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Current Sharing in Redundant Systems

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ABSTRACT

This application report describes a solution for *N+1* redundant systems that achieves both current sharing and OR-ing FET control. With current sharing, load current and power dissipation are distributed among multiple input power supplies. This architecture takes full advantage of the available system power supplies. OR-ing FETs are used to emulate low forward voltage diodes and reduce power dissipation with low R_{DSON} FETs. The combination of the current-sharing controller UCC39002 with the N+1 and OR-ing power rail Controller TPS2412 achieves true current sharing with reverse current protection. Test results are also presented.

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1 Introduction

A wide range of end user systems, including servers and telecom applications, often have either N+1 redundant power supplies, redundant power buses, or both. Redundant power sources must have the equivalent of an output diode OR to prevent reverse current during faults and hot swaps. Low forward voltage diodes are typically used as OR-ing devices to achieve this function. However, as onboard currents continue to increase, the power loss of the diode cannot be ignored any more, and the OR-ing diode thermal footprint can become quite large. An OR-ing FET controller such as the TPS2412, in conjunction with an external N-channel MOSFET, emulates the function of a low forward voltage diode and reduces conduction loss significantly. In most cases, this reduction is accomplished in the same or less area as the OR-ing diode. Figure 1 illustrates this type of redundant system.

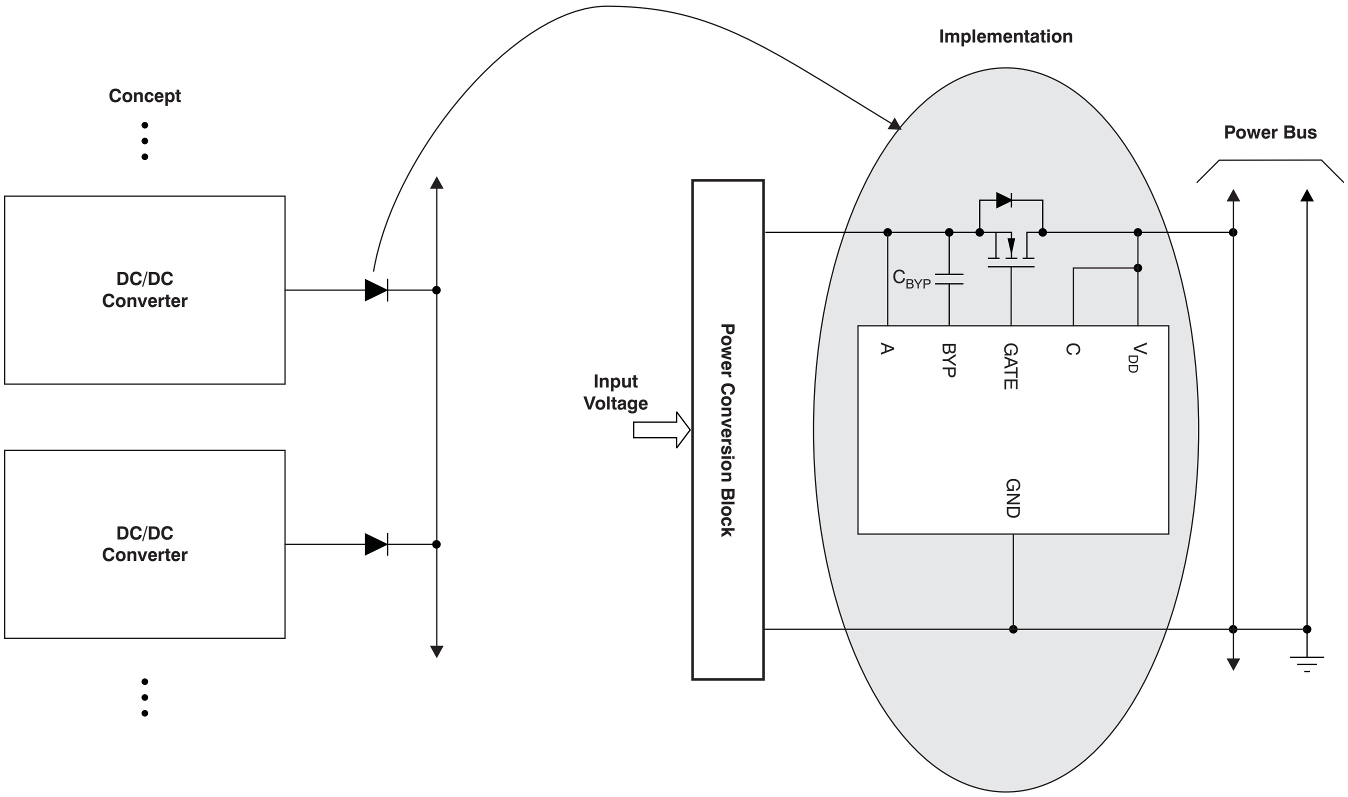


Figure 1. Redundant System Using TPS2412 OR-ing FET Controller

The *N+1* power-supply configuration shown in Figure 1 is used where multiple power supplies are used in parallel. The supplies are OR-ed together, rather than directly connected to the bus, in order to isolate the converter output from the bus when it is plugged in or a short occurs. If it requires *N* supplies to power the load, adding another extra, identical unit in parallel permits the load to continue operation in the event that any one of the N supplies fails.

The OR-ing diode can be replaced by low R_{DSON} MOSFETs and driven by an OR-ing FET controller. When simply employing OR-ing control without load sharing, it is possible to have all the MOSFETs on at once if the bus voltages are well matched. However, the tolerances of supply output voltage regulation, accuracy, and variations as a result of load transients make it very difficult to balance the current among the supplies. Current sharing has several features that improve