Inside the Power Supply

With the Desktop PC Supply as an Example

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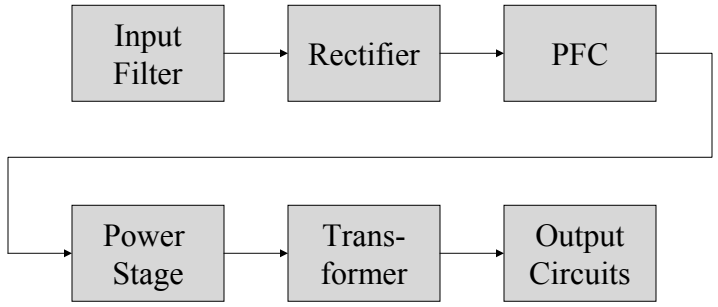
Outline

- Introduction, Technical Overview & Objectives
- Simplified Block Diagram
- Typical Specifications
- Regulatory Issues
- Functional Block Diagram
- Electronic Components
- Switched-Mode Basics
- Operation of Each Functional Block
- Inside the ATX12V Box
- Summary and Open Discussion

Simplified Block Diagram



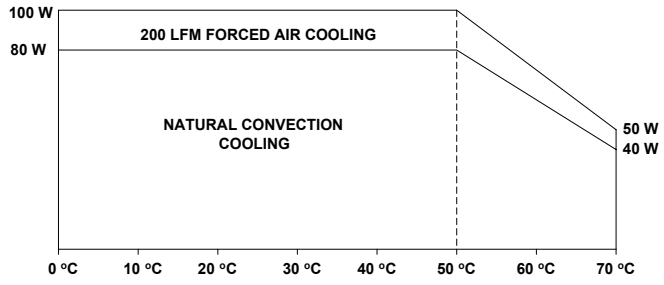
Specifications (Abbreviated)

- Input Voltage: 90 – 265 Vac, 47-63 Hz
- Input Current: 5 A maximum.
- Input Harmonics: Meets IEC1000-3-2 for all load conditions.
- Hold-up Time: 20 ms minimum.
- Inrush Current: Usually, must be less than the ratings of input components.
- Outputs (example of 250 W ATX power supply):

OUTPUT VOLTAGE (V)	OUTPUT CURRENT (A)		PEAK CURRENT (A)	RIPPLE & NOISE (mVpp)
	MIN.	MAX.		
+12	0	10	12	120
+5	0.3	25		50
+3.3	0.3	16		50
-5	0	0.3		100
-12	0	0.8		120
+5 SB	0	1.5	2.5	50

Specifications (cont'd.)
Some Power Supply Specs. Contain:

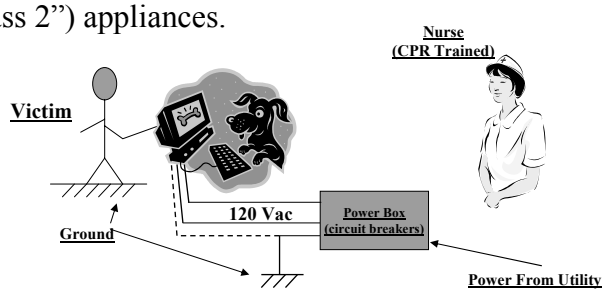
- Efficiency: 75% minimum at full load, 120 Vac input
- Temperature: Operating: See derating curve below
  - Storage -40 °C to +85 °C



Temperature Derating

Leakage Current

- Without insulation in the appliance, the user provides a path for the electrical current to return to ground! Even with insulation, some small *leakage current* flows.
- The dotted line shows the "third wire" ground, not present in 2-wire ("Class 2") appliances.



Safety Standards (Non-Medical)

- IEC950 (now IEC60950) and its derivatives (UL1950 --- now UL60950, CSA 22.2 No. 950)
- Primary-secondary spacings increase smoothly as voltage increases.
- Leakage current to "earth" (maximum limits, ac):
  - Double-insulated appliances: 250 uA
  - Grounded, hand-held products: 750 uA
  - Others: 3.5 mA
    - At 230 Vac, 60 Hz, this limits the total capacitance from line to ground to a value of $C = I / (2 \pi f V) = 0.04$ uF.
- Medical designs require larger spacings, lower leakage.

UL1950 (Cont'd.)

- Clearance: The shortest distance between two conductive parts, through air.
  - Depends on temperature, humidity and pollution level.
- Creepage: The shortest distance between two conductive parts, measured along the surface of the insulation.
  - Depends on temperature, humidity, pollution level, and the insulator's comparative tracking index (CTI).
- Typical practice in PC power supplies:
  - 4 mm spacing between primary conductors and safety ground.
  - 8 mm spacing between primary and secondary conductors.

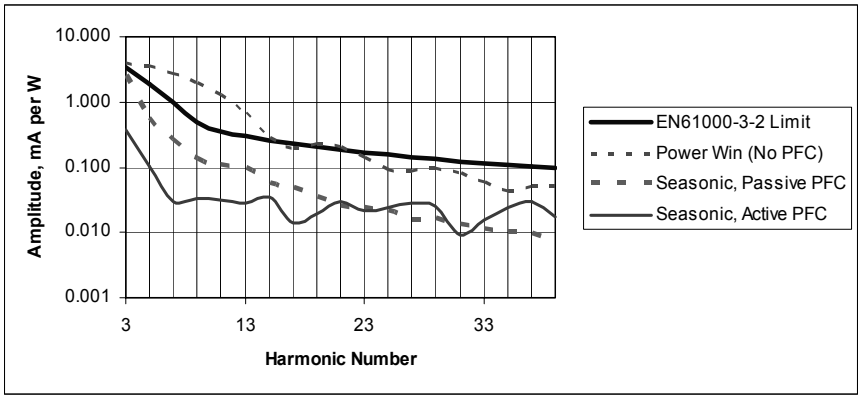
UL1950 (Cont'd.)

- Creepage distance is very important on circuit boards and in transformers.
  - Most insulation material on components, including the varnish on magnet wire, is not recognized as insulation. Therefore, the body of a resistor is considered an "uninsulated live part."
  - Inside a transformer that crosses the primary-to-secondary safety barrier, creepage distances force "margins" at the edges of windings, thereby increasing the size of the transformer.
  - Magnet wire is available with multi-layer Teflon or Kapton, which can be considered "insulated," but the wire is expensive.

UL1950 (Cont'd.)

- Ground bonding
  - Connection from the ground terminal to the chassis must be less than 0.1 ohm, measured with twice the rated current applied for 120 s.
- Component temperatures
  - Components, including transformer and inductor insulation systems, must operate within their ratings.
- Electric Strength (Hipot tests)
  - Primary-ground, primary-secondary: 1500 Vac
  - Secondary-ground: 500 Vac

Input Harmonics, per EN61000-3-2 (Class D)



- Without PFC, limits are exceeded.
- Passive PFC is almost at limit for 3rd harmonic.
- Note logarithmic scale for amplitude.

