ENCE 3501 – Lab 6: DC-to-DC Charge Pump Regulator

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## Abstract

This lab focuses on the design, simulation, and analysis of a DC-to-DC charge pump voltage regulator capable of producing a stable 2V output across a 2 MΩ load. The system integrates a ring oscillator with an enable control, a multi-stage charge pump, and a voltage regulation feedback circuit. All components were simulated using LTspice, and layouts were created to ensure correct functionality and connectivity within CMOS design constraints.

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## 1. Objective

The objective of this experiment is to design and simulate a CMOS-based DC-to-DC charge pump regulator that outputs 2V to a 2 MΩ resistive load. The design combines three key subsystems: a ring oscillator with enable functionality, a charge pump circuit for voltage boosting, and a regulation circuit for maintaining a constant voltage level.

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## 2. Introduction

Charge pumps are circuits that generate higher or lower voltages from a given supply voltage using capacitors as energy storage and transfer devices. They are widely used in integrated circuits where inductors are undesirable. The circuit designed in this lab employs a multi-stage charge pump driven by a ring oscillator to create a doubled DC voltage output, followed by a feedback-based regulator to maintain the output stability.

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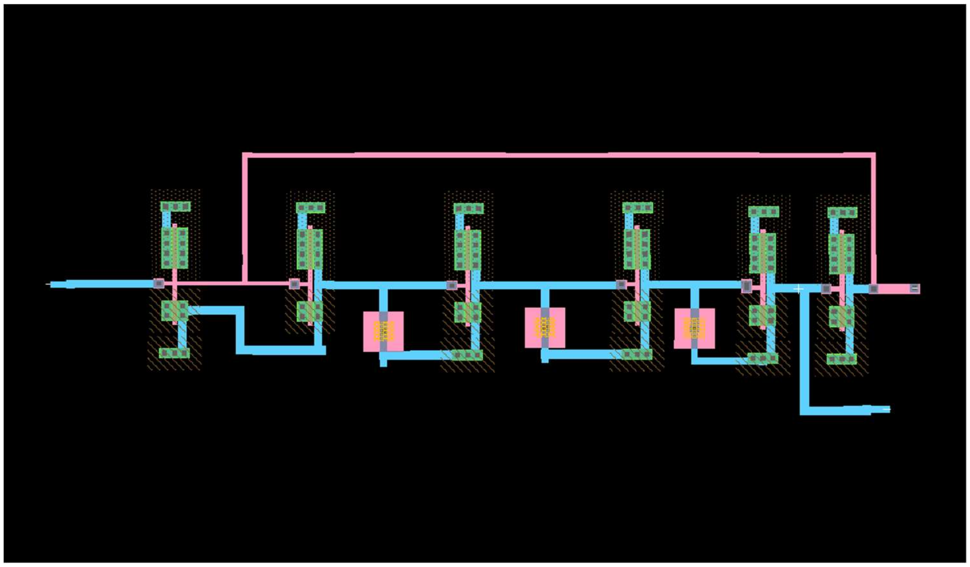
## 3. Methodology

### 3.1 Ring Oscillator with Enable

A 5-stage ring oscillator was designed using CMOS inverters connected in a feedback loop. The oscillator frequency depends on the number of stages and the delay of each inverter. An enable pin was added to control oscillation start and stop conditions.

