A Single Supply Bootstrapped Boost Regulator for Energy Harvesting Applications

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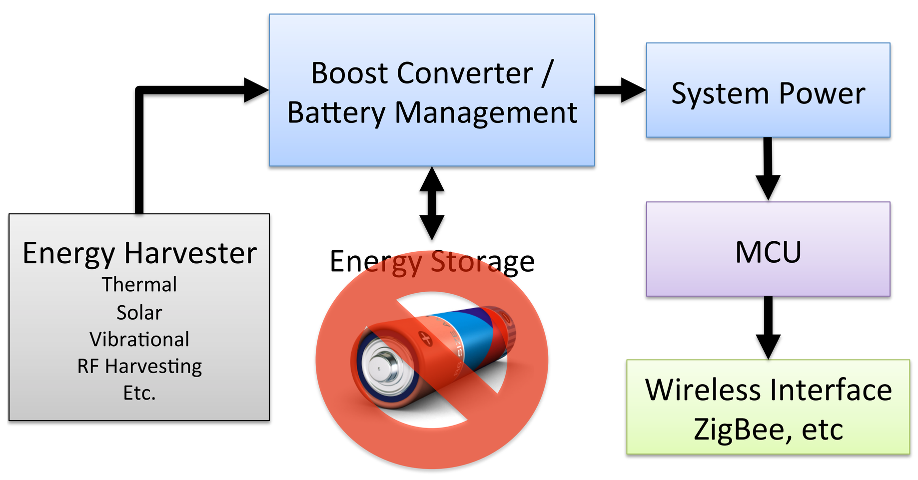
Introduction

1. Energy harvesting systems capture power from ambient sources
   - Examples: solar, vibrational, thermal transducers
2. Our approach targets real-world applications
   - Operates from a single input voltage
   - Only requires 3 external components (C_I, C_O, L)
   - Efficiency and load range maximized
   - Starts up with very low input voltage
   - Target → low-power Micro-Controller system

