FUNCTIONAL STUDY OF MAGNETOTACTIC BACTERIA IN VLSI DESIGN

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Abstract

Magnetotactic bacteria are a type of prokaryotic cells that can orient and migrate along the geomagnetic field lines in order to fulfill their physiological functions and anaerobic/microaerophilic requirements. This work investigates the magnetotaxis (sensitivity to magnetic field) of Magnetospirillum *magneticum* and studies the ability to apply this function to very large scale integration (VLSI) design and fabrication. It is known that magnetotaxis is closely associated with a chain of magnetic particles inside the bacterial cell that acts as a dipole. MATLAB analysis and modeling as well as control of a mesh of current carrying conductors using Mentor Graphics indicate that there is a possibility of these bacteria being manipulated (through their shapes, sizes and speeds) to use them as "skilled workers" to transport one or more atoms/molecules in order to form a nano-scale, bottom-up construction methodology beneficial to the field of integrated circuit fabrication. A further study would be to analyze the various pathways responsible for the formation of magnetic crystals through nucleation inside the bacterial cell in order to increase the sensitivity for cells much smaller than currently available. The engineering education component that stems from this research is to potentially realize the use of biomolecules to fabricate integrated circuits below the current state of art feature size possible.

Key Research Components

a. Magnetic field around a current carrying conductor.
b. Force exerted by a current carrying conductor.
c. Heat dissipation around a current carrying conductor.
d. Controller controlling the current through the conductor.
e. Binding capabilities of the flagellum to the inorganic molecules.

