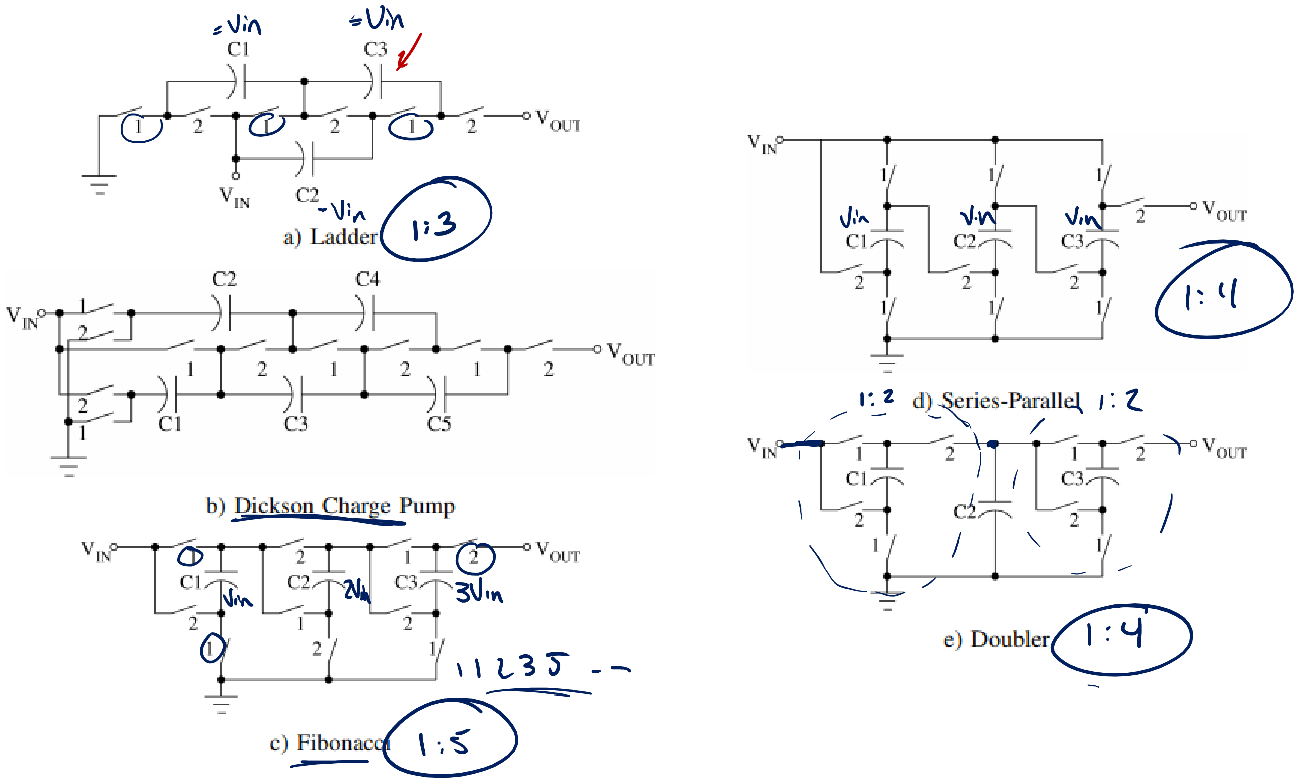
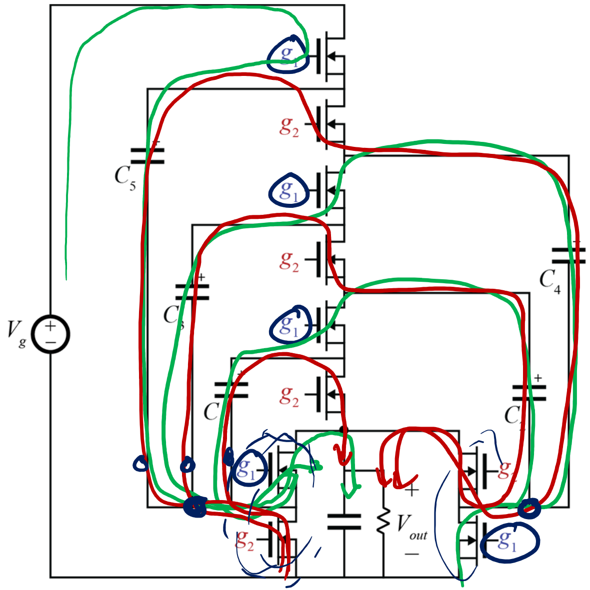
SC Converter Topologies



M Seeman and S. Sanders, “Analysis and Optimization of Switched-Capacitor DC-DC Converters”

