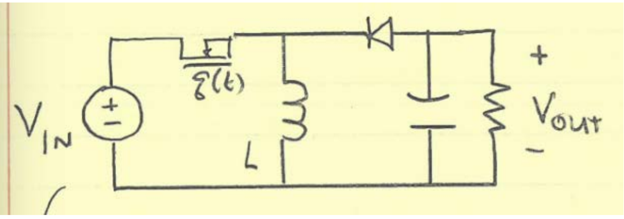
6.622 Power Electronics *Prof. David Perreault*

Lecture 13 - Isolated DC/DC

Isolated converter motivations:

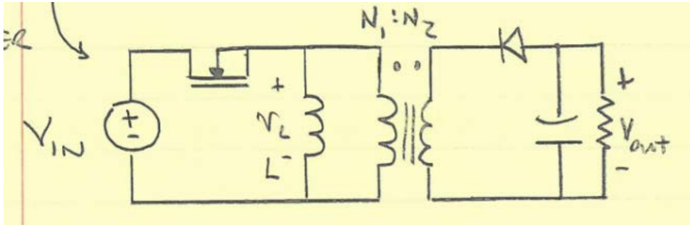
1. Galvenic isolation between input and output (+ different reference nodes)
2. High conversion ratios
3. Ease of generating multiple outputs

Example 1: Flyback converter (isolated buck/boost)



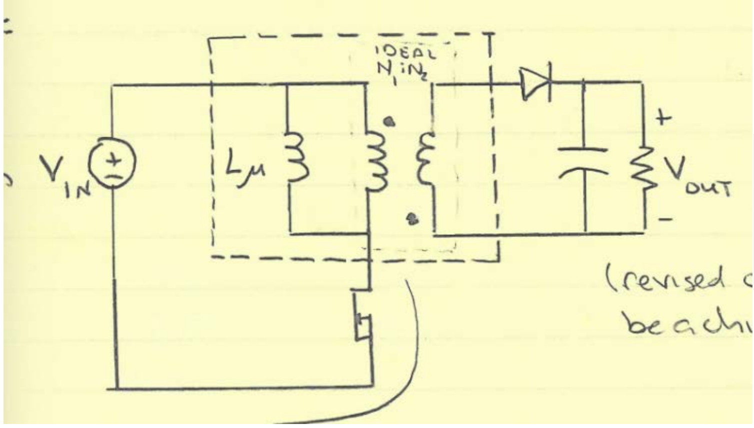
$$\frac{V_{out}}{V_{in}} = \frac{-D}{1-D}$$

Insert transformer into above:



$$< V_L >= DV_1 + (1-D)\frac{N_1}{N_2}V_2 = 0$$

$$\therefore \frac{V_2}{V_1} = -\frac{N_2}{N_1}\frac{D}{1-D}$$

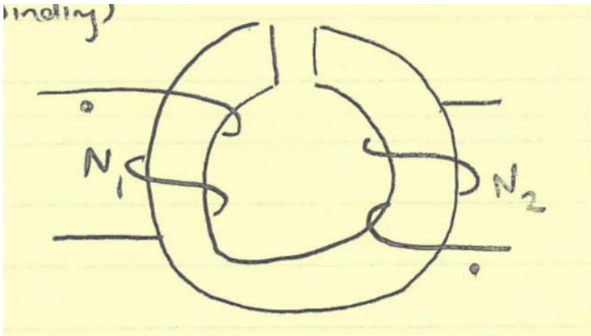


$$\boxed{\frac{V_2}{V_1} = +\frac{N_2}{N_1}\frac{D}{1-D}}$$

(Revised output polarity can be achieved when desired)

Design magnetics as one element: a gapped (energy storage) transformer where the energy is stored in the magnetizing inductance (like a buck-boost inductor with a second winding) ⇒ most energy stored in the gap!

1st part of cycle: store energy in transformer through winding #1
2nd part of cycle: remove energy from transformer through winding #2



⇒ Magnetizing energy is continiuous, but i_μ
Notes

1. Energy stored in the magnetizing inductance of the transformer. Design like an inductor (with gap for the energy storage) but add a second winding.
2. Voltage inversion required in non-isolated version may be elminated if desired by changing polarity of definition (no common terminals, so this is easy)
3. Can use ground-referenced active switch
4. Turns ratio helps reduce switch + component ratings (keep D near 0.5), consider 1KV @ $V_{in} = 100$, $V_{out} = 10$V.

