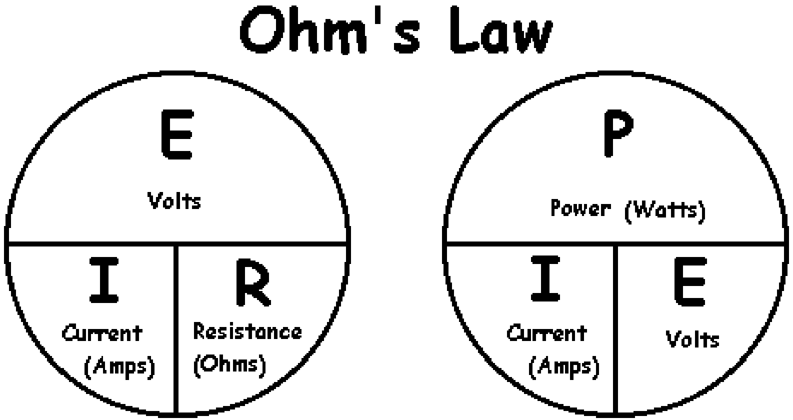
Switch Mode Power Supplies 101

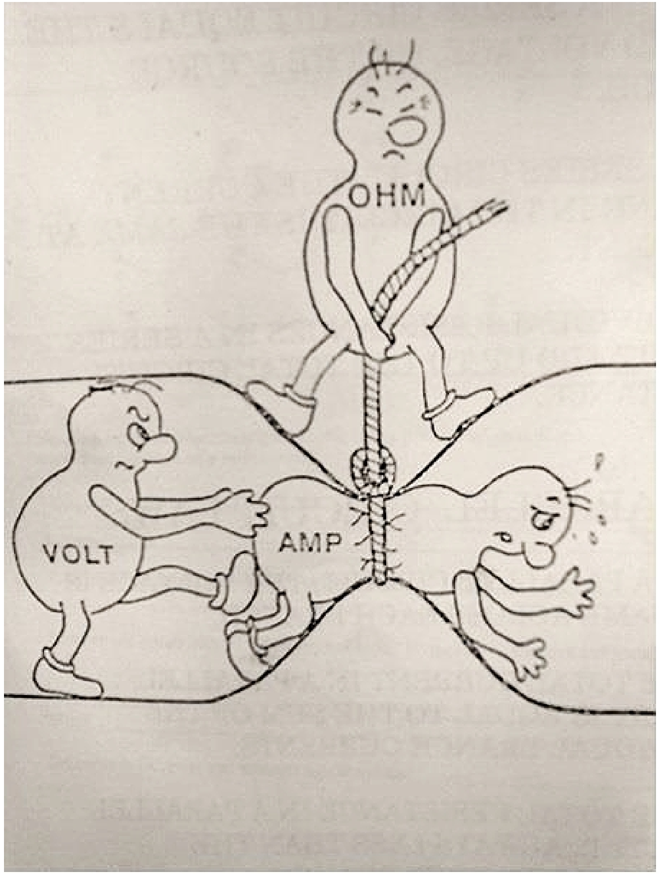
POWER!!!

Almost every device needs power regulation

So how do you regulate power?

An aside – Ohm’s Law





The basic – just a battery

The most basic power supply is none at all

Pick a max battery voltage and use that

Pros – Simple

Cons – No regulation. What happens when the battery discharges?

