

Protection of High-Voltage Power Supplies (HVPSs) in Single and Multiple HVPS Applications

If electrical equipment is exposed to extreme operating environments well beyond its ratings, then its useful life will shorten. Although UltraVolt high-voltage power supplies (HVPSs) have many internal protection mechanisms, there are a few applications in which supplemental external protection circuitry or special mounting procedures are recommended to achieve maximum performance. These special mounting procedures and supplemental circuits will also assure the longevity of the UltraVolt HVPS while it is exposed to these extreme environments.

Different applications will require different supplemental protection circuitry, depending on the anticipated faults the power supply may encounter. The UltraVolt high-voltage power supply has enough internal protection mechanisms, including an internal softening resistor and pulse-by-pulse current limiting, to adequately deal with HV output short-to-ground faults.

Faults and special situations that require supplemental protection circuitry include arcing between supplies of opposite polarity, a higher voltage HVPS arcing to a lower voltage HVPS, plasma discharge through an HVPS, high-speed current spikes, or opposite-polarity voltage spikes. These occurrences require supplemental protection circuitry in order to ensure satisfactory operation of the UltraVolt HVPS.

In addition to the above, there are also recommended mounting and electrical connection procedures which, if applied, will allow maximum reliability from the HVPS.

Special supplemental circuitry and procedures can be divided into two classifications: those applicable to both single and multiple HVPS systems and those applicable to only multiple HVPS systems. High-speed, high-energy pulse-application safeguards are covered in their own section in this application note due to the unique nature of the problems confronted in those applications.

Special Circuitry and Procedures Applicable to Both Single and Multiple HVPS Systems

It is strongly recommended to connect UltraVolt high-voltage power supplies electrically using the proper sockets, either PCB mounted or on a cable harness. Connections can, however, be made by soldering directly to the pins, as long as a few precautions are followed. When soldering to the pins, the maximum soldering-iron temperature of 300°C (570°F) should be applied for a maximum of 15 seconds. Exceeding these recommended maximums may result in internal damage to the HVPS.

The high-voltage power supply should be mechanically mounted so it does not impart any undue stress to its case, while allowing the HVPS to transfer its heat - if applicable to your particular unit - to an external heat sink using a thermal pad, paste, or grease. If a heat sink is required, see Application Note #6 on thermal management.

Regarding the supply-power and control-signal low-voltage sections of the UltraVolt HVPS, as long as a few guidelines are followed, trouble-free operation of the HVPS will be attained.

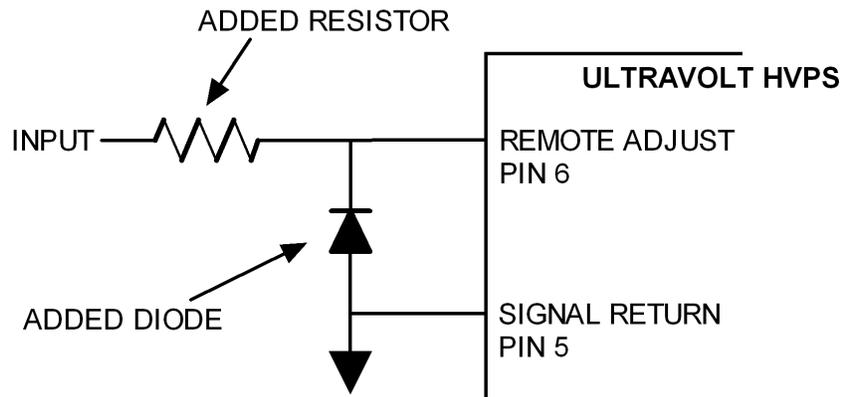
The supply voltages of UltraVolt HVPSs should never exceed the absolute maximum: 32V maximum supply input for 12V, 24V, or 28V units. The supply power for the high-voltage power supply should be fused and equipped with a tranzorb rated for approximately 32V.

In certain configurations, a voltage of greater than 5V may need to be applied to the *Remote Adjust Input* terminal (pin 6). These configurations usually involve negative HVPSs in which the user does

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not use the internal 5V reference, but still needs to adjust the HVPS's output voltage to 0 volts. In any case, the voltage applied to the *Remote Adjust Input* terminal (pin 6) must not exceed 6 volts for an extended amount of time, since this will cause excessive internal stress to the HVPS.

