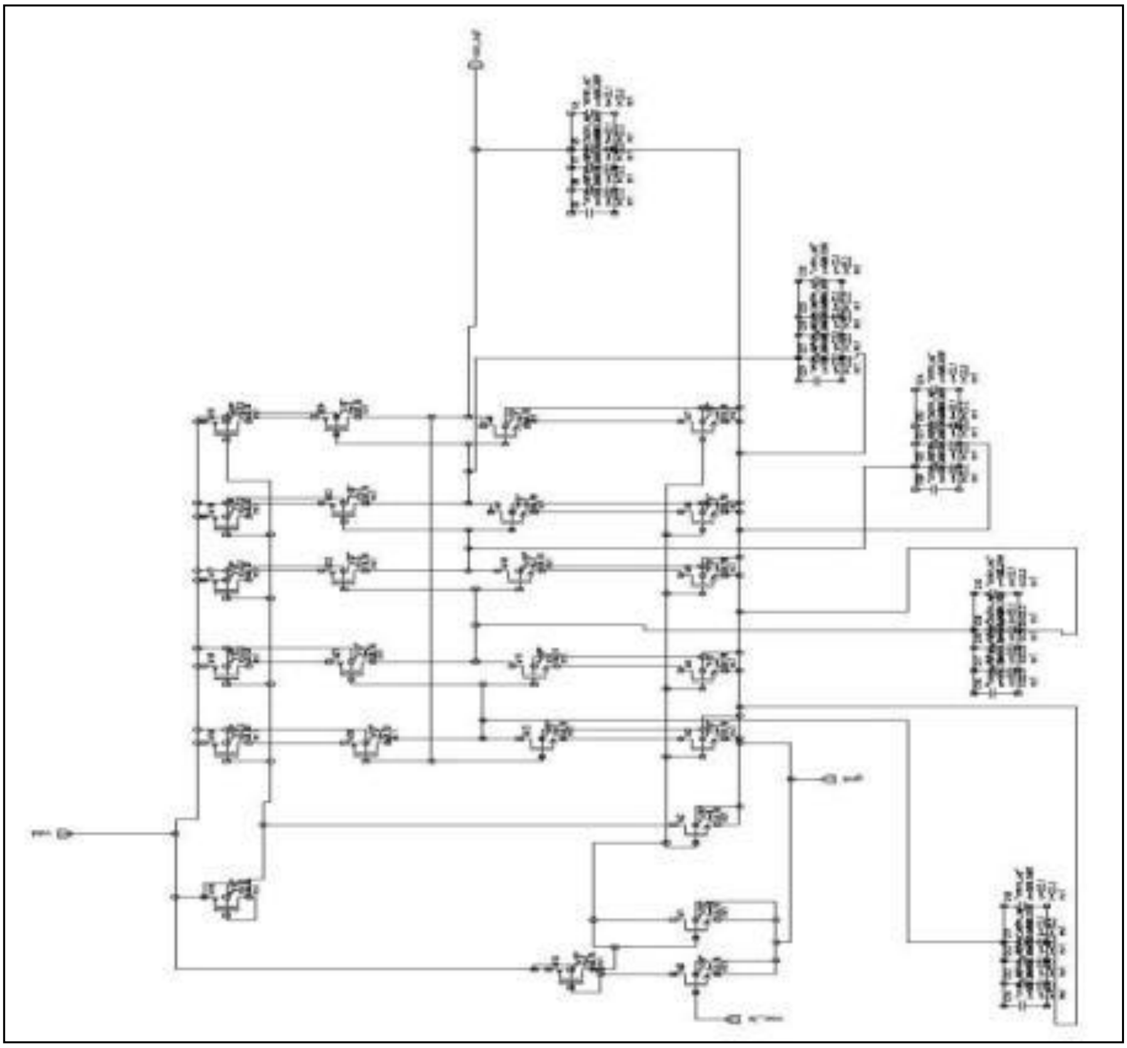

Fig. 5: Schematic of the Voltage Controlled Oscillator.

