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## *Improving Reliability Of Low-Cost Power-Source Inverters*

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In hardware and automotive stores you can find inverters that supply 120 V ac rms from your vehicle's 12-V battery bus. Various brands exist at various power outputs. How well are these inverters designed? Are they hard to repair? What can be done to improve their reliability?

The consumer market is flooded with low-cost inverters, such as those sold by Black & Decker, Koss, or from obscure 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. Engineers and others with electronics knowledge may be tempted to repair these products when they fail, and may even want to make upgrades to improve their reliability. However, the manufacturers do not support either of these activities as we will soon discuss.

In this article, we'll examine some inverter product examples, discuss why they are unreliable, and propose some possible solutions with the ultimate goal of enabling more robust low-cost inverter designs. Neither the repair nor the design of battery-source inverters can be adequately covered in this article though some of the more practical design aspects are considered.

### *Some Inverter Product Examples*

I reverse-engineered a half-dozen readily available inverters, nearly all of which had failed in ordinary use as power sources. Some are pictured below in Fig. 1. Perhaps you can identify your inverter in this collage.


*Fig. 1. To be price competitive, inverters manufactured for the consumer market have cut corners in the design, resulting in unreliable products as will be demonstrated in my "tear downs" of products such as the ones shown here.*

They all use the same basic two-stage scheme shown in Fig. 2.

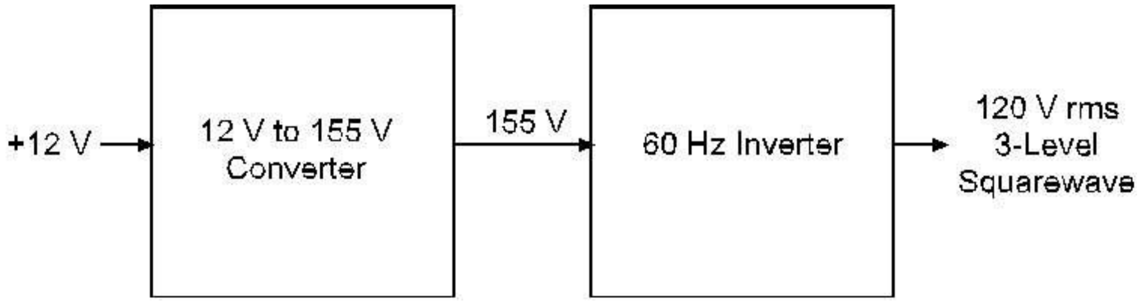


*Fig. 2. The typical two-stage architecture used in inverters developed for the consumer market.*

The first stage is a converter that converts from the 12-V battery supply to the 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, however, not much that is sinusoidal about a bipolar square-wave.

The power stage is always a push-pull chopper with high-current transistors and no series inductor, as shown below in the circuit diagram of the reverse-engineered Vector VEC034D 225 W inverter (Fig. 3).

