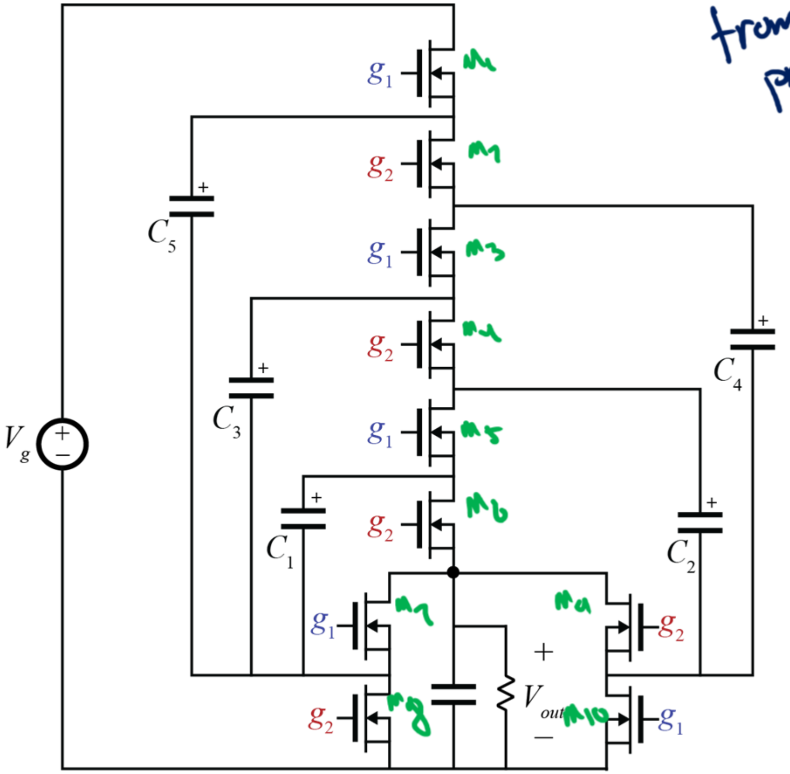
Dickson Converter FSL Output Resistance



from previous

$$\bar{a}^{I} = \left[-\tfrac{1}{6} \quad \tfrac{1}{6} \quad -\tfrac{1}{6} \quad \tfrac{1}{6} \quad -\tfrac{1}{6} \quad \tfrac{1}{6} \quad \tfrac{1}{2} \right]$$

$$\bar{a}^{II} = \left[\emptyset \quad -\tfrac{1}{6} \quad \tfrac{1}{6} \quad -\tfrac{1}{6} \quad \tfrac{1}{6} \quad -\tfrac{1}{6} \quad \tfrac{1}{2} \right]$$

$$\begin{array}{cccccccccccc} & M_1 & M_2 & M_3 & M_4 & M_5 & M_6 & M_7 & M_8 & M_9 & M_{10} & \\ \bar{a}_r = & \Big[\tfrac{1}{6} & \tfrac{1}{6} & \tfrac{1}{6} & \tfrac{1}{6} & \tfrac{1}{6} & \tfrac{1}{6} & \tfrac{1}{2} & \tfrac{1}{2} & \tfrac{1}{3} & \tfrac{1}{3} \Big] \end{array}$$

