

Event Driven Data Acquisition for the Recycler Ring BPM Front-end

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Introduction

The Recycler BPM front-end is designed to provide two types of data acquisition services:

- Command driven – on demand user initiated through application programs, and
- Event driven – automatic measurements initiated by predefined clock events.

The BPM front-end treats these two measurement types similarly; command driven is a special case of event driven acquisition. This note describes the operation of the event driven acquisition feature of the BPM front-end and touches on issues related to data retrieval by console application programs and the Shot Data Acquisition system.

Events

The events of interest nominally are those related to the transfer of beam into or out of the Recycler. A list of the six most common transfers and associated clock system events follows.

<u>Transfer type</u>	<u>Beam type</u>	<u>Tclk - arm</u>	<u>Bsync - trigger</u>
Main Injector -> Recycler	Proton	\$E2	\$A2
Main Injector -> Recycler	Pbar	\$E0	\$A0
Recycler -> Main Injector	Proton	\$E3	\$A3
Recycler -> Main Injector	Pbar	\$E4	\$A7
Recycler -> Accumulator	Proton	\$96	\$A6
Accumulator -> Recycler	Pbar	\$E1	\$A1

The scheme used to implement event triggered data acquisition involves an arm event transmitted over the Tclk system followed by a trigger event transmitted over the Bsync system. The Tclk arm and Bsync trigger events are always treated as a pair with each arm event occurring a minimum of 400 mSec before its related trigger event. The 400 mSec specification for the time between arm and trigger allows the BPM front-end to abort any untriggered previous measurement and then configure the data acquisition

hardware for the new measurement. Tclk arm events are dedicated indicators of beam state and do not have differing meaning across various machine operating contexts. All of the 254 possible Tclk arm events are available, but each enabled Tclk arm event must adhere to the minimum timing and exclusive use requirements stated above. (Note that although supported by the BPM front-end most Tclk events are not appropriate for use as arm events.) The Tclk arm event and Bsync trigger event pair will be referred to simply as an event in further discussion.

The BPM front-end supports data acquisition on a maximum of sixteen events with each capable of making any of the defined position measurements. Events are uniquely identified by the **eEventIndex** enumeration having the following definition:

```
typedef enum {
    kEventIndexMin = 0,
    kEventInteractive = kEventIndexMin,
    kEventRepetitive,
    kMainInjectorProtonToRecycler,
    kMainInjectorPbarToRecycler,
    kRecyclerProtonToMainInjector,
    kRecyclerPbarToMainInjector,
    kAccumulatorPbarToRecycler,
    kEventIndexMax = 15,
    kNumEventIndexes,
    kEventIndexDefault = kEventInteractive
} eEventIndex;
```

The text of the enumeration constants outlined above fairly succinctly documents the meaning of each value. Two enumeration values deserve additional discussion. The value **kEventInteractive** identifies command driven measurements made whenever a user at a console program issues a measurement request. Interactive measurements are unique in that their arm event is implied by the arrival of the measurement request at the front-end. The value **kEventRepetitive** identifies the (periodic) measurements often referred to as background measurements. If enabled the repetitive measurement runs whenever none of the other measurements are armed. All other enumeration values refer to measurements that will not occur until the related Tclk/Bsync event pair is realized.

Event Programming

The sixteen events described above represent sixteen measurements that may be programmed into the BPM front-end at any one time. The data to be acquired for each of

the sixteen measurements is specified by an **Acquisition Specification**¹ having the following definition:

```
// structure sent by ACNet to specify measurement global parameters
class AcquisitionSpecification {
    unsigned long int      _mustBeZero;
    eMeasurement           _measurement;
    eBeamMode              _beamMode;
    eBeamType              _beamType;
    eMeasurementType       _measurementType;
    eArmEvent              _armEvent;
    eTriggerEvent          _triggerEvent;
    ePretriggerControl      _pretriggerEnable;
    eTriggerDelay          _triggerDelay;
    eGlobalDelay           _globalDelay;
    float                  _intensityThreshold;
    eTriggerTimeout        _timeout;
};
```

Each member of the class is a four byte quantity resulting in a total size of 48 bytes. The definition of each member follows.

```
typedef enum {          // legitimate range of _measurement member
    kMeasurementMin = 0,
    kRepetitiveSingleGate = kMeasurementMin,
    kOneShotMultipleGate,
    kOneShotSingleGate,
    kPrearm,
    kTimingScan,
    kTurnToTurnPeriod,
    kMeasurementMax = kTurnByTurnPeriod,
    kNumMeasurements,
    kMeasurementDefault = kBackground
} eMeasurement;
```

