ELEC 3106
Study Notes

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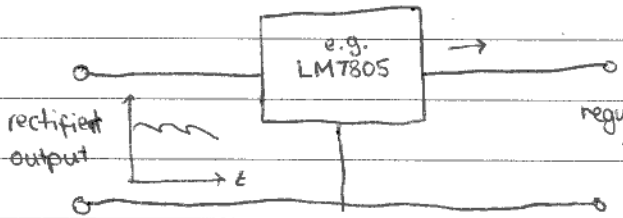
Semester 1 2013 – Electrical Engineering
The University of New South Wales

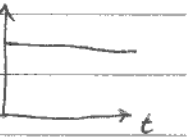
VOLTAGE REGULATORS

1. Linear voltage regulators
   - 3-terminal

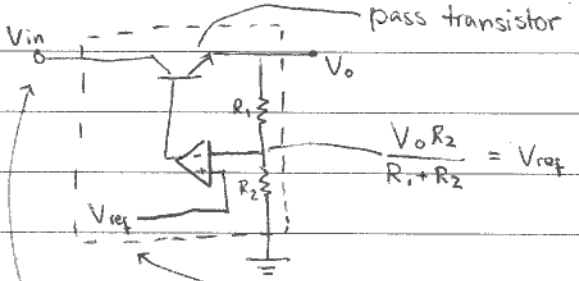


regulated output voltage $\simeq$ 5V from 7805

$\simeq$ 15V from 7815



- Schematic



pass transistor (gets hot, often mounted on a heatsink!)

$$\frac{V_o R_2}{R_1 + R_2} = V_{ref}$$

$$V_o = \left(1 + \frac{R_1}{R_2}\right) \times V_{ref}$$

from rectifier output

stability of V_{ref} is important (in time and temperature). often required to use a band gap reference voltage. (often integrated into a chip itself)

LOOK THIS UP!

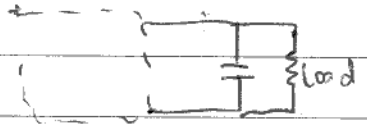
$\frac{dV_{ref}}{dt} \simeq$ 10-20 ppm/°C

EFFICIENCY: $\eta = \frac{P_o}{P_{in}} = \frac{V_o I_o}{V_{in} I_o} = \frac{V_o}{V_{in}}$

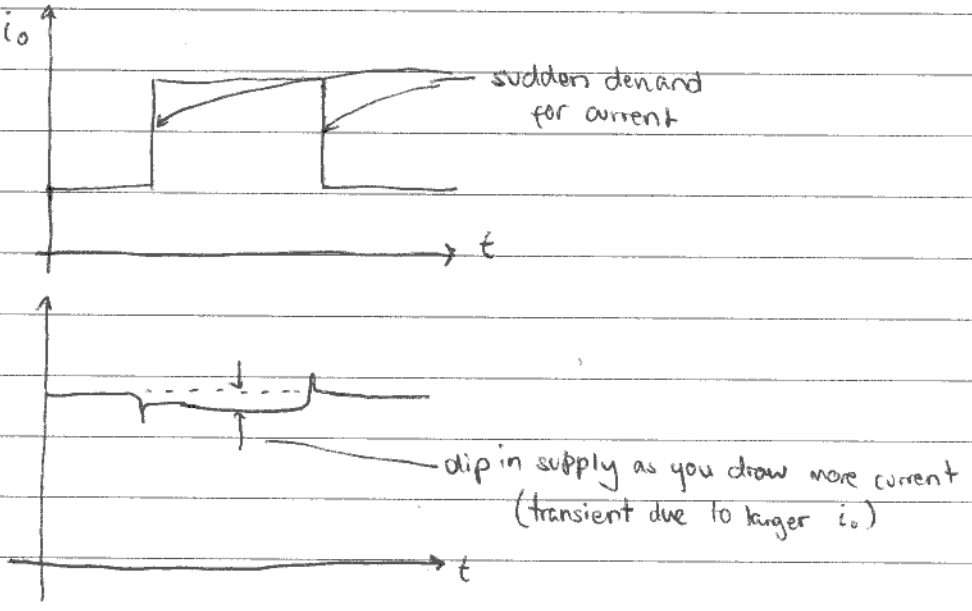
(increases as $V_o \to V_{in}$)