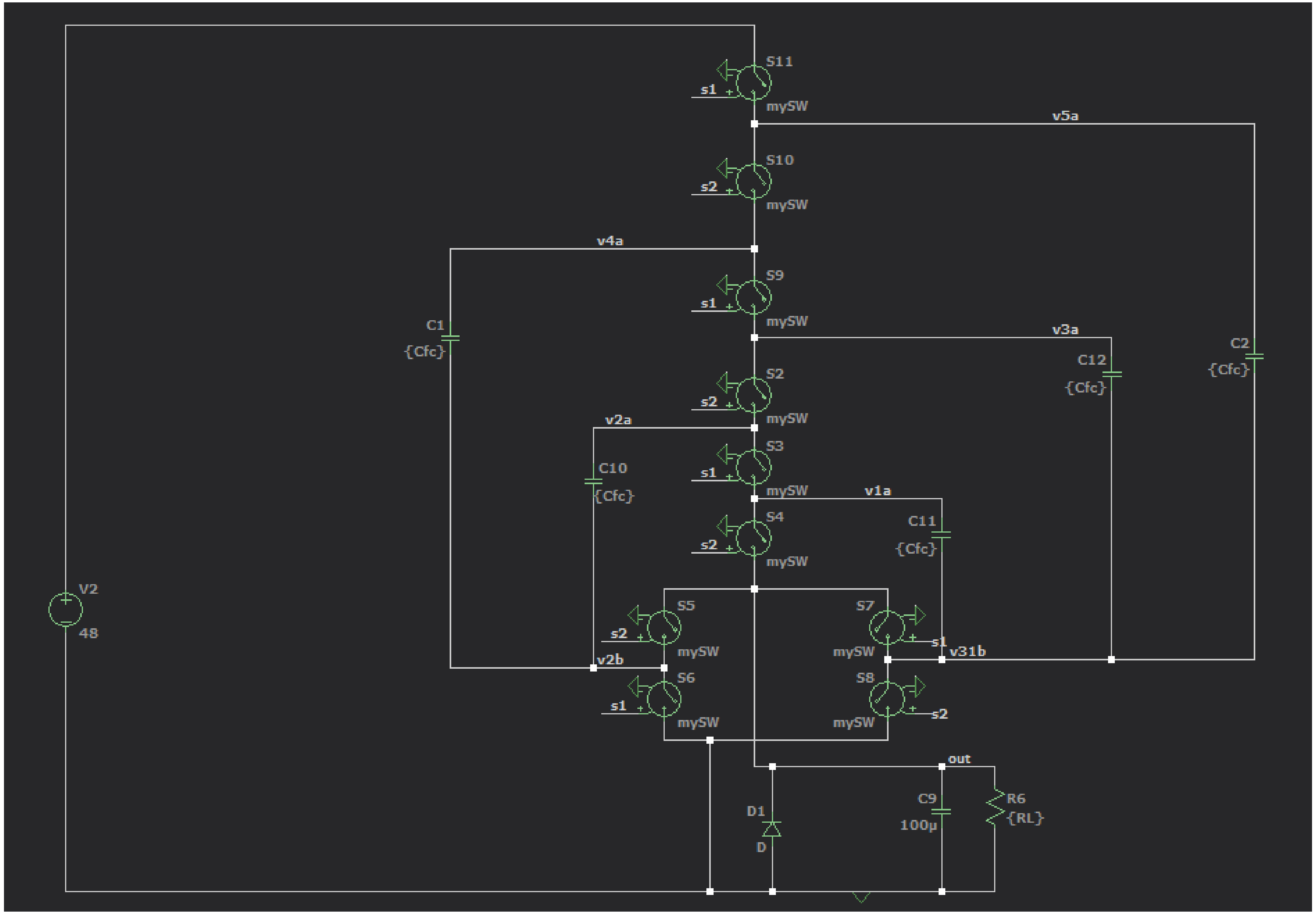
$$R_{o,FSL} = \sum_{\text{all } R\text{'s}} (a_{r_i})^2 \, 2 R_i$$

$$= \sum_{i=1}^{10} a_{r_i}^2 \cdot 2 R_i = \frac{6 + 9\times 2 + 4\times 2}{36} \cdot 2 R_{on}$$

$$= \frac{32}{36} \cdot 2 \cdot R_{on}$$

$$= \frac{16}{18} \cdot 2 \cdot R_{on} = \boxed{\frac{16}{9} R_{on} = R_{o,FSL}}$$