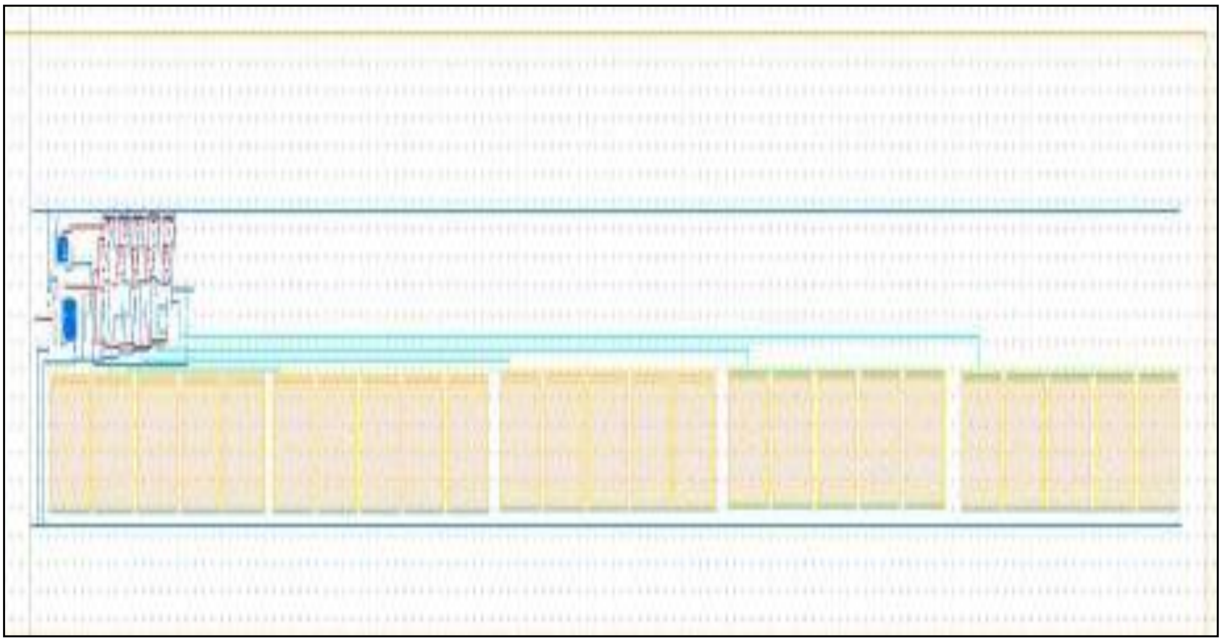

Fig. 6: Layout of the Voltage Controlled Oscillator.

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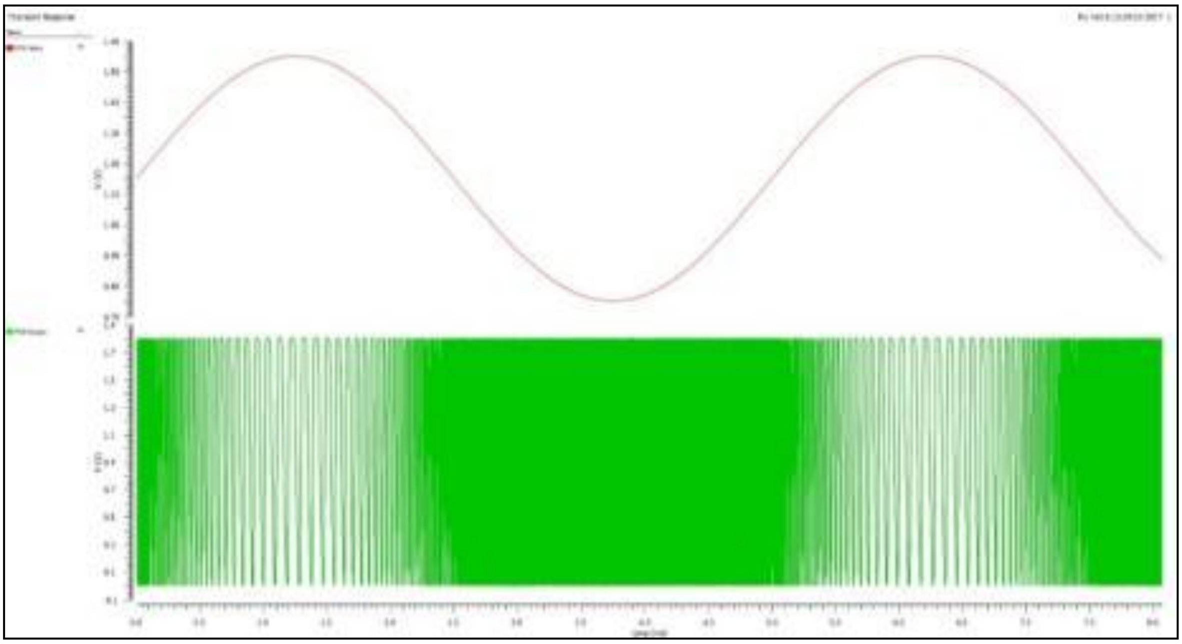

