Novel Current-Sharing IC Balances Two Supplies with Ease

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Failure is not an option. That's the likely motto for the architects of today's always-up electrical infrastructure—think telecommunications networks, the Internet and the electrical grid. The problem is that the bricks of this infrastructure, from the humble capacitor to the brainy blade-servers, have a limited lifetime usually ending at the most Murphy of moments. The usual workaround to the mortality problem is redundancy—backup systems ready to take over whenever a critical component fails.

For instance, high availability computer servers typically ship with two similar DC supplies feeding power to each individual board. Each supply is capable of taking on the entire load by itself, with the two supplies diode-ORed together via power diodes to create a single 1 + 1 redundant supply. That is, the higher voltage supply delivers power to the load, while the other supply idly stands by. If the active supply voltage drops or disappears, due to failure or removal, the once lower-voltage supply becomes the higher voltage supply, so it takes over the load. The diodes prevent back-feeding and cross-conduction between supplies while protecting the system from a supply failure.

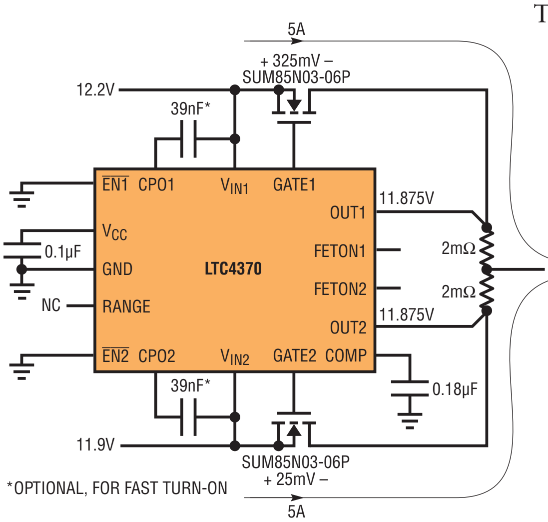


Figure 1. The LTC4370 balancing a 10A load current between two diode-ORed 12V supplies. Sharing is achieved by modulating the MOSFET voltage drops to offset the mismatch in the supply voltages.

The diode-OR is a simple winner-take-all system where the highest voltage supply sources the entire load current. The lower voltage supply remains idle until called into action. Although easy to implement, the 1 + 1 solution is inefficient, wasting resources that could be better used to improve overall operating efficiency and lifetime. It is far better for the supplies to share the load in tandem, offering several advantages:

- Supply lifetimes are extended if each takes on half the load, spreading the supply heat and reducing thermal stresses on supply components. A rule of thumb for the lifetime of electronics is that the failure rate of components halves for every 10°C fall in temperature. That's a significant dependability gain.
- Because the lower voltage supply is always operational, there is no surprise when transitioning to a backup supply that might have already silently failed—a possibility in a simple diode-OR system.
- It is possible in a load-sharing system to parallel smaller at-hand supplies to build a larger one.
- The recovery dynamics on supply failure are smoother and faster, since the supply changes are on the order of less and more, not off and on.
- A DC/DC converter formed by two supplies running at half capacity has better overall conversion efficiency than a single supply running near full capacity.

METHODS OF CURRENT SHARING

Connecting the outputs of multiple power supplies allows them to share a common load current. The division of the load current among the supplies depends on the individual supply output voltages and supply path resistances to the common load. This is known as droop sharing. To prevent back-feeding of a supply and to isolate the system from a faulting supply, diodes can be inserted in series with each supply. Of course, this added diode voltage drop affects the balance of the load sharing.

The LTC4370 introduces a new paradigm for current sharing, where the contributions from individual supplies are under full active control, but no share bus, with its extra wires, is required. Complete control is as easy to implement as a simple diode-OR droop sharing system, but the traditional passive diodes are replaced with adjustable diodes, with turn-on voltages that can be adjusted to achieve actively balanced current sharing.

Droop sharing is simple but sharing accuracy is poorly controlled, and the series diodes present a voltage and power loss. A more controlled way of current sharing is to monitor the supply current, compare it to an average current required from each supply, then adjust the supply voltage (through its trim pin or feedback network) until the supply current matches the required value. This method requires wires to every supply—a share bus—to signal the current contribution required from each. The current sharing loop compensation is customized to accommodate the power supply loop dynamics. Controlled current sharing requires careful design and access to all of the supplies—not possible in some systems.