CISPR 22 Class B Limits
for
Conducted and Radiated Emissions

CISPR 22 Conducted Emissions Limits		
Frequency Range (MHz)	CISPR Class B Limit (dBuV) Quasi-Peak	Average
0.15 - 0.50	66-56	56-46
0.5 - 5	56	46
5 - 30	60	50

CISPR 22 Radiated Emissions Limits	
Frequency Range (MHz)	CISPR Class B Limit at 10 m (dBuV)
30 - 88	30
88 - 216	30
216 - 230	30
230 - 960	37
960 - 1000	37
Above 1000	-

The Energy Conservation Scene

- Standby Power Reduction
  - 25% of total energy consumption is in low power/sleep/standby mode
  - Concerted effort by CECP, Energy Star, IEA and other international agencies to limit standby power
- Active Mode Efficiency Improvement
  - 75% of total energy consumption is in active mode
  - Changing efficiency from 60% to 75% can result in 15% energy savings
- Power Factor Correction (or Harmonic Reduction)
  - Applicable with IEC 1000-3-2 (Europe, Japan)
  - Some efficiency specifications also require >0.9 PF

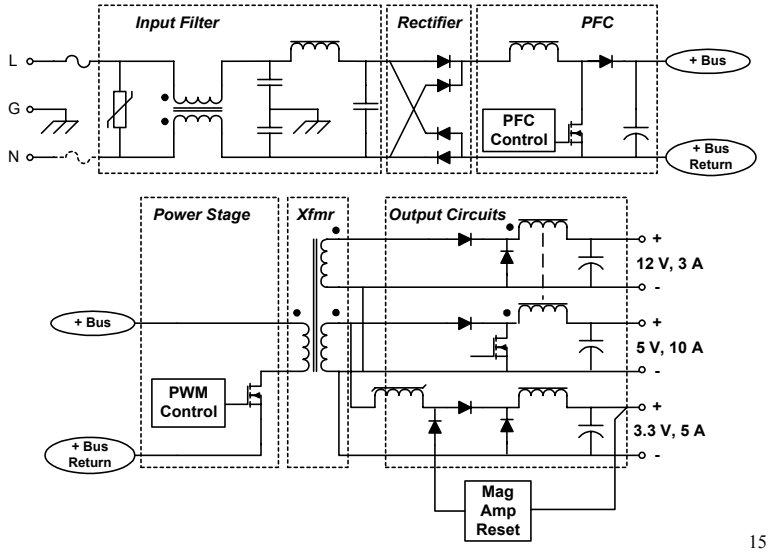
Active Efficiency Certification Programs

(External Power Supplies)

Code	Region/Country & Timing	Active Mode Efficiency
CUC1 **CE2**	CECP (China) & Energy Star (US) From January, 2005 (Tier 1) Europe (EC Code of Conduct) From January 1, 2007	≥0.49*Pno for 0-1 W ≥[0.09*Ln(Pno)]+0.49 for 1-49 W ≥0.84 for >49 W
CE1	Europe (EC Code of Conduct) From January 1, 2005	≥0.70 for 6-10 W ≥0.75 for 10-25 W ≥0.80 for 25-150 W
CUC2	CECP and Energy Star (Tier 2) From July, 2006	TBD (More stringent than Tier 1)
CA1	Australia (High Efficiency) From April, 2006	≥0.48*Pno for 0-1 W ≥[0.089*Ln(Pno)]+0.48 for 1-60 W ≥0.84 for >60 W

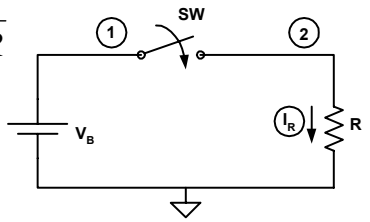
- Note: Pno is defined as the nameplate output power.

Functional Block Diagram



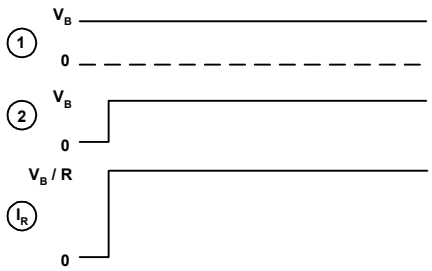
Resistor

Ohm's Law: $R = \frac{V}{I} \Rightarrow I = \frac{V}{R}$



- Where:
  - R = Resistance (ohms)
  - V = Voltage (volts)
  - I = Current (amperes)

$$I = \frac{dQ}{dT} = \frac{Q}{t}$$



- Where:
  - I = Current (amperes)
  - t = Time (seconds)
  - Q = Charge (coulombs)

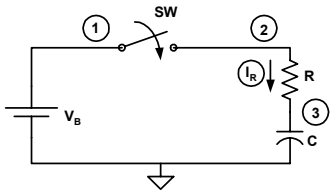
Capacitor

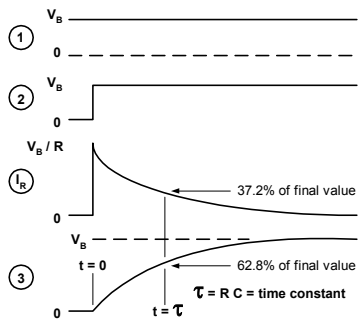
$$C = \frac{Q}{V} \quad \Rightarrow \quad V = \frac{Q}{C}$$

- Where:
  - C = Capacitance (farads)
  - Q = Charge (coulombs)
  - V = Voltage (volts)

$$Q = I \cdot t$$

- Where:
  - I = Current (amperes)
  - t = Time (seconds)
- So: <u>Voltage on a capacitor can't change instantaneously!</u>





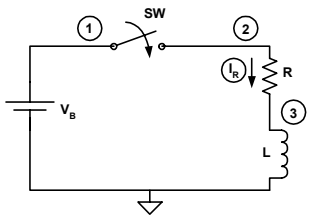
Inductor

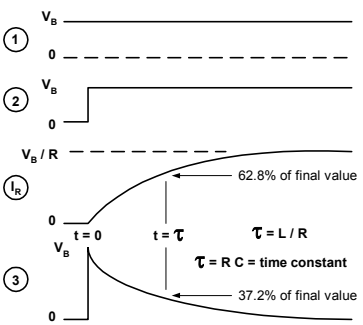
$$L = \frac{V}{dI/dt = rate\ of\ change\ of\ current}$$

- Where:
  - L = Inductance (henries)
  - I = Current (amperes)
  - t = Time (seconds)
  - dI/dt = I / t, if I is constant

$$\frac{dI}{dt} = \frac{V}{L}$$

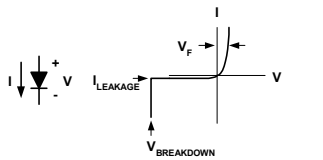
- So: <u>Current in an inductor can't change instantaneously!</u> (unless V is infinite or L is zero OR there are multiple windings or taps)!

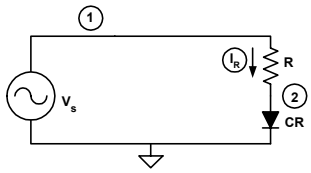


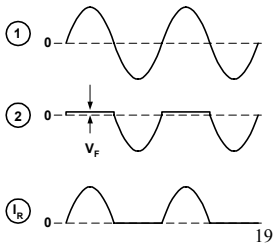


Diode

- Diode's purpose is to rectify (conduct current in only one direction).
- Nobody's perfect:
  - In the forward direction, there is a small voltage drop of 0.3 to 1.2 volts, depending on the material and amount of current.
  - In the reverse direction, there is a small "leakage" current of a few nanoamperes (silicon) to a few milliamperes (Schottky-barrier types).
  - FETs are sometimes used in place of diodes for lower forward voltage.