Fig. 7: Transient response of Voltage Controlled Oscillator.

2.3 Zero Crossing Detector with Output Buffer

The output obtained from the VCO is used as input for zero crossing detector to convert sinusoidal wave into square wave and further derived output of 0V to 1.8V of square wave through the capacitive load output buffer [15-18]. This schematic is consisting of a comparator with differential amplifier which is designed using 180nm CMOS technology with SCL pdk files is shown in Fig. 8 and the respective layout is shown in Fig. 9 [12-14]. The extracted simulation results are illustrated in Fig. 10.

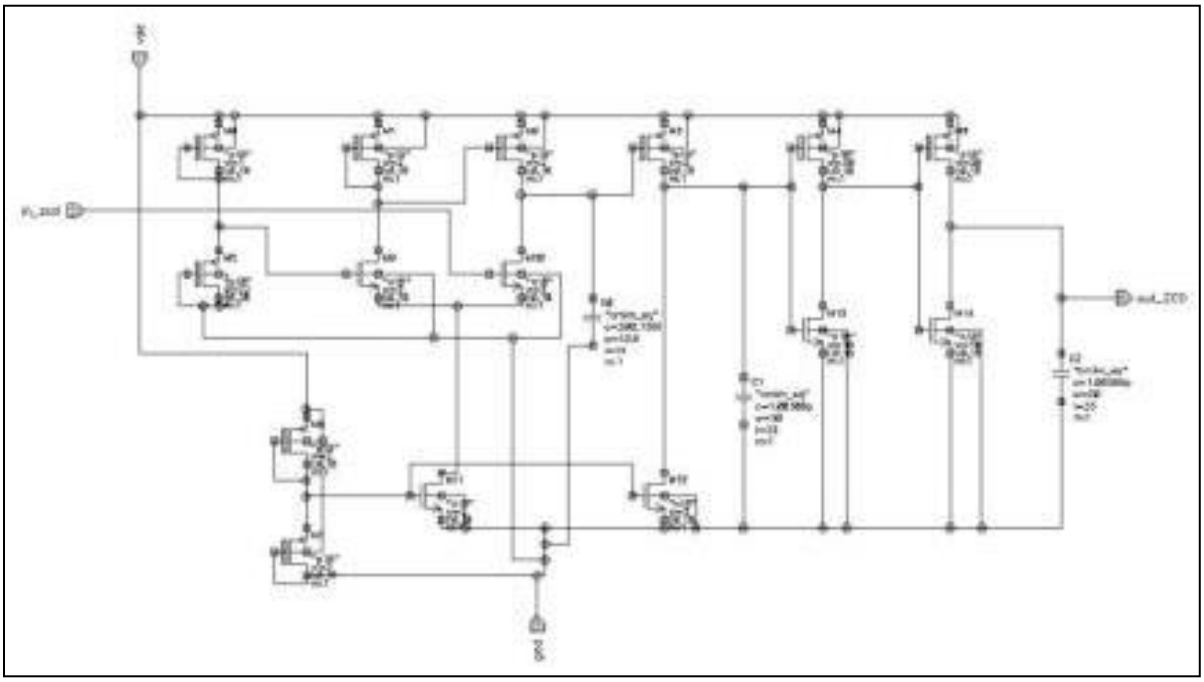

Fig.8: Schematic of zero crossing detector integrated with output buffer.