NOTES - Week 6: Power Supplies

Transient behaviour of Linear Regulators



measure of how fast it reacts to a sudden change in load current, determined by bandwidth of feedback loop. → BW of op amp in FB loop



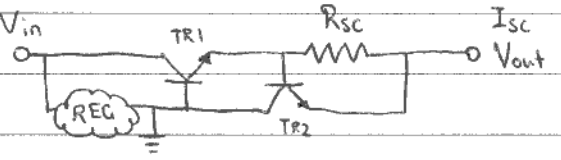
- Vo ripple is generally small.
- Efficiency is often poor.
- Design relatively simple
- Copes reasonably well under transient
- Input voltage range MAY be limited.

NOTES - Week 6: Power Supplies

Output Overload

Type i) Constant current limiting

- Ensures that output current available from power supply limits at a maximum only marginally above the full load rating of the unit.



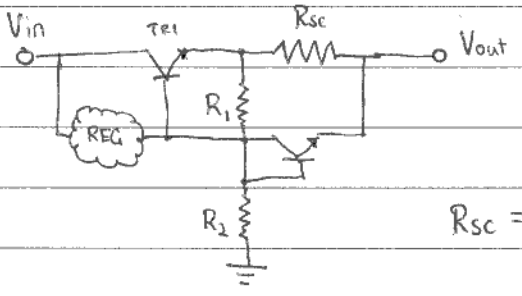
⚠ When V across Rsc > TR2's V_{BE}, it diverts base drive away from TR1, limiting collector current

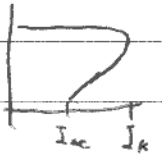
$$I_{sc} = \frac{V_{BE}}{R_{sc}}$$

- Dependent on V_{BE} of TR2, and temperature.
- Achieving this on a switched-mode power supply is more complex.

Type ii) Foldback current limiting

- Solves shortcoming of constant current limiting; to obtain a decent SOA, the pass element TR1 must have a higher than normal collector current capability.
- Reduces short circuit current whilst still allowing full output current during normal regulator operation.





$$R_{sc} = \frac{V_{out}}{I_{sc}\left(1 + V_{out}/V_{BE}\right) - I_K}$$

- As foldback ratio $\left(\frac{I_K}{I_{sc}}\right)$ is increased, the required value of Rsc increases calling for a greater input voltage if you actually want any output.

NOTES - Week 6: Power Supplies

Input Transients

Power supplies should be able to cope with short interruptions and dips in power (brownouts) without affecting the load. 'Hold-up time' specifies how long the output remains stable after losing the input. It is determined by the size of the MAIN RESERVOIR CAPACITOR.

- Hold-up time:
  - Linear power supply, full load at 240 V.
  - Ripple on $V_{in,dc}$ is 2V, 1A. Full-wave rectified, period = 10ms. $V_{in,dc\,(min)}$ = 10.05V
  - Minimum input voltage calculated to be 7.45V.

RESERVOIR CAPACITOR: $C = \frac{I \cdot t}{V} = \frac{1 \times 10 \times 10^{-3}}{2}$

$= 5000\mu F$

HOLD-UP TIME: $t_h = \frac{(V_{in\,(ripple\ trough)} - V_{in\,(actual)}) \times C}{I}$

$= \frac{(10.05 - 7.45) \times 5000 \times 10^{-6}}{1}$

$= 13ms$

Hold-up time reduces as power supply runs closer to its minimum input voltage.

Another common source of input transients is spikes and surges. To 'help' guard against impacting the load circuit, try
- ensuring circuit layout is good
- minimise ground inductance & stray coupling
- filtering inputs

for short, fast transients. To deal with slow but high energy transients,
- use transient suppressor devices in PS and will also provide overvoltage protection.

The switched-mode power supply

Efficient, versatile, step-down and step-up capable and compact. It eliminates the 50Hz mains transformer and replaces it with a high frequency one, say 30 - 300kHz.

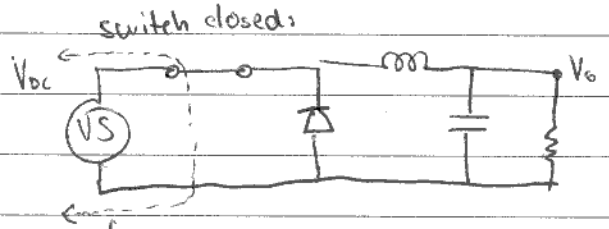
The input circuit is similar to a highly filtered linear power supply. It is then followed by a rectifier and reservoir (both still working at line voltage), and feeds the switching element which 'chops' the high voltage dc at the chosen switching frequency.