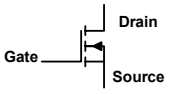


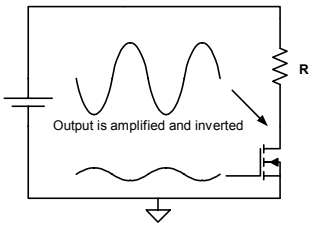


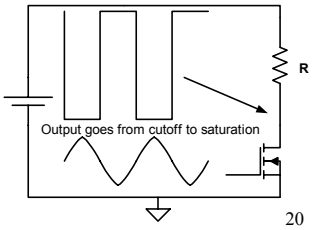


Field Effect Transistor (FET)

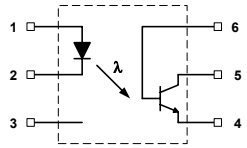
- A FET's primary purpose is to amplify.
- In the linear mode (as a linear amplifier), the output is a faithful replica of the input waveform.
- In the switched mode (operating as a switch), the output is driven from cutoff to saturation.
- Nobody's perfect.
  - While off, there's leakage current.
  - While on, there's the "on" resistance.
  - No matter how well you drive it, the turn-on and turn-off times aren't zero.
  - There's capacitance from each terminal to the others, and it must be charged and discharged every time the FET is switched.

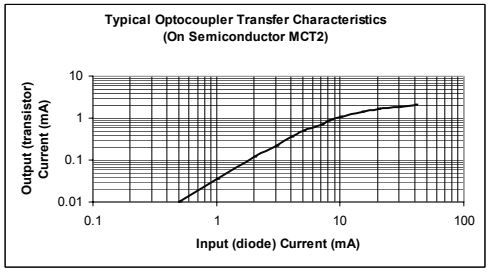






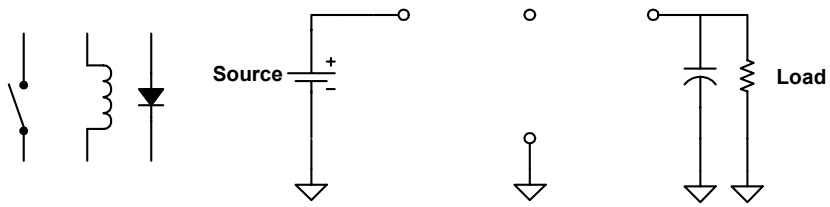
Optocouplers/Optoisolators





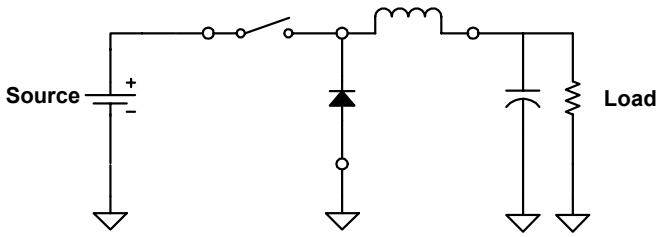
- Optocouplers (synonymously optoisolators) couple a signal across an isolation barrier. Current in the diode causes it to emit light, which falls on the transistor and causes it to conduct.
- Optocouplers provide a high degree of electrical isolation from the "mains" (primary side) to the output circuits. Most are rated to withstand 7500 volts peak.

Basic Switched-Mode Toolkit



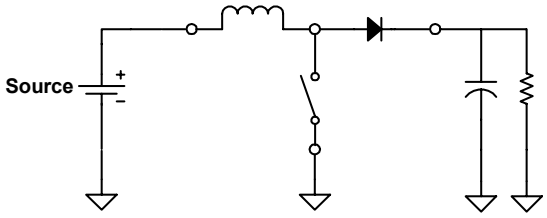
- By arranging the three elements, one can build each of the three most fundamental switched-mode converter topologies.

Buck Converter



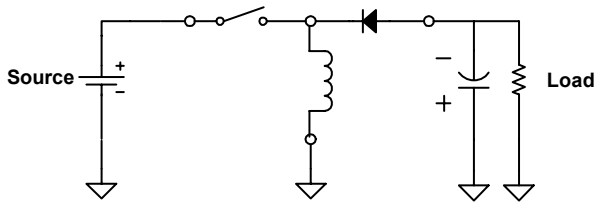
- Output must be less than the input.
- Input current is discontinuous; output current is smooth.

Boost Converter



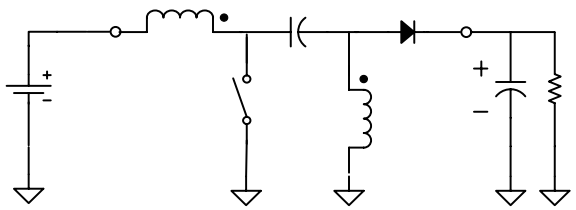
- Output must be greater than the input.
- Input current is smooth; output is discontinuous.

Buck-Boost Converter



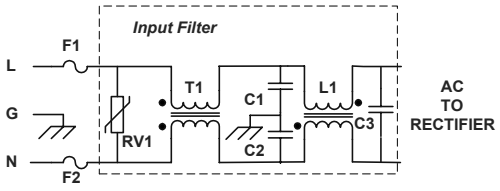
- Output is inverted from the input.
- Magnitude of the output can be less or greater than the input. Both the input and output currents are discontinuous.
- By substituting a transformer (two windings) this becomes a flyback.

Single-Ended Primary Inductance Converter (SEPIC)



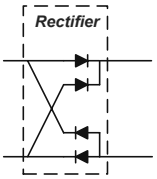
- An inductor has been added, but it can be combined with the first to form a single inductor with two windings.
- + The input can be above or below the output.
- - All energy passes through a capacitor.

Input Filter



- F1 Usual input fuse
- F2 2nd fuse for medical
- RV1 MOV transient suppressor
- T1 Common-mode choke
- C1, C2 "Y" capacitors (1 nF)
- C3 "X" capacitor (1 uF)

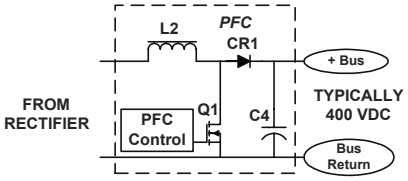
Input Rectifier



- Fairly simple when used with a PFC stage, due to good current waveshape
- Current rating of the bridge is just the input current of the power supply.
- Diodes tend to "snap off" when there is no PFC stage, since they turn off abruptly at the end of each charging peak. With PFC, the current decreases sinusoidally to zero at the end of each half cycle of the input voltage.

PFC Stage

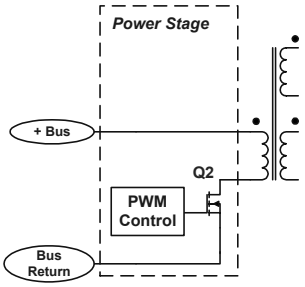
- Boost topology is by far the most popular.
  - Continuous input current
  - High output voltage for efficient energy storage (holdup time)



- Two popular types of boost converters:
  - Continuous conduction mode
    - Ripple current in L2 is small
  - Critical conduction (or "transition") mode
    - Ripple current in L2 is huge; peaks are 2x the sine shape
    - Controller ICs are simple and cheap, but the inductor design can be a serious challenge.