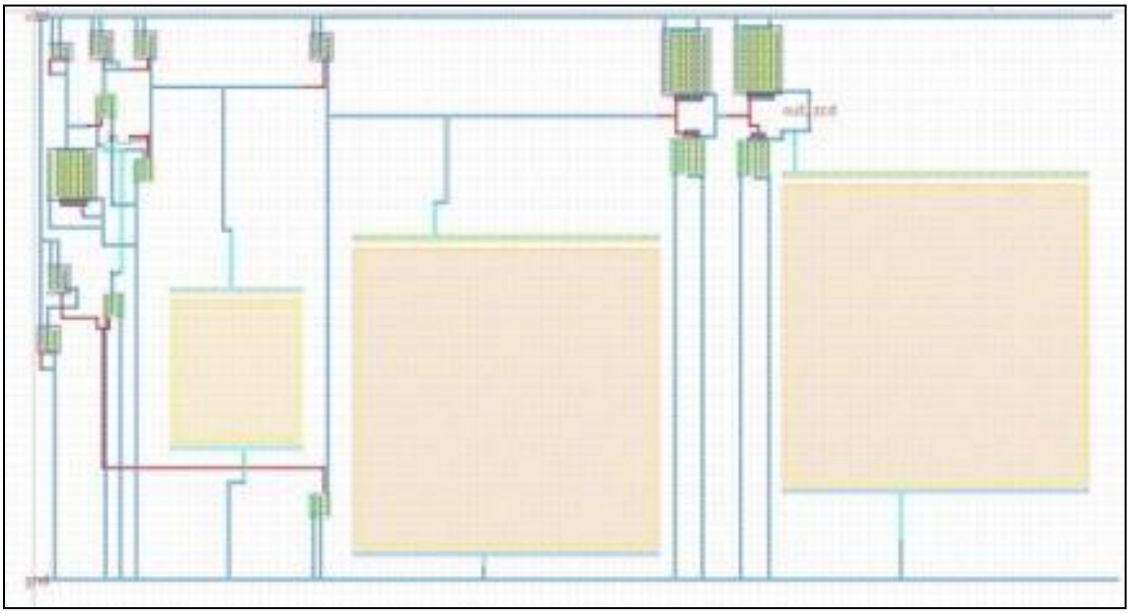

Fig.9: Layout of zero crossing detector integrated with output buffer.