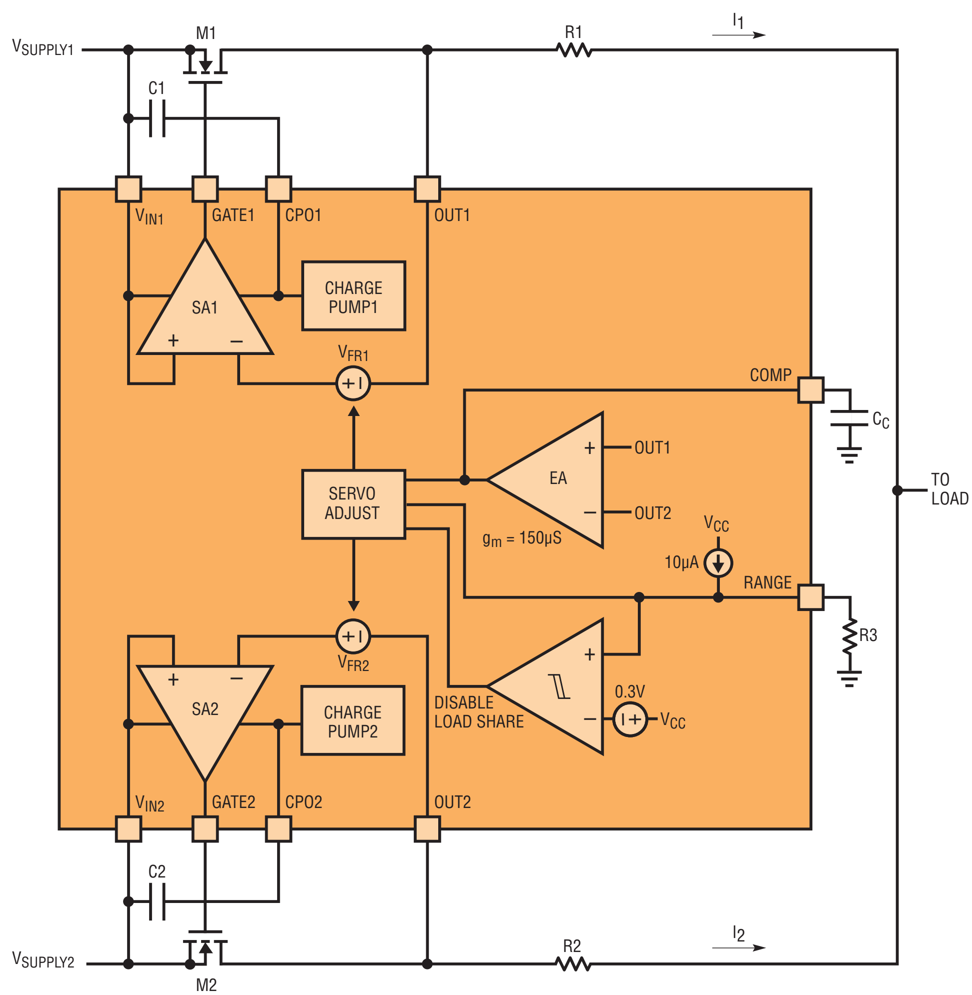
This article introduces a new method of current sharing, allowing active control of individual supply contributions, but with the simplicity of droop sharing. In this system, the diodes are replaced with adjustable diodes with turn-on voltages that can be adjusted to achieve balanced current sharing. This produces better sharing accuracy than droop sharing and the power spent in the adjustable diodes is the minimum required to achieve sharing, far less than that lost in a traditional diode. Because no sharing bus is required, it offers simpler supply-independent compensation and portable design. Supplies with difficult or no access to their trim pins and feedback networks are ideal for this technique.

THE CURRENT SHARING CONTROLLER

The LTC4370 features Linear Technology's proprietary adjustable-diode current sharing technique. It balances the load between two supplies using external N-channel MOSFETs that act as adjustable diodes whose turn-on voltage can be modulated to achieve balanced sharing. Figure 1 shows the LTC4370 sharing a 10A load between two 12V supplies

Figure 2 shows the device internals that affect load sharing. Error amplifier EA monitors the differential voltage between the OUT1 and OUT2 pins. It sets the forward regulation voltage V_{FR} of two servo amplifiers (SA1, SA2), one for each supply. The servo amplifier modulates the gate of the external MOSFET (hence its resistance) such that the forward drop across the MOSFET is equal to the forward regulation voltage. The error amplifier sets

