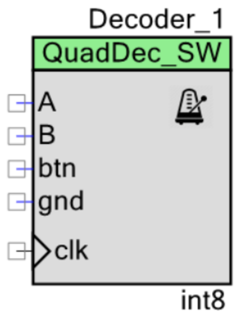
QuadDec_SW: Quadrature Decoder with Switch Button

0.2

Features



- Implements quadrature decoder for rotary shaft encoders.
- Returns position and direction of rotation.
- 8-bit, 16-bit, 32-bit, single or double position range.
- Optional button switch with debouncing.
- Optional increment step size.
- Optional range limits.
- Uses interrupt or polling technique.

General description

The QuadDec_SW component[*] represents quadrature decoder with optional button switch detection implemented entirely in software code (no UDB resources used). It can detect position of the rotary encoder and direction of rotation of mechanical shaft encoders using established algorithm [1]. Range selection (8,16,32-bit, single, double) and limit bounds option allow for simple interfacing with other PSoC components (VDAC8, PWM, etc.). Multiple instances of component can run simultaneously in the project interfacing several encoders.

When to use Decoder component

Component was developed for interfacing hand-operated rotary shaft encoders with PSoC projects with limited UDB resources. It is particularly useful when developing custom Verilog/Datapath code as it does not hide UDB resources consumption. Component was tested on PSoC4 and PSoC5 prototyping kits with encoders having 15-24 detents/revolution. Typical applications are HMI interface (such as LCD menu) or parameter input (servo position, volume control etc.). Component is not intended for critical applications, such as motor feedback control. Demo projects are provided.

[*] Hereafter referenced as ‘Decoder’

Input-output connections

A(B) – encoder line A(B)

External terminal for connecting A(B) line from the encoder annotation component (off-chip). The pin is always visible. Pin does not have to be connected, it is merely an external terminal to the annotation component. Actual assignment of the input pin is performed using Pins dialog on the Design Wide Resources (DWR) page. See Functional Description section for details.

Btn – button switch

External terminal for connecting to a switch button on the encoder annotation component (off-chip). Visibility of this pin is controlled by the **btn_enable** option in the Advanced dialog. The pin does not have to be connected, it is merely an external terminal to the annotation component. Actual assignment of the button pin is performed in the Pins dialog. See Functional Description section for details.

gnd – virtual ground

External terminal for connecting to a ground terminal on the encoder annotation component (off-chip). Visibility of this pin is controlled by the **gnd_enable** option in the Advanced dialog. The pin does not have to be connected, it is merely an external terminal to the annotation component. Actual assignment of the input pin is performed in the Pins dialog. See Functional Description section for details.

clk – clock input

In polling mode the encoder pins are sampled on rising edge of this signal. In interrupt mode the clock is used only for debouncing of the switch button(*). In the polling mode the pin is visible when internal interrupt option is selected; in the interrupt mode this pin is visible when button is enabled. When visible, the pin must be connected to a clock. Recommended frequency of the clock source must be about 1-2 kHz. Increasing sampling rate improves encoder position accuracy (in polling mode), but shortens debouncing time. In PSoC4 this pin can’t be directly driven by a clock and has to be bypassed using either UDB component or a pin. Such bypass consumes one macrocell.

* Default debouncing interval is 50 clocks as defined by the SW_DEBOUNCE_TIME in the API header file.

