

## TECHNICAL NOTE

# Sequence of Events Recording (SER) Device Selection Guide

### Summary

Critical power applications require precision timing for monitoring and control. Sequence of Events Recording (SER) systems are an essential part of an Electrical Power Monitoring System (EPMS), with time-stamping accuracy of 1ms required for system diagnostics and root-cause analysis.

Stand-alone Sequence of Events Recorders are specifically designed to provide reliable event recording. Other devices, such as meters, relays and PLCs are equipped with I/O, but not all are capable of performing the same level of SER functionality.

This document describes the five (5) main criteria for an effective Sequence of Events Recording device and provides a checklist of features to help the reader determine the appropriate SER device for a given project and budget.

### Introduction

Sequence of Events Recording (SER) systems are an essential part of Electrical Power Monitoring Systems (EPMS) for “critical power” applications, such as data centers, hospitals, and micro-grids. Unlike the simpler radial systems found in commercial buildings, these complex power networks are characterized by multiple power sources and parallel paths to serve loads. A single disturbance can initiate a series of events in rapid succession. Sequence of Events Recording systems answer the questions “what happened and when?” [1] Without the ability to reconstruct an incident in the proper sequence, root-cause analysis is impossible. Sometimes the information provides critical details about an outage, but it can also warn in advance about conditions of increased risk and prevent an outage. Because power system events can occur within milliseconds, a time accuracy of 1ms is the generally-accepted standard for sequence of events recording. [2]

### SER Devices

Sequence of Events Recorders monitor the status of up to 32 high-speed input channels and record a time-stamped event for each state change (Off-to-On or On-to-Off). Other devices with general-purpose I/O, such as relays, meters and PLCs may offer SER features. Regardless of hardware platform, several capabilities are required for sequence of events recording:

1. Precision time reference (internal clock accuracy of 100 microseconds or better)
2. High-speed response by discrete inputs (1 kHz sampling min.)
3. Event filtering (filter, debounce, and chatter functions)
4. Data logging to on-board non-volatile memory (8000 events or more)
5. Network communications for access to event records (Ethernet, Modbus TCP)

Unless a device meets all of these criteria, it may not be suitable for sequence of events recording. These are explained in more detail in the following sections.

Event	Date and Time	Channel	Event Type	Status	Time Quality	Seq #
1204	03/14/2014 10:00:28.548	Input 03	Input Status Change	On → Off	0:Good (< 1ms)	1204
1203	03/14/2014 10:00:28.534	Input 02	Input Status Change	On → Off	0:Good (< 1ms)	1203
1202	03/14/2014 10:00:28.520	Input 01	Input Status Change	On → Off	0:Good (< 1ms)	1202
1201	03/14/2014 10:00:28.512	Input 24	Input Status Change	Off → On	0:Good (< 1ms)	1201
1200	06/25/2013 17:47:53.022	Input 23	Input Status Change	On → Off	0:Good (< 1ms)	1200
1199	06/25/2013 17:42:58.008	Input 22	Input Status Change	On → Off	0:Good (< 1ms)	1199

Sample event log from Sequence of Events Recording system

## 1) PRECISION TIME

To achieve millisecond time-stamping, the accuracy of the SER device's internal time clock needs to be an order of magnitude better (<100 microseconds). Therefore, the first requirement for an SER device is that its onboard clock have provisions for synchronizing to a known accurate time source, such as a GPS time signal. [3] The most common precision time protocols used by power system devices are IRIG-B and DCF77. These are described in detail in Technical Notes TN-102 and TN-103 from Cyber Sciences. (See the "For More Information" section at the end of this document.)

NTP (Network Time Protocol) is also supported by some devices for obtaining time/date over an Ethernet network, but these are typically not sufficient to ensure 1ms accuracy of event time stamps. An emerging standard, IEEE-1588, defines a new protocol called PTP, which can achieve much higher accuracy over an Ethernet network, but this is not yet widely supported by power system devices.