6:1 Dickson Converter Simulation



Simulation Comparison to Model

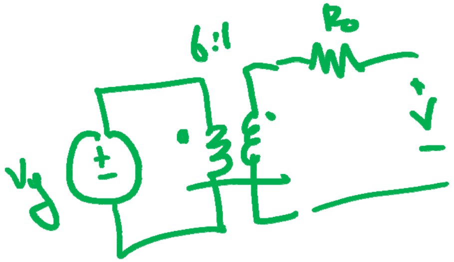
fixed f_s= 1MHZ

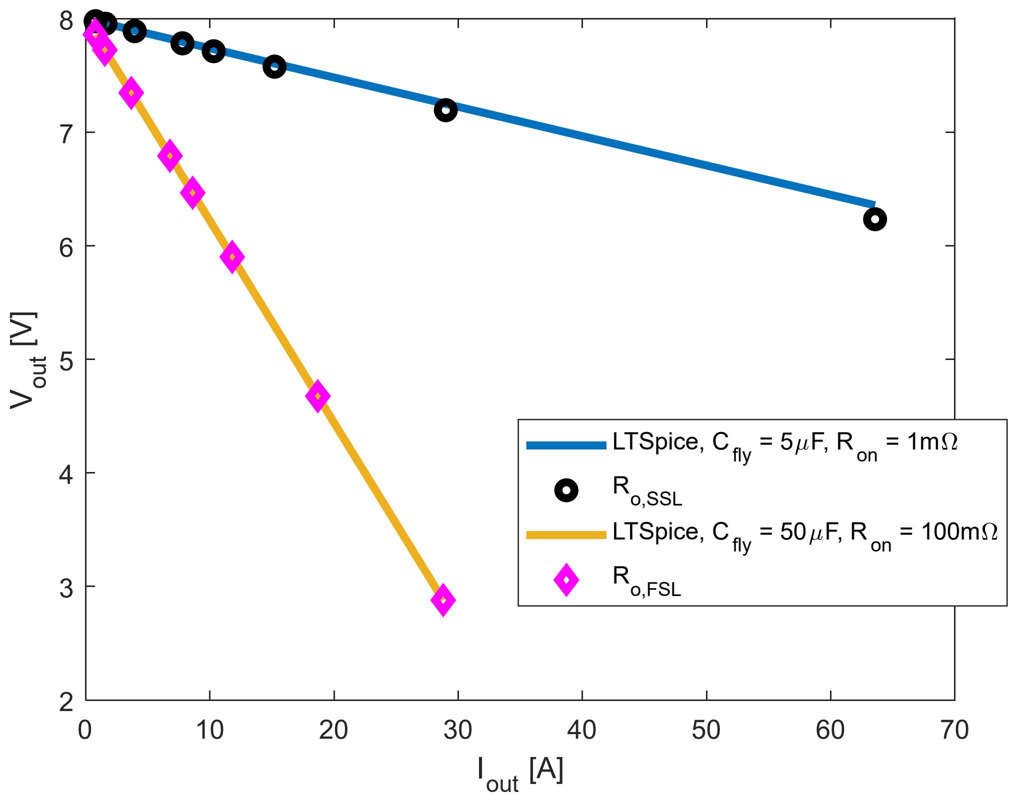
1) $C_{fly} = 5nF$, $R_{on} = 1m\Omega$

$$\frac{1}{2\pi C_{fly} R_{on}} = 30 MHz$$

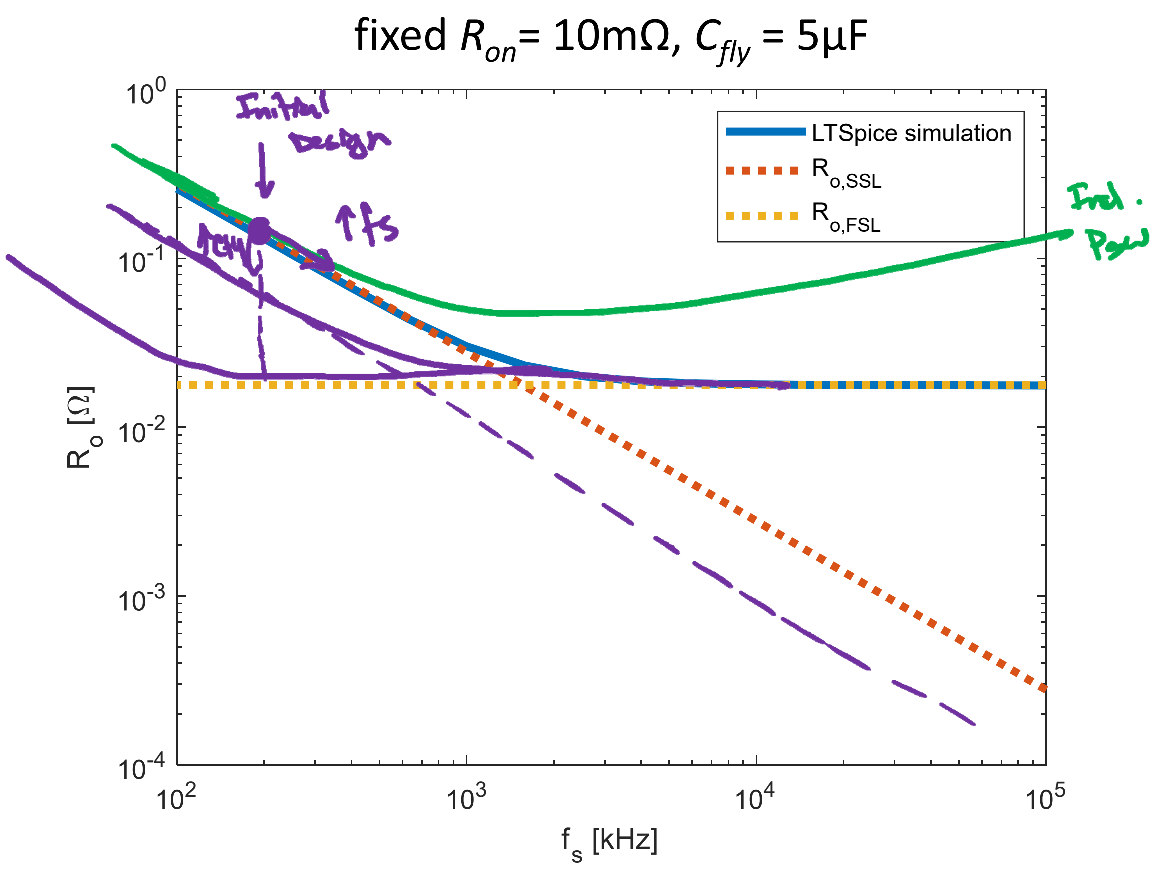
2) $C_{fly} = 50nF$ $R_{on} = 100m\Omega$

