Noise reduction in hybrid CMOS-NEMS oscillators

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Abstract. In this paper, a hybrid oscillator is proposed in which nano switch components are employed to reduce power dissipation and enhance the switching time. The work involves the design and simulation of a nano switch that has been combined with CMOS to achieve a new design of a ring oscillator. In addition, a noise reduction methodology which is based on improving the damping and spring factors has been adopted in the design to enhance the output and approaching the ideal signal.

1. Introduction

NEM switches are a device whose operation relies on moving a flexible beam to produce a conductive path. Among the variable operating mechanisms of the enlightened NEM switches, the electrostatic motor was identified as the most capable candidate due to simple procedure requirements and temperature independent operating features [1]. In electrically actuated three terminal switch NEM. The movable construction experiences an electrostatic force controlled by the gate station. The electrostatic force and spring recovery force can effectively form or isolate the elastic beam reaction area and the drain station.

Unlike the important path recognized by the pull in, all terminals are divided by an insulating material or an air gap. Although space tunnel currents and Brownian motion replacing currents still exist, the thickness of the insulation or air gap in the NEM switches is much larger than the leak path in modern CMOS transistors, and the leakage current is not important even at high temperatures [2].

CMOS, which is abbreviated for Complimentary Metal-Oxide Semiconductor, is a main technology for manufacturing integrated circuits. This dominance of CMOS technology in the construction of integrated Circuits or ICs will remain for decades to come. CMOS technology has physical limitations; current leakage effect and short length channel, uncontrollable reliability and leakage strength, therefore, designers are working hard to solve these problems by system extending CMOS range to the nanoscale. When CMOS continues to be scaled in the nanometre range, it causes challenges in electronic circuits. The CMOS volume was reduced in nm current leakage current (OFF state). The leakage current under normal conditions is considered about 30-50% of the total energy dissipation in appliances [3]. When introducing NEMS-CMOS technology, knowing how to implement this issue is an important point for the success of the work. NEMS (Nano Electro Mechanical Switch transistor) is a good example of Nano sizing technology, many studies have been suggested recently.

NEMS trick that eliminates current leakage and thus the loss of static energy. NEMS applications are predicted in sensing, presentations, and portable power generation, in energy harvesting, drug
delivery, and imaging. Examples of NEMS include nano resonators, nano accelerometers and integrated aggregate detectors.

In this paper a hybrid model for CMOS-NEMS is presented and used to construct a Ring oscillator. Hybrid CMOS-NEMS offers exclusive performance, virtually unlimited ON current, zero leakage current, a small size that can result in a low power dissipation. First, to design any electronic circuit, it is necessary to suggest the circuit, analyze and simulate it before manufacturing processes.

A circuit simulation model is needed. This model is the first step of design. This paper proposes conventional CMOS methodology, modeling and hybridization of NEMS in electronic circuits.

2. Literature review
This section views some of researchers whom high spot them work on NEMS transistor including modeling, fabrication and other things linked with NEMS transistor study. This review can be presented as follows:

G.S.M. Galandanci & K.O. Ewansiha, 2004 [4] In this work, simulations and analysis of variable frequency oscillator are performed using the multisui program and offers the possibility to study the frequency variance with a constant value of capacitance and variable inductance.

Makram M. Mansour, 2008 [5] It provides a summary of what it takes to design an extremely low-noise LC-tank oscillator and describes the LC-tank oscillator phenomena by analyzing a simplified LC oscillator circuit.

H. Dadgour, et al., 2010 [6] present modeling and fabrication of NEMS transistor. This model offers some advantages over the real structure of the NEMS. The model is proposed with different properties by solving the Euler-Bernoulli equation, while irregular electrostatic force is ignored.

Benjamin Pruvost, et la, 2010 [7] Offers design and analysis of MOSFETs and NEMS functional portal. It studied both the NEMS and NEMS-gate MOSFET structures, and showed us that hybrid simulations have allowed us to discover new functions that can be added to traditional MOSFET and SET, such as very sudden current switching, memory, or more behavior control. the device.

S. K. Manohar, et la., 2012 [8] present the current DC-DC converter with NEMS-CMOS hybrid, comparing the result with standard CMOS, it uses Nano technology to reduce the voltage limit to enhance the device and increase the efficiency.

Farshid Keivanian, 2014 [9] presents reduce the average power consumption in the 3-phase CMOS Ring Oscillator. The objective function is the average power of a 3-stage ring oscillator, this article is based on minimizing work that the single objective of average power is initially defined and becomes the minimum based on the behaviour algorithms.

3. CMOS modelling
To evaluate the CMOS model, equation (1) for NMOS and (2) for PMOS is performed using MATLAB / Simulink as shown in fig. (1) and fig. (2), respectively. It is need to generate an input voltage that contains 1.5 volts (p) at a frequency of 0.1 GHz and a 25% pulse width. The NMOS equation is:

\[
\frac{V_o}{V_i} = \left(1.53 \times 10^{-28} - \frac{2.2 \times 10^{-17}}{S} - \frac{6.45 \times 10^{-8}}{S^2} + \frac{217.57}{S^3}\right) \times \left(\frac{2.72 \times 10^{-35}}{S^3} + 4S + 4\right)
\]  

(1)

The PMOS equation is:

\[
\frac{V_o}{V_i} = \left(1.11 \times 10^{-28} - \frac{5 \times 10^{-18}}{S} - \frac{1.17 \times 10^{-8}}{S^2} + \frac{50.904}{S^3}\right) \times \left(\frac{1.9 \times 10^{-35}}{S^3} + 6.4 \times 10^{-17}S^2 + 4\right)
\]  

(2)
4. **NEMS modelling**

Nano Electro Mechanical switches (NEMS) are made of electromechanical devices that have critical dimensions from hundreds to few nanometers. NEMS-based devices can have initial frequencies in the microwave range (100 GHz), mechanical quality factors in the tens of thousands, meaning low power dissipation, active mass in the femtogram range; power sensitivity at the level of attonewtons, and mass sensitivity up to atto-levels gram and sub-atto-gram, the heat capacity is much lower than the
"calorie yoctohm", energy consumption is within 10 attowatt, integration levels are extremely high, approaching $10^{12}$ element per square centimeter. The new switch is modelled by MATLAB/Simulink as shown in fig. (4)[10].

