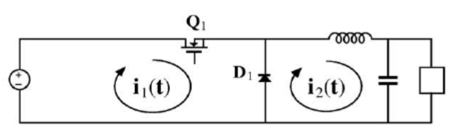
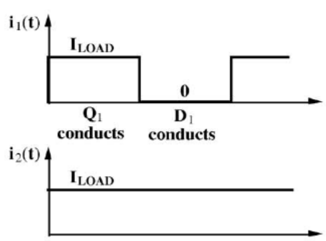
# FURTHER TOPICS IN POWER ELECTRONICS



## Practical Issues in PE: Parasitics

Use loop analysis




switched input current $i_1(t)$ contains large high frequency harmonics

—hence inductance of input loop is critical

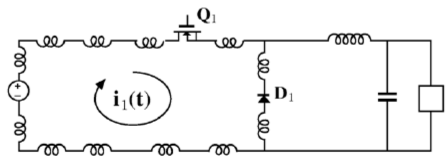
inductance causes ringing, voltage spikes, switching loss, generation of B- and E-fields, radiated EMI

the second loop contains a filter inductor, and hence its current $i_2(t)$ is nearly dc

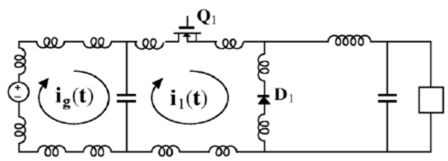
—hence additional inductance is not a significant problem in the second loop

# Decoupling

Parasitic inductances of input loop explicitly shown:

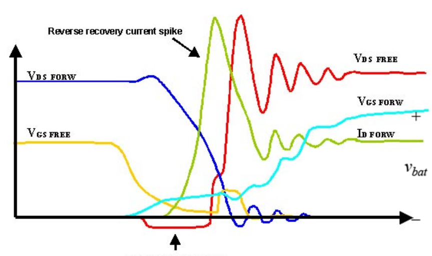


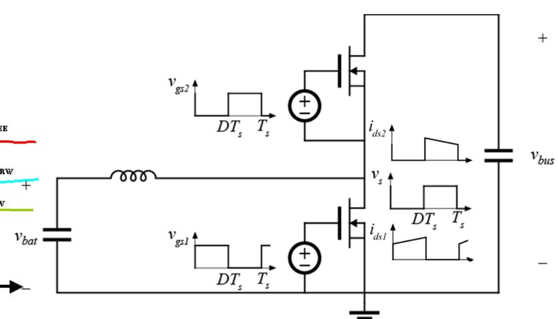

Addition of bypass capacitor confines the pulsating current to a smaller loop:



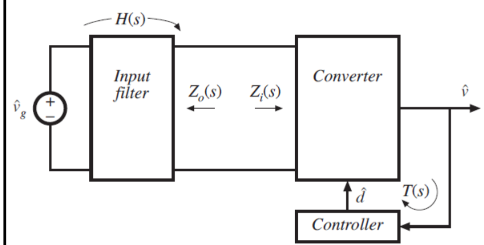

high frequency currents are shunted through capacitor instead of input source

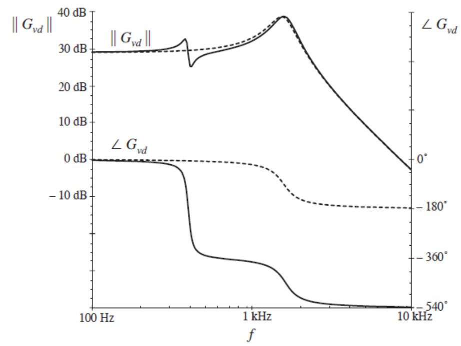
# Real Switching Waveforms



# Input Filter Design

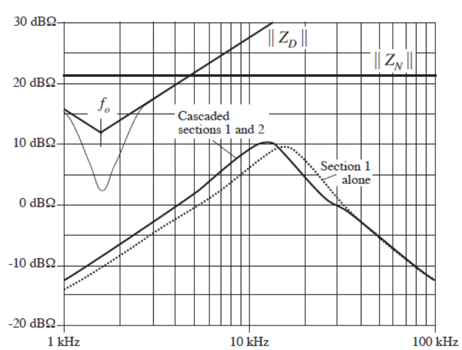


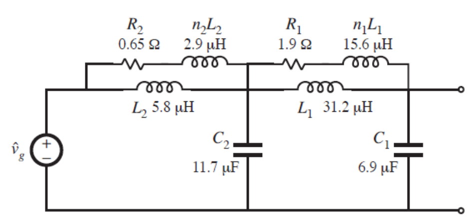

- Filter can seriously degrade converter control system behavior
- Use extra element theorem to derive conditions which ensure that converter dynamics are not affected by input filter
- Must design input filter having adequate damping

