Application Note
The benefits of integrated digital inputs with a latch function

Keywords
– Positioning accuracy
– Position detection
– Encoder interface
– Incremental encoder
– EL5112, EL51xx
– Latch
– Latch input
– Digital input
– Filter times
– Synchronization types

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This Application Note outlines the advantages of integrated digital inputs for saving the current position value (a process that is known as latching), using the example of Beckhoff terminals with an incremental encoder interface, as opposed to a latching process in which digital input terminals are used and the position value is determined in the PLC. Principles of EtherCAT communication are also outlined in this Application Note as a means of explaining how the terminal function and the communication affect the latching behavior.

There are various applications in which a position value can be latched to a particular point in time. As an example, this process can be used to determine the exact position of products as they travel on a conveyor belt. In many applications, product positions need to be detected with exceptional precision so that the products can be removed from the belt at the right time. This raises the question of whether integrated latch inputs are able to determine positions more precisely – and, if so, how much more precisely. In this context, it is also important to consider how the process of determining positions is affected by the various filter times demonstrated by different digital inputs.

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Types of synchronization in an EtherCAT network

To gain a general idea of the time-based links that exist in the process of position detection when using the different latch methods and, therefore, how accurate the process is, it is essential to understand how the devices in the EtherCAT network are synchronized. There are basically three overarching types of synchronization in an EtherCAT network.

Free run	The EtherCAT slave is not synchronized with EtherCAT. The slave operates autonomously based on its own cycle and is explicitly not synchronized with the EtherCAT cycle.
SM-synchronous	The EtherCAT slave is synchronized with the SyncManager 2 (SM2) event (if the cyclical outputs are transferred) or the SyncManager 3 (SM3) event (if only the cyclical inputs are transferred). The SM2/SM3 event is triggered by the SyncManager when a passing frame is processed.
DC-synchronous	The EtherCAT slave is synchronized with the SYNC0 and/or SYNC1 event of the distributed clock system. These events are triggered synchronously among the DC-enabled EtherCAT slaves.

For this reason, DC-synchronous mode is recommended in the case of particularly time-critical applications that require precision timing. However, this mode is not necessarily supported by every EtherCAT device.

Parameterization of a latch input using the EL5112 as an example

The EL5112 has two digital inputs (24 V DC) that can be used for latching. They are parameterized using CoE objects and PDOs.

CoE objects 0x80n0:22/23 can be used to parameterize the two inputs as single-latch or continuous-latch inputs.
In single-latch mode, there is only a response to the first edge and, if the input is enabled again, to the next edge. For this to happen, the "Enable latch extern on positive edge" or "… negative edge" PDO on the channel in question needs to be set to FALSE and then back to TRUE.

In continuous-latch mode, the current position value is saved for each parameterized edge. However, this can cause position data to be overwritten if signals are bouncing heavily or changing within the cycle time. The user therefore needs to keep this in mind during parameterization.

The "Enable latch extern on positive edge" or "… negative edge" PDOs are used to specify whether latching is to take place at the rising or falling edges. Similarly, the "Enable latch extern 2 on positive edge" or "… negative edge" PDOs are used for the second input.

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Comparison of different latch options

This comparison draws on three different latch methods:

- Latching via integrated inputs of an incremental encoder interface terminal
- Latching via a "normal" digital input in the PLC
- Latching via a "fast" digital input in the PLC

In the case of latching via the integrated inputs of an incremental encoder interface terminal, the position is saved internally in the terminal. In the case of latching via digital inputs in the PLC, the current position submitted to the PLC is saved at a digital input in the PLC if the edge is positive. Digital inputs with different filter times can be used for this, something which has an impact on the latch time.

The behavior and filter times are based on the EL5112 incremental encoder interface terminal, the EL1018 digital input terminal, and the EL1859.

Product	Function	Position data processing	Input filter	Operation mode
EL5112	2 x integrated digital inputs	In terminal	1 µs typ.	DC-synchronous (examples 1 and 2) SM-synchronous (example 3)
EL1018	8-channel digital input terminal	In PLC	10 µs typ.	SM-synchronous
EL1859	8-channel digital input + 8-channel digital output	In PLC	3 ms typ.	SM-synchronous

The graphics below show hardware events at different points during the cycle, representing real input signals at the terminal inputs. The cycle time in the graphics is 1.5 ms.

