6.334 Lecture Notes Intro to DC/DC

First Averaged circuit rules

KCL $\sum_j i_j = 0$

$$\frac{1}{T}\int_T \sum_j i_j \, dt = 0$$

$$\sum_j \frac{1}{T}\int i_j \, dt = 0$$

$$\boxed{\sum_j \langle i_j \rangle = 0}$$

KCL Applies to time-average currents (cons. charge)

The same is true for KVL $\sum_k \langle V_k \rangle = 0$

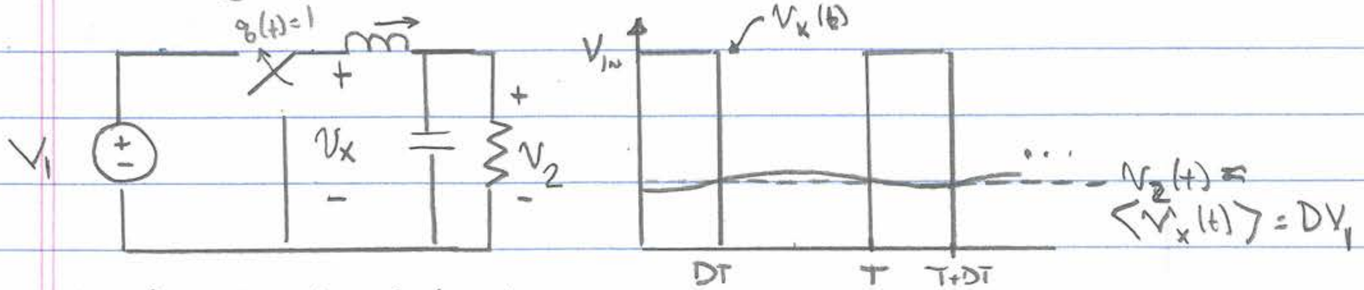
So for a power converter in <u>PERIODIC STEADY STATE</u>:

1. Average KCL $\sum_j \langle i_j \rangle = 0$
2. Average KVL $\sum_k \langle V_k \rangle = 0$
3. Capacitor in P.S.S. $\langle i_C \rangle = 0$
4. Inductor in P.S.S. $\langle V_L \rangle = 0$
5. If system lossless $\langle P_{IN} \rangle = \langle P_{OUT} \rangle$
   (cons. of energy)

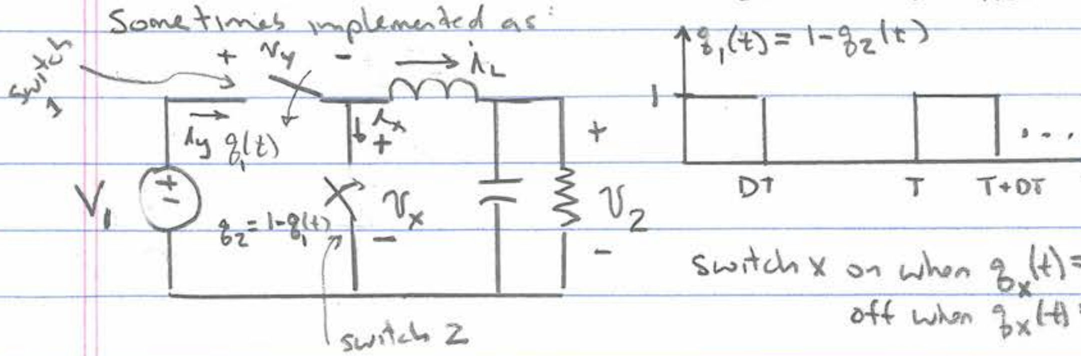
6.334 Lecture Notes — Intro to dc/dc

Review

<u>Switching Regulator Example</u> "Buck Converter"



Sometimes implemented as:



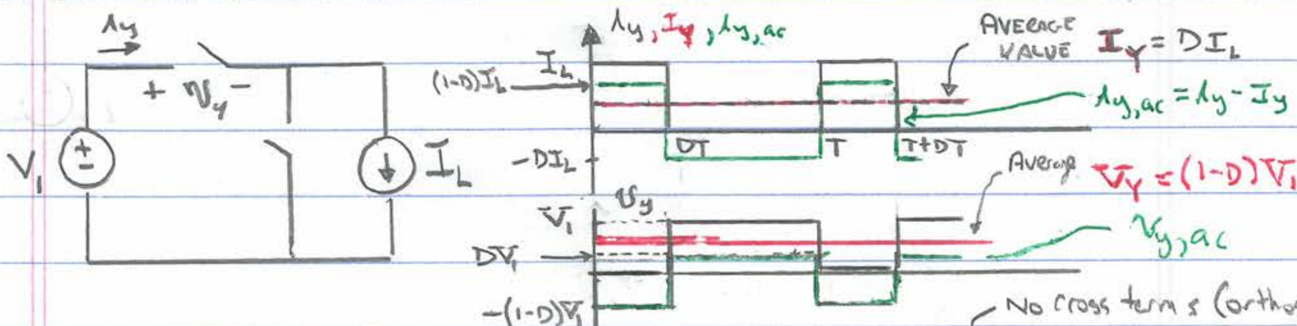
switch x on when $q_x(t)=1$
off when $q_x(t)=0$