The `_measurement` member describes the type of position measurement to be made. The three beam position measurement types include: repetitive single gate which makes a single turn measurement at a specified frequency, one-shot multiple gate which makes a multiple turn measurement upon a specified arm/trigger event, and one-shot single gate which makes a single turn measurement upon a specified arm/trigger event. The prearm measurement type is a dummy measurement capable of enabling and disabling other specified measurements upon a specified arm/trigger event. Additional measurement types are for system diagnostics and testing.

¹ Acquisition specifications are generally defined by machine personnel and remain unchanged for long periods of time. They may in fact be treated as constants.

```

typedef enum {          // legitimate range of _beamMode member
    kBeamModeMin = 0,
    kAntiProton = kBeamModeMin,
    kProton,
    kCalibration,
    kBeamModeMax = kCalibration,
    kNumBeamModes,
    kBeamModeDefault = kAntiProton
} eBeamMode;

```

The `_beamMode` member describes the timing characteristics of acquisition on the associated event. The measurement system uses different temporal offsets from the Bsync trigger event for proton or antiproton (and calibration) measurements. Note that when the calibration source is enabled this field will be ignored and unique calibration timing will be used.

```

typedef enum {          // range of _beamType member
    kBeamTypeMin = 0,
    kInjectExtract = kBeamTypeMin,
    kHot,
    kHotHead,
    kHotTail,
    kCold,
    kColdHead,
    kColdTail,
    kBeamTypeMax = kColdTail,
    kNumBeamTypes,
    kBeamTypeDefault = kInjectExtract
} eBeamType;

```

The `_beamType` member describes the timing characteristics of acquisition on the associated event. The measurement system uses temporal offset information derived from the Mdat system to measure the various types of beam (e.g., injected, hot or cold). This member specifies which Mdat message is to be used.

```

typedef enum {          // range of _beamMeasurement member
    kMeasurementTypeMin = 0,
    k2_5MHzEnsemble = kMeasurementTypeMin,
    k2_5MHzBunchbyBunch,
    k2_5MHzNarrowBand,
    kUnbunchedEnsemble,
    kUnbunchedHeadTail,
    k89KHzNarrowBand,
    kCount,
    kRaw,
    kRawLong,
    kMeasurementTypeMax = kRawLong,
    kNumMeasurementTypes,
    kMeasurementTypeDefault = k2_5MHzBunchEnsembleWB

```

```
} eMeasurementType;
```

The `_measurementType` member describes the frequency characteristics of acquisition on the associated event. The analog acquisition subsystem uses various digital filters to make measurements. This member specifies the filter to be used.

```
typedef enum { // range of _armEvent member
    kArmEventMin = 0x00,
    kArmTclk0x00 = kArmEventMin,
    kArmTclk0xfd = 0xfd,
    kArmAutomatic = 0x100,
    kArmEventMax = kArmAutomatic,
    kNumArmEvents,
    kArmEventDefault = kArmInteractive
} eArmEvent;
```

The `_armEvent` member describes the arm event characteristics of acquisition on the associated event. Measurement arm events can be any of the (reasonable) Tclk events, or in the case of interactive and repetitive measurements the measurement request itself.

```
typedef enum { // range of _triggerEvent member
    kTriggerEventMin = 0x00,
    kTriggerBsync0x00 = kTriggerEventMin,
    kTriggerBsync0xff = 0xff,
    kTriggerPeriodic,
    kTriggerExternal,
    kTriggerEventMax = kTriggerExternal,
    kNumTriggerEvents,
    kTriggerEventDefault = 0xda
} eTriggerEvent;
```

The `_triggerEvent` member describes the trigger event characteristics of acquisition on the associated event. Measurement trigger events can be any of the (reasonable) Bsync events, an external trigger input to the BPM front-end or the periodic trigger described below.

```
typedef enum { // range of _pretriggerEnable member
    kPretriggerControlMin = 0,
    kPretriggerDelayOff = kPretriggerControlMin,
    kPretriggerDelayOn,
    kPretriggerControlMax = kPretriggerDelayOn,
    kNumPretriggerControls,
    kPretriggerControlDefault = kPretriggerDelayOn
} ePretriggerControl;
```