$$\frac{1}{2\pi C_{fly} R_{on}} = 30 kHz$$





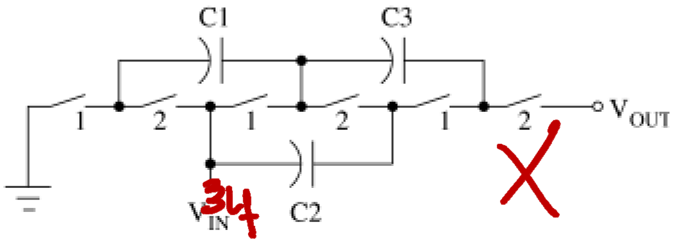
R_o vs Switching Frequency



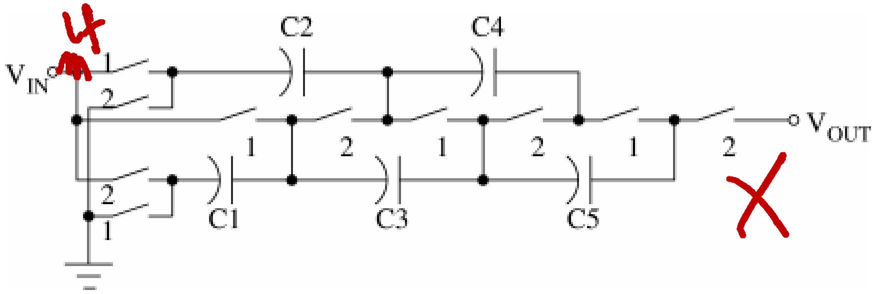
Reduce Charge sharing loss by

1) ↑ fs (penalty on Psw)
2) ↑ Cfly (penalty on size/cost)
3) Hybrid SC converter
(penalty on size/cost
but benefit of regulation possibility)

