SIS18-SpillAbortUnit Technical Design Report

1. Functional Requirements

Since a formal performance specification document does not exist, this chapter summarises the functional and technical requirements of the SIS-18 spill abort system.

- Spill aborts can be requested from several experimental stations. Initially the following signal sources will be implemented: HTA (Cave A), HTM (Cave M), FRS, HADES. Spare channels shall be foreseen for future use.
- Spill aborts may only be requested from the respective target station. Any target station may only request spill abort for itself (arbitration). Spill aborts from any other stations are not serviced.

Different use cases of spill aborts:

- Standard Spill Abort
  - There can be only one spill abort during a synchrotron cycle (spill extraction). Beam extraction shall be suppressed until the end of the regular (programmed) extraction time.
  - Spill abort is standard operation mode for Cave A and Cave M since these target stations use only low intensity beams (no machine activation). Any spill abort will be automatically reset (released) at the end of the cycle, unless the request for spill abort is still active.
- Emergency Spill Abort
  - For other target stations (FRS, HADES), spill abort shall be used only in emergency situations since these experiments typically are operated with high-intensity beams and SIS-18 is not designed for regular dumping of high-intensity beams (leading to significant machine activation).
  - For these target stations (FRS, HADES) a spill abort shall result in a beam interlock that needs to be reset by an operator (typically from the main control room).
- Spill Pause
  - Cave A and Cave M require some means of interrupting the beam for a short period of time during a spill. In this mode, the spill abort shall only be active for the duration of the users request (not necessarily till the end of the cycle).
  - It shall be possible to have more than one spill pause during a single synchrotron cycle.
  - Standard spill abort and spill pause are two distinct features and Cave A and Cave M shall have two separate channels to activate them separately.

Handling of spill aborts:

- Requested spill abort signals shall be registered by the control software (channel and White Rabbit timestamp). The information shall be published by a FESA server to any clients subscribed (e.g. Archiving System).
- The system shall implement a test mode. Only authorized users may enable the test mode (RBAC). When enabled the test mode shall allow to trigger the

beam abort functionality via a dedicated input on the hardware or via software and monitoring of outputs shall be possible.

- The SIS-18 spill abort system shall be conceptually integrated into the future FAIR machine protection systems. Preferably, the same technologies and interfaces shall be used.

General Comment

- The spill abort system acts on dedicated accelerator equipment, the so-called spill abort actors. This document assumes that spill abort actors are appropriate means to stop extracting the beam from the SIS-18 synchrotron. Associated accelerator physics are not within the scope of this document.

2. System Components (Input / Output Components)

The Spill abort system acts on different accelerator components (Actors, cf. 2.1) and receives input from different user stations (Spill Abort Requester, cf. 2.2). They are connected to the central unit of the spill abort system, located at BG.2.009 in rack BG2A.F8, via optical fibres (cf. A4).
The spill abort system is designed to be modular and extensible in the future. In the current configuration there are four target stations and the spill abort system is acting on three accelerator components.

2.1 Output Signals: Actors

The beam abort system acts on the following accelerator components:

- **[FQ]** Fast Quadrupole: GS02KQ1E
  The power converter for the fast quadrupole is located in BG.2.001. The executed function is “Reglersperre” (regulator stop), i.e. the magnet current is pulled down to ground as fast as possible.
- **[KO]** KO-Exciter: GS01BO1EH
  The control electronics of the RF Knock-Out (KO) Exciter is located in BG.1.016.
- **[RF]** RF Cavities: GSB02BE1
  The front-end controller for the HF cavities is also located in BG.1.016.

2.2 Input Signals: Spill Abort Requester

There are four experimental stations that can request a spill abort.

- Cave A   TH.2.005
- Cave M   AR.1.001
- FRS   Elektronikraum der FRS-Messhuette
- HADES   TH.1.004

Spill abort request from FRS or HADES will trigger an emergency spill abort. Cave A and Cave M each have two channels to request either a standard spill abort or a spill pause. The different use cases are discussed in detail in 3.1.3.

3. System Design

The spill abort system is designed to have one central unit that implements the logic needed to fulfil the functional requirements. Spill abort requester as well as actors are directly connected to the spill abort control unit. From a users perspective the spill abort control unit merely passes their request to the respective actors when the request is permitted to trigger a spill abort (during a slow extraction towards the users target station) or inhibits the signal otherwise.

