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Virtual Remote Sensing Improves Load Regulation by Compensating for Wiring Drops Without Remote Sense Lines

Tom Hack and Robert Dobkin

Accurately regulating a voltage at a load can be difficult when there are significant voltage drops between the power supply and the load. Even if a regulator produces a perfectly regulated voltage at its own output, variations in load current affect the IR drop along the wiring, resulting in significant voltage fluctuations at the load (see Figure 1).

The conventional solution to improving regulation at the load involves adding extra wires for remote sensing (Figure 2a), but adding extra wires is not always desirable, or even possible. A new control method, Virtual Remote Sensing™ (VRS™), easily replaces and avoids the pitfalls of conventional solutions and in some instances solves the previously insoluble.

LOAD-END REGULATION BEFORE VRS

Virtual Remote Sensing solves the problem of maintaining load regulation at the end of long wiring runs. VRS is easier to implement and generally performs better than conventional remote sensing techniques such as direct remote voltage sensing, voltage-drop compensation, and load-end regulation.

The first conventional technique, direct remote sensing (Figure 2a), produces excellent load-end regulation, but it requires two pairs of wires: one pair to provide the load current and a second pair to measure the voltage at the load for proper regulation. Traditionally, remote sensing requires foresight—it must be

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VRS avoids the limitations of conventional voltage drop compensation techniques while producing impressive load regulation over a wide range of conditions.

(LT4180, continued from the cover)

designed into the system. Unless an extra pair of sense wires is ready and waiting, remote sensing is impossible to implement after the fact.

The second conventional technique, voltage drop compensation, doesn't require extra wires, but it does require careful estimation of the voltage drop of the load lines. The supply voltage is adjusted to make up for the estimated inter-connection voltage drop. However, since the drop is only an estimated value and not measured, the accuracy of this method is questionable at best.

The third conventional technique involves placing a voltage regulator directly at the load (Figure 2b). This provides both accuracy and simplified wiring, but the regulator consumes valuable space at the load end, reduces overall power system efficiency and power dissipation near the load increases. In industrial and automotive systems, it may be impossible to place a regulator in the harsh environment at the load end.

VRS avoids all of these limitations while producing impressive load regulation over a wide range of conditions.

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Figure 1. A simple model shows the problem of load regulation over resistive interconnections.

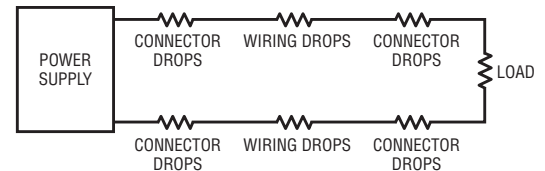
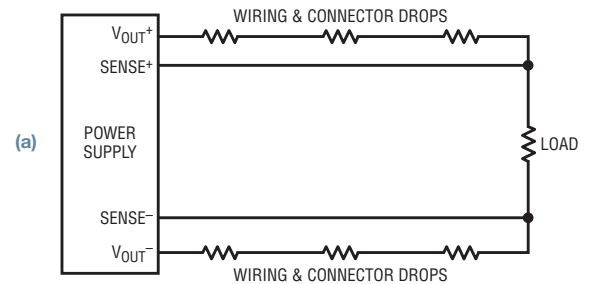


Figure 2. Two conventional methods for solving the problem of wiring voltage drops: (a) Remote sensing solves the problem of load regulation, but adds wires across the divide, (b) local regulation stabilizes load voltage but is inefficient.



The LT4180 works with nearly any power supply or regulator: linear or switching, isolated or non-isolated.