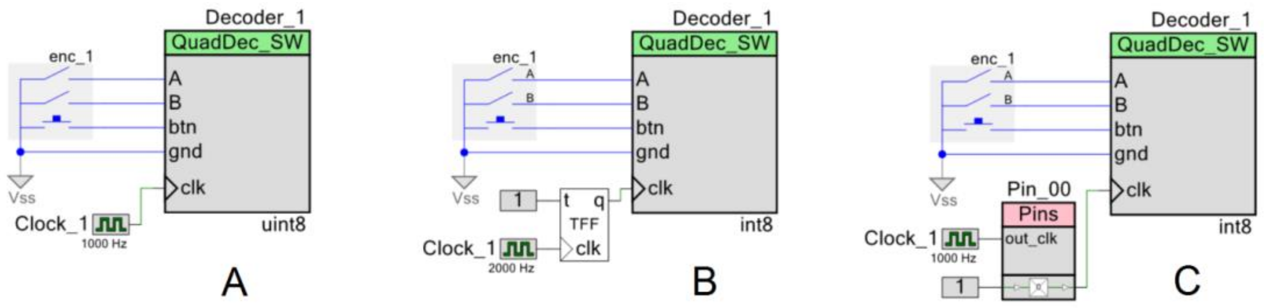
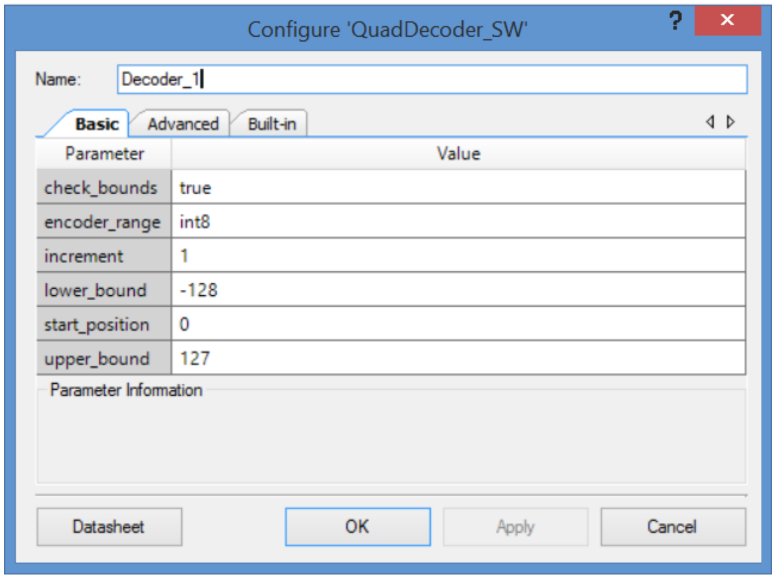


Figure 1. Clock connection: (A) PSoC5 - direct, (B, C) PSoC4 - bypassed.

Parameters and Settings

Basic dialog provides following parameters[*]:



Name: Decoder_1

Parameter	Value
check_bounds	true
encoder_range	int8
increment	1
lower_bound	-128
start_position	0
upper_bound	127

check_bounds (bool)

Enables lower and upper bounds for encoder position. Default value is false. If enabled, encoder position will be restricted to interval from **lower_bound** to **upper_bound**, saturating at bound limits. If disabled, position change is unrestricted, and will flip over range type limits. For example, for encoder range type **int8**, next position up from 127 is -128, etc.).

[*] Decoder component is intentionally compiled using Creator 4.0 for compatibility with v.4.1 and older versions

encoder_range (int8 / int16 / int32 / uint8 / uint16 / uint32 / single / double)

Encoder position range type **er_t** (int8, int16, int32, uint8, uint16, uint32, single or double). For example, valid range for position values using **er_t** = int8 is from -128 to 127.

increment (er_t)

Encoder step increment. Must be of positive non-zero value. Default value is 1. When **check_bounds** option is selected, the position will not change if incrementing it causes bound overflow. For example, if **start_position**=0, **increment**=10 and **upper_bound**=255, encoder position can reach maximum value of 250 (can't step over 255).

lower_bound (er_t)

Encoder lowest position. To have effect, the **check_bounds** option must be enabled.