## 2) HIGH-SPEED INPUTS

SER devices have "high-speed" inputs, with defined response times of 1ms or less. To achieve reliable time-stamping with 1ms accuracy, the SER device must monitor the status of input channels and take a "snapshot" of all inputs simultaneously at the start of every millisecond interval (1 kHz sampling).

Alternatively, an interrupt-driven scheme (report by exception) is sometimes used by meter and relay processors. However, the response time required to service the interrupt can vary, since it depends on processor loading, prioritization of tasks, etc. This can result in an unacceptable degree of uncertainty, perhaps not for the first event, but to accurately time-stamp subsequent events in rapid succession.

For reliable event recording, the response time of an SER device must be considered deterministic, not adversely affected by other demands on the processor. The device must be capable of detecting every single transition event within the 1ms window.

In addition to status-change events, it is often useful to have time-stamped voltage and current waveform data associated with the events. To accomplish this, a "Trigger output" contact is provided which can be configured to close when a given input channel changes state. This in turn triggers a waveform capture (WFC) feature of an advanced power meter.

Assuming an SER device can detect a transition reliably within this timeframe, additional processing is needed before a detected transition is recorded as an event. Filtering functions ensure that only relevant data is recorded as events.

## 3) EVENT FILTERING

In a practical SER application, filtering is required to ensure meaningful and reliable event recording. Without proper filtering, momentary spikes due to noise would be recorded as events, and single (real) events could be recorded multiple times. An SER device must include three different user-configurable filter functions which define the method it uses to process events. The names may vary by manufacturer, but the following three functions must be implemented:

**Filter**—The amount of time for which the state of a digital input point must remain detected in a valid "on" or "off" condition before it is considered to be in that position for event-recording purposes. This pre-event filter complements a post-event function called "debounce."

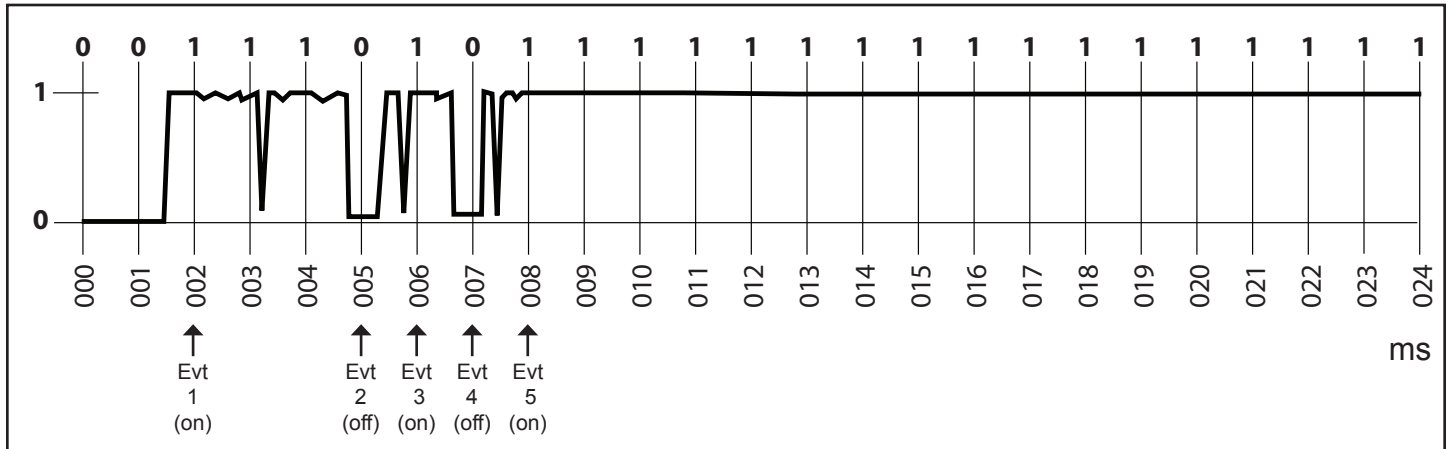
**Debounce**—period of time post-event during which event processing for a given input is suspended to avoid recording multiple events associated with the same state change. As the name suggests, this function filters out normal signal excursions ("bounce") which accompany the closure of mechanical contacts.