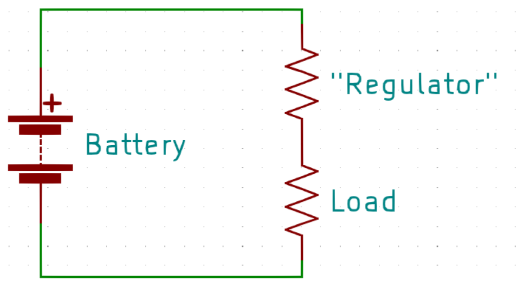
The slightly basic – a resistor regulator

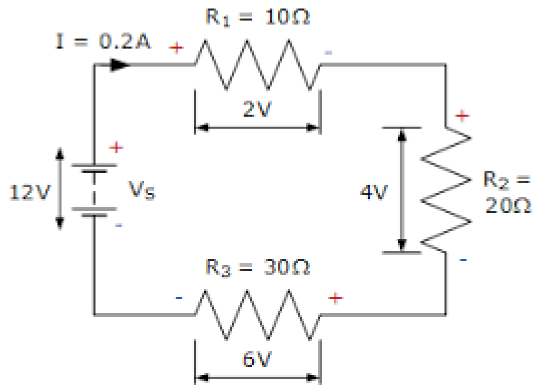
Need a voltage less than that of your battery?

Pick a couple of resistors and use that

Pros – Simple, can use Kirchoff's Law to calculate

Cons – What happens when the battery discharges? What happens if the load resistance changes? What happens if the load is drawing a lot of power?





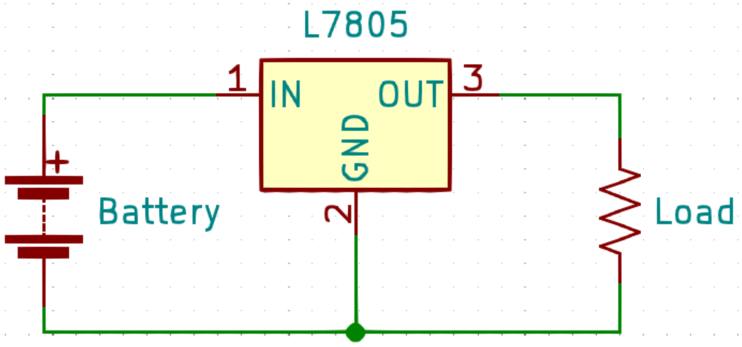
Regulations – a linear regulator

Need an exact voltage?

Grab a linear regulator

Pros – Still simple, cheap

Cons – A linear regulator converts the excess input power into heat! Input voltage must be about 1.5V above what you want out, unless you get a 'LDO' (low drop-out), and then 0.3V is typical



The switch up

So how do we transform voltage efficiently?

What if we want MOAR volts out than we have going in?

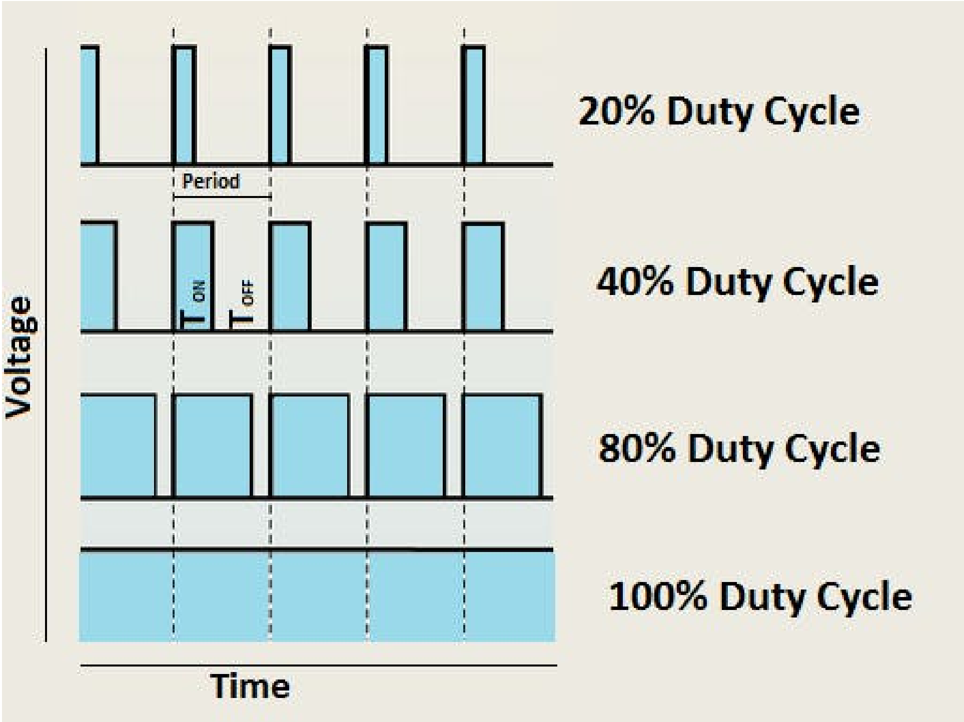
What if we want to go negative?