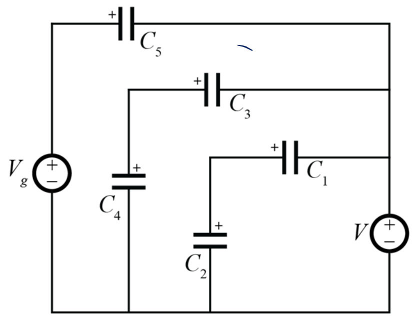
Dickson Converter



Dickson Subintervals

Ideal analysis → neglect any capacitor voltage ripple

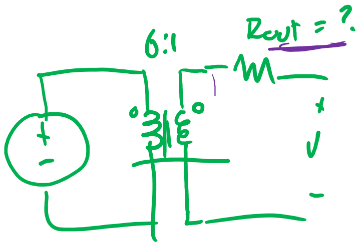
I



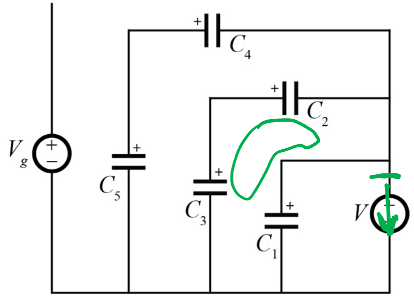
$V_g = 6V$ → this is a 6:1 Dickson converter

$V_{c1} = 4V$

$V_{c2} = 2V$



II

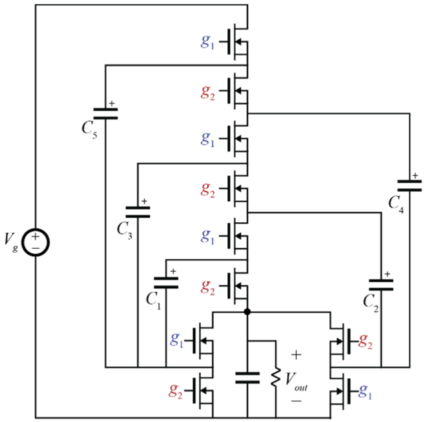


$V_{c5} = 5V$

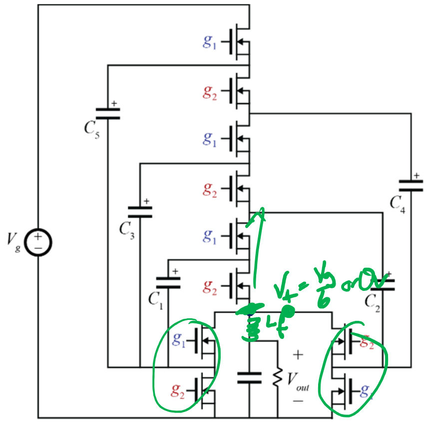
$V_{c3} = 3V$

$V_{c1} = V$

Dickson Converter Variants

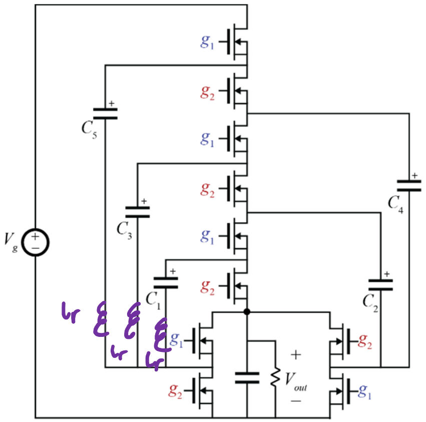


Standard Dickson Converter



Hybrid Dickson Converter

- On its own L_f allows some current source type charging
- Can add PWM regulation for $V_{out} \le \frac{1}{6} V_g$



Switched Tank Converter

- Unregulated, high η
- Resonant charging of all capacitors

Y. Lei, R. May, and R. Pilawa-Podgurski, "Split-Phase Control: Achieving Complete Soft-Charging Operation of a Dickson Switched- Capacitor Converter," 2016

Y. Li, X. Lyu, D. Cao, S. Jiang and C. Nan, "A 98.55% Efficiency Switched-Tank Converter for Data Center Application," 2018.

Charge Vector Analysis: Notation

Find N & k for arbitrary switched cap converter

- Applies cap-Q balance to every capacitor in the circuit

q_x^{I} = charge into element x in subinterval I ($q_{c1}^{I} \rightarrow$ charge in C_1 in I)

$a_x^{I} = \dfrac{q_x^{I}}{q_{out}}$ → Charge normalized by total output charge over all subintervals $\quad q_{out} = q_{out}^{I} + q_{out}^{II} + \dots$

$$\bar{a}^{I} = [\, \underbrace{a_{in}^{I}}_{\text{Input source}},\ \underbrace{\overbrace{a_{c1}^{I},\ a_{c2}^{I},\ \dots\ a_{cN}^{I}}^{\bar{a}_c^{I}}}_{\text{All capacitors}},\ \underbrace{a_{out}^{I}}_{\text{output port}} \,]$$