In no case should the *Remote Adjust Input* terminal (pin 6) be taken to less than -1VDC, since this will damage the high-voltage power supply. In applications where there is a possibility of the remote adjust input going negative, external protection circuitry must be employed to ensure the reliability of the HVPS. This protection circuitry consists of a current-limiting resistor in series and a shunt diode to ground.



The added shunt diode is a standard low forward voltage drop diode (for example, the low-cost 1N4001), and the added resistor is chosen to limit the current (for example, a 1kΩ resistor would limit a -5V input remote adjust input to 5mA).

A voltage greater than 6V should not be applied to the *5VDC Reference Output*. Should this occur, excessive heating within the HVPS will result.

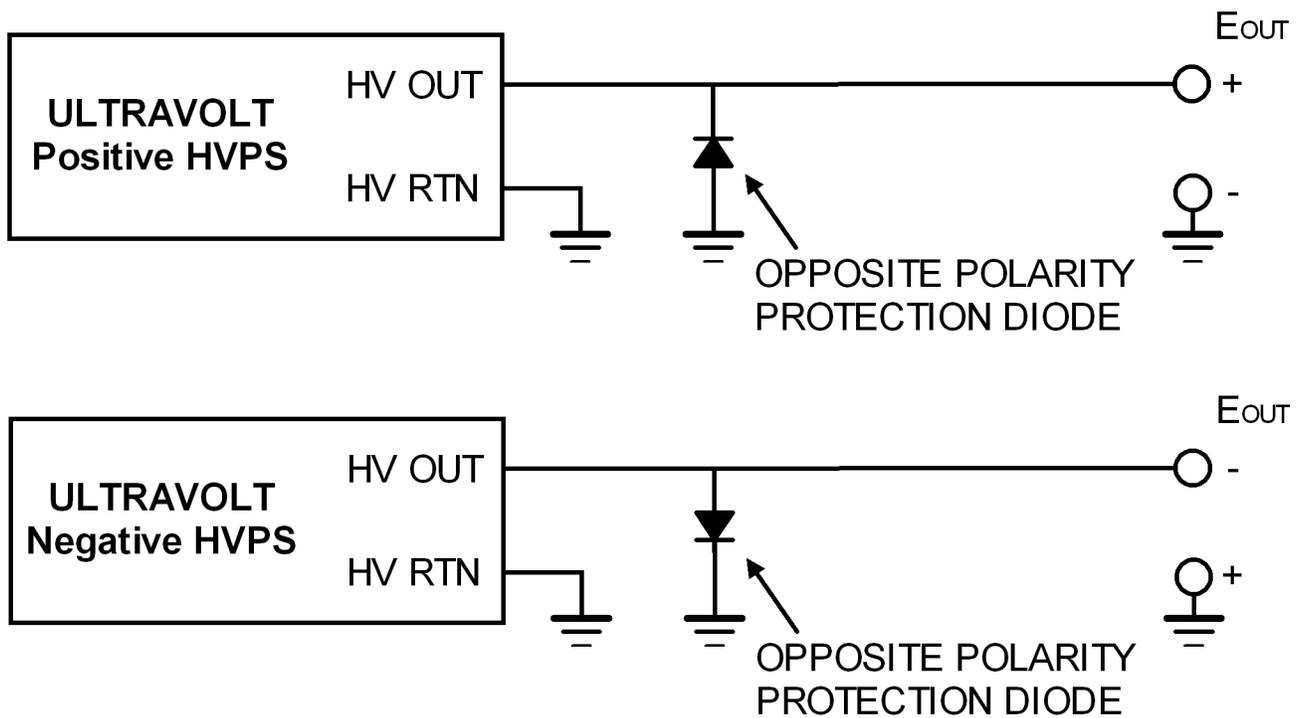
The signal-return pin must not be allowed to carry a large amount of current, but it can safely carry the return currents for the signal voltages. However, should this pin also carry the supply return current, instead of allowing this current to be safely carried by the *Input Power Ground Return* pin, damage may be done to the HVPS. Although the *Input Power Ground Return* and *Signal Ground Return* are internally connected, the *Signal Ground Return* pin cannot be used as an alternative for the *Input Power Ground Return* pin.

