SVX Bias Voltage Protection circuits.

The important characteristics of the needed circuits are 1) limiting the voltage that is applied to the silicon sensors, 2) rapid operation, 3) reliable operation and small impact on the bias voltage during normal operation.

Circuit Analysis

Three circuits that satisfy the above conditions can be labeled by their effect on the bias voltage when they operate. The crowbar circuit will short the bias output when the bias voltage exceeds the threshold value. The clamp circuits (2 styles) try to hold the bias voltage at the threshold value.
If a fuse is added to the circuit so it can isolate the silicon from the supply.

The protection circuit will have leakage currents that will add to the existing leakage of the silicon sensors. It is important to minimize these currents in the protection circuit because sensor leakage will be monitored as an indicator of radiation damage. There are four types of active devices used in these circuits that can contribute to the leakage currents. They are Zener Diodes, Silicon Controlled Rectifiers, Metal Oxide Semiconductor Field Effect Transistors, and Transient Voltage Suppressors. The table below shows example leakage currents for these devices.

	Zener Diode	SCR	MOSFET	TVS
Max Leakage (ua)	<0.1	2	1	1

Using selected parts and their data sheet specifications, the three circuits, crowbar, clamp1 and clamp2, add to the load on the power supply by amounts shown in the table below.

	Crowbar	Clamp1	Clamp2
Max Leakage (ua)	2.1	1.2	1

With a fuse in line the circuit must draw enough current to melt the fuse wire. The power supply is capable of 5 milliamps. The normal operating current is less than 500 micro amps. The smallest fuse value that is easily commercially available is 2 milliamps. This puts the fault current at 2.5 times the fuse rating. The manufacturer specifications rate the fuse opening time at 5 seconds (maximum) at twice the fuse rating. The crowbar circuit has an advantage in that it will minimize the voltage on the sensor during the time it takes to melt the fuse. The two clamp circuits will hold the sensor voltage at the threshold voltage during this time.