(LT4180, continued from page 2)

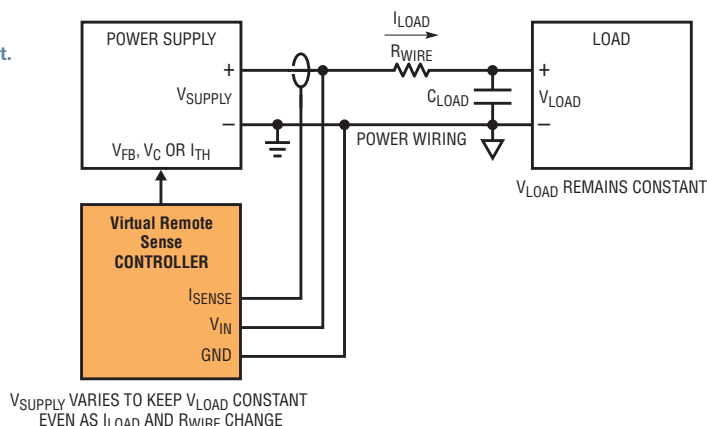
WHAT IS VRS?

Figure 3 shows a simplified schematic of a Virtual Remote Sense system consisting of a power supply or regulator driving a load over a resistive interconnection (consisting of wiring plus connectors). Without VRS, supply voltage (V_{SUPPLY}) and DC current (I_{LOAD}) are known, but there is no way to determine how much voltage is delivered to the load and how much voltage is lost in the wiring, so proper load voltage regulation can't be achieved.

The LT4180 VRS solves this problem by interrogating the line impedance and dynamically correcting for the voltage drops. It works by alternating the output current between 95% of the required output current and 105% of the required output current. In other words, the LT4180 forces the supply to provide a DC current plus a current square wave with peak-to-peak amplitude equal to 10% of the DC current. Decoupling capacitor C (which normally insures low impedance for load transients in non-VRS systems) takes on an additional role by filtering out voltage transients from the VRS square wave.

Because C is sized to produce an “AC short” at the square wave frequency, the interrogating voltage square wave produced at the power supply is equal to $V_{SUPPLY(AC)} = 0.1 \times I_{DC} \times R$, measured in V_{P-P} . The voltage square wave measured at the power supply has a peak-to-peak amplitude equal to one tenth the DC wiring drop. This is not an estimate—it is a direct measurement of the voltage drop across the wiring over all load currents.

Figure 3. Virtual Remote Sensing is easy to implement.



Minor signal processing creates a DC voltage from this AC signal, which is introduced into the supply's feedback loop to provide accurate load regulation.

SO HOW WELL DOES VRS WORK?

Static load regulation for the LT4180 is shown in Figure 4. In this case, load current was increased from zero until it produced a 2.5V drop in the wiring. The voltage at the load dropped only 73mV at maximum current from what it would be at no current. Even with an in-the-wire voltage drop equivalent to 50% of the nominal load voltage, the voltage at the load stayed within 1.5% of the no load current value. Less dramatic wiring drops produced even better results.

VRS IS EXTREMELY FLEXIBLE

The LT4180 works with nearly any power supply or regulator: linear or switching, isolated or non-isolated. Power supplies can be synchronized to the LT4180 or not. To accommodate a variety of system and power supply requirements, VRS operating frequency can be adjusted over more than three decades. It also offers spread

spectrum operation to provide partial immunity from single-tone interference. Its large input voltage range simplifies design.

SOLVING THE IMPOSSIBLE WITH VRS

Besides offering an alternative to conventional techniques, VRS opens up opportunities previously unavailable in battery charging, industrial and Ethernet, lighting, well logging and other applications.

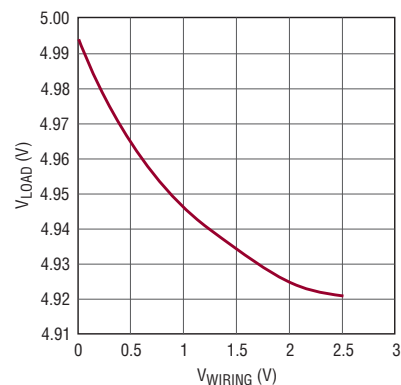


Figure 4. Static load regulation for the LT4180 is impressive over an extreme range of regulator-to-load wiring voltage drops.

The LT4180 VRS solves the problem of line voltage drops by interrogating the line impedance and dynamically correcting for the voltage drops.