**Chatter**—number of repeated events within a given time period, when exceeded, event processing is suspended on that channel.

Both the filter and debounce functions are used to distinguish real status change events from unintended "noise" from normal relay contact operation, while the chatter function ensures that the event log is not filled with superfluous events caused by a defective ("chattering") relay contact. The following sections illustrate each of these functions in more detail.

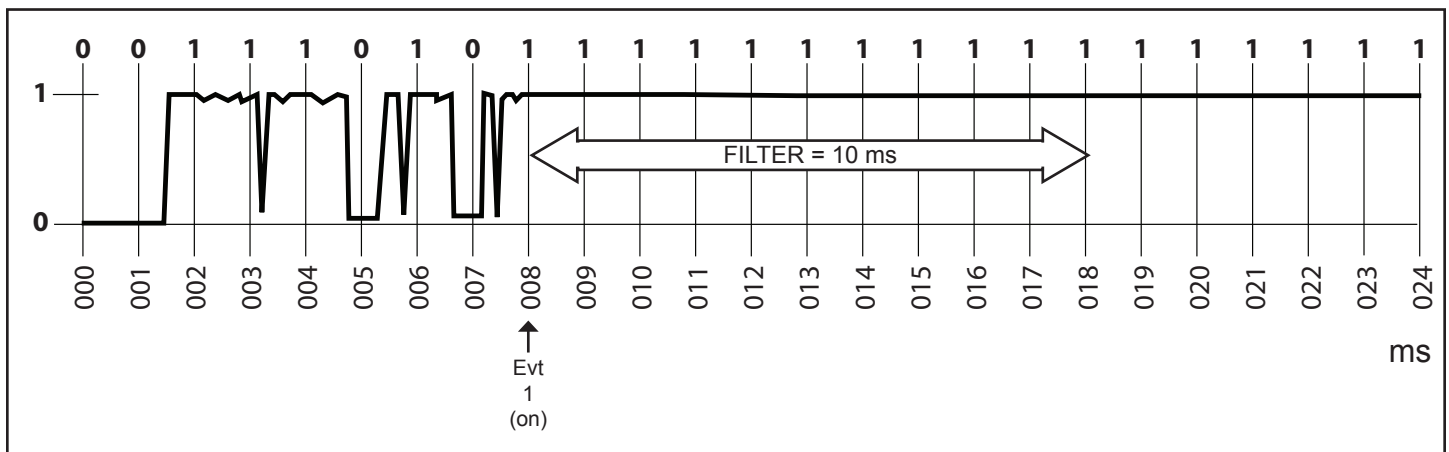
**Filtering Momentary Spikes**

Without proper filtering, momentary spikes caused by noise or interference would be recorded as events. Consider the example shown in the figure below. The graph shows the signal as seen by the input, and the numbers across the top show the status as determined by the device (0=off and 1=on).



*Filter = 0 ms (no special filtering)*

Without any filtering, the first spike is recorded as an event (Evt 1, time-stamp= 002 ms). The next dip (at 003 ms) is so short it is not detected as a new event. However, at 005ms, Evt 2 is recorded, followed immediately by successive events 3, 4 and 5—even though these are probably all due to a single contact closure.

