Cascaded ideal diodes: Solving 48V EV power challenges

Shiven Dhir
Applications Engineer
Input Power Protection and Distribution

Rakesh Panguloori
Applications Manager
Input Power Protection and Distribution

The increased use of 48V battery subsystems, in addition to conventional 12 V networks, is causing a noticeable change in the design of HEV/EV power systems. 48V delivers more power without the penalty of heavy cabling to reduce the power loss in the wire harness leading to extended drive range. With this change, the vehicle power distribution architecture is transitioning from traditional centralized to zonal approach where power distribution, communication and load actuation are grouped together based on location in the vehicle rather than by function, as shown in **Figure 1.** Zonal architecture reduces system complexity and gives original equipment manufacturers (OEMs) more modularity.

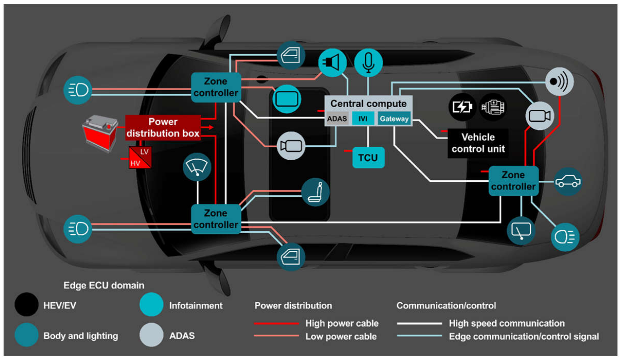

Figure 1. *A zone architecture in a modern vehicle*

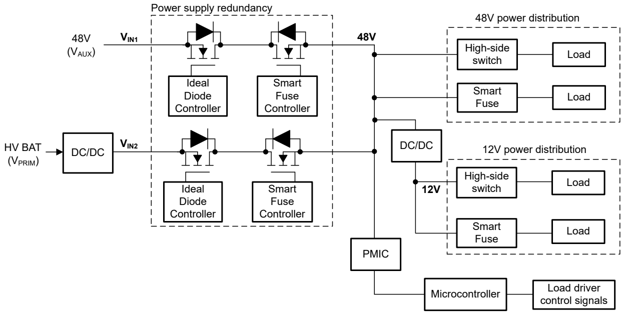

Figure 2. *Typical power distribution in a zone control module*

Figure 2 shows a typical power distribution where multiple power sources are used to realize redundant power supply for a zone control module. Ideal diodes, as discussed in the white paper, "**Basics of Ideal Diodes**," are great for applications that require reverse current blocking and/or reverse polarity. Since ideal diodes offer reverse current protection, they are also useful in applications where combining multiple supplies increases system redundancy **[2]**. However, the existing ideal diode controllers in the market are only rated for 72V absolute max and have limitations to support certain 48V system designs.

This article discusses the challenges of designing an ORing stage for a 48V system and how a cascaded ideal diode configuration enables a reliable ORing solution to safely handle the input supply interruptions and external transient events.

Challenge 1: High voltage stress during reverse supply fault

As seen in **Figure 2,** primary power distribution requires seamless power. High voltage battery (VPRIM) is stepped down by a DC/DC converter for a 48V rail and then a backup 48V auxiliary supply (VAUX) provides a redundant supply when ORed. In case of reverse polarity fault at VIN1, the DC/DC converter output VIN2 powers the entire load as shown in the simplified illustration **Figure 3**. However, this causes high voltage stress for the ORing on the auxiliary supply path. A 48V source can reach a maximum of 54V to create the large voltage difference of 108V between CATHODE to ANODE pins of the controller **LM74700D-Q1**, exceeding the absolute max rating of 75V. The solution also requires at least 120V-rated MOSFETs that are comparatively more expensive than 60V FETs and are hard to multi-source.

