

DCDC Power Conversion Training

"What is DCDC?"

Lonne Mays

Topic Overview

A Simplified Definition
Purpose and Application
Terminology and Key Words
Basic Components and their Functions
The Popular Topologies

DCDC: A Simplified Definition

"DC" stands for Direct Current. This is current which has a fixed polarity; i.e., it only flows in one direction from the output terminal of the supply.

"DCDC" is a shorthand term which refers to *circuitry* which *converts* direct current power from one voltage level to another.

In other words, a direct current power source at one voltage is converted into a direct current power of another voltage.

An example might be a telecom system rack mounted power supply which converts the 48Vdc used as main system power by the telecom infrastructure, to 5Vdc for powering the digital circuitry of routers and switchers.

Another example would be a camera strobe flash: two flashlight batteries (3Vdc input) powering a 200Vdc strobe lamp.

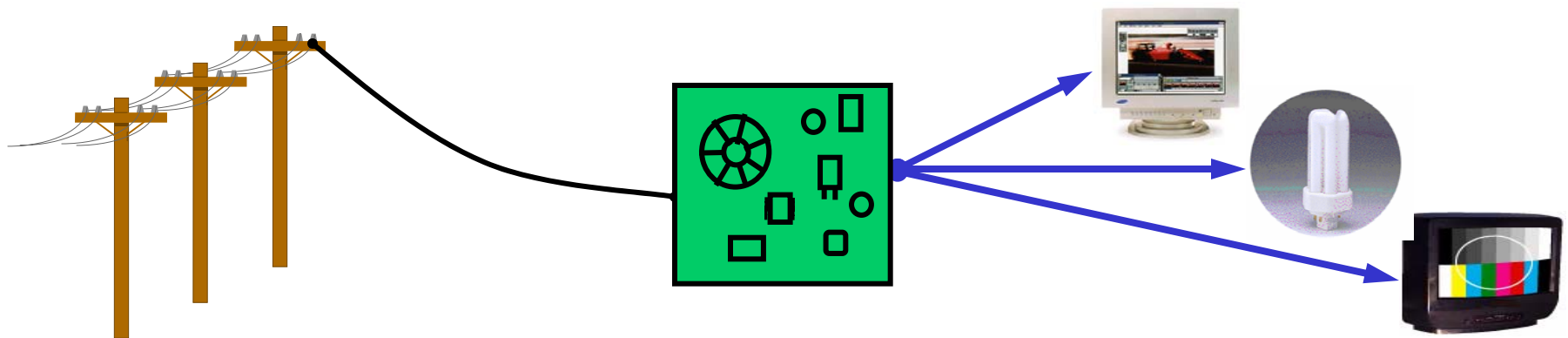
DCDC: A Simplified Definition (cont.)

DCDC vs. ACDC

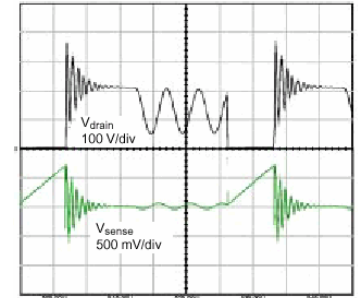
Some power supplies take their input directly from the AC mains. (60 Hz 120Vac in the USA, 50 Hz 220Vac in Europe.)

They must, therefore, included circuitry which converts the alternating current into direct current (a process called "rectification"), and then convert the resulting direct current's voltage to the desired output voltage.

Taken as a whole, such conversion circuitry is commonly referred to as ACDC, as shorthand for "AC-to-DC power converter".



DCDC: A Simplified Definition (cont.)



DCDC vs. Linear Power Supplies

Modern dc-to-dc power conversion is accomplished by "chopping" or "pulsing" the direct current so that it can be transformed from one voltage to another via pulsing the flux field in a magnetic component such as an inductor or transformer.

Earlier power supplies used a form of active resistance, through which the power was passed, to drop the excess voltage in a manner which was controlled so that the output voltage was held the same even though the load's current demand might change.

Such regulation is termed "linear regulation" because it is smoothly varied in response to load changes. (There is no "pulsing" of the current, and the current levels, when graphed versus time, will plot a *smooth line*.)

Linear regulation can only "drop" the voltage. It cannot "boost" it up to a higher level. (DCDC can both drop and boost voltage levels!)

DCDC: Purpose and Application

(Why is it used?)

Different "widges" need different voltages.

Batteries only come in standard voltages based on their cell chemistry x the number of cells*.

Electronic appliances of various types and applications often need voltages which may be different than a battery's.