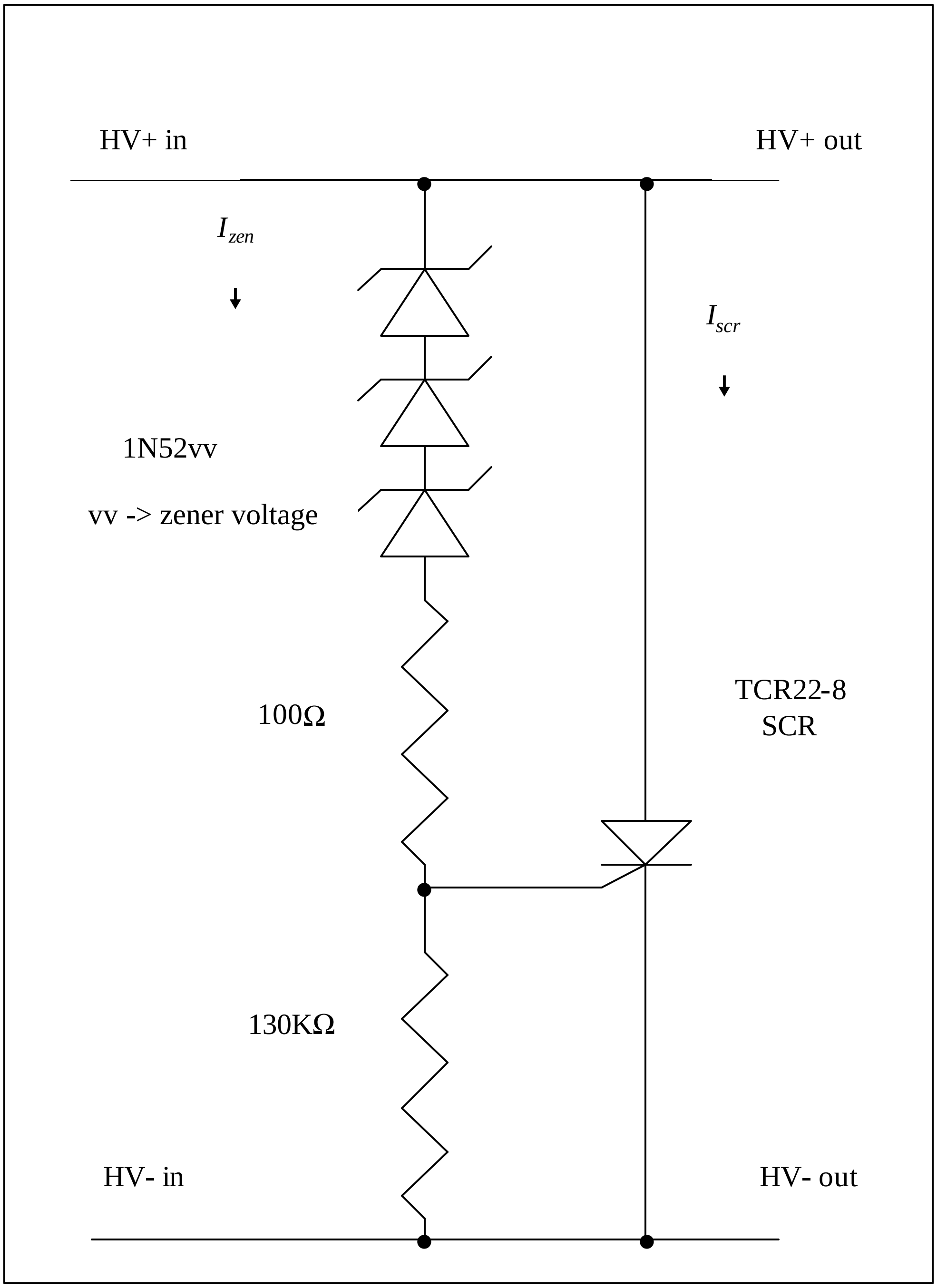

Figure 1 Crowbar Circuit

The “standard” power supply crowbar circuit is a good fit here. The working voltages and currents are not taxing and allow for physically small devices. The devices can be selected for low leakage currents. The fault operation of the circuit removes all of the voltage, and therefore the stress, from the SVX sensor.

