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FINFETLOW POWER CAPACITIVE PRESSURE SENSOR READOUT CIRCUIT

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ABSTRACT

This paper introduces a low power readout circuit for MEMS capacitive pressure sensor in industrial wireless sensing supplications. The proposed design relies on using FinFET technology in implementing a capacitance to frequency converter. The transmission frequency is chosen in the 2.4 GHz ISM band to allow for wireless transmission of measured pressure data in a near-field communication or a short range wireless sensor network. The results showed a pressure range of 10to 20 MPa (100 to 200 atm) under power consumption around214 µW.

KEYWORDS: FinFET, Low Power, Ring Oscillator, SiC Pressure Sensor

I. INTRODUCTION

Among the different techniques usually used to reduce power consumption in custom circuits is to replace the conventional CMOS MOSFETs by FinFETs. Basically FinFETs have low leakage current and negligible short channel effects leading to low power consumption [1]. Low power operation is essential for extending the life time of a wireless sensor networks. In this paper we address industrial-level pressure wireless sensors based on MEMS capacitive structures made of silicon carbide (SiC) to withstand high pressures [2]. Among the advantages of SiC MEMS capacitive pressure sensors we have high accuracy, low temperature coefficient and low power consumption. The main block in such systems is the low power readout circuit that converts the pressure-dependent capacitanceinto frequency. Two techniques can do the C-to-f conversion; LC oscillators and ring oscillators. Ring oscillators are the simplest among the two due to the absence of integrated inductors and noncritical transistor sizing. Ring oscillators show higher potential for low area low power design than LC oscillators.

The paper is organized as follows. Section II introduces the MEMS capacitive pressure sensor based on SiC technology and its performance. Section III addresses the FinFET models used in this design.

Next section describes the proposed FinFET ring oscillator and its simulation results. Discussion and conclusion then followed in section V. Finally we give future work to complete the proposed idea.

II. MEMS SIC CAPACITIVE PRESSURE SENSOR

The MEMS capacitive pressure sensor used in this work is shown in Figure 1. It consists of a SiC circular diaphragm of radius a_o and height h separated by an air gap g from a dielectric of thickness t_d on top of a Si substrate [3]. The deflection of the SiC thin diaphragm depends on the applied external pressure which consequently changes the capacitance between the diaphragm and the substrate. As shown in Figure 1 there are two modes of operation depending on the pressure range; the non-contact and the touch modes. Capacitive sensor types are preferred over piezoelectric or piezoresistive types because they are compatible with standard chip fabrication technology, insensitive to temperature, consume low static power andgenerate low electronic noise.

With the following structural parameters: a_o =350 µm, t_d= 0.35 µm , g= 8 µm and h= 30µm, the capacitance-pressure C(P) characteristic of Figure 2 is obtained using an internally developed analytical model[4] for pressures from 100 to 200 atm exhibiting slight nonlinearity. The circuit design will use a simple technique to linearize the C (P) curve.