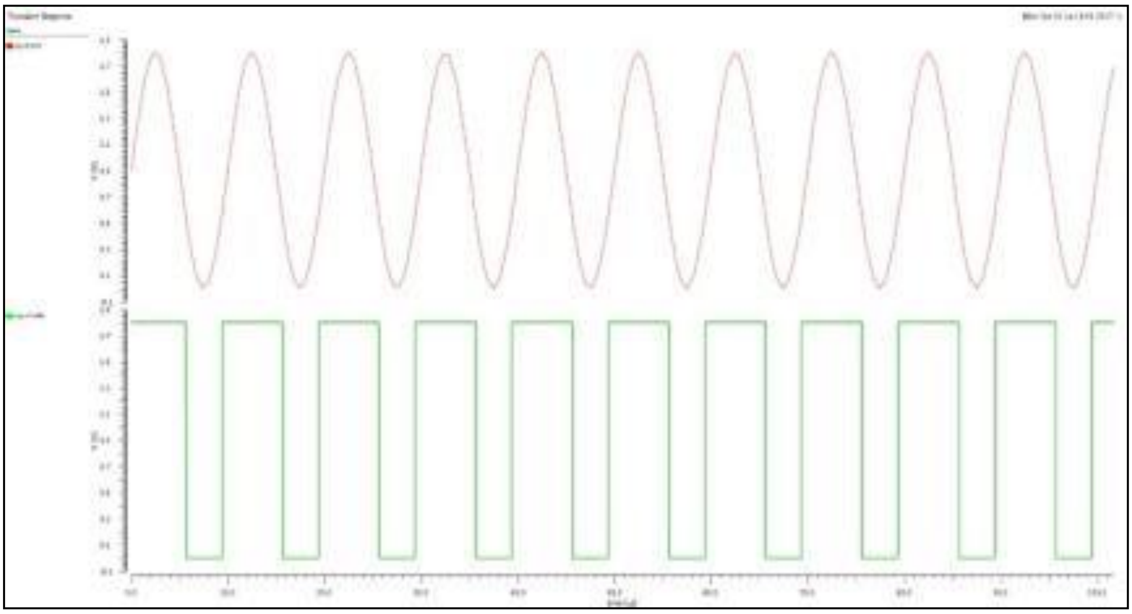

Fig.10: Transient response of zero crossing detector integrated with output buffer.

2.4 Results of overall signal conditioning ASIC design

The schematic of overall signal conditioning ASIC design as shown in Fig. 11. This ASIC is consisting of LNA which take input from sensor and amplifies the signal of 40mV to 100mV to signal of 0.4V to 1.4V with a gain of 14.9. The second stage of ASIC generates a sinusoidal output of frequency ranging from 10 KHz to 200 KHz and then it passes through a Zero Crossing Detector integrated with output buffer. Finally, a square wave of 0V to 1.8 V is obtained that can be used for further transmission. The overall power consumption of this ASIC is 3.92mW with an operating voltage of 1.8V. Transient response for overall ASIC is shown in the Fig. 12.

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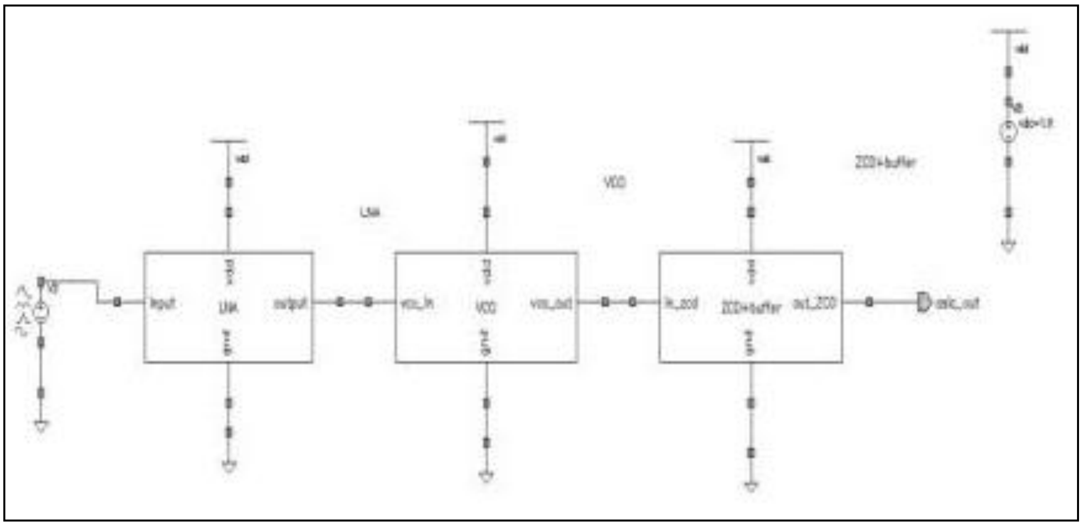

Fig. 11: Schematic of overall ASIC using symbols of all modules.