3.1 The Spill Abort Control Unit

The Spill Abort Control Unit is mounted in the accelerator electronics room BG.2.009 in rack BG2A.F8. The control unit is implemented as a 19” 3HU SCU crate, and comprises of a SCU equipment controller including a White Rabbit Timing receiver connected to the White Rabbit timing network, a dedicated DIOB slave board with digital electrical and optical connectors for the input and output interfaces, and a FESA instance as interface to applications and LSA.

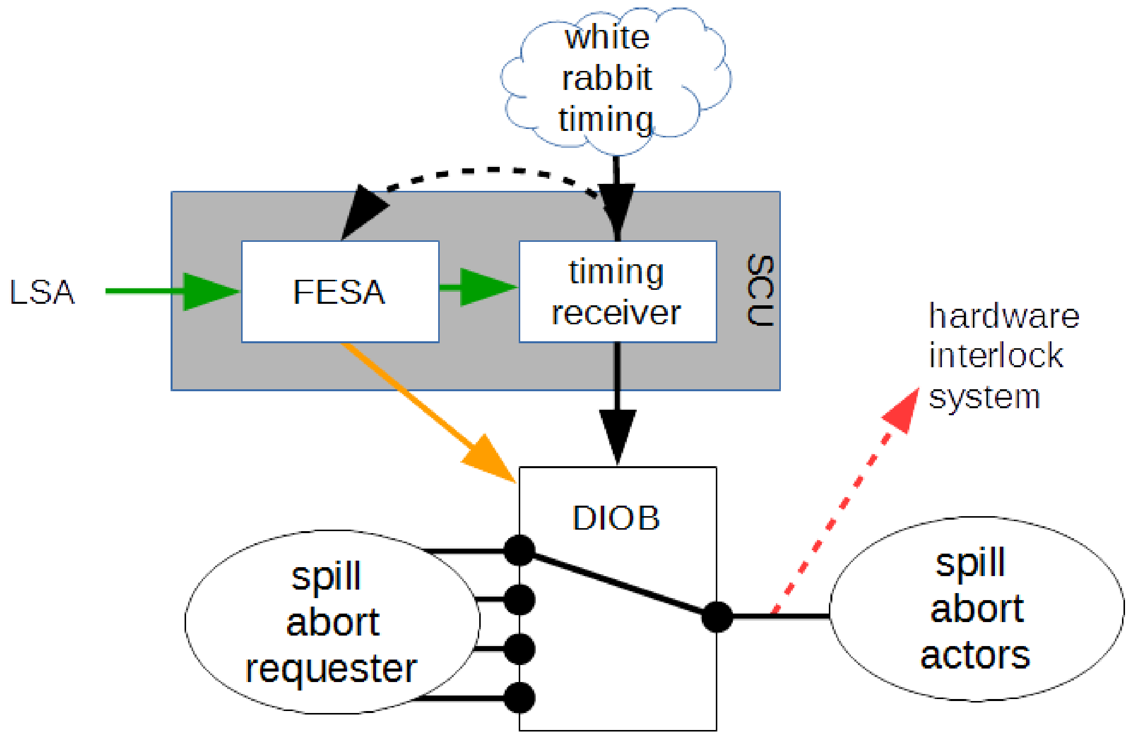


Figure 1: Spill Abort Control Unit

Figure 1 illustrates the interaction between the different components of the Spill Abort Control Unit:

The DIOB configuration is static and needs to be set only on system restart (orange arrow). When the beam schedule is modified by operators, LSA informs the spill abort control unit whether any of the target stations is allowed to abort the spill. The FESA instance receiving the setting will then reprogram the ECA of the timing receiver (green arrows). For enhanced reliability and robustness, there is no software involved in the process of receiving timing events and producing output as response to spill abort requests (black arrows).

The FESA instance also registers for timing events (dotted black arrow), though this is merely for monitoring. Processing the timing events in FESA does not interfere with the actual functionality implemented in hardware.

For the emergency spill abort (FRS, HADES) two of the DIOB outputs are connected to the hardware interlock system (red dotted arrow).

3.1.1 DIOB IO Mapping

The main logic of the Spill Abort Control Unit is implemented in the firmware of the DIOB. The DIOB is equipped with 10 interface modules, 2 electrical (and 8 optical (FG900.011-LWLIO2), each with one output and 5 input channels. for a total of 10 output and 50 input channels. In the future the interface modules will be replaced to have more outputs available, allowing for a more modular configuration.