Special circuitry and procedures applicable exclusively to multiple HVPS systems

As long as no faults can occur, multiple UltraVolt high-voltage power supplies can reliably form a multiple-voltage power-supply system. For long-term reliability and performance however, it is recommended that multiple HVPS systems have supplemental protection circuitry added to each supply to protect the high-voltage power supplies against normal fault conditions. Since each UltraVolt HVPS is fully short-circuit protected, only interactions between HVPSs of different polarities, or of very different voltages, need to concern the designer.

A. Protecting an UltraVolt HVPS from another supply of different polarity

Should two supplies of different polarity arc to each other, each HVPS will try to supply its rated current. If the supplies have different current limits, such as supplies of different power ratings but voltages equal in magnitude, the lesser current capable supply may be forced to sink or source current beyond its capability. This scenario will over-stress the lesser current capable supply, possibly damaging it. However, using a simple reverse-biased diode on the output of the HVPS to ground, the UltraVolt high-voltage power supply can be protected from the damage which would otherwise occur from the output being exposed to an opposite polarity, higher current supply.

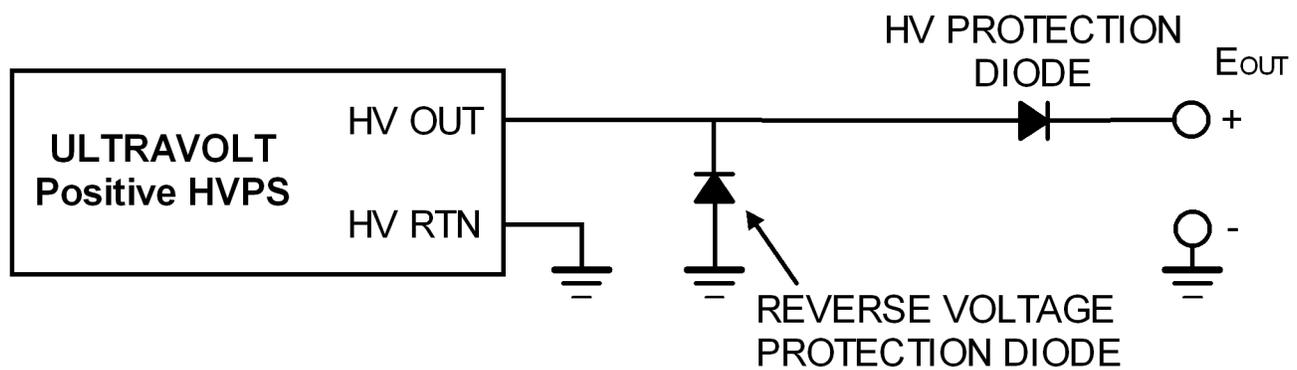


An example of a multiple HVPS system, see text for component discussion.

Referring to the above diagram, the reverse-biased ‘Opposite Polarity Protection’ diode must have a reverse-breakdown voltage higher than the highest voltage HVPS of the same polarity in the system. This diode must also be able to carry all of the current of the highest current rated opposite polarity supply.

B. Protecting an UltraVolt HVPS from another supply of higher voltage

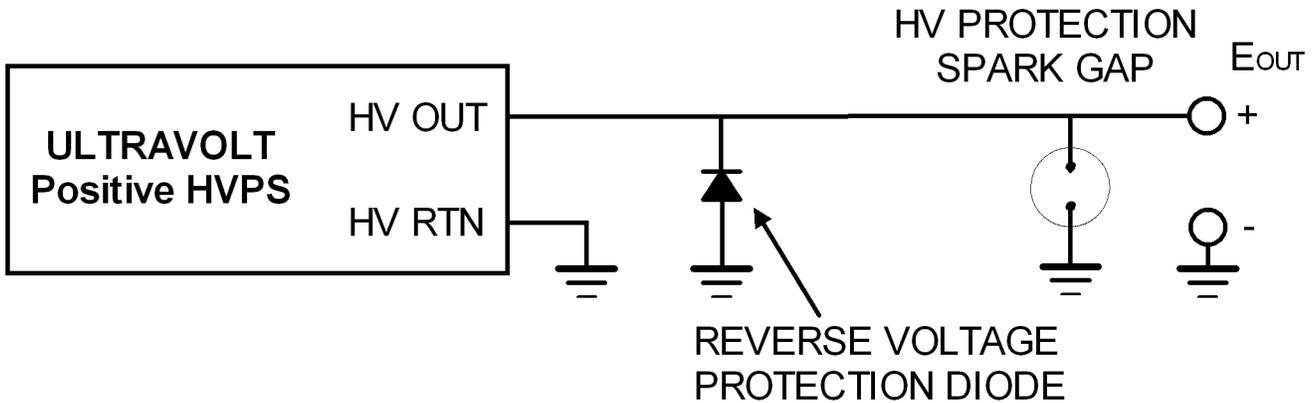
When two supplies of the same polarity but of much different output voltages arc to each other, over-voltage damage can be done to the lower voltage supply. This damage may occur because the output-diode reverse-breakdown voltage rating of the lower voltage supply may not be as high as the output voltage of the higher voltage supply. Potentially, the output diodes of the lower voltage supply could be damaged, causing the HVPS to fail. Although all UltraVolt HVPSs use output diodes that have reverse voltage ratings that are much higher than the voltage rating of the HVPS, they may not handle a high-voltage arc that is many times the voltage rating of the lower voltage supply. This problem is easily solved by adding a high-voltage protection diode to the lower voltage supply.