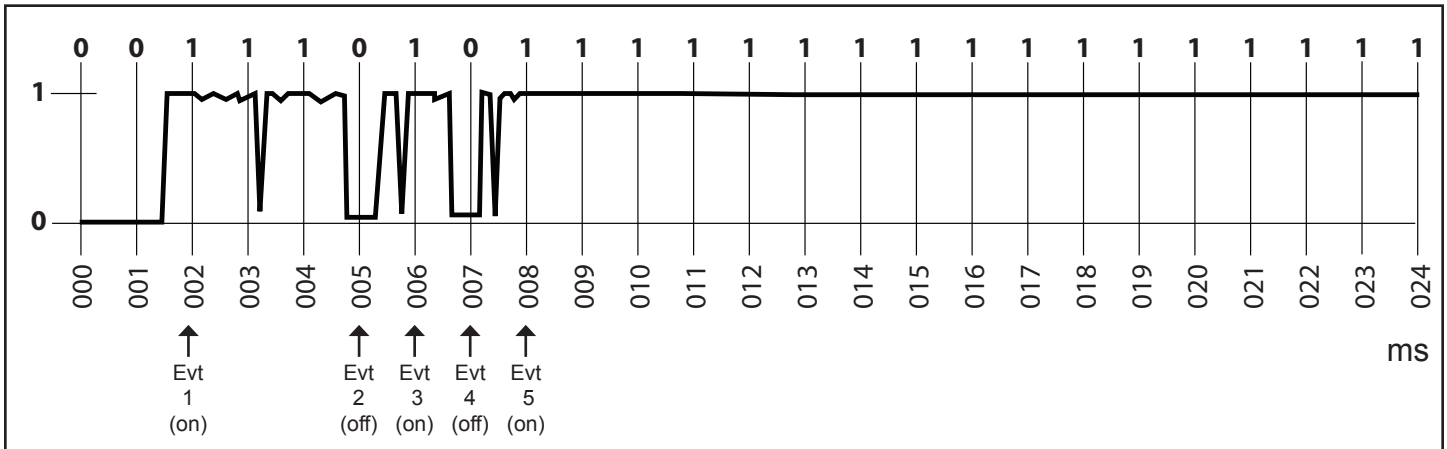


*Filter = 10 ms*

Next, we'll apply a 10ms filter to the same signal. Because none of the early spikes detected lasts longer than the filter setting of 10ms, these are all ignored for the purposes of event recording. At 018ms, the new state (1=on) has persisted for a period of time exceeding the filter setting of 10ms; therefore, the device records this as Event 1, with time-stamp of 008ms (since that is when the filtered condition began).

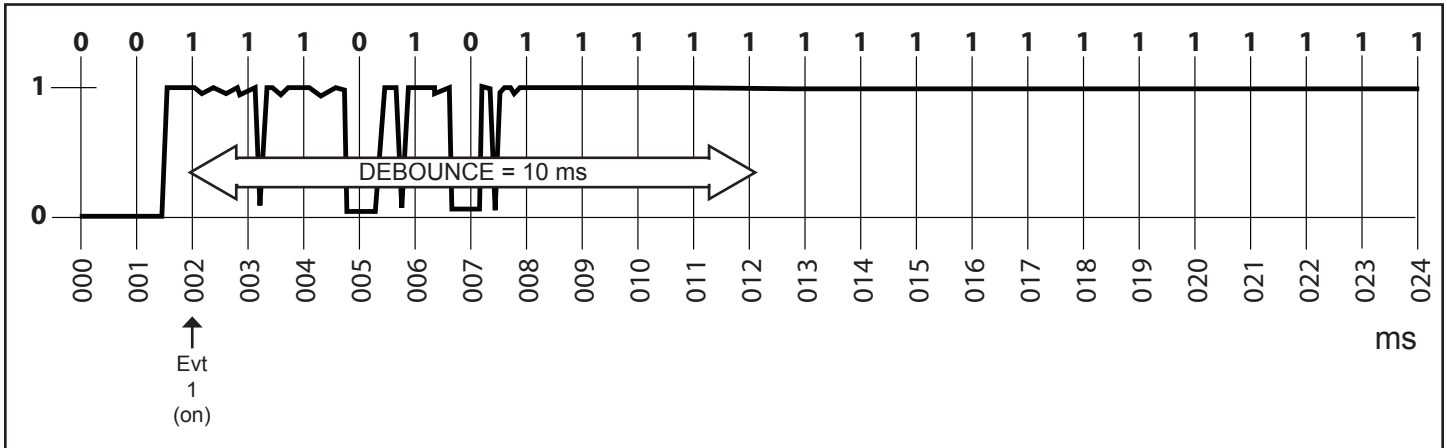
**Debounce Function**

Returning to our previous unfiltered example, the graph shows the signal applied to the input, and the status (0=off and 1=on) is indicated across the top.



