Switching Power Supply Technology for ATLAS Lar Calorimeter

J. Kierstead and H. Takai
Brookhaven National Laboratory
kierstead@bnl.gov, takai@bnl.gov

Abstract We present an update on the development of a 3kW DC-DC converter for the ATLAS Liquid Argon Calorimeters. The power supply will be located close to the Calorimeter front end crate in a region where magnetic field and nuclear radiation are present. In order to keep the cost low a solution based on components of the shelf is sought. Recent test results on single event effects on commercial converters is presented.

I. INTRODUCTION

Each liquid argon calorimeter front end crate will require seven different voltage lines and a total of 3 kW of power. At earlier stages of the design it was considered unacceptable to bring the power to the crates , located in the gap between the barrel and endcaps, from large distances. The power dissipated in the cables by ohmic losses would require the use of water cooled cables. In addition the use of large cable bundles would make the movement of the endcaps a very difficult task. Therefore the only acceptable solution considered was the use of DC-DC converters near to the front end crates. By bringing DC lines between 200 to 400V all desired voltages can be generated locally and would require the routing of small gauge cables to the interior of the detector.[1]

In this particular application the DC-DC converter will be installed in regions where magnetic field and nuclear radiation are present. Converters in this type of environment are only manufactured by the space industry at unreasonable cost. Therefore it was felt that we should investigate the use of components of the shelf (COTS) that could operate adequately in our environment.

I. FIGURES AND TABLES

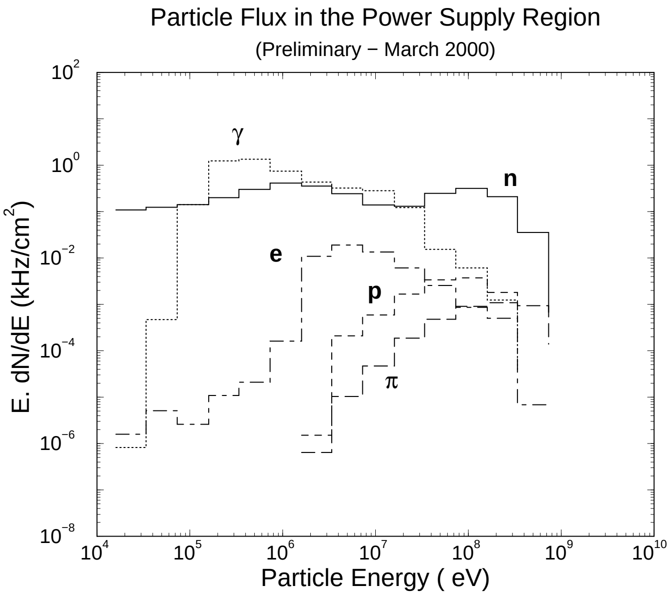
The environment where the power supplies will be located is summarized in table 1. The magnetic field value assumes a 20 mm iron shielding around the power supply and is a result of a simmulation performed by et. al. The radiation field is equaly a result of simulations and includes the safety factors recomended by the ATLAS experiment.

Table 1:Radiation and Magnetic Field in the power supply region. Doses are for 10 years of operation at full luminosity. Safety factors as suggested in ref 1 are included. Values are from ref 2,3.

Quantity	*Total in 10 years*
Total Ionizing Dose	5 kRad
Neutrons 1MeV equiv.	$3.0x10^{12}$ n/cm^2
Hadrons > 10 MeV	$1x10^{11}$ h/cm^2
Magnetic Field	20 Gauss

The presence of magnetic field causes is the first concern as far as operating DC-DC converters. High values of magnetic field will saturate the transformer cores. The radiation on the other hand causes damages in the internal semiconductor devices used in the feedback loops and switching transistors.

Figure 1:Particle Flux in the location of the power supplies[2]



Hadrons with E>10 MeV are responsible for single event effects in semiconductors. In DC-DC converters the main problem concerns the operation of power MOSFETs that could undergo a single event burn-out or gate rupture. Other semiconductors in the device can also suffer from upsets or latch-ups.

---

[1] Copies of the transparencies of the presentation given during the workshop can be found at the following web address: http://www.usatlas.bnl.gov/~takai/leb2000.

I. INDUSTRIAL PARTNERSHIP

The design of the power supply is made together with an industiral partner, an *integrator*, which specializes in the operation of DC-DC converters in environments similar to ours. To keep the cost within reasonable range we have chosen to use components of the shelf instead of more specialized radiation qualified parts. There are two implications with this choice. First it implies that we are forced to involve other industrial outfits, suppliers, other than the integrator itself. The second implication is that an extensive testing program has to be launched.

The first task undertaken between us and the *integrator* was to agree on the design of the power supply to be built. This has been summarized in a short specificiation document written by us. The second task is to establish a clear path for the qualification of commercial parts which is also done together with the integrator.

