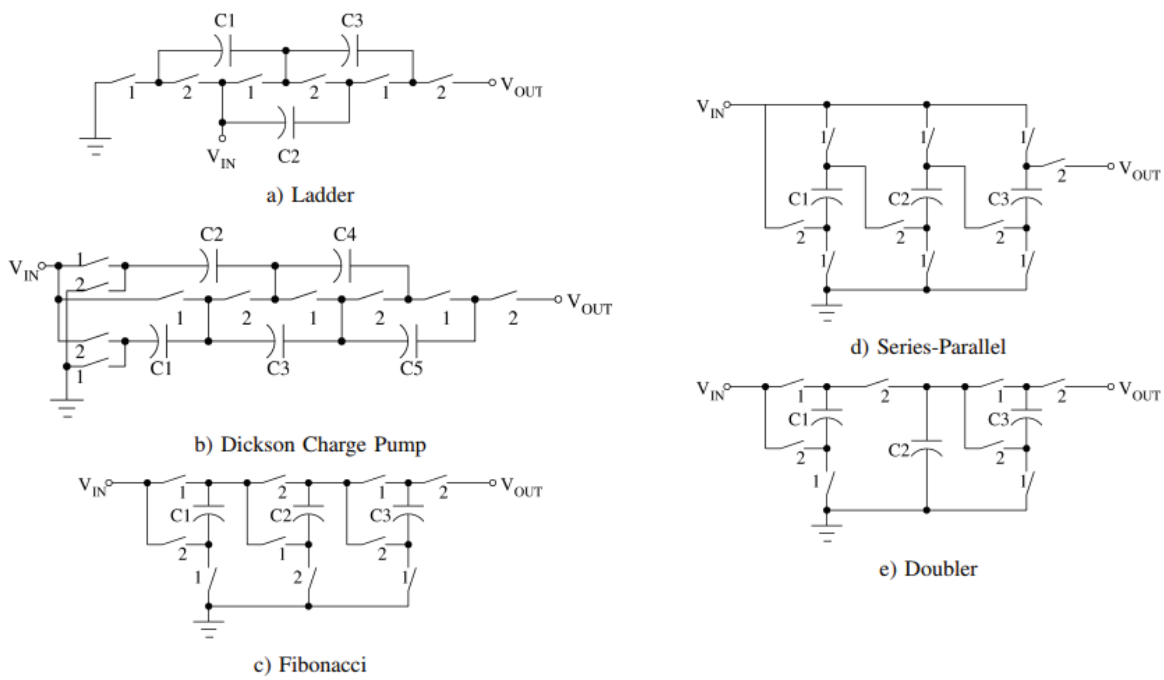
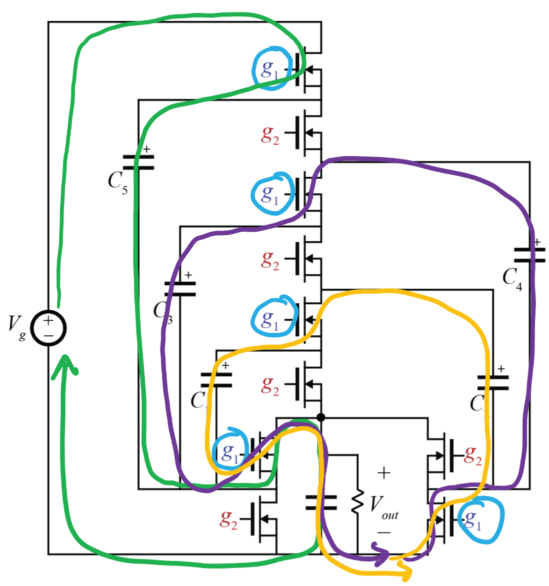
SC Converter Topologies

