Lecture 8 — DC/DC Lecture 4

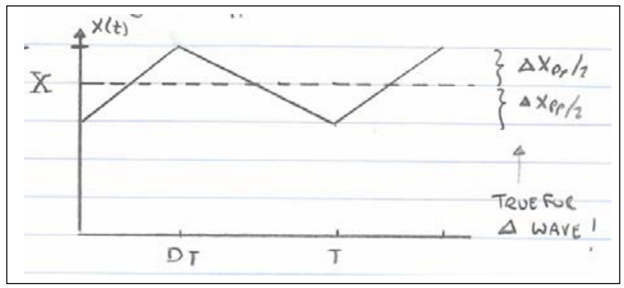
1 Ripple Ratios

Last class we saw that with certain idealizations/approximations converter waveforms have triangular ripple and we can use ripple ratios:

$$x_{pk} = X(1 + R_x)$$

$$\text{where } R_x \triangleq \frac{\Delta x_{pp}/2}{X}$$

Fractional deviation from dc



We can use ripple ratios in several ways.

1. Find peak stresses from dc terms, eg

   Direct converter:

   $$v_{sw,pk} = v_{d,pk} = v_{c,pk} = max(|V_1|, |V_2|)(1 + R_c)$$

   $$i_{sw,pk} = i_{d,pk} = i_{L,pk} = max(|I_1|, |I_2|)(1 + R_L)$$

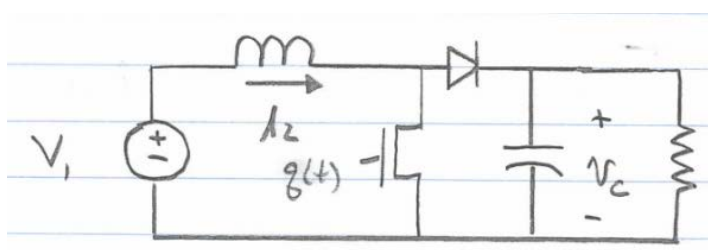
   Indirect converter:

   $$v_{sw,pk} = v_{d,pk} = v_{c,pk} = (|V_1| + |V_2|)(1 + R_c)$$

   $$i_{sw,pk} = i_{d,pk} = i_{L,pk} = (|I_1| + |I_2|)(1 + R_L)$$

2. Component sizing/stress

e.g. boost converter



$$C > \frac{D(1-D)TI_1}{2V_2R_c}$$

$$L > \frac{D(1-D)TV_2}{2I_1R_L}$$

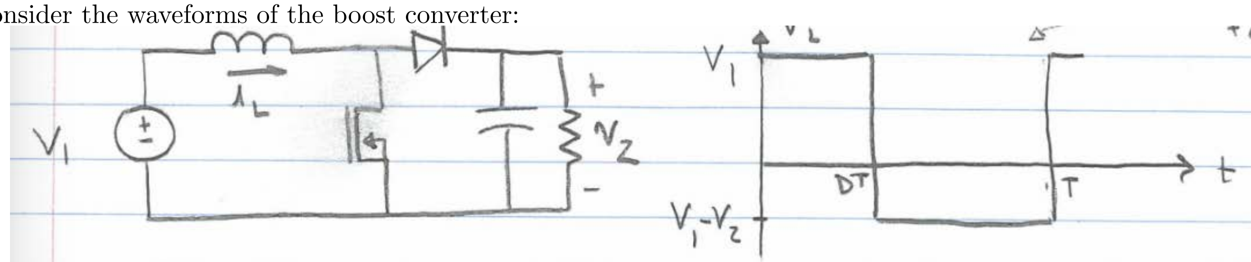
$$\rightarrow$$

$$E_c = \frac{1}{2}CV_{c,pk}^2 = \frac{DP_0}{4f_{sw}}[\frac{(1+R_C)^2}{R_C}]$$

$$E_L = \frac{1}{2}Li_{L,pk}^2 = \frac{(1-D)P_0}{4f_{sw}}[\frac{(1+R_L)^2}{R_L}]$$

2 Discontinuous Conduction Mode (DCM)

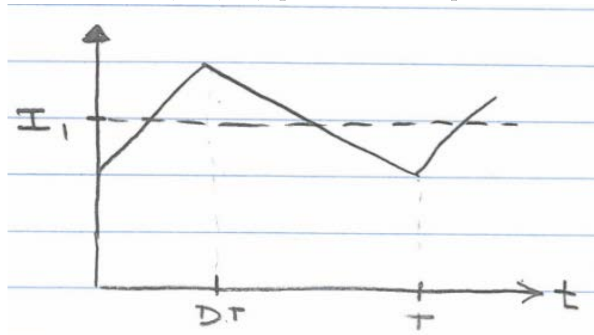
Consider the waveforms of the boost converter:



(Right graph has an arrow pointing to it saying ”could also show, sw, fn, q for switch + q_0 for diode”)

$$\Delta i_{L,pp} = \frac{V_1 DT}{L}$$

$$I_L = I_1 = \frac{V_2}{R(1-D)}$$

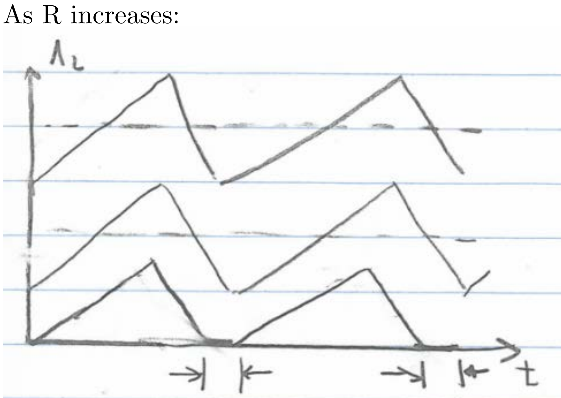


$$R_L = \frac{i_{L,pp}/2}{I_L} = \frac{V_1 D(1-D)TR}{2LV_2}$$

$$\therefore R_L = \frac{D(1-D)^2 TR}{2L}$$

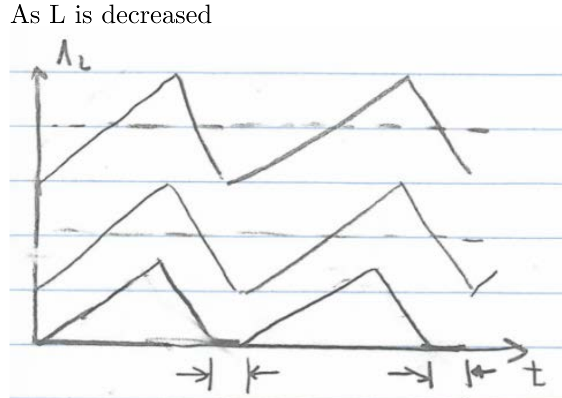
$$\therefore R_L \uparrow \text{as} R \uparrow \text{or} L \downarrow$$

As R increases:



Eventually, peak ripple > dc current, and <u>both</u> switch + diode are off for parts of the cycle

As L is decreased



This is known as Discontinuous Conduction Mode (DCM)

When does this happen? When $R_L \to 1$

$$R_L = \frac{D(1-D)^2 TR}{2L} \to \text{for} R > \frac{2L}{D(1-D)^2 T}$$

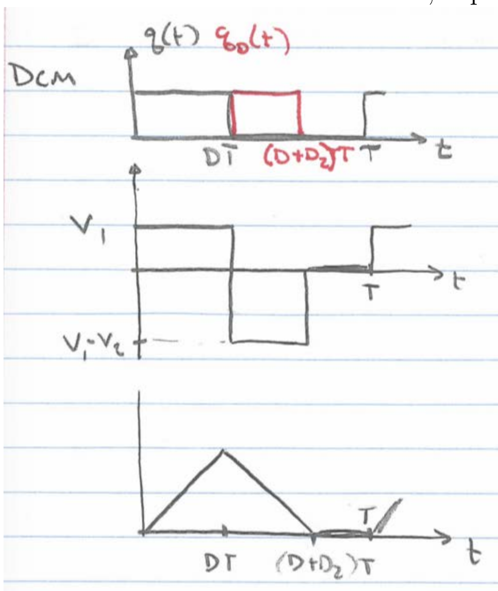
- @ “light” load (big R, low power) we get DCM
- Increasing L increases the R for CCM operation

DCM occurs for $\boxed{L \leq \frac{D(1-D)^2 TR}{2}}$

This is sometimse called the "critical inductance"

For some cases (e.g. when converter operates down to no load,) keeping CCM at all loads may not be reasonable.

Because of the new "switch state," operating conditions are different.



