2021

Understanding power sources

POWER SUPPLIES, TRANSFORMERS, RECTIFICATION, FILTERING & REGULATION

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INTRODUCTION TO POWER SUPPLIES
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PART 1: POWER DISTRIBUTION OPTIONS

- In “A”, power from Edison is “stepped-down” from thousands of volts to 240 for home use.
- In “C”, we see how AC power is converted to DC for our electronic equipment.
- In “B”, we see a Buck converter. This is a circuit that takes DC input voltage and regulates it to a new, lower voltage such as 12V to 3.3V, for example.
- In “D”, we see the model of an inverter. This circuit converts DC battery voltage to 120V AC for use in a RV.

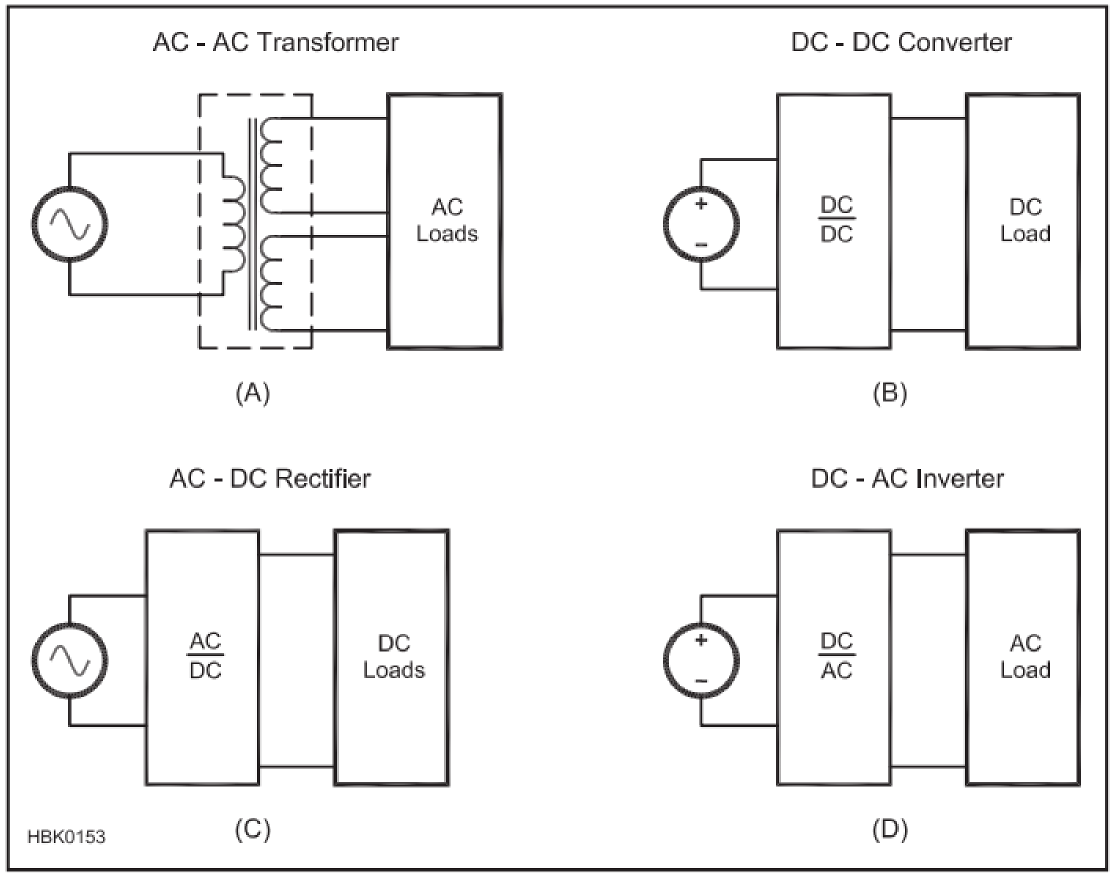
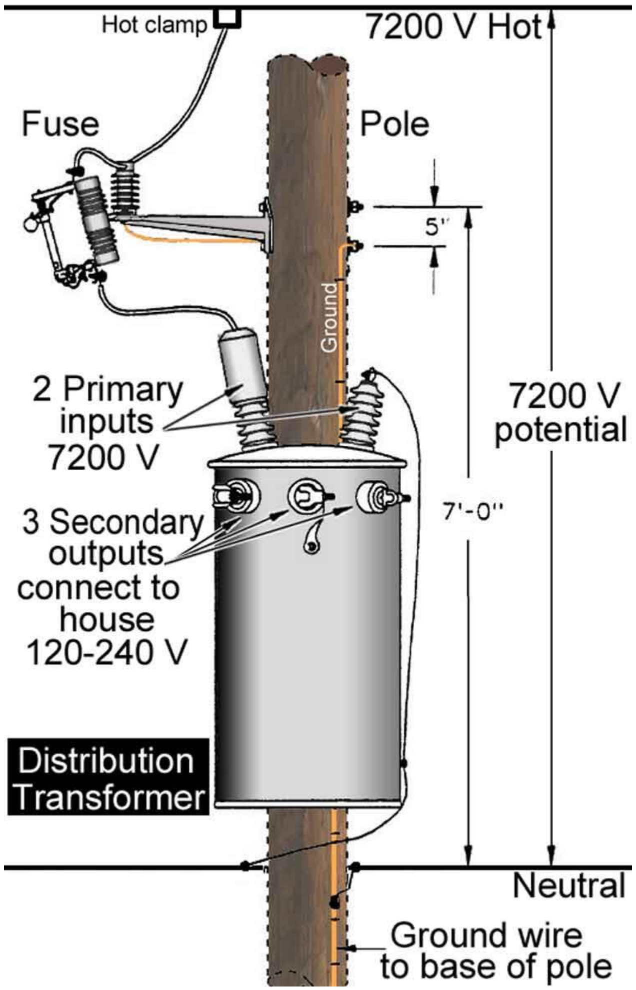


Fig 7.2 — Four power processing schemes: ac-ac, dc-dc, ac-dc and dc-ac.