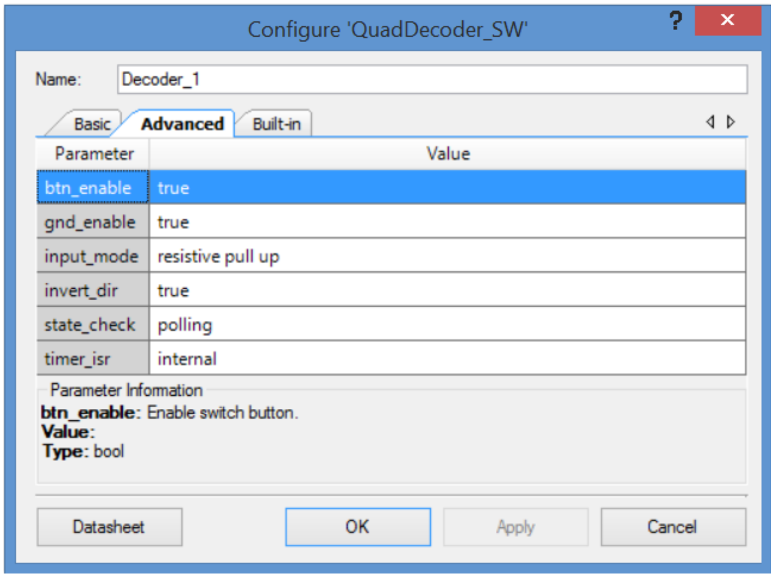
start_position (er_t)

Encoder position upon initialization. If **check_bounds** option is enabled, the value of the **start_position** must reside between **lower_bound** and **upper_bound**.

upper_bound (er_t)

Encoder highest position. To have effect, the **check_bounds** option must be enabled.

Advanced dialog provides following parameters:



Name: Decoder_1

Parameter	Value
btn_enable	true
gnd_enable	true
input_mode	resistive pull up
invert_dir	true
state_check	polling
timer_isr	internal

Parameter Information
btn_enable: Enable switch button.
Value:
Type: bool

btn_enable (bool)

Enables button pressed event. Default value is True. In interrupt mode this feature will consume extra interrupt for switch debouncing. See **Resources** section for details.

gnd_enable (bool)

Enables virtual ground though extra pin (open drain drives low). Default value is true. This feature is convenient when working with PSoC prototyping kits where ground terminals are limited. This feature consumes extra pin on PSoC. If enabled, the **gnd** external terminal appears on the symbol.

input_mode (resistive pull up / high impedance)

Sets input pins either to **resistive pull up** or **high impedance** digital drive mode. Default value is **resistive pull up**. Select **high impedance** option when encoder has external pullup resistors; select **resistive pull up** option when encoder is a bare switch. See **Functional Description** section for details.

invert_direction (bool)

Allows revering direction of the encoder in code. Default value is false. This feature has same effect as switching up encoder terminals A and B. It appears that various shaft encoders may have either line A or line B as leading edge source, resulting either in increment or decrement while rotating clockwise. This option allows correcting that issue.

state_check (polling / interrupt)

Method of detection of the encoder state change: repeatedly polling pins state or waiting for pin interrupt. Using interrupts consumes less CPU resources but is limited by only one encoder per port, and pins assignment has to be contiguous. The polling method poses no restrictions on number of encoders per port and on pins assignment, but consumes extra CPU resources. This may become significant when large numbers of encoders are used or when CPU is heavily loaded by other processes. See **Functional Description** and **Performance** sections for details.

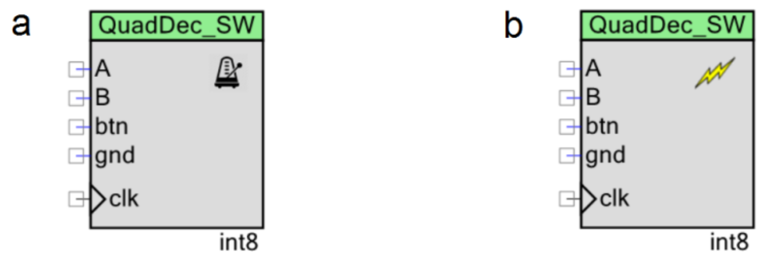


Figure 2. Component appearance in polling and interrupt modes: (a)-polling mode, timer clock appears on the symbol; (b)-interrupt mode, interrupt symbol appears on the symbol.

timer_isr (internal / external)

Select internal or external timer interrupt for polling of encoder pins. This option available only for polling mode. Internal option requires less code, but consumes extra interrupt for each Decoder component, which but can be prohibitive when large number of encoders used. External option allows for a single interrupt polling all encoders in the project, but requires extra custom code(*). When selected, the clock input becomes hidden. Default option is internal.

