Low-Cost Commercial Power-Source Inverters

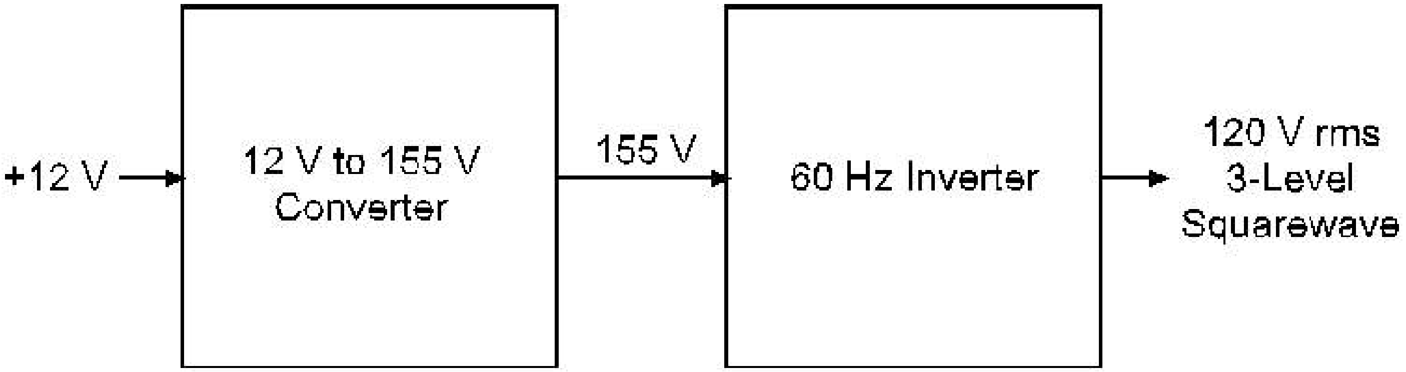
by Dennis Feucht

Q: I bought a low-cost 300 W inverter and it has failed. Are they hard to repair? What can I do to improve its reliability?

A: The market is flooded with low-cost commercial inverters, such as those sold by Vector Mfg Co, Koss, or those from undisclosed Asian sources. Many of these inverters have one characteristic in common: to be price competitive, they have cut corners in the design, resulting in unreliable products. Neither the repair nor the design of power-source inverters can be adequately covered in this article, or its sequels. In the style of the Circuit Design Clinic, some more practical design aspects will be considered, leaving the more involved theoretical aspects for TechNotes.