An aside – Pulse Width Modulation

PWM is toggling a switch on and off at varying duty cycle

Duty cycle is expressed in percent on time

Independent of base frequency!



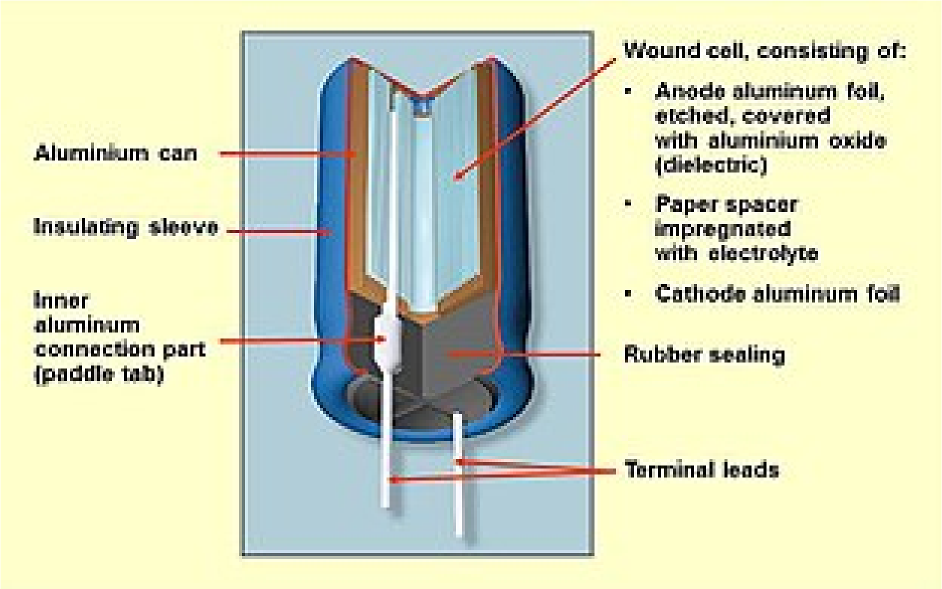
An aside – Capacitors vs Inductors

Capacitor

Stores charge in parallel plates

Resists changes in voltage

Measured in Farads – 1 Farad = 1 coulomb at 1 volt



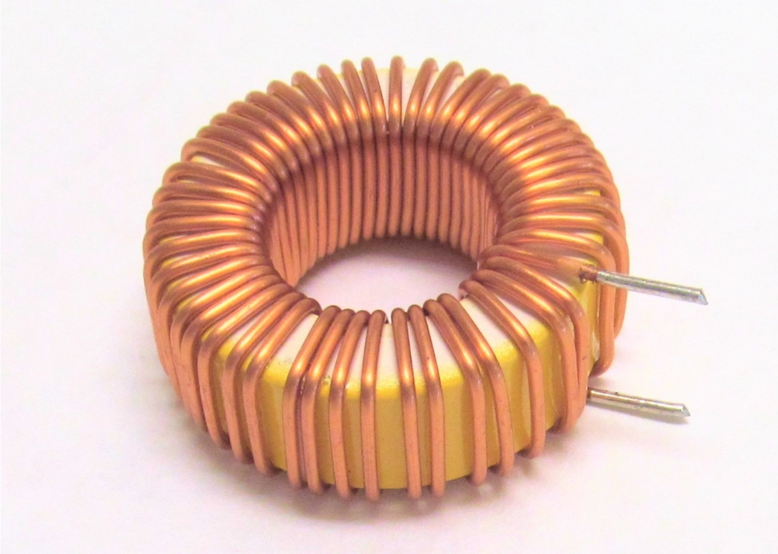
An aside – Capacitors vs Inductors

Inductor

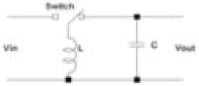
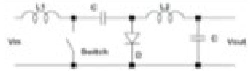
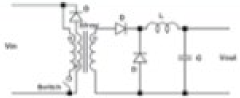
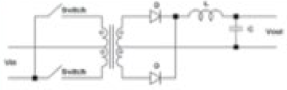
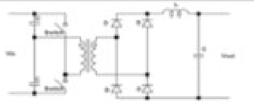
Stores magnetic field in coil
Resists changes in current

Measured in Henry – 1 Henry = 1 ampere flowing through the coil producing flux linkage of 1 weber turn (what)

‘Saturation’ is when the magnetic field is no longer rising



Topologies