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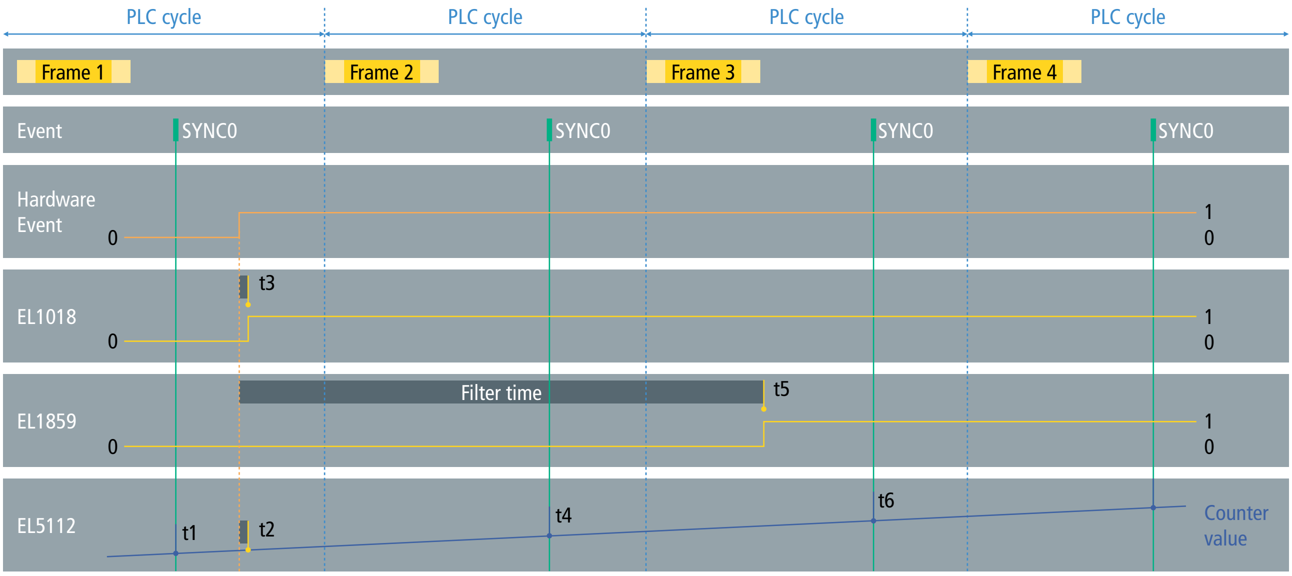
In the case of time-critical applications (drive control, for instance), the position values need to be determined at equidistant points in time. With the EL5112, this process uses DC mode, which always saves the counter value for the SYNC0 event and transmits it to the PLC with the next frame. When the position values are saved at equidistant points in time, it will not necessarily be possible to determine the chronology of various events using these saved values. This is because the various components support different operating modes, which means that not all of them are operated in DC mode. The two digital input terminals EL1018 and EL1859 only support the SM-synchronous operating mode and synchronize their data with the SM3 event, not the SYNC0 event. The following examples illustrate this:

Example 1: EL5112 in DC mode, hardware event (change from low signal to high signal) occurs after the SYNC0 event in the EL5112



The illustration above shows the chronology of various events in relation to a hardware event that triggers latching. The statuses of the terminals and relevant bus events are displayed, as are the EtherCAT frames affected by jitter and the corresponding filter time (which is not necessarily proportional to the real filter times demonstrated by the terminals). The current position value is shown in blue.

Looking at the hardware event as an example, the EL1018 input is still valid in the next cycle (t3) and is therefore passed on to the PLC in the next frame (frame 2). In this second frame, the EL5112 passes on the position that was valid at the first SYNC0 (see t1); that is, a position that was saved before the hardware event. Consequently, this value is already one cycle old. The position latched by the EL5112 is saved at point in time t2; i.e., shortly after the real event according to the EL5112 filter time.

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If the position is directly assigned in the PLC with the EL1018 input signal, this means that the position at point in time t1 is identified as the latch value by means of the EL1018. During forward movement, the position value is therefore lower than the position value that the EL5112 provides as a latched position (at point in time t2). Without knowledge of the relationship between the events, as described here, this could be incorrectly interpreted as a lower value does not correlate to faster latching. Latching via the EL5112 provides a more precise position value than latching via the PLC using digital input terminals.

