9x.13 Beware Counterfeits (or, Don't Bite into That *Apple*)

When we bought a hand-me-down (i.e., used) iPhone recently, it was listed as

> **Condition: New** – This Certified Refurbished product is factory refurbished, shows limited or no wear, and includes all original accessories plus a 90-day warranty.

Although one could take exception to this use of the word "new," the phone itself was fine – but the "original accessories" were highly suspicious. Most interesting was the little white 5 W power brick, outwardly a pretty good imitation of the real thing (Fig. 9x.45), but on closer inspection an obvious fake. It put up a good fight, but a misspelling clearly brands it counterfeit. And although it copied the model number, manufacturer, and most other aspects of the design, it had the decency to omit the top line, and to replace the official Underwriters Laboratories (UL) symbol with a meaningless "M." And, perhaps revealing of a guilty conscience,[32] the author(s) downgraded the country of origin to a lower-case "china."

On the bench

We powered up these puppies and looked at the dc output under various loads. The Apple charger delivered on its promise of "5 V, 1 A" (Fig. 9x.46), with a worst-case ripple of 20 mVpp, and 25 mV drop going from no-load to full-load. By contrast, the fake's performance was, well, *terrible* (Fig. 9x.47), with 1 V spikes (at about 20 Hz) when unloaded, 1 Vpp ripple and high-frequency hash when loaded, and a maximum output current of just half its rated 1 A. As The Donald might say, "you're fired!"

The inside story

As the entertaining Dave Jones (of eevblog.com) likes to say, "don't turn it on, *take it apart!*" We did both. The powerline side of the fake seemed loose, and it popped out easily, held in place only by a pair of diminutive 0.5 mm plastic protrusions. The real Apple charger was a different story – no amount of pulling or prying did anything – we had to cut all the way around with a Dremel rotary tool to separate the base. Figure 9x.48 compares the innards, revealing a complex high-density PCB board pair in the genuine charger, each packed with SMT parts, compared with a simple single-sided phenolic PCB with just a few through-hole parts in the fake. Obviously there's a lot less circuitry in the fake, and it shows in the measured performance.

We'll get to the circuits presently, but a few first impressions upon examining the fake: (a) it has no filter inductors, neither at input nor at output; (b) it has no line-rated "Y-capacitor" bridging the input and output, instead using a generic ceramic disc type; this is a real safety hazard, see §9.5.1E; (c) an ever greater hazard is the lack of sufficient "creepage" path (§9.7.2D) between input and output – we measured extensive trace pairs separated by a scant 0.6 mm; and (d) it has no overtemperature protection, and no fuse to interrupt power in the event of a component failure. Bottom line: this thing should be illegal.

The circuits: the counterfeit

We traced out the circuit of the counterfeit charger, an easy task because it has only 15 parts, all of which are discrete components (no ICs); it is shown in Figure 9x.49. The powerline ac is applied directly to a full-wave rectifier (no fuse, no interference filter), whose output powers a simple *blocking oscillator* running at about 100 kHz. The secondary is configured as a flyback (i.e., no conduction during the primary power cycle), again without RFI filtration. Voltage regulation (if you can dignify it with that name) is provided by the optocoupler, which shunts oscillator drive when 3.9 V zener Z_1 conducts.

The circuits: the genuine item (a "Design by the Masters" candidate)

The genuine Apple charger's circuit[33] (Fig. 9x.50) is a different beast entirely. The designers, while packing 68 components into the same 1 cubic inch, adhered to industry standards: overtemperature shutdown, input fusing, RFI filtration at both input and output, ac-rated Y-capacitor (Y_1), and 5 mm minimum creepage paths. The assembly is exemplary: all components are well anchored, with insulating tape and elastomeric material applied liberally, and with a metallic shield covering the SMPS control circuitry (seen in the lower left image of Fig. 9x.48.) Their circuit exploits a "quasi-resonant" current-mode controller (ST's L6565, evidently, according to Shirriff), which minimizes

[32] Or maybe thinking of this item as highly breakable (like dishware), which, as we'll see presently, is close to the truth.

[33] Rearranged and annotated from the very fine work of Ken Shirriff, see his teardown and tutorial at righto.com/charger.

Figure 9x.45. Real Apple chargers don't misspell "equipment," nor do they forget that the powerline input current is way less than the 5 V dc output current.

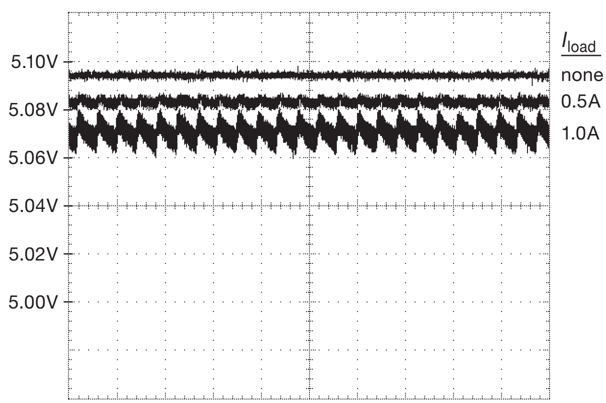

Figure 9x.46. Apple A1265 5 W charger output, for full-load, half-load, and no-load conditions; note expanded vertical scale, with offset zero. Horizontal: 20 ms/div.

