Fermi National Accelerator Laboratory

SVX II Silicon Detector Upgrade Project
Readout Electronics

High-Voltage Bias Protection Modules

--PRELIMINARY--

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1 GENERAL INFORMATION

1.1 System Introduction

The Silicon Vertex tracking detector in the CDF experiment uses bulk silicon strips to detect the passage of high-energy particles, which leave a charge trail in the silicon material. The silicon is reverse biased to enhance charge collection. The Caen high-voltage power supplies providing this bias voltage experienced a high rate of failure after installation. The failing part, the output regulator, shorted and provided the maximum possible voltage to the output connections. The sensor silicon can be damaged by excess bias so protection circuitry was needed to protect against this failure. Space constrains dictated a module external to the power supplies.

1.2 Description Of Component & How It Fits Into The System

The module will be inserted in series with the bias supply cable at the back of the Caen power supplies. All five channels of the bias voltages from one supply will pass entirely through one module. The module will be a plastic case that completely encloses the electronic circuitry. Electrical connectors at either end of the module match the connectors on the cable and Caen power supply.

1.3 List Of Component Requirements

The important characteristics of the needed circuits are 1) limiting the maximum voltage that can be applied to the silicon sensors, 2) rapid operation, 3) reliable operation with minimal impact on the bias voltage, due to leakage, during normal operation.

2 THEORY OF OPERATION AND OPERATING MODES

2.1 Basic Features & Operation 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 between the power supply and the circuit then it can isolate the silicon detector (and the crowbar) from the failed power supply.

2.2 Analysis of candidate circuits

The “standard” power supply crowbar circuit as shown in Figure 1 is a good fit here. The required working voltages and currents can be handled by commonly available parts 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 silicon sensor.

