Application of CNFETs and MOSFETs Circuits at Sub threshold

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For many years VLSI chip designers have been using metal-oxide semiconductor field-effect transistors (MOSFETs). Designers have used MOSFET circuits in their designs because MOSFET use little power and they are cheaper to develop or fabricate [1]. To satisfy the demands of making the chips smaller, the designers just simply shrank the dimensions to fit the circuit layouts. The shrinkage is also known as scaling. Unfortunately, the continuous scaling of the circuit design will eventually cause problems within the design characteristics of a typical silicon-based transistor. These problems include short channel effect, power dissipation, leakage current, and process variation [2]. Because of the many problems that have occurred, the designers are now searching for a more efficient transistor design to satisfy the same circuit characteristics as the MOSFETs. Engineers have been experimenting with different types of material. One of the materials is carbon-based. Carbon nanotubes are described as a sheet of graphine rolled up into a cylindrical shape. This rolled up sheet of graphine can take on two characteristics depending upon the way the sheet is rolled-up. These two characteristics are metal and semiconductor [3]. The semiconductor-type material is what is needed to develop a carbon-nanotubes field-effect transistor (CNFET). In order to determine whether or not the CNFET meets the performance/device requirement, a comparison of the traditional MOSFET and the newly developed CNFET is needed.

Before the comparison, one must first make the assumption that the CNFET take on the same characteristics as the MOSFET [3]. To compare the two different types of field-effect transistors, we first built a simple inverter made of the traditional MOSFET. From the inverter, we were able to develop a ring oscillator using multiple inverters. A ring oscillator was designed and simulated using computer software called HSPICE. The parameter code for the MOSFET and CNFET was developed by Arijit Raychowdury, graduate student mentor. We did not use the typical MOSFET parameter when comparing the two transistors. We used a 65 nano-meter scaled MOSFET so that it would be possible to compare MOSFETs with CNFETs. To develop the correct FETs circuits, we used the parameter codes as include file within our main circuit codes. The first circuit design built was a simple inverter made of both MOSFETs and CNFETs. The ring oscillator was the next circuit design built. The ring oscillator has to have an odd number of inverter for a continuous oscillating affect. We designed the ring oscillator with MOSFETs and CNFETs as well. To increase the level of difficulty, we developed a full adder. This was done to further examine whether or not a CNFET could take the place of a MOSFET. The logic gate diagram of the full adder is shown in Figure 1. The full adder design allowed us to measure the time delays between the inputs and the outputs. We also were able to obtain the current and power consumption. The 4 bit ripple carrier was also designed to make the comparison more complex. This design is 4 full adders combined together to make one more complex circuit.

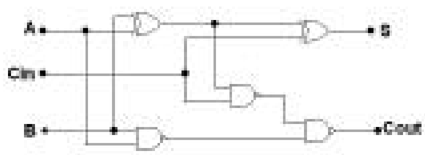

Figure 1: Logic gate diagram of full adder

Once the basic circuit layout and code were developed and simulated, we decided to further examine our circuit at a different level. We worked at super threshold for the first set of comparison; then, we decided to test the four different circuits at sub threshold. Sub threshold is the regime on the MOSFET I-V characteristics when the gate voltage is below the threshold voltage. At sub threshold, the current in the channel flow by diffusion, movement of carriers due to a concentration gradient [4]. Where as, in super threshold, current flows through drift, movement of charge carriers due to an external field [4]. The average textbook teaches that once the gate voltage goes below the threshold value the transistor turns off. In reality, the transistor does not turn off immediately; it gradually turns off [3]. With the knowledge known about working at sub threshold, we tested the inverter, ring oscillator, full adder, and the 4-bit ripple carrier adder at sub threshold.

To compare the two types of transistors in sub threshold, we found the actual threshold voltage for the MOSFET and CNFET. The MOSFET threshold voltage is equal to 300 milli-meter; and the CNFET threshold voltage is equal to 150 mill-meters.

The sub threshold values that we worked in are 250 milli-meters for the MOSFET and 100 milli-meters for the CNFET. Below are the results of the inverters at sub threshold and the results of ring oscillators at sub threshold.