Power Stage

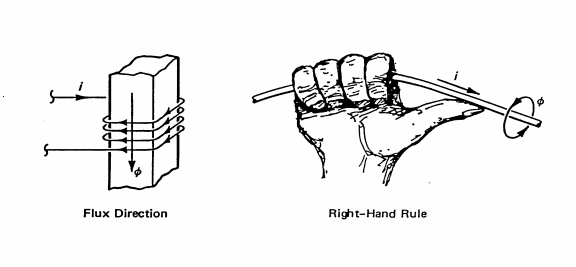
- Single-ended forward converter
- There are many variations:
  - Clamped reset (another pri. wdg.)
  - Resonant reset
- Control types
  - Current-mode control
  - Voltage-mode control
  - Hysteretic (variable freq.)
  - And more…



Other Popular Topologies

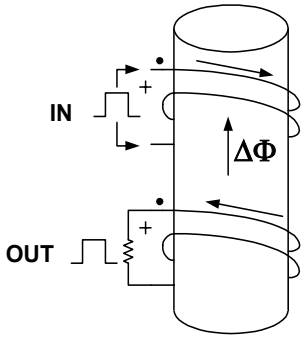
- Flyback
- Single-Transistor Forward
- Two-Transistor Forward
- Half-Bridge
- Full-Bridge
- Push-Pull
- All are transformer-coupled, so here are the fundamentals…

Right-Hand Rule



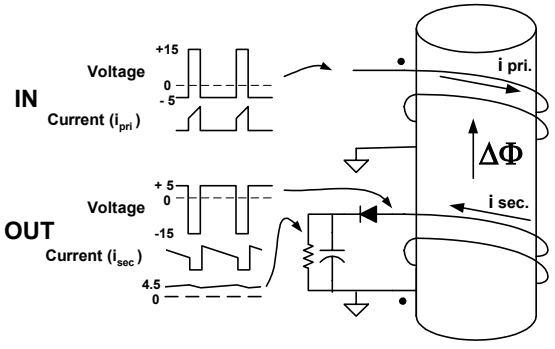
- According to Ampere's Law, current causes a magnetic field. Its direction is easily remembered via the "right-hand rule."

Transformer (No Energy Storage)



- Ampere-turns of all windings sum to zero.
  - Right-hand rule applies to the applied current and the resulting flux. The opposite occurs on the output winding.

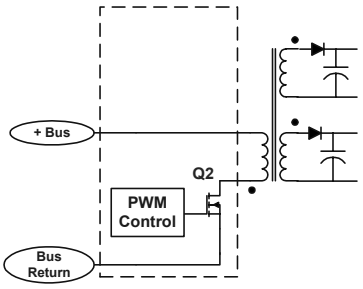
Transformer (Energy Storage)



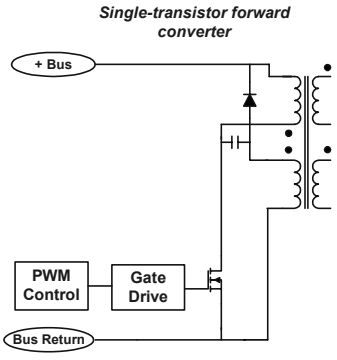
- This is a conventional flyback transformer.
- Energy is delivered to the magnetic core during the positive pulse applied to the primary.
- Energy is transferred from the core to the load during the remaining portion of the cycle.
- Ampere-turns of all windings still sum to zero over each cycle.

Flyback

- Transformer stores energy
  - Designed like an inductor
  - Causes it to be larger
  - Really an "integrated magnetic," because it combines the transformer and inductor functions in one core

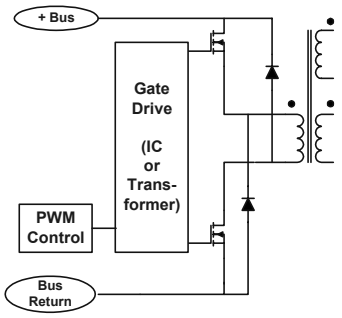


Single-Transistor Forward



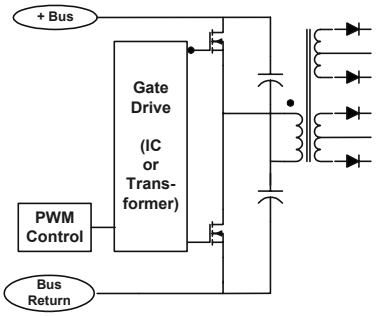
- With equal turns on both primary windings, the FET drain and diode anode move together. Adding the capacitor between them eliminates the decoupling due to leakage inductance.

Two-Transistor Forward



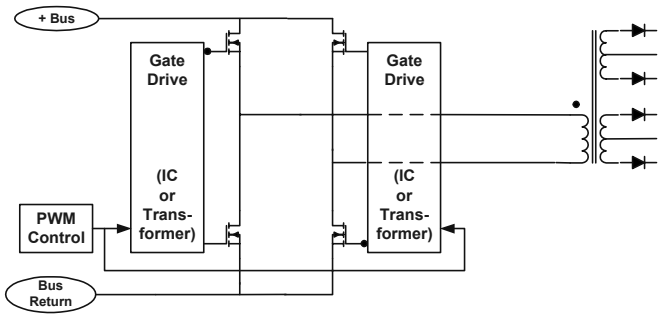
- Although there are two FETs, the circuit is desirable, because the maximum voltage on either one is never more than the input bus voltage.

Half Bridge



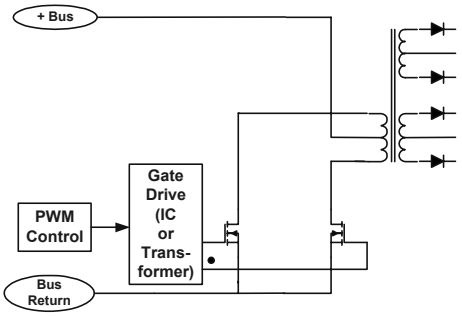
- Maximum voltage on each FET is the bus voltage.
- Major advantage is in the transformer. It can be smaller, since it transfers energy on both half-cycles.

Full-Bridge



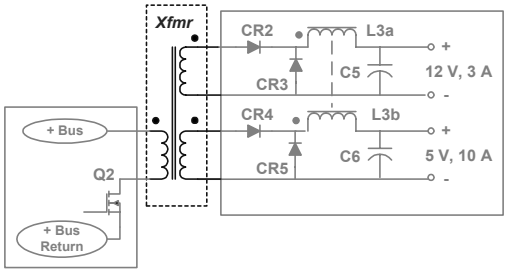
- Compared to a half-bridge, each FET operates at the same voltage (+Bus), but half the current.
  - Good for FETs, where loss is proportional to I^2.
  - Therefore, power handling capability is higher.

Push-Pull



- Another full-wave topology, but this one's FETs are subjected to twice the bus voltage.

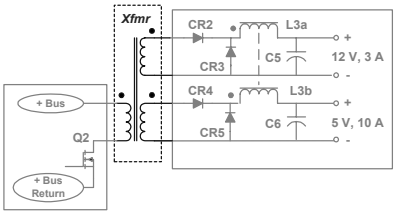
Transformer



- In forward converters, as in most topologies, the transformer simply transmits energy from primary to secondary, with no intent of energy storage.
- Core area must support the flux, and window area must accommodate the current. => Area product.

Transformer (cont'd)

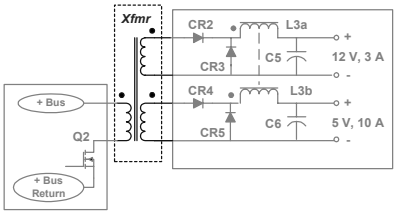
- Note the polarity dots.
  - Outputs conduct while Q2 is on.
  - Secondary Vpeaks = +Bus • Ns/Np



- With output chokes in continuous conduction, each output voltage is the average of its secondary voltage (neglecting diode drops).
- Therefore, each output voltage is its secondary peak voltage times the duty ratio of the primary bus voltage, +Bus, (neglecting diode drops and Q2's ON voltage).

Transformer (cont'd)

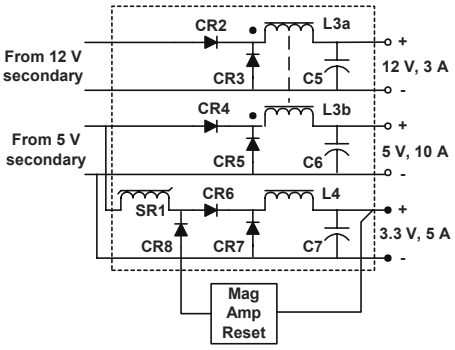
- Note the coupled output choke, L3.
  - Windings must have same turns ratios as transformer, which is the same as output voltages plus diode drops of CR3 and CR5.