**Figure 1 – Ring Oscillator Schematic and Layout**



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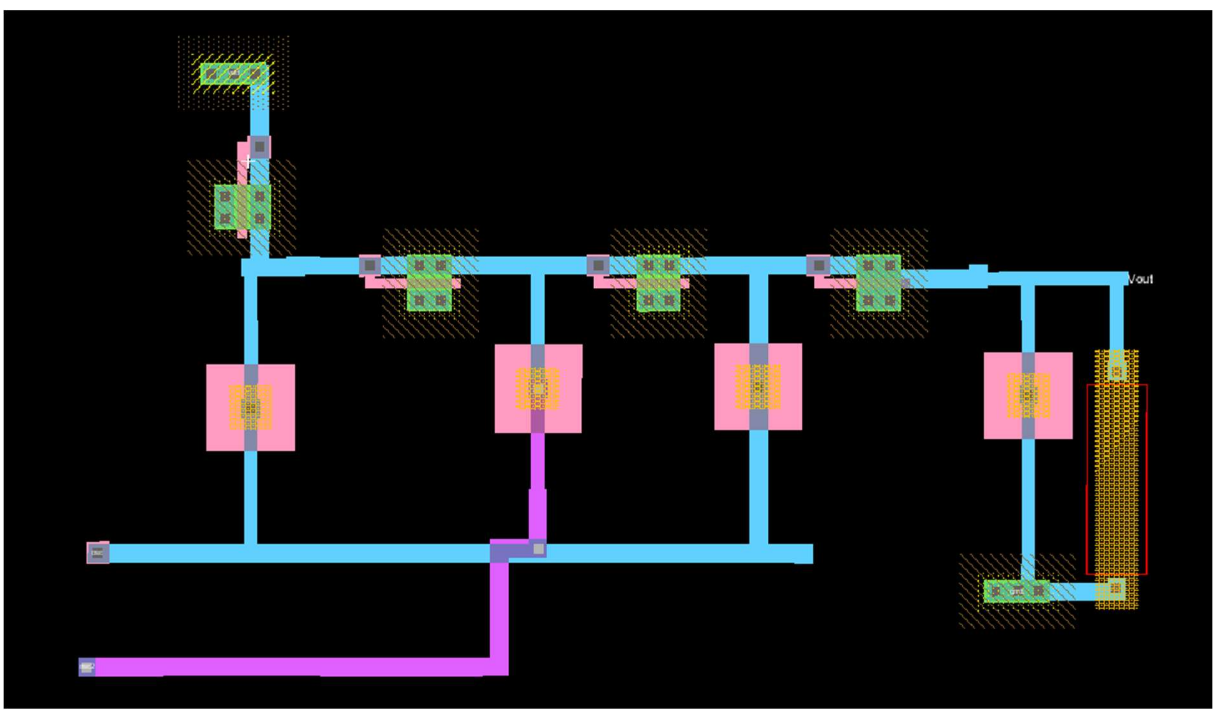
## 3.2 Charge Pump Stages

A three-stage charge pump circuit was implemented to boost the input DC voltage. The circuit uses capacitors and diode-connected MOSFETs in a ladder configuration, driven by out-of-phase oscillator signals.

**Figure 2 – Charge Pump Schematic and Layout**

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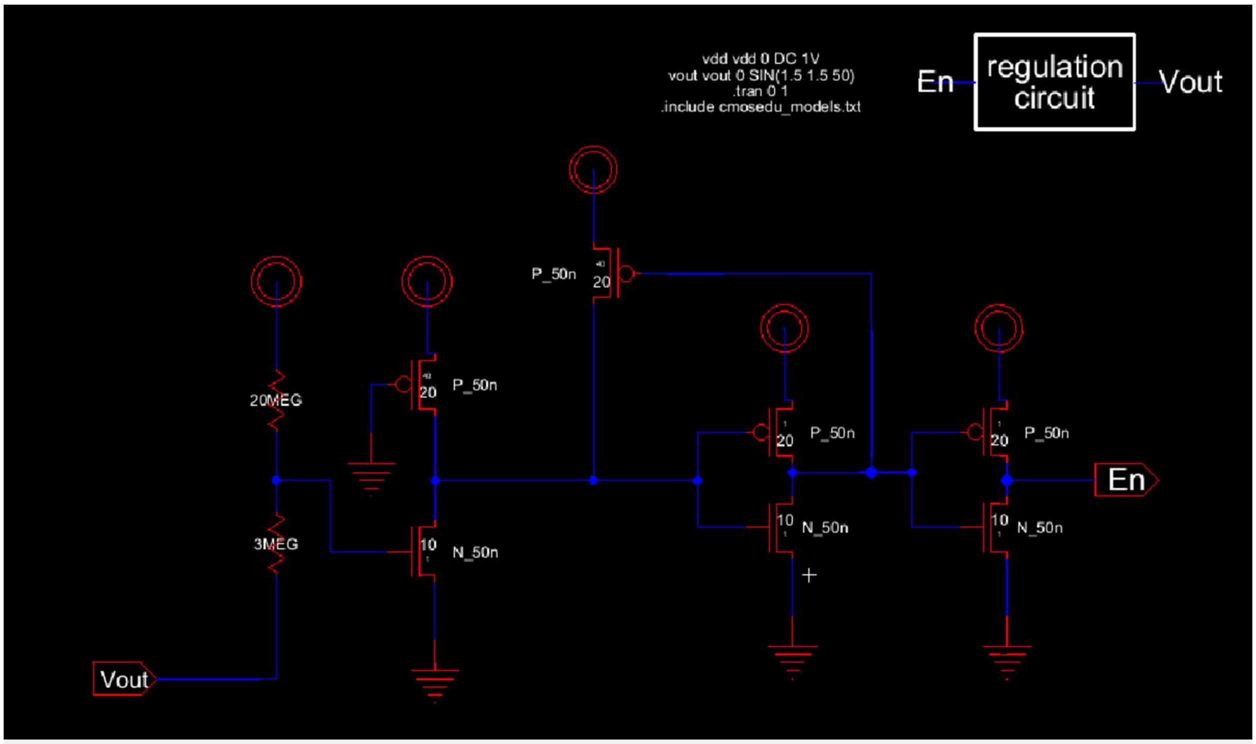
## 3.3 Regulation Circuit