POWER POLE TRANSFORMERS

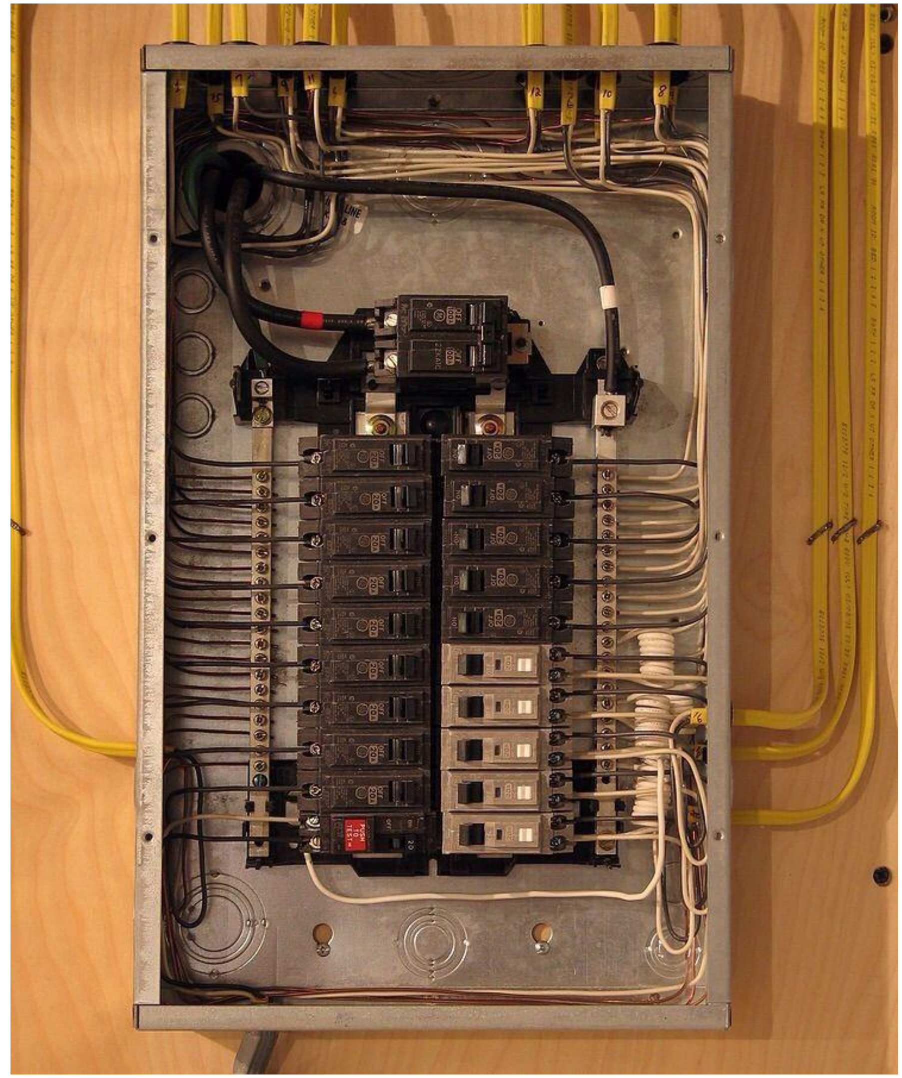
1. Nearly 13,000 volts is delivered to our neighborhood via power poles or underground. In either case, large *step-down* transformers are used to reduce the super high voltage down to the 120V we use in our homes.
2. The two high voltage power lines are connected to the INPUT or PRIMARY side of the transformer. Inside this device, there are two sets of coils. The magnetic field created from the moving current causes smaller voltage in the OUTPUT or SECONDARY coil.
3. The secondary outputs are then connected to our home. Notice there are 3 wires that are connected to our homes. Two of the black wires carry 120V of alternating current (AC) and the third wire is called the neutral or return wire.
4. Those 3 wires and a ground wire are connected to the main junction box in our home. This is the box that contains the circuit breakers.
5. A ground wire is also connected to the power equipment/pole and connected on the other end to our main breaker box. This ground is for safety. If there is a short circuit, the ground wires keep the electricty from shocking us.



The power wires in our homes is called ROMEX and contains the 3 wires I described above.


Sample of ROMEX cable with the Black "Hot" wire, the white "Neutral", and the bare Ground wire.

This is a typcial household Main Junction Box. The black power wires are connected to the top breakers and you can see the other black wire with the white tape is the neutral or return wire.



The circuit breakers act like a fuse and supply power to our indiciual circuits. One sends power to the microwave, the refridgerator, garage door opener, and so on.