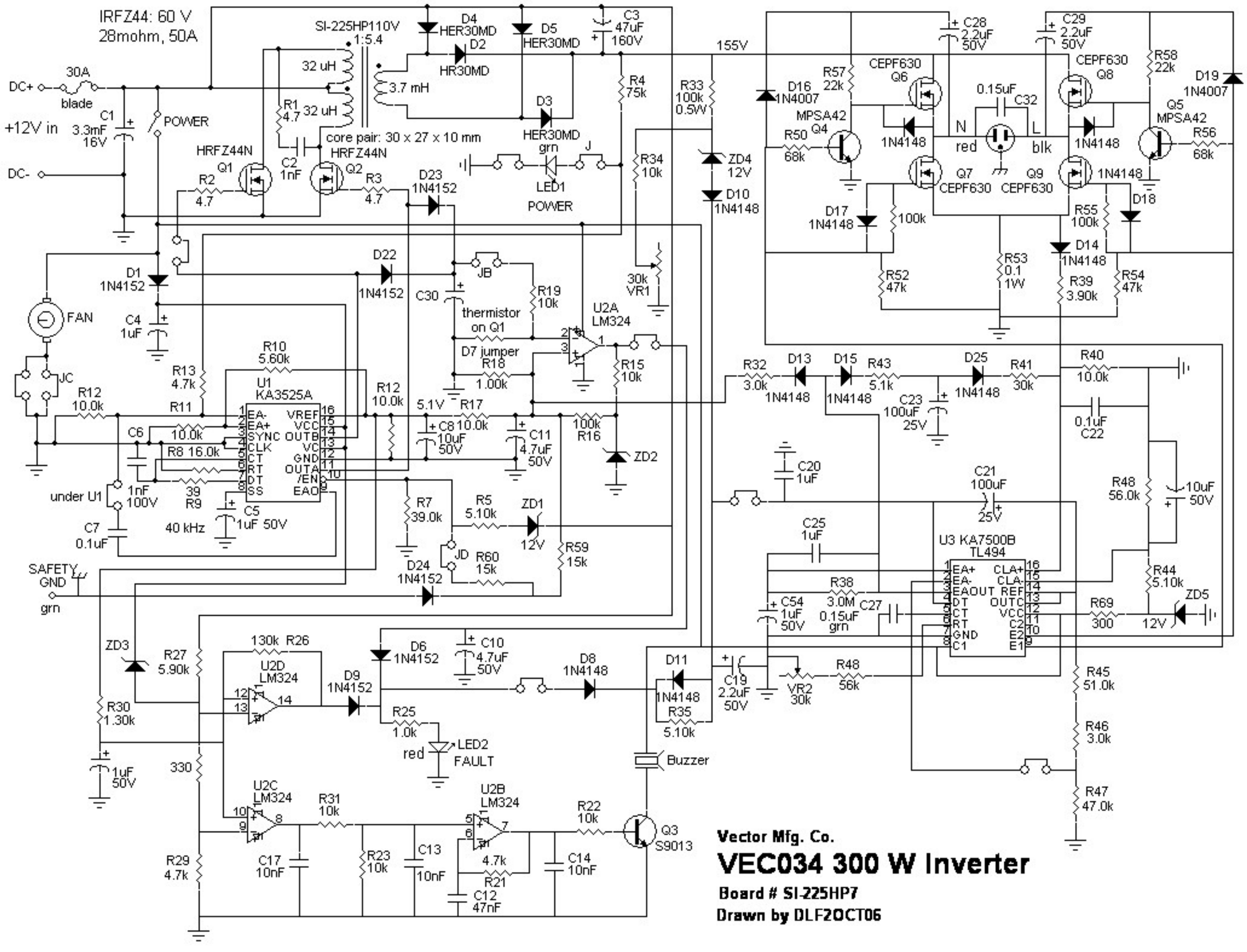
I reverse engineered a half-dozen commercial inverters, nearly all of which had failed in ordinary use as power sources for residential, off-grid use. Below are pictures of some of them. (Perhaps you can identify *your* inverter in this collage.)

They all use the same basic two-stage scheme:



The first stage is a dc-dc converter that converts from the 12 V of the battery to the ac output amplitude of anywhere from 170 V to as low as 145 V. The second stage is an H-bridge for generating a bipolar square-wave, sometimes advertised as a "quasi-sine-wave". There is nothing sinusoidal about a bipolar square-wave, however!

The converter stage is always of push-pull topology, using high-current transistors and no inductor, as shown below in the reverse-engineered schematic diagram of the Vector VEC034D 225 W inverter.



These converters have transformer secondary circuits that are peak-charging, like linear power supplies with a transformer, bridge rectifier and storage capacitor. By omitting the inductor in series with the power switch, cost is reduced along with reliability, for any load over-current transient will propagate back to the converter transistors. The converter increases the voltage from the nominal +12 V battery to about 15% under nominal line peak voltage, or about 155 V. Then a second stage inverter consisting of an H-bridge, chops the converter output voltage at 60 Hz to produce a bipolar square-wave. The duty ratio is usually controlled to keep the rms value at 120 V, though the peak is significantly lower than the 170 V of a 120 V sine-wave.

When (not if) your low-cost inverter fails, if it is an Asian product of an unnamed brand, you are presumably expected to throw it away and buy another. This wasteful and frustrating approach to inverter use must by now be producing a growing market sector willing to spend more for something durable. If your inverter is a Vector Mfg Co product, the only expected recourse for repair is to mail it to them in Florida. If you want to fix it yourself and request additional technical information, be prepared to be snubbed, as I was.

