BELLE2-NOTE-xx-2021-xxx
Version 0.1
March 4, 2021

Expression of interest: radiation monitor and beam abort upgrades

RMBA working group*

Abstract

Limitations and possible upgrades of the radiation monitors and beam abort (RMBA) systems in the interaction region of SuperKEKB have been analyzed by the RMBA working group. This upgrade proposal is mainly focused on the electronics of the system based on diamond detectors. We update the requirements, exploiting the experience of operations on the present system; we use the state of the art of similar systems as a guide for new design options. We outline an upgrade path for the electronics, including R&D, prototyping and construction, with a preliminary timeline and estimates of the required human resources and budget. Minor modifications of the present electronics are also discussed. Two additional items are briefly mentioned: the imminent inclusion of abort request signals from the CLAWS scintillator system, and preliminary plans to improve the instrumentation of SuperKEKB collimators.

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1. INTRODUCTION

In this proposal, we focus on an upgrade of the read-out electronics controlling the diamond detectors of the VXD radiation monitoring and beam abort system. After a description of its main features (section 1 1.1) and limitations (section 1 1.2), we outline an upgrade path, including preliminary comments on human resources, cost and schedule. In section 6 we briefly discuss possible minor modifications of the present electronics, the implementation of a beam abort request signal from the CLAWS scintillator system, and possible upgrades of the instrumentation of collimators. This EoI is based on the discussions within the radiation monitoring and beam abort (RMBA) working group; the documentation of the working group is collected at:

`https://confluence.desy.de/display/BI/Long-term+future+of+Radiation+Monitoring+and+Beam+Abort`.

1.1. The beam-loss monitor system, based on diamond detectors

The radiation monitor and beam abort system based on diamond detectors was designed following initial specifications summarized in a Belle II note [1]. It consists of 28 detectors, installed on the beam pipe (8), the SVD support cones (12), and the QCS bellows (8). The detectors were constructed and characterized at INFN Trieste [2]. Their current signals are proportional to the dose rates. The calibration coefficients of individual detectors are measured with a systematic uncertainty of 8% and have an average value of 35 (mrad/s)/nA. The maximum relative difference of the calibration coefficients from their average value is about ±50%.

The 28 detectors are read-out and controlled by seven diamond control units (DCU). The main functions and properties of the DCUs are documented in reference [3], and in a more detailed programming user's manual [4]. The DCUs are designed and assembled by the Instrumentation and Detectors Laboratory of Elettra Sincrotrone Trieste ScpA [5], in collaboration with INFN Trieste.

Each DCU pilots four diamond detectors, as sketched in the block diagram of Figure 1 .

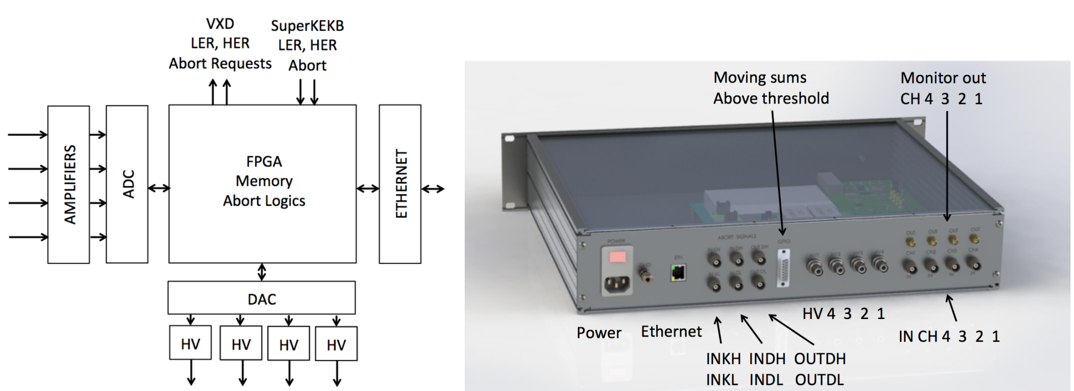

FIG. 1. (left) DCU block diagram. Arrows on the left side indicate currents from diamond sensors and arrows on the down side indicate high voltage applied on the diamond sensors; (right) DCU back panel with input and output connectors.