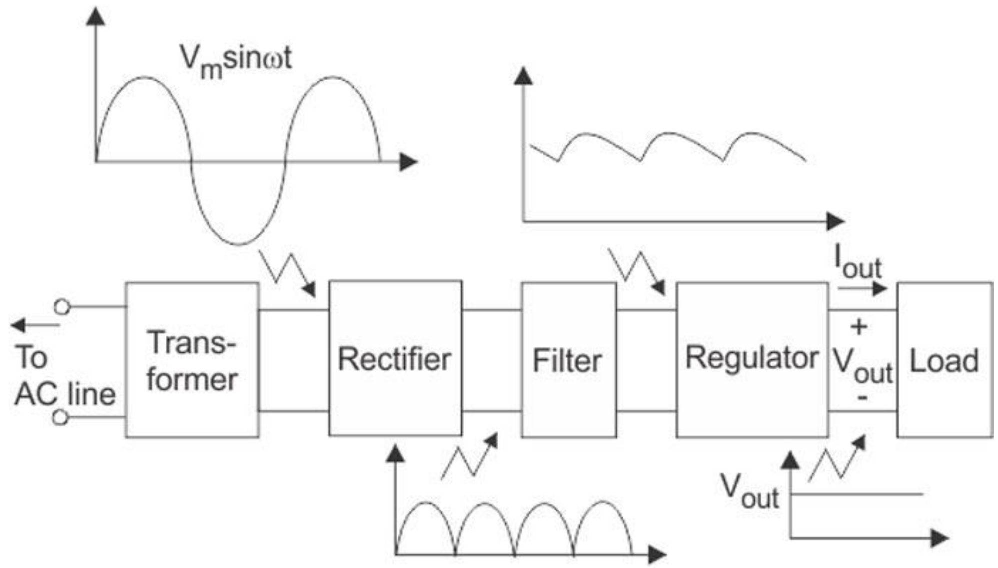
Each black wire from a breaker is connected to a specific appliance such as the dish washer let’s say. This wire is attached to one of the wires on the dishwasher motor. The other motor wire is connected to the white wire. This white wire is connected to the other white wires on the right side of the box. All those return/neutral wires are connected to the black wire with th white stripe. In this way, we have a complete circuit. Power goes out the black wires to the load and returns through the white wires.

Now that we have an idea of how power enters our home or workplace, let’s see how that AC power is converted to direct current (DC) so we can charge our phones and run our other electronic devices.

Here is a block diagram of a typcial low voltage power supply (5-24V). We have already seen how step-down transformers from the electric company are used to get 120 volts to our homes. But now we need to take a look at how those phone chargers and similar plug-in power supplies work.

Our small wall power supply must first reduce the 120 volts from the wall receptacle to something more managable. It is common to reduce the power to 5 or 12 volts AC. This is done with a small transformer. This small transformer works in the same way the power company transformer works. The difference is we are working with much lower power levels. Click here for an animation that makes this clear.

The power from the wall is connected to the primary side of the transformer and the output voltage from the secondary coil is connected to the second stage of our circuit: namely the rectifier section.



Components of typical linear power supply

PART 2: RECIFICATION

Full-Wave Bridge Rectifier Operation

The purpose of this stage is to convert AC to DC voltage. In this example I am using a bridge rectifier model. The four silicone diodes convert the AC sine wave into a positive DC voltage. Yes it looks funny because of those humps. But we will clean that up in the next stage of our circuit. DC or direct current means that the voltage never changes polarity like the AC sine wave does. In our case, it is going to be a positive voltage.

Choosing the correct diode is critical because they must withstand the initial in-rush current caused by the smoothing capacitor. See Part 3 below.

A good rule of thumb is to choose a diode where Peak inverse voltage (PIV) is equal to the expected IV + 15%. So, if the PIV = 50V, choose a diode with PIV = 75.

Also, make sure the diode is rated for the average forward current you expect + 15%.