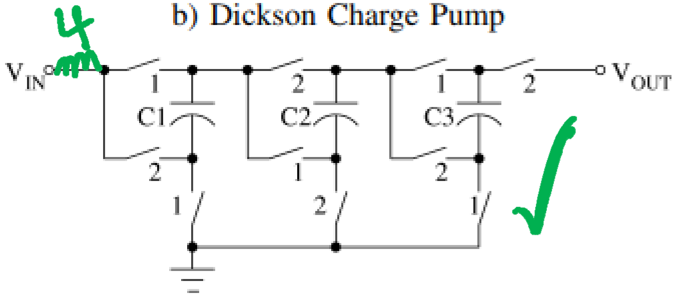
Soft Charging



a) Ladder

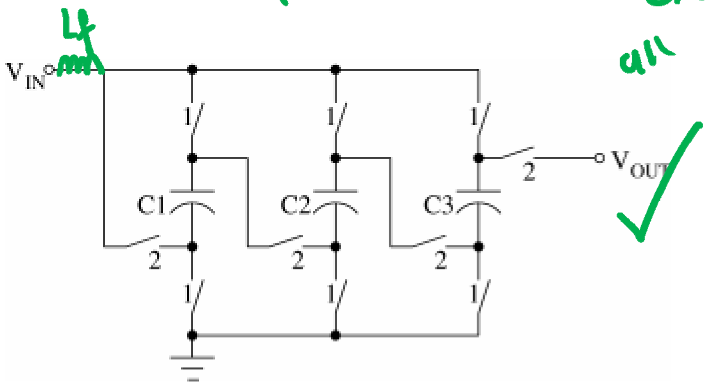


b) Dickson Charge Pump

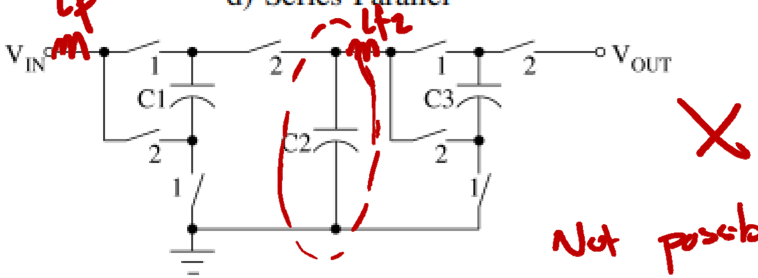


c) Fibonacci

One inductor is sufficient for "complete soft charging" of all caps



d) Series-Parallel



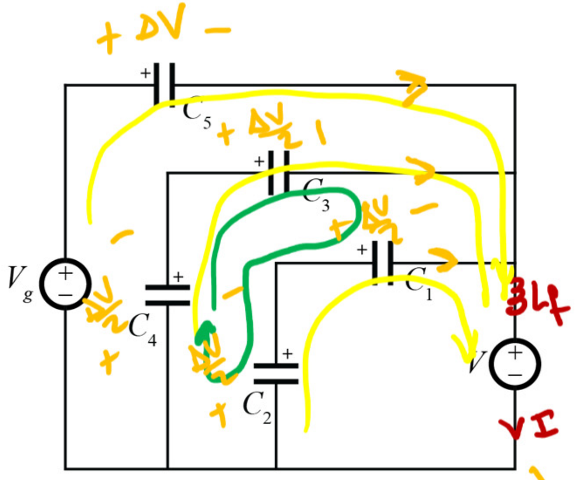
e) Doubler

Not possible with one L

Y. Lei and R. Pilawa, "A General Method for Analyzing Resonant and Soft-Charging Operation of Switched-Capacitor Converters" TPEL 2014
S. R. Pasternak, M. H. Kiani, J. S. Rentmeister and J. T. Stauth, "Modeling and Performance Limits of Switched-Capacitor DC–DC Converters Capable of Resonant Operation With a Single Inductor", JESTPE 2017