Circuit from A. with a HV protection diode added.

Referring to the diagram, protection from a high-voltage arc can be achieved with a single high-voltage diode. This added diode should have an open-air, reverse-voltage breakdown rating equal to the highest voltage HVPS of the same polarity in the system. The current rating of this diode should be the greater of the maximum current that can be drawn from the protected HVPS or the maximum current that can be supplied by any of the oppositely polarized HVPSs in the system. With this HV protection diode in place, an arc from a higher voltage HVPS will not damage the lower voltage HVPS, since the arc will not have sufficient voltage to reverse breakdown the HV protection diode.

Alternately, a spark gap can be used to protect the supply from arcs originating from a higher voltage HVPS. The arc-over point of the spark gap should be slightly higher than the peak voltage of the HVPS being protected.



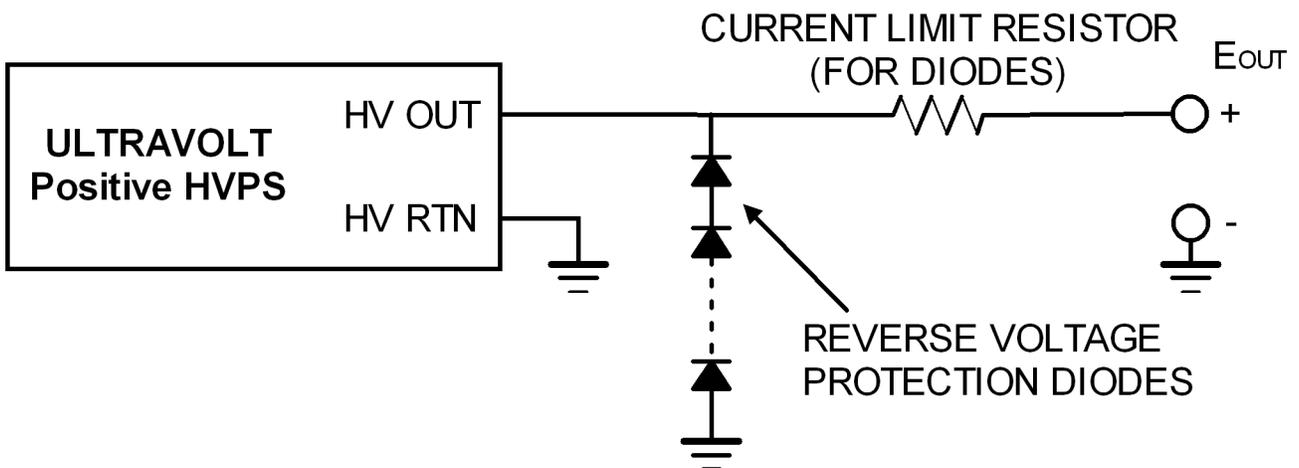
HV protection diode replaced with a spark gap.

The spark gap will also protect against plasma-discharge damage to the HVPS. The spark gap device must be rated to discharge all of the energy of the plasma safely.

Protecting an UltraVolt HVPS in high-speed, high-energy pulse applications

High-speed, high-energy pulse applications can create very large current spikes, which could potentially harm the power supply unless the proper precautions are taken. High-speed switching, with its fast rise-and-fall times, will create large high-frequency current and voltage spikes which must be attenuated.

Voltage spikes of the opposite polarity to that of the power supply (for example, from inductive effects) can be easily managed with a couple of high-voltage, high-speed, low forward-voltage-drop diodes and a resistor.



