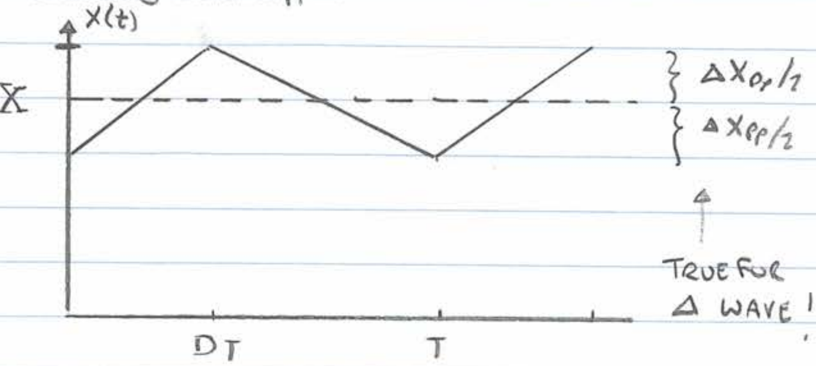
6.334 Lecture Notes — DC/DC Lecture # 4

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



TRUE FOR Δ WAVE!

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

where $R_x \triangleq \dfrac{\Delta X_{pp}/2}{X}$ fractional deviation from dc

we can use ripple ratios in several ways.

NEW "PEAK TO AVERAGE" FACTOR

1. Find peak stresses from dc terms

e.g. Direct converter

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

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

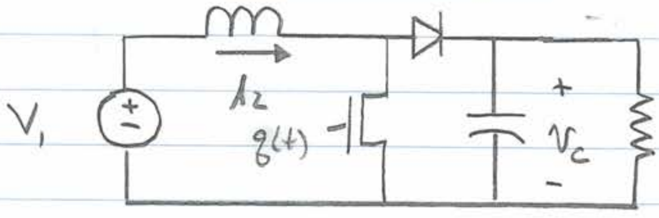
Indirect Converter

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

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

2. Component Sizing/Stress

e.g. boost converter



$$C > \frac{D(1-D)TI_1}{2V_2R_c} \Rightarrow E_c = \tfrac{1}{2}CV_{c,pk}^2 = \frac{D\cdot P_o}{4f_{sw}}\left[\frac{(1+R_c)^2}{R_c}\right]$$

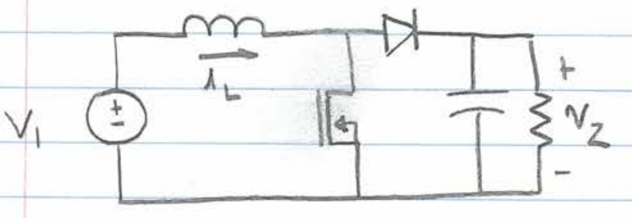
$$L > \frac{D(1-D)TV_2}{2I_1R_L} \qquad E_L = \tfrac{1}{2}Li_{L,pk}^2 = \frac{(1-D)P_o}{4f_{sw}}\left[\frac{(1+R_L)^2}{R_L}\right]$$

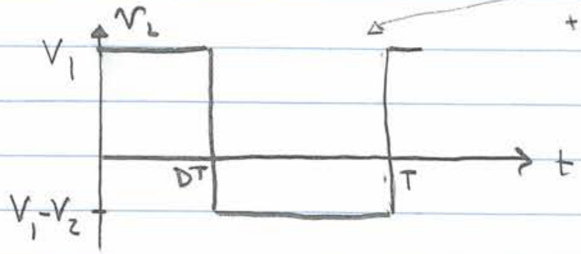
6.334 Lecture DC/DC Lecture # 4

DISCONTINUOUS CONDUCTION MODE (DCM):

Could also show sw. fn. q for switch + q_D for diode

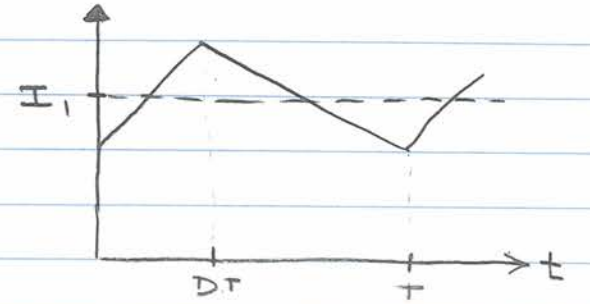
Consider the waveforms of the boost converter:





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

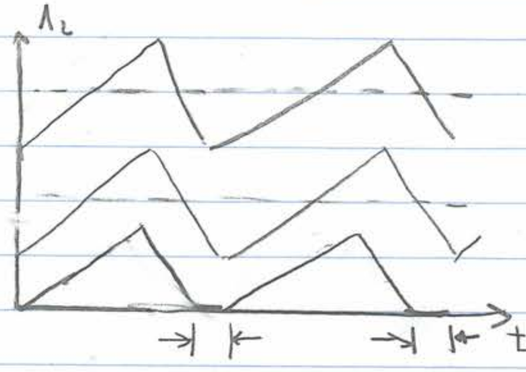
$$I_L = I_1 = \frac{V_2}{R(1-D)}$$



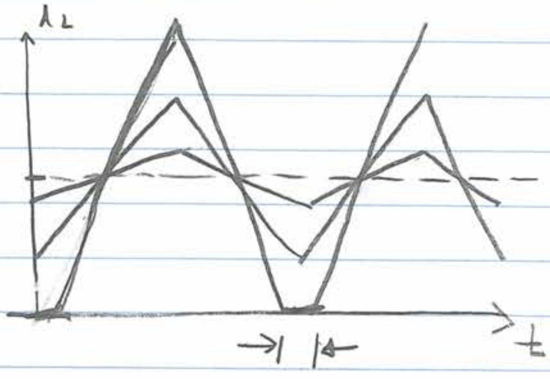
$$R_L = \frac{\Delta i_{L,pp}/2}{I_L} = \frac{V_1 D(1-D) TR}{2LV_2}$$

$$\therefore \boxed{R_L = \frac{D(1-D)^2 TR}{2L}} \qquad \therefore R_L \uparrow \text{ as } R\uparrow \text{ or } L\downarrow$$

As R increases



As L is decreased



EVENTUALLY, PEAK ripple > dc current, and <u>both</u> switch + diode are off for part of the cycle

This is known as Discontinuous Conduction Mode (DCM) when does this happen? when $R_L \to 1$

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

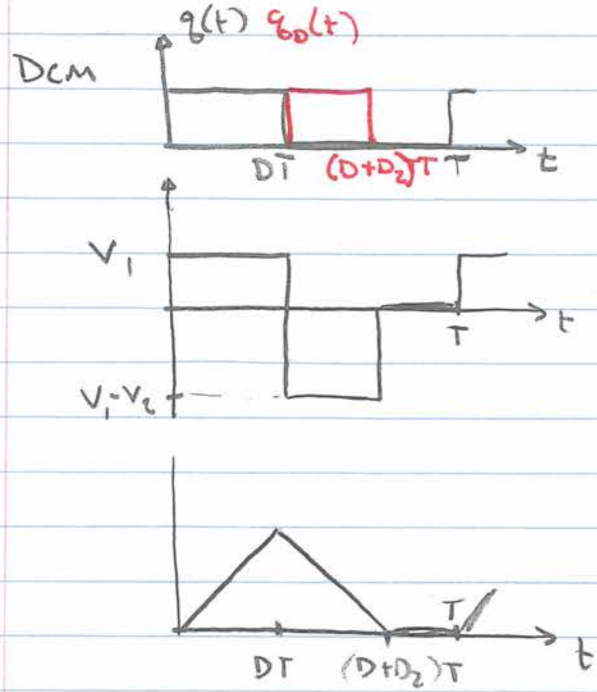
- @ "light" load (big R, low power) we get DCM
- Increasing L increases the R for CCM operation.

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

This is sometimes 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.



Voltage conversion ratio:

$\langle V_L \rangle = 0$ 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?