# Damped Input Filters

*Design criteria derived via Extra Element theorem:*



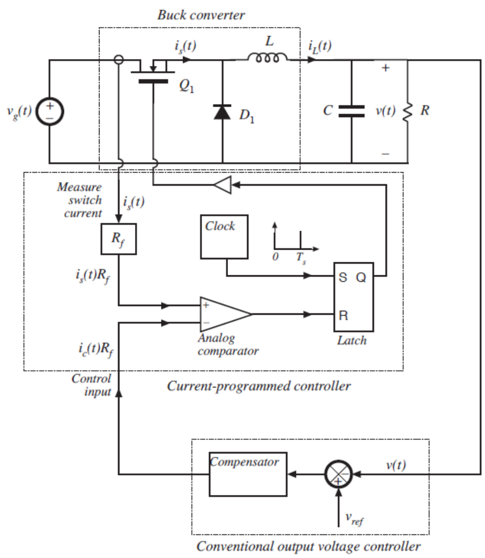

*Two-section damped input filter design:*



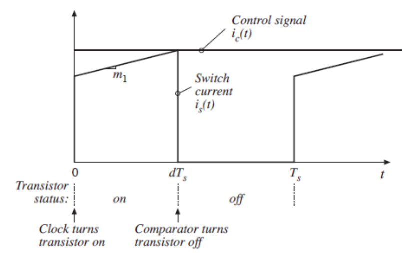

$$\left\| Z(j\omega) \right\| \gg \left\| Z_N(j\omega) \right\|$$

$$\left\| Z(j\omega) \right\| \gg \left\| Z_D(j\omega) \right\|$$

# Current Programmed Control




- Chapter 12
- A very popular method for controlling PWM converters
- Transistor turns off when its current $i_s(t)$ is equal to the control input $i_c(t)$
- Simpler dynamics, more robust compensator

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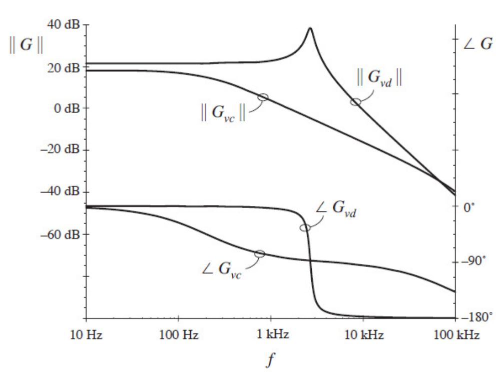
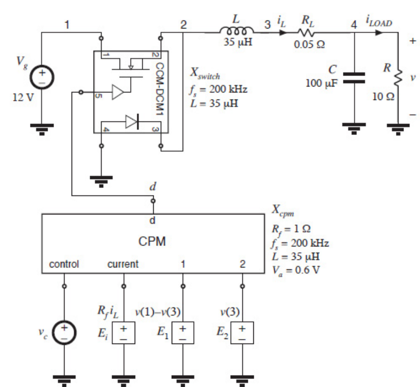
# Buck Converter With CPM