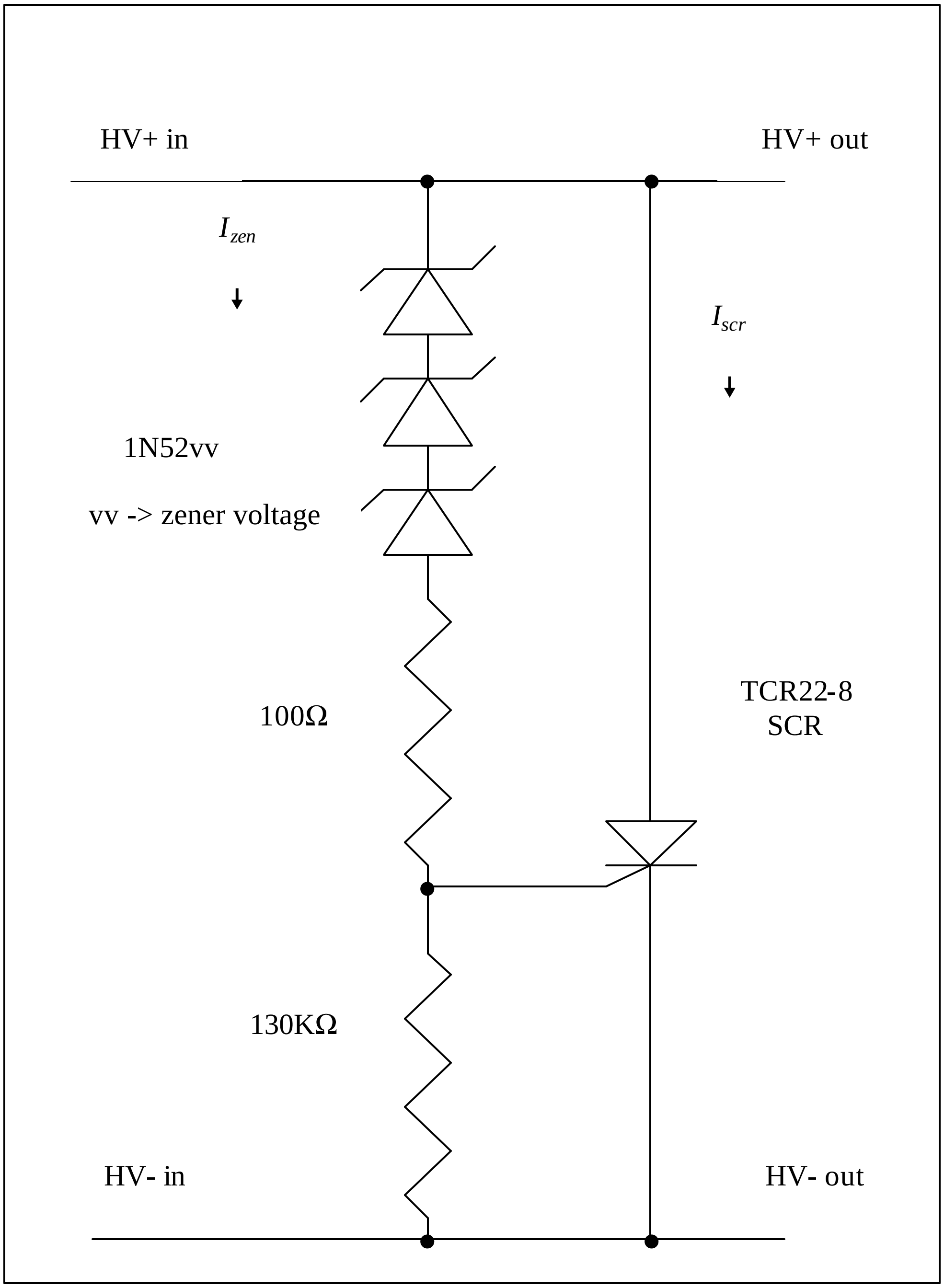

Figure 1 Crowbar Circuit

The clamp circuit shown in Figure 2 can also be optimized for low leakage current and use physically small devices. However, there are a higher number of parts to the circuit, which affects cost and might affect reliability. Also undesirable is the feature that if the fuse does not open, the clamp voltage remains on the sensor until an operator takes action in response to the fault. The power dissipated across the MOSFET device is of concern if the fuse does not open.