- With output chokes in continuous conduction, each output voltage is the <u>average</u> of its secondary voltage (neglecting diode drops).
- Therefore, each output voltage is its secondary peak voltage times the duty ratio of the primary bus voltage, +Bus, (neglecting diode drops and Q2's conduction voltage).

Output Circuits

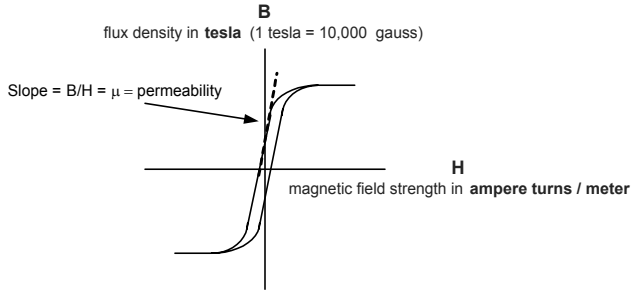
- Popular configuration for these voltages---two secondaries, with a lower voltage output derived from the 5 V output using a mag amp postregulator.



- Feedback to primary PWM is usually from the 5 V output, leaving the +12 V output quasi-regulated.

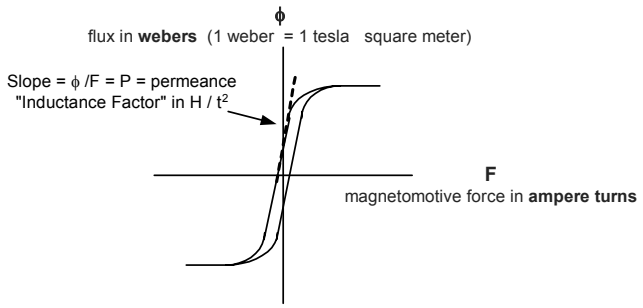
Review of Some Magnetic Concepts

Material Characteristics



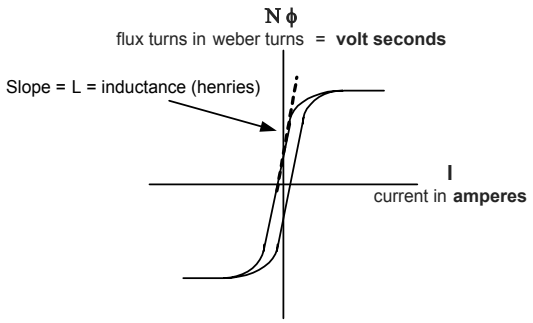
- Bulk property of the material
- $H = NI/l_e$ = ampere · turns per meter
  - Classic definition is amperes per meter (assumes only one turn)
  - l_e = magnetic path length
- μ = permeability, usually relative to air ($\mu_{air} = 4 \cdot \pi \cdot 10^{-7}$ H/m)

Core Characteristics



- Core with no winding (but has physical size).
- Material characteristics, with A_e and l_e added.
  - A_e = core area, l_e = effective magnetic path length
  - Common unit for the slope is "Inductance Factor," usually given in nH / t^2

Wound Coil Characteristics



- Using volt-seconds and amperes, the wound component can be analyzed easily by circuit engineers using time-domain analysis.

The "Transformer Equation"

$$\frac{E}{N} = 4B \cdot A_e \cdot f$$

- Bmax in tesla, Ae in m^2, f in Hz
  - Modern SI units
- OR:

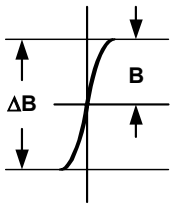
$$\frac{E}{N} = 4B \cdot A_e \cdot f \cdot 10^{-8}$$

- Bmax in gauss, Ae in cm^2, f in Hz
  - Medieval cgs units
- Where did this mess come from, anyway?

Watch closely, now:

Transformer Equation from Faraday's Law

$$E = N\frac{\Delta\Phi}{\Delta t}$$



$$\Phi = B \cdot A_e \qquad \Delta\Phi = \Delta B \cdot A_e = 2B \cdot A_e$$

$$\Delta t = \frac{1}{2}T = \frac{1}{2} \cdot \frac{1}{f}$$

Finally: $$\frac{E}{N} = \frac{\Delta\Phi}{\Delta t} = 2B \cdot A_e \cdot \frac{1}{\frac{1}{2f}} = 4B \cdot A_e \cdot f$$

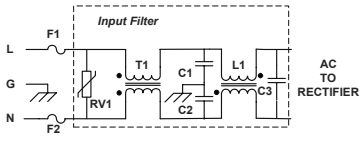
An Extremely Important Fact

$$\frac{E}{N} = \frac{\Delta\Phi}{\Delta t} = 4B \cdot A_e \cdot f$$

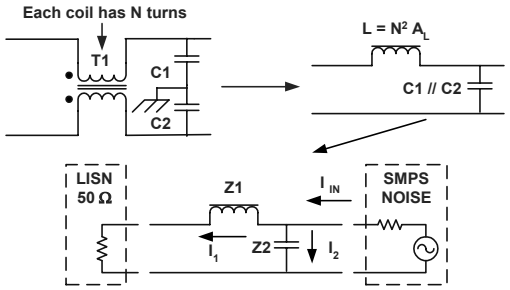
- Unless the flux is changing, there will be no voltage.
- If the flux swings back and forth, so will the voltage.
- In order for there to be a net dc voltage, the flux must be continually increasing.
- Therefore, our chances of inventing a magnetic rectifier are ZERO.
- The average voltage (dc) across a winding (neglecting winding resistance) is ALWAYS ZERO. This is one of the most useful facts in our bag of tools.

Input Filter Design

- Beginning at the input (left) side:
  - F2 required for many medical designs
- RV1 is an MOV transient suppressor
- T1 design follows:
- T1 is the common-mode inductor (note the polarity marks)
- Theoretically, no amount of input current should saturate it, because the ampere-turns cancel. Not entirely true!
  - Coupling isn't perfect, so expect around 1% leakage inductance (depends on the winding structure).
- C1 and C2 are the capacitors to ground ("Y" capacitors), and their value is limited by the allowable input leakage current per the safety standard for the product.



Common-Mode Filter Section

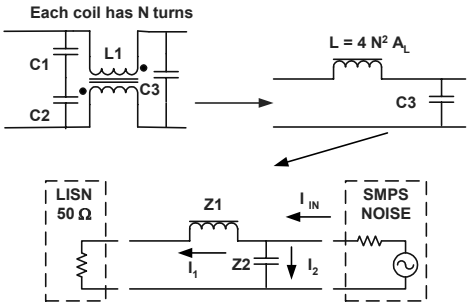


- View this as a single-stage LC filter
  - Noise current will divide per Z_1 & Z_2
  - Z_2 is constrained by allowable leakage current

$$\frac{I_1}{I_2} = \frac{Z_2}{Z_1}$$

(assumes $Z_1 >> Z_2$)

Differential-Mode Filter Section



- As before, view this as a single-stage LC filter
  - Noise current will divide:
    - (assumes $Z_1 >> Z_2$)
  - Z_2 is not constrained by allowable leakage current.