The `_pretriggerEnable` member allows for enabling and disabling a delay, measured in turns, between the specified trigger event and the beginning of data acquisition. This pretrigger delay is normally only enabled for injection and extraction measurements where it is used to adjust for kicker system to first turn latency. In the Recycler this value is nominally 33 turns.

```
typedef enum { // range of _triggerDelay member - turns
```

```

    kTriggerDelayMin    = 0,
    kPeriodicFrequencyMin    = 2,
    kTriggerDelayMax    = 65535 - 535,
    kNumTriggerDelays,
    kTriggerDelayDefault = 0,
    kPeriodicFrequencyDefault = 200,
    kPeriodicFrequencyMax    = 500
} eTriggerDelay;

```

The `_triggerDelay` member describes the timing characteristics of acquisition on the associated event. The trigger delay member has differing meaning depending upon the value of the `_triggerEvent` member described above. If a Bsync trigger event is specified then trigger delay is in units of turns and represents a delay between the Bsync trigger event and the first measured data. Normally on event triggered acquisitions the BPM front-end acquires data from the first 1024 turns after the trigger. The trigger delay allows this 1024 sample ‘window’ to be moved out in time by up to an additional 65,535 turns. If an external trigger event is specified then trigger delay has no meaning. If a periodic trigger event is specified then trigger delay is in units of Hertz and represents the repetitive trigger frequency.

```

const unsigned long int kRfBucketsPerTurn = 588;
typedef enum {
    // range of _globalDelay member - RF buckets
    kGlobalDelayMin    = kRfBucketsPerTurn * -2,
    kGlobalDelayMax    = kRfBucketsPerTurn * 2,
    kNumGlobalDelays,
    kGlobalDelayDefault = 0
} eGlobalDelay;

```

The `_globalDelay` member describes the timing characteristics of acquisition on the associated event. The global delay is a signed value in units of 53MHz buckets that represents a delay between the Bsync trigger event and the first measured data. This is a finer adjustment than the trigger delay member described above. The normal value for the global delay member is ZERO.

The `_intensityThreshold` member is a single precision float that is used for intensity discrimination. This one value is used for all channels on all measurements. In turn-by-turn mode the comparison is made against the first turn value only. Note that the intensity data does not have an absolute calibration of particles per bunch.

```

typedef enum {
    // range of _timeout member - seconds
    kTriggerTimeoutMin    = 1,           // one second
    kTriggerTimeoutMax    = 5 * 60,     // five minutes
    kNumTriggerTimeouts = kTriggerTimeoutMax - kTriggerTimeoutMin + 1,
    kTriggerTimeoutDefault = 4 * 60,    // four minutes
    kTriggerWaitForever    = 0xffffffff
} eTriggerTimeout;

```

The `_timeout` member describes the timing characteristics of acquisition on the associated event. The timeout value is in units of seconds and specifies how long the BPM front-end should wait after the arrival of an arm event for an associated trigger event. If the trigger does not arrive within the timeout period the measurement will be aborted to allow the repetitive flash to resume.

The sixteen acquisition specifications are stored in an array and indexed by the **eEventIndex** enumeration described above. The first two acquisition specifications (element zero – **kEventInteractive** and element 1 - **kEventRepetitive**) are reserved for use by interactive application programs. The **armEvent** field of these acquisition specifications must always be set to **kArmAutomatic**; conversely, all other acquisition specifications must not have an **armEvent** field value of **kArmAutomatic**.

Individual acquisition specifications are enabled or disabled through an array of sixteen boolean control variables indexed in the same manner as the specifications themselves. The boolean on/off control is mapped to the basic control property of the acquisition specification control array device. Events may be reconfigured at will by reprogramming the appropriate acquisition specification. When setting an acquisition specification all fields must be set at once – individual acquisition specification fields are not available to application programs.

Data Acquisition

The BPM front-end maintains an individual raw data buffer for each of the sixteen possible acquisition specifications. As a result the data acquired on any given event will be available for retrieval until the next time that measurement becomes armed. Each raw data buffer contains sufficient information to support the three classic position measurements:

- Flash (`turnNumber = 1..1024`),
- Closed Orbit (`beginTurn = 1..1024, numTurns = 1..1024`) and
- Turn-by-turn (`beginTurn = 1..1024, numTurns = 1..1024`).