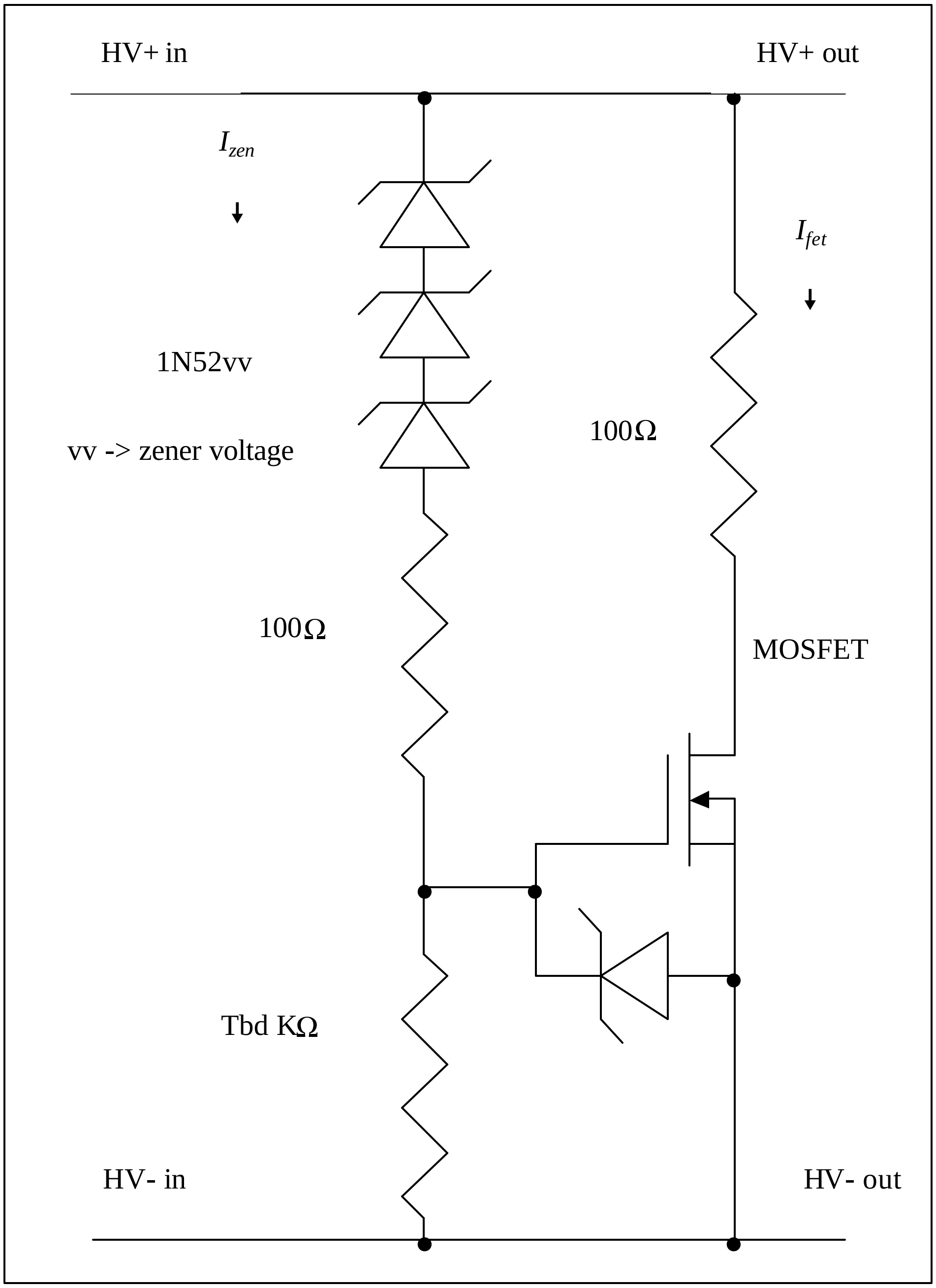

Figure 2 Clamp1 Circuit

The clamp can also be optimized for leakage current and use small devices. However, there are more parts to the circuit. Also undesirable is the fact that if the fuse does not open, the clamp voltage remains on the sensor until an operator takes action in response to the fault.

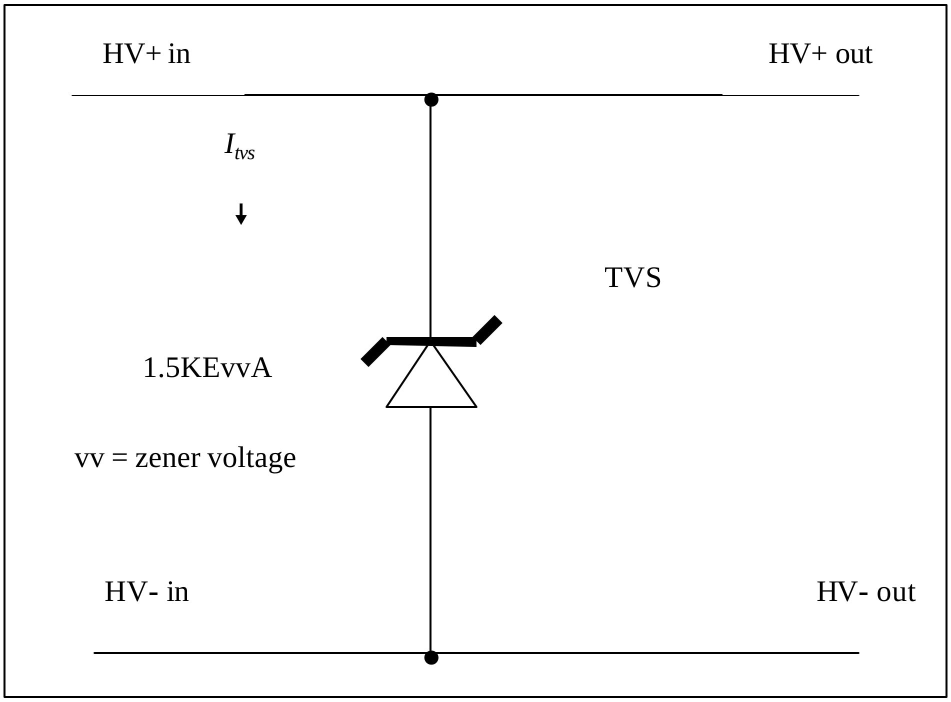

Figure 3 Clamp2 Circuit - Transient Voltage Suppressor

The transient voltage suppressor is more suited protection from lightening strikes and large voltage spikes. The voltage threshold is “soft” with the device only beginning to draw current at the threshold voltage. I tested a 160-volt device and the device was not drawing 5 ma. until 170 volts. This circuit also does not remove the voltage from the sensor but clamps it at the threshold voltage. In this case, however, the voltage was not even firmly clamped.

Conclusion

The crowbar circuit is the first choice and will be implemented with an in line fuse. The zener diodes will be selected for the different power supply and ladder configurations but can be limited to three or four voltages. The circuit will have sites for three zeners to allow flexibility in setting the voltage. A single circuit board with five crowbars can be contained within a plastic case similar to the existing “scrambling” adapter used on some of the Caen supplies. Thus it will be a stand-alone module with connectors at each end that can be put in line with the cable to the detector. The fuse will be removable but for safety they will not be accessible without opening the case.

Safety Issues.