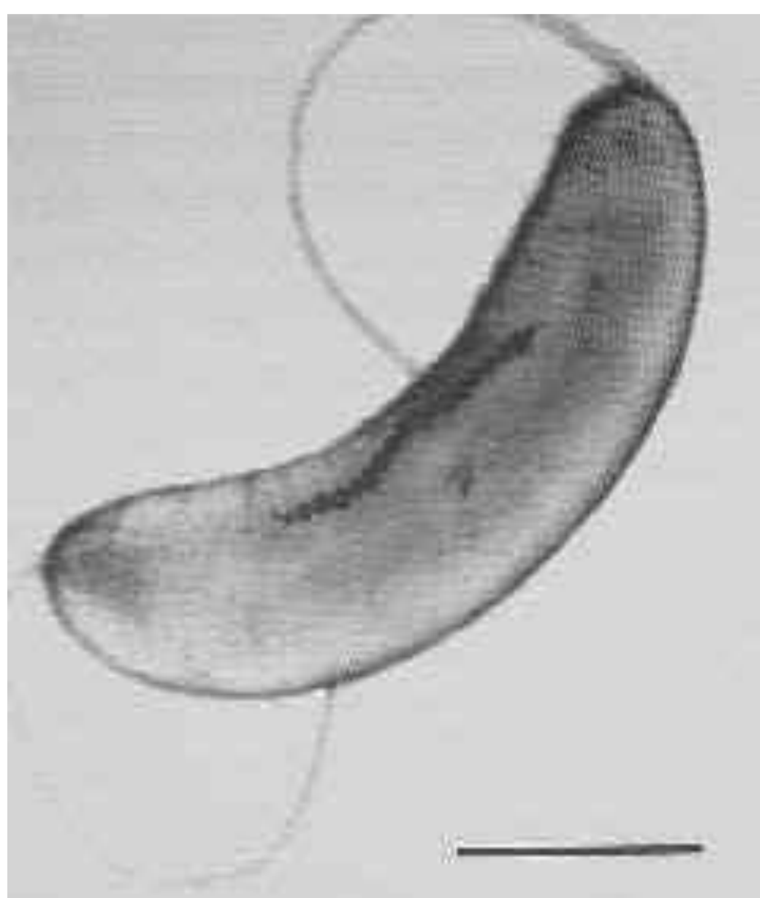

Figure 1. Magnetospirillum *magneticum*

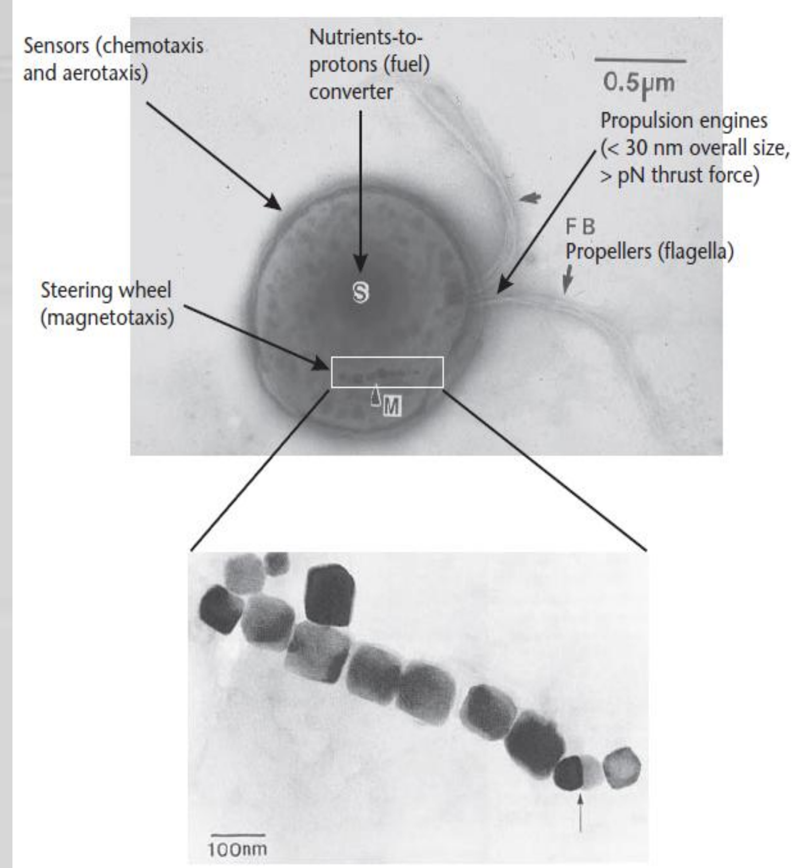

Figure 2. Magnetospirillum Gryphiswaldense

Conductor Mesh Modeling

Magnetic field around a current carrying conductor:
$B = \mu_0 I/2\pi R$

Force exerted by a current carrying conductor:
$F = Q\ (VXB)$
OR
$F = I\ (LXB)$

Resistance of a current carrying conductor:

$$R = \rho\frac{L}{A} = \rho\frac{L}{Wt} \qquad R = \frac{\rho}{t}\frac{L}{W} = R_s\frac{L}{W}$$

From Ohm's law:
I = V/R
V = 5V for 0.5μ process; R_s for the metal layer is process- and foundry-dependent.