TABLE I. Selectable current-measurement ranges of diamond control units, with the corresponding rms noise values, measured in 100 kHz data (third column) and in 10 Hz data (fifth column). The typical corresponding ranges and rms noise values in dose-rate units can be obtained multiplying by the average calibration factor $k = 35$ (mrad/s)/nA. The effective dynamic ranges expressed in decibel at 100 kHz and 10 Hz are also shown in the fourth and sixth columns.

Range index	Current range	Rms noise @100 kHz	dyn.range @100 kHz	Rms noise @10 Hz	dyn.range @10 Hz
0	36 nA	0.23 nA	44 dB	0.8 pA	93 dB
1	9 μA	3 nA	70 dB	70 pA	102 dB
2	4.5 mA	0.22 μA	86 dB	40 nA	101 dB

The digital core is a board hosting a FPGA [6], which receives commands via an Ethernet interface, drives four HV modules independently through a DAC, and accepts input data from an analog module with amplifiers and ADC conversion. The DCU is also able to deliver VXD abort requests separately for the electron higher-energy ring (HER) and the positron lower-energy ring (LER), and receives the SuperKEKB abort signals.

The diamond currents are amplified by trans-impedance amplifiers, digitised by a 16-bit ADC [7] at 50 Msamples/s, and processed by the FPGA. Three amplifier gain values can be selected by resistors in the feedback loop of the front-end operational amplifier [8], to provide three different current measurement ranges, indexed as 0, 1, and 2, as shown in Table I. The analogue bandwidth at the lowest gain (range 2) is about 10 MHz, matched to large and fast signals; it is reduced to the order of 10 kHz at the highest gain (range 0) used for monitoring smaller signals at 10 Hz. The range 0 (36 nA) allows precise monitoring of relatively small beam losses, while the range 2 (4.5 mA) avoids saturation in the detection of large radiation spikes: the latter is used if the DCU is specifically dedicated to provide beam abort requests. The quoted noise is measured in the complete experimental set up during normal accelerator operations. The intrinsic electronics noise, measured in a test bench in a laboratory, is about 10 (4) times better at 100 kHz (10 Hz).

The oversampling 16-bit ADC followed by digital integration performs similarly to slower ADCs with a larger number of bits. At the design stage, this solution was preferred for its flexibility in choosing the level of digital integration.

The sum of 125 samples is obtained every 2.5 μs, at 400 kHz. These sums, called in the following "400 kHz data", are written in a 4 Gbit DDR circular buffer memory. In a previous version of the firmware, sums of 500 samples were obtained at 100 kHz, every 10 μs. Two "moving sums" of "400 kHz data" are updated for each diamond sensor at each memory cycle, by subtracting the oldest added value of "400 kHz data" and adding the newest one. If a moving sum exceeds a corresponding programmed dose threshold, a logical signal is generated; in total, eight signals are available per DCU. Individual masks can be applied to exclude noisy channels, if needed.

"Abort request" signals are generated separately for LER and HER, as wired-OR of daisy-chained DCUs, then sent to SuperKEKB, when a programmed minimum number of unmasked signals above threshold is reached. After activating the beam abort kicker magnets, the accelerator control system broadcasts "SuperKEKB Abort" signals, which are input to DCUs. Incoming "SuperKEKB LER Abort" and "SuperKEKB HER Abort" signals from SuperKEKB stop the memory writing. The 400 kHz data can then be read out and written to a file for "post-abort" analysis of the beam losses preceding the abort.

Some external logic circuits are used to delay and stretch the SuperKEKB signals, to require a coincidence (see section 1 1.2), and convert from NIM to TTL and fan-out the result to the seven DCUs inputs. Similarly, a fan-out is used to deliver the DCU abort output requests to SuperKEKB, CLAWS and PXD. These external circuits are housed in a NIM crate.