Improve Battery Chargers

Figure 5 illustrates a poorly conceived power system for notebook computers, PDAs, cell phones or portable entertainment devices. An external power supply/battery charger is used to minimize the size of the portable electronic device. The

charger only works properly when the device is off and not drawing current. As the battery approaches full capacity, battery charging current (I_{BAT}) is nearly zero. With $I = 0$, the battery charger voltage V_{SUPPLY} equals the battery float voltage and charge termination works properly.

But what happens if the system voltage regulator is drawing current? The battery voltage V_{BAT} can be less than the needed battery charger voltage, V_{SUPPLY} , thus slowing charging or even stopping it altogether. Interconnection resistance can't be lowered enough to solve this. The 1% Li-ion float voltage accuracy requirement translates into a 42mV float voltage error (for a one cell Li-ion battery). Because there are other float-voltage error sources, the wiring drop must be kept well below this.

The conventional solution uses a complex architecture like that shown in Figure 6, which incorporates the charger and a power path controller into the device. While this reduces wiring-related charging errors, it increases the size of the device and the power dissipation within the device because the charger and power path controller must be packed inside.

Figure 7 shows the no-compromise solution using VRS. Charger voltage is properly controlled at the device, independent of load current (I), so an external battery charger supply can be used and a power path controller eliminated.

Easily Compensate Line Drops in Power over Ethernet Applications

Power over Ethernet and industrial applications also benefit from VRS. VRS allows low voltage devices (with high operating current) to operate over CAT5 and CAT6 cable—without the drops caused by long runs. Even 10V-20V line drops can be compensated, allowing either no regulator or a simple linear regulator at the far end.

Figure 5. A (flawed) battery charging architecture aims to reduce the device size with an external battery charger.

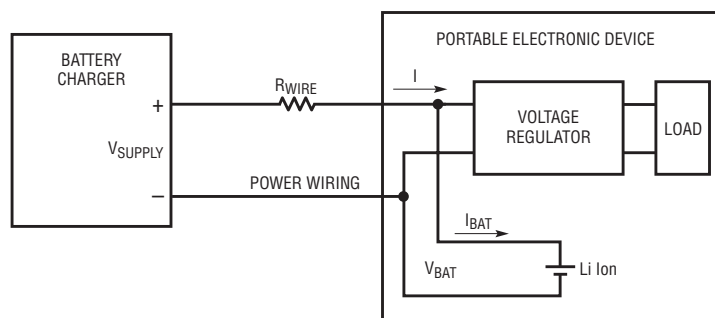


Figure 6. Typical battery charging architecture without VRS

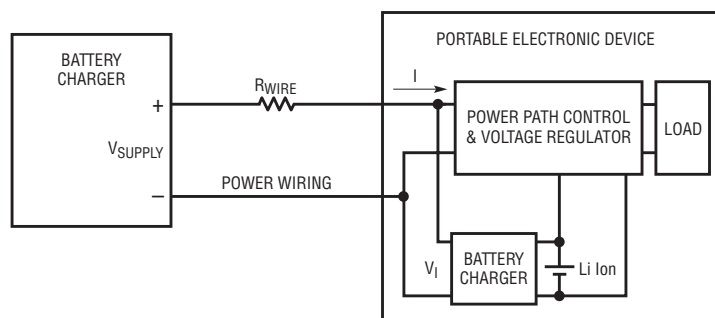
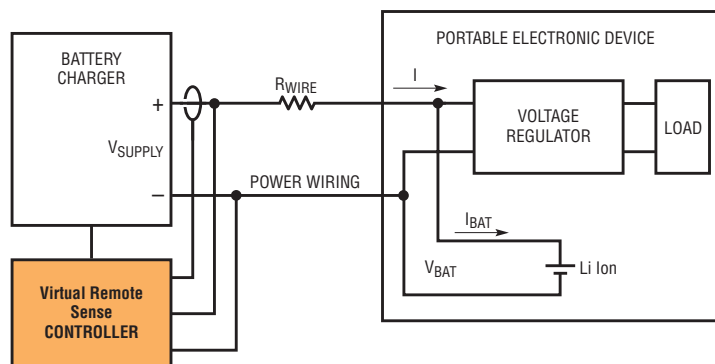


Figure 7. Simplified battery charging with VRS reduces the overall device size, achieving what the solution in Figure 5 could not.