Energy Harvesting Block Diagram

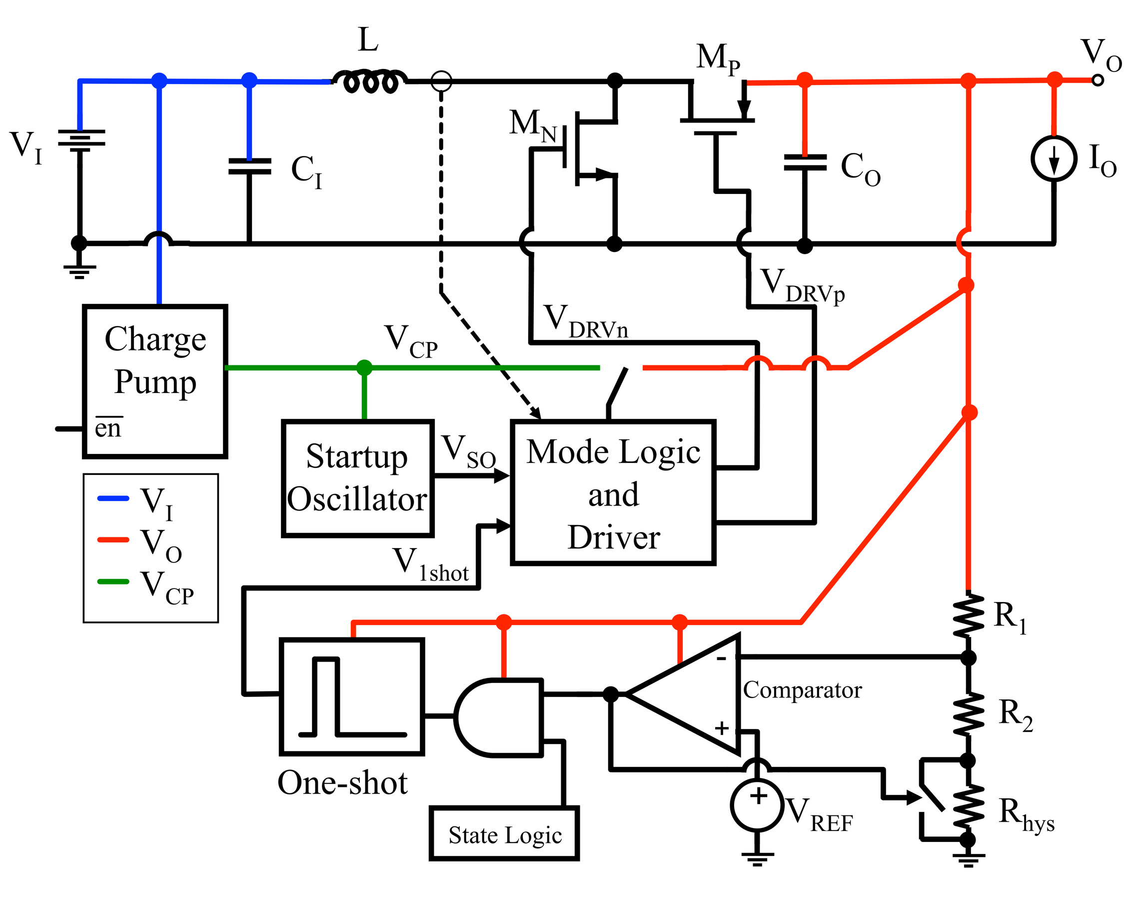


- The proposed circuit does not require an energy storage device (battery)

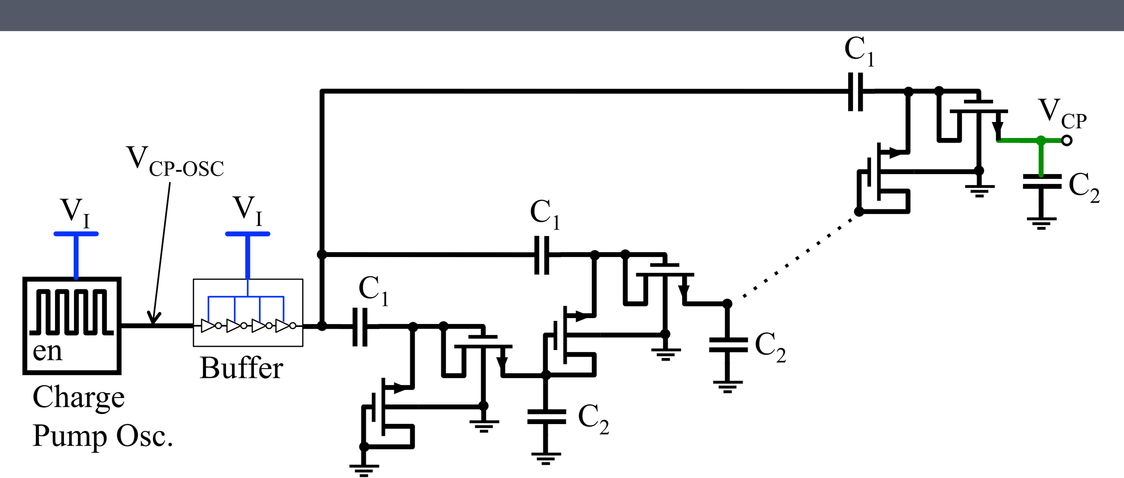
Proposed Circuit – Design Specifications

1. Bootstrapped boost regulator
   - Can startup from input voltage below $V_{t(NMOS)}$
   - Works down to $V_{IN} = 240$mV
2. Efficiency > 95%
   - Low I_Q ($\approx 15\mu$A)
   - Low conduction/switching losses
3. Output Load > 5mW