Two forms of SMPS, Buck Converter & Boost converter, will be covered later.

NOTES: Week 6 - Power supplies

Buck Converter

(Step-down switched mode power supply)



$V_{output} < V_{input}$

- inductor current is continuous (doesn't change instantaneously)
- τ of L, C etc is much larger than switching period.

- For analysis, assume elements are ideal
- Switching response is periodic.

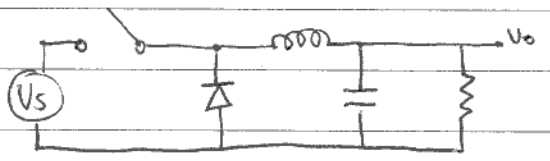
Initially, unregulated dc is input and Diode is off. Current flows left to right across the inductor, as follows:

$$L \frac{di_L}{dt} = V_S - V_o$$

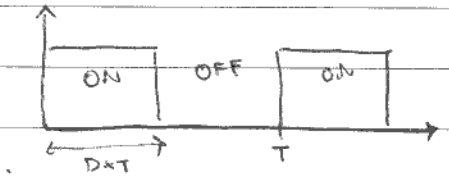
$$i_L = C\frac{dv}{dt} + \frac{V_o}{R}$$

T: period
D: duty cycle
DxT: length of time the switch is closed

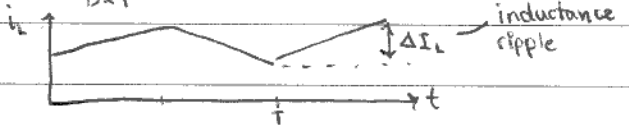
switched opened:



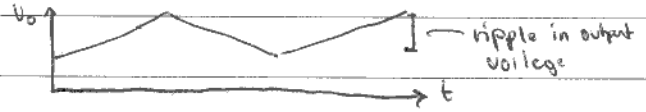
- inductor current will "free wheel" through the diode
- inductor transfers energy to the RC network:



$$L \frac{di_L}{dt} = -V_o$$



$$\frac{dv_o}{dt} = \frac{i_L - \frac{V_o}{R}}{C}$$



NOTES: Week 6 - Power Supplies

We assume a continuous i_L & time constants of L & C are greater than T

$$i_L(0) = i_L(T)$$

$$\int_0^T V_L(t) = L \int_0^T \frac{di_L}{dt}$$

$$= L\,[i_L(T) - i(0)]$$

$$= 0$$

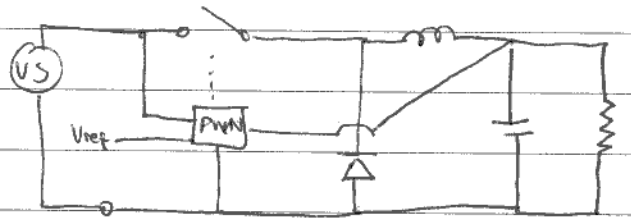
From $0 \to DT$, $V_L = V_S - V_o$

From $DT \to T$, $V_L = -V_o$

$$\int_0^T V_L(t)\,dt = (V_S - V_o)\cdot DT + (-V_o)(1-D)T$$

$$\therefore \quad V_o = D \cdot V_S \qquad (V_o < V_S)$$

Implementation:



We need:

- Inductor
- Capacitor
- Correct V-rating diode
- Transistor to act as switch
- PWM controller.

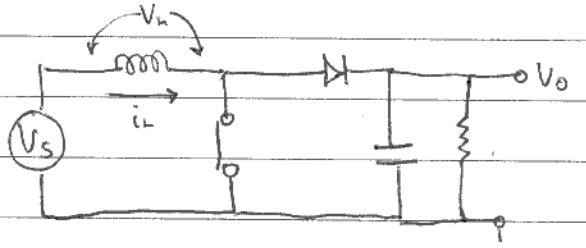
V_{rms}, ripple voltage $\simeq \dfrac{D(V_S - V_o)}{16\sqrt{2}\, f^2 LC}$

(for BUCK SMPS)

NOTES: Week 6 - Power Supplies

Boost converter

(Step-up SMPS)



Define: $T \simeq$ period

$D \times T \simeq$ duty cycle

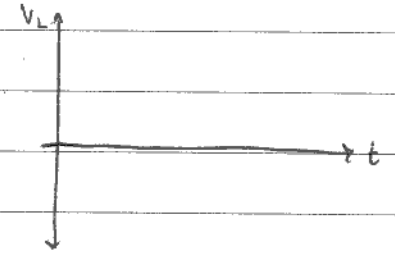
Assume: Ideal components and the rest like Buck Converter.