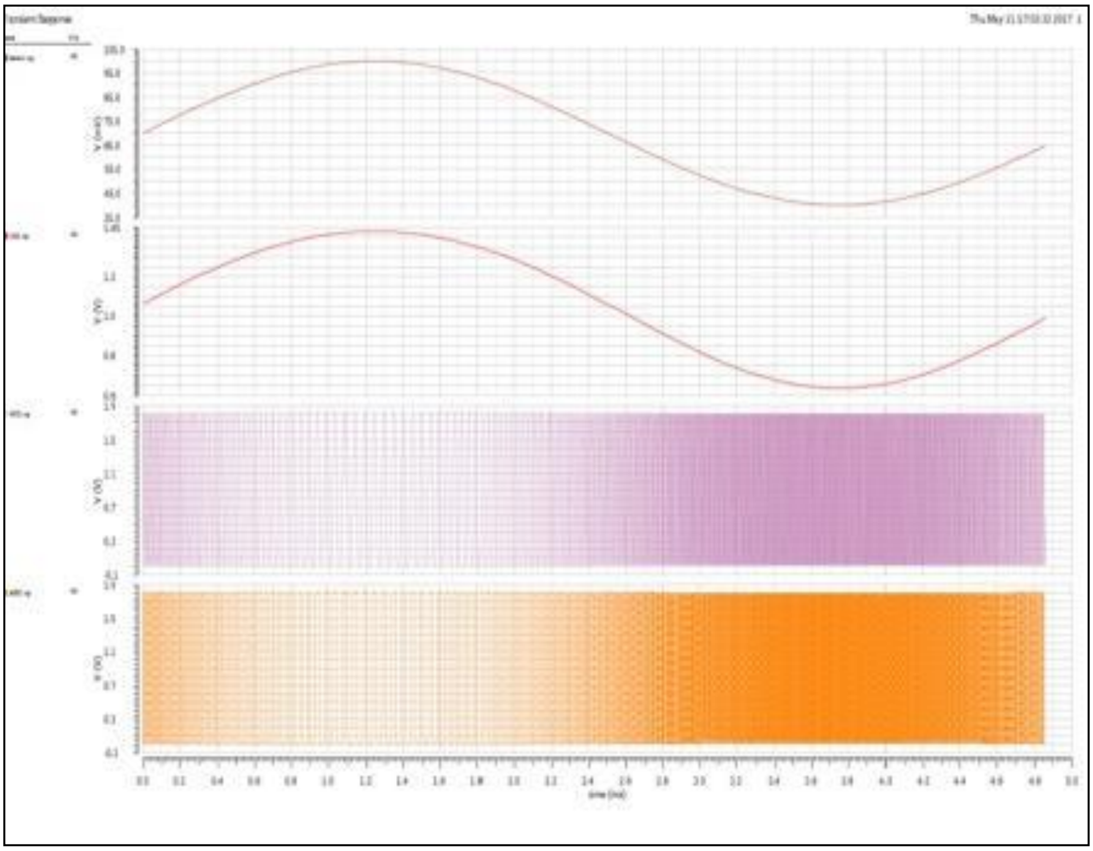

Fig. 12: Transient response of overall ASIC.

3 Conclusion

This work is focused on design a monitoring system for inflammable poisonous gases detection for 0.1% change in the gas concentration. To this purpose, an ASIC based on 180 nm CMOS technology node is designed using SCL pdk files in Cadence Virtuoso tool. The different modules of ASIC including Low Noise Amplifier (LNA), Voltage Controlled Oscillator (VCO) and Zero Crossing Detector integrated with an output buffer has been designed and then simulated. The overall power consumption of the chip is 3.92mW and acquired noise voltage for the low noise amplifier is 2-7μV/Hz$^{1/2}$ with a gain of 14.9 and tuning frequency range of VCO is 10 KHz to 200 KHz to meet up desired resolution. The output of the VCO is passed through zero crossing detector integrated with output buffer and further derived an output of 0V to 1.8V of square wave through the capacitive load which can be transmitted to the control room. The designed ASIC is cost effective monitoring system with low power consumption for the safety purpose from the hazardous gases.

4 Acknowledgment

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