Overall System Block Diagram

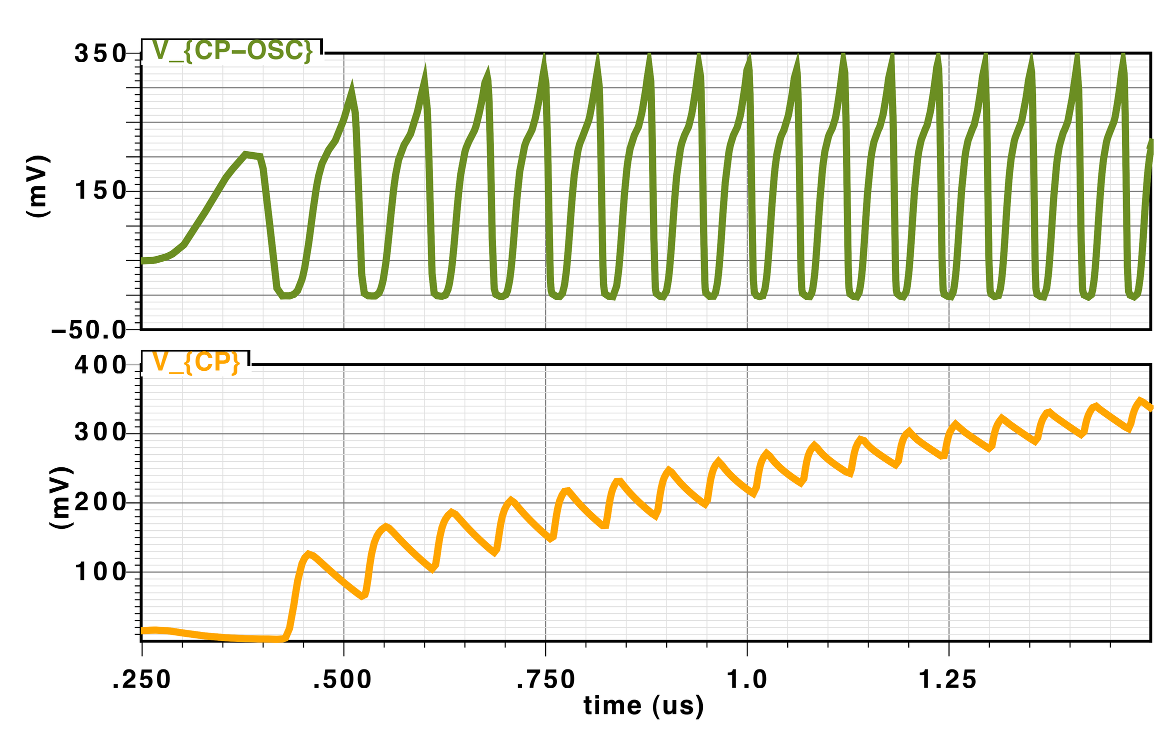


Startup Charge Pump Schematic

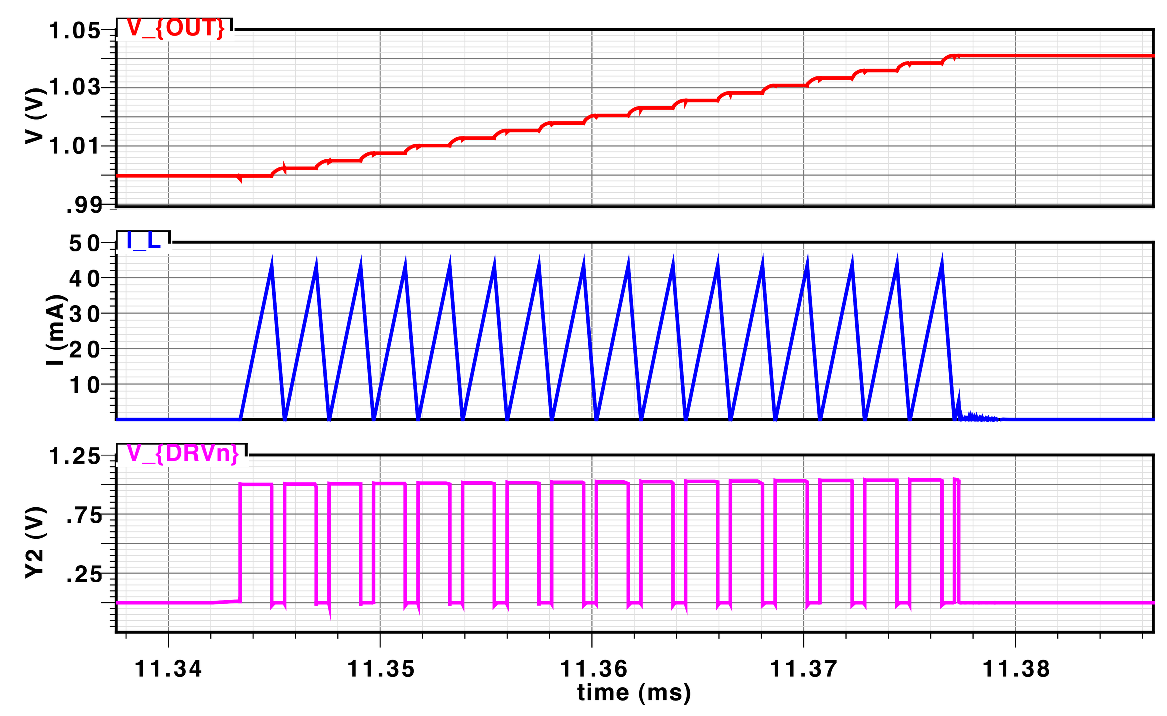


1. Native NMOS, C_1 = 5pF, C_2 = 40pF
2. Values optimized to startup main switches

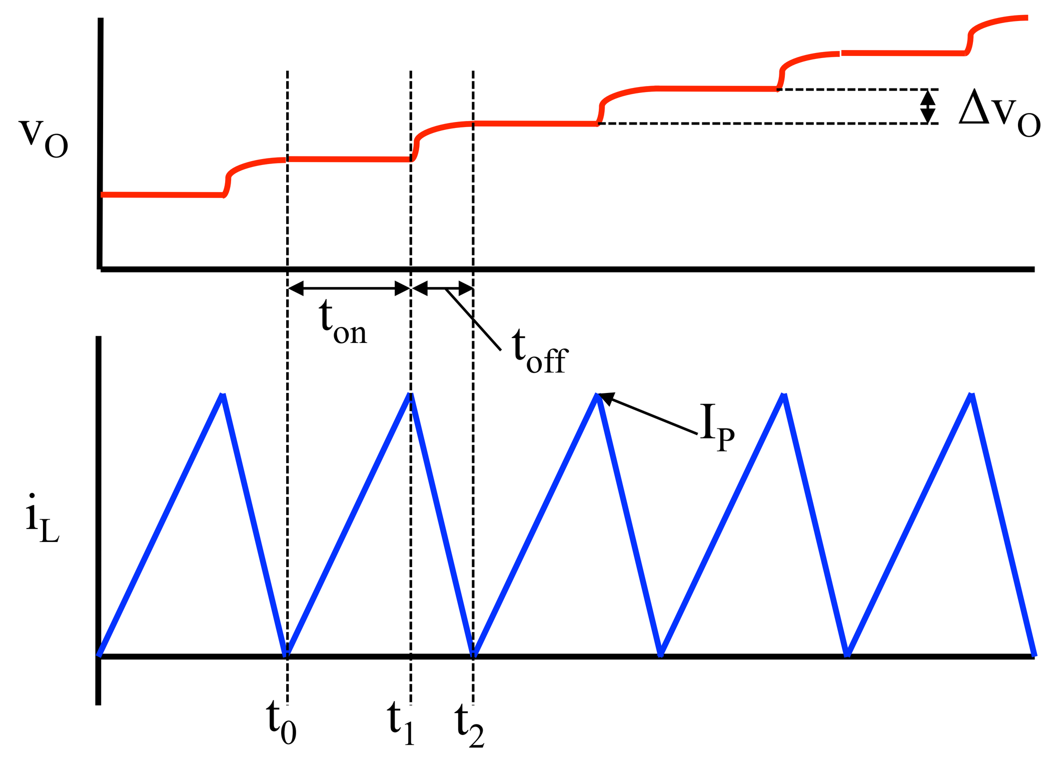
Charge Pump Startup Simulation



Steady State Simulation



Circuit Calculations



- Inductor current equation

$$i_L(t) = \begin{cases} \dfrac{V_I}{L}t, & t_0 < t \le t_1 \\ I_P - \dfrac{V_O - V_I}{L}(t - t_1), & t_1 < t \le t_2 \end{cases}$$

- Output voltage ripple

$$\Delta v_O = \frac{1}{C_O}\int i_L(t)\,\mathrm{d}t = \frac{I_P^2 L}{2C_O(V_O - V_I)}$$

