

Potential FEB Over-Voltage Issue

Overview

During the weekly NOvA DAQ/Electronics meeting on 22 March 2010, a potential over-voltage issue with the FEBs was discussed. This discussion was in response to recent emails between Craig Dukes and John Oliver on this matter. The issue is that the Wiener PL506 power supply can output up to 7.0V on the 3.3V FEB power rail, but the power regulator on the FEB has an absolute maximum of 6.0V. It is unclear what would happen if a voltage greater than 6.0V is applied to the FEBs but it is assumed that any FEBs under these conditions would quite likely suffer a critical failure. The worse case failure would be a significant increase in temperature of the regulator components resulting in a fire.

This potential over-voltage issue was originally discussed during the early design stage of this project. The solution then was for the FEBs to be able to handle up to 7.0V. However, during changes leading up to the current design of the FEB, that regulator design was modified, resulting in an absolute maximum 6.0V rating.

Possible Solutions

There are a few possible solutions to mitigate this issue. One solution involves using the software-modifiable settings of the Wiener PL506 power supply to limit the FEB voltage to a value safely below 6.0V. Another solution is to replace the existing TVS on the FEB channel electronics within the Power Distribution Box with a zener-controlled SCR circuit that is capable of limiting voltage below 6.0V. A third solution is for the regulator design on the FEB to be changed so that it can handle up to 7.0V. A fourth solution involves replacing the low voltage power supplies with a different model that has a maximum voltage capability of 6.0V. A fifth solution involves paying Wiener extra to modify their power supplies so that they cannot output a voltage that could be harmful to the FEBs.

Software Solution

The Wiener PL506 power supplies use both USB and Ethernet connectivity to both read and alter configuration settings. In the current installation on the near detector in the NDOS surface building, there is no remote connection to the USB port but the Ethernet port of all power supplies are networked together, providing remote monitoring and control access. Although not every configuration setting is available when connecting by Ethernet, most of them are available. For the needs of this solution, Ethernet provides access to a maximum sense voltage setting, a maximum terminal voltage setting and a behavior setting which defines how the power supply responds to either over-voltage condition, as well as other out-of-bounds conditions. In addition, the power supply knows its absolute limits and rejects any command that tries to set the output voltage, maximum sense voltage or maximum terminal voltage to a value greater than 7.0V.

In order to protect the FEBs, the power supplies could be configured with a maximum sense voltage and maximum terminal voltage that is safely below 6.0V. The behavior configuration would then be set so that the power supply turns itself off in response to detection of an over-voltage event.

Software Solution Pros

The main benefit of the proposed software solution is that the cost to implement is negligible. A consistent configuration that is programmed into all power supplies is needed anyway and that configuration can include these maximum voltage settings along with the power-down response.

Software Solution Cons

The downside of the proposed software solution is that it can be easily defeated via software. There are several errors that would be required to occur in order to put the FEBs in danger. Either the behavior configuration would need a change, causing the power supply to ignore any over-voltage event, or both maximum voltage settings would have to be mistakenly set to a value between 6.0V and 7.0V (the power supply ignores settings over 7.0V) followed by the output voltage commanded to a value between 6.0V and 7.0V. The likelihood of these events occurring is low, especially since there is no known reason for someone to try to set any power supply to between 6.0V and 7.0V. However, the consequence of this error could be catastrophic to the project.

Although the power supplies will be on a protected network, if a malicious user gained access via Ethernet to the power supplies and knew of this weakness in the design, they could easily exploit it. This may seem laughably paranoid, but the [StuxNet](#) virus is a recent example of malicious software designed to target industrial equipment and modify software controls in order to destroy equipment that has no apparent hardware fail-safes. So although this too seems to have a low likelihood of occurrence, it is possible and the consequences could be grave.

PDB/FEB Channel Hardware Modification Solution

The existing PDB/FEB channel electronics include a transient voltage suppressor (TVS) with a clamping voltage within the 8.33 V – 9.21 V range. The simplest hardware modification would be to use a different TVS with a much lower clamping voltage. However, 7.0V is the lowest maximum clamping voltage for a TVS that satisfies all of the other design requirements. This change would not protect within the critical 6.0V to 7.0V region.