N = total number of flying caps in the circuit

$$\bar{V}^{I} = [\, V_g,\ V_{c1}^{I},\ V_{c2}^{I},\ \dots,\ V_{cN}^{I},\ V \,]$$

V_{cx}^{I} = Voltage on C_x at the end of subinterval I (assumed SSL)

M. Makowski and D. Maksimovic, "Performance Limits of Switched-Capacitor DC-DC Converters," 1995
M Seeman and S. Sanders, "Analysis and Optimization of Switched-Capacitor DC-DC Converters," 2008

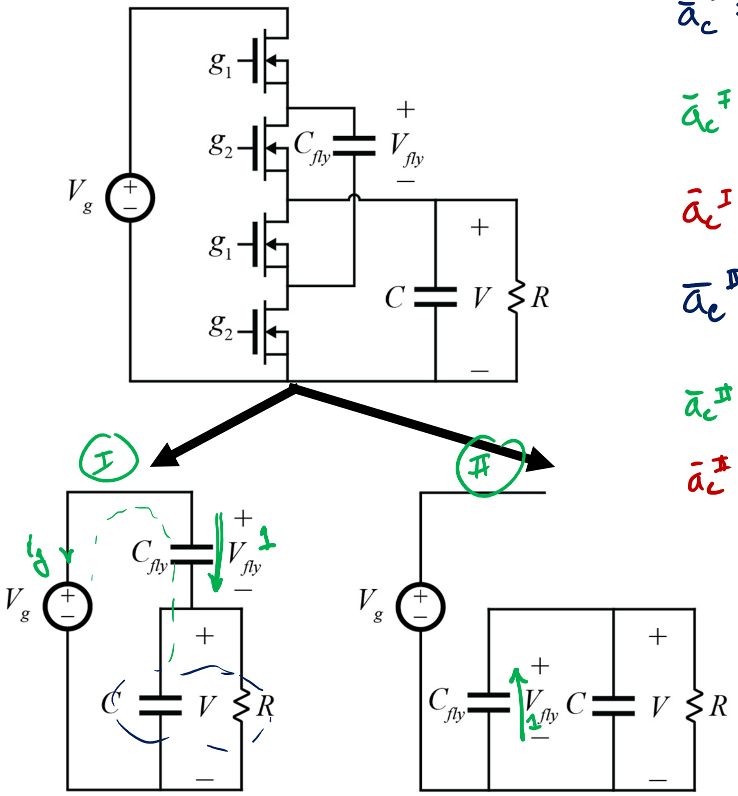
Charge Vector Analysis: Rules

- KVL & KCL apply
- for all caps $\int_0^{T_s} i_{cx}\,dt = \sum_{\text{all ints}} q_{cx} = \phi$ (cap-charge balance)

  for a 2-subinterval converter $q_{cx}^{I} + q_{cx}^{II} = \phi \rightarrow q_{cx}^{I} = -q_{cx}^{II}$

  same is true for a_{cx}

2:1 Converter Charge Vector Analysis



$\bar{a}_c^{I} = [\, q_{in}^{I} \quad q_{fly}^{I} \quad q_{out}^{I} \,] / q_{out}$

$\bar{a}_c^{I} \; [\, -1 \quad 1 \quad 1 \,] / q_{out}$

$\bar{a}_c^{I} = [\, -1/2 \quad 1/2 \quad 1/2 \,]$

$\bar{a}_c^{II} = [\, q_{in}^{II} \quad q_{fly}^{II} \quad q_{out}^{II} \,] / q_{out}$

$\bar{a}_c^{II} = [\, \phi \quad -1 \quad 1 \,] / q_{out}$

$\bar{a}_c^{II} = [\, \phi \quad -1/2 \quad 1/2 \,]$

$q_{out} = q_{out}^{I} + q_{out}^{II}$
$= 2$

Normalized $q_{out} = 1$ always

$q_{in} = -1/2$

$V_g = 2V \rightarrow N = 2$ in equivalent circuit

$M = \frac{V}{V_g} = \frac{-q_{in}}{q_{out}} = -q_{in}$

Tellegen's Theorem

For any valid circuit (KVL & KCL apply)

$$\sum_{i \in \text{elements}} V_i I_i = \emptyset$$

$V_i \rightarrow$ Voltage across

$I_i \rightarrow$ current through

Passive sign convention held on all elements

For our 2-interval SC converter

$$\bar{a}^{I}\bar{v}^{I} + \bar{a}^{II}\bar{a}^{II} = \emptyset \qquad \& \qquad \bar{a}^{I}\bar{v}^{I} = \bar{a}^{II}\bar{v}^{II} = \emptyset$$