Governing equations: $V_L = L \cdot \frac{di_L}{dt} \rightarrow L \frac{\Delta i_L}{\Delta t} \rightarrow L \frac{\Delta i_L}{DT}$

(:) BUTT... $V_S = V_L$!

$$\therefore \frac{V_S}{L} = \frac{\Delta i_L}{DT}$$

Switch open:



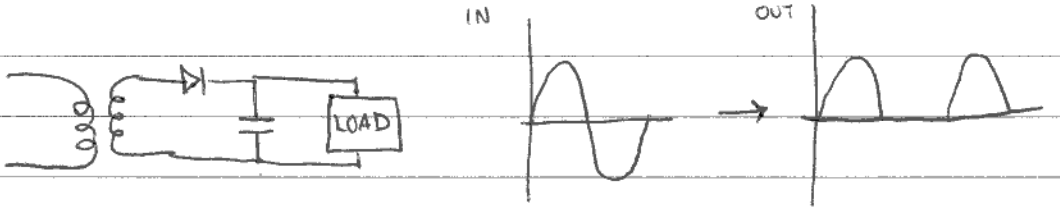
- Diode turns on, assume $V_O = 0$
- $V_L = V_S - V_O$
- $\frac{di_L}{dt} = \frac{V_S - V_O}{L} = \frac{\Delta i_L}{(1-DT)}$
- periodic assumption means $|\Delta L|$ is the same as when switched is closed, sum of the change in currents must be zero

$$- \quad V_O = \frac{V_S}{1-D} > V_S \quad \circ$$

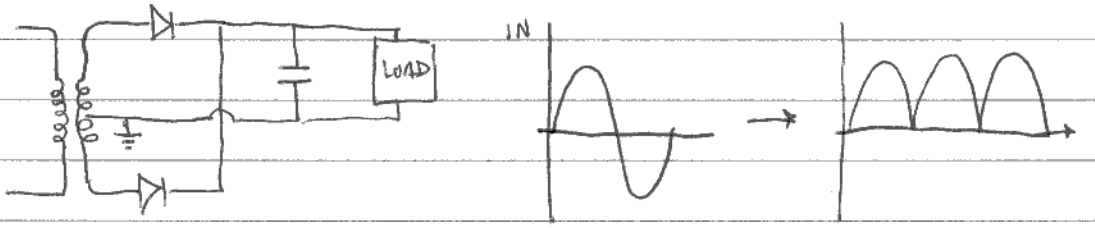
NOTES: Week 6 - Power Supplies

Rectifiers

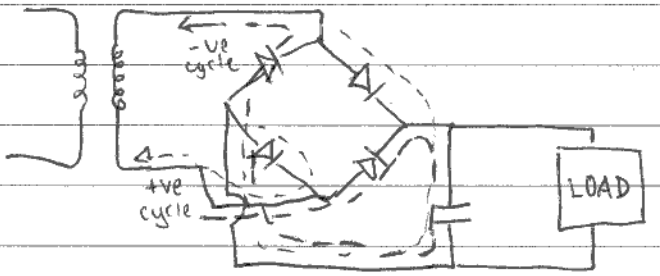
→ Half-wave



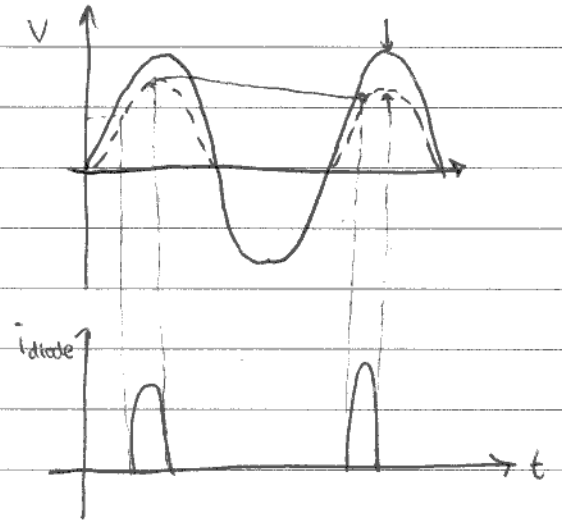
→ Full-wave (2 diodes)