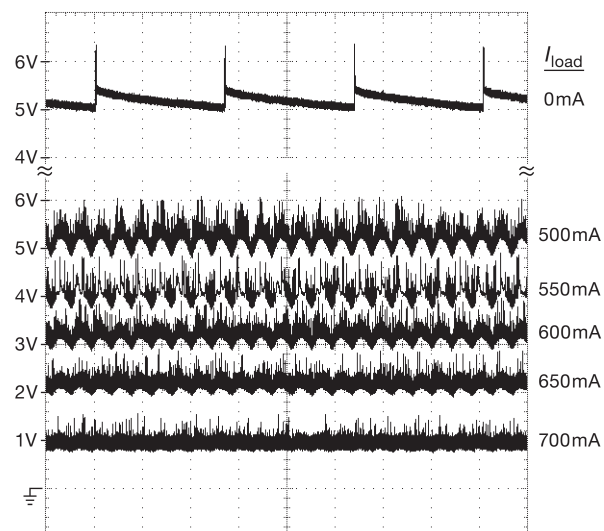

Figure 9x.47. Imitation 5 W charger output under several load conditions (the no-load trace is plotted separately because it overlaps the half-load trace). Note coarse vertical scale, compared with Fig. 9x.46 where the vertical axis was expanded 50×. Horizontal: 20 ms/div.

switching losses through zero-voltage switching (ZVS, see §9.6.8D) by sensing transformer demagnetization (the ZCD "zero-current detect" input), and which implements low-power features such as very low quiescent current and frequency foldback at light loads. The result is a safe and electrically quiet power supply with good efficiency: 77% at 50% load, compared with 72% for the simpler counterfeit charger.[34]

Some comments on the circuit:

[34] Perhaps surprisingly, the sophisticated Apple charger consumes more *standby* power than the cheap imitation: 200 mW versus 30 mW, respectively, by actual measurement. To put these numbers into perspective, running 200 mW for a year consumes about $0.35 worth of electricity (at a typical domestic electricity cost of $0.20/kWh). That's not much – but then again if you have a dozen little gadgets idling at 200 mW, the

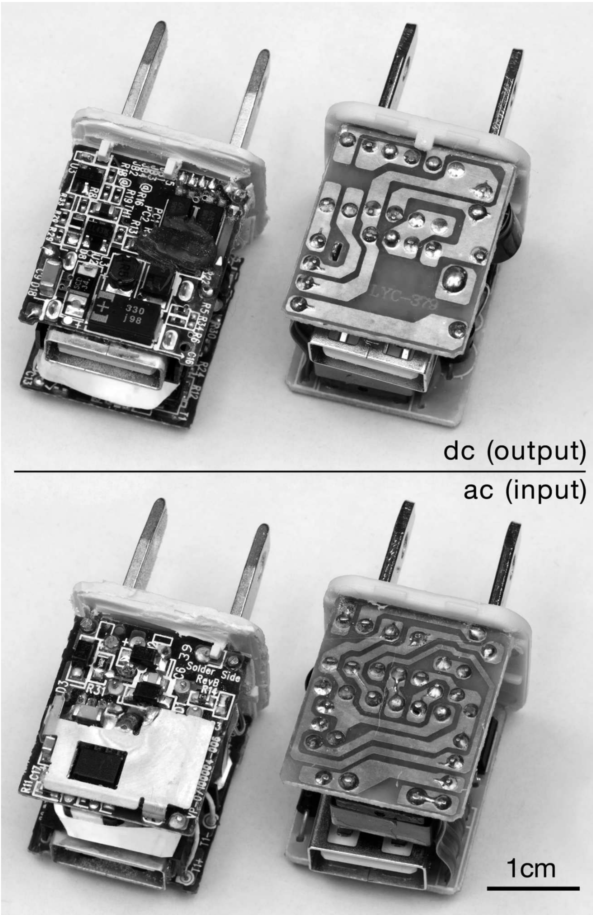

Figure 9x.48. A world of difference inside: the Apple charger (left side) is replete with quality SMT parts on a pair of double-sided and plated-through fiberglass FR-4 PCBs, with careful attention to mandated safety clearances; the imitation is built with cheap through-hole parts on single-sided phenolic PCBs with no through-hole plating.

(a) voltage feedback compares the dc output with the 2.5 V threshold of TL431 shunt regulator U_2, optically coupled via OC_1 to the controller's error amplifier;
(b) a separate feedback path is used to trigger shutdown (via latch Q_3Q_4) on either of overvoltage or overtemperature, again using a TL431 (U_3) to set thresholds, but without the need for linear compensation;
(c) because the switching cycle depends on zero-current timing, the frequency changes with load, going from 135 kHz (full load) to 320 kHz (no load);
(d) the circuitry surrounding Q_2 is a "resonant clamp," evidently devised by Flextronics (the manufacturer of this device, see their US patent 7,924,578), to achieve ZVS for both MOSFETs while minimizing voltage transients and recycling reactive energy;
(e) to further suppress inductive spikes, this design includes *RC* dampers in the input rectifier bridge (see §9x.6).