The potential improvement in position accuracy depends on multiple factors, particularly speed, cycle time, and the jitter that affects the hardware being used. Additionally, the TwinCAT configuration in relation to the event times has a significant impact on accuracy,

something that becomes especially clear when the position values latched with the EL1859 are compared to the other latch values. In this case, the EL1859 input is not valid until the third cycle (t5) because of the longer filter time, typically 3 ms, and is therefore not transmitted to the PLC until the fourth frame (frame 4). The value of the third SYNC0 event (at point in time t6) is then provided as the current position in this frame. This means that significant differences may arise in each application.

As an example calculation in the case of a cycle time of 1.5 ms, a speed of 2,000 mm/s, and the position starting at 0 mm at the beginning of the first cycle, approximately the following position values would be determined by the various latch methods (it is also assumed that the hardware event takes place 1 ms after the start and the SYNC0 is at 60% of the cycle time):

Latch method	Position value	Relative measurement error
Real position	**2 mm**	
Integrated latch inputs	**2.002 mm**	**+0.1%**
PLC via EL1018	**1.8 mm**	**-10%**
PLC via EL1859	**7.8 mm**	**+290%**

The integrated latch inputs achieve the best accuracy.

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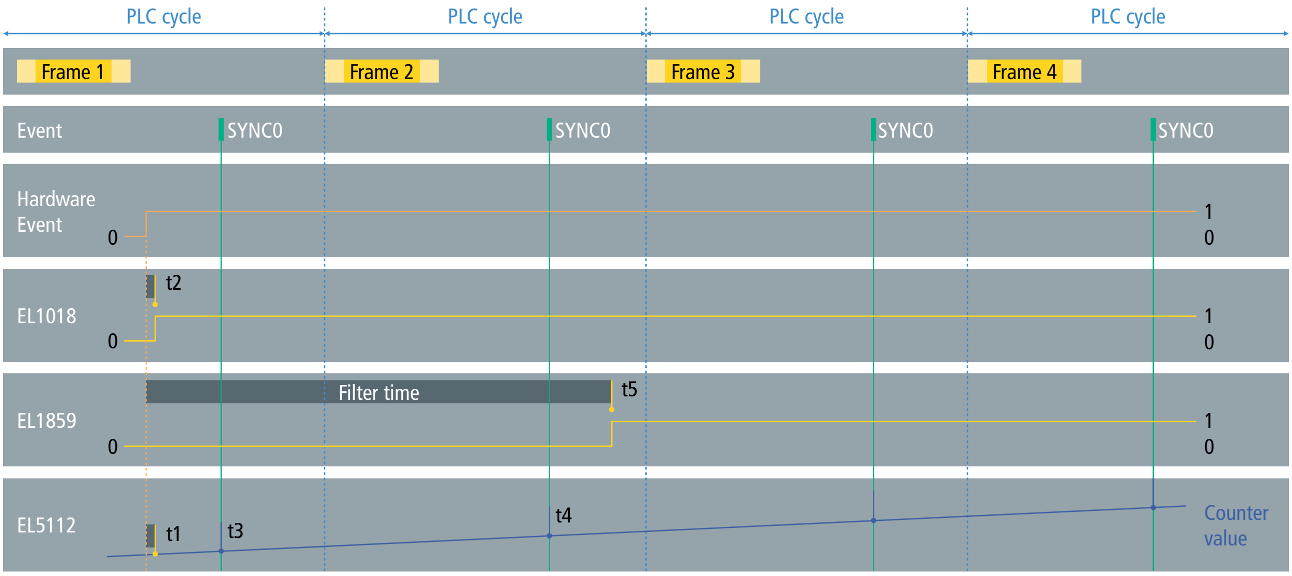
Example 2: EL5112 in DC mode, hardware event occurs before the SYNC0 event in the EL5112

To provide another illustration, the graphic below shows a case in which the hardware event occurs before the SYNC0 event:



In this case, the latch position (t3) determined with the EL1018 in combination with the PLC is higher than the position determined by the EL5112 using the latch inputs (see t1). Although the EL1018 input is also valid in the first cycle (t2), as with the previous example, and is transmitted to the PLC with the second frame, the current position that is transmitted by the EL5112 is still determined at the SYNC0 event that now takes place after the hardware event.