Data at 400 kHz are further added up by the FPGA in groups of 40000, to provide sums of 5000000 ADC values that can be read out at 10 Hz ("10 Hz data") for monitoring purposes. The EPICS software performs pedestal measurements and subtraction, and conversion of ADC data to dose-rate units for display and archival.

1.2. DCU limitations

The diamond-based system has been providing useful information on beam losses in the interaction region, used for accelerator tuning (injection, collimators), estimates of beam-induced background composition, and integrated radiation doses in the VXD region. It protects PXD, SVD and QCS from damaging beam losses, by beam-abort requests. For the diagnostics of beam aborts, it contributes records of pre-abort dose rates with 2.5 μs time resolution.

Some limitations of the DCU electronics are however evident from the experience of operations during Phase 3 of SuperKEKB.

a. Dynamic range The DCU dynamic range (Table I) is not sufficient to accommodate all needs. In particular: (a) accelerator tuning needs measurements of dose-rates down to the order of 1 mrad/s, with a 10% precision of about 0.1 mrad/s, corresponding on average to about 3 pA; (b) beam losses correlated with aborts can reach or exceed $10 - 100$ krad/s, corresponding to currents of the order of several milli-ampere; (c) in continuous injection mode, the beam-losses peak during short time intervals at values exceeding the average losses by more than two orders of magnitude. The separation of the functions of 24 detectors (6 DCUs) dedicated to monitoring smaller currents in range 0, and four detectors (one DCU) dedicated to generate beam aborts on large signals in range 2, is a compromise solution, working only to some extent; in particular, injection spikes still saturate range 0. A wider dynamic range is needed.

b. Common mode noise spikes The noise quoted in Table I does not take into account some high-frequency common-mode noise, not completely filtered out by averaging the 50 MHz ADC data at 10 Hz. In some channels, we observed a peculiar environment-induced pick-up producing 1 s pulses every 14 s, particularly evident in range 1. The origin of this effect has been studied; its mitigation is discussed in section 6 6.1.

c. Memory read The reading of the DCU internal buffer memory, containing the 400 kHz data, is designed as a memory dump after the arrival of an abort signal from SuperKEKB. The abort "freezes" the memory by stopping the increase of the memory pointer, and allows the subsequent read-out of the appropriate memory section by EPICS. This mechanism is too rigid and has some drawbacks. During the readout time interval the abort function (computation of moving sums and comparison with abort thresholds) is suspended: memory read and abort are incompatible. This is not a problem after simultaneous aborts of both beams, as those generated now by the diamond-based system. However it makes it impossible, for VXD detector safety reasons, to read the memory after a singlebeam abort or during normal operations with circulating beams, while periodically obtaining the information of dose-rates from diamond detectors with full 2.5 μs time resolution might be relevant.

d. Synchronization The synchronization with SuperKEKB is limited to the exchange of abort signals: abort requests from DCUs to SuperKEKB and the abort confirmation timing signals from SuperKEKB. A rough alignment of 400 kHz data recorded by the DCUs with SuperKEKB data and events is only possible through the SuperKEKB abort timing signal. A tighter synchronization using an accelerator clock and some sort of time stamps from SuperKEKB had been considered as possible part of the initial specifications, but was abandoned due to lack of feedback from SuperKEKB and for the sake of simplicity. For the future, at least an additional timing signal from SuperKEKB injection should be considered.

e. Injection-related dose rates As mentioned previously, injection-related dose-rate peaks are clearly visible in the 400 kHz data, read out after aborts or for some special studies of range 0 saturation effects. The time resolution of 2.5 μs is largely sufficient to observe the beam-loss increase and oscillation patterns following injection, studied by CLAWS in Phase 1 [9]. Upgraded electronics should be able both to avoid saturation and to integrate the radiation dose due to injection separately, using SuperKEKB injection timing signals as time reference, for proper monitoring of injection quality.