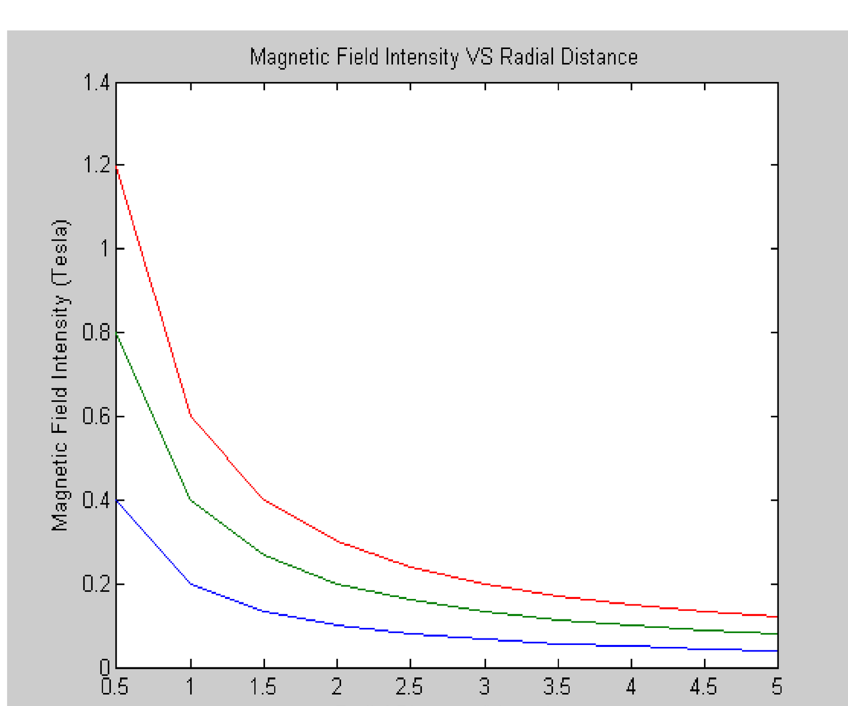

Figure 3. MATLAB analysis of B Vs. R

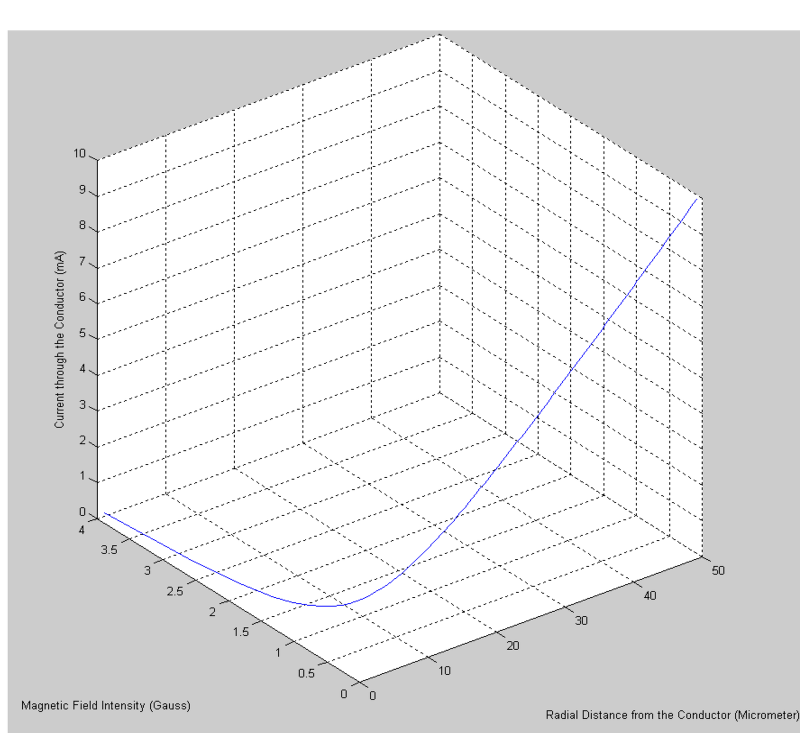

Figure 4. 3-D graph showing relation between B, R & I

MATLAB analysis shows the complex relationship between magnetic field intensity (B), Radial distance from the surface of the conductor (R) and Current flowing through the conductor (I).
It is found that as the radial distance increases, the magnetic field intensity would decrease. Also the magnetic field intensity is directly proportional to the current but there is a trade-off between the magnetic field intensity and the heat dissipation from the surface of the conductor for which ANSYS & COMSOL are being used to model the heat flow.

Controller Modeling

a. Use of finite state machine (Moore machine) involving five states for the placement of each microbead.
b. Three counters & one master counter governing the assertion of entire state machine.
c. Five states namely 'Reset', 'Chamber Selection', 'Mesh Wire Selection', 'Micro-bead Placement' & 'Current Reversal'.
d. Consists of four steps in total for the component fabrication.