*Comparison of control-to-output transfer functions*




*Averaged switch model used in PSPICE simulations*

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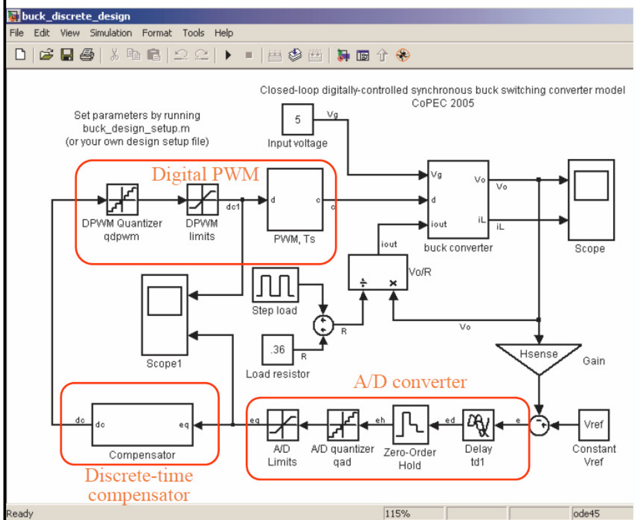
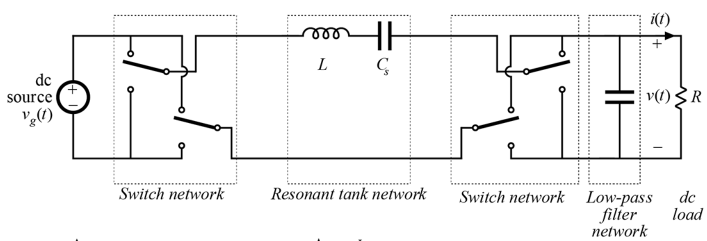
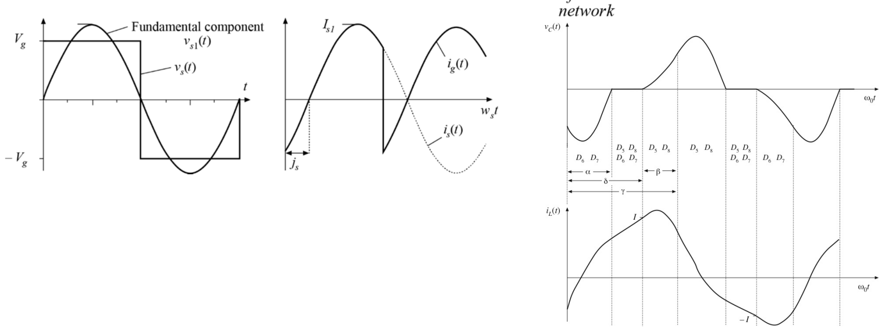
# Digital Control of SMPS



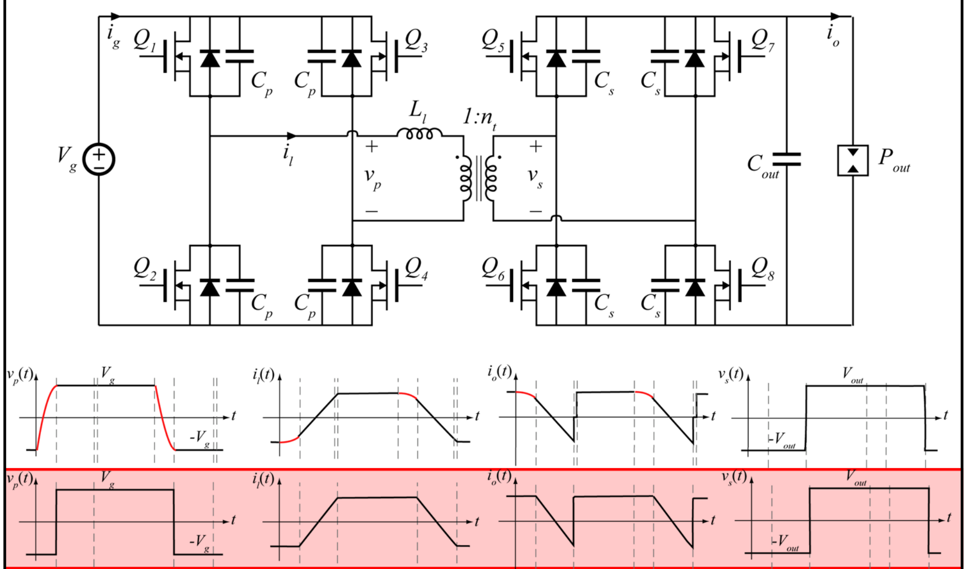

- Digital Control can improve noise immunity, element variation, size/cost
- Advanced tuning algorithms can be included to change compensator dynamically or over lifetime
- Can model power stage without averaging assumptions
- Need to include sampling, delay, saturation, and quantization effects