Power Factor Correction

- Power Factor (PF) is a term describing the input characteristic of an electrical appliance that is powered by alternating current (ac).
- It is the ratio of "real power" to "apparent power" or:

$$PF = \frac{P_{\text{real}}}{P_{\text{apparent}}} = \frac{(v \cdot i)_{\text{averaged over one cycle}}}{V_{\text{rms}} \cdot I_{\text{rms}}}$$

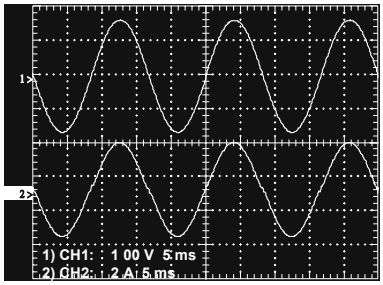
- Where *v* and *i* are instantaneous values of voltage and current, and rms indicates the root-mean-squared value of the voltage or current. The apparent power (Vrms x Irms), in effect, limits the available output power.

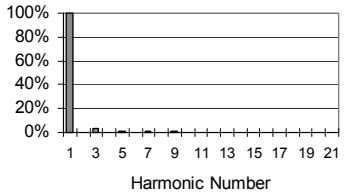
What About IEC 1000-3-2?

- It applies in most European countries (CENELEC members), and was modified in January, 2001, by Amendment 14.
- It poses limits on the harmonic content of input current of various classes of electrical equipment with input power of 75 W or greater.
- Class D, which contains stringent limits for low-power equipment (75 W and greater) no longer applies to anything except personal computers, monitors, and TV receivers, per Amendment 14. This is good news for many manufacturers!
- Most of our applications are regulated by Class A, which applies between 75 W and 16 A. Its limits are fixed, with the values that applied in Class D at 600 W. Below 600 W, we're getting a break!
- *Bottom line: It may turn out that non-PFC-input power supplies are now in conformance, where in the past they weren't.*

Power Factor Correction

- Ideally, power factor is 1.00; the input current waveshape (lower trace) matches the voltage waveshape (upper trace) and is in phase with it (not displaced to the left or right).

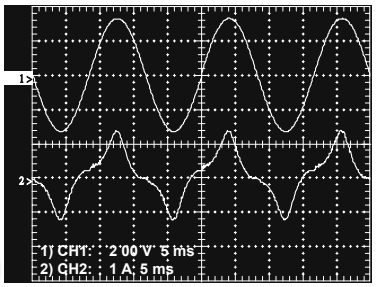


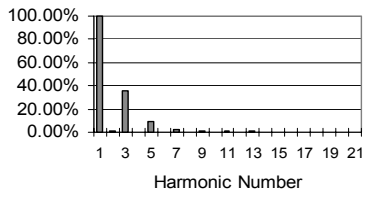


Also, the input current harmonics are near zero (harmonic #1 is the Fundamental frequency).

Power Factor Correction

- In order to meet international standards, and from a practical standpoint, it isn't necessary to do a perfect job of shaping the input current. "Quasi PFC" (found in some present products in the 60 to 120 watt range) meets the standards without the cost of near-perfect PFC.

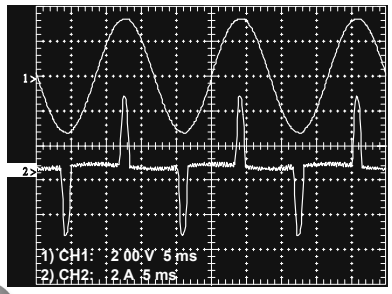


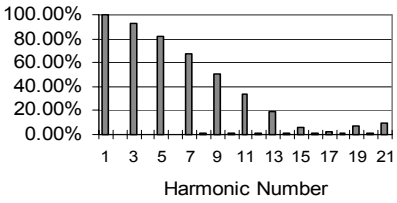


Here, the 3rd and 5th harmonics are noticeable, but well within limits.

Power Factor Correction

- Here's the input current of a power supply without PFC. The current is concentrated at the peak of the voltage waveform, where the input rectifier conducts to charge the input energy-storage capacitor.

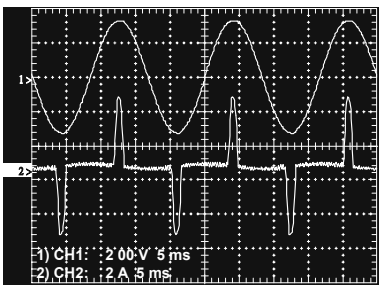




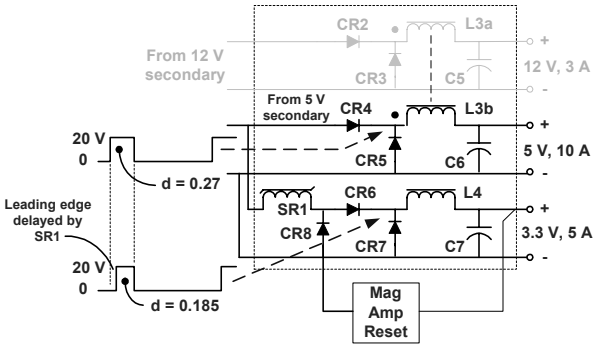
In this case the harmonics are huge, because much of the power is concentrated in a short period of time in each cycle.

Power Factor Correction

- The rms value of this current is much higher than that of a pure sine wave with the same average value, due to the instantaneous value for each small element is squared before the result is averaged and the square root is taken. The rms value is what heats up the wiring to the power supply and is what the power generation plant must be designed for.
- Because power factor and input harmonics are closely related, the harmonic content is a common way to express these limits. The power factor of this power supply is about 0.6. This is acceptable in low-power applications.

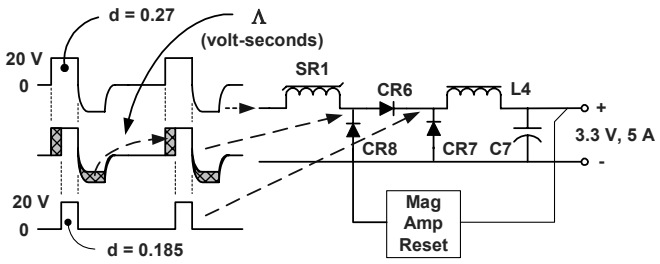


The Mag Amp Output



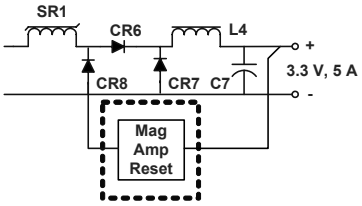
- Saturable reactor SR1 has very high impedance until it saturates; then it is practically a short circuit.
- The time it takes to saturate after the input pulse is applied depends on the amount of reset volt-seconds applied during the previous half-cycle.

More Details of the Mag Amp



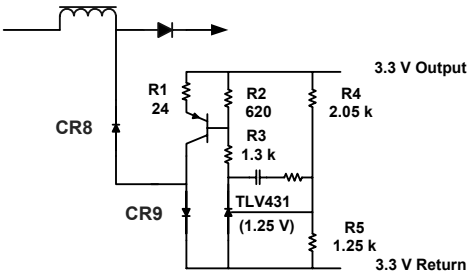
- The mag amp reset circuit compares the output to a reference, then delivers current (or voltage) to SR1 via CR8.
- The reset current "pulls up" on the output side of SR1, inducing a reset voltage across it. This voltage, multiplied by the width of the negative pulse, is the volt-second reset, Λ (lambda), that is blocked at the beginning of the next pulse.