A VRS system can be used to improve lighting. For medium and large lighting systems, the improvement in energy efficiency easily pays for the upgrade from a standard transformer to a DC/DC converter. Additional benefits of using a VRS system include better color-temperature control and longer, more consistent bulb lifetimes.

Retrofit Industrial Applications

VRS can also be used to simplify system retrofits for industrial applications. For example, a pair of power wires is available for new equipment, but regulation at the load-end is not up to the equipment spec. VRS can be easily dropped in to control the existing power supply or regulator. This is far easier and cheaper than adding another pair of wires for remote sensing or adding load-end regulation.

Increase the Efficiency and Light Output of High Intensity Lighting Applications

While incandescent lighting is on the decline, high intensity halogen lights continue to be popular. The operating voltage of halogens directly affects their light output, efficiency,

lifetime and color temperature as shown in Figure 8, and as follows:

- Light output is approximately proportional to $v^{3.4}$
- Power consumption is approximately proportional to $v^{1.6}$
- Lifetime is approximately *inversely* proportional to v^{16}
- Color temperature is approximately proportional to $v^{0.42}$

Normally these devices operate at 12V, but their operating current is relatively high, so line drops between the regulator and the light can be high. In this case, the load-end discrepancy can easily reach 1V or more. A 12V halogen operated at 11V produces 25% less light than when operated at 12V, with only a 13% power

savings. So to produce light at 11V that is equivalent to that produced at 12V would require 25% more bulbs running relatively less efficiently. Simply put, running

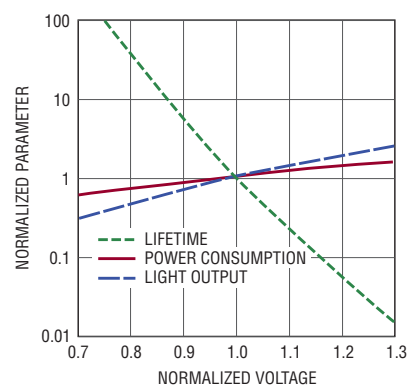
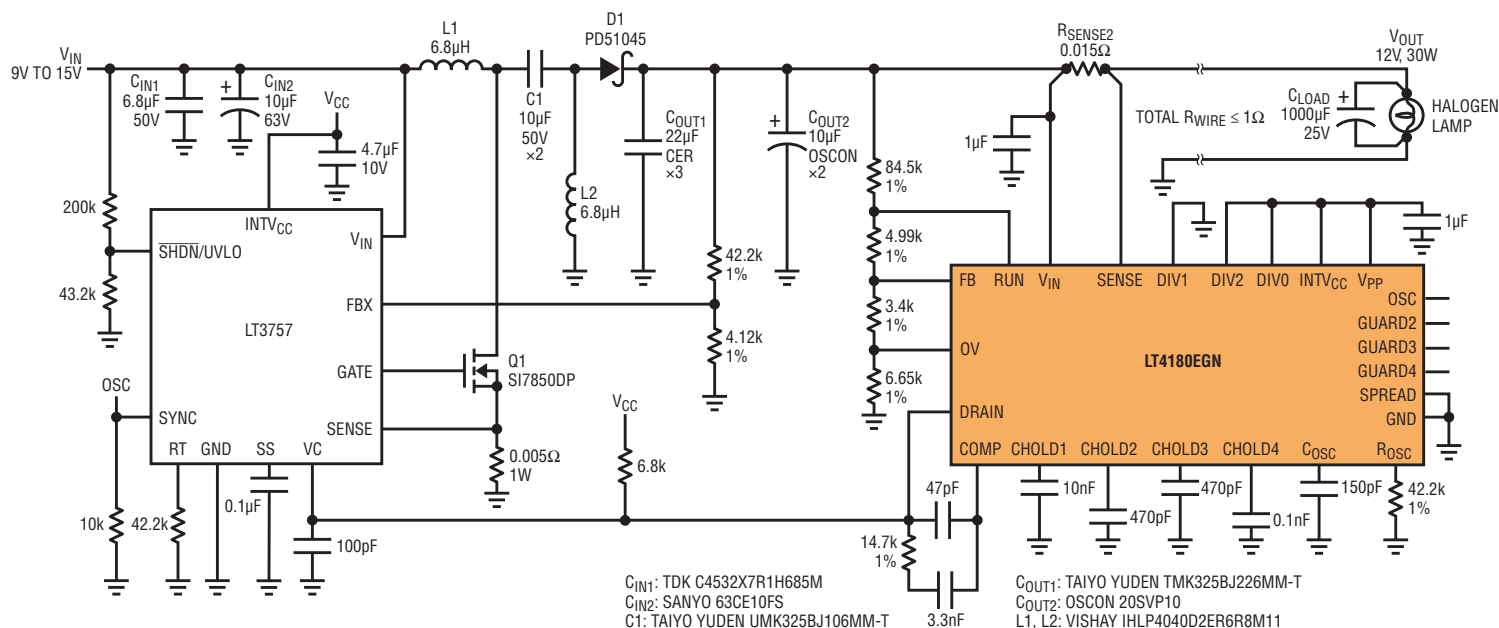


