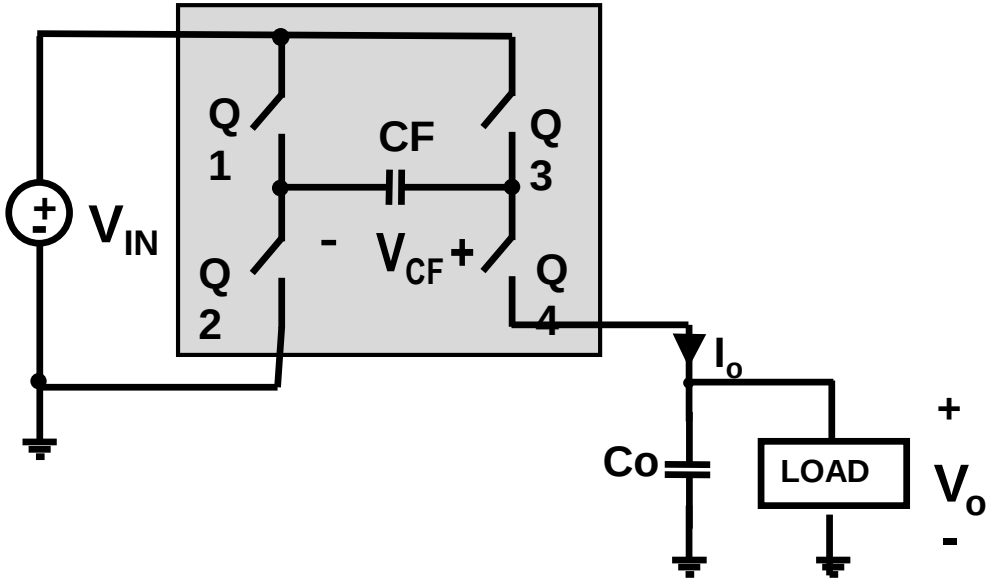
DC-DC Fundamentals

1.4 Charge Pump Regulator

What is a Charge Pump Regulator?

- The charge pump regulator is a kind of switching regulator that delivers power by only alternatively charging and discharging capacitors.
- It's suitable applications with low load current and moderate input to output voltage difference



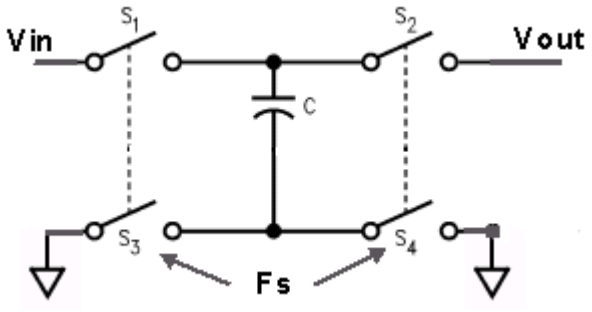
Pros and Cons

Advantages	Disadvantages
• No inductor is needed, smaller size • Moderate Efficiency, higher than linear regulators • V_{out} can be higher or lower than V_{in} • Fewer components needed make the charge pump easier to design and lower cost	• Switching produces higher output ripple & noise • The output current capacity is limited by the capacitors

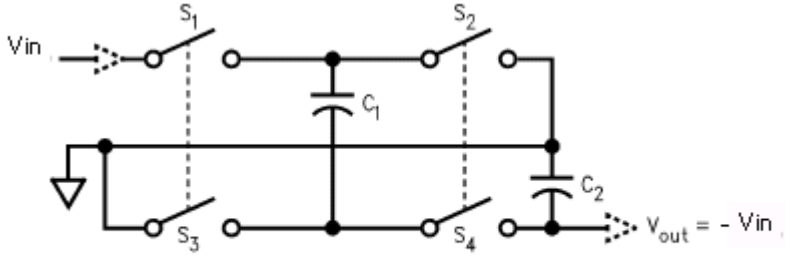
How Does a Charge Pump Work?