*Filter = 0 ms (no special filtering)*

Instead of using a pre-event filter, let's apply a post-event filter, called "debounce." In this scenario, the event detection is very sensitive, and afterwards, event recording is suspended for the duration of the debounce setting. (See graph below.)



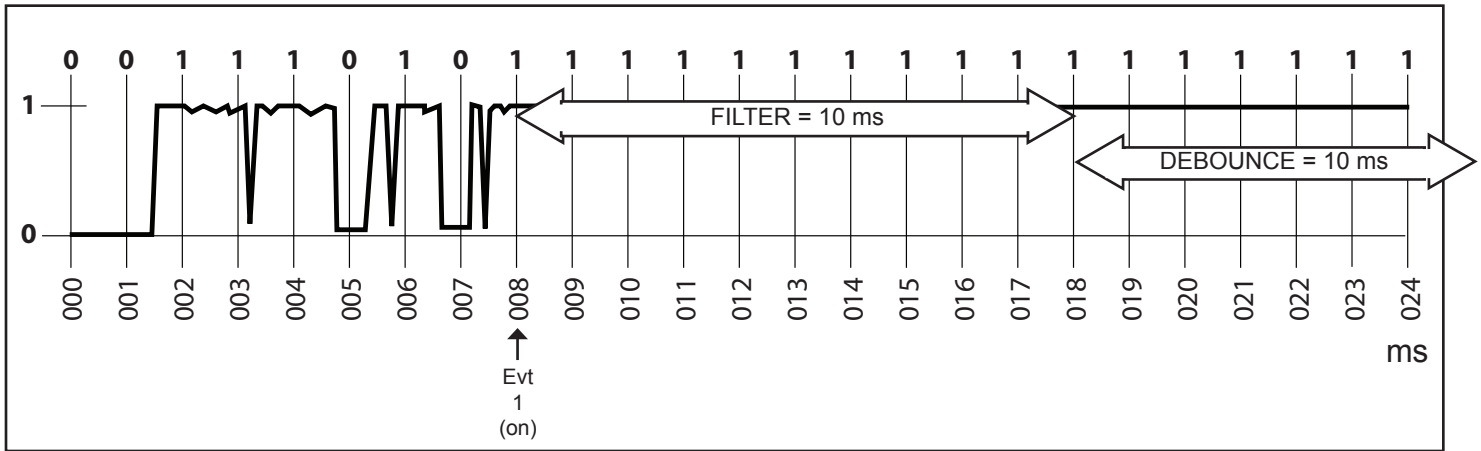
*Debounce function = 10 ms*

Event 1 is recorded at the very first detected change in state (time = 002ms), and the debounce filter "desensitizes" event recording on that channel for the 10ms following the event. The other dips and spikes were likely caused by the "bouncing" of the contact, and so these are—in this case—appropriately ignored.