Slot	Opt/elec.	OUT	IN1	IN2	IN3	IN4	IN5
1	opt	FQ: abort	Cave A abort req.	Cave A pause req.	FRS req		
2	opt	FQ: reset	Cave M abort req.	Cave M pause req.	HADES req		
3	opt	Cavities: abort					
4	opt	KO: abort					
5	opt						
6	opt						
7	opt						
8	elec	TS: abort					
9	Lemo (5V)	HWILK: FRS					
10	Lemo (5V)	HWILK: HADES					

The table shows the IO mapping for the 10 interface modules. In the following input channel x at slot y is referred to as **y.inx** and output channels as **y.out**.

3.1.2 DIOB Tag configuration: spill_abort_permit

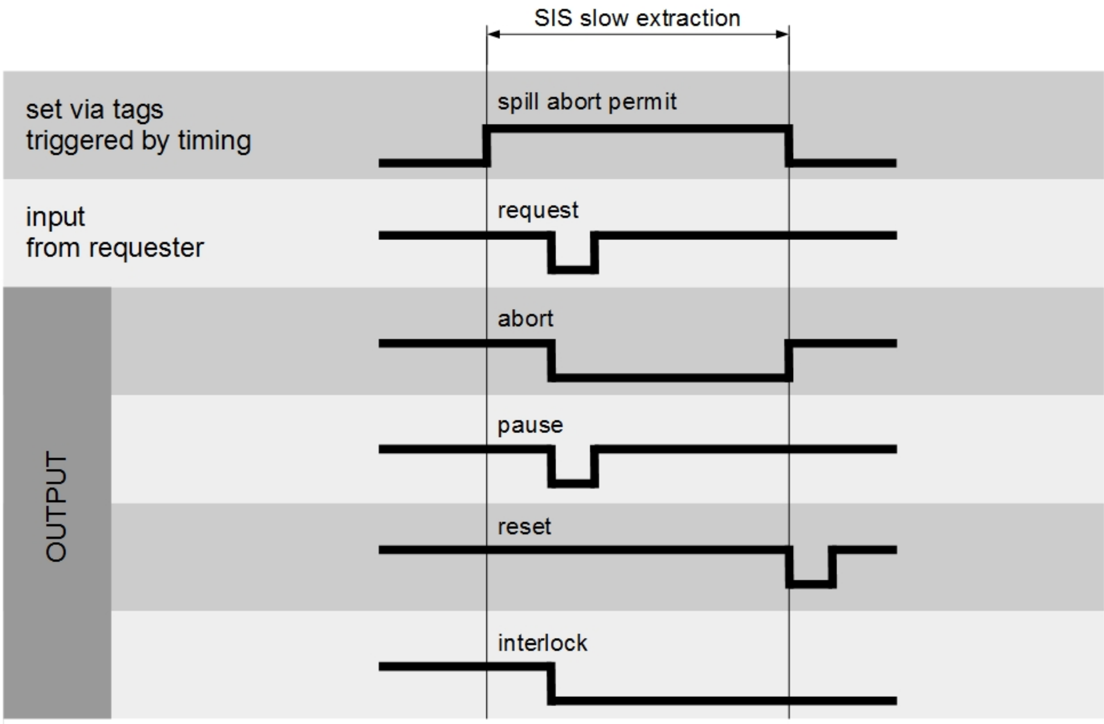
To each user station / spill abort requester corresponds a dedicated spill_abort_permit bit that indicates whether a given requester may abort the current spill. These bits are set in response to timing events via the standard scu-bus tag mechanism. For each user station there is a dedicated tag that is configured to set the corresponding spill_abort_permit bit. One additional tag (1) is used to unset all spill_abort_permit bits:

Tag 1	All spill_abort_permit are reset
Tag 2	CAVE A spill_abort_permit is set
Tag 3	CAVE M spill_abort_permit is set
Tag 4	FRS spill_abort_permit is set
Tag 5	HADES spill_abort_permit is set