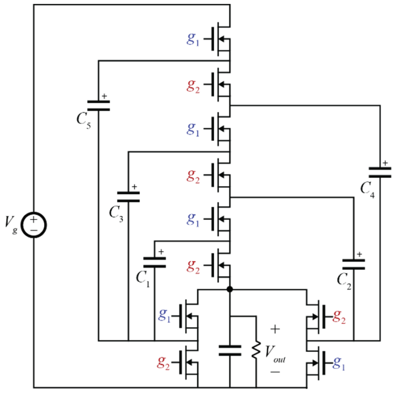


M Seeman and S. Sanders, “Analysis and Optimization of Switched-Capacitor DC-DC Converters”

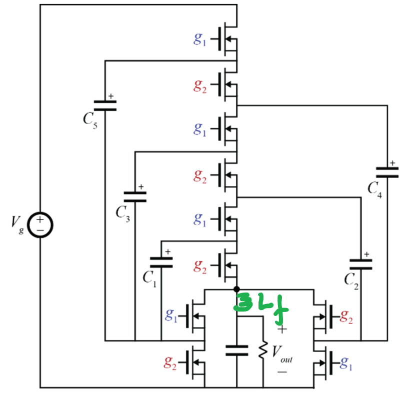
Dickson Converter



Dickson Converter Variants



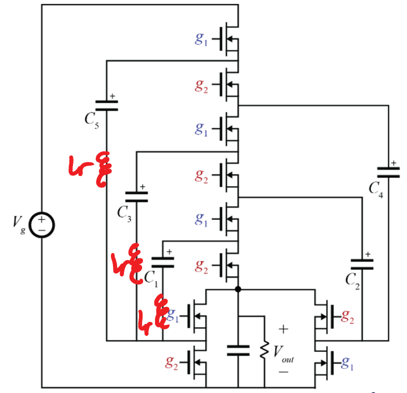
Standard Dickson
(SSL / FSL)



Hybrid Dickson

Add Lf → can't get current-source type charging of all caps w/ just one inductor

Regulation possible



Switched Tank Converter

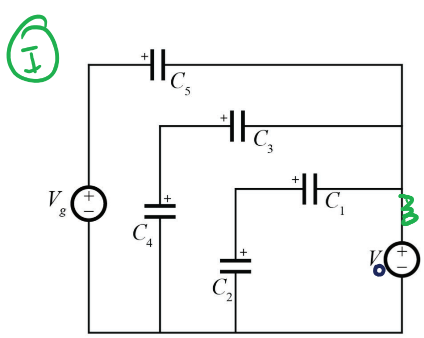
Unregulated for high ?

Resonant charging of all caps.

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.

Dickson Subintervals



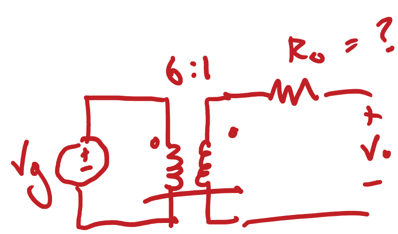
Ideal Analysis

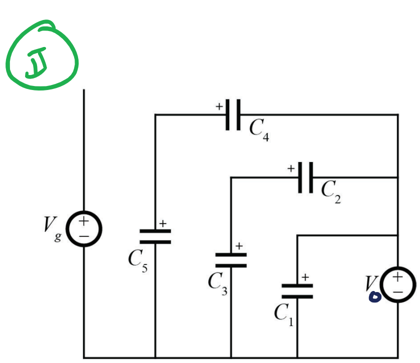
– All caps have ~ zero ripple

$V_g = 6V_o$ → This is a 6:1 implementation

$V_{c4} = 4V_o$

$V_{c2} = 2V_o$





$V_{c5} = 5V_o$

$V_{c3} = 3V_o$

$V_{c1} = V_o$

Charge Vector Analysis: Notation

Finds M $ R_o for arbitrary switched cap converter
- Applies cap-charge balance to every capacitor in circuit

q_x^{I} = charge into capacitor x during switching subinterval I

$a_x^{I} = \frac{q_x^{I}}{q_{out}}$ → normalized with respect to $q_{out} = q_{out}^{I} + q_{out}^{II} + \dots$

$$\bar{a}^{I} = [a_{in}^{I}, \underbrace{a_{c1}^{I}, a_{c2}^{I}, \dots, a_{cN}^{I}}_{\bar{a}_c^{I}}, a_{out}^{I}]$$