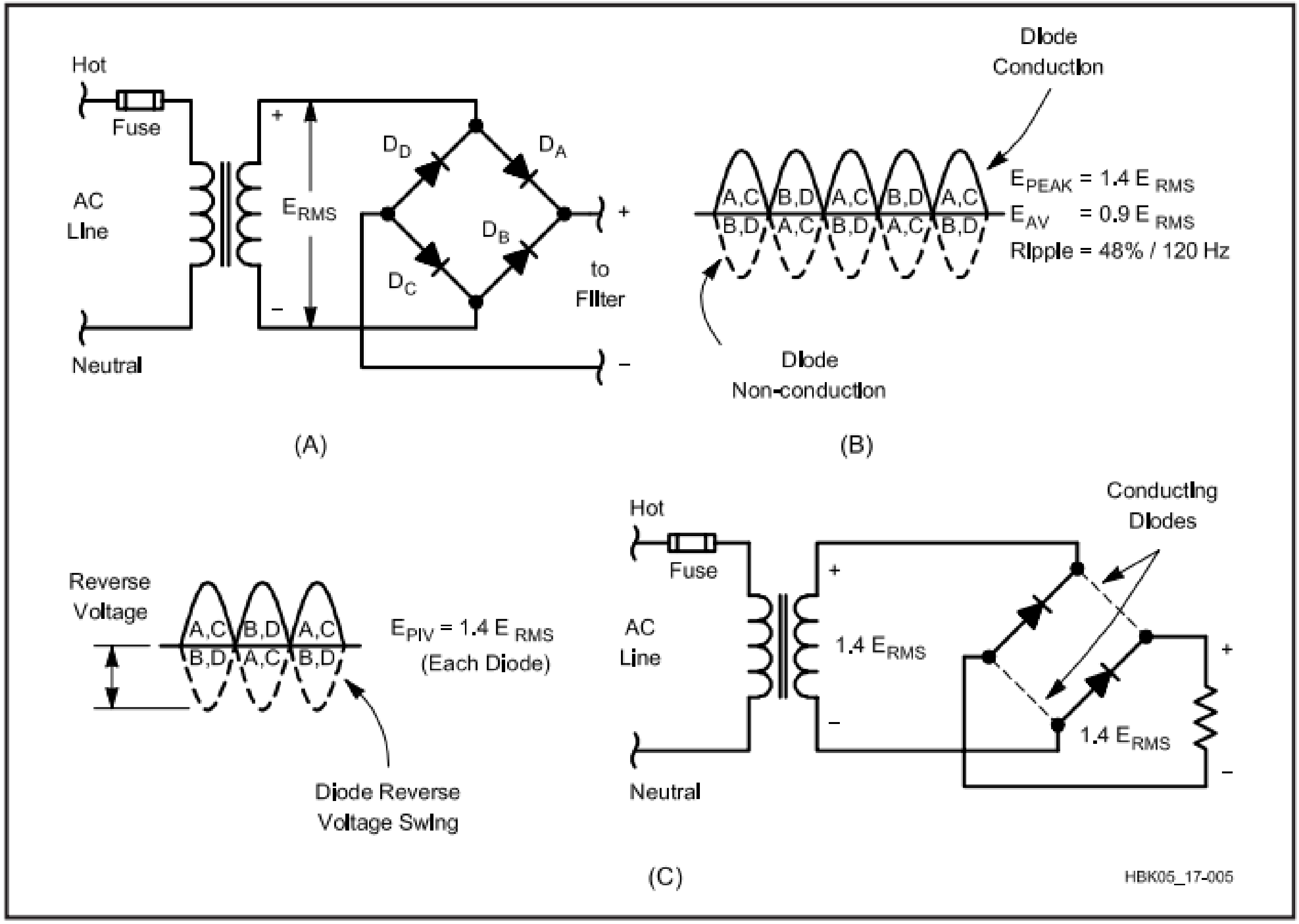
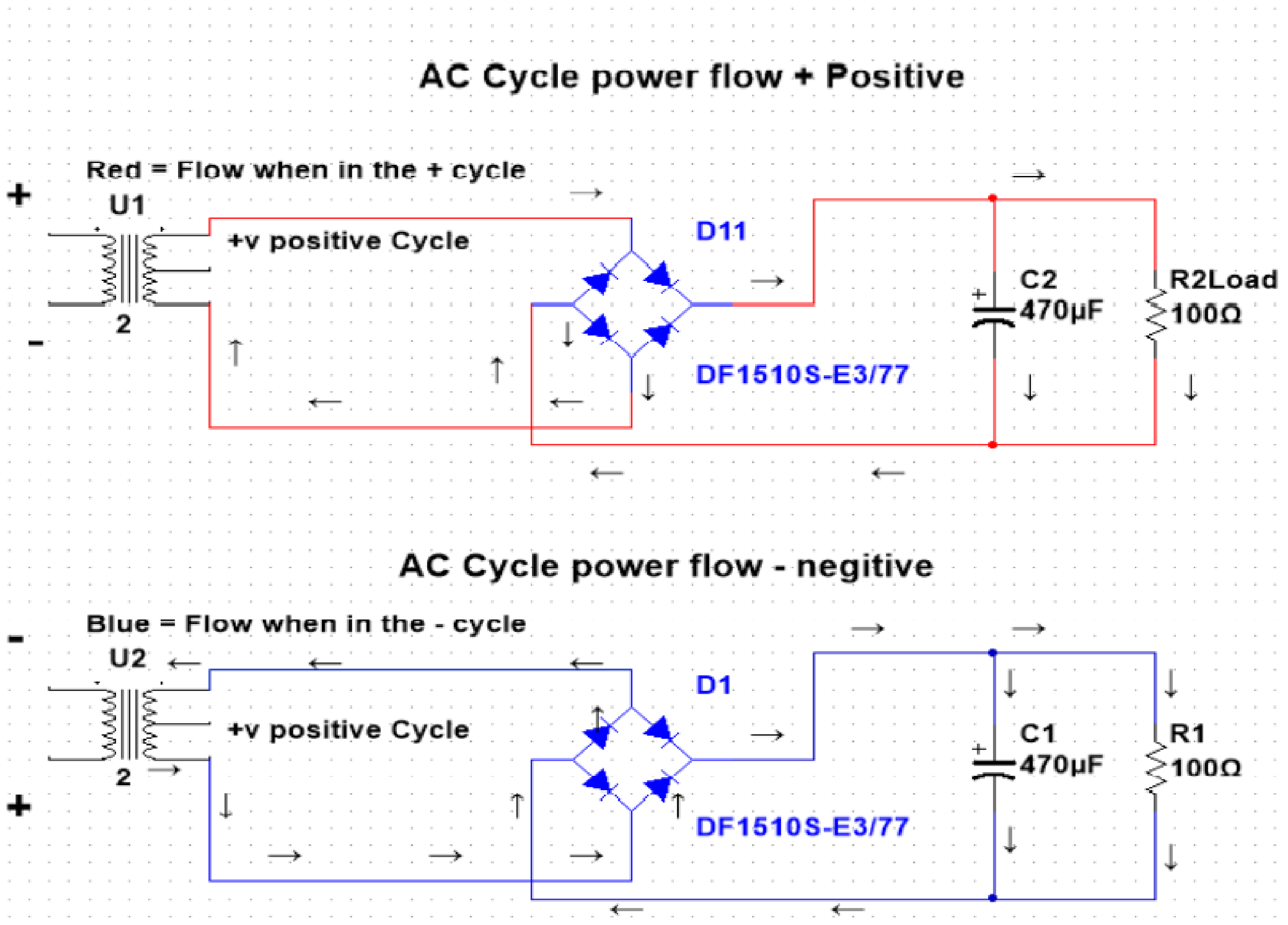


Fig 7.8 — Full-wave bridge rectifier circuits. The basic circuit is illustrated at A. Diode conduction and nonconduction times are shown at B. Diodes A and C conduct on one half of the input cycle, while diodes B and D conduct on the other. C displays the peak inverse voltage for one half cycle. Since this circuit reverse-biases two diodes essentially in parallel, 1.4 E_{RMS} is applied across each diode.