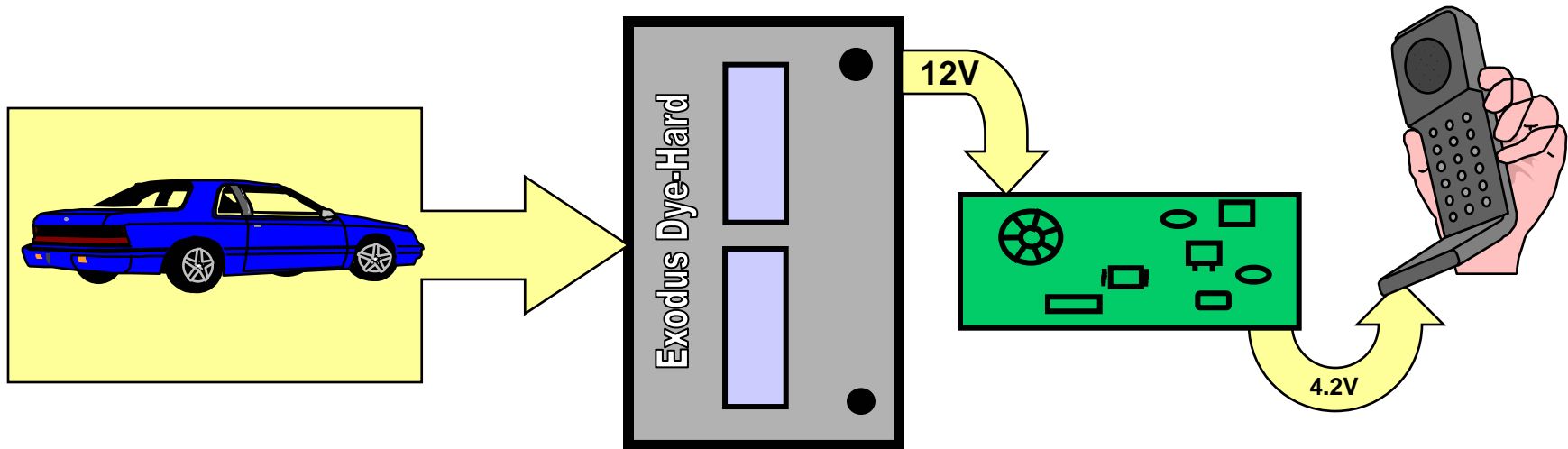
*Technical Trivia: Batteries get their name from the fact that they often consist of an organized grouping of cells, and the antiquated term for an organized grouping was "battery", as in a battery of artillery, or an infantry battalion.

DCDC: Purpose and Application

(Cont.)

Besides needing different voltages, many electronic appliances contain circuitry which requires that it be supplied a voltage which does not change with time or with load.

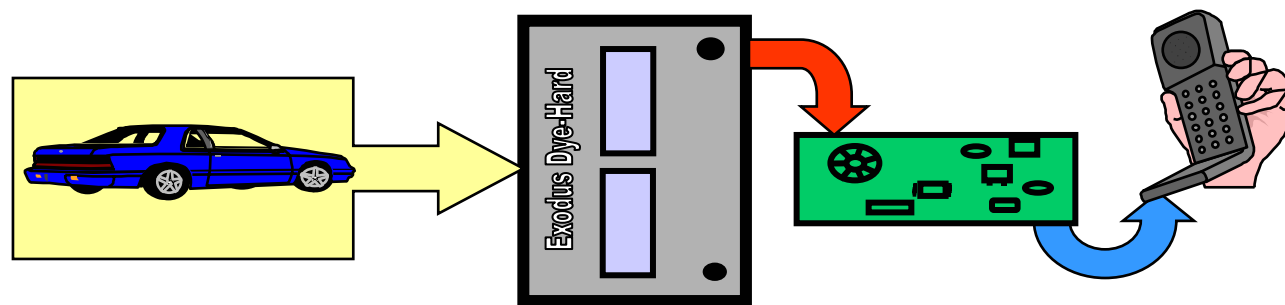
A "digital" cell phone, for example, varies the load current required depending not only on whether it is transmitting or receiving, but also depending on how far it is from the nearest cell tower. (I.e., transmit power is made a function of received signal strength in order to provide longer talk times per charge.)



DCDC: Purpose and Application (Cont.)

This means loads can change by several orders of magnitude (i.e., go from milliamperes to amperes) in fractions of a second, and yet the power supply must respond to these changes in such a manner that the voltage remains constant.

Therefore, the "load transient" response parameter to high di/dt loads, is an important requirement in the design of dc/dc power converters. (This requires fast, but stable, loop response.)