The Reset Circuit



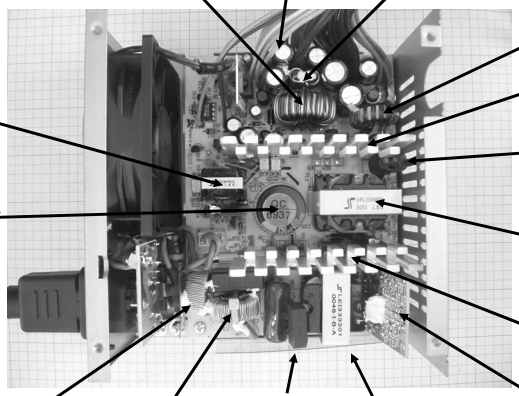
- The reset circuit can provide either voltage reset or current reset. The only difference is the output of the reset block, either a voltage source or a current source (most popular and easiest to implement).
- This example shows reset being accomplished on the only winding of the reactor. However, an additional winding can be used for reset. This allows many other circuit configurations.

Reset Circuit (cont'd.)

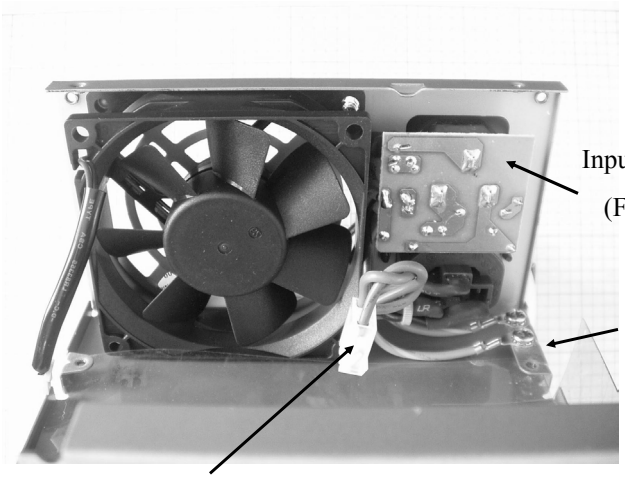


- These are typical circuit values of the reset circuit.
- The purpose of CR9 is to keep the reset transistor from saturating when CR8 is not conducting.
- R24 is added to make the circuit more independent of the transistor characteristics.

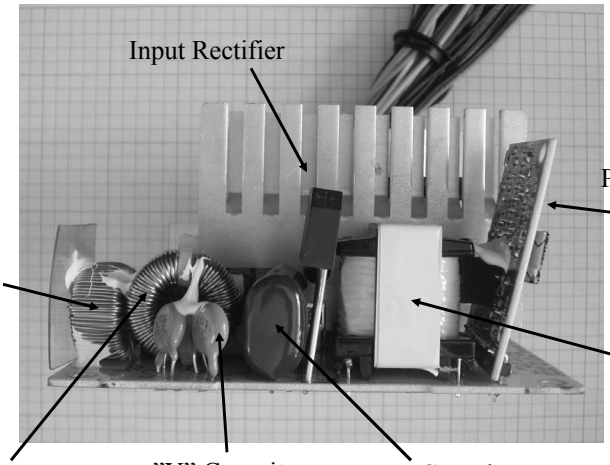
Typical PS With Active PFC



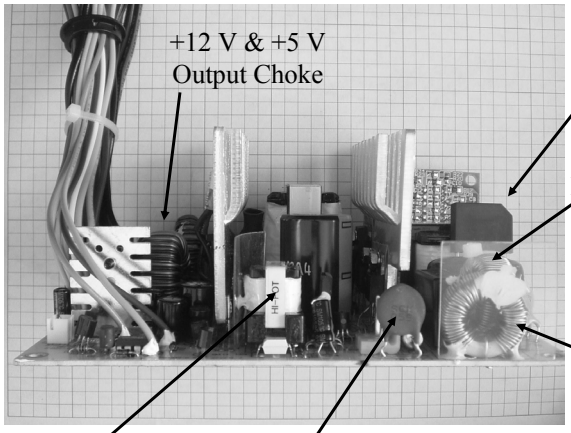
Fan & Input Filter



EMI Filter, Rectifier, PFC Choke

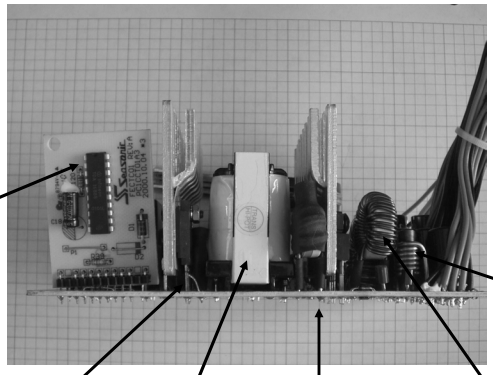


Side View
Bias Transformer in Front

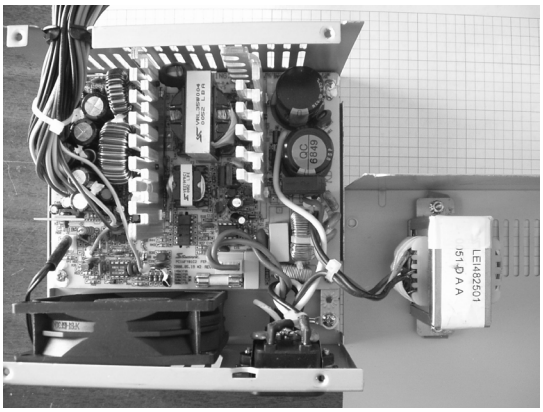


Side View

PFC & PFC Controller at Left
Main Transformer in Center

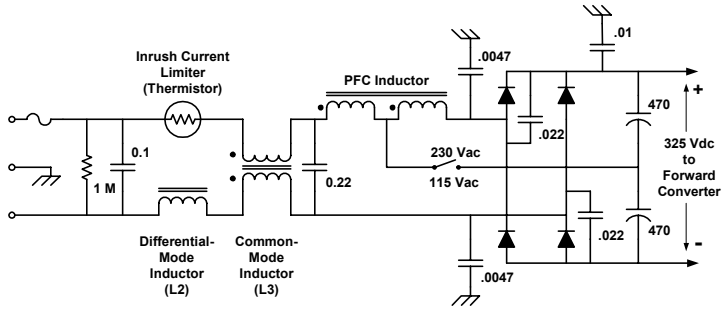


Passive PFC



- Here, the PFC circuit has been replaced by a line-frequency inductor. It's big, heavy, and cheap.

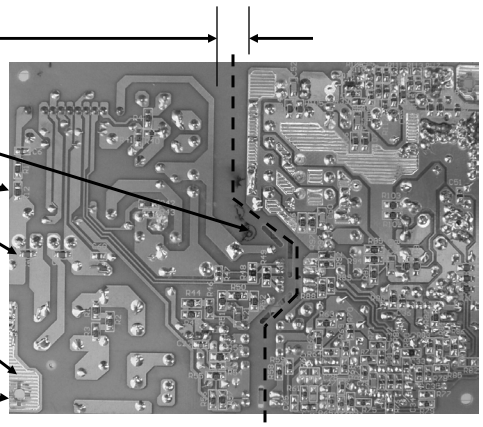
Passive PFC Circuit Details



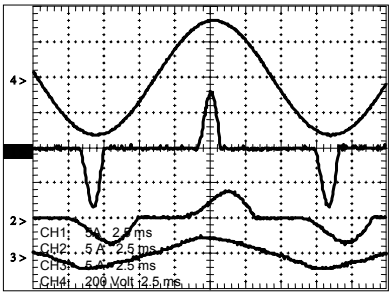
- PFC inductor smoothes the input current, reducing harmonics.
- On the 115 Vac range the right side of the PFC inductor and the left side of the bridge rectifier carry no current, and the right side of the bridge functions as a half-wave doubler to produce 325 Vdc.
- On the 230 Vac range the entire PFC inductor conducts, and the four-diode bridge functions as a full-wave rectifier, again producing 325 Vdc.