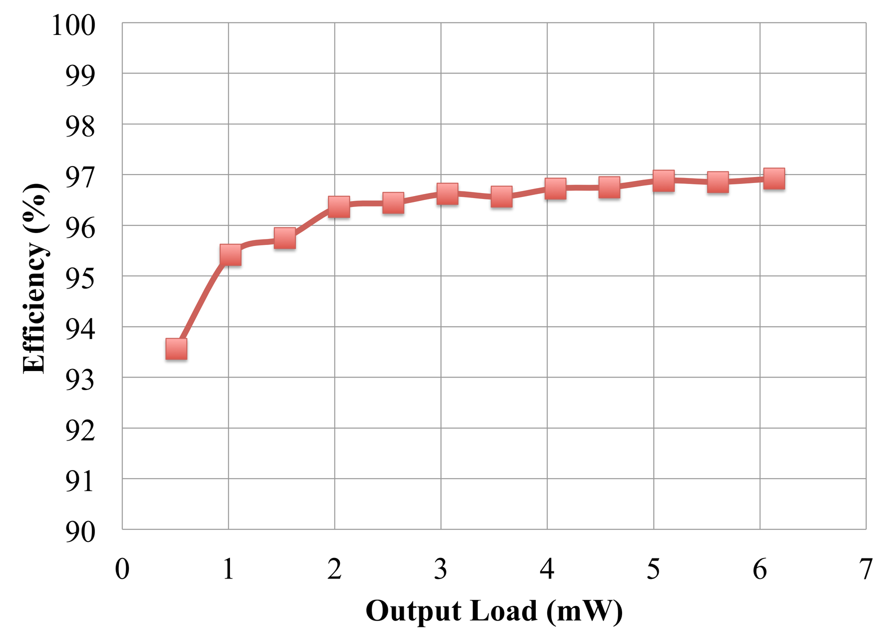
$$\Delta v_O = t_{on}^2 \frac{V_I^2}{2LC_O(V_O - V_I)}$$

- Maximum load current

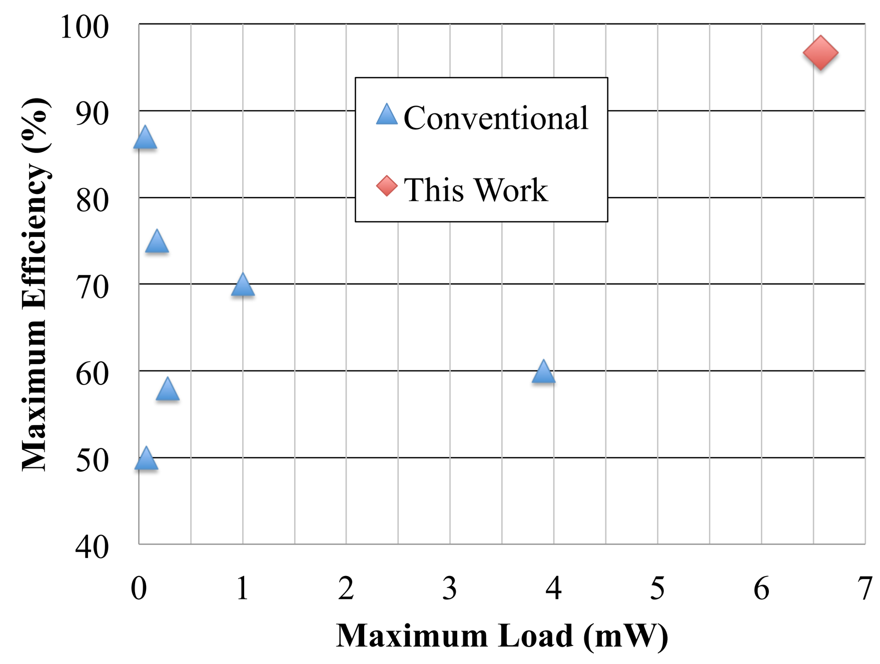
$$I_{O(max)} = t_{on}\frac{V_I^2}{2LV_O}$$

- Smaller inductor → larger peak current
- Larger inductor current → more losses
- Optimum inductor value selected