Figure 2. Load-sharing-related internals of the LTC4370



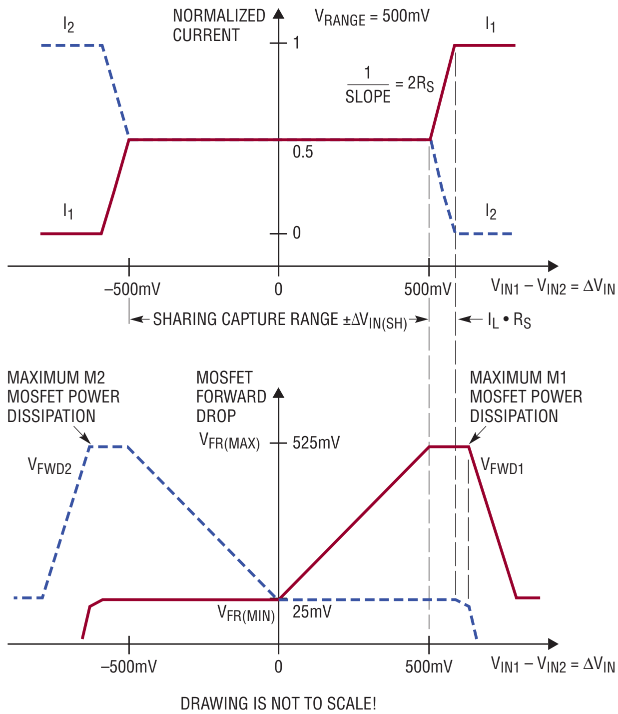


Figure 3. Current sharing characteristic of the LTC4370 method as the supply voltage difference varies.

the V_{FR} on the lower voltage supply to a minimum value of 25mV. The servo on the higher voltage supply is set to 25mV plus the difference in the two supply voltages. In this way both the OUT pin voltages are equalized. OUT1 = OUT2 implies $I_1 • R_1 = I_2 • R_2$. Hence, $I_1 = I_2$ if $R_1 = R_2$. A simple adjustment to different-valued sense resistors can be used to set up ratiometric sharing, i.e., $I_1/I_2 = R_2/R_1$. Note that the load voltage tracks 25mV below the lowest supply voltage.

The MOSFET in conjunction with the servo amplifier behaves like a diode whose turn-on voltage is the forward regulation voltage. The MOSFET is turned off when its forward drop falls below the regulation voltage. With increasing MOSFET current, the gate voltage rises to reduce the on-resistance to maintain the forward drop at V_{FR}. This happens until the gate voltage rails out at 12V above the source. Further rise in current increases the drop across the MOSFET linearly as $I_{FET} • R_{DS(ON)}$.

Given the above, when the error amplifier sets the forward regulation voltage of the servo amplifier, it is functionally equivalent to adjusting the turn-on voltage of the (MOSFET-based) diode. The adjustment range runs from a minimum of 25mV to a maximum set by the RANGE pin (see “Design Considerations” below).

The controller can load share supplies from 0V to 18V. When both supplies are below 2.9V, an external supply in the range 2.9V to 6V is required at the V_{CC} pin to power the LTC4370. Under reverse current conditions the gate of the MOSFET is turned off within 1µs. The gate is also turned on in under a microsecond for a large forward drop. The fast turn-on, important for low voltage supplies, is achieved with a reservoir capacitor on the integrated charge pump output. It stores charge at device power-up and delivers 1.4A of gate pull-up current during a fast turn-on event.

The $\overline{EN1}$ and $\overline{EN2}$ pins can be used to turn off their respective MOSFETs. Note that current can still flow through the body diode of the MOSFET. When both channels are off, the device current consumption is reduced to 80µA per supply. The FETON outputs indicate whether the respective MOSFET is on or off.

THE CURRENT SHARING CHARACTERISTIC

Figure 3 shows the current sharing characteristic of the LTC4370, adjustable-diode method. There are two plots, both with the supply voltage difference, $ΔV_{IN} = V_{IN1} – V_{IN2}$, on the x-axis. The top plot shows the two supply currents normalized to the load current; the lower shows the forward voltage drops, V_{FWDx}, across the MOSFETs. When both supply voltages are equal ($ΔV_{IN}$ = 0V), the supply currents are equal, and both forward voltages are at the minimum servo voltage of 25mV. As V_{IN1} increases above V_{IN2} (positive $ΔV_{IN}$), V_{FWD2} stays at 25mV, while V_{FWD1} increases exactly with $ΔV_{IN}$ to maintain OUT1 = OUT2. This is turn keeps $I_1 = I_2 = 0.5I_{LOAD}$.

There is an upper limit to the adjustment on V_{FWD} set by the RANGE pin. For the example in Figure 3, that limit is 525mV, set by the RANGE pin at 500mV. Once V_{FWD1} hits this limit, sharing becomes imbalanced and any further rise in V_{IN1} pushes OUT1 above OUT2.