N = total # of caps in converter

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

$V_{c1}^{I} \equiv$ Voltage on C_1 at the end of subinterval I (assumed operation in SSL)

Charge Vector Analysis: Rules

- KVL $ KCL apply always
- for all caps $\langle i_{ci} \rangle_{T_s} = \emptyset$ in steady-state (cap-charge balance)

$$\frac{1}{T_s}\int_0^{T_s} i_{ci}\, dt = \emptyset \longleftrightarrow q_{ci}^{I} + q_{ci}^{II} + \dots = \emptyset$$

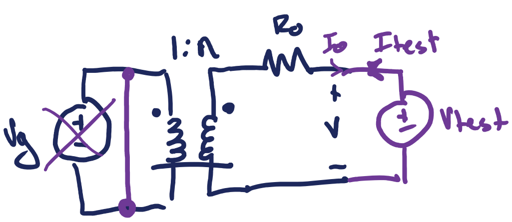
also, $a_{ci}^{I} + a_{ci}^{II} + \dots = \emptyset$

ex for just two subintervals, $a_{ci}^{I} = -a_{ci}^{II}$

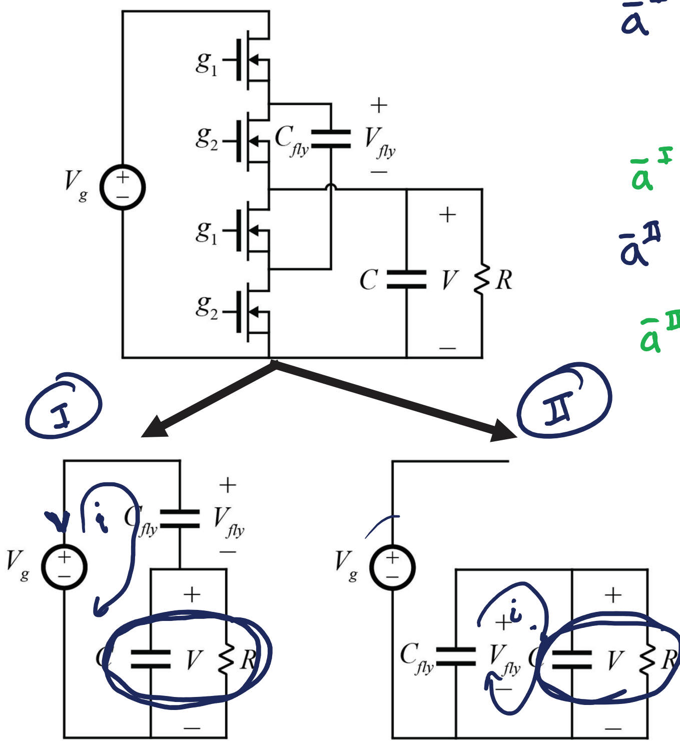
To find output resistance

turn off V_g, apply test source at output

$$R_o = \frac{V_{test}}{I_{test}} = \frac{V}{-I_o}$$



2:1 Converter Charge Vector Analysis



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

$$= [-1, \; 1, \; 1] / q_{out}$$

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

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

$$\bar{a}^{II} = [0, \; -1/2, \; 1/2]$$

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

$a_{out} = 1$ (always, by normalize)

$a_{in} = -1/2$

↳ Ideal conversion ratio

$$M = \frac{V}{V_g} = \frac{-a_{in}}{a_{out}} = \frac{1}{2}$$