Assume L's, C's are very big $\therefore v_o(t) \simeq V_o$, $i_L(t) \simeq I_L$

Using average relations in p.s.s. $\langle v_L \rangle = \langle v_x \rangle - \langle v_2 \rangle$

$$\langle v_L \rangle = \frac{1}{T}\left[DT(V_1 - V_2) + (1-D)T(-V_2)\right] = 0 \Rightarrow \boxed{V_2 = DV_1}$$

ASIDE: WHAT DO SWITCH 1 + SWITCH 2 DO? LETS IGNORE INDUCTOR RIPPLE



No cross terms (orthogonal)

Ave Power into sw1: $\langle p_1 \rangle = \langle (V_Y + v_{y,ac})(I_Y + i_{y,ac}) \rangle = \langle V_Y I_Y \rangle + \langle v_{y,ac} i_{y,ac} \rangle$

$$\langle p_1 \rangle = D(1-D) I_L V_1 + \left\{ D\left[-(1-D)^2 I_L V_1\right] + (1-D)\left[-D^2 I_L V_1\right] \right\}$$

Avg. Power into switch due to dc i, v — Avg. power into switch due to ac i, v

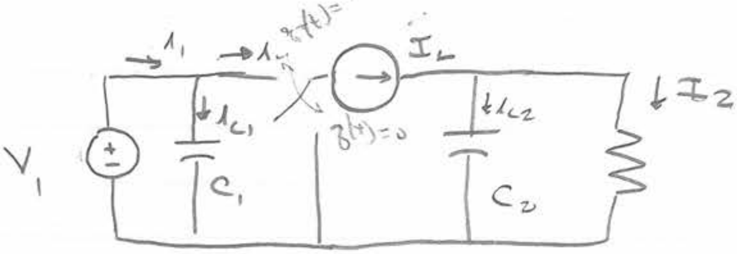
$$= \boxed{D(1-D) I_L V_1} \quad \boxed{-D(1-D) I_L V_1} = 0$$

Switch S_1 takes average power in from dc current, voltage and puts equal power <u>out</u> at ac current, voltage. Converts power (efficiently) from dc to ac waveforms! ("inverting" switch)

Note: Switch S_2 Does the opposite (converts power from ac waveforms to dc waveforms)! (rectifying switch)

6.334 Lecture Notes — Intro. to dc/dc

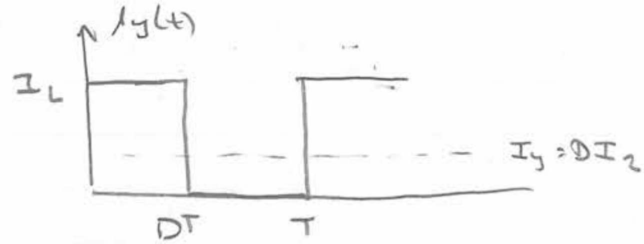
Consider input current:



L's, C's big, $i_L(t) \approx I_L$

p.s.s. $\langle i_{c2} \rangle = 0 \therefore I_2 = I_L$

p.s.s. $\langle i_{c1} \rangle = 0 \therefore$



$$I_1 = \langle i_1 \rangle = \langle i_y \rangle = DI_2$$

$$\therefore \boxed{I_1 = DI_2}$$

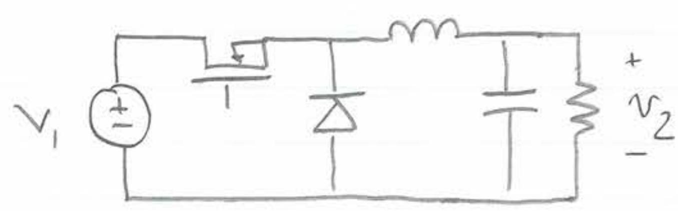
Combining w/ previous results $DV_1 = V_2$

$I_1 V_1 = I_2 V_2$ ← lossless system!