The following transfer function equation takes the first step of modelling as shown area1 in fig (4).

$$H(S) = \frac{X(S)}{A(S)} = \frac{1}{S^2 + S \left( \frac{b}{m} \right) + \frac{k}{m}}$$

(3)

In this design, the influence of the van der war force is measured because the dimension of the electro mechanical switch is at the Nano scale (4.5(nm) thickness of mass). The input waveform is a square wave which has 1.5 V (p) amplitude, (70) % duty cycle) and frequency is 0.1 GHZ. This voltage multiplies by gain which is (9.81) to variation it to the comparable acceleration signal. The electrostatic and Van der Waals' forces are considered as shown area2 in fig. (4). The two forces add with the damping force and the spring force by the adder. The damping force ($D$) can be determined by the equation below:

$$D = \sqrt{\frac{k \cdot m}{Q}}$$

(4)
The output waveform signal that is monitored on the oscilloscope as shown fig. (5), specifies if the switch turn on exactly. Testing and controlling of the voltage \( V_g \) and drain to source current \( I_{ds} \) occur only during ON state. The final step area3 is separation step, to obtain correct result.

![Output waveform](image)

**Fig. (5).** The output waveform of NEMS model

A value of the effective mass for bendable beam \( m_{eff} \) is determined from the equation below:

\[
m_{eff} = \frac{k_{eff}}{(2\pi f_c)^2}
\]

(5)

where \( k_{eff} \) is showed in equation below:

\[
k_{eff} = \frac{2E_m}{u^2}
\]

(6)

At last, from the models of the CMOS and NEMS, different logic gates can be implemented such as NAND & NOR and Ring oscillator as shown in the following application.

### 5. Ring oscillator for low noise application

Ring oscillators are commonly used in NEMS sensor applications. In the NEMS electronic system, the ring oscillator must contain the features of low temperature coefficient (T.C.), low power dissipation and low sensitivity to display and operation changes [11].

The inverter-based ring oscillator is simple, easy to integrate and consumes little energy when compared to other forms of oscillators such as RC oscillators, crystal oscillators and relaxation oscillators. Thus, it is appropriate for switch capacitor applications in sensor structures that do not require a very accurate sampling frequency. To construct the hybrid circuit of the Ring oscillator circuit in the MATLAB, the following steps are required to be implemented. The design of the hybrid Ring oscillator circuit contains three models for CMOS transistors and two models for NEMS transistors as shown fig. (6).
It can be seen that; the first inverter has two traditional transistors (zone1). The outputs of these transistors are added and fed to the input of the second inverter (zone2). This inverter consists of two NEMS transistors and their outputs are added and connected to the input of the third inverter (zone3). The third inverter consists of two traditional CMOS transistors and its output is added and fed to forth inverter(zone4). The output of forth inverter which consists of two NEMS transistors) are added and fed to the input of fifth inverter(zone5). The fifth inverter consists of two traditional CMOS transistors and its outputs are added and fed back to the first inverter to make a chine Ring Oscillator.

6. Noise reduction in hybrid ring oscillator

By change the spring factor and the effect of this change on the elastic force where elastic force is a repellent force that is created if the moving part is moved under the influence of external or internal force. This force is also called sprig force, and can be identified using the Hooke law as shown in equation below:

\[ F_{\text{elastic}} = K \times x \]  

(7)

Where:

- \( k \): spring factor of the movable part
- \( x \): Displacement of the movable part

The spring factor depends on the structure of the NEMS, for instant \( \gamma \), where \( \gamma \) is a variable, its value depends on the structure of device (in cantilever structure, ~0.25). the spring constant is a function of distances, material, and the structure of the device and can be determine using the equation below:

\[ K = \gamma E h \left( \frac{W}{L} \right) \]

(8)

Where:

- \( \gamma \): Empirical constant
- \( E \): The Young ‘s modulus
- \( h \): thickness of the movable electrode
W: width of the movable electrode
L: length of the movable electrode

We can see from fig. (6) when we put a spring factor equal to -300, the operating cycle of the square wave is not 50%. By changing the value of the spring factor from -300 to -200 the cycle of operation is better than the waveform that uses the spring factor equal to -300 as shown in fig. (7). When we put a spring factor equal to -100, the operating cycle becomes 50%. In this spring factor we encounter an almost perfect square wave without noise as shown in fig. (8).
7. Conclusion
In this work, the design and simulation of a CMOS-NEMS hybrid ring oscillator is presented where a significant enhancement in the power dissipation and switching time has been achieved. The waveform produced by this oscillator has been improved compared to the normal oscillator where the noise is reduced by improving the value of the spring and damping factors that affect the material, the length of the beam and the spring force in the NEMS.

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