Vector is not unique; it is typical nowadays for consumer manufacturer policy to be *closed-source*. Unlike the *open-source* efforts of the past to provide the customer (or the customer's local repair technician) the technical data needed to understand and repair the company products -- a policy typical of Tektronix, HP, or any of the semiconductor companies -- the closed-source company instead treats technical inquiries with attitudes ranging from disregard to hostility. Those who want to maintain their own electronics will need to share their reverse-engineered information that these closed companies refuse to provide. A website would be a good medium for exchange of product information.

VEC034 Inverter Example

The Vector Mfg inverters, such as the VEC034, are somewhat less poorly designed than the worst (and lowest-cost) design, Item # 40111, apparently from an unnamed source in Asia. The VEC034 has current-limiting, using a sense resistor in the inverter stage. The average current limiting, however, is insufficient to protect against failures from quick load current transients.

Here is a quick list of cut-corners that I found in the VEC034 design that impact reliability:

- Inverter stage average overcurrent protection, not transient load overcurrent that can cause switch failure
- No push-pull converter stage current limiting exists either
- No push-pull circuit protection against flux imbalance, causing average current to increase unbounded
- No converter stage inductor, causing the secondary to be peak-charging, and causing overcurrent transients to ripple through to the converter stage, unimpeded
- No stable converter feedback loop control, resulting in bursts of high-duty-ratio charging at output. A change in duty ratio does not cause a continuous change in output voltage except as affected by load current demand variations
- Thermistor overtemperature protection can be done more simply (and accurately) using *p-n* junctions
- High-side inverter H-bridge MOSFETs have small-current diodes (1N4148) from source-to-gate, to protect against gate-source overvoltage, yet these diodes would have to conduct any load-sourced current flowing into the inverter (such as from the induced voltage of a motor load), and it could easily exceed the current capacity of these diodes
- If Q3 becomes stuck on, the electromechanical buzzer is cooked

Some interesting aspects of this design are:

- The converter secondary circuit is placed in series with the battery. This increases the output voltage by $n/(n-1)$ while keeping the turns ratio of the transformer up the by same amount, allowing for somewhat more secondary current. This, of course, defeats isolation, but usually none is intended for 300 W inverters
- D22 and D23 charge C30 to an average voltage proportional to the duty ratio. This average voltage supplies, through R19, the thermistor and sets the voltage at the U2A inverting input. The temperature limit thereby tracks the drive to the MOSFETs so that for higher drive, a higher temperature limit is expected and compensated for, and the overtemperature fault is not triggered
- The POWER LED is not turned on from a switch from the battery, but from the output of the converter, thus indicating that the converter is working

Improvement of inverter reliability is a major task. The basic design scheme can be improved upon by adding a series output inductor so that the push-pull stage becomes a buck-derived converter. Then the feedback loop should be redesigned to ensure stability. The negative consequence is that a higher secondary voltage is required, from a higher duty ratio on the power switches, which will dissipate more conduction power loss. The turns ratio of the transformer might not even allow a secondary series inductor of a reasonably small value. This is a major redesign problem.

Peak (not average) current limiting on both stages protects against transients and flux imbalance in the converter stage, which really ought to have peak current, not voltage, control. The output H-bridge might be followed by an EMI filter to protect it against load transients and to deliver fewer high-frequency noise components in the output waveform. H-bridge protection against reactive loads would also be on my list.

Usually, when low-cost inverters break, it is almost always one or more of the power MOSFETs that fail. Check these first. Electrolytic storage capacitors are next on the list. The very first, of course, is the fuse(s), often mounted on the internal ECB.

The worst aspect of low-cost inverter repair is the realization that, once fixed, it will fail against unless the design is repaired. The above tips for redesign should give you a place to start. It is a nontrivial effort, and more might be said about it in future articles, either here or in the TechNotes, or both.

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