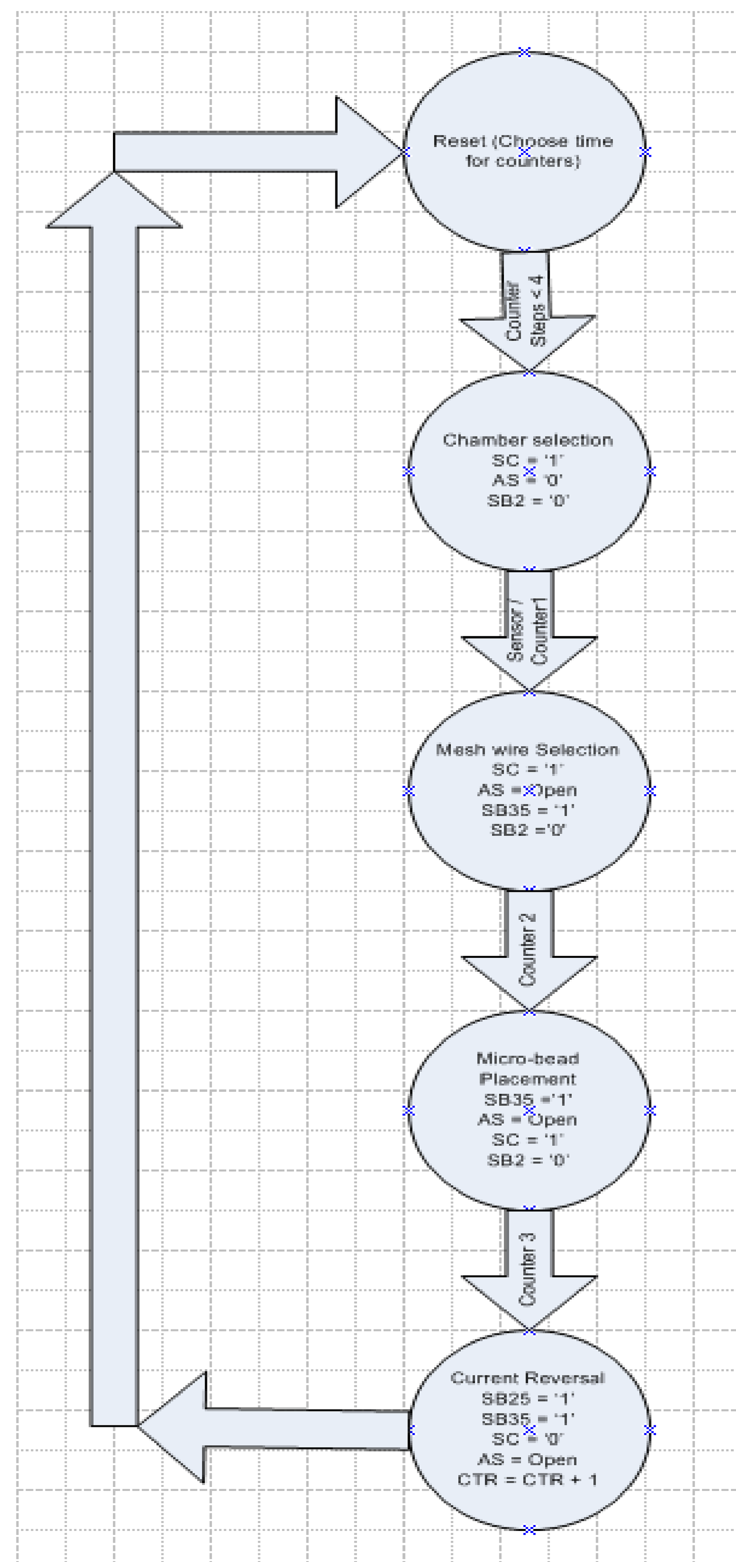

Figure 5. Finite State Machine (Controller)