overall system performance. For example, current sharing can equalize the load current and thermal stress among the different power supplies. This approach provides an advantage in terms of electrical component reliability; for example, Mean Time Between Failure (MTBF) roughly doubles with every 10°C decrease in operating temperature. Enforcing proper load sharing can also result in using power supplies with lower nominal ratings because of the reduced current in each. This technique, in turn, can translate into an overall lower system cost.

There are several typical load sharing methods, including the droop approach, using a dedicated master, the average current and highest current techniques, and so on. It is important to understand and select the correct control method because it is possible that not all of the output OR-ing devices may be on, depending on the bus loading, distribution resistances, and OR-ing controller settings.

The UCC39002 is an advanced, high-performance load sharing controller that implements an automatic master/slave architecture. The paralleling power modules/supplies that co-operate with the UCC39002 should be equipped with true remote sensing or access to the feedback divider of the module error amplifier.

With the appropriate power modules applied, the combination of the UCC39002 and the TPS2412 can thus achieve current sharing as well as OR-ing FET controlling function for and *N+1* redundant system. The test results discussed in the following section are based on the combination of the UCC39002EVM (HPA027A) and the TPS2412EVM (HPA227) (refer to Figure 2) that demonstrates the feasibility of the proposed solution. The OR-ed bus voltage is 5-V regulated and the delivered current is 10 A. Each module can deliver 12 A (maximum) in case either module falls into failure mode. To implement current sharing, both modules have a remote sense feature.

The conduction loss in the power path according to different designs is:

- OR-ing FET (CSD16403Q5A) with a current-sharing function (5 A each loss of R_{sen} included):
  $P_{Diss} = 2 \times (I_d/2)^2 \times R_{DSON} + 2 \times (I_d/2)^2 \times R_{sen} = 0.435$ W
- OR-ing FET (CSD16403Q5A) without current-sharing function:
  $P_{Diss} = I_d{}^2 \times R_{DSON} = 0.37$ W
- OR-ing DIODE (STPS10L25D):
  $P_{Diss} = 0.22 \times I_{F(AV)} + 0.013 I_F{}^2{}_{(RMS)} = 3.5$ W

In this system, a loss of approximately 3 W can be saved by replacing the OR-ing diodes with OR-ing FETs and current sharing. This new design results in an efficiency improvement of ±2.5%. Figure 3 shows the load sharing error for the two input modules. Greater than 2.5% accuracy is achieved at full load.

Figure 4 and Figure 5 show the operating conditions when module 2 is enabled/disabled or running into a short.