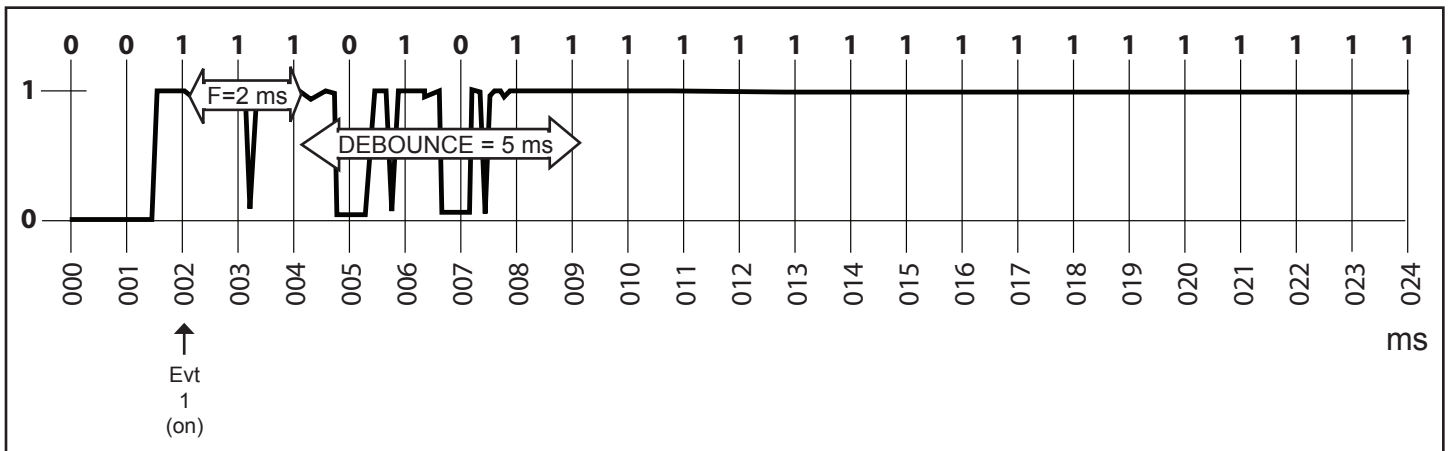
This avoids multiple events being recorded for the same contact closure, and has the advantage of time-stamping the event record at the earliest time at which the change is detected. However, as mentioned previously, without (pre-event) filtering, the unit is vulnerable to recording "nuisance events" due to momentary spikes.

Debounce Function (cont.)

If the filter and debounce functions are both increased (e.g., 10ms or higher), then contact bounce may be filtered out, but the time stamp for the event will be delayed until the starting point at which the input reached its steady state (remained in the new state throughout the filter time period), not necessarily the true contact closure.



Filter = 10ms / Debounce = 10 ms



Filter = 2ms / Debounce = 5 ms

The optimal combination of settings would be to set the filter as low as possible to screen out momentary spikes and set the debounce long enough to ride-through contact bounce. Consider the example above in which the filter is set to 2 ms and debounce is set to 5 ms. In this case, the event is detected and time-stamped at 002ms, and the contact bounce is filtered out.

The choice of filter and debounce settings depends on the expected characteristics of the monitored contacts and a trade-off between highly-accurate time-stamping and the risk of recording spurious events.

A conservative setting for both functions might be 20ms. However, depending on the application, it may be desirable to adjust one or both of these values per input channel to achieve optimal results. Most SER devices support such flexibility.

## Chatter Count Function

In addition to the filter and debounce functions, a chatter count function is provided to further guard against superfluous events being recorded and filling the event log. Per the 2007 IEEE Standard for SCADA and Automation Systems [4], the definition of chatter function is as follows:

“Chatter function—a facility that is used to disable a digital input point if the number of state changes of that point during a defined time interval is excessively high.”

Typically, SER devices support values for chatter-count setting from 0 to 255 (where 0 indicates the function is disabled). If the number of state changes exceeds this value within a given period (e.g., one minute), the SER device suspends event processing for that input, and an event is recorded in the event log to indicate this condition. Event recording is suspended for that channel until the input is considered stable (the chatter count for a subsequent one-minute interval drops to less than the user-specified value).

## 4) ON-BOARD NON-VOLATILE MEMORY

Supervisory software may access the data from each SER every 15 minutes, every hour or even once a day. Since numerous events can occur in a very short period of time, an SER device must have its own on-board, non-volatile memory and be sized sufficiently to store hundreds or even thousands of event records—typically 8000 events or more, stored “First In, First Out”(FIFO).

In an SER event log, each event record must contain at least the following data:

- Event number (index number)
- Time/Date stamp (referenced to UTC, with ms resolution)
- Channel name (user-configurable text)
- Event type (e.g., status change, time-sync lock/fail, setup change, chatter, etc.)
- Status (Off-to-On or On-to-Off—with user-configurable descriptive text)
- Time quality (indication of time-stamp fidelity)
- Sequence number (unique serial number, even if FIFO log “rolls over”)

In addition, an alternate set of data logs can be useful where status of input/output channels must be reported as a group.