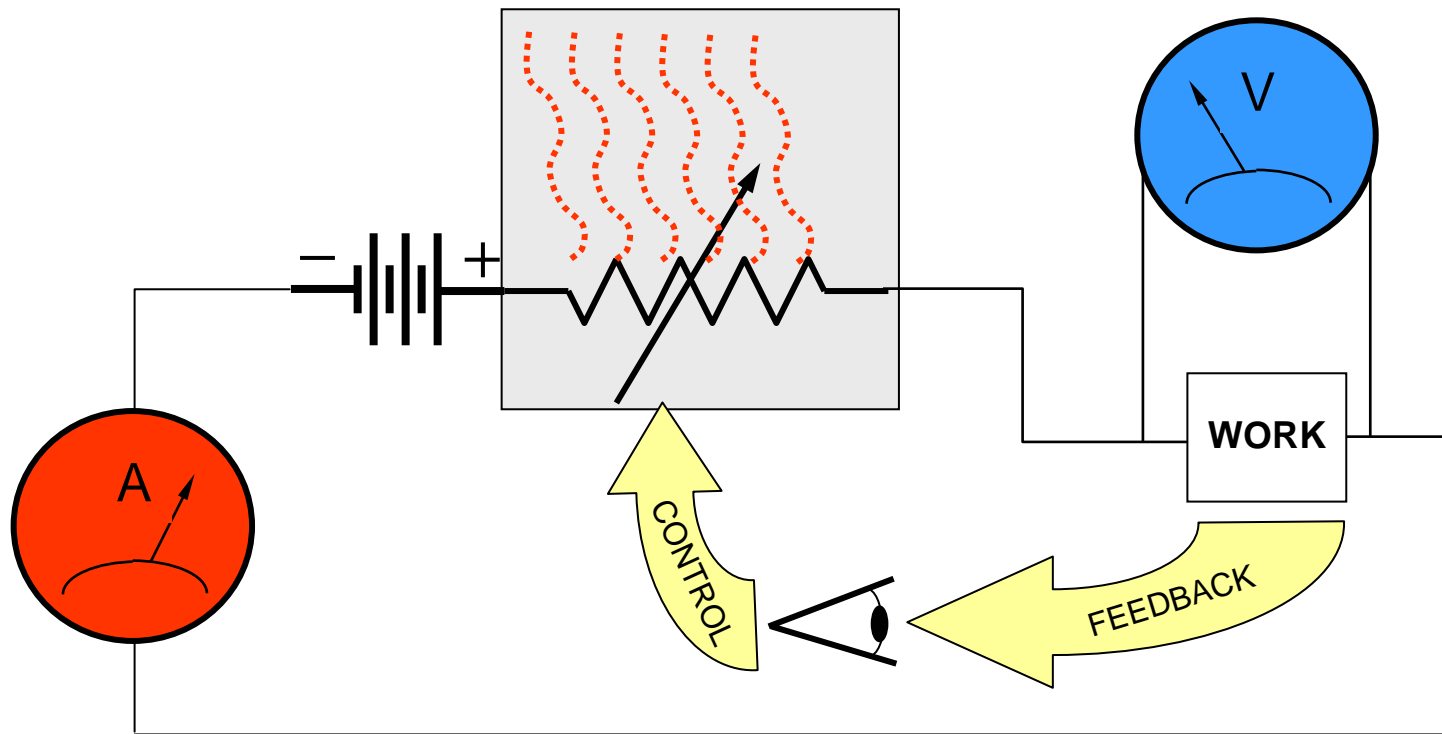


DCDC: Purpose and Application (Cont.)

But why DCDC instead of Linear Regulators?

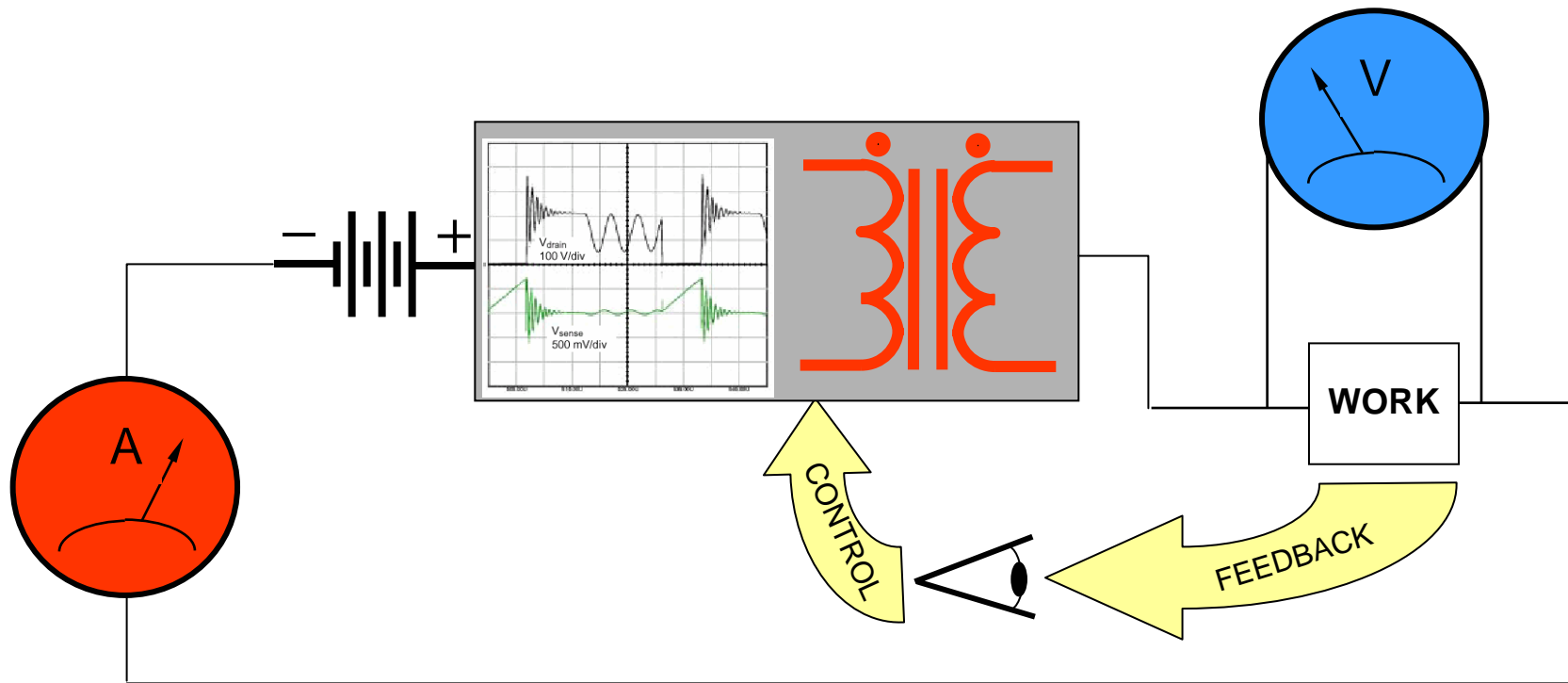
Linear regulators can only be used to step-down a voltage, and they do so by *an inherently inefficient means!*

A "pass transistor", acting as a variable resistor, drops the voltage in series with the load, but has to turn the $V \times A$ product into *HEAT!*



DCDC: Purpose and Application (Cont.)