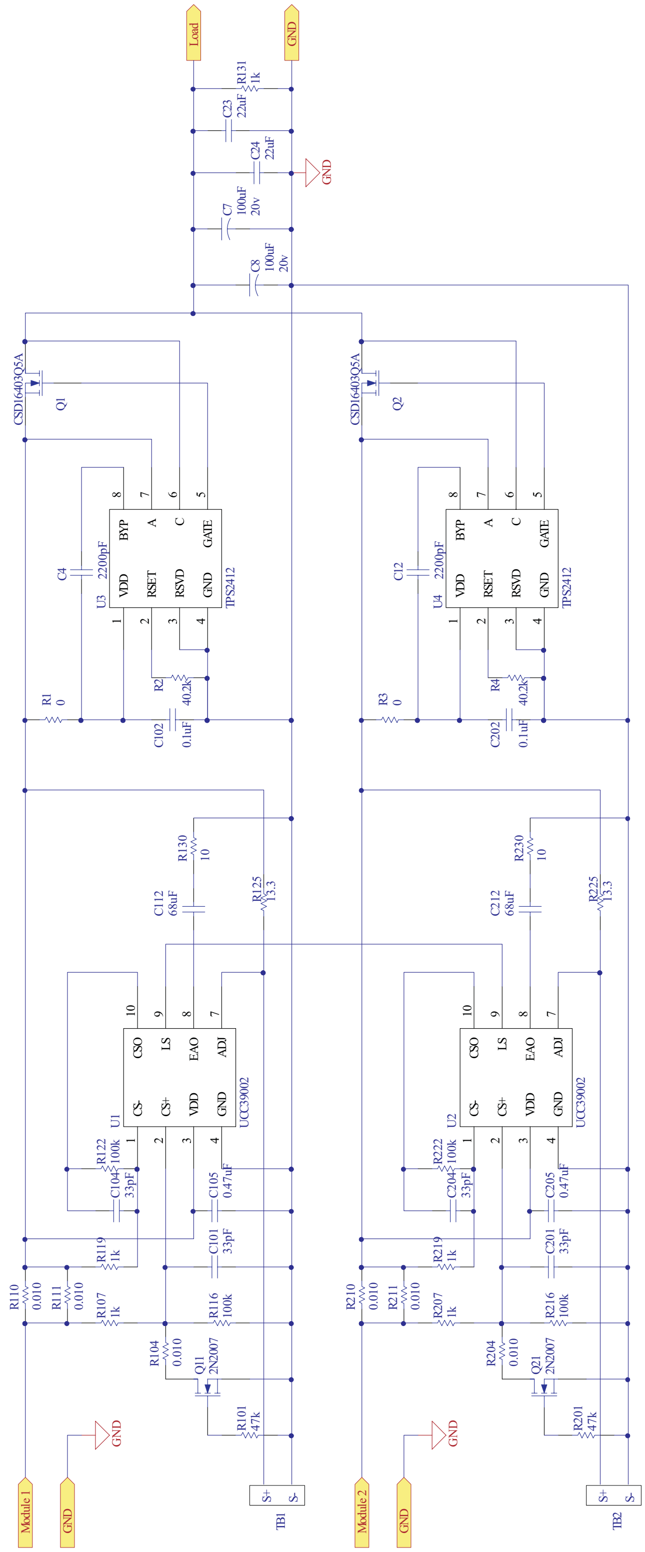


Figure 2. UCC39002+TPS2412 for Current Sharing and Redundant Solution

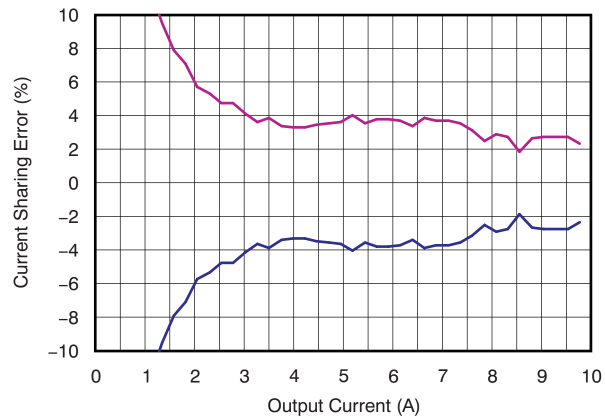
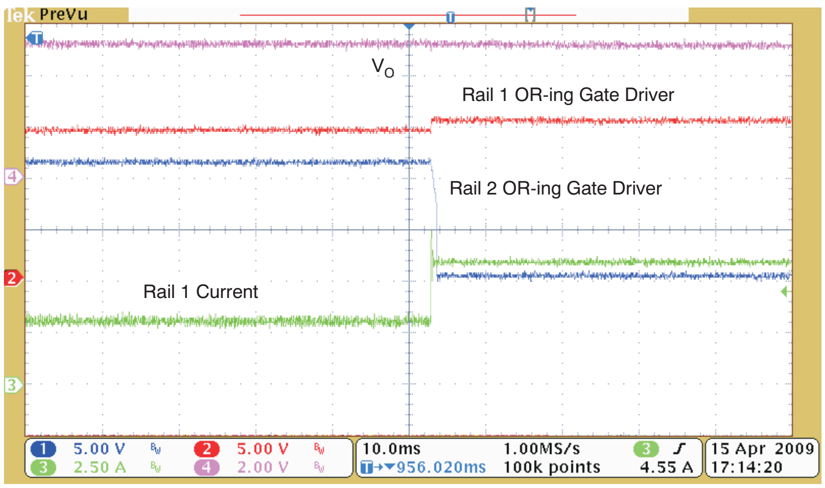