For example, to generate test reports for an Emergency Power Supply System (EPSS), it is necessary to report the states of each device in the generator test process. While it might be possible to deduce the state of one member of a test group by scanning the entire event log, a simpler method is to record the states of all group members each time any member changes state. This greatly simplifies report generation and ensures reliable results.

## 5) NETWORK COMMUNICATIONS

Thanks to distributed processing and highly-accurate time-stamping of events, SER devices do not need to be scanned rapidly by supervisory software. Instead, SER devices can be polled periodically for new events and these can be uploaded to a master database.

For best results, SER devices must integrate with other electrical power monitoring system (EPMS) devices using the same protocol, typically over an Ethernet local area network using Modbus TCP. SER devices should support a minimum set of Modbus function codes, including FC 20 for efficient file record access.

A pre-defined Modbus register list allows pre-engineered “native device drivers” to be developed for standard EPMS software. Multiple masters must be supported. Proprietary schemes (sometimes used with PLCs) in which event records are erased after being read by the master are not permitted.

An embedded web server in the SER device is used for setup and monitoring, often before the EPMS software is operational. Indeed, these web pages can facilitate commissioning of the EPMS software itself and contribute to overall system reliability.

SER DEVICES



CyTime Sequence of Events Recorder, SER-3200 (32 inputs) or SER-2408 (24-inputs / 8 outputs)

Sequence of Events Recorders

Sequence of Events Recorders are stand-alone devices designed specifically for event recording, and so these typically meet all criteria for sequence of events recording discussed previously.

CyTime™ Sequence of Events Recorders from Cyber Sciences are available with two I/O options:

- SER-3200—32 Inputs
- SER-2408—24 Inputs and 8 Outputs

A summary checklist of all features is shown in the table below.

SER DEVICE FEATURE CHECKLIST

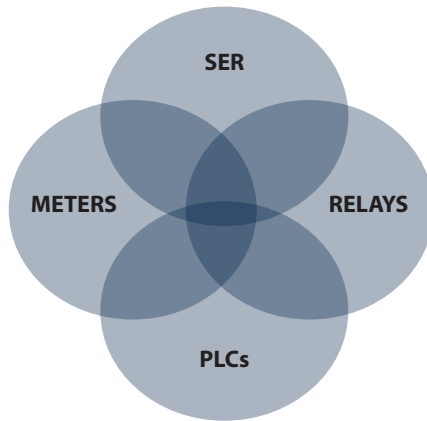


SER Device Function	Requirement	CyTime SER-3200 (32 inputs)	CyTime SER-2408 (24 Inputs / 8 Outputs)
Precision Time-Sync (clock accuracy 100 μsec)	IRIG-B	✓	✓
	DCF77	✓	✓
	Other (SER inter-device)	✓	✓
High-speed I/O response	Time-stamp accuracy of 1ms	✓ ①	✓ ①
	Trigger output	✓	✓
Event filtering	Filter (0 to 65535 ms)	✓	✓
	Debounce (0 to 65535 ms)	✓	✓
	Chatter (0 to 255)	✓	✓
Data logging	Non-volatile memory	✓ ②	✓ ②
	Time/date, Channel, Type, Status, Time Quality, Serial No.	✓ ③	✓ ③
	EPSS reporting data logs	✓ ④	✓ ④
Network communications	Ethernet (10/100BaseTx)	✓	✓
	Modbus TCP	✓	✓
	Web server	✓	✓
	Multiple masters supported	✓	✓

① A dedicated events processor ensures reliable 1ms response for I/O  
 ② Event log stores up to 8192 events.  
 ③ Channel name, off-text and on-text are all user-configurable.  
 ④ Total of 16 data log groups for EPSS test reporting (in addition to main SER event log).