DCDC converters, on the other hand, accomplish the conversion and regulation tasks by pulsing the direct current source into a magnetic device (usually a metallic oxide core with coils of wire wound on it). The magnetic device "transforms" the voltage and current pulses with greater than 99% efficiency! (There are no losses in Faraday's Law.)



Terminology and Key Words

There are dozens of buzz-words associated with dcdc converters

SINGLE-ENDED
STEP DOWN
DOUBLE-ENDED
BOOST
STEP UP
2-SW FORWARD
1-SW FORWARD
IDLE MODE
FULL BRIDGE
HALF BRIDGE
HIGH di/dt LOAD
BUCK
CURRENT MODE
PUSH-PULL

CONVECTION COOLED
FAN COOLED
OFFLINE
CUBIC FORM
SURFACE MOUNT
FLYBACK
SINGLE OUTPUT
MULTIPLE OUTPUT
STATIC LOAD
AUTOMOTIVE
CONSUMER
AEROSPACE
TRIED & TRUE
HIGH PRECISION
PORTABLE
LOW DENSITY

EXOTIC COOLED
SYNC-REC
LOW COST
CPU VID DAC
HICCUP MODE
SINGLE OUTPUT
BUILT-IN UVLO
FIXED FREQ
HV INPUT
HIGH G SHOCK
NON-ISOLATED

GATE DRIVERS
CLOCK SYNC-ING
MULTIPHASE
PLANAR FORM
LOW EMI/RFI
HIGH FREQ
NEG OUTPUT
SMALL XFMR
BUCK-BOOST (INV.)
HV OUTPUT
HIGH EFFICIENCY
ADJ VOLTAGE
FIXED VOLTAGE

VFM
SOFTSTART
THRU HOLE
POS OUTPUT
ADJ FREQ
STEP DOWN
HIGH DENSITY
HIGH RATIO
CURRENT LIMITING
ISOLATED
VOLTAGE MODE
SC PROTECTION

Terminology and Key Words

(Some Basic Terms and Definitions)

DCDC converters are also known as:

SMPS (switch mode power supplies)

Switching power supplies

Chopper power supplies

dc/dc, dc-dc converters

DCDC converters employ different switching/pulsing methods to control the packets of energy delivered to the magnetics:

PWM = Pulse Width Modulation

PFM = Pulse Frequency Modulation

VFM = Variable Frequency Modulation

And different methods to achieve closed loop control:

Current Mode Control

Voltage Mode Control

V² Control

Terminology and Key Words

(More Basic Terms and Definitions)

Topology = the particular circuit arrangement of the switch, magnetics, rectifier, and filter capacitor.

Power Switch* = the transistor (MOSFET, IGBT, BJT) which chops the direct current into pulses.

Regulation = the action of the entire converter circuit to keep the voltage the same while the load's demand for current changes.

Transient = a rapid change in voltage and/or current which occurs over a very brief period of time (usually measured in microseconds).

di/dt = a mathematical shorthand for the rate at which current changes with time. (Often used to describe load transients.)

dv/dt = a mathematical shorthand for the rate at which voltage changes with time. (Often used to describe the high frequency content in a voltage transient waveform.)

Resonant Switching = a technique for "soft-switching" the power switch so that it is not subjected to high di/dt and dv/dt stresses.

*not to be confused with the on/off switch on the end application device

Terminology and Key Words

(More Basic Terms and Definitions)

Duty Cycle = the percentage of time during which the power switch is "ON" during the entire ON-OFF switching cycle.

1-D = the percentage of time the power switch is "OFF" during the entire ON-OFF switching cycle.

Isolated = means the output of the supply is electrically separate from the input of the supply. (A potential measured at the output can not be referenced or "felt" by the ground circuit of the input, and vice-versa.)

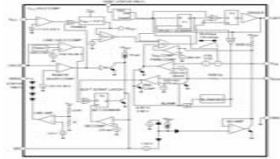
Step-down = the output of the power supply is a lower voltage than the input of the supply.

Boost = the output of the power supply is a higher voltage than the input of the supply.

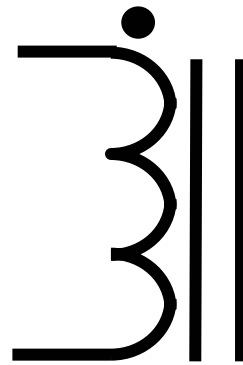
Offline = the input of the supply is achieved by rectifying the AC mains. (aka ACDC).

Basic Components and Their Functions

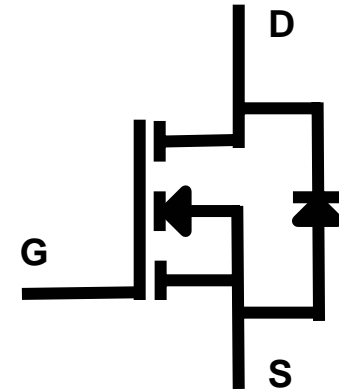
The five basic circuit elements (and symbols) of a dc/dc power supply



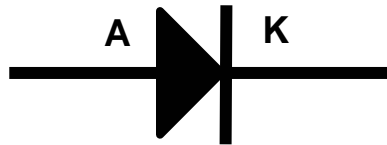
CONTROLLER IC



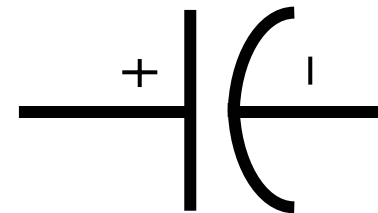
INDUCTOR OR
TRANSFORMER
(MAGNETICS)