For closed orbit measurements the **beginTurn** and **numTurns** values must combine to be less than or equal to 1024, and for turn-by-turn measurements the total number of turns must not exceed 1024.

Data Readout

The raw data collected with each acquisition provides the opportunity to obtain data for many different position measurements. After an acquisition has completed the application program specifies the desired position measurement with a **Readout Specification**. Readout specifications identify the raw data to be used, the position algorithm to be employed and the amount of data to be processed. Readout specifications have the following definition:

```
// structure sent by ACNet to request specific measurement data
class ReadoutSpecification {
    eEventIndex          _eventIndex;
    eDataType            _dataType;
    eTurnNumber          _beginTurn;
    eTurnCount           _numTurns;
    eDataChannel         _channel;
};
```

Each member of the class is a four byte quantity resulting in a total size of 20 bytes. The definition of each member follows.

```
typedef enum {          // range of _eventIndex member
    kEventIndexMin = 0,
    kEventInteractive = kEventIndexMin,
    kEventRepetitive,
    kMainInjectorProtonToRecycler,
    kMainInjectorPbarToRecycler,
    kRecyclerProtonToMainInjector,
    kRecyclerPbarToMainInjector,
    kRecyclerProtonToAccumulator,
    kAccumulatorPbarToRecycler,
    kEventIndexMax = 15,
    kNumEventIndexes,
    kEventIndexDefault = kEventInteractive
} eEventIndex;
```

The `_eventIndex` member identifies the event that produced the data of interest. This is the same `eEventIndex` described above. The user can request data associated with any of the sixteen triggering events.

```
typedef enum {          // range of _dataType member
    kDataTypeMin = 0,
    kBunchedData = kDataTypeMin,
    kBunch1Data,
    kBunch2Data,
    kBunch3Data,
    kBunch4Data,
    kDataTypeMax = kBunch4Data,
    kNumDataTypes,
```

```

    kDataTypeDefault = kBunchedData
} eDataType;

```

The `_dataType` member identifies the data type of interest. The value specified with this member must be coordinated with the value in the specified event's AcquisitionSpecification `_beamType` and `_beamMeasurement` members. For example you can't specify cold beam data if the acquisition specification had requested a bunched beam measurement.

```

typedef enum {          // range of _beginTurn member - turns
    kTurnNumberMin     = 1,
    kTurnNumberMax     = 1024,
    kNumTurnNumbers    = kTurnNumberMax - kTurnNumberMin + 1,
    kTurnNumberDefault = 1
} eTurnNumber;

```

The `_beginTurn` member identifies the turn or turns of interest for flash, closed orbit and turn-by-turn measurements. For flash measurements it specifies the single turn of interest in the range 1 to 1024. For closed orbit and turn-by-turn measurements it specifies the first turn of interest and works in combination with the `_numTurns` member. Users should note that the sum of the `_beginTurn` and `_numTurns` member values may not exceed 1024.

```

typedef enum {          // range of _numTurns member - turns
    kTurnCountMin      = 1,
    kTurnCountMax      = 1024,
    kNumTurnCounts     = kTurnCountMax - kTurnCountMin + 1,
    kTurnCountDefault  = 1,
    kClosedOrbitCountDefault = 100,
    kTurnByTurnCountDefault = 1024
} eTurnCount;

```

The `_numTurns` member identifies the number of turns of interest for closed orbit and turn-by-turn measurements and works in combination with the `_beginTurn` member. Users should note that the sum of the `_beginTurn` and `_numTurns` member values may not exceed 1024.

```

typedef enum {          // range of _channel member
    kDataChannelMin    = 0,
    kDataChannelMax    = 47,
    kDataChannels
} eDataChannel;

```

The `_channel` member identifies the channel of interest for turn-by-turn measurements. The turn-by-turn data type returns position and intensity data for a single channel only.

There are six readout specification devices and six readout data devices, one for each of the BPM data types. Data devices are provided with values scaled to engineering units

and with values normalized to percent of full scale. The table below indicates the names for the devices.

Specification Device	Scaled Device	Normalized Device	Data Type
R:BPxBFS	R:BPxBFV	R:BPxBFN	background
R:BPxBCS	R:BPxBCV	R:BPxBCN	background closed orbit
R:BPxFLS	R:BPxFLV	R:BPxFLN	flash
R:BPxCOS	R:BPxCOV	R:BPxCON	closed orbit
R:BPxTBS	R:BPxTBV	R:BPxTBN	turn-by-turn
R:BPxTSS	N/A	R:BPxTSN	timing scan

With this scheme the client specifies the desired data by setting the readout specification device for the desired BPM data type and then reads the result from the associated readout data device². The analog and timing diagnostic data devices may be read at any time without the requirement of first setting an associated specification device.