The regulation circuit monitors the output voltage and adjusts the control signals to maintain a steady 2V output. The feedback loop ensures stability under varying load conditions.

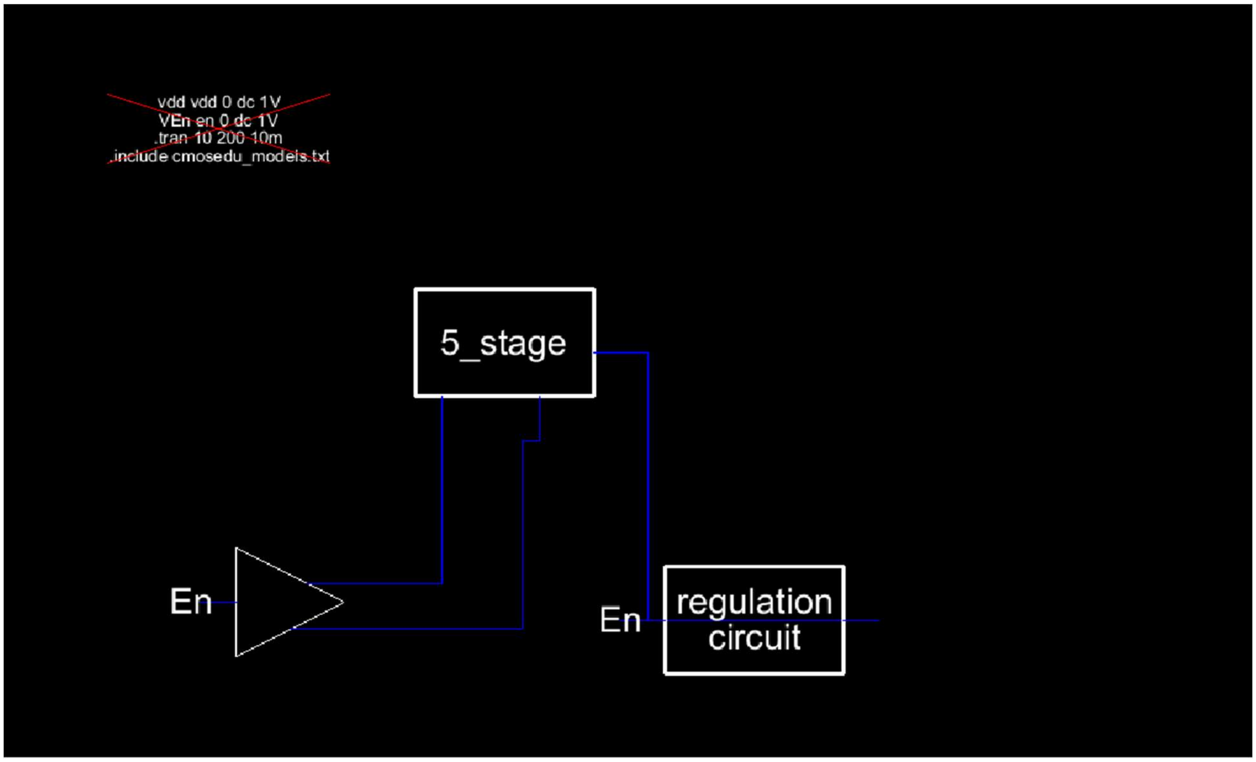
**Figure 3 – Voltage Regulation Circuit**




## 3.4 Full-System Integration

All three subsystems—ring oscillator, charge pump, and regulator—were connected to create a functional DC-to-DC converter. The system was simulated in LTspice to verify stable operation and correct voltage output.