## DEVICES FOR SER



### SER functions by other devices

Meters, relays and PLCs are all optimized for their primary functions, respectively, but some also offer SER functionality. However, unless a device meets all of the criteria discussed previously, it may not be suitable for sequence of events recording. Consult the device manufacturer and refer to product literature or test results which document SER performance. Following are general observations about each of these device types and their suitability for sequence of events recording.

#### Meters

Advanced power meters may have provisions for GPS time sync via IRIG-B or DCF77, and so these have the added advantage of time-stamped waveform capture data. However, given demands on the processor to calculate a wide range of complex quantities, their I/O may not have the guaranteed response times needed for SER. Even if interrupt-driven, these devices may be capable of accurately time-stamping the first event, but not the second or third if occurring in rapid succession. Since the performance may depend on processor loading and task prioritization, SER response may be very difficult to determine with certainty, even with testing.

#### Relays

Protective relays may have inputs that can be used for SER; however, the primary purpose of these devices is circuit protection, and so their response time may be a limiting factor. In order to give priority to the protection function, some relays scan their inputs every quarter cycle (4ms) or half cycle (8ms). They may also omit the desired event filtering.

#### PLCs

The general-purpose I/O of PLCs normally cannot be used for SER. The scan times of PLCs are either too long or are not considered deterministic. Often, a separate SER module is used which mounts in the PLC rack and shares the PLC's backplane communications. This has the advantage of tight-coupling with the PLC, but this can be a drawback as well. This architecture dictates that all event records must be accessed through the PLC, and so custom PLC programming is required just for EPMS software to retrieve this data. In addition, such special-purpose SER modules may not meet all of the criteria described previously, resulting in compromises to SER functionality.

## SUMMARY

Stand-alone Sequence of Events Recorders are specifically designed for high-speed recording of status changes, time-stamped to 1ms. Devices such as meters, relays and PLCs may also include SER functionality, in addition to their primary functions. All SER devices should satisfy the following selection criteria:

1. Precision time reference (internal clock accuracy of 100 microseconds or better)
2. High-speed response by discrete inputs (1 kHz sampling min.)
3. Event filtering (filter, debounce, and chatter functions)
4. Data logging to on-board, non-volatile memory (8000 events or more)
5. Network communications for access to event records (Ethernet, Modbus TCP)

The best way to judge a device's suitability for SER performance is to consult the manufacturer's literature or test results pertaining to the criteria above. Whether to use dedicated SER devices or built-in SER features of meters or relays will depend on project specifications, performance goals and budget constraints.



**For More Information**

*CyTime SER-3200/2408 User's Guide (IB-SER-01)*

*CyTime SER Reference Guide (IB-SER-02)*

*STR-100 Instruction Bulletin (IB-STR-01)*

*STR-100/IRIG-B Addendum (IB-STR-02)*

*STR-IDM Instruction Bulletin (IB-IDM-01)*

*Tech Note: SER System Architectures (TN-101)*

*Tech Note: IRIG-B Time Codes (TN-102)*

*Tech Note: DCF77 Time Protocol (TN-103)*

**References**

- [1] Kennedy, Robert A., P.E., "GPS Time Synchronization: How precision timing and sequence of events recording will make the Smart Grid even smarter," *Electrical Construction & Maintenance (EC&M)* magazine, August 19, 2011, pp. 18-20. <http://ecmweb.com/computers-amp-software/gps-time-synchronization>
- [2] Brown, PE, Bill, and Mark Kozłowski, "Power System Event Reconstruction Technologies for Modern Data Centers," Square D Critical Power Competency Center. Aug. 2006. <http://www.criticalpowernow.com>
- [3] Dickerson, Bill, P.Eng., Arbiter Systems, Inc. "Time in the Power Industry: How and Why We Use It." <http://www.arbiter.com/solutions/event-time-and-reconstruction.php>
- [4] "IEEE Standard for SCADA and Automation Systems," *IEEE Std C37.1-2007* (Revision of IEEE Std C37.1-1994).

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