Figure 3. Load Share Error Result for Two Rails



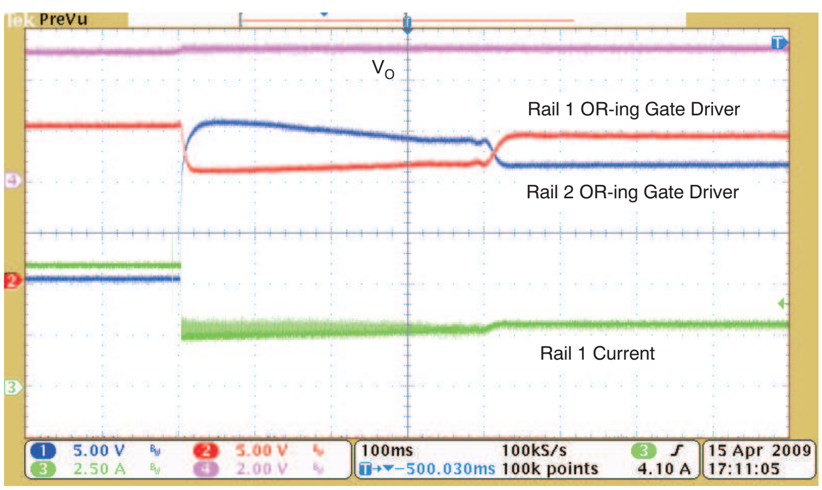


Figure 4. Rail2 Disabled/Enabled for Redundant System (Load current 6A)

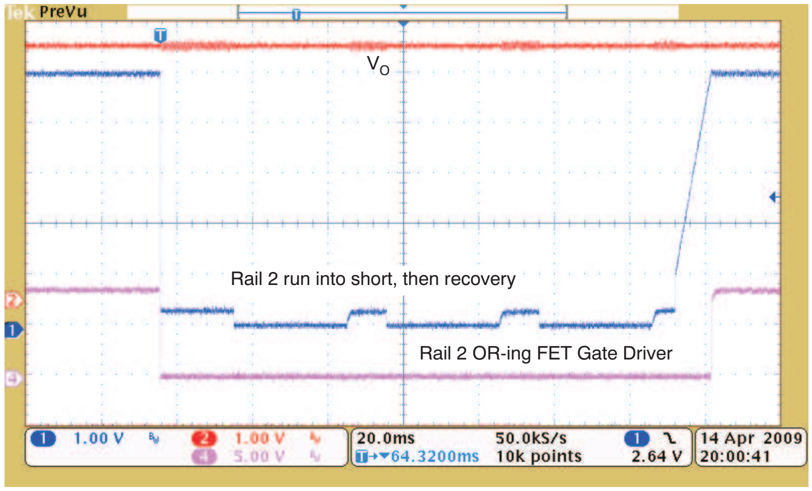


Figure 5. Rail 2 Run Into Shorted Then Recovery

In Figure 2, power resistors are used for current-sharing sensing. However, increasing the onboard current requires high-power resistors, or the use of several resistors in parallel to manage the I^2R losses. Figure 6 shows another current sense method that simply uses the OR-ing FET $R_{DS,On}$. In this way, ADJ resistors R125 and R225 are connected to the OR-ed voltage bus after OR-ing FETs. This connection change helps to simplify the UCC39002 control loop because the ADJ connection for both controllers is now a fixed common point. With the ADJ resistors connected before the OR-ing controller as shown in Figure 6, the fact that the OR-ing controller can turn the FET on or off may result in unwanted oscillations. To prevent such oscillations, the current-sharing controllers keep the two OR-ed rails active and the TPS2412s turn the MOSFETs on with a linear control loop that regulates $V_{(AC)}$ to 10 mV. If the V_{DS} across the FET exceeds this value, the gate drive of the TPS2412 is clamped to its maximum value. In light load conditions, regulating each FET VDS to 10 mV ensures that the two input voltage rails are very close while no current information is delivered to current sharing controllers. In light load mode, the current distribution in two rails primarily depends on the module voltage droop characteristics and the run impedance. When sensing FET V_{DS}, the current-sharing balance at light loads is not as tight as only sensing power resistor voltage as Figure 7 shows. However, it achieves much higher performance as load current increases; the balance accuracy is better than 1% when $R_{DSON} \times I_{(DRAIN)}$ exceeds 10 mV. Additionally, at light loads, it is less critical to have very tight matching because there is less of a load to share and the power supplies are not working too hard.