Another look at the bridge rectifier

[Click here for an animation](#)



Part 3: Filtering or "Smoothing the Ripple" Capacitors (electrolytic) & Inductors

When the power is turned on and the filter is discharged, a large in-rush current occurs. This is because the capacitor is like a short circuit. As it charges, the current diminishes. But, for the first half-cycle of rectification, the in-rush current can be 12 times the nominal level. That puts tremendous stress on the diodes. In-Rush current can be reduced by making C1 smaller and adding choke sections as shown in Fig 7-16. "B" is very common and is called a "Pi" filter.

When choosing rectifier diodes, pick one that can handle 12x the average DC current rating.

In a 60Hz sine wave, each cycle (period) occurs at 1/60 or .016 seconds (16.6ms). So, the first half-cycle takes 8.3ms and this is enough time to damage the diodes. This current is sometimes included in the datasheet as I_{FSM} and is described as a *non-repetitive peak surge current*.

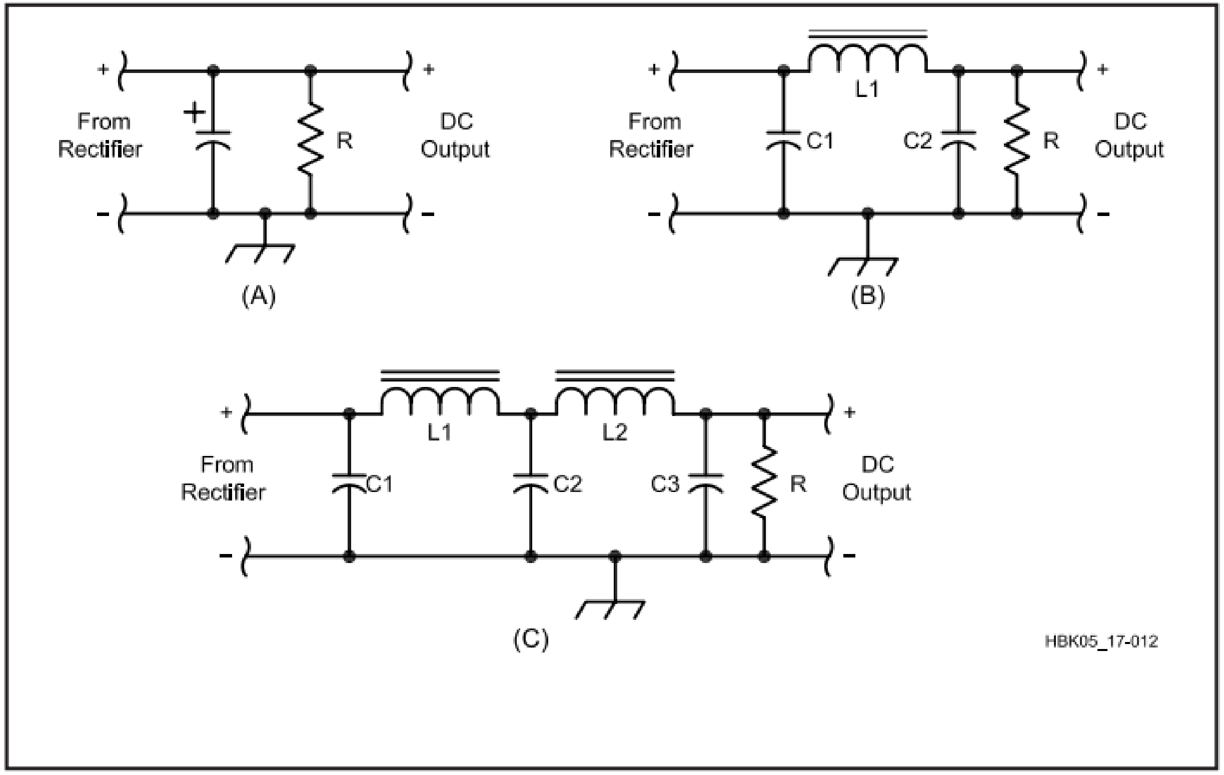


Fig 7.16 — Capacitor-input filter circuits. At A is a simple capacitor filter. B and C are single- and double-section filters, respectively.

The 1N4xxx family of diodes are rated at 30A for 1 cycle and a steady forward current of 1A. The 1N4001 is a good choice for low-voltage supplies (5-12V).

Datasheet from Digi-Key for the 1N4xxx Family of Rectifier Diodes

The arrows denote the PIV and Surge Current specifications discussed above.

1N4001, 1N4002, 1N4003, 1N4004, 1N4005, 1N4006, 1N4007

MAXIMUM RATINGS

Rating	Symbol	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	Unit
†Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	V
†Non–Repetitive Peak Reverse Voltage (halfwave, single phase, 60 Hz)	V_{RSM}	60	120	240	480	720	1000	1200	V
†RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	V
†Average Rectified Forward Current (single phase, resistive load, 60 Hz, T_A = 75°C)	I_O	1.0							A
†Non–Repetitive Peak Surge Current (surge applied at rated load conditions)	I_{FSM}	30 (for 1 cycle)							A
Operating and Storage Junction Temperature Range	T_J T_{stg}	−65 to +175							°C

Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.
†Indicates JEDEC Registered Data

THERMAL CHARACTERISTICS

Rating	Symbol	Max	Unit
Maximum Thermal Resistance, Junction–to–Ambient	$R_{\theta JA}$	Note 1	°C/W