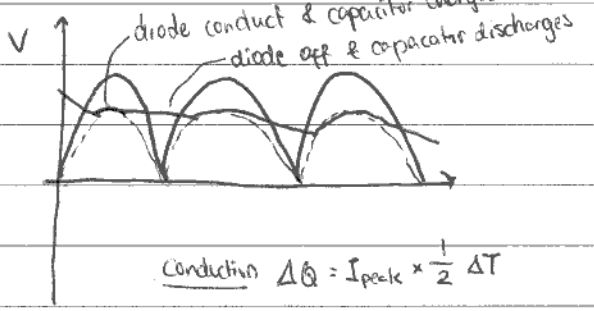
→ Full-wave (bridge)



Half-wave - in depth



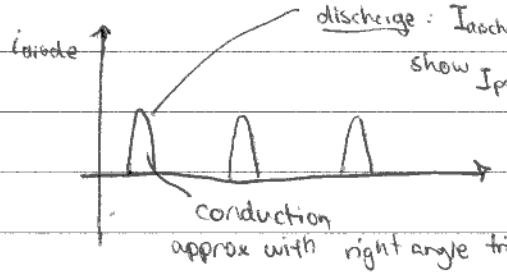
Full-wave



conduction $\Delta Q = I_{peak} \times \frac{1}{2} \Delta T$

discharge : $I_{discharge}\,(T - \Delta T)$

show $I_{peak} \simeq 2I_{dc}\left(\frac{T}{\Delta T} - 1\right)$



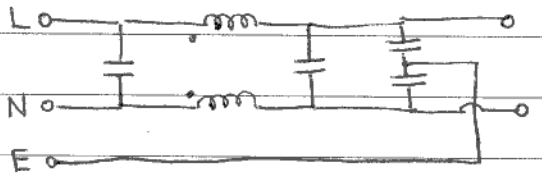
conduction approx with right angle triangle

NOTES: Week 6 - Power Supplies

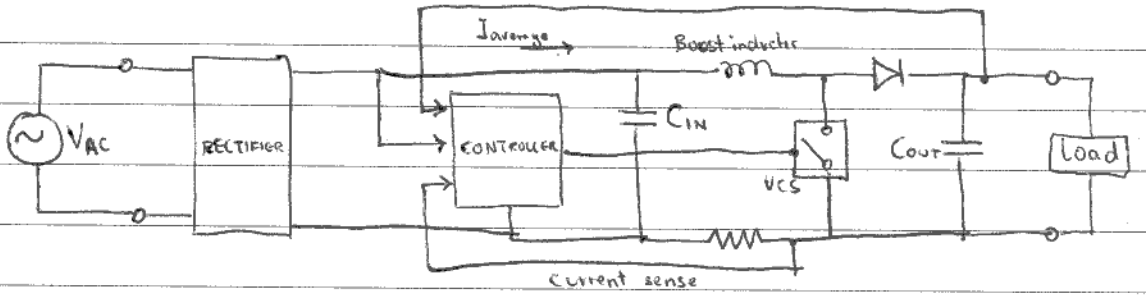
Power factor correction

- 240V supply is sinusoidal but current is spiky or peaky → that's a substential harmonic component. Applies to all apparatus with I_{in} up to 16A.
- PF < 1 when imaginary power components exist → voltage & current not in phase
- PF is the ratio of REAL POWER (with losses) and APPARENT POWER.
- A purely resistive load has a PF of 1. Correction requires that the input current waveform must be made as close to sinusoidal as possible to reduce its harmonic component.

i, Passive PFC (line filter)



ii, Active PFC



Suppose the rectifier supplies a full wave rectified half-sine voltage across C_{IN}, which is too low to affect the 50Hz input, but is able to act as a reservoir at the switching frequency (50-100 kHz). The switching controller senses from the input voltage, and adjusts frequency & duty cycle to make the average current output (feedback path aids with this) in phase with the input voltage.