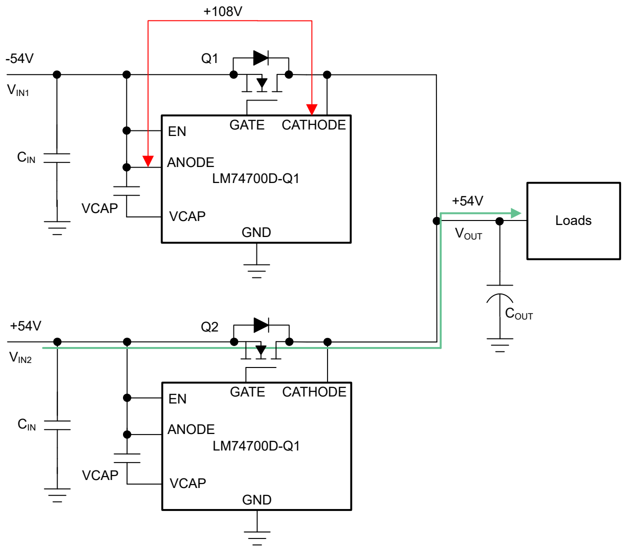

Figure 3. *Voltage stress under input reverse polarity condition*

Challenge 2: Compliance to LV148 load dump and switching transients

Transient overvoltage may occur in the electric system due to the switching off loads and short accelerator tip-ins. For 48V systems, the standards available today (ISO 21780 and Liefervorschriften [LV] 148) specify the E48-02 transient overvoltage profile, shown in **Figure 4**. This profile goes up to 70V and stays there for 40 ms, and some OEMs even require 100ms. The device under test (DUT) must survive these events with Functional Status A, and the DUT must perform all the functions. Note that clamping using TVS or Zener diodes is impractical for such high power and wider transients. Simply said, integrated circuits connected directly to the 48V rail must withstand 70V under all conditions. But. when factoring for switching transients or component margin, the devices should support much greater than 70V. The existing ideal diode controllers with 72V absolute max rating from ANODE to GND leave less margin for the system designers.

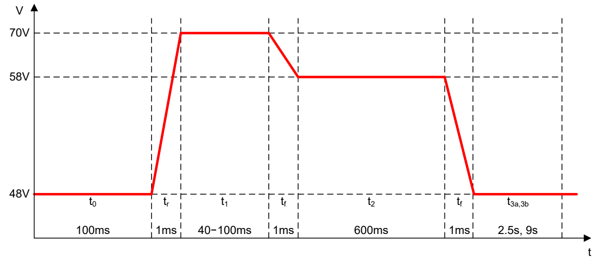

Figure 4. *The E48-02 transient overvoltage profile from LV 148*

Single controller-based solution

Figure 5 shows a solution using a single **LM74700D-Q1**, but using a Zener clamp circuit reduces the large voltage difference of 108V between the CATHODE to ANODE pins of the controller. The Zener diode DZ can limit the voltage between CATHODE to ANODE below its absolute max rating (75V) and the resistor RZ can bias DZ appropriately. However, the solution still requires at least 120V rated MOSFETs which are comparatively expensive than 60V FETs and are hard to multi-source. Also, in normal operation the resistor RZ causes additional drop in the CATHODE path, which impacts the reverse current protection threshold.

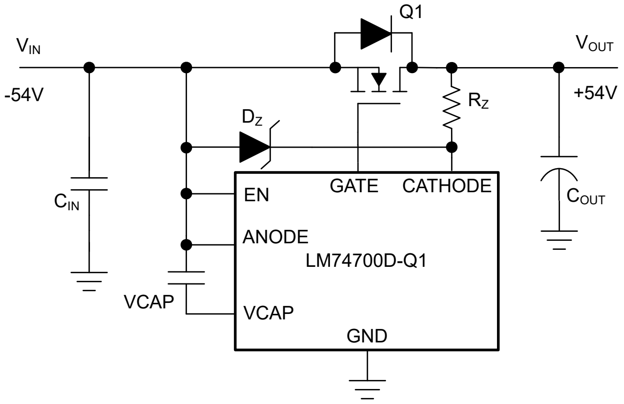

***Figure 5.** Solution with single high voltage MOSFET*

Proposed cascaded ideal diode configuration

The proposed solution uses two ideal diode controllers with respective MOSFETs Q1 and Q2 connected in series configuration, as shown in **Figure 6**. The clamping circuits of each controller not only ensure keeping CATHODE to ANODE below 75V but also act as an equalizing network to share equal voltage between Q1 and Q2 during fault events. Let us consider how the circuit works for two common fault scenarios

Case 1: During startup, with the output (VOUT) powered at 54V and input VIN at 0V, the mid-point voltage VMID stays at 0V. The second **LM74700D-Q1** controller keeps GATE2 shut-down due to reverse current blocking scenario with VOUT > VMID and Q2 blocks 54V. In this case, the user applies reverse voltage of 54V at VIN, and the first LM74700D-Q1 controller keeps GATE1 in OFF state due to a reverse polarity scenario with ANODE < 0V and Q1 blocks 54V.