So instead of using the existing TVS, a zener-controlled silicon-controlled rectifier (SCR) crowbar circuit could be used which would have a clamping voltage safely below 6.0V. This would require a zener diode, a SCR, two resistors and a small capacitor. Performing a quick search of current component prices, it appears that these new components would actually cost slightly less than the TVS they replace. So no increase in component cost is expected. However, the design would require prototyping, changes to schematic and layout and validation testing, delaying the production of PDB/FEB and PDB/DCM cards (the PDB/DCM card has two spare FEB channels). There is also a small chance that these new components would not fit within the space vacated by the removed TVS, forcing a major design change to accommodate the additional components.

Just like with the existing TVS circuit, the SCR circuit would protect the FEBs by essentially converting the over-voltage into current shunted to ground. Depending on the degree of over-voltage, such an event would most likely cause fuses to blow. So although the FEBs would be protected from the over-voltage, the detector would experience some down time as the effected fuses are manually replaced.

PDB/FEB Channel Hardware Modification Solution Pros

The primary benefit of this solution is that the FEBs are protected from over-voltage regardless of how the power supplies are controlled. No software malfunction could jeopardize the health of the FEBs, at least from an over-voltage standpoint. In addition, the FEBs would be better protected from any potential hardware malfunction of the power supplies or power distribution box, reducing the maximum clamping voltage from 9.2 V to below 6 V. This would also protect the FEBs in the case of 24V getting shorted to the 3.3V rail. All of these benefits could be realized with little or no increase in hardware component costs.

PDB/FEB Channel Hardware Modification Solution Cons

However, this change in the PDB/FEB channel design would delay the production of the PDB electronics, potentially impacting the overall schedule, and it would increase the engineering costs of the project. The SCR circuit would need to be prototyped and tested with the final design incorporated in the PDB schematics and layout. Although not a complicated task, this could delay the assembly of PDB electronics by 2-4 weeks.

Since this proposed voltage limiter circuit protects the FEBs by causing fuses to blow in an over-voltage event, there is still a threat that a software issue could disrupt the function of the detector. In the worst case possibility, over 12,000 fuses would need to be manually replaced. This could take several days to complete and cost nearly \$5000 in fuses plus labor. So it would not be without consequences, but it would not be catastrophic.

With a lower clamping voltage limit, the risk of blowing fuses due to unexpected voltage transients increases. Although unlikely, it is possible that under certain operating conditions, there exists a brief voltage spike that would not be harmful to the FEB regulator but may trigger fuses to blow. Due to the low impedance of the power cables, only about 30 millivolts over the clamping voltage is required to draw enough current to quickly blow the 2A fuses. With the existing TVS design, the near detector has experienced very few fuse issues but this could change with this proposed design change. It would be best to build a small run of new PDB/FEB and PDB/DCM cards with the new proposed voltage limit circuit so that the near detector could be outfitted and the design could be tested in a more realistic environment. Online vendors could be used to quickly make the small number of printed circuit boards required for testing, but this would easily add 3-6 weeks to the schedule and increase the costs of such a design change. The impact to the project schedule and costs would be greater if an issue was not found until after building the thousands of cards required for the far detector.

Table 1: Estimated Engineering Effort For This Solution

Tasks	Applied Hours	Elapsed Hours
Design, prototype and testing of the new circuit	50	75
Update of schematics	16	24
Update of layout	24	80
Testing of new boards in the lab	40	60
Testing on the near detector	40	40
Totals	170	279

The estimates of engineering time, both applied and elapsed, are in Table 1. This does not include the approximately 4 weeks of elapsed time to have prototype boards assembled and it does not include any “burn-in” time on the near detector if we go that route. So based on these estimates, it would take roughly 12 weeks after the decision to start on this solution before the far detector boards could be built. Some of the tasks may be handled in parallel, reducing the elapsed time, and the building of prototype boards could possibly be reduced to 1-2 weeks by choosing expedited manufacturing, thus increasing costs.

FEB Regulator Hardware Modification Solution

The originally proposed solution of requiring the FEB regulator circuit to handle up to 7.0V is still a possible solution. This would require a redesign and testing of the FEB electronics, potentially increasing its component costs and production schedule. Without familiarity of the FEB design, it would be difficult to estimate this impact.