- The capacitors connection is altered by the switches so that the charge and discharge is controlled
- Switches S1, S3 and S2, S4 are switching in complementary:
  - S1, S3 on, S2, S4 off, charging
  - S1, S3 off, S2, S4 on, discharging
- By reversing the connections of the output to ground, the unity gain converter becomes negative gain inverter

Unity gain



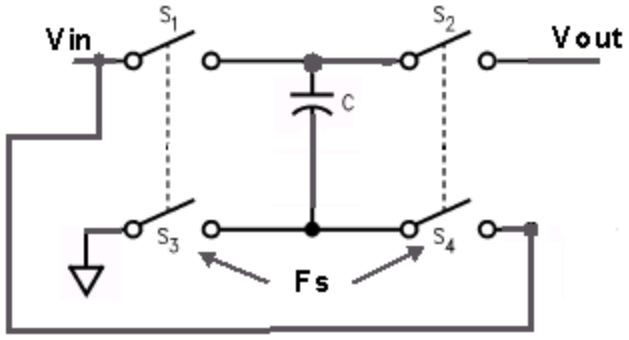
Inverting gain



Voltage Doubler

- The voltage doubler circuit shown below still has a single capacitor in the topology, only the connections are different
- The switching of the four switches are still the same
  - S1, S3 on, S2, S4 off, gain phase
  - S1, S3 off, S2, S4 on, common phase
- However, in the common phase, the input source is still connected to the capacitor: $V_{out} = V_c + V_{in} = 2V_{in}$

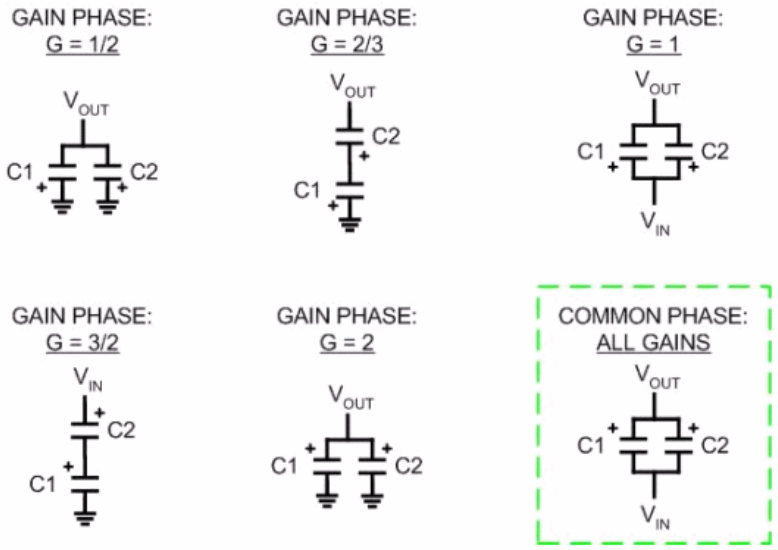
Voltage Doubler



By swapping V_{in} and V_{out}, the same doubler circuit will give half gain

More Gain Combinations

- Include two capacitors in the charge pump, and many different gain can be generated by varying the connection combinations
- The following figure shows some configuration of two capacitor connection and the resulting gain that can be achieved:

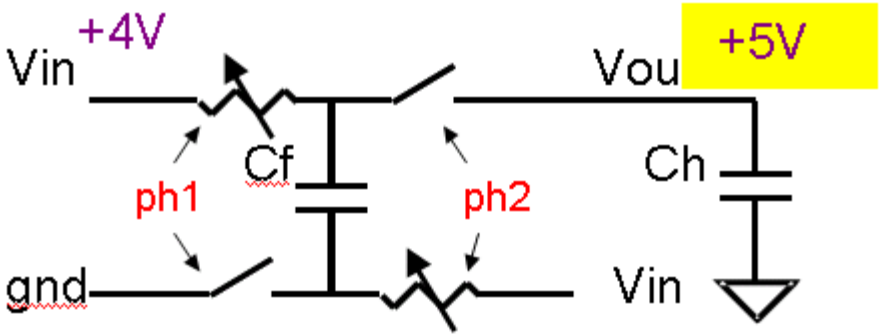


Same common phase connection for all gains

*Assuming C1 = C2

Charge Pump Regulation

- By including a post regulator stage, the charge pump can achieve fine granular of the output voltage
- Also, the switch impedance can be controlled to act effectively as a post regulator
  - R_{out} is the effective output impedance including the switch impedance R_{sw}, and the switched cap impedance ($1/F_{sw}*C_f$)
  - Fine adjustment can be accomplished by controlling F_{sw} or R_{sw}