   Buck/Boost

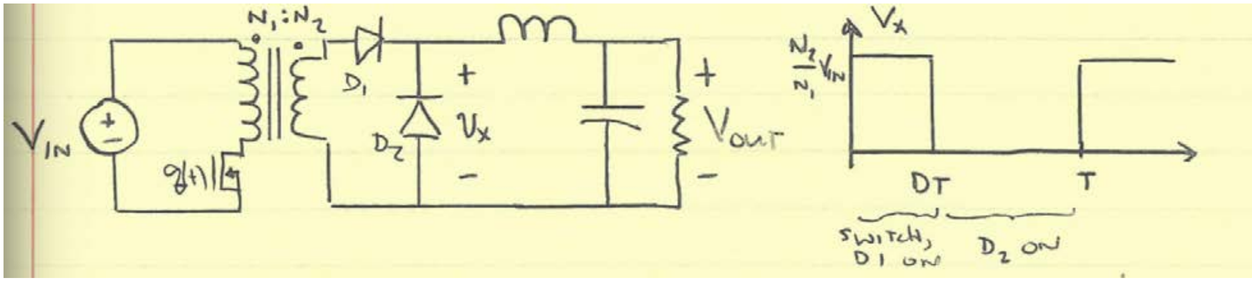
   $$V_{sw}, V_D = 100V_{pk}$$
   $$i_{sw}, i_D = 110A_{pk}$$

   Flyback @ $N_2 : N_1 = 1 : 10$

   $$V_{sw} = 200V, V_D = 20V$$
   $$i_{sw} = 20A, i_d = 200A$$

5. Easy to obtain multiple outputs by adding more windings

Isolation in a direct converter: Single-ended forward converter



This is essentially a buck converter w/a transformer!

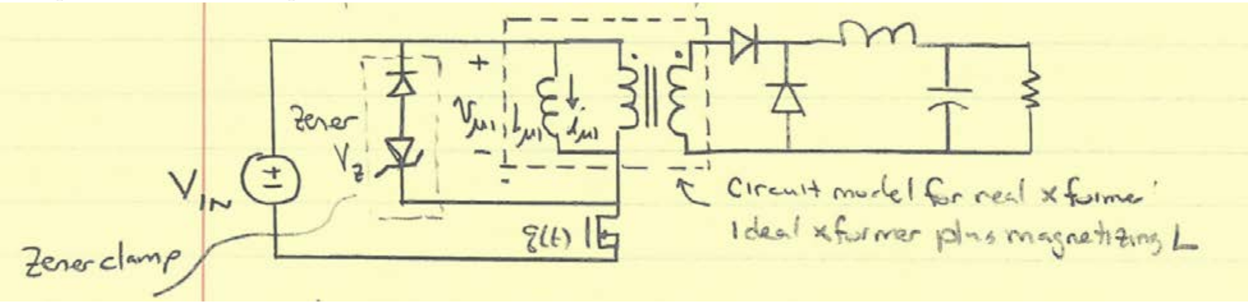
$$< V_{out} >=< V_x >= D(\frac{N_2}{N_1}V_{in}) + (1 - D) \cdot 0 \Rightarrow \frac{V_{out}}{V_{in}} = \frac{N_2}{N_1}D$$

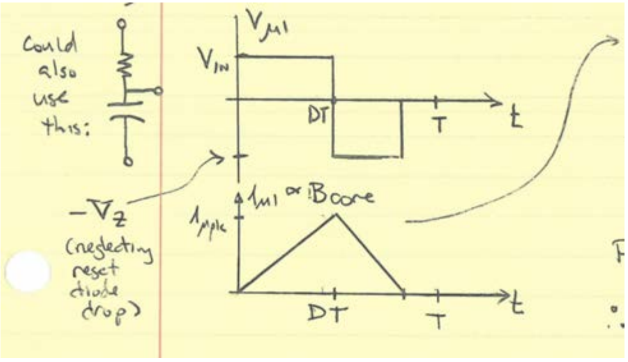
But consider the effect of the (undesired) magnetizing inductance L_μ of the transformer!