# Resonant and Soft-Switching Topologies



## Converters with Significant ZVS Interval

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## Power Electronics Courses at UTK

| Junior | Senior | Graduate | |
|---|---|---|---|
| ECE 325 Electric Energy System Components | ECE 481 Power Electronics | ECE 523 Power Electronics and Drives | ECE 623 Advanced Power Electronics and Drives |
| | ECE 482 Power Electronic Circuits | ECE 525 Alternative Energy Sources | ECE 625 Utility Applications of Power Electronics |
| | | ECE 581 High Frequency Power Electronics | ECE 626 Solid State Power Semiconductors |
| | | ECE 692 Power Electronics Technologies I | ECE 692 Power Electronics Technologies I |
| | | + 4 more | |

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# APPLICATION OF ECE481 THEORY

# Example: Low-Power AC Adapters

Apple "Ultracompact USB Power Adapter"

Design Constraints:

- Single converter needs power stage which can operate over wide input voltage range
- For $V_{dc}$ = +5 V (USB output) need very large step-down capability (M = 0.018)
- Isolation may be necessary for safety

Goals:

- Produce regulated DC Voltage from universal input (85 to 276 Vrms, 47-63 Hz)
- Maintain high power factor / Low EMI
- High efficiency to allow small size

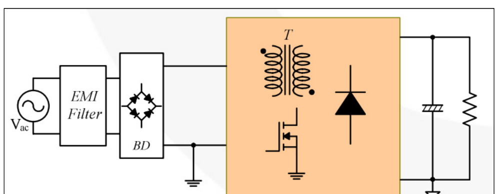


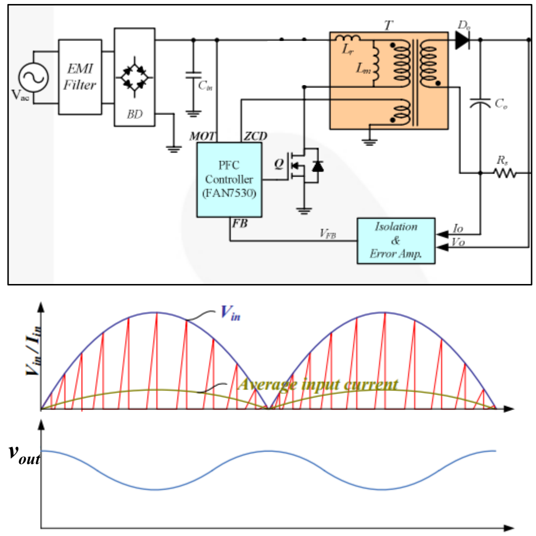

**Figure 1. Single-Stage AC-DC Converter**

Fairchild Semi, "Design Guideline of Single-Stage Flyback AC-DC Converter Using FAN7530 for LED Lighting"

# Flyback Implementation

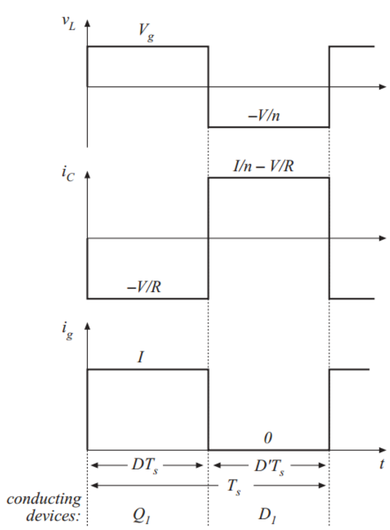
- Flyback selected as a simple, low part-count topology
- Used almost exclusively in Ac-to-LVDC applications at power levels less than ~100W
- DCM may be used for reduced diode RR and increased $f_s$

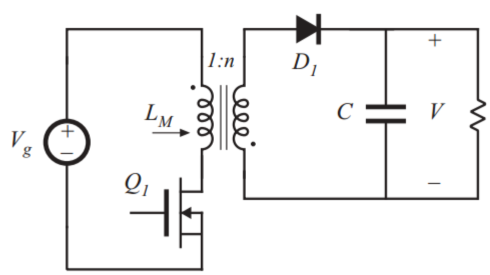
- Pulsating input current requires filtering
- If unity power factor is obtained, significant output ripple results




Fairchild Semi, "Design Guideline of Single-Stage Flyback AC-DC Converter Using FAN7530 for LED Lighting"