	Topology	Schematic	Power (Watts)	Typical Efficiency	Relative Cost	Magnetics Required	DC Transfer Function (V_{out}/V_{in})	Maximum Practical Duty Cycle	Universal Input (90-264) V_{ac}	Multiple Outputs	$V_{out}<V_{in}$ Range	$V_{out}>V_{in}$ Range
Non-Isolated Topologies	Buck		500	85	1	Single Inductor	D	0.9	No	No	Yes	No
	Boost		150	70	1	Single Inductor	$\frac{1}{1-D}$	0.9	No	No	No	Yes
	Buck-Boost		150	70	1	Single Inductor	$\frac{-D}{1-D}$	0.9	No	No	Yes	Yes
	SEPIC		150	75	1.2	Coupled or Two Inductors	$\frac{D}{1-D}$	0.9	No	No	Yes	Yes
	Ćuk		150	75	1.2	Coupled or Two Inductors	$\frac{-D}{1-D}$	0.9	No	No	Yes	Yes
Isolated Topologies	Flyback		150	75	1.5	Transformer	$\sqrt{\frac{2xP_{out}xL_{pri}xFreq}{V_{in}}}$	0.9	Yes	Yes	Yes	Yes
	Forward		150	75	1.8	Transformer and Inductor	$\frac{2N_s}{N_p} x D$	0.45	Yes	Yes	Yes	Yes
	Push-Pull		500	80	1.8	Transformer and Inductor	$\frac{N_s}{N_p} x D$	0.45	No	Yes	Yes	Yes
	Half-Bridge		500	85	2	Transformer and Inductor	$\frac{N_s}{N_p} x D$	0.45	Yes	Yes	Yes	Yes
	Resonant LLC		500	90	2	Transformer	Frequency Dependent Based on Resonant Tank Transfer Function	0.45	Yes	Yes	Yes	Yes