1. We must keep $< V_{lu} >= 0$ or transformer will saturate
2. Must provide a path for i_μ until core "resets" to zero flux

⇒ unlike in the flyback converter, the magnetizing inductance is not a desired circuit element, hurts performance

We must “reset” the core flux to zero each cycle!
One simple menthod: “clamp” reset circuit





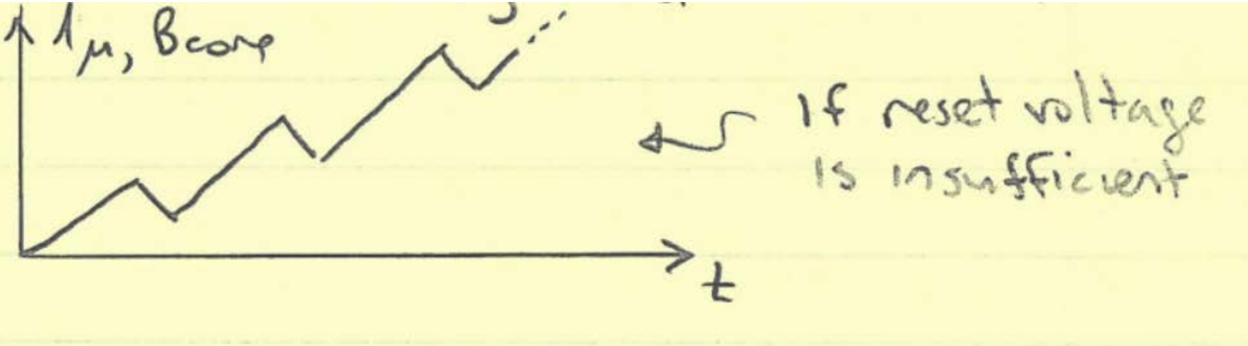
$$\lambda_{\mu 1} = L_{\mu 1} i_{\mu 1} = N_1 B_{core} A_c$$

$$\therefore B_{core} = \frac{L_{\mu 1}}{N_1 A_c} \cdot i_{\mu 1} = \frac{\lambda_1}{N_1 A_c}$$

Peak core flux $\Delta i_{\mu 1} = \frac{V_1}{L_{\mu 1}} DT$

$$\therefore B_{pk} = \frac{V_1 DT}{N_1 A_c}$$

We need to ensure that $\int V_\mu dt \to 0$ to “reset” the core. Otherwise i_μ, B_{core} can “run away” over time and saturate the core:



To reset the core:

$$V_z(1-D)T \geq V_{in} DT \Rightarrow V_z \geq V_{in} \frac{D}{1-D}$$

The peak switch voltage is $V_{sw,pk} = V_z + V_{in}$
So, $V_{pk} \geq V_{in}(\frac{1-D}{1-D}) + V_{in}(\frac{D}{1-D}) = V_{in}\frac{1}{1-D}$!

$$@D_{max} = 0.5 \to V_{sw,pk} = 2V_{in}$$

$$D_{max} = 0.75 \to V_{sw,pk} = 4V_{in}$$

With minimum clamp voltage

This is poor compared to the non-isolated buck where $V_{pk} = V_{in}$!

How much power do we lose in resetting the core this way? (We dissipated stored magnetizing energy in zener)

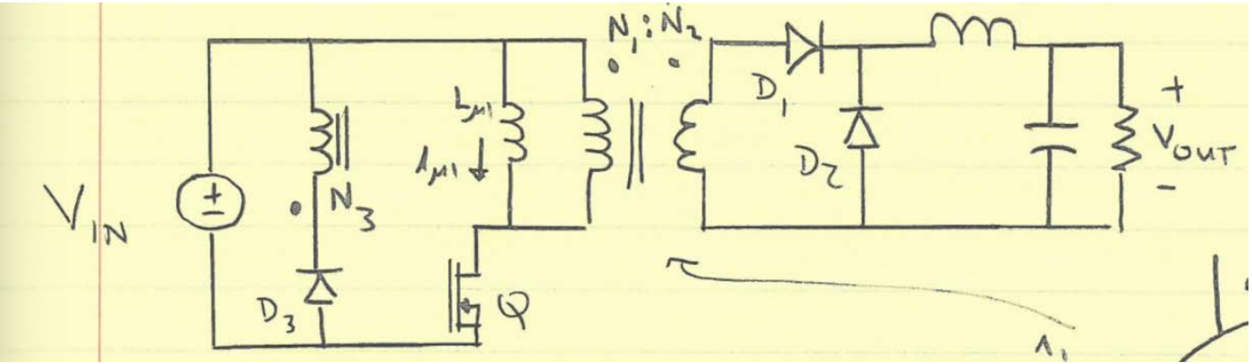
$$W_{diss} = \frac{1}{2} L_{\mu 1} i_{\mu 1,pk}^2 = \frac{1}{2} L_\mu (\frac{V_{in} DT}{L_\mu})^2 = \frac{V_{in}^2 D^2 T^2}{2L_\mu}$$

