NDnano Undergraduate Research Fellowship (NURF)
2014 Project Summary

1. Student name: **Arsal Habib**

2. Faculty mentor name: **Prof. Sharon Hu**

3. Project title: **Design and Evaluation of CNN-Based Circuits Using Beyond-CMOS Devices**

4. Briefly describe any new skills you acquired during your summer research:
I learnt how to write HSPICE netlists and perform various simulations using HSPICE. Also, I learnt various features to analyze simulated waveforms on WaveView.
5. Briefly share a practical application/end use of your research:
Oscillators are used in various electronic devices. Uses include: signals broadcast by radio and television transmitters, clock signals, electronic beepers and video games.

Begin two-paragraph project summary here (~ one type-written page) to describe problem and project goal and your activities / results:

The standard for measuring the performance of the semiconductor industry for the past several decades has been Moore's Law which states that the density of transistors on a chip doubles approximately every two years. While CMOS technology has enabled this law to hold true for the last few decades, it is speculated that the growth rate of CMOS density is near its end. Beyond-CMOS devices are being worked on and have the potential to continue the growth semiconductor industry has witnessed over last decades. Among one of these devices is symFET (symmetric graphene tunneling field effect transistor). The physical structure of a symFET comprises of an insulator sandwiched between two graphene layers which allow for a 4-terminal device. Such a physical structure also makes it a tunneling device which gives it an added feature of negative differential resistance (NDR). This device is yet in its initial stages and its advantages over CMOS transistor are yet to be fully realized and exploited. The goal for this summer project was to implement symFET in various circuits and further explore its advantages and uses. Focus was to explore the feasibility of symFET in oscillator circuits.

Due to the NDR feature of this device, oscillators employing NDR were studied in the beginning of the summer project. Tunnel diode is one device that also exhibits NDR and has been used inside oscillators. Such oscillators as well as previous work in employing semiconductors to build oscillators was studied in detail. For building ring oscillators, inverters based on symFETs (Fig 1) as well as those based on MOSFETs were built on HSPICE and simulated to ensure their proper working. The inverters were then employed to build 3-stage ring oscillators as shown in Fig 2. Two ring oscillators, one based on MOSFETs and the other on symFETs, were simulated and transient analysis was run on HSPICE for both oscillators. Both oscillators were simulated under various conditions to achieve output signals of a range of frequencies. At the same time a power analysis was performed of both the oscillators. SymFET based ring oscillator (3-stage)

was able to obtain output frequencies in MHz range while the MOSFET based ring oscillator was able to get much higher frequency output. However, symFET based ring oscillator had much lower power consumption than the MOSFET based oscillator. Also, the symFET based ring oscillator did not require a capacitor and a resistor inside the circuit to function properly unlike the MOSFET based ring oscillator.

To vary the frequency of the output signal in the symFET based oscillator, voltage across the bottom gates of the symFETs (V_B in Fig 1) was changed to achieve desired frequencies. For the MOSFET based oscillator, a change in frequency was achieved by either changing the value of capacitance or the drain voltage. Another way of changing the frequency is to increase the size of the ring oscillator (5-stage, 7-stage, 9-stage, etc), however, in this analysis, both the oscillators were restricted to 3-stage oscillators since that allowed for a better power analysis (since increasing the size of oscillator increases number of transistors and hence effects power consumption).

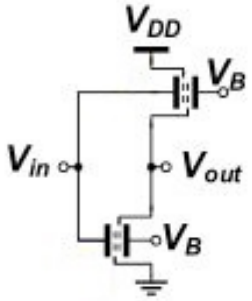

Figure 1: SymFET based inverter

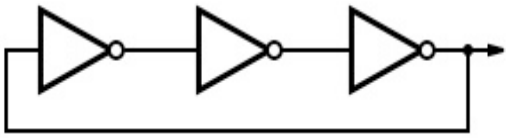

Figure 2: 3-Stage Ring Oscillator