Figure 8. Lamp parameters vs normalized lamp voltage show that better voltage regulation at the lamp improves output, saves energy and prolongs lamp life.

Figure 9. An automotive halogen headlamp power supply



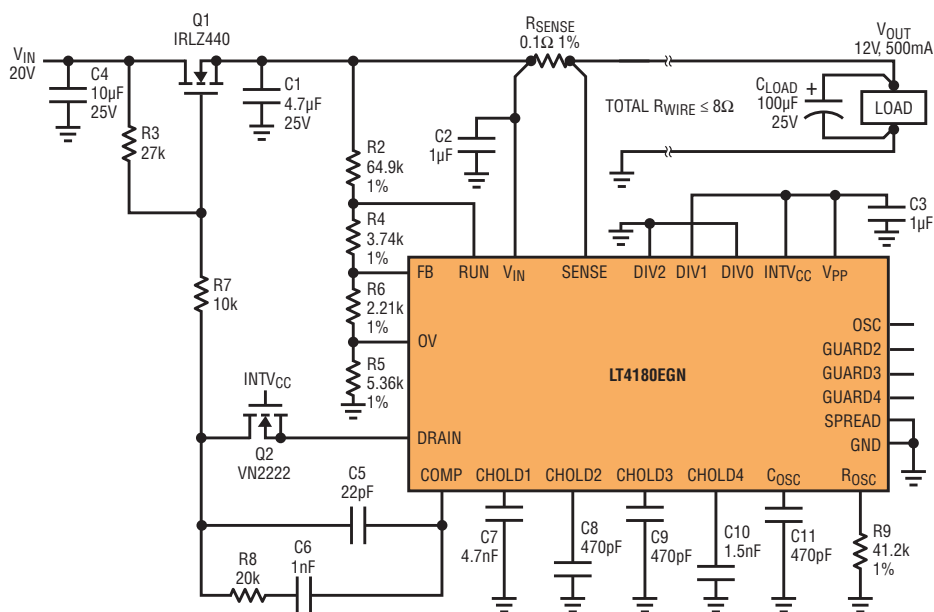


Figure 10. A full featured VRS linear supply

halogens at the correct voltage offers more precise lighting control, more predictable color temperature and better efficiency.

A VRS system can be used to accurately maintain correct bulb intensity. A capacitor is placed in the vicinity of the bulbs, and the voltage is controlled at that point. For medium and large lighting systems, the improvement in energy efficiency easily pays for the upgrade from a standard transformer to a DC/DC converter. Additional benefits of using a VRS system include better color-temperature control and longer, more consistent bulb lifetimes.