The crowbar circuit should be usable on all types of CAEN power supplies used in the CDF silicon systems, Types A509 – SVX, A509H – Layer 00, and A510 – ISL. The pin outs are different between some of these modules but are matched to the single detector cable pin out by the use of scrambling adapters. A single crowbar module should satisfy the needs of all three systems if it is matched to the bias cable pin out.

Printed Circuit Details

For purposes of this design and the following specification, references to "high voltage" are defined as 512 DC volts under worst-case conditions. Only one of the existing power supplies (A509H) is capable of this voltage.

High voltage traces will be run on internal layers whenever possible to minimize electrical leakage due to high humidity or condensation.

High voltage traces will be run on as few internal layers as possible, and a minimum dielectric thickness/spacing of 0.28mm (IPC-2221 Table 6-1) around any layer (z-axis) carrying high voltage will be specified on the master drawing. All layers carrying high voltage will be designated on the master drawing as well.

The minimum dielectric strength of the printed circuit core material and bonding material shall be specified on the master drawing as 750 volts/mil. The PC board fabricator will be specifically instructed to choose prepreg resins and adhesives with similar dielectric strength characteristics to that of the of the dielectric core material being bonded.

The circuit board will utilize a conformal coating (soldermask) on all external conductor layers. Via holes carrying high voltage will be given a conformal coating over their external pads.

Adhering to IPC guidelines (IPC-2221 Table 6-1), the following minimum high voltage trace spacing will be adhered to:

Internal HV conductors: 0.28mm (11.02 mils)
External HV conductors with conformal coating: 0.83mm (32.68 mils)
External HV component lead termination (uncoated): 1.53mm (60.24 mils)
External HV via hole pads with conformal coating: 0.83mm (32.68 mils)
External HV via hole pads without conformal coating: not permitted

The minimum spacing defined here will also apply between conductive patterns, layer-to-layer conductive materials (z-axis) and between conductive materials such as mounting hardware.

Minimum and maximum high voltage trace widths will be dependant upon the current being delivered, the amount of acceptable temperature rise in the circuit traces and the copper weight of the layers carrying the high voltage traces. A safety factor of 100% in current capacity will be implemented.

In normal operation the circuit will have up to 180 volts across it. In the event of a power supply failure that applies the maximum possible voltage to the output, the crowbar will operate at the threshold voltage and reduce the voltage on the modules output connector to less than 2 volts. If the fuse operates normally and melts under the over current condition, it will disconnect the crowbar from the power supply output. If the fuse does not open, the voltage across the crowbar will be held below 2 volts until an operator turns off the power supply.

The devices chosen for the prototype crowbar have these specifications:

Device	Type	Max fwd or Rev Voltage	Fwd I	Rev I - leakage
TCR22-8	SCR	600 Vdc	1.5 A	2 ua
1N52vv	Zener	75 Vdc, 3 places	6 ma I_z	0.1 ua
272.002	Fuse	125 V working, >500 V open	2 ma	NA
Rn	Resistor	400 V	NA	NA

Failure analysis

Failure modes of the crowbar devices after the power supply has failed:

- If the SCR fails shorted, the crowbar will not allow the voltage to rise above a low voltage.
- If the SCR fails open, the crowbar will not protect the sensor. The zener diodes and the resistors will have the full power supply voltage across them. The zeners will conduct as much current as the resistors will allow.

  $$V_{resistors} = V_{output} - V_{zeners}.$$
  $$I_{resistors} = I_{zeners} = V_{resistors} / R_{resistors}$$

  The zeners for this design are expected to be in the range of 75 to 180 volts. The resistors are approximately 130 K ohms. The current should be less than 3.3 ma. The lowest zener value (75v) will allow the voltage across the resistor to exceed the specification of the resistor by about 10%.
- If the zeners or upper resistors fail open the crowbar will not protect the sensor. The crowbar circuit will survive the 512 volts across it.
- If the lower resistor fails open the crowbar will not allow the voltage to rise above a low voltage.
- If one of the zeners fail shorted the crowbar will operate at a significantly lower voltage.
- If upper resistor fails shorted the SCR gate current will be higher than needed until the fuse operates of the operator turns off the supply. The maximum current will be 1/200th the maximum allowed for this device.

- If the lower resistor fails shorted, the crowbar will clamp the output voltage at the zener threshold voltage plus a few volts due to the voltage developed across the conducting zeners and the upper resistor.

Materials safety

The plastic enclosure used for the Layer 00 module is a CN-0303 model from PacTec Enclosures (www.pactecenclosures.com). The case material is a Polylac® ABS plastic and it holds a UL94HB flame class rating. The printed circuit board material is standard FR4 fiberglass that is used throughout the industry. The components are common types and packages used throughout the industry and HEP systems.