Case 2: In this scenario, VIN starts in fault state (at -54V, for example) and then the system is powered up with VOUT = 54V. The mid-point voltage VMID stays at 0V as the first **LM74700D-Q1** controller keeps GATE1 in OFF state to block reverse voltage at VMID. Similarly, the second **LM74700D-Q1** controller keeps GATE2 shut-down due to reverse current blocking condition. Both MOSFETs Q1 and Q2 incur voltage stress of 54V. Because the voltage across MOSFETs is below 60V during the fault cases, the solution provides flexibility for the customer to select legacy 60V-rated FETs that are easy to multi-source.

As seen in **Figure 6**, the solution also incorporates a transient clamping network (DC, Q3, RB and DB) in the ground path to handle switching transient voltages beyond the absolute max rating of the LM74700D-Q1. In normal operation, the potential difference between device ground and system ground is just VBE of Q3, but whenever VIN exceeds the breakdown voltage (VBR-DC) of diode DC, the transistor Q3 drops voltage across it and lifts up the device ground potential. This helps to limit the ANODE-GND voltage of the **LM74700D-Q1** close to the breakdown voltage of DC, facilitating a scalable transient handling solution. The purpose of diode DB is to block the reverse current path under input supply reverse condition.

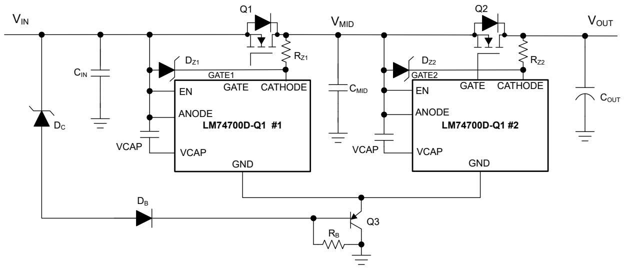

***Figure 6.** Cascaded ideal diode configuration*

Component selection and test results

It is important to consider how to select the key components in the system to achieve these results.

For the **Ideal diode MOSFETs Q1 & Q2**, a 60V VDS(MAX) with +/-20V VGS(MAX) provides enough margin for all the fault conditions. RDS_ON at nominal current: (20 mV/Nominal Current) ≤**RDSON**≤ (50mV/Nominal Current) is important to have lower reverse current. For example, in a 5A design, RDS_ON ranges from 4 mΩ to12.5 mΩ.

The MOSFET gate threshold voltage Vth should be at 2V maximum.

The **PNP transistor Q3** sees the maximum voltage drop after the Zener diode DC is activated and should be rated for voltage greater than (VIN-MAX – VBR-

DC). It also must support the quiescent current of the LM74700D-Q1, which is less than a mA. A transistor like BC857-Q can be used.

For **Zener diodes DZ1 & DZ2:** a 62V Zener like BZX84J-B62 should be chosen to limitCATHODE to ANODE below 75V.For **Zener diode DC,** the breakdown voltage (VBR-DC) of DC determines the clamping voltage between ANODE-GND pins for switching transients on VIN. Utilizing a 62V Zener like BZX84J-B62 can limit the voltages with enough margin for the LM74700D-Q1.The **blocking diode DB** should have blocking voltage capability close to the maximum input supply reverse voltage, so choose at least a 60V-rated diode like the NSR0170P2T5G.

Resistors RZ1 & RZ2are biasing resistors for DZ1 & DZ2. Any value in the range of 1 kΩ to 2 kΩ should be sufficient. **Resistors RB** is the biasing resistor for DC, and any value in the range of 10 kΩ to 47 kΩ will suffices.