A SEPIC-based automotive halogen headlight power supply (Figure 9) improves bulb reliability while also ensuring optimum illumination. The design maintains 12V at headlight voltage over a 9V to 15V input voltage range. It works well up to 1Ω interconnection resistance. Using VRS allows the SEPIC converter to be placed far from the load—say in the passenger compartment, away from extreme under-the-hood environments, thus improving reliability.

Residential and commercial track-style lighting also benefit. The cost of properly regulating lamp voltage is quickly recouped in the form of lower power consumption and higher efficiency. Two to three kilowatt-hours can be saved per day on a 250W string while maintaining the same amount of light. Color temperature (while not as dependent on voltage as other lamp parameters) also benefits. VRS allows remote voltage regulation of a single lamp, or provides

first-order regulation of several lamps distributed over a single power rail.

VRS Might be the Only Solution When the Line Lengths Are in Miles

VRS can be used in oil and gas well logging applications where instrumentation is often connected by cables from thousands, to tens of thousands of feet long.

A COLLECTION OF APPLICATIONS

The LT4180 includes all components needed for a linear power supply (except for the pass transistor). Undervoltage lockout, overvoltage lockout and soft-correct are also available, so a full featured linear

VRS power supply can be built with few components (Figure 10). The linear supply in Figure 10 provides 12V at 500mA with an 18V input. Pass transistor Q1 is driven via R3, R7 and Q2 via the DRAIN pin. Q2 serves to keep DRAIN pin voltage below the absolute maximum rating. C5, R8, and C6 provide compensation. R2, R4, R5, and R6 set output voltage and lockout thresholds. R1 is the current sense resistor. C7–C10 are hold capacitors used by the VRS, while C11 and R9 set the square wave frequency. Typical load-step response is shown in Figures 11 and 12 with 4Ω wiring resistance and 100µF and 1100µF load-end

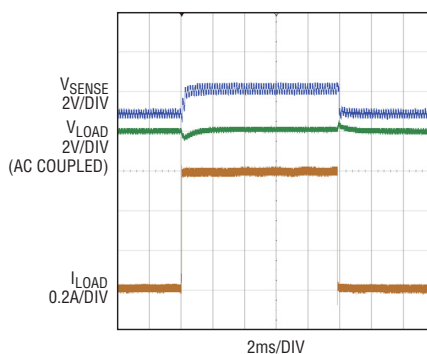


Figure 11. Load step response of the linear supply shown in Figure 10 with 100µF decoupling capacitance.