A negative high-voltage power supply will simply have the diodes in the above diagram reversed. The diodes here should have fast switching times, less than 100nS (in order to protect the HVPS from quick, opposite-polarity pulses), low forward-voltage drop (for example, 14V), and a high reverse-standoff voltage rating. The reverse-standoff voltage rating of the diodes utilized determines the number of diodes required. For example, a 10kV HVPS will require three 5kV diodes or one 15kV diode. The current limit resistor's value should be chosen to limit the maximum peak current through the diodes, common values normally being in the 1Ω to 100Ω range (to determine an exact value would require a high-frequency oscilloscope to view the amplitude of the reverse voltage spikes; it is easier to choose the largest resistance value that does not prohibitively degrade HVPS performance, and yet still prevents over-current damage to the diodes).

Grounding Considerations

Very large current spikes can also be troublesome to high-voltage power supplies. During the initial system configuration and prototyping, voltage levels across external ground connections should be checked and improved (if necessary). It would also be prudent to check the voltage between the *HV Ground Return* and the *Input Power Ground Return* of the HVPS unit. If a noticeable voltage occurs between the *HV Ground Return* and the *Input Power Ground Return*, then an external connection between these pins should be established. As long as the proper precautions are taken, the UltraVolt HVPS will operate under high-speed/high-energy switching applications.

High-voltage-power-supply grounding schemes are critical to assuring proper performance and reliability. Each ground should be connected via a dedicated grounding wire. While all the grounds are common inside the UltraVolt HVPS, in a star-point/single-point ground configuration, it is important to note with high voltage they are never truly "the same." An example is when an HV arc occurs in the system to chassis ground and the HV load has some capacitance. A 1000VDC arc to ground through as little as 1Ω of resistance/impedance will result in a peak surge current of 1000 Amps! Another example is the input current causing a voltage drop between the LVPS and the HVPS. A .01Ω impedance build-up from wiring, connectors, etc. is not uncommon, nor is the 10mV error it creates on the +12 or +24VDC power ground. This error is of no consequence unless you were to use the same ground for your LV control circuitry, where 5VDC on remote adjust may equal an output of 1000V, so a 10mV error would be amplified to 2VDC on the HV output! UltraVolt has directly addressed the need for these various ground connections. With the UltraVolt models it is important to denote the different functions of the grounds.

Input Power Ground Return:

This ground is for the most **direct connection** between the HVPS input power stage ground and the LVPS powering it. After the most direct connection is made, other connections may be made as required. An acceptable, common "other connection" is to take a multi-output LVPS's common ground to UltraVolt's *Input Power Ground Return*. An unacceptable "common connection" would be taking the ground to the HVPS *HV Ground Return*, typically when the *HV Ground Return* is connected to the chassis. This is never recommended due to the peak current that can be created during HV discharge (see paragraph on the *HV Ground Return*).

Signal Ground Return:

This ground is for the most **direct connection** between the system LV control circuitry and the UltraVolt HVPS controls, such as enable/disable, remote programming, I_{out} Monitor, E_{out} Monitor and V_{ref}. A ground wire separate from the ground wire to the HVPS power return should always

be used. An acceptable “other connection” is to take the LVPS ground to signal ground. While this can be done safely, it will introduce LV power ground noise into the signals and should be avoided, if possible. An unacceptable “common connection” is to take the signal ground to the HVPS return pin, typically when the *HV Ground Return* is connected to the chassis. This is never recommended due to the peak current that can be created during HV discharge (see paragraph on *HV Ground Return*).

High Voltage Ground Return:

This ground is for the most **direct connection** between the HVPS output stage and the HV circuitry powered by the UltraVolt high-voltage power supply. All HV loads such as capacitors, resistors, tubes, switches, etc. should be returned to this connection. If the LVPS output ground is to be connected to chassis ground, a good technique for safety purposes, the connection to the chassis should be made through the UltraVolt HVPS. This is done by connecting the LVPS output ground to the UltraVolt LVPS input return and the UltraVolt HVPS HV return to the system chassis ground. This is done so if there is an HV arc to the chassis the most direct path for the HV energy is to return to its source, the HVPS output stage, through the HV return. If this is not done, the most direct return path may be through the LV input pins, destroying the LVPS or the HVPS power stage in the process!

These grounds are illustrated in Conn-Dwg #16.