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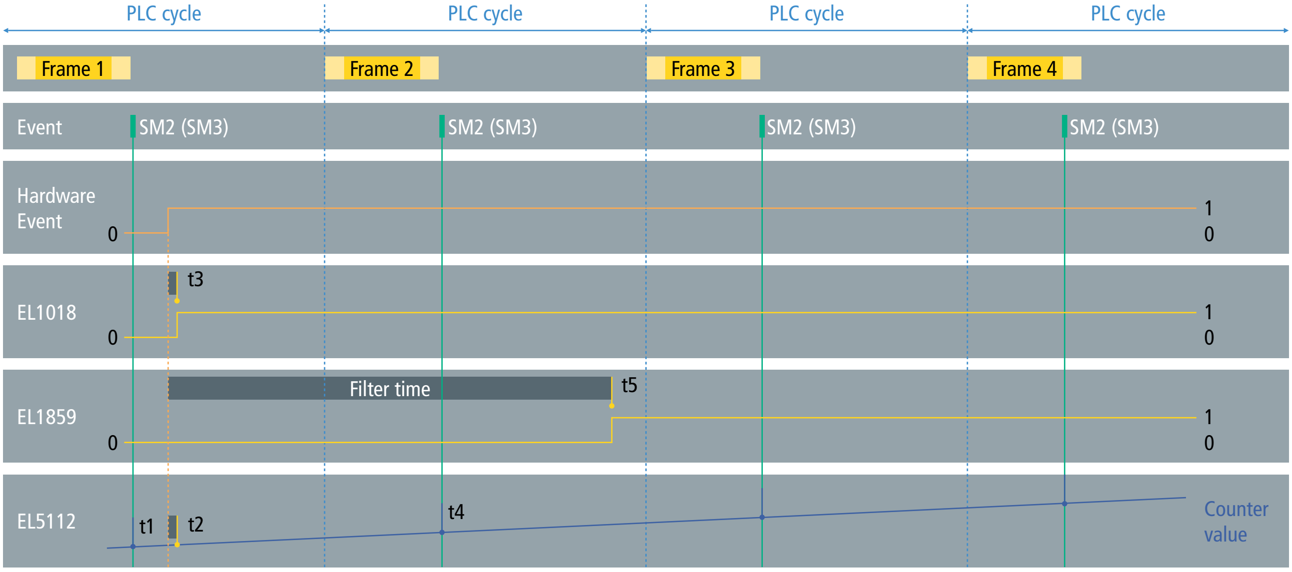
Example 3: All components (EL5112, EL1018, EL1859) are in SM-synchronous mode

In SM-synchronous mode, the EL5112 records the position at the point when the SM2 or SM3 event (which is triggered by the EtherCAT frame) occurs, or very soon afterwards. The position is therefore passed on to the PLC in the next frame (frame 2):



This means that the position value latched by the EL5112 (at point in time t2) is higher than the position determined by the PLC using the EL1018 (see t1). This applies vice versa to the input with a higher filter time (EL1859), and the position value that is determined by the PLC using the EL1859 (t4) is higher than the value latched by the EL5112.
It is important to note that this behavior cannot be applied to all angle or displacement measurement terminals as, in the case of terminals used to evaluate absolute encoders, the position value is queried exactly once per cycle from the encoder. As the position value within the terminal does not change during the cycle, the behavior as it refers to the relationships explained above changes.

It is important to note that the integrated digital inputs always provide a more accurate position value in line with the hardware event. This is because of the EtherCAT-related events that trigger the process of recording the current position.
Of course, there may also be applications in which it makes sense to use a separate input terminal to latch a position via the PLC. If an application involves long distances (as is often the case in plant design, for instance), local digital inputs are sometimes a more suitable option than connecting to encoder terminals that are further away. The required position accuracy should be used as a basis for considering whether a dedicated digital input or the integrated latch input should be used. The achievable accuracy must be evaluated in relation to the specific application.

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Time relationship	Relationship between position values
HW event before SYNC0	Latch value in the PLC > position value via integrated latch inputs
HW event after SYNC0	Latch value in the PLC < position value via integrated latch inputs
All in SM mode	Latch value in the PLC < position value via integrated latch inputs

Choosing the right latch method

Using the integrated latch inputs of the incremental encoder interface terminals is recommended, as there is a clear relationship between the latch time and the position in this case. This option also has the advantages of lower costs and less required space, as there is no need for additional hardware.

In the conveyor belt application example, using integrated latch inputs makes it possible to remove products with accuracy.

Advantages of integrated latch inputs:

- Exact position assignment for hardware event via digital inputs
- Less space required in control cabinet
- Less programming work required due to integrated function
- Reduced costs

If there are no latch inputs at the incremental encoder interface terminal, it is vital to use the right hardware for latching via the PLC. Free digital inputs in a machine are usually only suitable for this if they have a short filter time and support DC-synchronous mode. If the speed is constant, timestamp inputs can be used to determine a relatively precise position.