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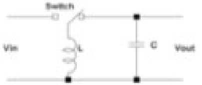
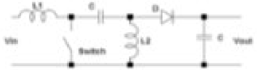
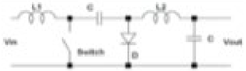
	Buck-Boost		150	70	1	Single Inductor	$\frac{-D}{1-D}$	0.9	No	No	Yes	Yes
	SEPIC		150	75	1.2	Coupled or Two Inductors	$\frac{D}{1-D}$	0.9	No	No	Yes	Yes
	Ćuk		150	75	1.2	Coupled or Two Inductors	$\frac{-D}{1-D}$	0.9	No	No	Yes	Yes
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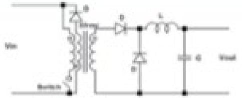
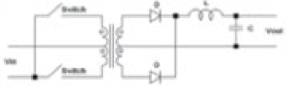
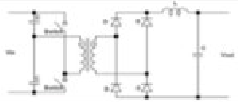
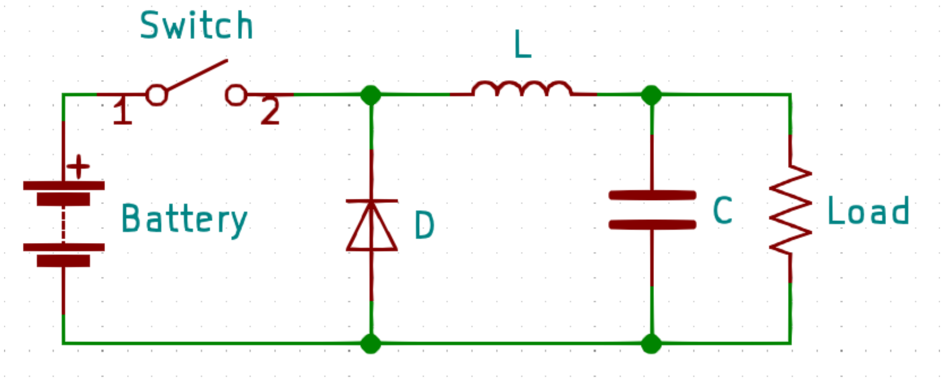
	Forward		150	75	1.8	Transformer and Inductor	$\frac{2N_s}{N_p} x D$	0.45	Yes	Yes	Yes	Yes
	Push-Pull		500	80	1.8	Transformer and Inductor	$\frac{N_s}{N_p} x D$	0.45	No	Yes	Yes	Yes
	Half-Bridge		500	85	2	Transformer and Inductor	$\frac{N_s}{N_p} x D$	0.45	Yes	Yes	Yes	Yes
	Resonant LLC		500	90	2	Transformer	Frequency Dependent Based on Resonant Tank Transfer Function	0.45	Yes	Yes	Yes	Yes

… what?

Buck converter topology

Parts:

- A switch
- A diode
- An inductor
- A capacitor



Buck converter operation

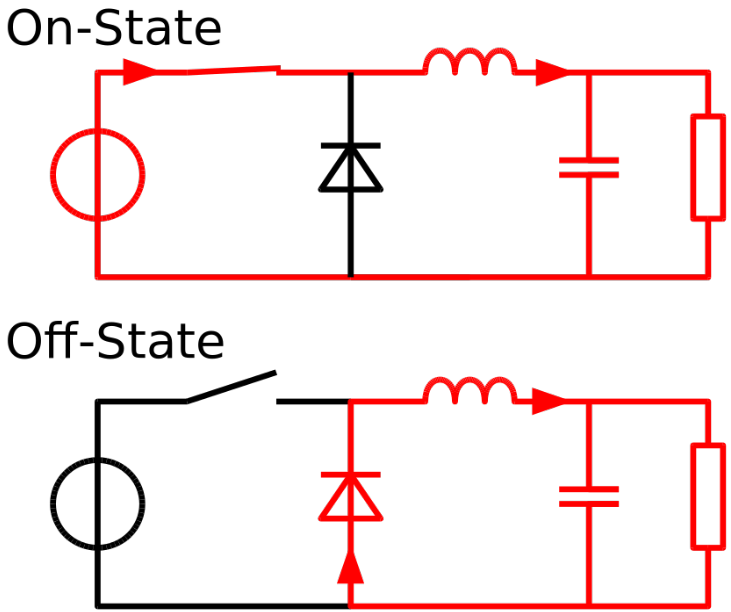
Theory of operation

Only want some of the power? Just sip from the firehose!

On State – Directly connected to load. As soon as the output voltage hits the limit, turn it off.