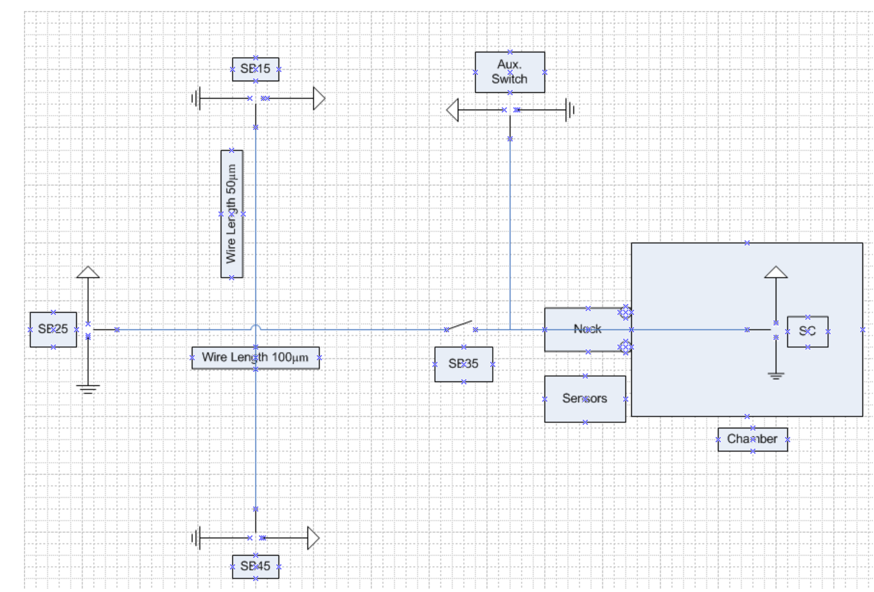

Figure 6. Controller Schematic

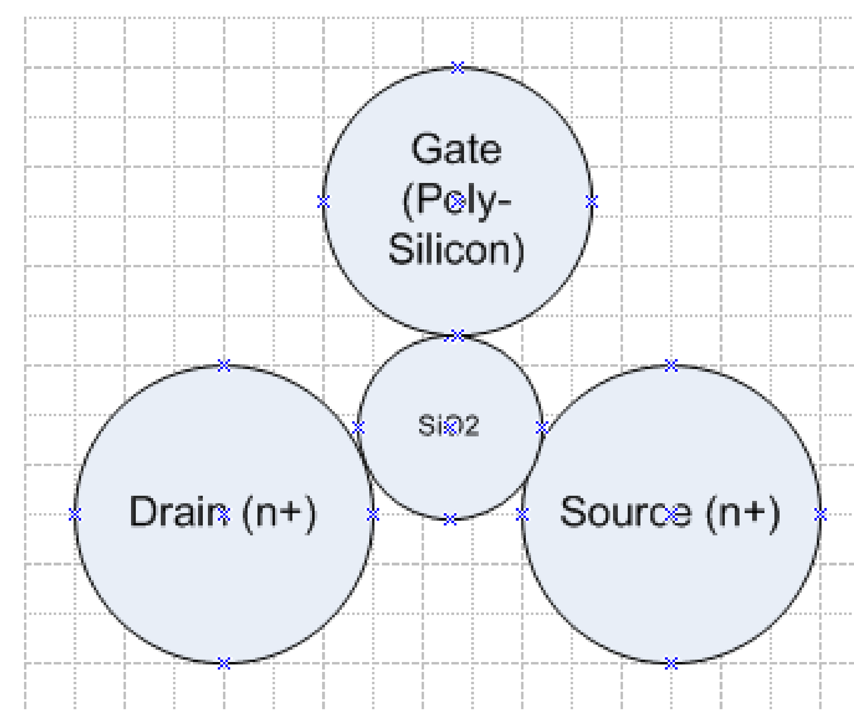

Figure 7. Expected Device (NMOS)

Controller Simulation

A five state controller is designed using D flip-flops in Mentor Graphics and is tested for functional verification. Initially pre-calculated number of clock cycles are used to set the counters and the results obtained are satisfactory. This preliminary design gives an approximate position of the switches (transistors) involved in the control of the current through the mesh. Figure 8 shows the transistor-level schematic using Design Architect in Mentor Graphics whereas figure 9 shows simulation waveforms using Accusim in Mentor Graphics.