POWER SWITCH



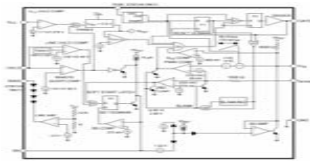
OUTPUT RECTIFIER



FILTER CAPACITOR

Basic Components and Their Functions

The five basic circuit elements (and symbols) of a dc/dc power supply



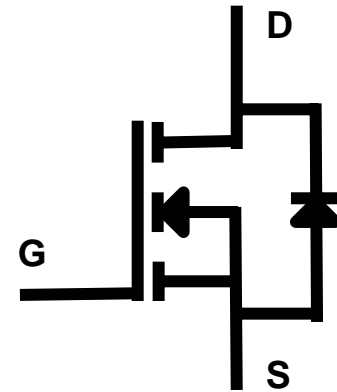
CONTROLLER IC

The **controller IC** is the "brains" of the dc/dc converter. The more sophisticated its circuitry, the more features it offers the engineer in creating his dc/dc power supply design. At a minimum, It monitors the output voltages and currents and controls the action of the power switch to hold the output voltage steady even though the load may be changing or the input voltage supply may be changing.

Basic Components and Their Functions

The five basic circuit elements (and symbols) of a dc/dc power supply

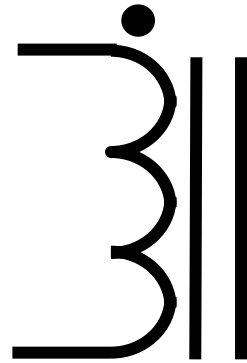
The **power switch** is the "muscle" of the dc/dc converter circuitry. By virtue of its brute force switching action, it breaks the flow of direct current into pulses which dynamically excite the flux field of the converter's magnetic components.



POWER SWITCH

Basic Components and Their Functions

The five basic circuit elements (and symbols) of a dc/dc power supply



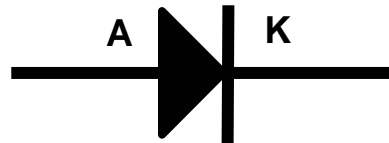
INDUCTOR OR
TRANSFORMER
(MAGNETICS)

The **magnetics** (a transformer or inductor) is the heart of the converter. It pumps the current through the circuitry, either raising or lowering the pressure (voltage) as it pulsates.

Basic Components and Their Functions

The five basic circuit elements (and symbols) of a dc/dc power supply

The rectifier is the component which "steers" the current pulses in the power circuitry so that the current is presented to the output in only one polarity. It does this by only allowing current to be conducted in one direction, thus "rectifying" the current flow.

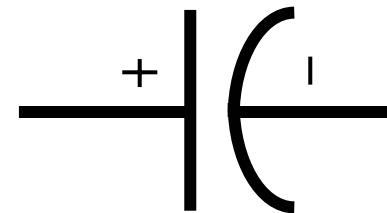


OUTPUT RECTIFIER

Basic Components and Their Functions

The five basic circuit elements (and symbols) of a dc/dc power supply

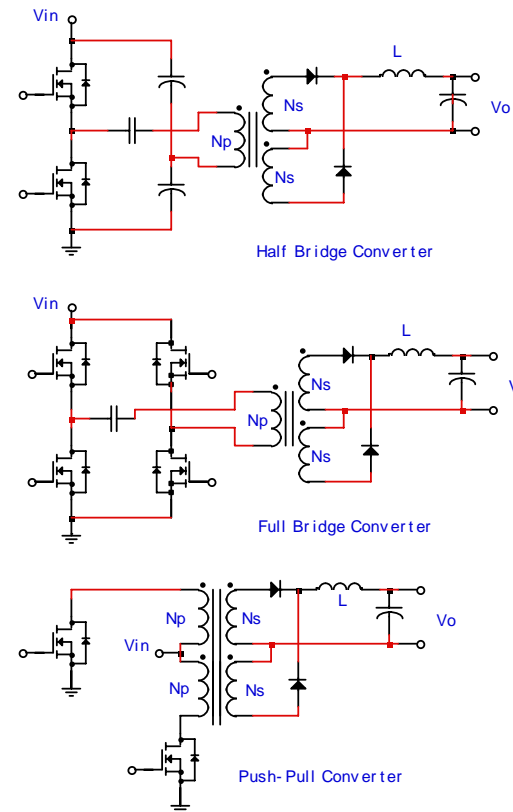
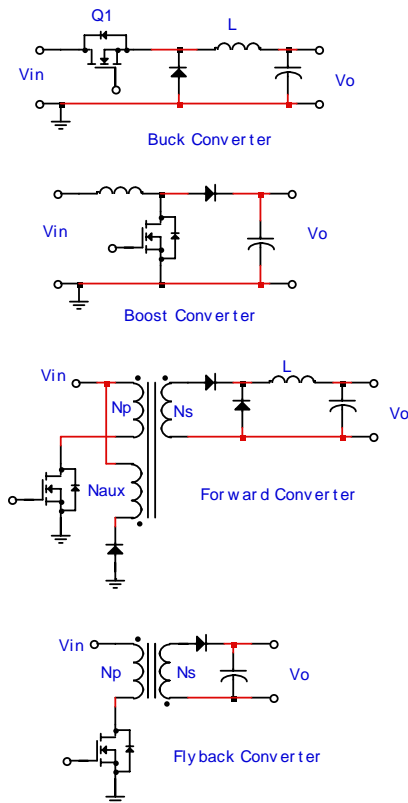
The filter capacitor acts as an integrator to smooth out and average the energy pulses delivered from the magnetics; much the same as the shock absorbers in your car average out the bumps in the road to produce a smooth, level ride.