Shot Data Acquisition

Data for the Shot Data Acquisition system is handled through the cooperative efforts of the Machine Sequencer and Shot Data Acquisition applications. The Machine Sequencer makes measurement requests and the Shot Data Acquisition program reads the resulting data at the appropriate time. This collaborative effort will be referred to simply as SDA in further discussion.

SDA can program any or all of the sixteen acquisition specifications described above, but has unique readout specification devices and readout data devices. The unique devices prevent conflicts with interactive users enabling SDA to read data without the need for device arbitration. SDA has access to the same data as interactive users. The table below indicates the ACNet device names for the SDA data devices.

Specification	Data	Data
---------------	------	------

² Because ACNET is a connectionless protocol that does not support atomic request-reply operations a simple protocol for a blocking set-read has been developed for requesting beam position data. See Appendix A for a description of this protocol.

<u>Device</u>	<u>Device</u>	<u>Type</u>
R:BPxBFC	R:BPxBFD	background
R:BPxBCC	R:BPxBCD	background closed orbit
R:BPxFLC	R:BPxFLD	flash
R:BPxCOC	R:BPxCOD	closed orbit
R:BPxTBC	R:BPxTBD	turn-by-turn

Command Driven Acquisition

Requests for position measurements coming from interactive users at console application programs are treated similarly to event driven requests. The first (element zero) acquisition specification described above is a special acquisition specification device that acts as a software arm event. When this device is set the BPM front-end will configure the specified measurement, wait for the trigger event and collect the specified data.

Priorities and Preemption

The functional specification for the BPM system requires that newly arriving measurement requests have priority over and abort any previously armed measurements that have not completed. This philosophy is applied to acquisition specifications set by interactive users and SDA. All events are processed in the order of arrival. An event must be armed, triggered and acquired to be complete. If the BPM front-end has been armed for an event but not triggered when a new arming event arrives the previous measurement will be aborted and the newly armed measurement will be processed.

Interactive user measurement requests will be bumped by event or SDA generated requests that come along while the front-end is waiting for the interactive request to be triggered!

APPENDIX A

Readout Protocol

The BPM front-end attempts to provide as much position information as possible for each acquisition cycle by buffering enough raw data to produce Flash, Closed Orbit and Turn-by-turn measurements from each trigger. Clients must specify which of these measurements is desired before reading any data. This request-read activity can lead to collisions if multiple clients are requesting data because ACNet does not support atomic request-reply operations. A simple protocol has been devised to support data requests. The protocol works as follows:

Client side:

- read BPM status to see if measurement is completed
- set readout specification
 - if error delay a while and try again
 - else read data ASAP

This is over simplified, it would be good style to include a maximum loop count for example.

Front-end side:

- when measurement is completed set BPM status appropriately
- receive readout specification
 - if waiting for a read of this readout specification return error
 - else begin watchdog timer on new readout specification and wait for read
- if readout specification watchdog timer expires invalidate the readout specification
- receive data read request, cancel timer and return data according to readout specification

With this protocol client requests normally proceed rapidly with a setting of a request and a reading of the associated data. If another client tries to request data before the first client has completed its read the second client will get a busy status. That's OK because the second client will wait a moment and try again. When the first client has completed its data read the BPM front-end will become not busy and be able to accept the second client's request. The watchdog timer used by the front end is set to a nominal value that allows a client to successfully do a setting followed by a reading under normal ACNET conditions – perhaps 2, 3 or more 15 Hz ticks.

APPENDIX B

Document Revisions

050315 – Replaced acquisition specification enable/disable control via `_enable` field of the structure with the ACNet basic control on/off property to allow the sequencer to enable measurements.

050315 – Reduced the number of samples available in multiple gate measurements from 2048 to 1024 to improve the measurement execution time performance.

050315 – Changed `eDataType` enumeration to reflect new Echotek driver operation where a value of zero represents the default processing in filters that are not bunch-by-bunch, and the average bunch value with bunch-by-bunch filters. All other enumeration values are meaningful only with bunch-by-bunch filters where they indicate the bunch number.