# Practical Issue: Ringing in Flyback

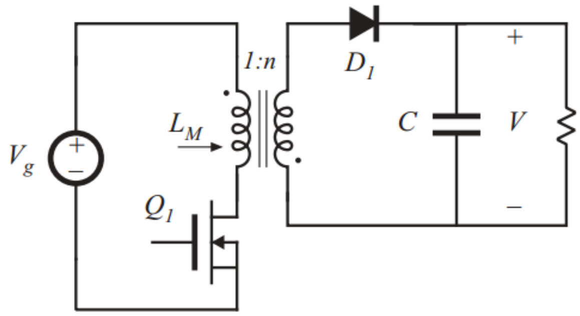



- Practical transformer implementation has nonzero leakage inductance
- When MOSFET switches off, it interrupts leakage current
- Inductor energy dumped into MOSFET output capacitance
- Lossy, high EMI, Potentially can over-voltage MOSFET $Q_1$

# Snubber Design

- Goal is to provide a path for leakage current to circulate




# Snubber Design

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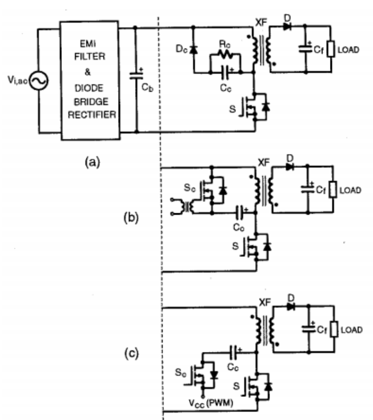
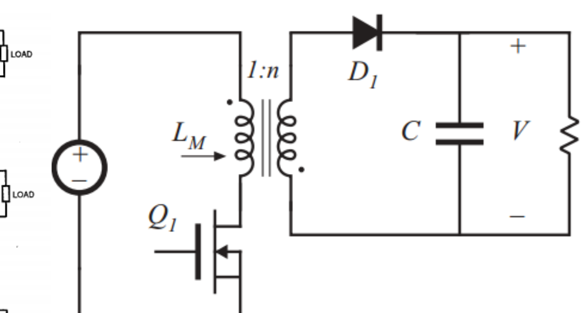


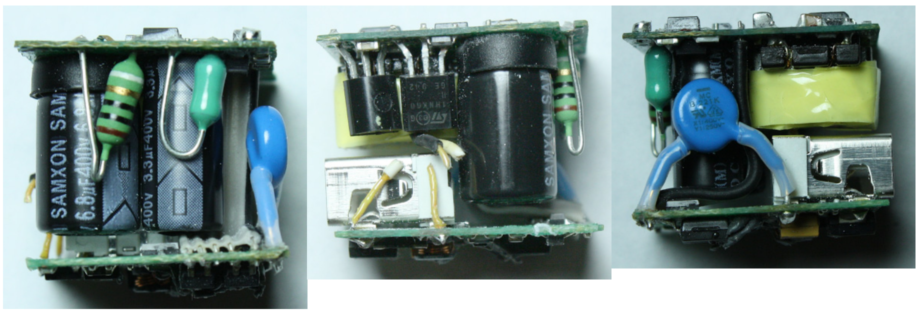

Fig. 1 Simplified circuit diagram of (a) RCD-clamp, (b) NMOS active-clamp, and (c) PMOS active-clamp flyback adapter/charger




L Huber and M Jovanovic, "Evaluation of Flyback Topologies for Notebook AC/DC Adapter/Charger Applications

# Apple Power Adapter Implementation

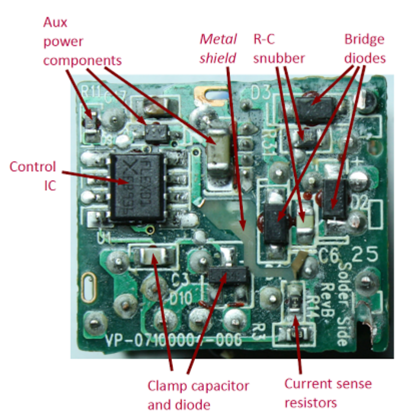
Example:
- 5 Watt AC-to-5V adapter

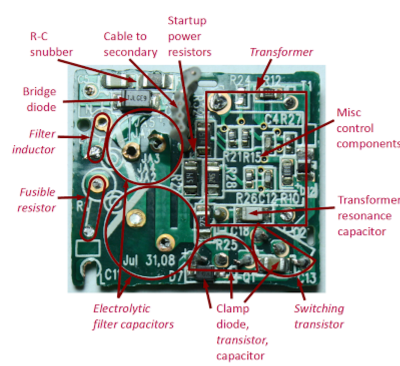


K Shirriff, "Apple iPhone charger teardown: quality in a tiny expensive package"