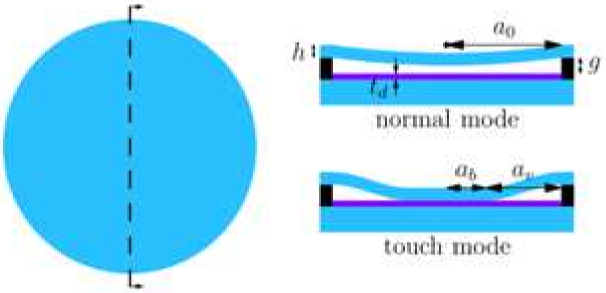


Figure 1: MEMS Capacitive Pressure Sensor

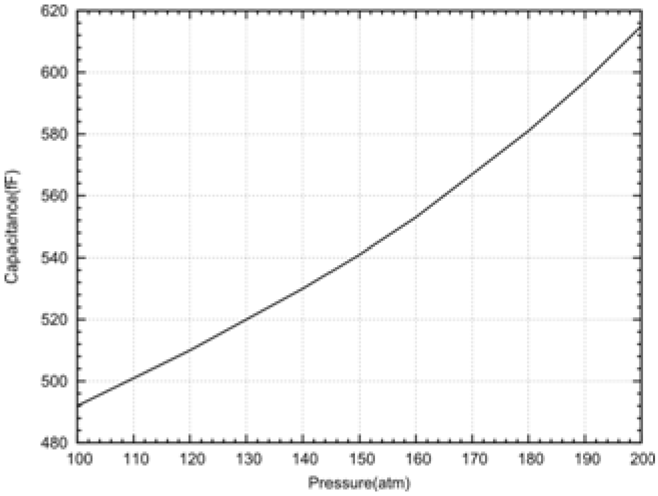


Figure 2: C (P) Characteristic

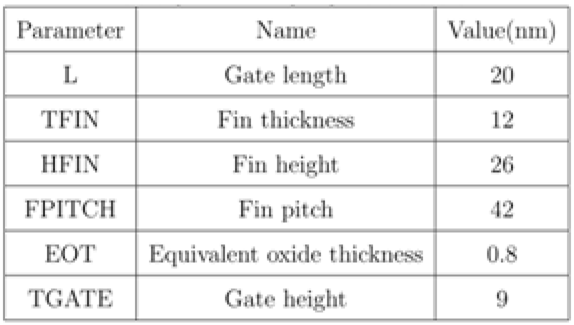
III. FINFET MODELING

FinFET technology is one of the promising choices to extend standard planar CMOS scaling beyond the 20 nm node. The main advantage of FinFET technology is the enhanced control of short channel effects. This is attributed to many factors including fully depletion of the thin fins, reduction of dopant randomness, mobility enhancement, and reduction in parasitic capacitances, area, leakage and power.

In this work we have used the open-source model known under the name of BSIM-CMG developed in Berkeley for Common Multi-Gate transistors [5].More specifically we considered the tri-gate (TG) FinFET BSIM-CMG model with model parameters taken from the Predictive Technology Model PTM developed in Arizona State University for sub-20 nm devices [6].

Table [1] below gives the key parameters used; their definition (see Figure [3]) and assigned values for the 16 nm FinFET technology used in this work.

Table 1: PTM – CMG Parameters



Parameter	Name	Value(nm)
L	Gate length	20
TFIN	Fin thickness	12
HFIN	Fin height	26
FPITCH	Fin pitch	42
EOT	Equivalent oxide thickness	0.8
TGATE	Gate height	9

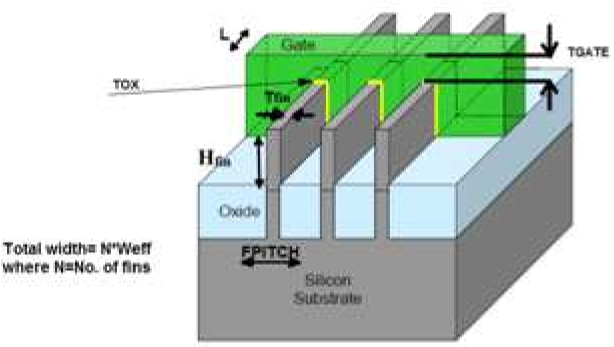


Figure 3: (a) 3D View Showing the Key Parameter in Table [1]

Iv. Proposed Ring Oscillator Design and Simulation Results

The ring oscillator is simply based on cascading odd number of delay inverters with output-input positive feedback. The oscillation frequency is basically dependent on the delay of the inverter (T_{inv}). There are 5 design parameters that can tune the output frequency to within the chosen 2.4 GHz band. These parameters are: the number of inverter stages, the voltage supply, the size of the sensor's driver stage (last stage in the inverter chain), the size of all other stages and the capacitive loading on the different stages.