The break point is $V_{FR(MAX)} – V_{FR(MIN)}$, where more of the load current comes from the higher voltage supply. When OUT1 – OUT2 = $I_{LOAD} • R_{SENSE}$, the entire load current transfers over to I_1. This is the operating point with the maximum power dissipation in MOSFET M1, since the entire load current flows through it with the maximum forward drop. For example, a 10A load current causes 5.3W (= 10A • 525mV) dissipated in the MOSFET. For any further rise in $ΔV_{IN}$, the controller ramps down the forward

The LTC4370's novel approach to load-sharing power supplies results in easy design, especially with supplies that don't lend themselves to on-the-fly tweaking. Inherent diode behavior protects supplies from reverse currents and the system from faulting supplies.

drop across M1 to the minimum 25mV. This minimizes power dissipation in the MOSFET for large V_{IN} when the load current is not being shared. The behavior is symmetric for negative ΔV_{IN}.

The sharing capture range in this example is 500mV and is set by the RANGE pin voltage. With this range the controller can share supplies that have a tolerance of ±250mV. This translates to the following: ±7.5% tolerance on a 3.3V supply, ±5% on a 5V, and ±2% on a 12V supply.

DESIGN CONSIDERATIONS

These are some of the high level considerations for a load share design.

MOSFET Choice — Ideally the MOSFET's $R_{DS(ON)}$ should be small enough that the controller can servo the minimum forward regulation voltage of 25mV across the MOSFET with half of the load current flowing through it. A higher $R_{DS(ON)}$ prevents the controller from regulating 25mV. In this case, the unregulated drop is $0.5I_L \bullet R_{DS(ON)}$. As this drop rises, the sharing break point (now defined by $V_{FR(MAX)} - 0.5I_L \bullet R_{DS(ON)}$) occurs earlier, shrinking the capture range.

Since the MOSFET dissipates power, up to $I_L \bullet V_{FR(MAX)}$ as in Figure 3, its package and heat sink should be chosen appropriately. The only way to dissipate less power in the MOSFET is by using more accurate supplies or by forgoing sharing range.

RANGE Pin — The RANGE pin sets the sharing capture range of the application, which in turn depends on the accuracy of the supplies. For example, a 5V system with ±3% tolerance supplies would need a sharing range of 2 • 5V • 3% or 300mV (higher supply is 5.15V while lower is 4.85V). The RANGE pin has a precise internal pull-up current of 10µA. Placing a 30.1k resistor on the RANGE pin sets its voltage to 301mV and now the controller can compensate for the 300mV supply difference (see Figure 4).

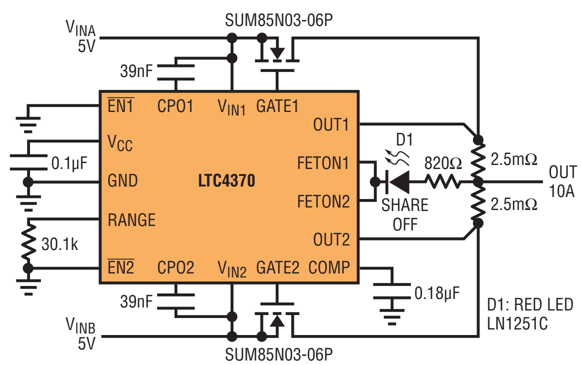


Figure 4. 5V diode-OR load share with status light. Red LED D1 lights up whenever any MOSFET is off, indicating a break in sharing.

Leaving the RANGE pin open (as shown in Figure 1) gives the maximum possible sharing range of 600mV. But when servo voltages approach the diode voltage, currents can flow through the body diode of the MOSFET causing loss of sharing. Connecting RANGE to V_{CC} disables load share to transform the device into a dual ideal-diode controller.

Compensation — The load share loop is compensated by a single capacitor from the COMP pin to ground. This capacitor must be 50× the input (gate) capacitance of the MOSFET, C_{ISS}. If fast gate turn-on is not being used (CPO capacitors absent) then the capacitor can be just 10× C_{ISS}.

Sense Resistors — The sense resistors determine the load sharing accuracy. Accuracy improves as resistor voltage drops increase. The maximum error amplifier offset is 2mV. Therefore, a 25mV sense resistor drop yields a 4% sharing error. The resistance can be lowered if power dissipation is more important than accuracy.

CONCLUSION

Balancing load currents between supplies is a historically difficult problem, conjuring visions of juggling on a tightrope. When power modules or bricks don't offer built-in support, some designers will spend significant time designing a well-controlled system (and redesigning it whenever the supply type changes); others will settle for crude resistance-based droop sharing.

The LTC4370 takes a completely different approach to load-sharing supplies than any other controller. It eases design, especially with supplies that don't lend themselves to on-the-fly tweaking, and it can be ported to various types of supplies. Inherent diode behavior protects supplies from reverse currents and the system from faulting supplies. The LTC4370 provides a simple, elegant and compact solution to a complicated problem. ■