f. HV control The high voltage (HV) modules included in the DCUs are quite stable and reliable. However an internal reading of the output HV value is not available at present; a manual measurement of the voltage at the output connector is needed to cross-check the voltage setting. In one occasion, an EPICS software bug resulted in a wrong HV setting for a substantial period of time, during which diamond detector signals were reduced by about a factor two. Recorded data could be corrected for this effect afterwards, but clearly a better protection against such accidents is needed.

g. External logics The type conversion and distribution of SuperKEKB abort signals to DCUs and the fan-out of DCU abort requests to SuperKEKB, CLAWS and PXD are performed by NIM modules hosted in a NIM crate. This solution is simple, flexible and reliable, but the availability of spares for the NIM crate and modules might be questioned in the long term. The DCUs also have an output connector with eight logic signals (two abort thresholds for each of four diamond detectors), which is not used at the moment. We developed an external logic including signal level adapters and a programmable CAEN FPGA for added flexibility in defining abort conditions and correlations among different DCUs. It is available at INFN Trieste for future installation.

2. UPGRADE PROPOSAL

The proposed upgrade concerns the electronics of the diamond-based radiation monitor and beam abort system, and is aimed at overcoming the limitations listed in section 1 1.2.

2.1. Specifications

To avoid confusion deriving from different calibration factors for the diamond detectors, we will use current units everywhere, keeping in mind the average conversion factor 35 (mrad/s)/nA to dose rate units, and the relative variation of individual factors of up to $\pm 50\%$ with respect to the average.

TABLE II. Summary of dynamic range parameters, assuming an average current to dose-rate conversion factor $k = 35$ (mrad/s)/nA. Explanations are given in the text.

Parameter	value	sampling
Dose rate monitoring		
Current (dose-rate) rms noise	3 pA (0.1 mrad/s)	10 Hz
Max. current (dose-rate)	5 mA (175 krad/s)	10 Hz
Total dynamic range	184 dB	10 Hz
Max. injection peaks	20 μA (0.7 krad/s)	10 Hz
Continuous injection: dynamic range	136 dB	10 Hz
Beam abort generation		
Current (dose-rate) rms noise	0.2 μA (7 rad/s)	400 kHz
Max. current (dose-rate)	5 mA (175 krad/s)	400 kHz
Dynamic range	88 dB	400 kHz

The new electronics for the readout and control of diamond detectors will have the same functions as the DCUs, in particular: (1) individual HV control for the diamond detectors; (2) amplification and digitization of current (dose-rate) signals; (3) integration and memorization of charge (dose) samples in a ring buffer memory at 400 kHz; (4) computation of moving sums of programmable numbers of memorized samples; (5) comparison with abort thresholds to generate logical signals; (6) generation of abort requests, using programmable logical combinations of these logical signals, and programmable masks; (7) read-out of ring buffer memory; (8) computation of 10 Hz monitoring data from sums of memorized samples, and their read-out; (9) initialization of parameters such as abort thresholds etc.

The DCU limitations listed in the previous sections will be overcome by complying with the requirements listed here; the corresponding numbers are summarized in Table II.

The crucial reliability of this system requires the introduction of self-test features in the electronics, generating a SuperKEKB interlock (beam abort request) if faults are detected.

The present method of generating two beam abort request signals for HER and LER (computation of moving sums from 400 kHz data, comparison with abort thresholds, channel masking and combinatorial logics) has proven to be adequate and does not need to be changed or upgraded. The operating experience shows that the useful time intervals for the computation of the moving sums do not exceed about 1 ms, corresponding to 400 buffer memory locations at 400 kHz. The main possible modification concerns the limited dynamic range, which does not allow the use of each individual diamond detector for both monitoring (smaller signals) and beam abort (higher signals), as explained below.