Hybrid Dickson Converter

I

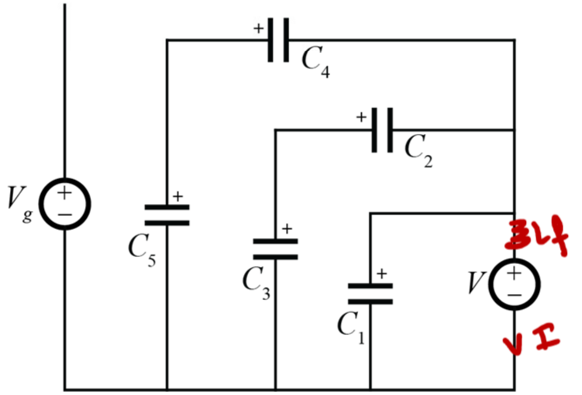


At start, need

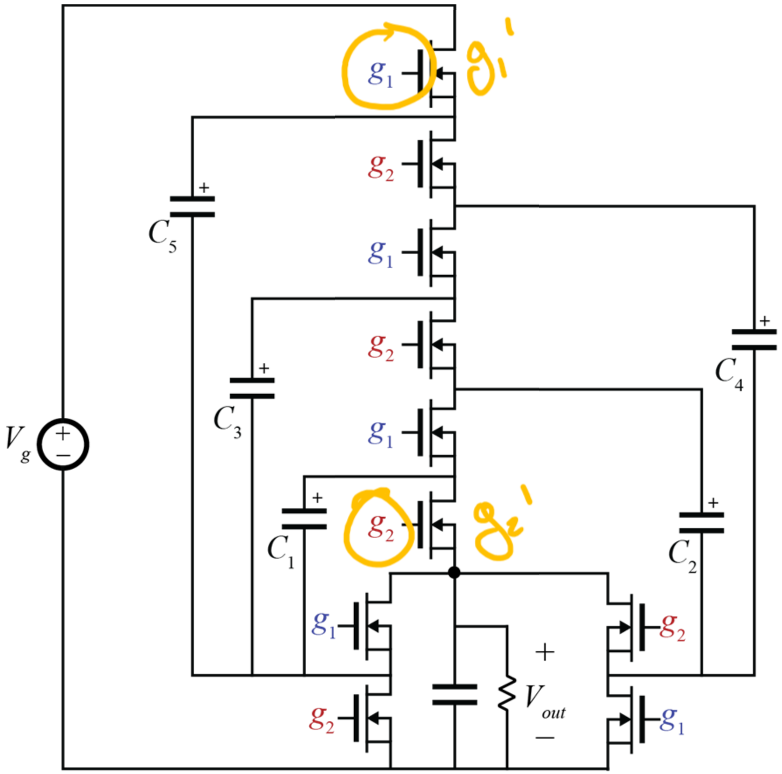
$V_g - V_{c5} = V_{c4} - V_{c3} = V_{c2} - V_{c1}$