ELECTRICAL CHARACTERISTICS†

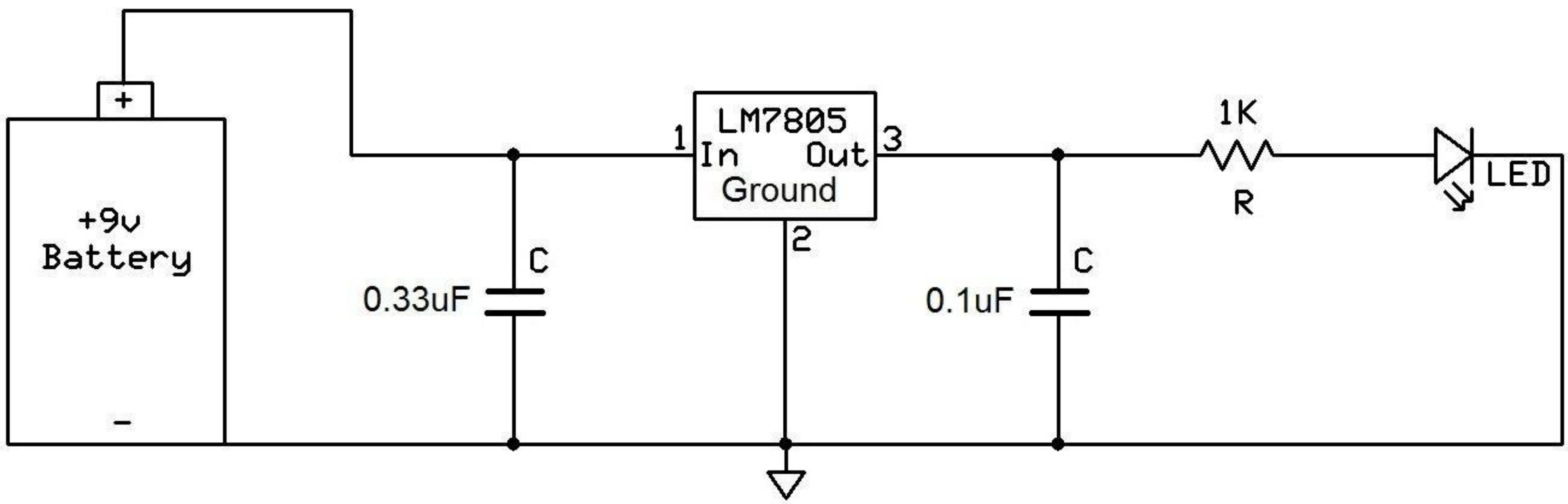
Rating	Symbol	Typ	Max	Unit
Maximum Instantaneous Forward Voltage Drop, (i_F = 1.0 Amp, T_J = 25°C)	v_F	0.93	1.1	V
Maximum Full–Cycle Average Forward Voltage Drop, (I_O = 1.0 Amp, T_L = 75°C, 1 inch leads)	$V_{F(AV)}$	–	0.8	V
Maximum Reverse Current (rated DC voltage) (T_J = 25°C) (T_J = 100°C)	I_R	 0.05 1.0	 10 50	μA
Maximum Full–Cycle Average Reverse Current, (I_O = 1.0 Amp, T_L = 75°C, 1 inch leads)	$I_{R(AV)}$	–	30	μA

Product parametric performance is indicated in the Electrical Characteristics for the listed test conditions, unless otherwise noted. Product performance may not be indicated by the Electrical Characteristics if operated under different conditions.
†Indicates JEDEC Registered Data