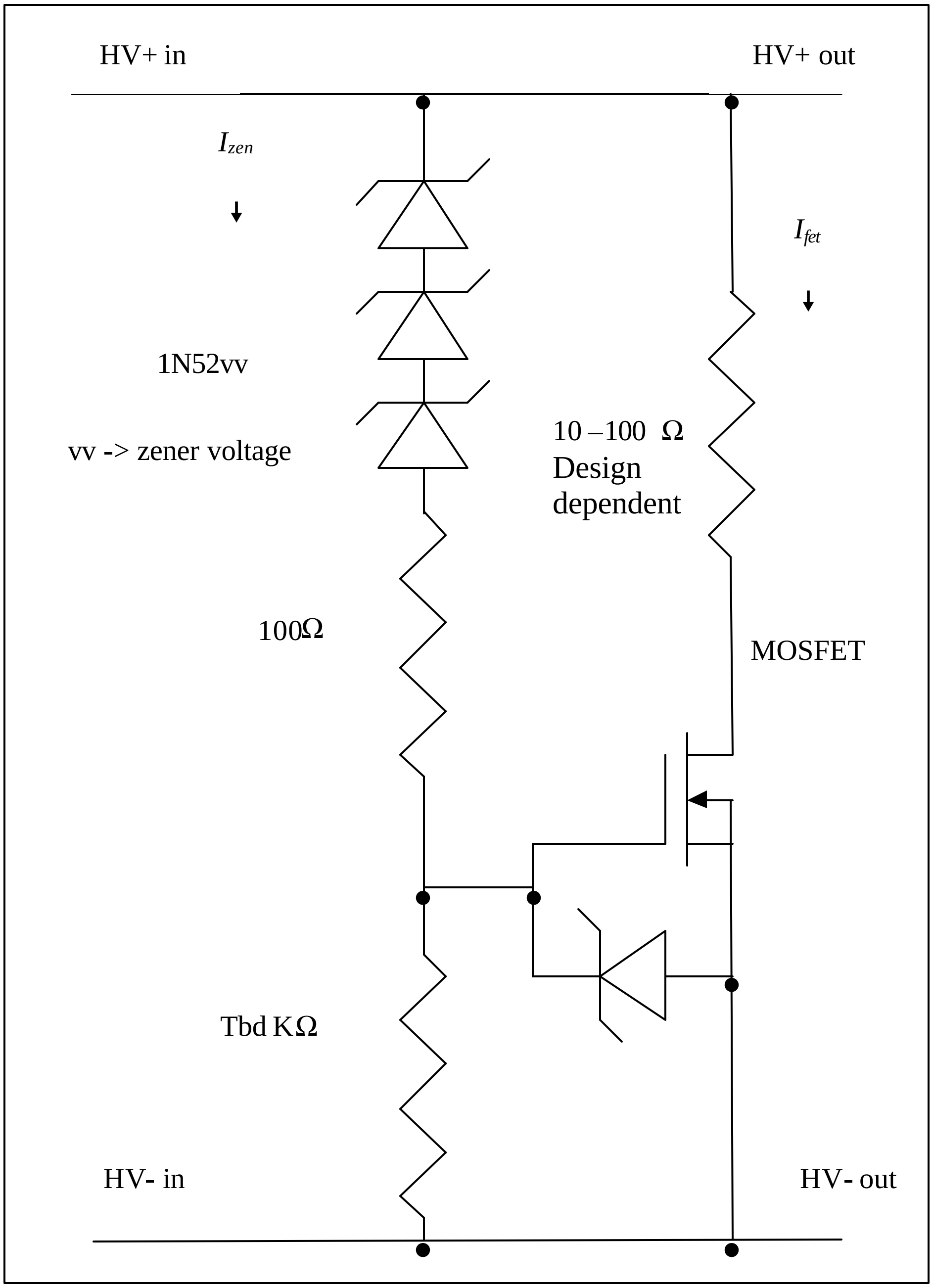

Figure 2 Clamp 1 Circuit - Regulator

The transient voltage suppressor shown in Figure 3 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 specified threshold voltage. a 160-volt device was tested and the device threshold, determined by a noticeable increase in current above the leakage current, was approximately 162 volts. However, the device was not drawing 5 milliamps 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.

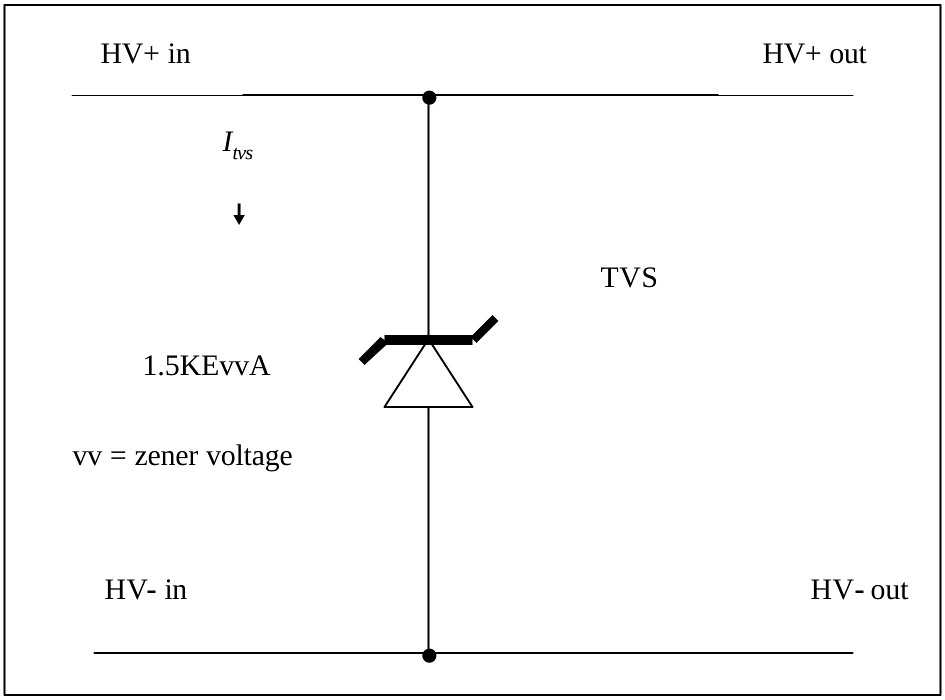

Figure 3 Clamp 2 Circuit - Transient Voltage Suppressor

2.2.1 Leakage Analysis

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 output is rated at 5 milliamps but testing has determined that a failed channel is capable of approximately

20 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 least 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.

2.2.2 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 specific voltages. The circuit will have component positions 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.

3 INTERFACE SPECIFICATIONS

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.

The crowbar module mounts in line between the high voltage power supply and the silicon bias cable into the detector. The Layer 00 module is assembled in a plastic case with the DB-25 connectors accessible at either end. The connectors are polarized (male and female) so the module cannot be inserted backwards, although there is no electrical directionality to that module.