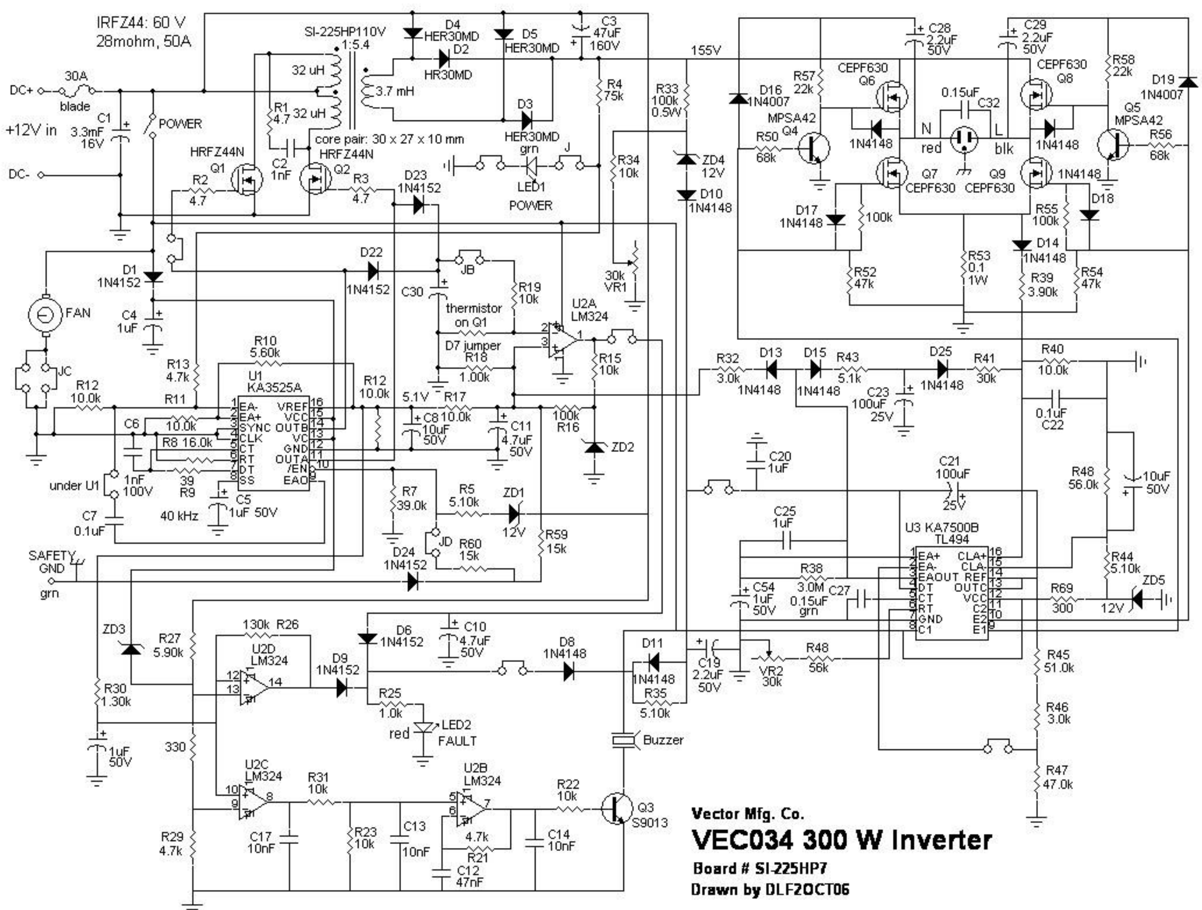


*Fig. 3. This schematic was obtained through a tear down of a Vector VEC034D 225 W inverter.*

 

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, the power-transfer stage is not a buck or other PWM-switch configuration but is a *chopper*. By omitting an additional magnetic component, cost is reduced along with reliability in that a load overcurrent transient will quickly 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, switches the converter output voltage at about 60 Hz to produce a bipolar square-wave. The duty ratio is usually controlled to keep the RMS output value at 120 V, though the peak is significantly lower than the 170 V of a 120-V sine wave.

When (not if) these low-cost inverters fail, as it's a low-cost consumer product 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 (now Black & Decker), 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. (I hope that some of you engineers who have the VEC034 can use the above circuit diagram for repair. All the parts are commodity components and readily available. The circuitry is typical of inverters in this category.)

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's products—a policy typical of earlier T&M instrument and semiconductor companies—the closed-source company instead treats technical inquiries with attitudes ranging from disregard to hostility.

Users who want to maintain their own closed-source electronics will need to share with each other their reverse-engineered information that these closed companies refuse to provide. A technical product disclosure website could be a good medium for exchange of such information. No wonder there is a growing open-source movement in technology nowadays.

## *More About The VEC034*

Vector Mfg. inverters, such as the VEC034, are somewhat less poorly designed than the worst (and lowest-cost) design, Item #40111, which comes from an unidentified Asian source. (I too would want to remain anonymous had I designed this product!)