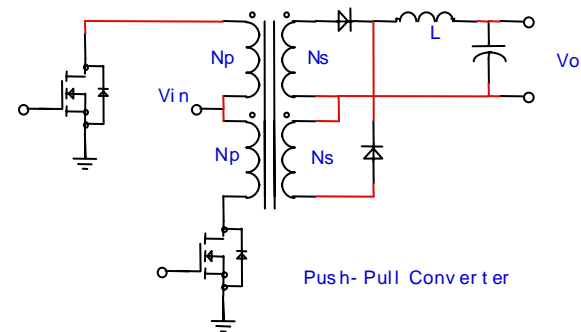
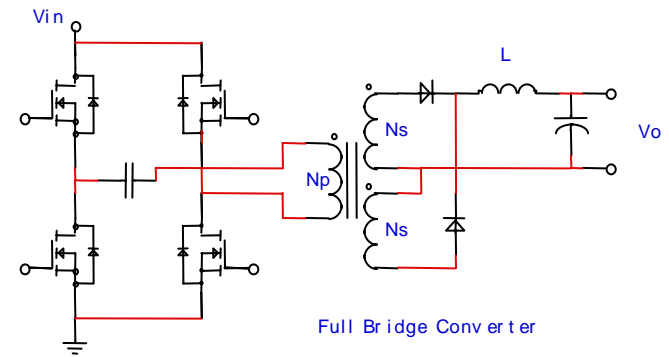
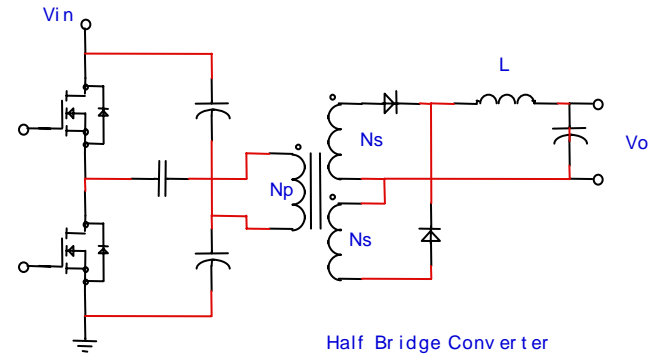
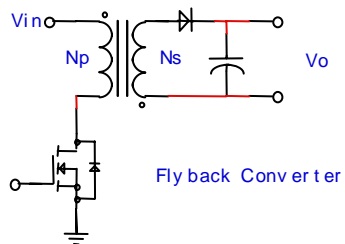
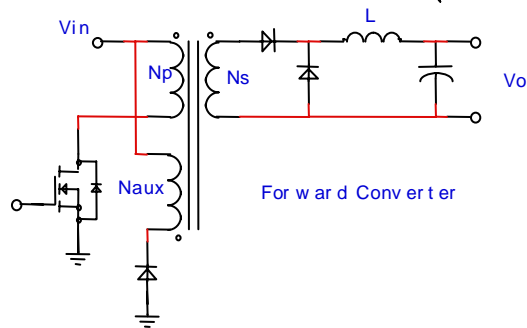
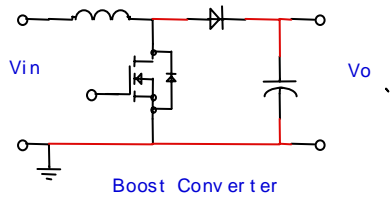
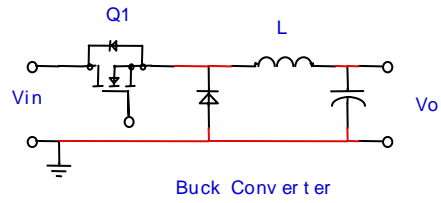
FILTER CAPACITOR

The Popular Topologies

- There have been literally hundreds of different topologies presented in technical journals over the last two decades; each one claiming to be the best of all possible dc/dc topologies.
- In practice, only a few different topologies are commonly used.



The Popular Topologies (Cont.)



The Popular Topologies (Cont.)

CHOOSING A TOPOLOGY

POWER RANGE	TOPOLOGY	STEPUP/DN?	MULTI-OUTPUT?	ISOLATED?
UP TO 150W	BOOST	UP	NO	NO
	BUCK-BOOST	UP/DN/INV	NO	NO
	FLYBACK	UP/DN/INV	YES	YES
UP TO 250W	1-SW FORWARD	UP/DN/INV	YES	YES
UP TO 500W	2-SW FORWARD	UP/DN/INV	YES	YES
	HALF BRIDGE	UP/DN/INV	YES	YES
UP TO 1KW	BUCK	DOWN	NO	NO
	PUSH-PULL	UP/DN/INV	YES	YES
UP TO 2KW	FULL BRIDGE	UP/DN/INV	YES	YES