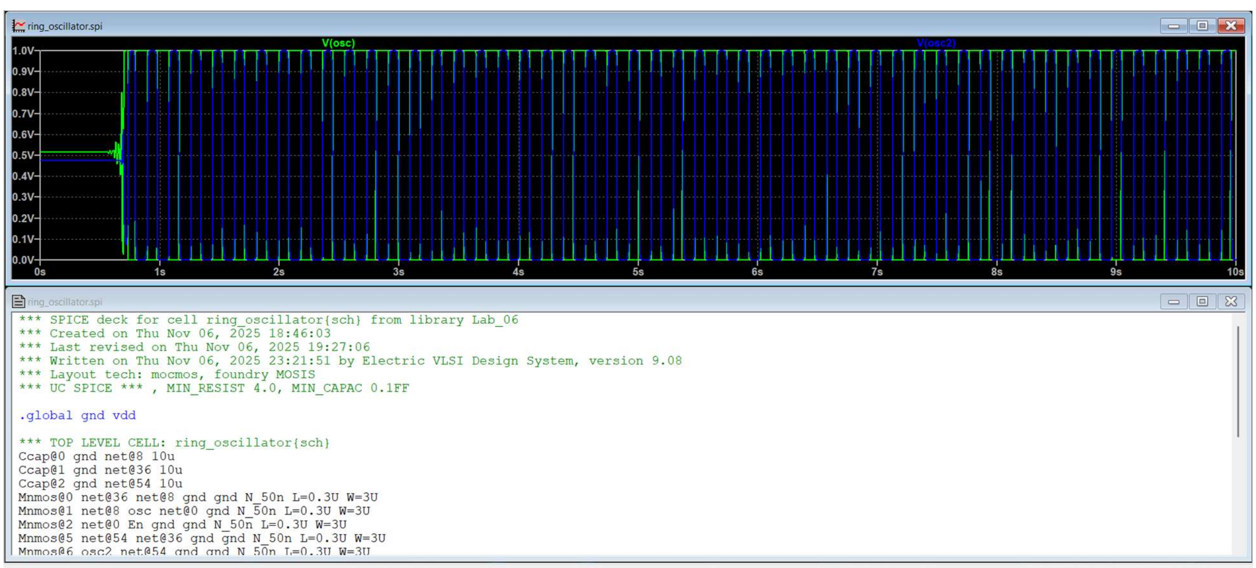
**Figure 4 – Complete System Schematic**



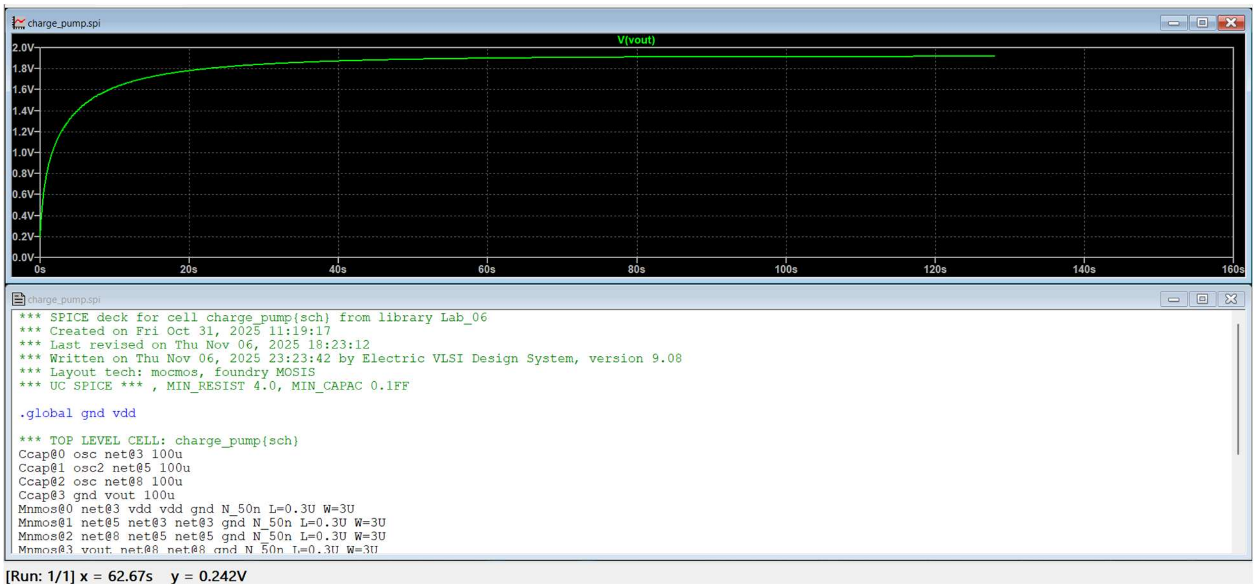

## 4. Simulation Results and Analysis

Transient simulations confirmed the charge pump output reached approximately 2V with stable operation over time. The oscillator generated periodic signals used to drive the charge pump stages effectively.