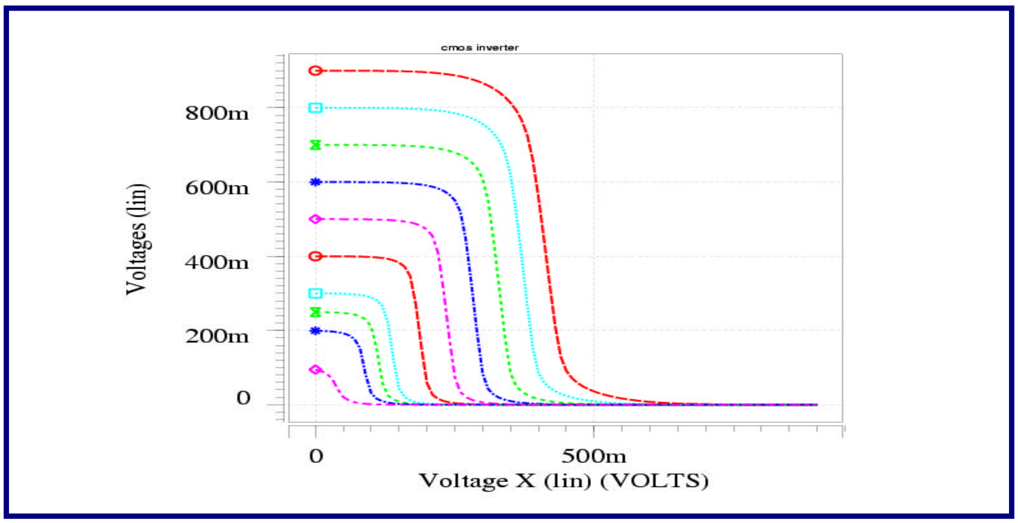

Figure 2: MOSFET Inverter at various threshold values

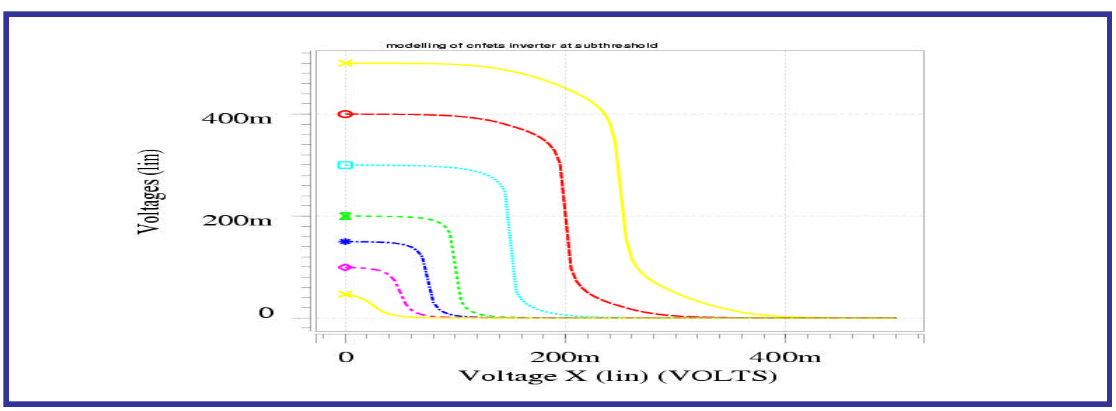

Figure 3: CNFET Inverter at various threshold values

Figure 2 is a MOSFET inverter at various voltage values. At sub threshold (dark blue curve and below) the slope of the dc curve gets steeper and steeper; but, as it reaches 0 the dc curves is no longer an inverter because the gain is below 1. Figure 3 is the CNFET inverter at various voltage values it does the same as the MOSFET inverter. As the voltage gets smaller and smaller the graph no longer demonstrates that of an inverter because the gain is below 1.

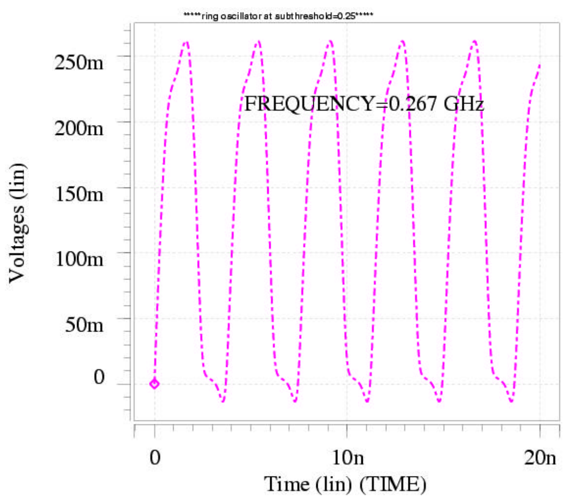

Figure 4: MOSFET Ring Oscillator at sub threshold

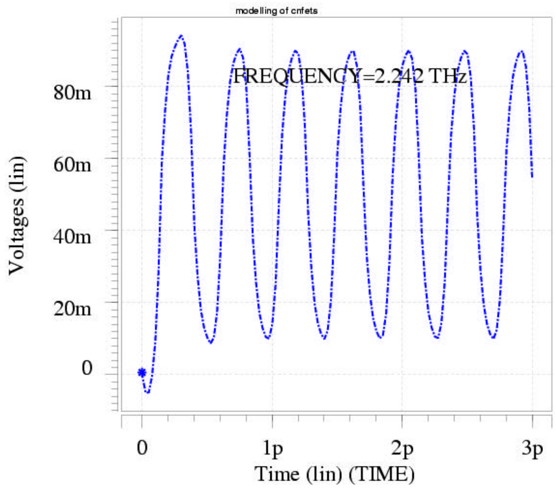

Figure 5: CNFET Ring Oscillator at sub threshold

Figures 4 is the MOSFET ring oscillator at sub threshold. As shown in the graph, the frequency is 0.267 GHz. The CNFET ring oscillator has a frequency of 2.242 THz which is 100 times faster than the MOSFET.

From the given examples above, CNFETs can take on the same if not better characteristics of MOSFETs. They can be used in the place of MOSFETs because there is no new circuit methodology to be used. The circuit and design layouts can be used. One of the problems with the CNFETs is the assumptions made at the beginning of the project. That is CNFETs take on the same circuit characteristics as that of a MOSFET [3]. In this project, we have proven that the CNFET at sub threshold has less power consumption and the power delay product is lower. We have also proven in the ring oscillators the frequency is 1000 times higher than that of a MOSFET at sub threshold. For future work, examine simple circuits at sub threshold using characteristics of a 65 nm-MOSFETs and the true characteristics of CNFETs from earlier work.

Reference:

[1] David Goldhaber, et. al., "Overview of Nanoelectronic Devices," Proceedings of the IEEE, vol. 85, no. 4, April 1997 pp. 522

[2] K. Roy, et. al., "Leakage Current Mechanisms and Leakage Reduction Techniques in Deep-Submicron CMOS Circuits," Proceedings of the IEEE, February 2003, pp. 305-327.

[3] R. Martel, et. al., "Carbon nanotube field effect transistor for logic applications", Electron Devices Meeting, 20 IEDM Technical Digest. International, 2001 pp 7.5.1-7.5.4

[4] "MOS transistors" http://www.ini.unizh.ch/avlsi/winterlabs/iec2.pdf