Figures 7 and **8** show the drain-source voltage distribution across MOSFETs when input reverse polarity is applied before system startup and after system startup. As seen, the MOSFETs share equal voltage with maximum voltage of <60V across each MOSFET. **Figure 9** shows the performance of the ground path transient clamping network where the ANODE to IC-GND is clamped to 62V for 70V load dump event at VIN.

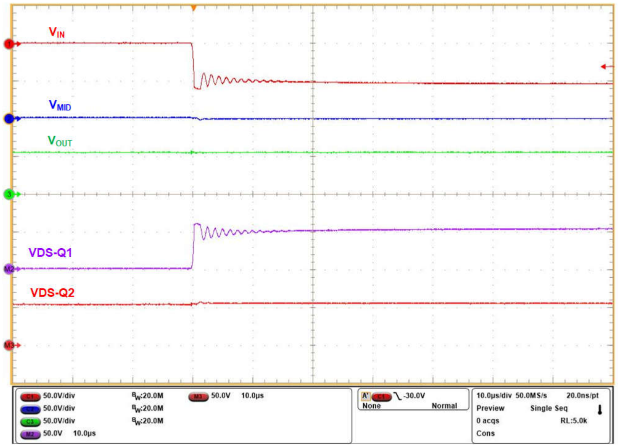

Figure 7. *Voltage sharing across MOSFETs during input reverse polarity condition*

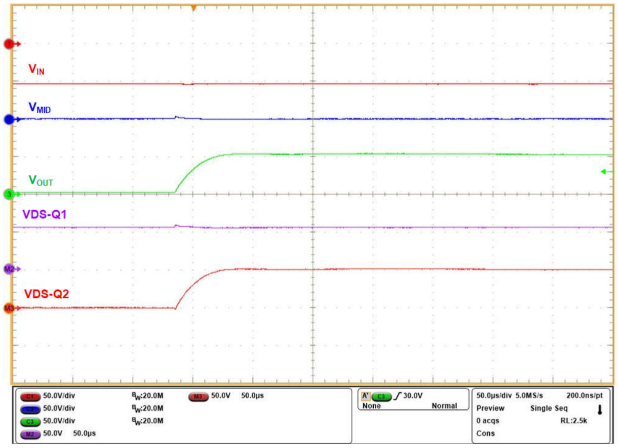

Figure 8. *Voltage sharing across MOSFETs during hot-plug at the output (VIN = -54V)*

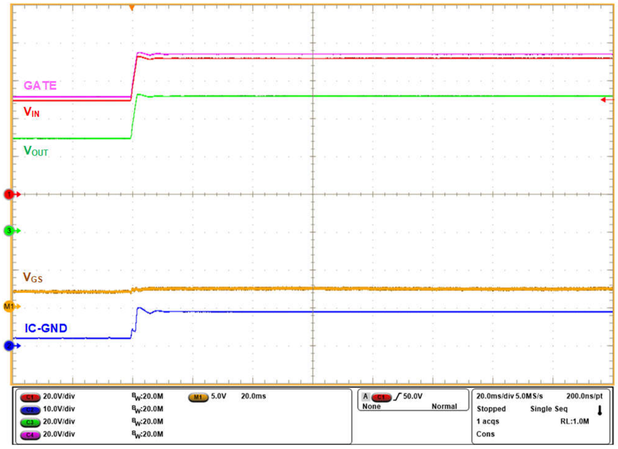

Figure 9. *Response of proposed solution to 70V load dump event*

Conclusion

While 48V systems offer many benefits, they also bring a new set of challenges for redundant supply ORing in power distribution stages. The proposed cascaded ideal diode configuration with ground path transient clamping network enables system design with legacy 60V-rated FETs that are easy to multi-source. The proposed approach also provides adequate voltage margin for switching transients, enabling a reliable ORing solution in 48V systems.

References

1. **Basics of Ideal Diodes**” Texas Instruments application report, literature No. SLVAE57B, February 2021.
2. “**Redundant supply topologies for automotive applications using ideal diode controllers**” Texas Instruments Analog Design Journal, literature No. SLYT848, March 2024.
3. Texas Instruments, **LM74700D-Q1 Automotive Low IQ Reverse Battery Protection Ideal Diode Controller**, Data Sheet.

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