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

<table>
<thead>
<tr>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• No inductor is needed, smaller size</td>
</tr>
<tr>
<td>• Moderate Efficiency, higher than linear regulators</td>
</tr>
<tr>
<td>• $V_{\text{out}}$ can be higher or lower than $V_{\text{in}}$</td>
</tr>
<tr>
<td>• Fewer components needed make the charge pump easier to design and lower cost</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Switching produces higher output ripple &amp; noise</td>
</tr>
<tr>
<td>• The output current capacity is limited by the capacitors</td>
</tr>
</tbody>
</table>
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.
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: $V_{\text{out}} = V_c + V_{\text{in}} = 2V_{\text{in}}$

By swapping $V_{\text{in}}$ and $V_{\text{out}}$, 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 $(1/F_{sw} \times C_f)$
  – Fine adjustment can be accomplished by controlling $F_{sw}$ or $R_{sw}$

$$V_{out} = 2 \times V_{in} - (I_{out} \times Rout)$$

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

$$R_{OUT} = (G \times R_{SW}) + \left[ \frac{1}{(F_{SW} \times C_F)} \right]$$
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!