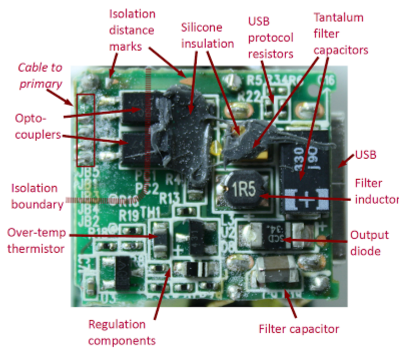


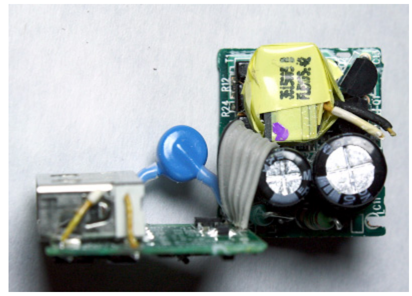
# Apple Circuit Primary



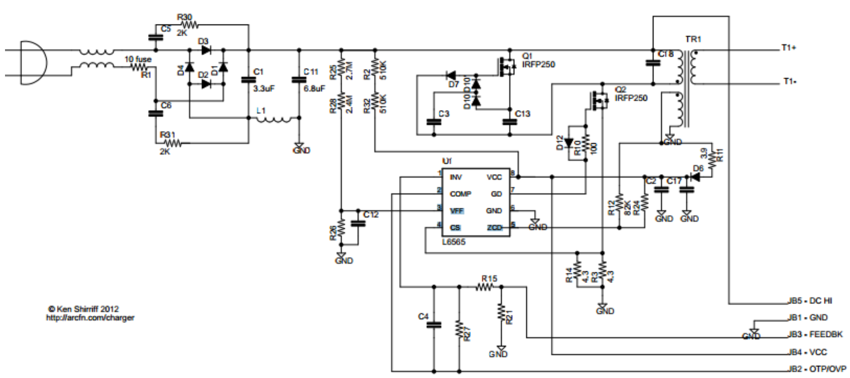
# Apple Circuit Secondary



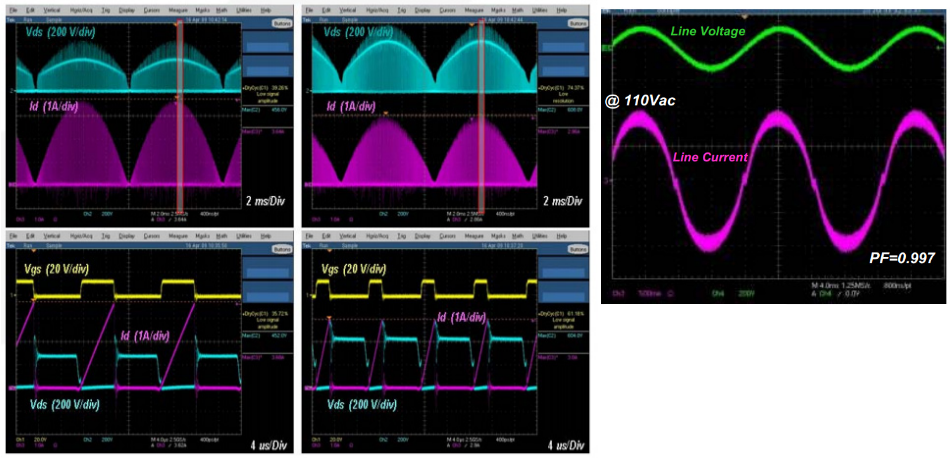





# Apple Adapter Schematic



# Example Waveforms




**(a) at 110 $V_{ac}$ Input (b) at 220 $V_{ac}$ Input**
**Figure 12. Switching Voltage and Current**

L Huber and M Jovanovic, “Evaluation of Flyback Topologies for Notebook AC/DC Adapter/Charger Applications