Currently the firmware limits the number of tag configurations to 8

3.1.3 DIOB Firmware Logic

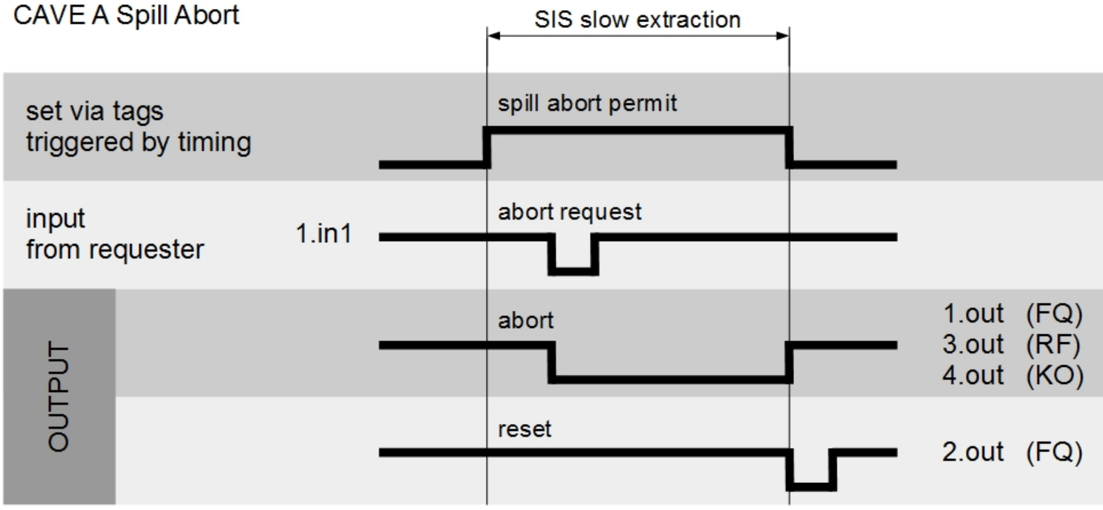
The DIOB firmware implements the last step in determining whether a users request results in a signal send to the actors. In the following the different use cases are depicted. Each user station has a dedicated spill_abort_permit and the tag configurations (cf. 3.1.2) ensure that at any time at most one of the spill_abort_permits is set.



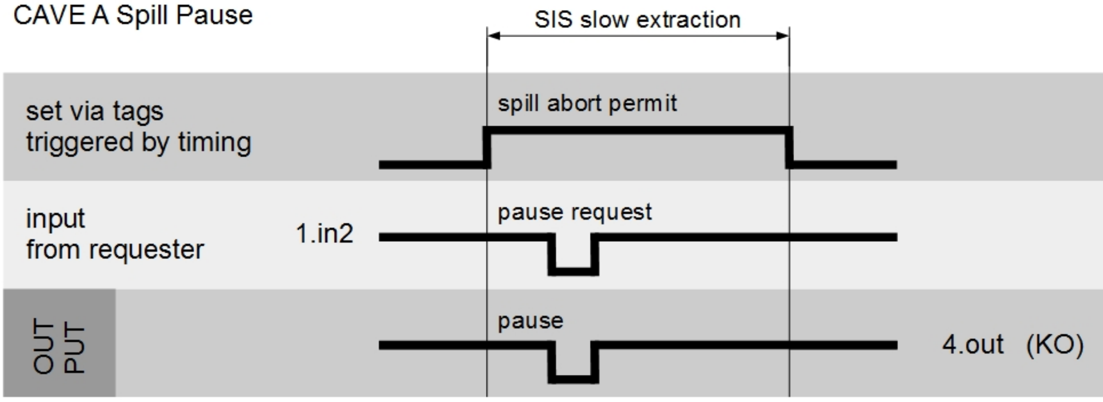
The above figure displays a generic scheme for a single use case of the spill abort logic.

- The **spill_abort_permit** is set as response to timing events. It indicates that there currently is slow extraction from the SIS towards the respective target station.
- Only **request** signals within this time window result in a spill abort abort / pause command at the corresponding output.
- A pending **request** will trigger a spill abort as soon as the **spill_abort_permit** is active, i.e. the system is triggered by the level of the request, not by its rising/falling edge (this applies to spill abort requests as well as spill pause requests).
- The **abort** command is reset at the end of the slow extraction.
- The spill **pause** signal is reset when the **request** is reset or at the end of the slow extraction (whatever comes first).
- There can be more than one spill pause during a single slow extraction.
- Some actors require a short **reset** command shortly after the abort command is reset.
- For the emergency mode spill abort (FRS, HADES) there are signals to the hardware interlock system. The **interlock** signals are latched until reset by operators (not shown in the picture).