As shown in Figure [1] a capacitance variation of 123 fF results in an output frequency variation given by:

$$\Delta f_{osc} = \frac{-f_{osc}}{C} \times \Delta C$$

This gives a variation of 557 MHz in the output frequency which is bigger than the 100 MHz band allowed for the 2.4 GHz standard. Therefore a linearizing capacitor of 153fF is connected in series with the sensor to limit the variation in the output frequency to almost 50 MHz around the center frequency. The remaining 50 MHz is assumed to be a sufficient margin to allow for any practical PVT variation. The output peak to peak voltage has been designed to get almost 80% of the supply voltage fixed at 0.9 V. This is achieved by proper sizing of the sensor's driver. The block diagram of the proposed design is given in Figure [4]. It consists of 5 stages with the number of fins for both N- and P-MOS transistors as indicated. This fin counts give NMOS widths of 704 nm for the sensor's driver stage, 64nm for the other stages, Wp/Wn = 1 and L = 20 nm for all devices. The last stage is loaded with the linearized sensor capacitance and all other inverters were loaded with NMOS capacitors.

The simulated waveforms can be obtained at the different nodes. The last stage input and output signals are as shown in Figure [5].The frequency of the output signal vs. the pressure is given in Figure [6] exhibiting acceptable linearity. The consumed power is in the range of 214 μW (varies from 209 to 217 μW according to the output frequency) assuming continuous operation.