a. Dynamic range The total dynamic range required to accept the input current signals exceeds about 180 dB, that is more than nine decades: from a minimum of about 3 pA, set by rms noise and requested precision on small signals, to about 5 mA, which should be measurable in the 10 Hz data. Present measurements of beam-loss spikes corresponding to injection, extrapolated to future injection conditions, indicate that a lower dynamic range of about 136 dB would be needed to cover currents from the minimum set by noise up to the about 20 μA (0.7 krad/s) of projected injection peaks. To keep the present flexibility for abort thresholds settings, a dynamic range of at least 88 dB is needed in the 400 kHz data: from about 0.2 μA up to 5 mA. These numbers are summarized in Table II.

b. Bandwidth and noise rejection The accepted signal bandwidth should be of the order of 1 MHz to match the 400 kHz data sampling in the ring buffer memory and the radiation dose integration requirements. A reduction in common-mode noise pick-up might be obtained by an optimization of cabling and of the grounding scheme.

c. Memory read The internal ring buffer memory should store data at 400 kHz, and have a depth corresponding to at least 600 ms (the present one has a depth corresponding to 85 s). It must be readable at any time, without interruption of the computation of the moving sums and the generation of abort signals. This may be obtained by writing the 400 kHz in two separate memories, one of which must be reserved to the beam abort function. The other memory can then be read out at any time, in particular: (a) after a beam abort the reading is triggered by the SuperKEKB abort timing confirmation; (b) for injection background studies, the reading must be triggered by the SuperKEKB injection timing signal (to be added as an input); (c) for other purposes, an operator should be allowed to initiate the reading of a memory section any time.

d. Synchronization At present only a rough synchronization with SuperKEKB is obtained by the SuperKEKB abort timing confirmation signal. At least another synchronization signal must be available as input, the SuperKEKB injection timing. This signal initiates an adjustable veto in the Belle II trigger system; the information on the veto width must also be available as a hardware signal or via programming of slow controls. It should be clarified if a deeper integration with the SuperKEKB control system is needed and possible, in particular if the accelerator clock should be used and if some time-stamp mechanism could be used to identify local events in the SuperKEKB context.

e. Injection monitoring The numerical integration of digitized charge (dose) data by the FPGA firmware should take advantage of the improved synchronization including injection timing. In particular, the doses in the injection veto time intervals and in the complementary time intervals should be separately available.

f. HV control At present, all diamond detectors are biased at the same HV value: 100 V. In principle, the requirements of separate HV adjustment for each detector might be relaxed. However, an important feature must be added: the possibility of reading back the bias voltage value without manually measuring it at the output HV connector.

g. External logics The new system design should minimize the amount of external logics needed to interface the system with SuperKEKB and should avoid the use of NIM crates and modules, which may pose problems for long-term availability.

2.2. Technical solutions

The basic building blocks of an upgraded system will be similar to those of the existing electronics, described in section 1 1.1: (a) a digital core based on a FPGA complemented by external memory; (b) an analog front-end with amplifiers and analog-to-digital conversion; (c) HV modules; (d) communication interface for commands exchange, parameters initialization, and for readout of 10 Hz and 400 kHz data.

A preliminary technical choice concerns the modularity and form factor of the system.

An approach based on some standard crate with power supply, hosting modules that exchange signals via a back-plane, has some advantages. In particular, it may allow the use of existing modules restricting the new design to some custom part. External cabling is minimized in this approach. It is also well suited to large systems with many channels, where the management of repairs and spare modules may be simplified. However, the overhead of crate infrastructure for test stations may significantly increase the cost for systems with a limited number of channels.

The approach of the present system may be advantageous for a relatively small number of readout channels: the self-contained DCUs, each dealing with four detectors, include all the components (power supply, FPGA board, analog front-end, HV modules, communications board). It is easy to set up a stand-alone bench for tests and maintenance; the drawback in this case is the need of some external cabling and interfacing to exchange signals among DCUs and between SuperKEKB and DCUs.

The major challenge in the upgrade project is undoubtedly the re-design of the analog front-end with a wider dynamic range. A summary of the state-of-the art in this field is given in section 3 3.1, followed by some hints of possible design approaches.