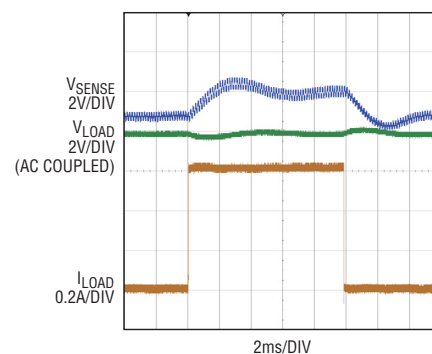
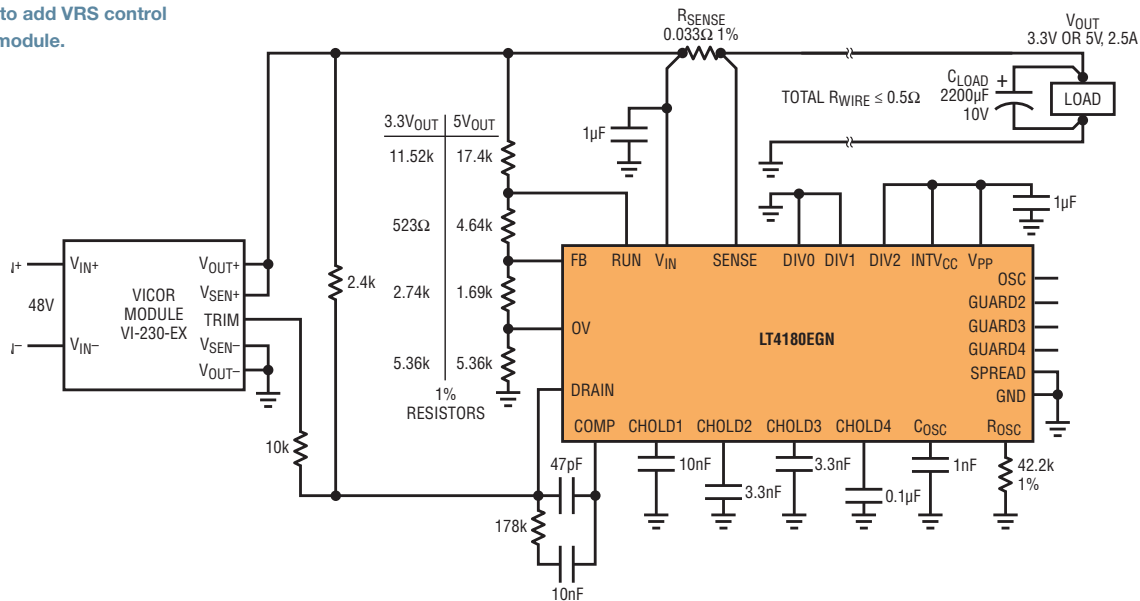


Figure 12. Load step response of the linear supply shown in Figure 10 with 1100µF decoupling capacitance.

Figure 13. It's easy to add VRS control to a power supply module.



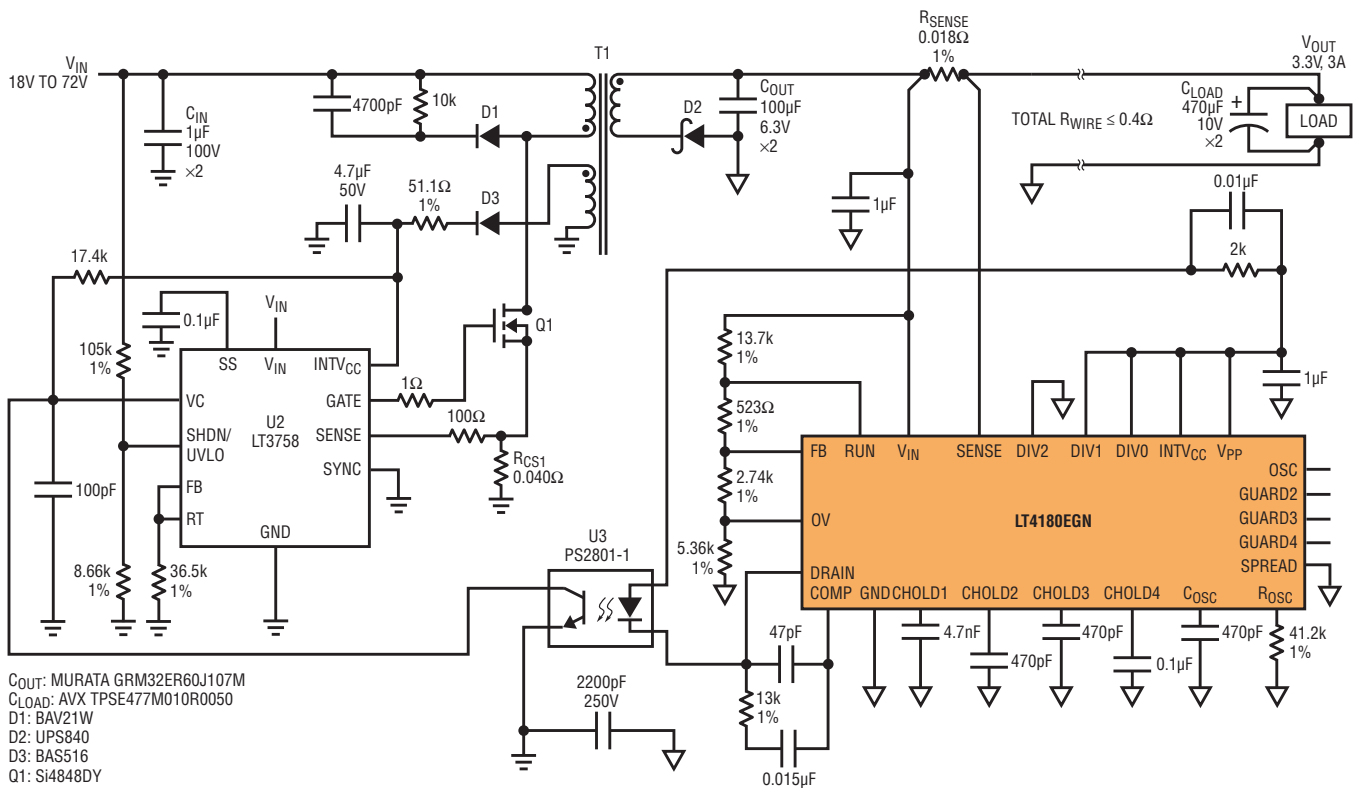
capacitances. VRS transient response is well controlled with widely varying C_{LOAD} .