> **Note:** The trick is to be careful about when one is dealing with instantaneous variables, and when one is dealing with average variables!

e.g. at a given instant, $i_y(t) \neq \langle i_y(t) \rangle$

Switch implementation for this case, $V_1, V_2 > 0$

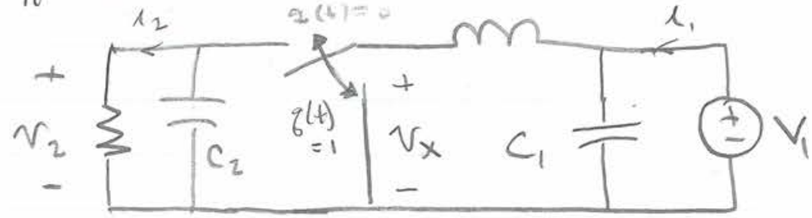


Power flows 1→2

"Down" or "buck" converter. A type of "direct" converter because in one switch state, power flows directly from input to output

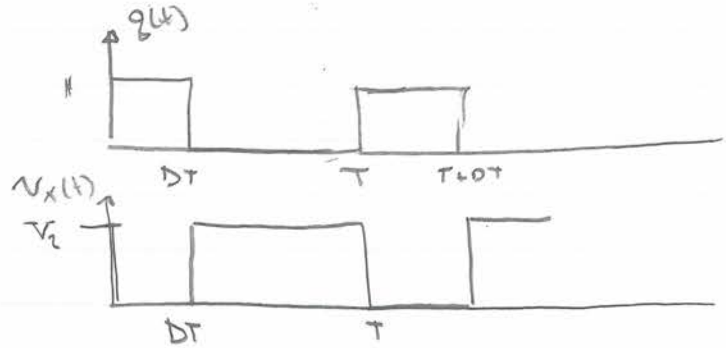
6.334 Lecture Notes Intro. to dc/dc

Suppose we switch source + resistor.



★ note, redefine $q(t)=1$ as switch "down" position

If C's, L's big, same analysis:



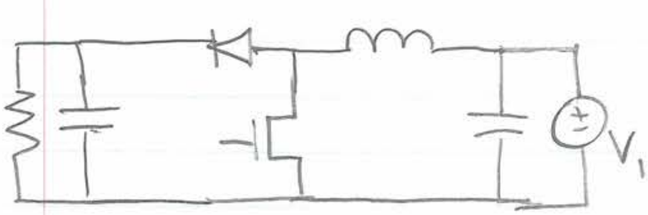
$$\langle v_L \rangle = 0 \quad \therefore \quad \langle v_x \rangle = (1-D)V_2 = V_1$$

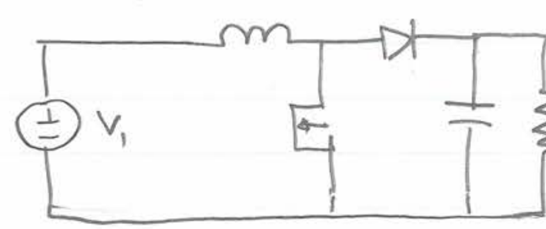
$$\therefore \quad \boxed{V_2 = \frac{V_1}{1-D}} \quad \text{AND} \quad \boxed{\frac{I_2}{1-D} = I_1}$$

If $V_1, V_2 > 0$, then power flows $2 \leftarrow 1$ AND $V_2 > V_1$

Boost converter:
(or "up" converter)

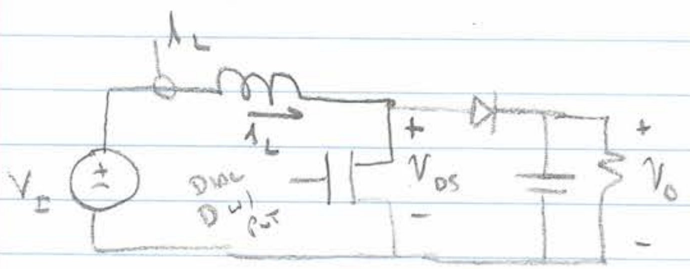
Sometimes drawn L→R power flow
(but nothing fundamental about it).





6.334 Lecture Notes — Intro to DC/DC

★ SHOW BOOST CONVERTER DEMO CIRCUIT
→ BUILT BY KATIE R. + SAUPARNA DAS

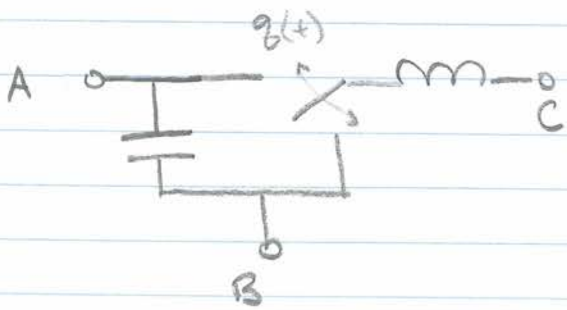


SHOW:
1. V_{DS}
2. i_L
3. V_o on scope

Explain Boost Operation:

- Switch turns on, i_L rises + incrementally stores energy in L from V_I
- Switch turns off + this energy plus additional energy from V_I is transferred to output
- Steady state voltages are determined by $V_2 = \frac{V_1}{1-D}$

Either buck or boost can be viewed as a connection of a "canonical cell"



- "Direct" connection has B common
- one cannot tell power flow direction without knowing
  1. external networks
  2. switch implementation
  3. Control