Not possible to be balanced voltages in bot subintervals

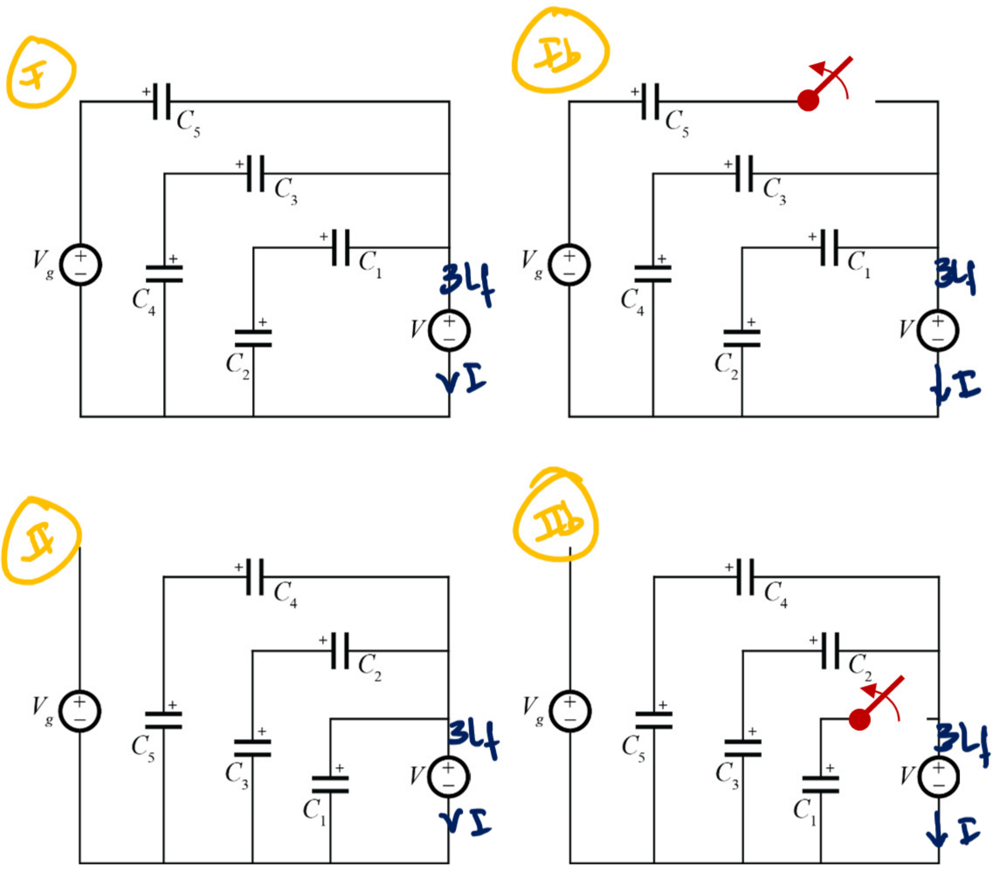
II



Split-Phase Control



Split-Phase Control



$$\begin{array}{cccccccc} & a_{in} & a_1 & a_2 & a_3 & a_4 & a_5 & a_{out} \end{array}$$

$$\begin{cases} \bar{a}^{I} = \left[-\frac{1}{4} \ \ \frac{1}{8} \ \ -\frac{1}{8} \ \ \frac{1}{8} \ \ -\frac{1}{8} \ \ \frac{1}{4} \ \ \frac{1}{2} \right] / q_{out} \\ \bar{a}^{Ib} = \left[\emptyset \ \ \frac{1}{4} \ \ -\frac{1}{4} \ \ \frac{1}{4} \ \ -\frac{1}{4} \ \ \emptyset \ \ \frac{1}{2} \right] / q_{out} \end{cases}$$

$$\begin{cases} \bar{a}^{II} = \left[\emptyset \ \ -\frac{1}{4} \ \ \frac{1}{8} \ \ -\frac{1}{8} \ \ \frac{1}{8} \ \ -\frac{1}{8} \ \ \frac{1}{2} \right] / q_{out} \\ \bar{a}^{IIb} = \left[\emptyset \ \ \emptyset \ \ \frac{1}{4} \ \ -\frac{1}{4} \ \ \frac{1}{4} \ \ -\frac{1}{4} \ \ \frac{1}{2} \right] / q_{out} \end{cases}$$