<u>Voltage conversion ratio:</u>

$$< V_L >= 0 in P.S.S.$$

$$\therefore V_1 D = (V_2 - V_1) D_2$$

$$V_1(D + D_2) = V_2 D_2$$

$$\boxed{\frac{V_2}{V_1} = \frac{D + D_2}{D_2} = 1 + \frac{D}{D_2} \quad \text{where } D_2 < 1 - D}$$

How does this compare to CCM?

$$\text{CCM } \frac{V_2}{V_1} = \frac{1}{1 - D} = \frac{1 + D - D}{1 - D} = 1 + \frac{D}{1 - D}$$

Since D_2 in DCM $< 1 - D$, $\frac{V_2}{V_1} = 1 + \frac{D}{D_2}$

$$\rightarrow V_2/V_1 \text{ is bigger in DCM than in CCM!} (> \frac{1}{1 - D})$$

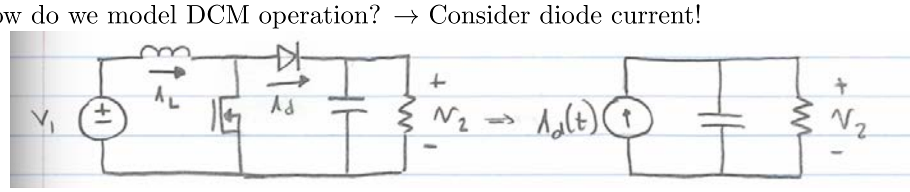
Eliminating D_2 from the equation, it can be shown for boost:

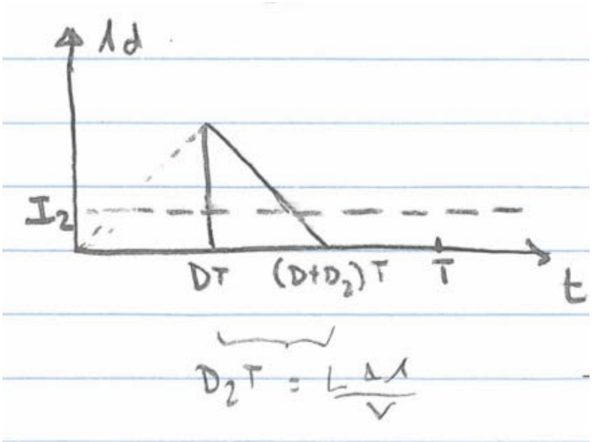
$$\boxed{\frac{V_2}{V_1} = \frac{1}{2} + \frac{1}{2}\sqrt{1 + \frac{2D^2 RT}{L}}}$$

$\therefore$ Conversion ratio depends on R, T, L,...unlike CCM!

$\rightarrow$ This makes control tricky, since our characteristics change once we enter DCM.

How do we model DCM operation? $\rightarrow$ Consider diode current!





$$i_pk = \frac{V_1 DT}{L}$$

$$D_2T = \Delta t = L\frac{\Delta i}{v} = \frac{V_1 DT}{V_2 - V_1}$$

$$D_2 = \frac{V_1 D}{V_2 - V_1}$$

Bottom equation reads: $D_2T = \frac{L}{v}$

$$< i_d >=< i_out >= \frac{1}{T}(\frac{1}{2}D_2T\frac{V_1DT}{L})$$
$$= \frac{V_1DD_2T}{2L}$$

$$< i_d >= \frac{V_1^2T}{2L(V_2 - V_1)}D^2$$

Model as controlled current source f(D)

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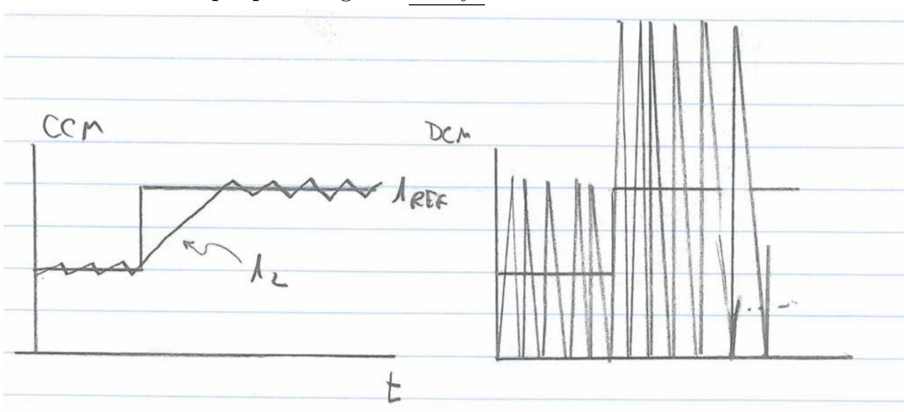
* Demo DCM boost converter

- show voltage, current waveforms
- "normal" conversion ratio doesn't apply
- BLOW UP OUTPUT CAP WHEN LOAD REMOVED!

Note: Sometimes people design to always be in dcm



In this case, we get

1. Very fast $\frac{di}{dt}$ capability
2. Simple control model (i_out = f(0))
3. Small inductor ($E_{L,min}@R_L \to 1$)

BUT we must live with

1. Parasitic ringing
2. High peak + rms currents
3. Need more filtering

$\rightarrow$ DCM Is sometimes used, esp if means to cancel ripple are available, but is often avoided.