At this stage, one needs to involve the suppliers at the level of understanding which is much deeper than what is available through standard documentation. For example, it is interesting to learn what their parts qualification procedure is. This usually requires the signing of a *non-disclosure* agreement which is not only time consuming but could be confusing at times because the depth of the *non-disclosure* is not always clear. However the acquired information may have consequences in the estimating the most appropriate safety factors for the overall radiation doses.

The *integrator* chosen is Modular Devices[4], a company that has experience in providing power supplies for communication satelites. We have also chosen three different sources for the most critial component: the DC-DC converter bricks. However due to manpower limitations we are concentrating our efforts in understanding the performace of the Vicor[5] bricks. The other choices are seen as backup solutions with the implicit understanding that if the first choice fails delays in the program will occur.

I. SINGLE EVENT EFFECTS

The behaviour of the Vicor power bricks as far as magnetic field, integrated dose, and 1 MeV equivalent neutron damage has been reported during the last Workshop.

We have carried out initial single event effect tests. The single event effects which are relevant to power supplies are two types: destructive and transient. The destructive upsets may happen for all types of DC-DC converters which uses Vin larger than 100V. The transient type of upsets could happen to DC-DC converters that uses integrated circuits in the controls of the switching circuit. To carry out the tests we felt important to also add all the representative anciliary circuits that will be used for the controls of the power supply. Therefore a special board was manufactured by Modular Devices for the test.

The irradiation was carried out at the Harvard Cyclotron Facility. The cyclotron delivers 150 MeV protons at rates of $1x10^8$ protons/cm^2/s. We use protons instead of neutrons which as far as SEU probabilities are concerned they are equivalent[6]. The rate is chosen so that we can irradiate samples with the same number of particles expected in 10 years of operation. The supplies were mounted on stages and a laser alignment system to locate the center of the beam spot which is 30 mm in diameter was used. The exact positioning of the power supply was checked by placing a polaroid film behind the supply.

The DC-DC converters irradiated were loaded to 5% of their full capacity with the rational that SEGR/SEB is most likely to happen while the supply is not conducting. We have exposed a combination of Mini and Maxi converters.

I. SUMMARY OF RESULTS

The following conclusions were drawn as a result of the irradiation tests.

a. The failure cross section at V_{in}=300V is $0.5x10^{-10}$ cm^2. This results are based on three destructed power supplies by irradiating their power MOSFETs. The destruction mode, SEGR, was reported by Vicor which have send us their Failure Analysis Report. This is one aspect where involving the suppliers is very important.

b. At V_{in}=200V no failure was observed. We determine that the failure cross section is < $1x10^{-12}$ cm^2. This is a expected behaviour for power MOSFETs. By derating the input voltage the probability of burnout/gate rupture is greatly decreased[6].

c. None of the logic in the power supply seems to suffer from single event effects to the level of $1x10^{-12}cm^2$.

d. None of the logic on the test board seems to suffer from single event effects to the same level.

I. CONCLUSIONS

At this point of the development we conclude that the power supply meets the requirements as far as magnetic field, total integrated dose, and 1 MeV equivalent neutron damage. As far as single event effects are concerned we conclude that at 5% of total load the failure cross section is smaller than $1x10^{-12}cm^2$. The exact failure cross sections as function of the V_{in} are not known at this point. Because the total number of converters is nearly 1000, a cross section of $1x10^{-12}$ would imply in a loss of approximately 100 converters in a 10 years operation. Even with a *N+1* redundancy it is very likely that we would loose few power supplies because of the single event effects. Note that this failure rate needs to be compounded with other more traditional failure modes.

As far as the operating point is concerned, it is clear that we need to operate the power supply at reduced voltage. We are in the process of designing a more complete test with de-rated input voltage, V_{in}=200V. The results of the tests will permit us to decide if we continue with the present supplier, Vicor, or we would need to exercise a second option that we have: use radiation hardned converters. Of course the cost increment will be substantial.

The involvement of commercial partners in the power supply has been very fruitful. Both the integration house and the supplier of DC-DC converters has provided us with information that allow us the understanding of how different parts are being assembled. One of the most important aspects when dealing with COTS is to acquire enough information as far as how suppliers do component selection. This allows for lower risks as far as radiation is concerned.

I. REFERENCES

1. M. Dentan, ATLAS Policy on Radiation Tolerant Electronics. Draft Version 03/04/00, april 2000.

2. M. Shupe, University of Arizona, private communication.

3. Vorojtsov, Dubrovin and Nessi, private communication agust 1999.

4. Modular Devices Inc, Brookhaven R&D Plaza, One Roned Road, Shirley NY 11967.http//www.modev.com

5. Vicor Corporation. 25 Frontage Road, Andover MA01810-5413. http://www.vicr.com

6. D.L. Oberg et al., IEEE Trans on Nucl Science 43(1996)2913