Duty Cycles $D_I, D_{Ib}, D_{II}, D_{IIb}$

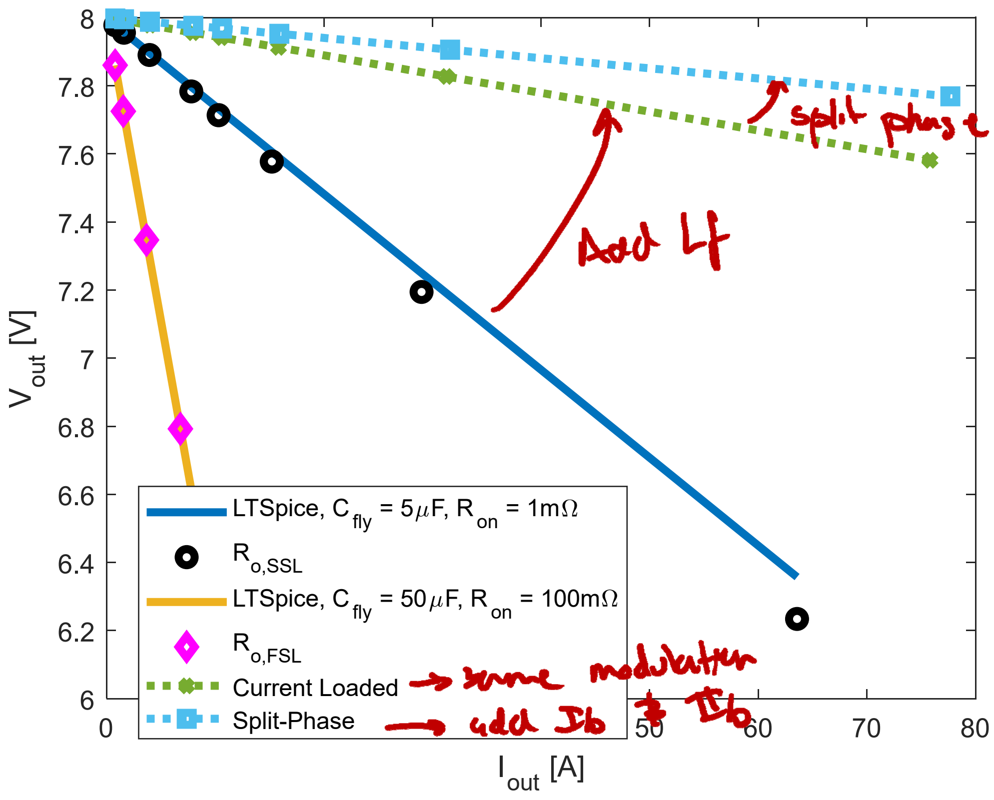
$$D_I + D_{Ib} = 50\% = D_{II} + D_{IIb}$$

$$\begin{bmatrix} D_I & D_{Ib} & D_{II} & D_{IIb} \end{bmatrix} \cdot \begin{bmatrix} \bar{a}^{I} \\ \bar{a}^{Ib} \\ \bar{a}^{II} \\ \bar{a}^{IIb} \end{bmatrix} = \begin{bmatrix} -\frac{1}{6} & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$D_I = D_{II} = 2/6$$

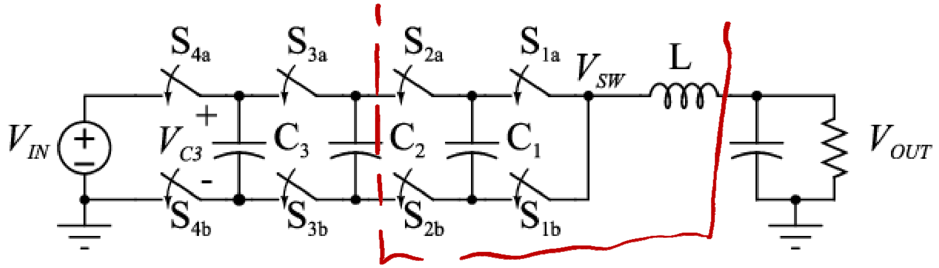
$$D_{Ib} = D_{IIb} = 1/6$$

LTSpice Simulation



FCML and SC Buck

3-level buck

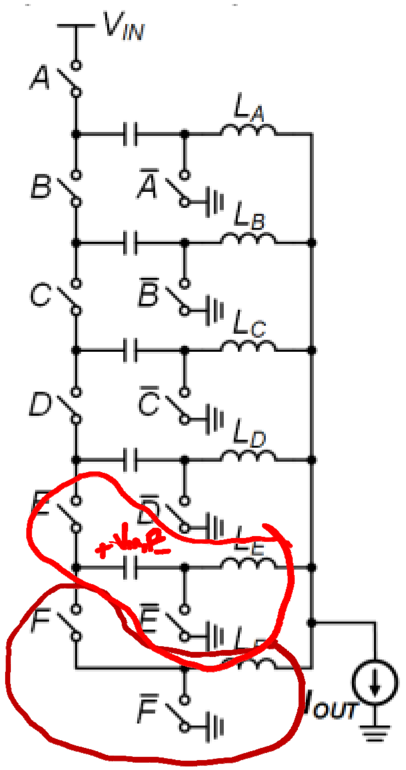


FCML

Flying capacitor multilevel

"multilevel buck"

series-capacitor buck



Buck converter