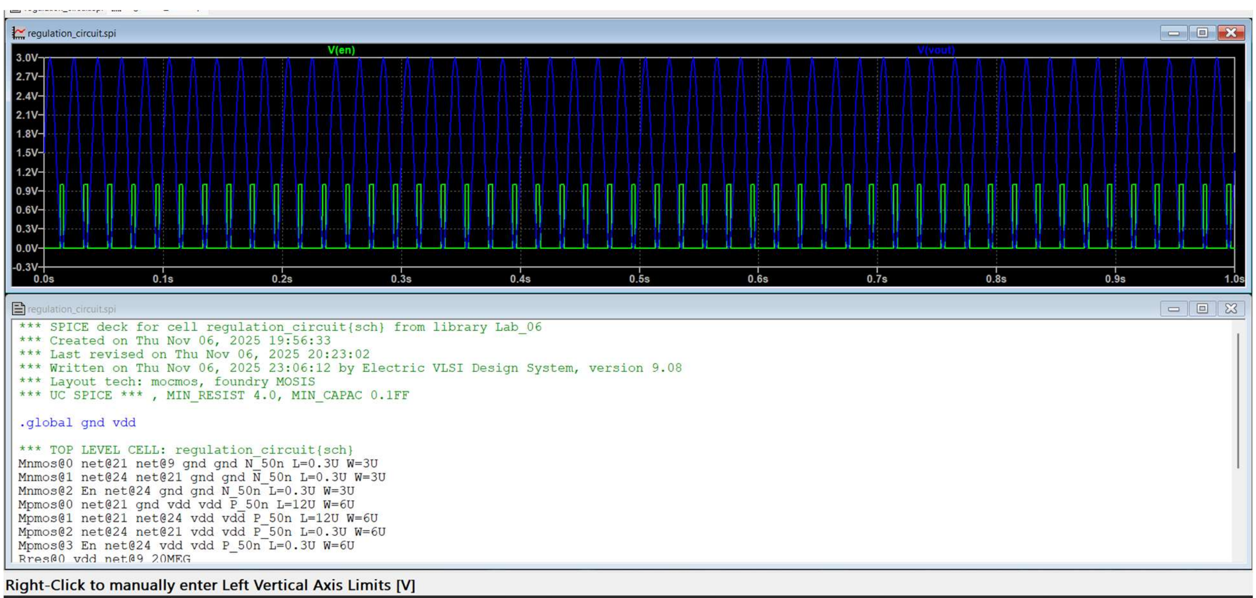
**Figure 5 – Ring Oscillator Output Waveform**



### Figure 6 – Charge Pump Output Voltage Simulation




### Figure 7 – Regulated Output with Load Connected




Analysis of the waveforms indicates that the system achieved the desired 2V regulated output. The charge pump demonstrated expected voltage step increases at each stage, while the regulator maintained output stability.

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## 5. Layout Design

Layouts for all subcircuits were drafted ensuring DRC/LVS compliance. Interconnections between stages were verified to ensure continuity and proper node assignments for VDD, GND, and control signals.

**Figure 8 – Layouts of Submodules and Final Integration**

*(Insert layout screenshots here)*

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## 6. Discussion

The overall design performed as expected, producing a stable 2V output across the specified load. The results validated the theoretical principles of charge pump operation and voltage regulation. Some voltage ripple was observed, primarily due to parasitic capacitances and the non-ideal switching characteristics of MOSFETs. Increasing the number of stages or optimizing capacitor values could further improve performance.

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## 7. Conclusion

The DC-to-DC charge pump regulator successfully achieved a 2V regulated output using a 3-stage charge pump driven by a ring oscillator. The design met all lab objectives and demonstrated a practical application of CMOS analog design principles.

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## 8. References


1. CMOSedu, “Charge Pump Design Tutorial.”
2. LTspice Simulation Tool, Analog Devices.
3. ENCE 3501 Lab 6 Handout (October 2025).