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

$\Rightarrow$ $\frac{V_2}{V_1}$ is bigger in DCM than in CCM! $\left(> \frac{1}{1-D}\right)$

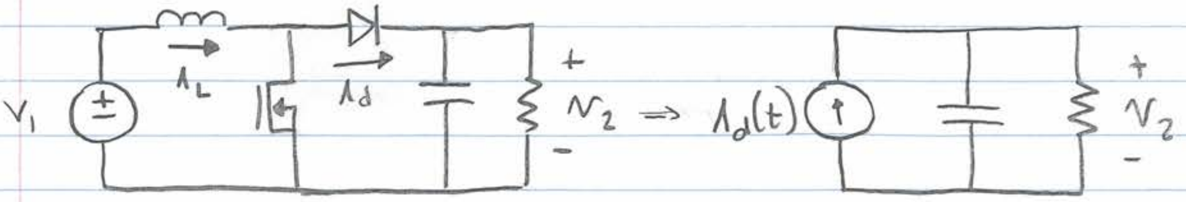
Eliminating D_2 from the equation, it can be shown for boost:

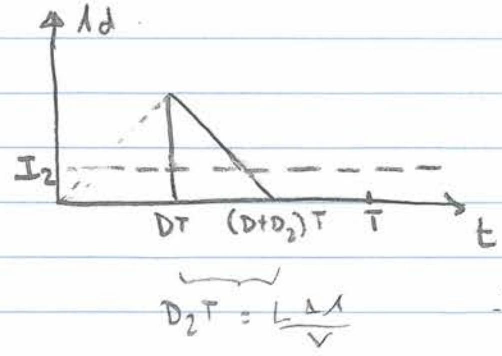
$$\boxed{\frac{V_2}{V_1} = \frac{1}{2} + \frac{1}{2}\sqrt{1 + \frac{2D^2RT}{L}}}$$

$\therefore$ 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!





$$i_{pk} = \frac{V_1 DT}{L}$$

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

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

$$\langle i_d \rangle = \langle i_{out} \rangle = \frac{1}{T}\cdot\left(\frac{1}{2} D_2 T \cdot \frac{V_1 D T}{L}\right)$$

$$= \frac{V_1 D D_2 T}{2L}$$

$$\boxed{\langle i_d \rangle = \frac{V_1^2 T}{2L(V_2 - V_1)} \cdot D^2}$$

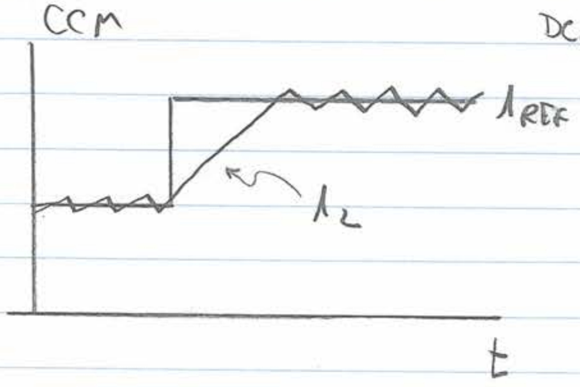
model as controlled current source f(D)

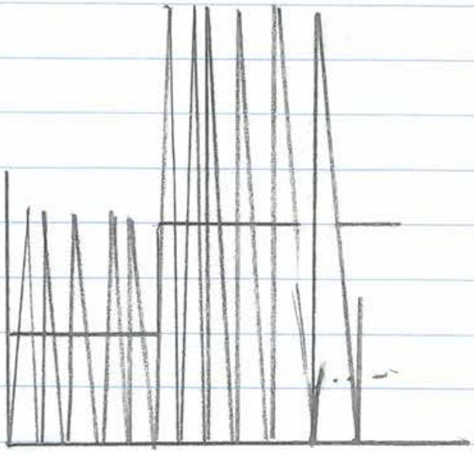
NOTE: DID NOT GET TO DEMO IN some years

★ 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 <u>always</u> be in dcm





In this case, we get
① Very fast $\frac{d\lambda}{dt}$ capability
② simple control model $(\lambda_{OUT} = f(D))$
③ Small inductor $(E_{L,MIN} @ R_L \rightarrow 1)$

BUT we must live with
① PARASITIC ringing
② high peak + rms currents
③ need more filtering

⇒ DCM is sometimes used, esp. if means to cancel ripple are available, but is often avoided.

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