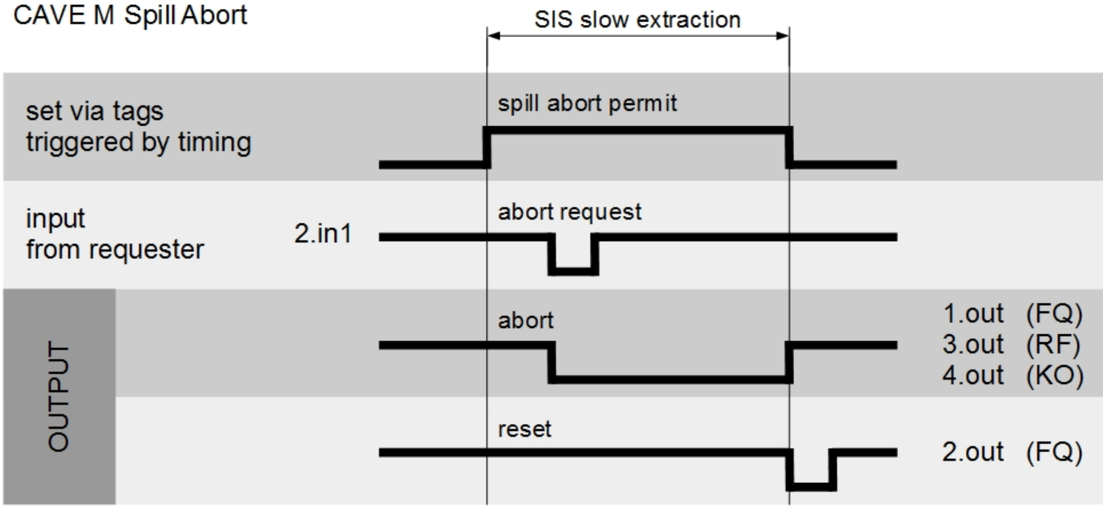
CAVE A Spill Abort



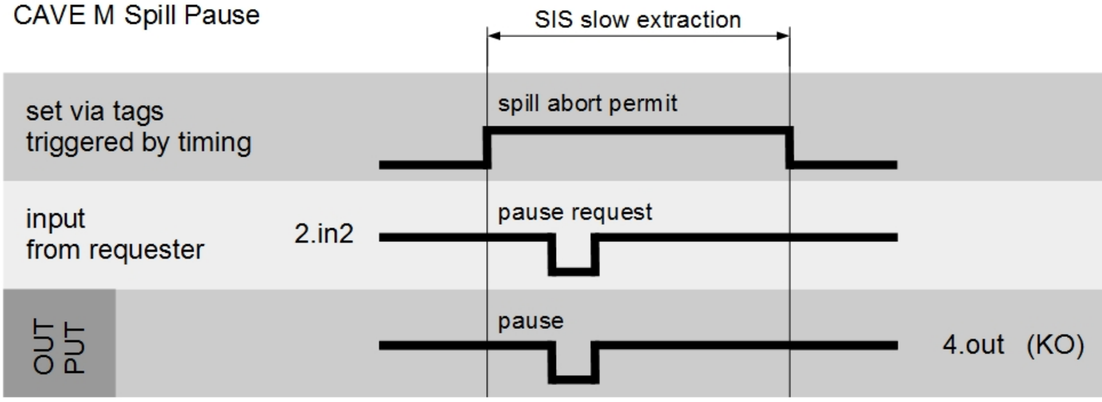
CAVE A Spill Pause



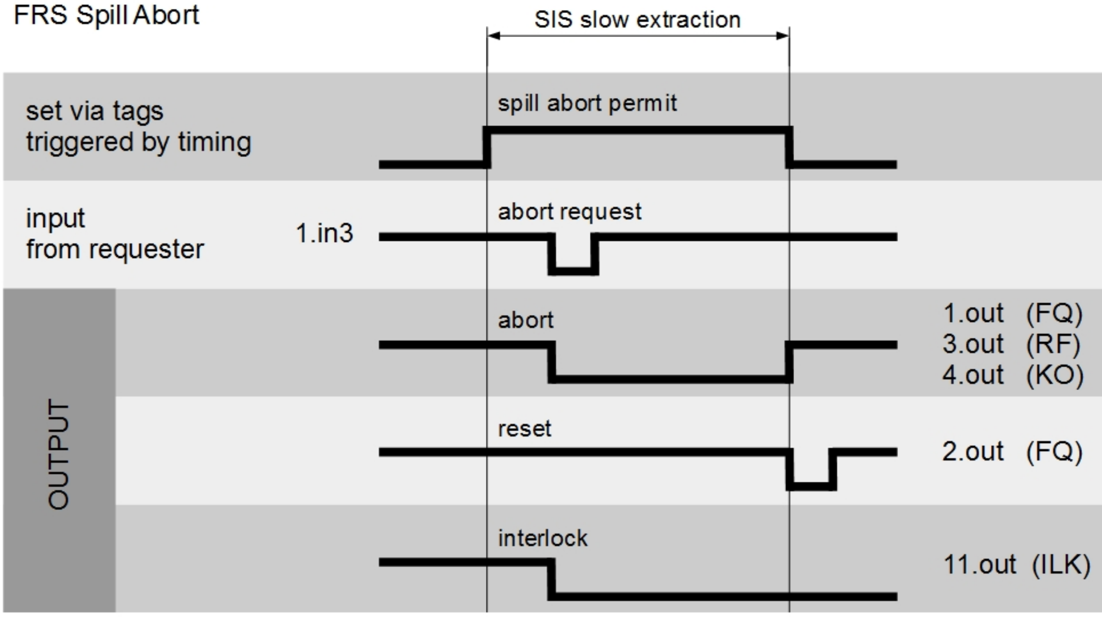
CAVE M Spill Abort



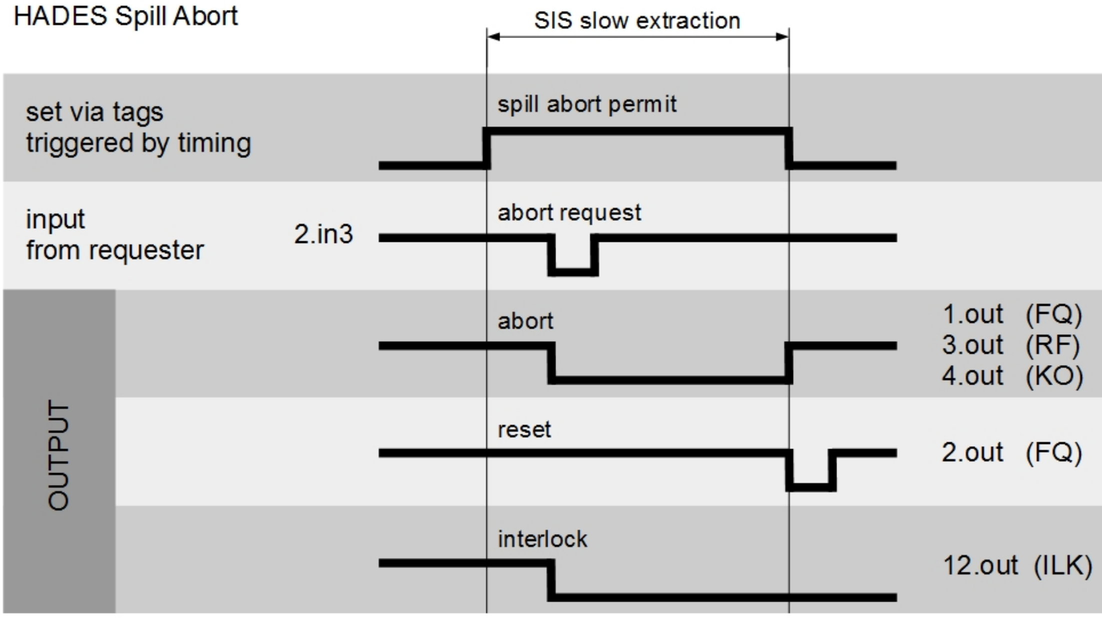
CAVE M Spill Pause



FRS Spill Abort



HADES Spill Abort



3.1.4 Timing Receiver / ECA

As the beam process index and sequence index during which the slow extraction takes place can change when the schedule is modified, the timing receiver has to be configured dynamically.

Each time the spill abort control unit is supplied with settings from LSA (cf 3.2 Data Supply from LSA), it will first be checked whether a new conditions has to be created or old conditions have to be discarded, then the ECA is reprogrammed accordingly.

The type of event that indicates start and stop of slow extraction is CMD_BP_START (#256) and CMD_GAP_START (#258), respectively. The stop condition does not need to be dynamic, because a CMD_GAP_START always indicates the end of slow extraction for any user station.

Once the conditions are configured on the ECA, the processing of timing events takes place in hardware only. The Timing Receiver receives the White Rabbit timing events, matches them with conditions on the ECA, and triggers the corresponding tag on the DIOB. Lastly, the tag is configured to either enable or disable the respective spill abort permit and the DIOB firmware will forward requests to the actors accordingly.

3.1.5 FESA Class

The spill abort FESA class serves as interface for applications and data supply from LSA. While the main logic of the spill abort control unit is implemented in the DIOB firmware, the FESA instance is responsible for

- Initializing the hardware
- Program the ECA in response to settings supplied from LSA

In addition to that the FESA class also offers the following functionality:

- Monitoring of the input/output signals.
  The status of the io-channels of the DIOB is read out periodically and published via Acquisition Properties
- Acquiring timestamps for spill aborts
  The spill abort control unit implements a mechanism to record timestamps for every spill abort (cf. A.3). These timestamps are made available via acquisition properties.
- Testing Mode
  The FESA interface offers means to switch the spill abort control unit into a command mode. In this mode the DIOB input can be simulated via (Expert) setting properties.