Figure 7 shows the test results with the two sense methods. This approach is advantageous because under light loads, the benefit of sharing is significantly less than the benefit of sharing at heavy loads. Under conditions where light load current sharing accuracy is still desired, the TPS2413 (which turns the MOSFET on and off as a comparator with hysteresis) could be a different option. The TPS2413 can achieve high current-sharing balance over the load range. The disadvantage for the TPS2413 in this application is that the turn-off threshold must be negative to avoid an unstable condition under light loads (unless a minimum load is always present), thus permitting a continuous reverse current. Appropriate OR-ing controllers and a current-sharing sense method should be considered according to different system requirement.

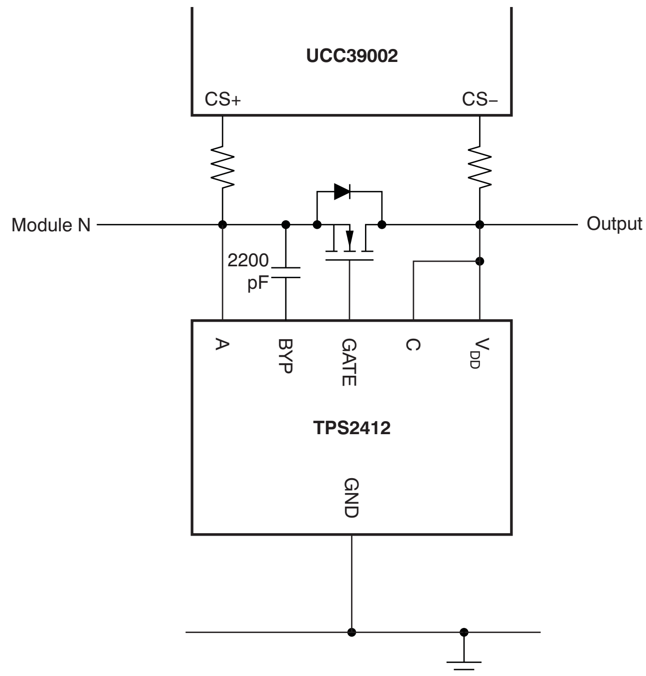


Figure 6. OR-ing FET $R_{DS,On}$ Used for Share Current Sensing

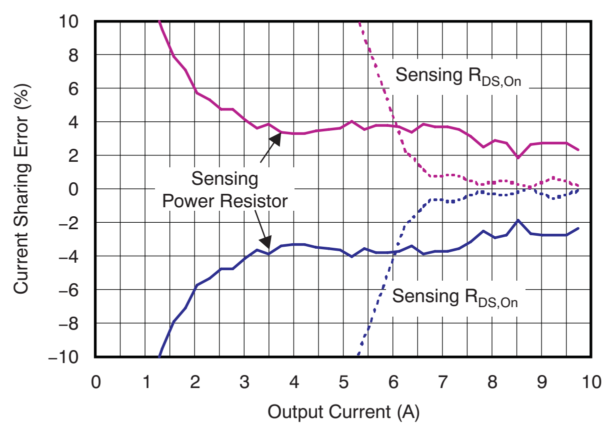


Figure 7. Current Sharing Error Result Using Different Current Sense Methods

2 Conclusion

In redundant systems, two or more power supplies are used in parallel to improve reliability. To maximize reliability, the load current should be shared equally among these modules. Current-sharing technology in combination with OR-ing FET control can help achieve precision sharing in redundant systems, which results in cooler, more efficient, and more reliable systems. The OR-ing FET can be used as a current-sensing element as well as an OR-ing device, which further improves system efficiency.

3 References

1. UC3907 Load Share IC Simplifies Parallel Power Supply Design (U-129)
2. UCC39002 Advanced Load-Share Controller User's Guide (HPA027A)
3. UCC39002: Advanced 8-Pin Load-Share Controller (SLUS495H)
4. TPS2412: N+1 and ORing Power Rail Controller (SLVS728B)
5. TPS2412/13 Evaluation Module (HPA227)
6. Operational Differences TPS2410/11/12/13 (SLUA417)

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