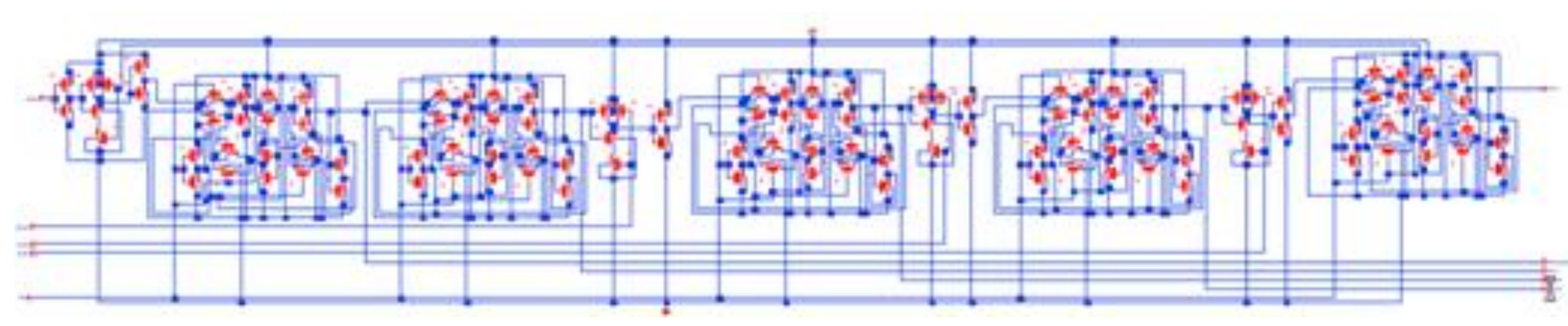

Figure 8. Transistor level schematic of the controller using Design Architect

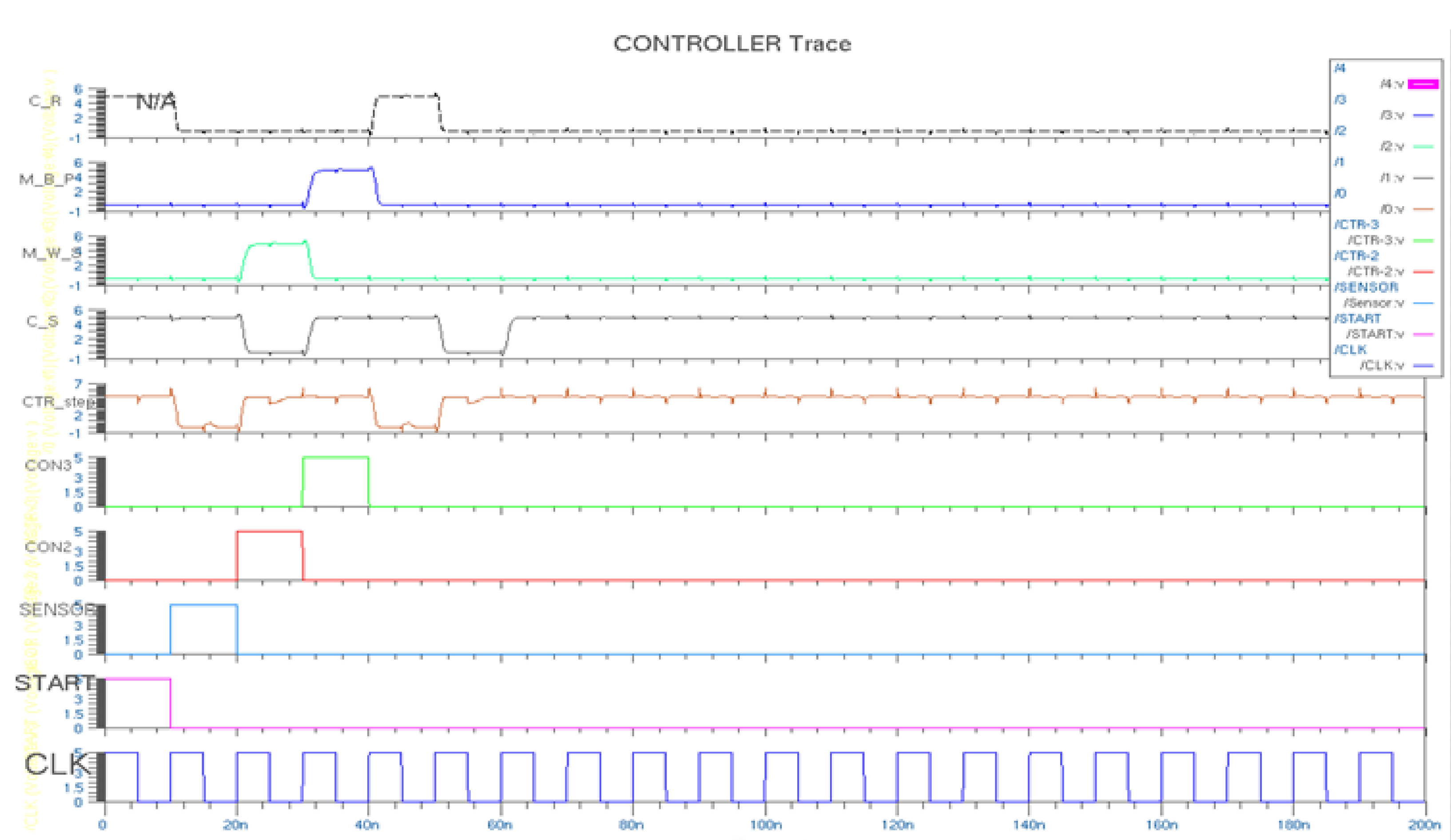

Figure 9. Controller Simulation using Accusim in Mentor Graphics

Conclusion & Future Work

This research work mainly focuses on the design and fabrication of integrated circuits (VLSI chips) beyond 16nm below which traditional fabrication techniques involving UV light are unpractical due to the limit on the wavelength of light. So far, modeling of the conductor mesh using MATLAB has been achieved. Analysis of heat dissipation using COMSOL & ANSYS is underway, which will give enough information to set the size of conductors in the mesh so as to produce enough magnetic field with a little rise in the temperature. Another area to look into would be MEMS for the fabrication of the chamber in which the bacteria resides..Experiments using Altera DE-II board, bacterial motion under increasing temperature over the micro-wire (straight & solenoid) as well as flagella binding will be conducted in the future to confirm the proposed approach.