3.1.1.1 Properties

- Setting (beam process multiplexed)
  The setting is beam process multiplexed. It has one item called beamAbortPermit to select which user is permitted to abort the beam during the given beam process (cf. 3.2).
- Reset FRS-Interlock & Reset HADES-Interlock Commands (non-multiplexed)
  Spill aborts from the FRS or HADES user stations cause an interlock that has to be reset by operators.
- Acquisition (non-multiplexed)
  A list of the last 100 spill aborts with WR-timestamps

  - Expert Setting
    Allows to simulate user input for testing purposes
  - Expert Acquisition
    Status of all inputs/outputs of the spill abort unit.

3.2 Data Supply From LSA

LSA supplies the Spill Abort Control Unit with settings for each scheduled beam process (i.e. beam process index is the multiplexing criterion). For each beam process LSA informs the spill abort control unit whether any of the target stations is allowed to abort the spill. The setting consists of an enum with the following values:

- SPILL_ABORT_INACTIVE
- SPILL_ABORT_CAVE_A_PERMIT
- SPILL_ABORT_CAVE_M_PERMIT
- SPILL_ABORT_FRS_PERMIT
- SPILL_ABORT_HADES_PERMIT

The enum values directly correspond to the five different tag configurations as listed in 3.1.2. As the slow extraction takes place during a single beam process, it is sufficient to notify the spill abort system about the start of slow extraction. The end of slow extraction is always indicated by the next CMD_GAP_START event (cf. 3.1.4).

3.3 Interface to the Hardware Interlock System

Spill aborts from FRS or HADES generate a hardware interlock. Two outputs of the DIOB interface modules are dedicated for connection to the hardware interlock system. The hardware interlock system is mounted in the same rack as the spill abort control unit and the interlock collector is mounted in a different rack in the same room at ~5m distance.

3.4 Interface to MASP

In addition to the hardware interlocks caused by FRS/HADES spill aborts, the spill abort control unit incorporates a MASP status emitter that signals interlocks to MASP. Malfunctioning of the spill abort control unit itself are reported to MASP and cause an interlock at the SIS18 particle transfer.

3.5 User Interface

In addition to general monitoring for users, operators need to be able to reset the interlocks caused by FRS and HADES spill aborts. How this will be realized needs to be clarified.

A1: Possible Errors/Interlock causes

- Too many ECA conditions
  There can be up to 256 conditions programmed in the ECA at the same time. Under normal circumstances the way LSA assigns beam process indices (up to 1024) is sufficient to make sure that the number of simultaneous programmed conditions stays well below that limit.
  If the spill abort control unit determines in the FESA-ServerAction that applying the setting would require more than 256 conditions, an exception is thrown, effectively rejecting the setting. Even with that check, there is still potential for exceeding the limit in which case an interlock is raised.
- Other critical failure conditions may be identified that can only be dealt with by raising an interlock that requires a reset of the spill abort control unit.

A2: Log messages

The FESA instance is using standard methods for logging. A log message is created:

- for all errors/interlocks listed in A1.
- when a spill abort requester successfully requests a spill abort. The log message contains a WR timestamp (cf. A.3).
- when a spill abort interlock is reset by an operator (cf. 3.5).

A3: Timestamping Spill Aborts

The spill abort system is using the following mechanism to record timestamps in the event of an actual spill abort (i.e. a request that does result in a spill abort):

- The DIOB is equipped with one electrical interface module. Whenever there is a successful (i.e. permitted and actually executed) spill abort, the DIOB sends a short pulse on this modules output.
- The signal is fed into one of the lemo inputs of the timing receiver.
- The FESA instance programs a condition on the ECA to receive a software callback on the rising edge of the signal.
- Retrieval of the callback is implemented such that it triggers a FESA-EventSource at which point the standard FESA-mechanism can be used to fill Acquisition fields with information on the executed spill abort (requester and WR timestamp)

A4: Spill Abort Control Unit Cabling

Both the spill abort requesters and the spill abort actors are connected with the spill abort control unit installed at **BG.2.009 in rack BG2A.F8**. No direct connections from the requesters to the actors are needed or foreseen. All connections are made via multi-mode optical fibres of type 50/125µm OM3. It follows a table of all cable routes. Not included in the list are the 2 cables from the spill abort control unit to the hardware interlock collector, which is installed in the same room.