To put some perspective on a design like this, remember that much of the circuitry is helpfully provided by the semiconductor manufacturers, in the form of so-called "reference designs," and also in application notes. In this case, for example, much of the critical circuitry is found in the datasheet for the L6565 SMPS controller IC and in the Flextronics patent. The larger part of Apple's challenge was to package a reliable implementation in an elegant and compact enclosure, while adhering to constraints of safety, and of radiated and conducted interference. In this they succeeded admirably.

electricity cost could have gotten you one Big Mac® each year on your birthday.

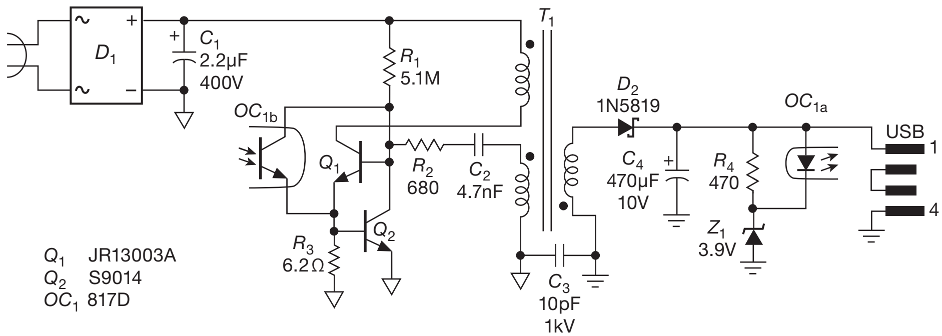

Figure 9x.49. Circuit of the counterfeit Apple "5 W" charger: 15 components in all, in a simple blocking oscillator configuration that provides at most 2.5 W. Regulatory and safety violations include lack of fuse or temperature sensing, lack of input or output filters, non-ac rated C_3, and multiple dangerous 0.6 mm creepage paths.

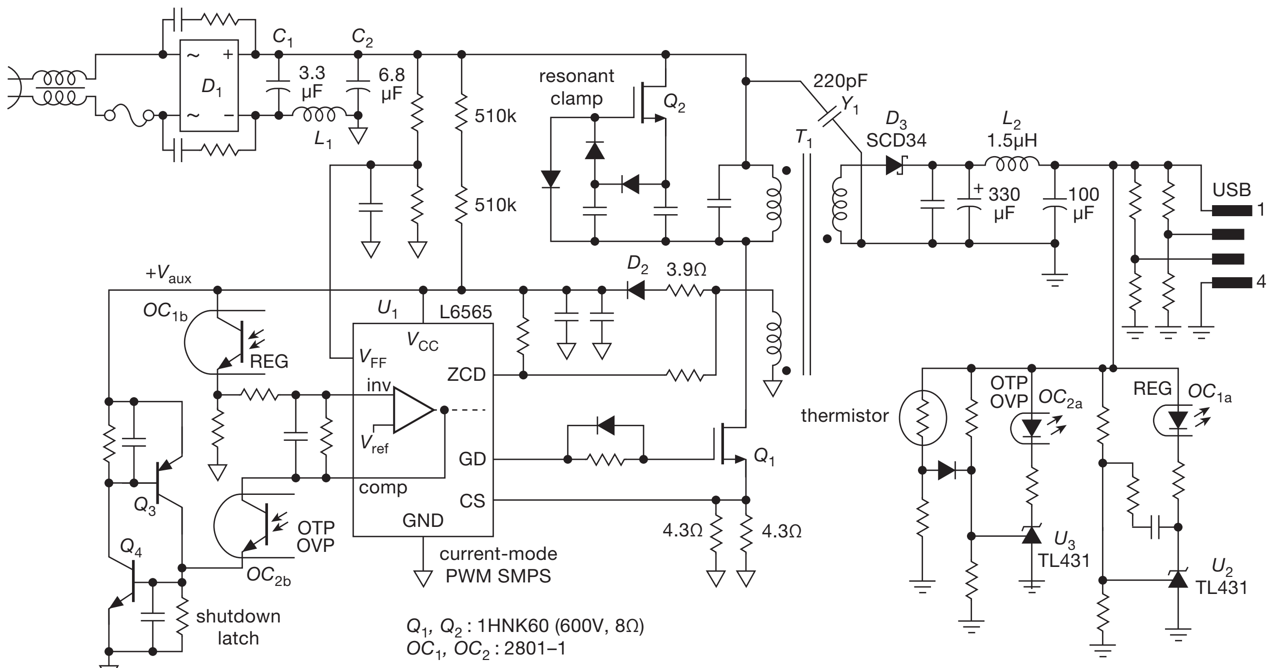

Figure 9x.50. Circuit of a genuine Apple 5 W charger, adapted from the reverse-engineered schematic by Ken Shirriff: 68 components in a sophisticated current-mode configuration, with a full complement of safety and interference measures – fuse, filters, overtemperature sensing, zero-voltage switching, spike suppression, resonant clamping, and fully compliant creepage and gap dimensions.