Figure 13 shows how the LT4180 interfaces to a Vicor power module, providing Virtual Remote Sensing for a 3.3V/2.5A or 5V, 2.5A load through 0.5Ω wiring resistance. Output voltage is adjusted by

changing the values of the feedback and overvoltage resistors. Nominal input voltage is 48V. VRS is produced via the module's trim pin. This design works with 0.5Ω wiring resistance and 2200μF decoupling capacitance.

A fully isolated flyback converter capable of supplying 3.3V at 3A from an 18V to 72V input is shown in Figure 14. It is designed to correct for up to 0.4Ω of wiring resistance. Recommended load-decoupling capacitance is 940μF. Isolation is achieved through T1 and

Figure 14. A fully isolated VRS flyback converter



The LT4180 gives power supply designers a valuable new tool, enabling use of Virtual Remote Sensing for accurate load voltage regulation over highly resistive interconnections. Virtual Remote Sensing provides alternatives previously unavailable for simplifying or improving designs.

opto-isolator U3. While not shown in this design, it is also possible to provide an opto-isolated OSC signal from the LT4180 to a power supply for synchronization.

Figure 15 shows a buck regulator capable of supplying 12V at 1.5A to a load with up to 2.5Ω of wiring resistance. 470μF load decoupling capacitance is recommended. Input voltage range is 22V to 36V.

CONCLUSION

While conventional 2-wire remote sensing gives proper voltage at the load, there are many drawbacks. The sense wires are an additional cost in the system as well as consuming connector space for the system. Reliability issues can occur if the sense wires are disconnected or broken.

In contrast, a Virtual Remote Sense system produces excellent regulation at the load, with none of the drawbacks of wired remote sense. Unlike other compensation schemes such as negative resistance, Virtual Remote Sensing continuously corrects the output—even if the line-drop resistance changes—by determining real-time wire drops and connector drops. The additional noise on the power supply lines from the Virtual Remote Sense circuitry is easily removed by the capacitor at the load, which is always included in remote sense systems anyway.

The LT4180 can interface with IC regulators as well as preconfigured purchased offline supplies. In most cases,

the cost of adding a VRS IC to a power supply system is much less than laying wires for traditional remote sensing.

The LT4180 gives power supply designers a valuable new tool to accurately regulate load voltage over highly resistive interconnections. Virtual Remote Sensing provides alternatives previously unavailable for simplifying or improving designs. The LT4180 VRS works with virtually any power supply or regulator: switching or linear, isolated or non-isolated, synchronized or unsynchronized. It contains a VRS regulation circuit and a variety of features such as undervoltage and overvoltage lockout, and opto-isolator drivers. ■

Figure 15. A VRS buck converter