The VEC034 at least has output current-limiting, using a sense resistor in the inverter stage. It is average current limiting, however, and is insufficient to protect against failures from quick load current transients.

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

- Inverter stage average overcurrent protection cannot prevent H-bridge failure from transient load overcurrent.
- 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 inductor; the circuit is a *chopper*, the secondary is peak-charging, and this causes overcurrent transients to ripple through to the converter stage, undelayed. Peak-charging also stresses the output capacitor.
- Unstable converter feedback loop control results in bursts of high-duty-ratio charging at the 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 replaced more simply (and accurately) using *p-n* junction pairs.
- 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) which could easily exceed the current capacity of these diodes.
- If Q3 becomes stuck on, the electromechanical buzzer is cooked.
- Converter control can exhibit load-related output instability. This is a whole topic in itself.

Some interesting and beneficial 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, $n$, of the transformer up by the same amount, allowing for somewhat more secondary current. This, of course, defeats isolation, but usually none is needed for 225-W inverters.
- D22 and D23 charge C30 to an average voltage proportional to the duty ratio. This average voltage drives, 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 consumer inverter reliability is a major task. The basic design scheme can be improved by adding a series input inductor so that the push-pull stage becomes a boost-derived PWM-switch converter. Then the voltage at the center-tap of the transformer is higher than the maximum battery voltage and the MOSFET current ratings can be reduced for the same power.

If the primary-referred secondary voltage, $V_S'$ that appears at the center-tap is a design margin above the maximum input voltage, then the transformer power rating is only slightly greater than the rated converter power, but the inductor rating is far lower—typically 50% or less. Thus, adding the inductor does not hugely increase the parts cost. Finally, the feedback loop should be redesigned to insure stability, in converting the power-transfer circuit from a chopper to a PWM-switch common-active (boost) circuit.

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 to keep current within bounds on a per-cycle basis. The output H-bridge might be followed by a differential inductor, to protect it against load transients and to reduce high-frequency noise components in the output waveform. It also can protect the H-bridge against reactive loads.

Another reason for load isolation by a "common-mode choke" is that some inverters become unstable when subjected to CFL lamp loads. The Vector Mfg. Co. VEC050D 1.5-kW inverter output oscillates at times when a CFL lamp is switched on, requiring recycling of inverter power and sometimes multiple load recyclings before the inverter operates stably.

Usually when low-cost inverters fail, the very first components to check are of course, the fuses, often mounted on the internal ECB. Component failure is almost always one or more of the power MOSFETs. Check these next using an ohmmeter set to the 20-kΩ full-scale setting, with positive lead on the drain (center terminal). The gate and source should show an open reading. Electrolytic storage capacitors are third on the list. If they are bulged (not flat) on top, they are highly suspect of failure.

The worst aspect of low-cost inverter repair is the realization that, once fixed, it will fail again unless the design is improved. Redesign is a nontrivial effort, and as noted above, a website for such discussion would be a way to share design and repair information.

The need for a reliable inverter design led me to start an endeavor I have dubbed the "Volksinverter project," which has the goal of developing a reliable open-source inverter design with minimal custom parts—only the circuit board(s) and magnetic components, though they can be described in enough detail to be built by hand.

A future article series on the Volksinverter design, with emphasis on the magnetics, is in the development stage. This series will be published here in the How2Power Today newsletter. In tandem with publishing this series, I would like to form a group of those who want to build a Volksinverter as an open-source collaboration, much like the Linux community has become. Those interested in joining this group can contact me at this email.

**About The Author**

*Dennis Feucht has been involved in power electronics for 35 years, designing motor-drives and power converters. He has an instrument background from Tektronix, where he designed test and measurement equipment and did research in Tek Labs. He has lately been working on projects in theoretical magnetics and power converter research.*

*For further reading on inverter design, see the How2Power Design Guide, locate the Power Supply Function category and select "DC-AC power inverters."*