Off State – The capacitor ‘tanks’ voltage, the inductor ‘tanks’ current – for a short while

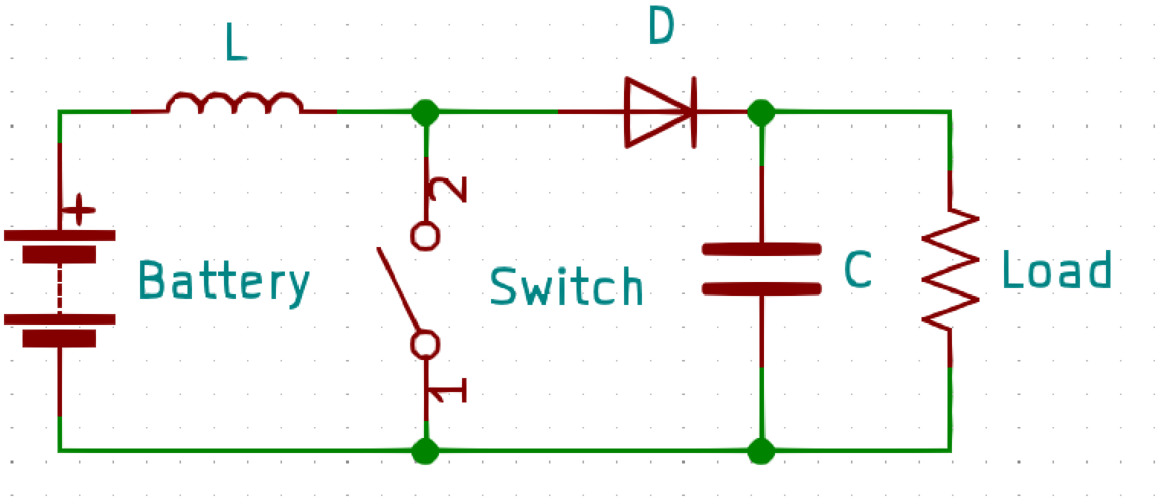
The diode completes the circuit when the switch is open



Boost converter topology

Same parts as the buck

New exciting wiring configuration



Boost converter operation

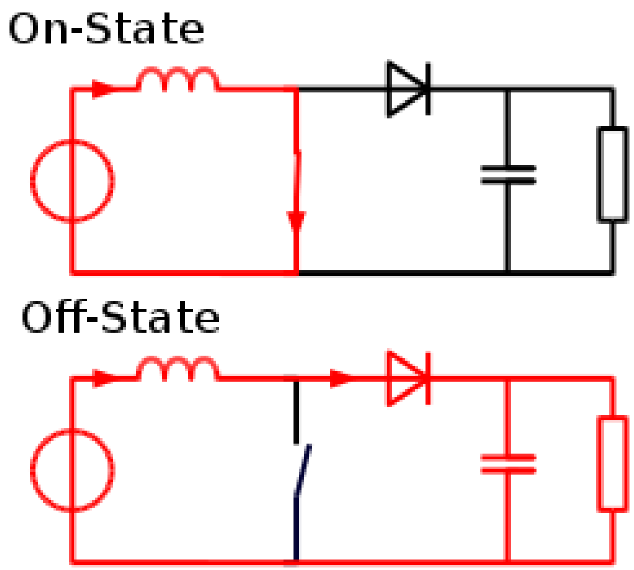
Theory of operation

Make the inductor work for you

On State – Short-circuit input into coil to build magnetic field (be mindful of saturation!)

Off State – As the magnetic field in the inductor drops, it increases the voltage to keep the current through it stable. The diode prevents back leakage.