2.3. Installation issues

The DCUs of the present system are installed in the E-hut, and are always accessible; moreover, there is some redundancy in the installed diamond detectors. Arranging tests of prototypes during normal data taking will be therefore possible without significantly impacting the functionality of the present system. For the same reason, a relatively short shut down period will be sufficient for the installation of the new system, specially if the present cabling scheme will be kept unchanged.

3. DESIGN

We outline here the R&D steps needed by the project, and a plan for prototypes and tests. The main properties of existing systems are summarized as a starting point.

3.1. State of the art

The RMBA working group performed a survey of existing electronics for beam-loss monitoring and beam abort (machine protection), attending presentations from several experts in the field. We considered in particular the beam-loss monitors at SuperKEKB [10], at LHC [11], and at the LHC injector complex [12]. We also had presentations concerning the machine protection systems commercially developed by CAENels [13] in collaboration with DESY, and future developments in this field by the Detectors and Instrumentation Laboratory of Elettra Sincrotrone Trieste SCpA [5]. A summary of some parameters of these different systems is shown in Table III.

A wide dynamic range can be obtained with current-to-frequency converters (CFC) [14, 15]. The front-end modules of the LHC beam-loss monitor system are based on this approach, further developed for the LHC injector complex. As shown in Table III, a global dynamic range from 10 pA to 200 mA is obtained at the LHC injector from the superposition of two overlapping intervals: 10 pA-10 mA and 100 μA-200 mA. The first is covered by a "fully differential frequency converter"(FDFC), the second by a "direct ADC"(DADC). A fast switch between the two conversion methods is driven by the FPGA controlling the

TABLE III. Some parameters of existing beam-loss monitor systems. The definitions of the acronyms and more detailed explanations can be found in references [10, 12, 13].

Item	SuperKEKB [10]	CERN LHC Inject. [12]	CAENels [13]
Form Factors	VME + Loggers	Extended VME64	microTCA
Crates:Modules	Integrator	BLEAC: BLEDP, BLECU	AMC-Pico-8
	monitor, interlock	Proc: BLEPT, BLECS	EXAMPS
	16-bit ADC, 1 MHz		
Dynamic range	?	10 pA-10 mA (FDFC)	1 mA: 102 – 120 dB
		100 μA-200 mA (DADC)	1 μA: 96 – 112 dB
Best resolution @ frequency	?	1 pA @ 1 Hz	2.5 pA @ 2 kHz
Analog front end	P&H Integrator	FDFC & DADC	1 MSPS 20-bit 8-ch
FPGA/Logger	Graphtek GL7000	Cyclone IV GX	Zync Ultrascale
Abort cycle	2 μs	2 μs	4 μs
Buffer memory	Graphtek GL7000	Dual-port	?
Readout	?	Ethernet + optical	Eth.Gigabit SFP+
HV bias	separate	separate	HV-Panda

digitization, and is compatible with the 2 μs acquisition cycle, so that the entire range, covering 10 orders of magnitude, is continuously available.

3.2. R&D steps

R&D is primarily required to investigate a viable solution for the dynamic range of the analog front end. The CFC approach should be compared with possible alternatives, like for instance the 24-bit, 2 Msps ADC LTC2380-24 from Analog Devices, featuring a dynamic range of 100 dB at 1.5 Msp and 145 dB at 30.5 sps. A fast switch between two input amplifiers with different gains would still be needed to cover the total dynamic range of about 184 dB (see Table II). Also the digital part would need some preliminary R&D, in particular the management of two memories by the FPGA, to fulfil the requirement of compatibility between memory-read and beam-abort.

A continuation of the collaboration with Elettra, initiated with the development and construction of DCUs, could speed up the R&D and design phase, since some parts of the present design could be re-used. The Instrumentation and Detectors Laboratory of Elettra is developing a new line of instruments for the Elettra 2.0 upgrade of the synchrotron light source. They will be based on 2U "boxes" for four or eight channels, including four sections: (1) a common main board with FPGA, memories, and UDP data transmission, with application-dependent firmware; (2) an application-dependent ADC board; (3) an application-dependent front-end board; (4) an optional DAC + HV board. The Elettra Laboratory is interested in developing front-end and ADC boards with a LHC-like fast switch extending the dynamic range according to our specifications.