Regulate Gate Drive on 2 Switches to Control Vout

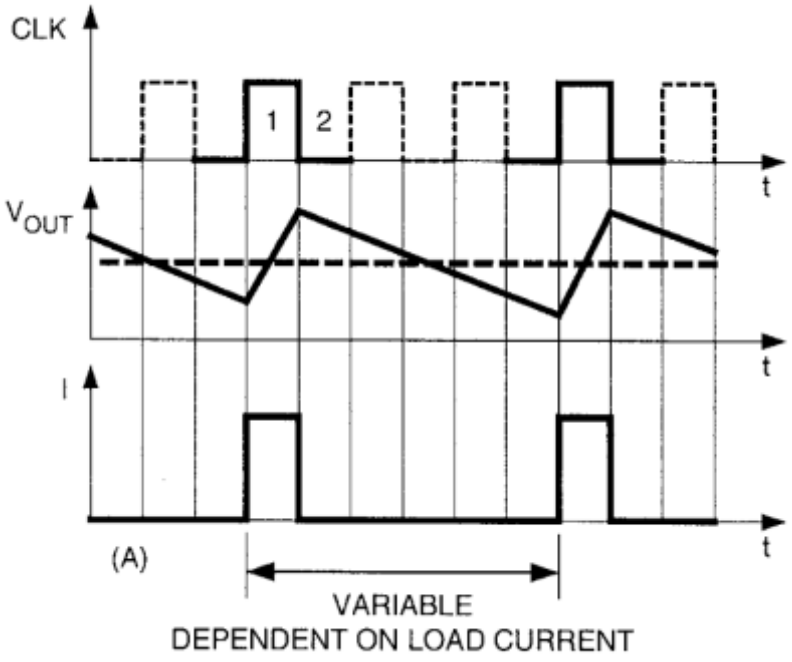
$$Vout = 2 \times Vin - (Iout \times Rout)$$

Fine adjust: Modulate Output Resistance (R_{OUT})

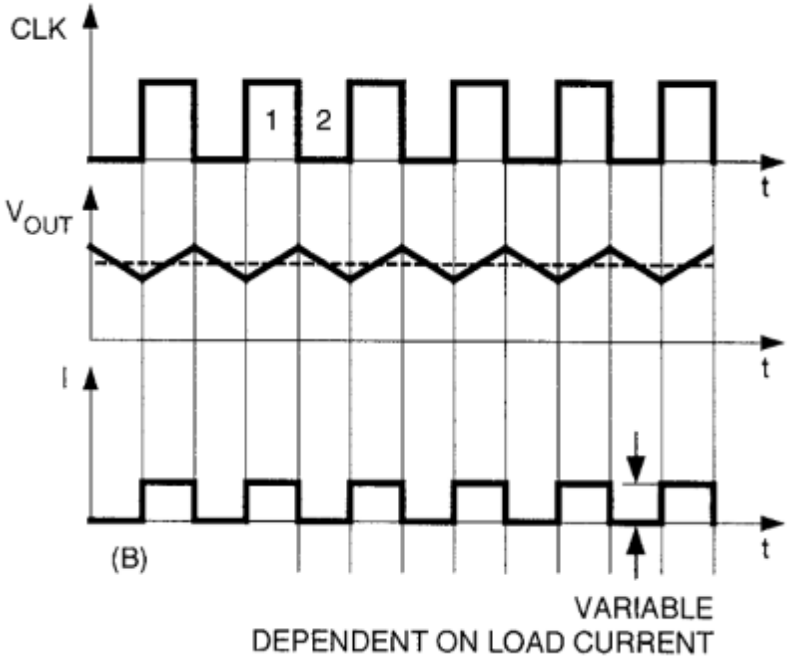
$$R_{OUT} = (G \times R_{SW}) + [1 / (F_{SW} \times C_F)]$$

Charge Pump Regulation

- Control the frequency: Pulse-Frequency Modulation (PFM)
  - The output voltage is held constant by skipping unneeded pulses
  - **Advantages**: very low quiescent current, higher efficiency
  - **Disadvantages**: Higher output voltage ripple, frequency varies



- Control the resistance: Constant-Frequency Regulation
  - Regulate the output by changing the resistance of the internal switches
  - **Advantages**: low voltage ripple, fixed frequency
  - **Disadvantage**: high quiescent current



Summary

- Introduction to charge pump regulator
- The operation and configuration of switching regulator
- The charge pump regulation

Thank you!