$$P_{diss} = \frac{1}{T} \cdot W_{diss} = \frac{V_{in}^2 D^2 T}{2L_\mu}$$

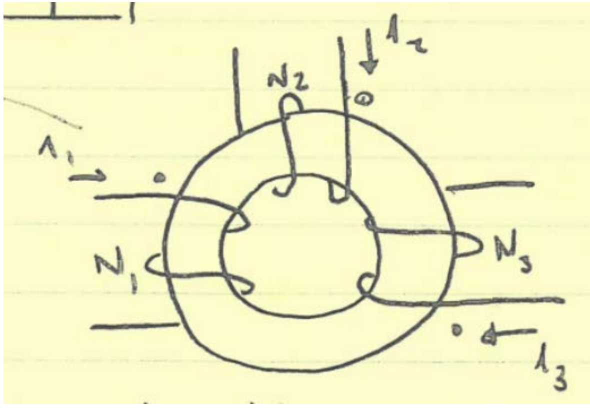
$\therefore$ we want L_μ as big as possible to minimize energy stored in transformer and dissipated. $\therefore$ we typically use an ungapped (or minimally gapped) core to maximize L_μ and minimize reset loss.

Other clamp methods allows us to recover magnetizing energy:

① Tertiary winding clamp: recover energy back to input



When Q is off D_3 turns on until magnetizing energy returned to input (or next cycle starts)



To reset the core we require

$$\frac{V_1}{N_1} = \frac{V_2}{N_2} = \frac{V_3}{N_3}$$

$$\boxed{DV_{in}T \leq (1-D)(\frac{N_1}{N_3})V_{in}T}$$

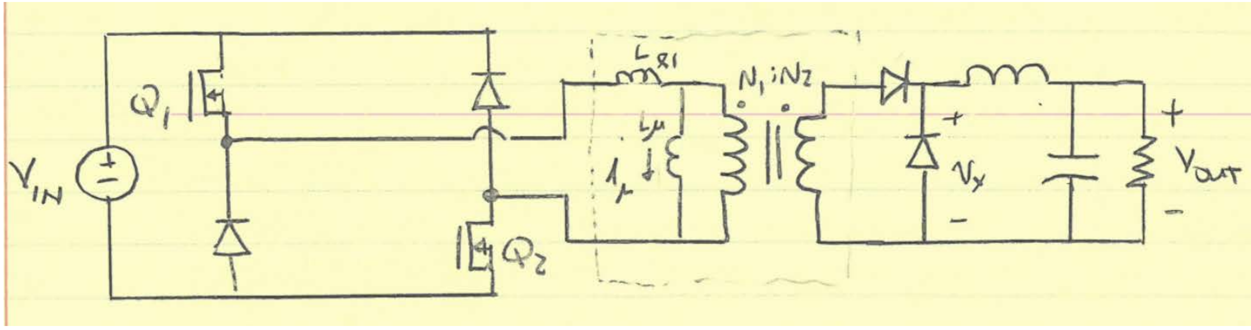
The voltage stresses are the same (neglecting leakage inductance effects)

Advantages: Magnetizing energy is (mostly) recovered

Disadvantages:

- still need a snubber to handle leakage inductance
- more transformer windings

② Two-switch single-ended forward converter



- Turn switches Q_1, Q_2 on and off together with duty ratio D

  $\Rightarrow 0 < D < 0.5$ to guarantee core reset (energy recovered back to input)

  $\Rightarrow$ leakage energy of transformer is also recaptured

- Requires two active switches, each with $V_{sw,pk} > V_{in}$ (only one is ground referenced). This compares to a singles witch rated at $> 2V_{in}$ for a normal forward with a maximum 50% duty ratio.

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