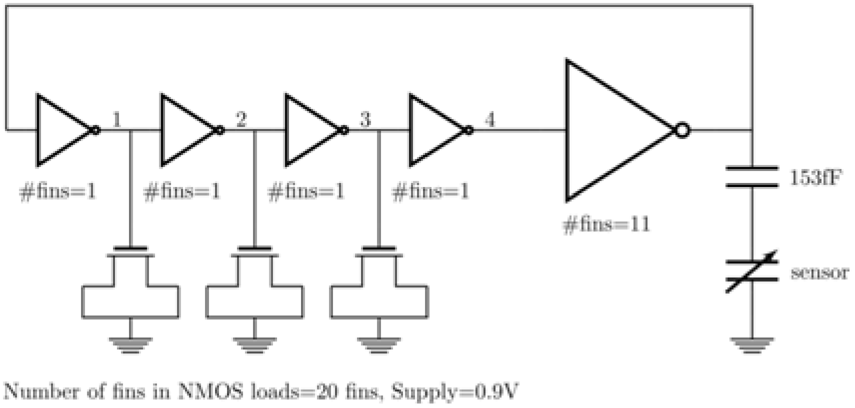


Figure 4: Proposed FinFET C-to-f Converter

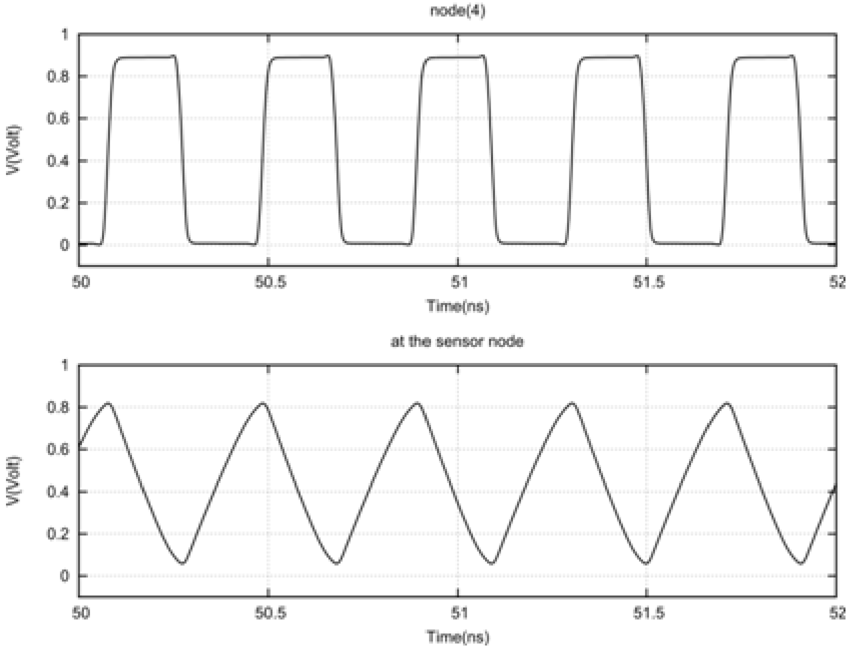


Figure 5: Sensor’s Driver Input and Output Waveforms

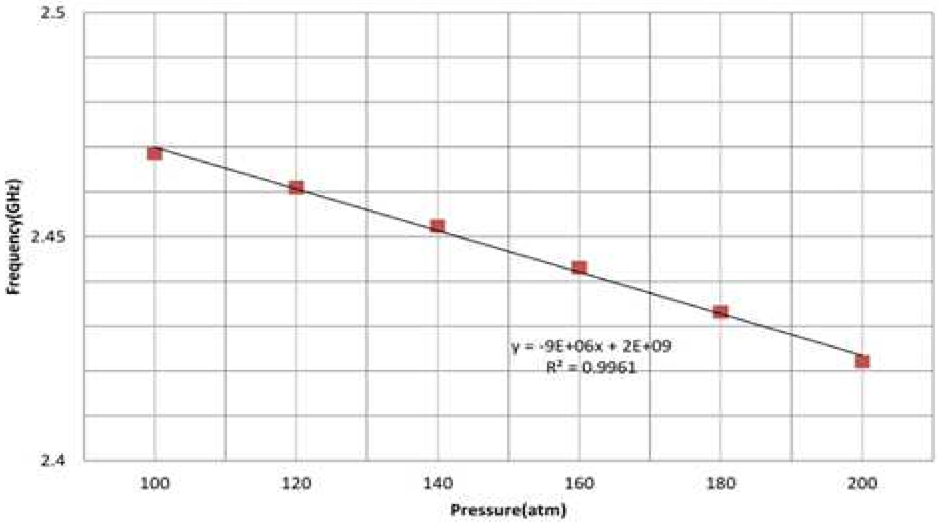


Figure 6: Output Frequency vs. Pressure

V. DISCUSSIONS AND CONCLUSIONS

In this paper, a 16 nm FinFET capacitance to frequency converter for industrial pressure sensing has been designed. The design adapts the ring oscillator architecture with 5 stages loaded with a linearized SiCMEMS capacitive pressure transducer for harsh high pressure industrial applications. The main characteristics obtained are: pressure range from 100 to 200 atm, sensor capacitance variation from 490 to 615fF, output frequency range from around 2.42 to 2.47 GHz, power consumption from 209 to 217 µW in contentious operation, sensitivity of 0.5MHz/atm, resolution of 20atm as a result of the used 8-bit frequency counter [7], and supply of 0.9V.This pressure range is typical in control systems of chemical industries especially in Ammonia production plants [8].The targeted low power consumption is directly related to higher reliability and lower cost. Other features of this device is its high long term stability related to the utilization of SiC, response agility (a sudden change of 100 atm takes 0.25ns for output frequency to stabilize), and high overload characteristics(the pressure for the touch mode is equal to 300 atm and SiC membrane breaking pressure is 21GPa[9]).

In order to demonstrate the potential of FinFET in reducing power consumption a reference ring oscillator design using 50 nm CMOS technology [10] is reproduced with replacing all the transistors with 20 nm FinFETs adjusted in the number of fins to give the same oscillation frequency at 2.6 GHz. The reference design consumes 64 µW while the FinFET one consumes about 1/3rd of this value (20 µW) [7].It is worth mentioning that the proposed ring oscillator has non-symmetric capacitive loading. The last stage load which includes the sensor is different from that of the previous stages. The values of all added capacitors other than the sensor are chosen to adjust the output characteristics to that shown in Figure [6]

In conclusion the proposed FinFET pressure-to-frequency converter following the SiC capacitive pressure sensor is promising for industrial applications in terms of the high pressure level and low power consumption.

To complete the characterization of the proposed design we need to study its robustness against PVT variations. FinFET process parameter dispersion would be available through measurement or published data. Supply variation can be limited by introducing a FinFET band-gap reference [11]. Finally the temperature effect has to be assessed and compensated by proper circuit techniques [12].

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