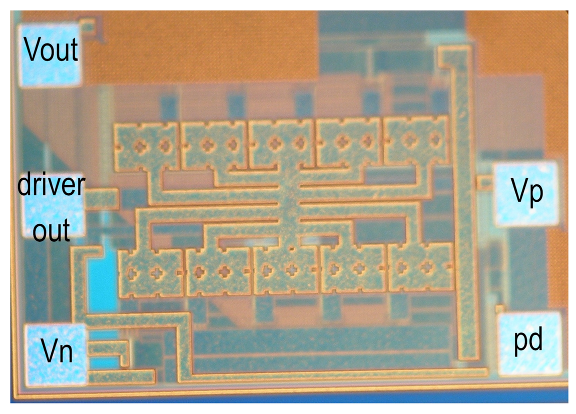
Circuit Efficiency



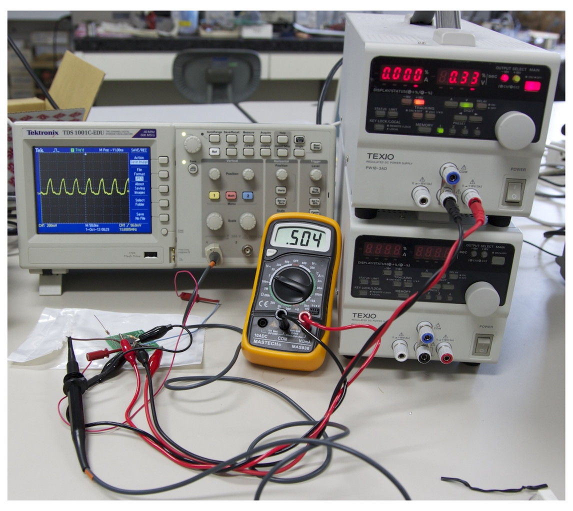
Efficiency Comparison



Charge Pump Test Chip

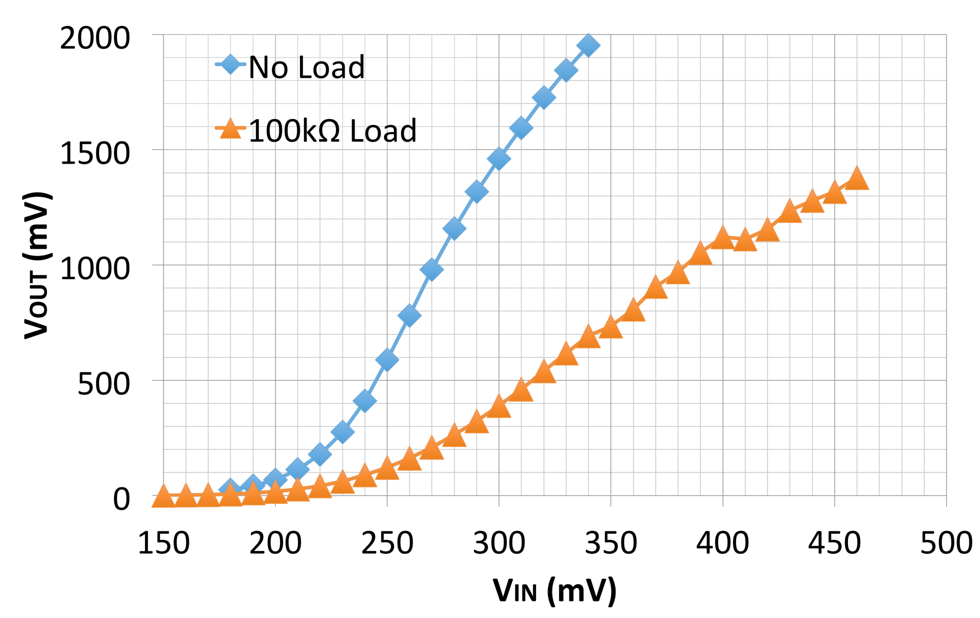


Chip photomicrograph



Lab bench setup

Test Chip Data



Conclusion

1. Introduced bootstrapped boost for EH applications
2. Better performance than previous works
   - Higher efficiency
   - Extended load range
3. Only requires 3 external components
   - Input capacitor, output capacitor, inductor
   - No external energy storage components

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