No load = output voltage going to the moon



Other topologies

Buck/Boost – a bit of both

Ćuk – (chook) a Buck/Boost but negative output

Flyback – Isolation of input/output via transformer

Many, many variations…

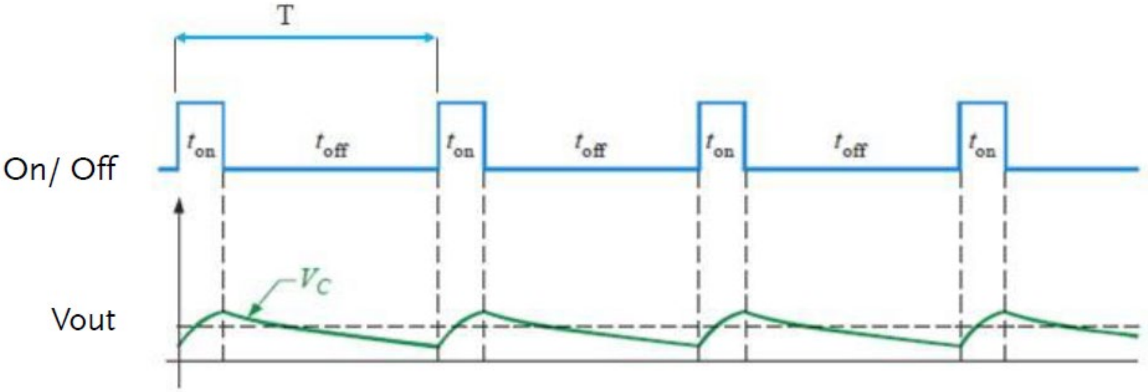
Output Ripple

Ripple in output is gonna happen

More output C, lower ripple

Faster switch, smaller bites, lower ripple

High frequency can generate RF noise, or mess with clocks on your microcontroller

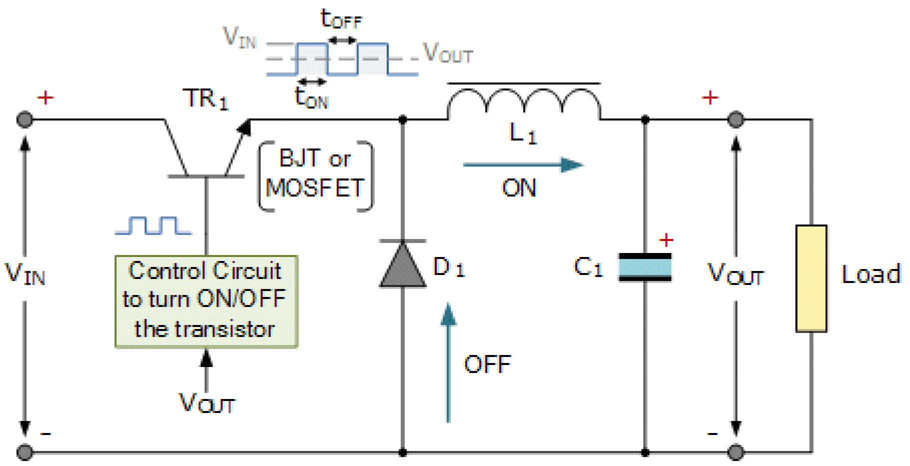


Control

Switch is actually a transistor (surprise!)

Controller can be ‘open loop’ or ‘closed loop’