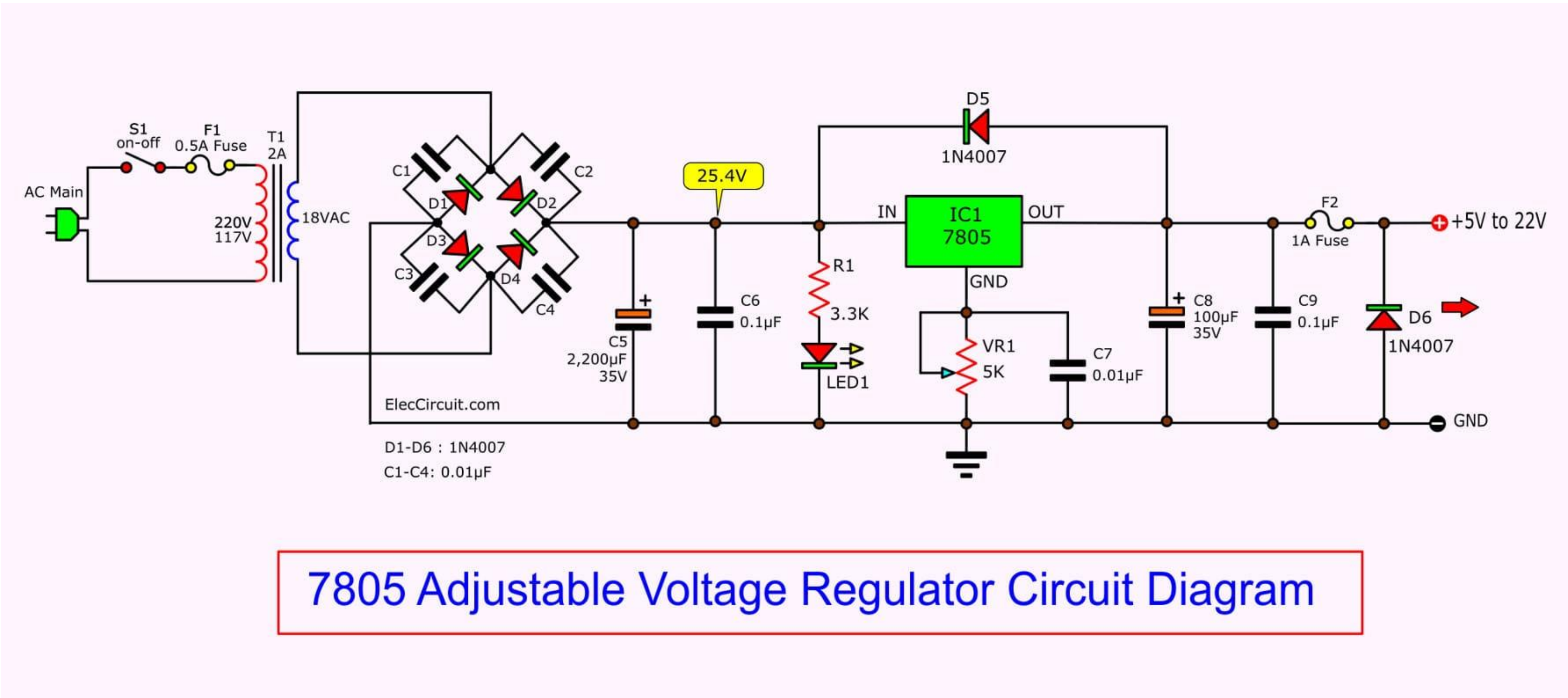
Part 4: Voltage Regulation

The 78xx Series Linear Regulators

The 78xx series linear regulators maintain voltage by opposing current like a resistor. They dissipate a lot of heat and always need a heat sink. They also need about 3V higher input voltage than the regulated output. They are very effective but not very efficient. The 7805 is a 5V chip, the 7833 is 3.3V, and so on. Here, 9VDC is regulated to 5. The two capacitors are by-pass caps like we used on our breadboards to trap high frequencies.



Part 5: Typical Switching Power Supply with All the Stages



- Notice capacitors across each rectifier diode to limit noise.
- C5 is the smoothing low-frequency filter and C6 catches high frequencies just like we did on our breadboard layouts. This is the **INPUT** filter.
- VR1 is a variable resistor to the output can be adjusted. C6 & C7 catch noise as the regulator chip switches on and off.
- C8 & C9 decouple (isolate) the regulator stage from the output stage to trap any left-over noise. This is called an **OUTPUT** filter.

Part 6: Buck/Boost Converters (DC-DC Regulation)

- Q1 is a MOSFET that acts as the regulator. The chip monitors input and output voltage and uses the duty cycle to manage the output voltage.
- L1 and C1 make up the low-pass input filter.
- L and C2 are the low-pass output filter components.
- R represents the LOAD or the thing we are powering.
- D1 conducts when Q1 is off. Energy stored in the capacitor flows downwards into the diode and into the coil (L) to keep power going to the load.
- When Q1 is on, the diode does not play any role because it is reversed biased. This is the same way we used a diode across a relay coil.
- In Fig 7-30, "B" shows how the circuit works when Q1 is turned on and "C" shows the equivalent circuit when Q1 is off.

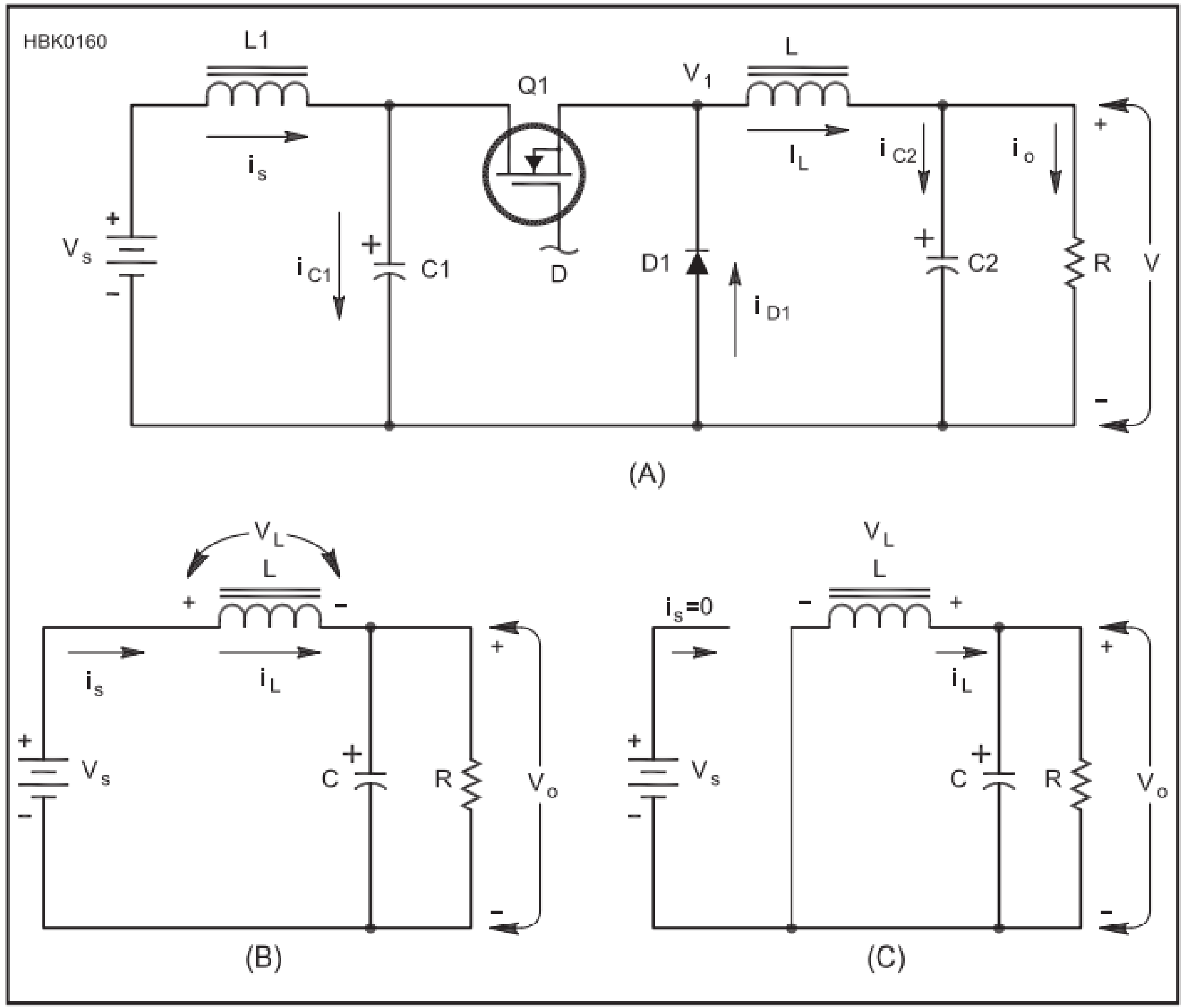


Fig 7.30 — Typical buck converter.