3.1 Connector Pin Configurations

The following pin out (from the web documentation "CDF Silicon Vertex Detector Power Supply and FIB Cables - 2/15/00") supersedes the pin out in the technical drawing.

PIN @ CAEN	PIN @ JuncB	Conductor Number	Description	CAEN Designation	Comment
1	-	-	ENABLE	EN_0	Connected to PIN 14 in the Connector at CAEN
14	-	-	ENABLE	EN_1	See Pin 1
2	1	1	+VBIAS layer 0 pos.	VBPISL0	
15	2	2	VBIAS layer 0 neg.	VBNISL0	
3	3	3	H.V.Ref layer 0	VBFISL0	
16	n/c	n/c	n/c		
4	4	4	+VBIAS layer 1 pos.	VBPISL0	
17	5	5	-VBIAS layer 1 neg.	VBNISL0	
5	6	6	H.V.Ref layer 1	VBFISL1	
18	n/c	n/c	n/c		
6	7	7	+VBIAS layer 2 pos.	VBPISL1	
19	8	8	-VBIAS layer 2 neg.	VBNISL1	
7	9	9	H.V.Ref layer 2	VBFISL2	
20	n/c	n/c	n/c		
8	10	10	+VBIAS layer 3 pos.	VBPISL3	
21	11	11	-VBIAS layer 3 neg.	VBNISL3	
9	12	12	H.V.Ref layer 3	VBFISL3	

22	n/c	n/c	n/c		
10	13	13	+VBIAS layer 4 pos.	VBPISL4	
21	14	14	-VBIAS layer 4 neg.	VBNISL4	
11	15	15	H.V.Ref layer 4	VBFISL4	
23	n/c	n/c	n/c		
12	-	-	GROUND	EARTH	n/c
25	-	-	SHIELD	SHIELD	The shield pin on the CAEN supply should be attached to the shield of the cable. The shield will attach to the junction board as discussed above.
13	-	-	GROUND	EARTH	n/c

3.2 Signal Descriptions

The two ENABLE and the SHIELD signals are passed through the module.

Each of the five Layer 00 bias voltages for the silicon layers is carried on three connections. The total voltage is between the +VBIAS and –VBIAS connections. The HV Ref connection is carried through the crowbar module but the sensors make no connection to this voltage. Essentially this wire is a no connect and is ignored by the module.

4 ELECTRICAL & MECHANICAL SPECIFICATIONS

4.1 Packaging & Physical Size

The module is package in a PakTech CNL-0303 plastic case. The case secures the printed circuit card and has openings at each end to allow access to the PCB electrical connectors. The whole module is just less than 2 ¼ inches wide by 4 inches long by 1 inch thick.

4.2 PC Board Construction

The printed circuit board is standard technology FR4 fiberglass construction with high voltage (500 volt) design rules applied to the trace and part spacing. The board is composed four layers totaling 0.032 inches thick. The layers are evenly distributed in thickness to After the PC board is assembled and tested, Krylon 1302 Crystal Clear protective spray coating was applied as additional protection against the possibility of arcing even in a humid environment. The coating has a dielectric strength of over 1000 volts per mil of thickness and three coats are applied to ensure complete coverage. A single test coat measured XX mills.

4.3 Power Requirements and Cooling Requirements

The module is entirely powered by the bias voltages passing through it. There are no cooling issues with this module.

5 SAFETY FEATURES and FAILURE ANALYSIS

(Details of all component safety features such as module fusing as well as methods to assure high quality of this component such as environmental testing should be included in this section. Note that this is not a request but is a requirement of Fermilab that modules are built in a safe manner. We will not be able to install and use any equipment that is not built to operate safely. In fact, this system and all its components will be thoroughly reviewed by official lab safety personnel to certify its safety)

5.1 Printed Circuit Board Safety

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 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

NA = not applicable or not measureable.

5.2 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.

5.3 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.

6 APPENDICES

6.1 Component Documentation

The files for this project reside in the ESE department. The most commonly needed information can be reached through the department web server at

http://www-ese.fnal.gov/eseproj/svx/Adapters/Caen_crowbar/crowbar_index.html

The schematic and layout were done with Orcad and those files are available on request. Some of those files follow.

6.2 Schematics

Acrobat Document

6.3 Parts List

Acrobat Document

6.4 Additional Appendices

Acrobat Document