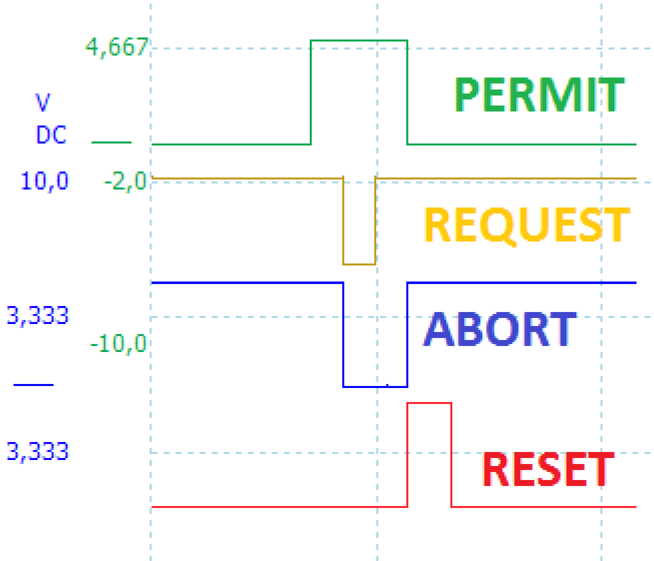
Location	Cable Assembly	Comment / Requester / Actor	Signals
TH2.005	ST	Cave A	spill abort, spill pause
AR1.001	ST	Cave M	spill abort, spill pause
EX1.026	ST	FRS Messhuette Elektronikraum	spill abort
TH1.004	ST	HADES	spill abort
BG2.001	ST	Fast Quadrupole (GS02KQ1E)	spill abort, spill abort reset
BG1.016	Splicebox	KO-Exciter (GS01BO1EH), HF Cavities (GSB02BE1)	spill abort, spill abort permit

A5: Test Setup

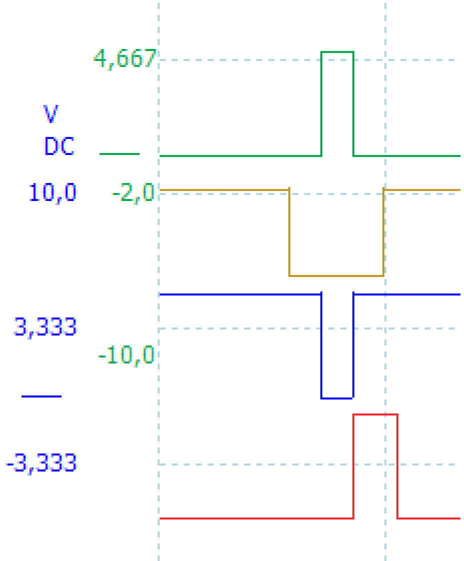
For first bench tests a SCU equipped with 3 FG902.021 interface modules, and a prototype DIOB firmware was employed. Timing-Events are injected and inputs are driven via dedicated test scripts. Outputs are monitored and recorded using a PicoScope 4000.

Note that the test cases below are for the emergency spill abort (ie FRS/HADES) where the abort signal is latched till the end of the extraction. The interlock signal that would prevent the extraction on the next cycle (until reset by operators) was not yet included in the tests. The reset signal is stretched for the tests and will be shorter in the actual firmware.

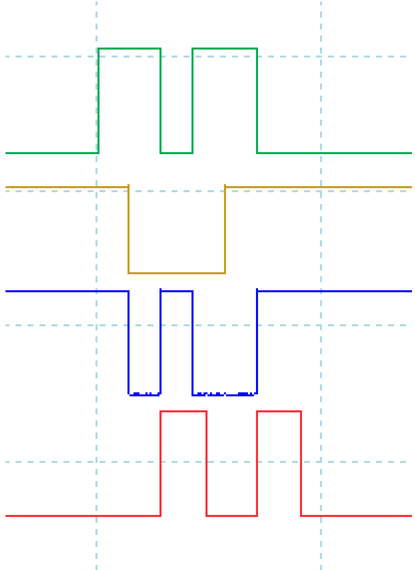
TestCase 0: Typical use case: User requests spill abort while they are permitted to do so.



TestCase 1: Early Request: User request spill abort before they are permitted to do so.



TestCase 2: Abort the next extraction: User requests a spill abort and the request stays until the next extraction beam process starts.



(**TestCase 3:** there is no TestCase3 yet, listed here only for consistent numbering)

TestCase 4: Late reset of request: User requests a spill abort and resets the request only after the extraction beam process ended. For the next beam process with extraction another spill abort is requested.