3.3. Plans for prototypes and tests

R&D and initial design could take from one semester to one year, depending on the available resources. About one year will be needed to complete the design, to build and test prototypes. The initial functional tests in a laboratory will be followed by tests in the experiment, during normal data taking. The final production, installation and commissioning of the full system could take another year, approximately. If the present cables will be kept, the installation will be limited to the substitution of electronics in the E-hut, compatible with a short yearly shut-down.

4. HUMAN RESOURCES

Ideally, as part of the beam-loss monitor system, the project should be completely integrated in the accelerator control environment and managed by accelerator experts. The involvement of Belle II physicists is motivated by the location of the diamond detectors at the IR and by their function of primarily protecting PXD and SVD.

For the long-term sustainability of the system, the project of upgrading the electronics of the diamond detectors will require Belle II to provide substantial human resources, even in the case of partial outsourcing to a commercial enterprise like CAENels, or collaboration with an external laboratory, like Elettra.

As a minimum, the project will need a liaison physicist from Belle II, monitoring the fulfilment of the requirements coming from both the accelerator and the detector side. The main design choices and the performance evaluations will need the intervention of a senior electronics engineer from Belle II. Moreover, engineers and technicians from Belle II should be involved in the development of the analog front-end and especially of the FPGA firmware, to ensure that they can be maintained or improved in the long term future.

The Belle II Trieste group is committed to provide, calibrate and maintain the diamond detectors, and to maintain the present electronics, including DCUs, spares and test stands. The group cannot provide the leadership for the project (physicist and senior engineer). In the future a junior PhD engineer and an experienced technician from Trieste might join the project part-time.

5. COST AND SCHEDULE

The cost of the present system of DCUs (7 + 2 spare units) is approximately 54 kEuro for parts and components only; the manpower (prototyping, design, assembly and test) costs are not included.

We received a preliminary quote of about 120 kEuro plus taxes from CAENels: the offer includes a microTCA crate, some standard high voltage and digitizer modules, and a custom-designed combiner module (developed at DESY) to produce beam abort requests.

The continuation of the collaboration with Elettra for a customisation of their new line of modules would probably require an intermediate budget, of the order of 100 kEuro.

From the start of the project, about two years and a half to three years will be required until installation and commissioning.

6. OTHER ITEMS

6.1. Minor modifications of the present electronics

Some minor modifications of the present DCUs may marginally improve their performance.

a. Range 0 optimization Giving up some sensitivity to very small signals, the saturation effects on injection spikes will be mitigated. From a preliminary estimate, the new range should be equivalent to range 0 (36 nA) $\times 20 - 50$. This will require changing the resistors in the amplifier feedback loop.

b. Elimination of noise spikes Noise spikes lasting for about 1 s every 14 s were traced to an unidentified external source (a compressor pump in the environment?) inducing regularly some high-frequency common mode noise, which is only partially filtered out by the averaging in the 10 Hz data. The trans-impedance amplification is bipolar, but the ADC range is matched to the positive signals and cuts negative signals below certain values. The increased noise fluctuations in some time intervals have a negative cut-off that moves up the 10 Hz average: in practice originating a pedestal shift during 1 s time intervals. This effect can be mitigated by ferrite clamps on the signal cables close to the DCU signal inputs. A more radical solution is to revert to the original condition of symmetric ADC ranges around zero, for instance ± 18 nA instead of $0 - 36$ nA.

6.2. CLAWS abort request signals

We may add here some information on CLAWS and on their plan to include their signal in the abort request, anticipating most VXD abort requests by about $10 - 20$ μs.

6.3. Instrumentation of collimators

A comment on possible improvements in the instrumentation of collimators?

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