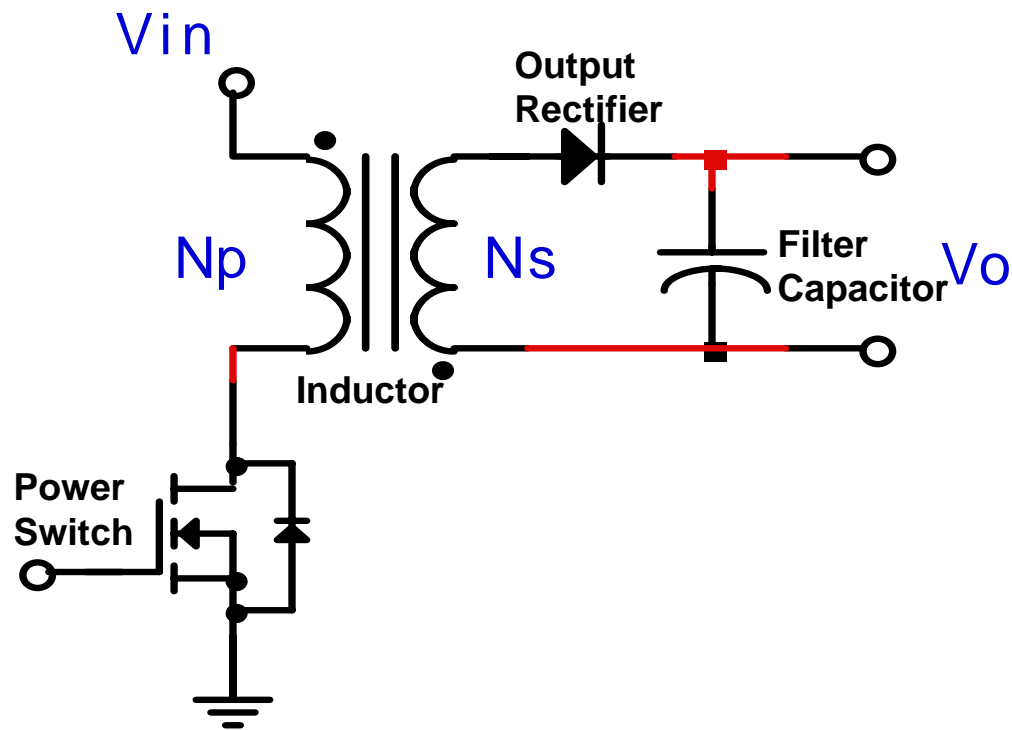
The Popular Topologies (Cont.)

Application vs. Typical Topology and Devices

<i>Performance</i> <i>Topology</i>	BIPOLAR < 100kHz	MOSFET >50kHz	IGBT <20kHz	SCHOTTKY >50kHz	ULTRA FAST <100kHz
BUCK or STEP DOWN	N/A	<ul style="list-style-type: none"> • Telecom • Computer • 3.3v, 5v out • <150W 	N/A	<ul style="list-style-type: none"> • Telecom • Computer • 3.3v, 5v out • <150W 	N/A
BOOST or STEP UP	Seldom Used	PFC <1000W	PFC >1000W	Seldom Used	PFC
FLYBACK	•TVMonitors < 300W	•Computer < 150W	•TV/Monitors •Computer < 300W	•Computer <150W	•TV/Monitors •Computer < 100kHz < 150W
FORWARD	•Industrial < 500W	<ul style="list-style-type: none"> • Telecom • Computer • 5v-48v out • <500W 	<ul style="list-style-type: none"> • Telecom • Computer • Industrial • 5v-48v out 	<ul style="list-style-type: none"> • Telecom • Computer • Industrial • 5v-48v out 	<ul style="list-style-type: none"> • Telecom • Computer • Industrial • 48v- 400 out
HALF & FULL BRIDGE	Seldom Used	<ul style="list-style-type: none"> • Telecom • Industrial • 5v-400v out • >400W 	<ul style="list-style-type: none"> • Industrial • 5v-400v out • >400W 	<ul style="list-style-type: none"> • Telecom • Computer • Industrial • 5v-400v out 	<ul style="list-style-type: none"> • Telecom • Computer • Industrial • 48v- 400 out

This table shows the type of power semiconductor discretes employed in the typical topologies as well as the application areas.

Basic Flyback Converter



Some key Points:

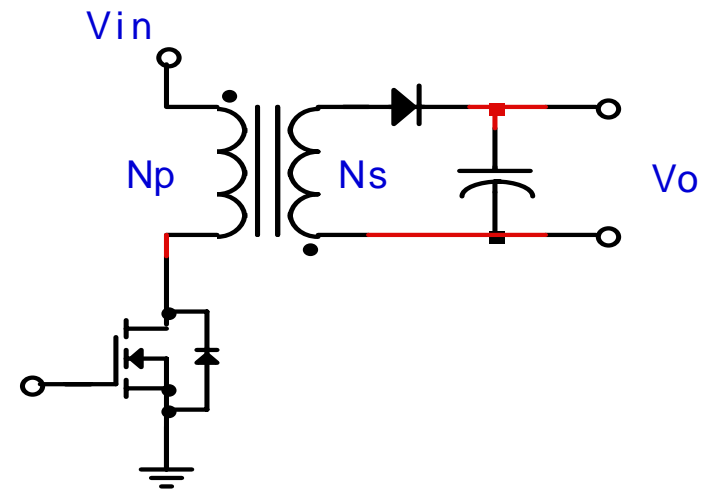
Multiple outputs easily accomplished with additional inductor windings

High voltage MOSFETs are easily implemented as the power switch

Bipolar transistor power switches also function well in this topology

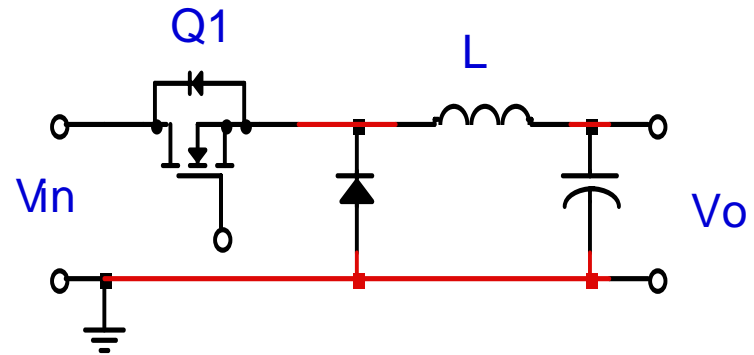
Common topology used in monitors, televisions, and set top boxes