Printed Wiring Board (PWB)
Typical ATX supply with Active PFC

- Primary-Secondary Safety spacing (8 mm).
- Slots to increase creepage distance.
- Surface-mount resistors
- Surface-mount capacitors
- Copper reinforced with solder to carry more current.
- Chassis ground connection (here and at opposite corner).

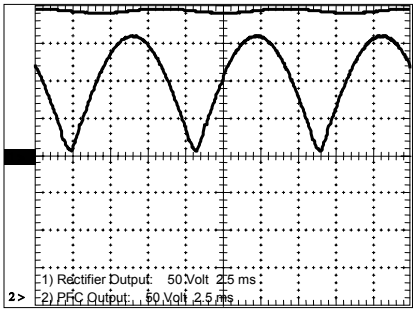


Input Current Shaping



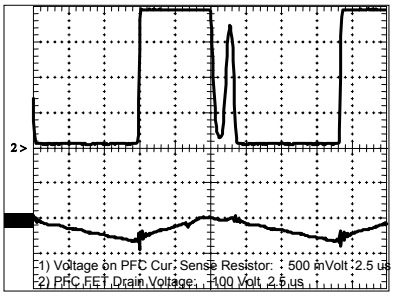
- Top (Ch 4): Input voltage, 230 Vac (325 Vpk)
- Ch 1: Input current, Power Win (no PFC)
- Ch 2: Input current, Seasonic with passive PFC
- Ch 3. Input current, Seasonic with active PFC

Boost PFC Circuit Performance



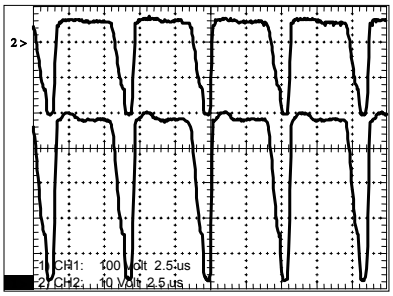
- Rectifier output is fed to the input of the PFC Inductor.
- Output (380 Vdc) is fed to the power converter.
- Note minor ripple on the 380 V at 120 Hz.

PFC Voltage and Current



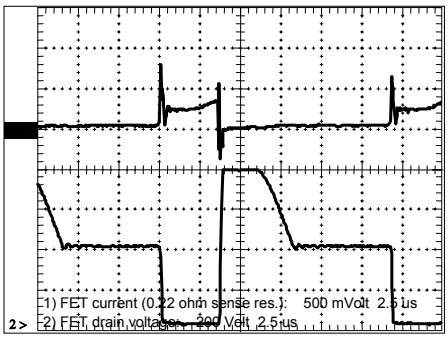
- Upper trace shows PFC boost FET voltage.
- Lower trace is current in return (same as current in the PFC inductor). Downslope indicates increasing current, due to the polarity of sensing.

Standby Power Converter



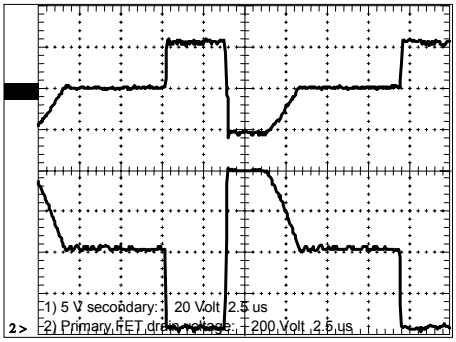
- Ch. 1 (lower trace) is FET drain voltage.
- Ch. 2 (upper trace) is secondary waveform.
- This is a flyback converter to provide +5 VSB @ 1.5 A.
  - When FET is on (voltage is near zero), Secondary is off. When FET is off, secondary is approx. +6 V.

Main Converter FET Waveforms



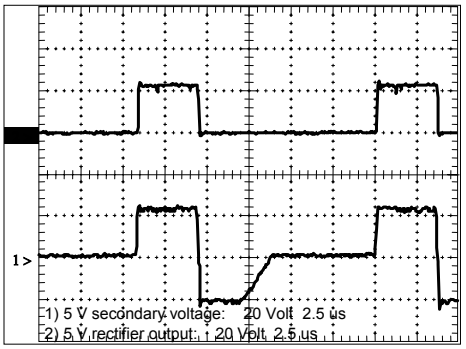
- Top trace is FET current, measured across the 0.22 ohm source resistor.
- Lower trace is the FET drain voltage at 200 V/div.
- This is a single-FET forward converter.

Main Converter Waveforms



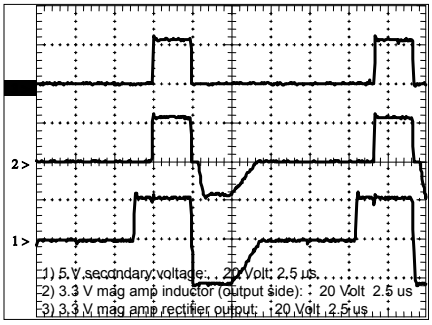
- Operation of the forward converter transformer:
  - Lower trace is FET drain voltage (800 V peak).
  - Upper trace is 5 V secondary (approx. 22 V peak).

5 V Rectifier Waveforms



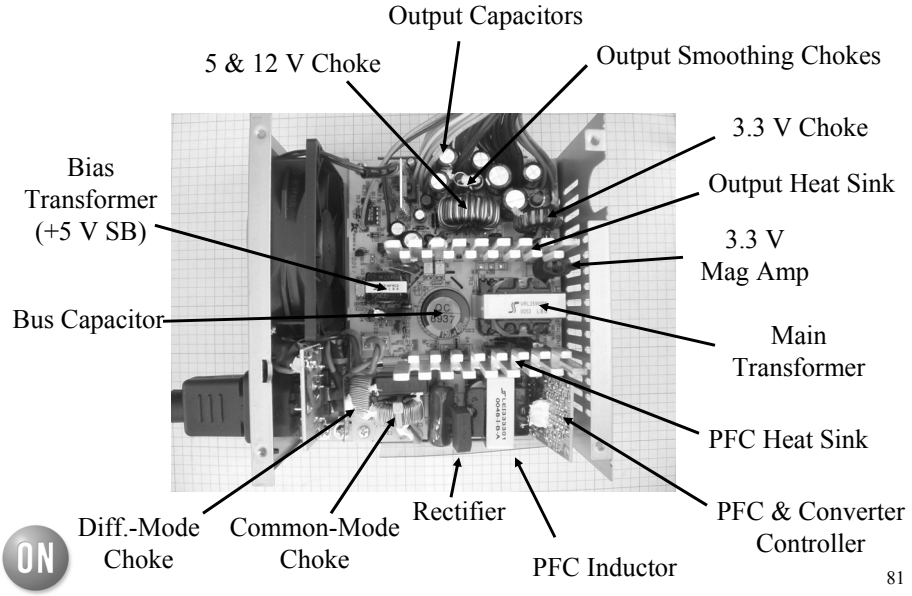
- Lower trace is the secondary voltage, appearing at the input to the series rectifier diode.
- Upper trace is at the diodes' cathodes (input to the filter inductor). The average of this waveform is 5 Vdc.

3.3 V Mag Amp Waveforms



- Lower trace is the 5 V secondary. This is connected to the input of the 3.3 V mag amp.
- Center trace is the output side of the mag amp. Note the reduced negative amplitude, due to the applied reset.
- Top trace is the output of the 3.3 V rectifier. Average is 3.3 Vdc.

Review (PS With Active PFC)



I hope you've enjoyed

***Inside the Power Supply*!**

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