Buck Converter Non-Continous Mode Using Switching MOSET

Notice it uses PWM to control the output voltage

This is why it needs input and output filtering.

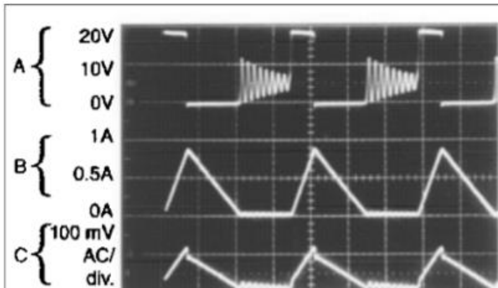
TEXAS INSTRUMENTS

LM2596

www.ti.com SNVS124E – NOVEMBER 1999 – REVISED FEBRUARY 2020

For surface mount designs, solid tantalum capacitors can be used, but exercise caution with regard to the capacitor surge current rating (see *Input Capacitor (C_{IN})* in this data sheet). The TPS series available from AVX, and the 593D series from Sprague are both surge current tested.

9.2.2.3 Application Curves



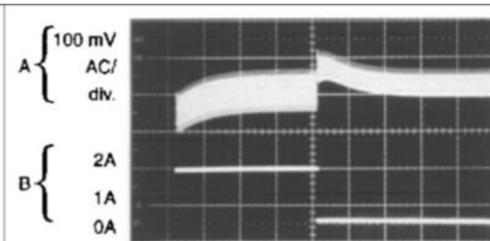
Discontinuous Mode Switching Waveforms V_{IN} = 20 V, V_{OUT} = 5 V, I_{LOAD} = 500 mA L = 10 µH, C_{OUT} = 330 µF, C_{OUT} ESR = 45 mΩ

A: Output Pin Voltage, 10 V/div.

B: Inductor Current 0.5 A/div.

C: Output Ripple Voltage, 100 mV/div.

Figure 36. Horizontal Time Base: 2 µs/div



Load Transient Response for Discontinuous Mode V_{IN} = 20 V, V_{OUT} = 5V, I_{LOAD} = 500 mA to 2 A, L = 10 µH, C_{OUT} = 330 µF, C_{OUT} ESR = 45 mΩ

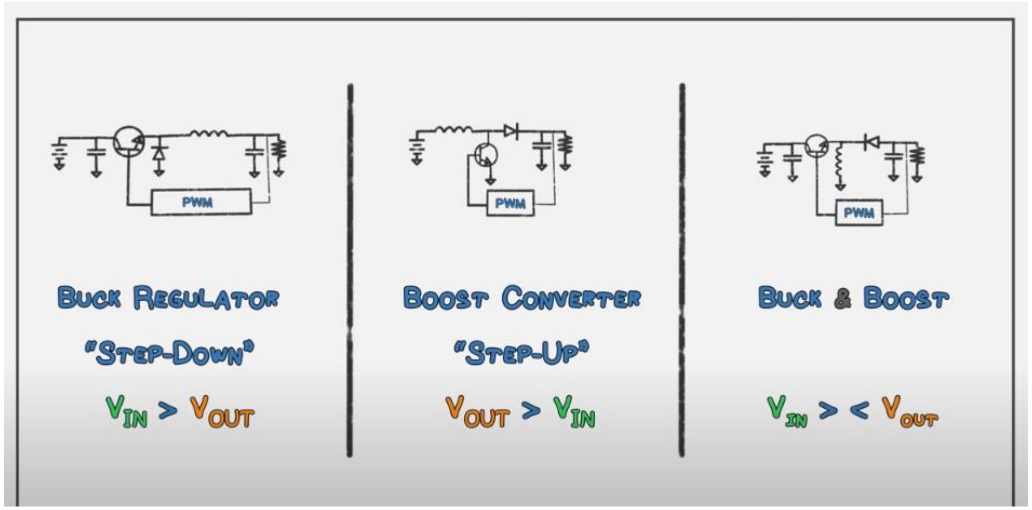
A: Output Voltage, 100 mV/div. (AC)

B: 500-mA to 2-A Load Pulse

Figure 37. Horizontal Time Base: 200 µs/div

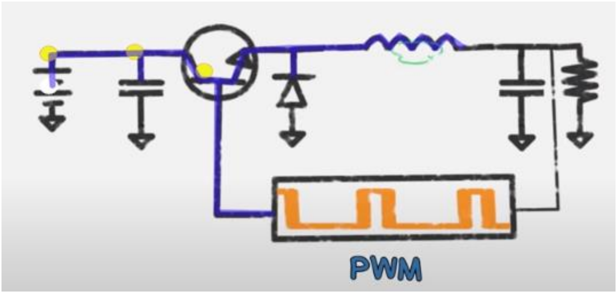
DC-DC CONVERTER SUMMARY

- The arrangement of the same components allows us to create three types of switching regulators.



Energy stored in the output inductor supplies the load with current and C2 removes ripple. The duty cycle is widened/narrowed to maintain just the right V_{OUT}.

- When voltage is too high, the duty cycle is reduced.



- On the other hand, when the voltage is too low the duty cycle is increased.