Open loop is not common



Control

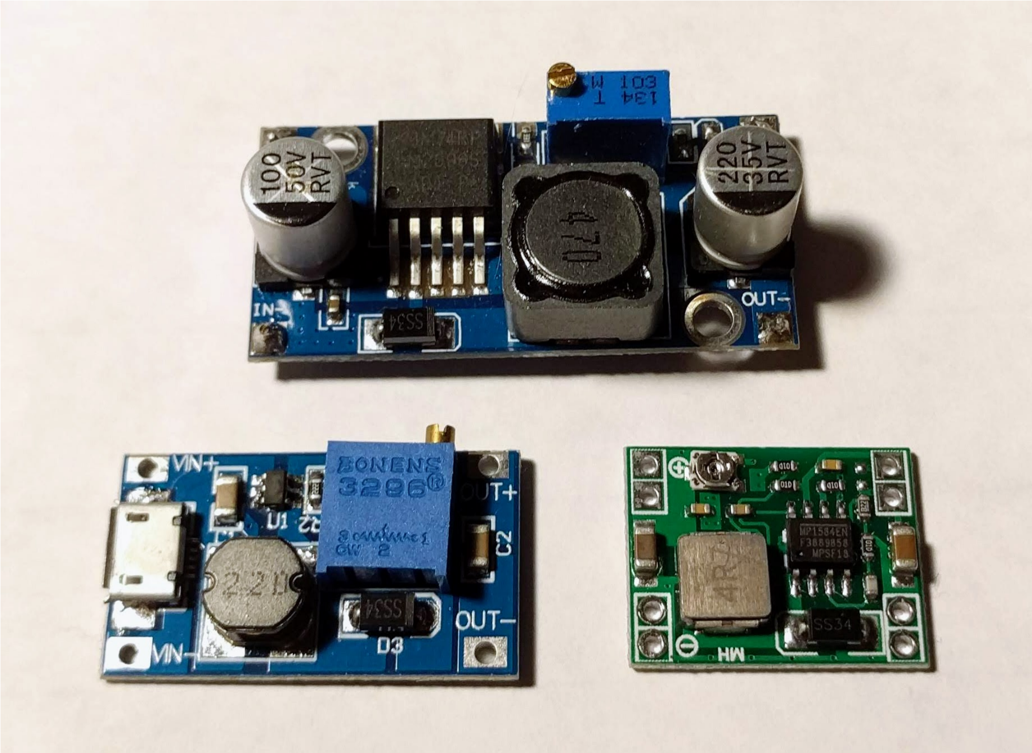
Controller can be a dedicated chip

Or a 555 timer with a feedback element

Or a microcontroller

Or a monkey with a push button

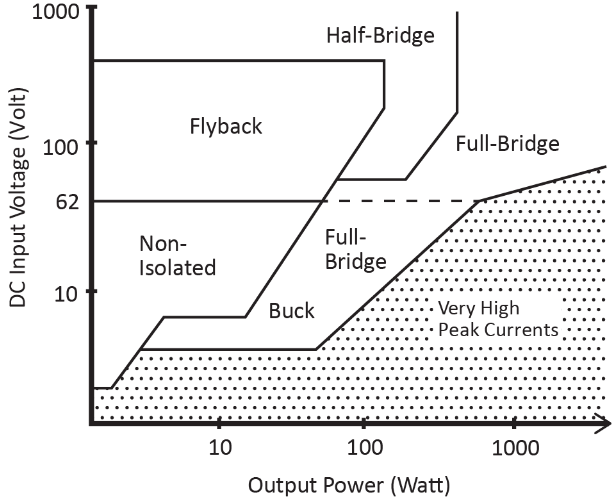
PID, open loop, other methods



Efficiency

Power Supply	Linear	SMPS
Size	Large and Heavy	Small and Light
Efficiency	30-40%	70-95%
Complexity	Simple	Complex
EMI	Low Noise	Filtering Required
Cost	High (Due to Material)	Low

Topology selection guide



Topology	Power Range (W)	$V_{in(dc)}$ Range	In/Out Isolation	Typical Efficiency (%)	Relative Parts Cost
Buck	<1000	5-40	No	78	1.0
Boost	<150	5-40	No	80	1.0
Buck-boost	<150	5-40	No	80	1.0
1T forward	<150	5-500	Yes	78	1.4
Flyback	<150	5-500	Yes	80	1.2
Push-pull	100-1000	50-1000	Yes	75	2.0
Half-bridge	100-500	50-1000	Yes	75	2.2
Full-bridge	400-2000+	50-1000	Yes	73	2.5

https://electronics.stackexchange.com/questions/299435/pros-and-cons-between-smps-switched-mode-power-supply-and-heavy-line-frequency-t

Questions?

@hamster

github.com/hamster/classroom