Flyback Converter



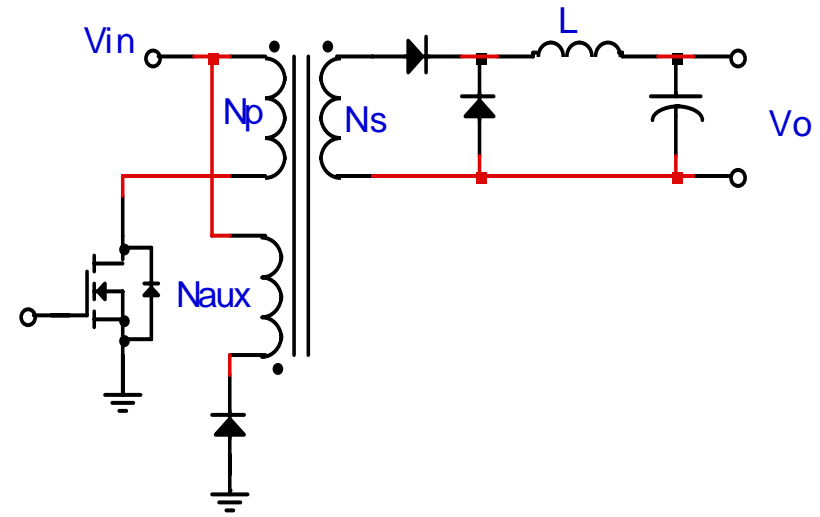
- Least costly of all isolated switching power supplies.
- *Multiple outputs easily accomplished with additional transformer windings*
- Limited to approximately 300W due to high peak currents.
- Need 1000 volt devices or greater for universal input.
- Bipolar devices function well in this topology eg: MJE18004
- High voltage MOSFETs are easily implemented but more expensive.
- Fast IGBTs should offer the best performance/cost combination
- Commonly used in monitors and televisions.

Buck or Step-down Converter



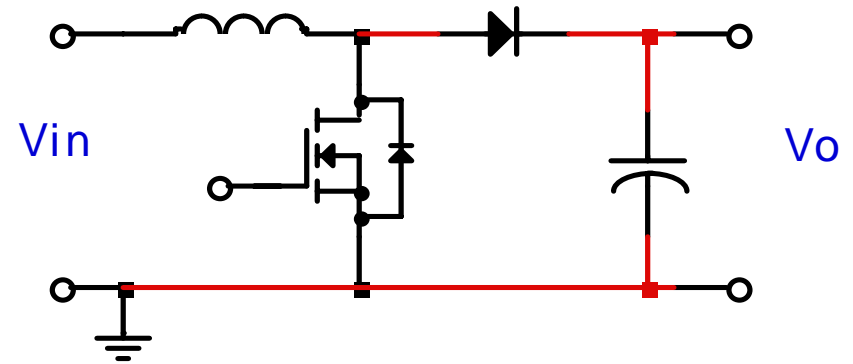
- Used as a low voltage DC-DC converter.
- This topology is known for its low output ripple voltage and its relatively precise regulation.
- Ratio of output to input voltage is approximately equal to the PWM duty cycle.
- The freewheeling diode is predominantly a Schottky Rectifier.

Forward Converter



- Limited to approximately 500W due to high peak currents.
- Multiple Outputs - low voltage / high current
- Need 800 - 1000 Volt devices or greater.
- High Voltage MOSFETs are easily implemented but more expensive.
- IGBTs can offer a good performance/cost combination.

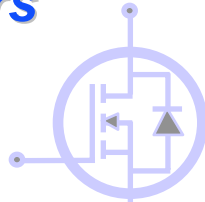
Boost or Step-up Converter



- Bipolar devices can function in a boost converter but are extremely difficult to implement. The base drive is non-trivial.
- MOSFETs provide a good solution but more expensive at high power levels.
- Fast IGBTs should offer the best performance/cost combination at high power and voltage levels.
- Need 500 - 600 volt devices or greater for a universal input PFC (transistors and rectifiers).
- Power range for this topology is very wide.

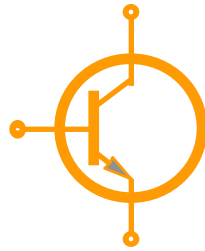
Power Control Semiconductors

MOSFET



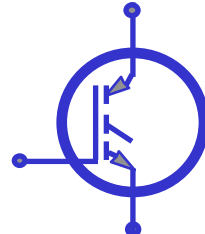
LOW VOLTAGE
HIGH CURRENT

BJT



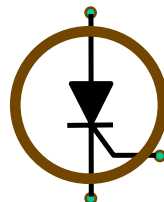
HIGH VOLTAGE
LOW CURRENT

IGBT



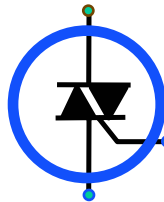
HIGH VOLTAGE
HIGH CURRENT

SCR



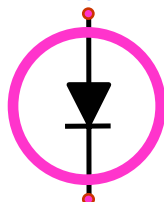
PULSATING DC
H,M,L CURRENT

Triac



AC VOLTAGE
H,M,L CURRENT

Rectifier



DIODE FOR HIGH
CURRENT (AC=>DC)

Voltage and Current Determine Power Switch Choice