FEB Regulator Hardware Modification Solution Pros

The primary benefit of this solution is that no software or hardware malfunction resulting in a voltage greater than 6.0V would cause harm to the FEB regulator circuit. If such a malfunction occurred, the FEB would withstand the event and as long as the over-voltage is not greater than the TVS clamping voltage, no fuses would need to be replaced. The TVS in the PDB/FEB and PDB/DCM cards would still need to be changed to the lowest clamping value in order to protect against voltages greater than 7.0V. However, this would be a simple component change.

FEB Regulator Hardware Modification Solution Cons

It is assumed that the impact to the project schedule and costs would be greater with this hardware change than with the proposed change to the PDB electronics, but it is currently unknown what this impact would be. The FEB electronics are already being changed for the far detector, so these changes could potentially be rolled in with those other changes.

Different Power Supply Solution

Another possible solution is for the low voltage power supplies to be changed from the current Wiener PL506 models to some unknown model that has a 6.0V maximum voltage. However, this would require drastic changes in the relay racks, power wiring and the system in general. There have been many months of detector operation with the Wiener PL506 power supplies and they have proven to be adequate for the detector design. A change in power supplies would be a major disruption.

Different Power Supply Solution Pros

By changing the low voltage power supplies to a different model, the proposed changes to custom electronics would not be required. In fact, there may be a power supply without the software vulnerability of the Wiener PL506 power supplies. With a better understanding of the needs of the detector design, it is possible that a lower cost power supply could be chosen, saving money for the project.

Different Power Supply Solution Cons

The project has already conducted a power supply selection process and the Wiener PL506 was chosen as the best fit for the requirements of the project. Although the detector electronic requirements are better understood now, it is unclear whether a different suitable power supply exists. A different power supply may even cost more, forcing the project to absorb a potentially major increase in costs. Regardless, it could be a major effort to test and evaluate power supply choices and then produce the design changes required to fit a different power supply within the current framework. The change to the detector would be great enough that any new power supply model would absolutely be required to undergo testing on the near detector. The impact to the schedule is expected to be far greater with this solution than with any of the others proposed above.

Modified Power Supply Solution

A fifth possible solution is to order the same Wiener PL-506 power supplies that are on the near detector, but pay extra for them so that they will be modified by Wiener to have a lower maximum voltage. The sales representative for Wiener recently informed us that this is a possible modification. The amount of extra cost is currently unknown as well as what the increased lead-time would be to perform this modification on all shipped power supplies. However, this information is currently being researched.

Modified Power Supply Solution Pros

By ordering modified power supplies, no custom electronics would need to be modified. The modified power supplies could easily replace the existing ones on the near detector, providing both safety for the near detector FEBs and some "burn-in" time with the proposed solution. Also, this is a more efficient solution than modifying custom electronics since there would never be the ability to create an over-voltage event via software or hardware. This solution would also require fewer changes to the system as a whole versus changing the electronics of every PDB/FEB card, PDB/DCM card or FEB board.

Modified Power Supply Solution Cons

This solution does increase the cost and is expected to increase the lead-time of the power supplies, but is expected that this will be minimal as compared to the other proposed solutions. This solution does not address the shortcomings of the existing TVS voltage limiting circuit on the PDB/FEB and PDB/DCM cards. That may be best handled by changing the TVS component from a 7.5V to a 5.0V working voltage TVS, which protects with a clamping voltage between 6V and 7V.

Conclusions

Under certain, yet unlikely, circumstances, the FEB regulator circuit could be subjected to voltages over its absolute maximum of 6.0 V. This potential issue could be mitigated through software configuration settings of the power supply, but the possibility of catastrophic system failure still exists. Hardware changes would significantly reduce this possibility through changes to either the power distribution box electronics or changes to the FEB regulator circuit. Either change would require test and design changes, pushing out the project schedule and increasing costs. A more drastic solution would be to change the low voltage power supply, but the impacts to schedule and cost with this solution appear to be far greater than the other proposed hardware changes. The best solution so far appears to be to pay

Wiener to modify the power supplies so that their upper voltage limit is below the absolute maximum voltage rating of the FEB regulators. This too has a negative impact on costs and the project schedule but it is assumed that both of these will be minimal as compared to the other proposed solutions. The impact will be better known once Wiener provides a quote for this modification.

It is unfortunate that this issue exists, but it was at least caught prior to installation of the far detector and it has not caused any problems in the existing near detector. The fix to this issue will clearly impact schedule and cost, so the sooner a solution is selected, the better.