* See Multiple Encoders example in the Application Note

Application Programming Interface

Function	Description
`Decoder_Start()`	Initialize and start component
`Decoder_Stop()`	Stop component
`Decoder_SetPosition()`	Sets encoder position
`Decoder_SetIncrement()`	Sets position increment step
`Decoder_SetBounds()`	Sets lower and upper bounds
`Decoder_SetCheckBounds()`	Sets **check_bounds** property
`Decoder_Setup()`	Sets position, increment and bounds
`Decoder_CheckStatus()`	Step through the state machine
Variable	**Description**
`Decoder_Position`	Encoder position
`Decoder_Direction`	Encoder last direction of rotation
`Decoder_PositionChanged`	Position changed flag
`Decoder_BtnPressed`	Button pressed flag
`Decoder_Initialized`	Component initialized status
`Decoder_Enabled`	Decoder enabled status
`Decoder_Increment`	Position increment step
`Decoder_LowerBound`	Position lower bound
`Decoder_UpperBound`	Position upper bound
`Decoder_CheckBounds`	Decoder **check_bounds** state

void Decoder_Start()

Description: Initializes and starts component. Sets input pins drive mode (resistive pull up / high impedance) according to **input_mode** selection.

Parameters: none

Return Value: none

void Decoder_Stop()

Description: Stops and disables component. Stops internal interrupts and sets input pins drive mode to high impedance state.

Parameters: none

Return Value: none

uint8 Decoder_SetPosition(er_t value)

Description: Sets encoder position.

Parameters: new encoder position, must be of defined encoder range type **er_t**[*]. If **check_bounds** option is enabled, the value must be in range from **lower_bound** to **upper_bound**.

Return Value: 1- if set value is within the range, otherwise return is 0.

uint8 Decoder_SetIncrement (er_t value)

Description: Sets position increment step.

Parameters: non-zero, positive value, must be of selected encoder range type **er_t**.

Return Value: 1- if value > 0, otherwise return is 0.

uint8 Decoder_SetBounds (er_t lower_bound, er_t upper_bound)

Description: Sets encoder **lower_bound** and **upper_bound**.

Parameters: **lower_bound** and **upper_bound** must be of selected encoder range type **er_t**, satisfying condition **lower_bound** <= **upper_bound**. Note that changing the bounds will not update encoder position automatically, and may result in position falling outside of the bound limits. Use API SetPosition() to update the position right after SetBounds() call.

Return Value: 1 – if **lower_bound** < **upper_bound**, otherwise return value is 0.

[*] **er_t** is of type int8, int16, int32, uint8, uint16, uint32, single or double, as selected by the **encoder_range** option.

uint8 Decoder_SetCheckBounds(uint8 value)

Description: Sets bounds check option.

Parameters: 1 – enable bounds check, 0 – disable bounds check.

Return Value: 1 – (i) bounds check enabled and current position lies between lower and upper bounds, or (ii) bounds check is disabled. Otherwise return value is 0.

uint8 Decoder_Setup (er_t position, er_t increment, er_t lower_bound, er_t upper_bound, uint8 check_bounds)

Description: Sets encoder position, increment and bounds properties in a single call.

Parameters: **Position**, **lower_bound** and **upper_bound** must be of selected encoder range type, **check_bounds** – boolean (1- enable, 0- disable). The **increment** should be greater than 0. If bounds option is activated, the input values must satisfy the conditions: **lower_bound** <= **position** <= **upper_bound.**

Return Value: 1– if all conditions are satisfied, otherwise return is 0.

int8 Decoder_CheckStatus ()

Description: Reads encoder pins state and passes it to the state machine. In the polling mode this function is called automatically when **timer_isr** option set to **internal.** When **timer_isr** option set to **external**, this function has to be called repeatedly to capture state change. Function has no effect in interrupt mode.

Parameters: None.

Return Value: 1 – encoder rotated clockwise; -1 – encoder rotated counterclockwise; 0 – position changed by API call (no physical rotation).

er_t Decoder_Position

Description: Returns encoder current position. Read-only.

Return Value: encoder position.

int8 Decoder_Direction

Description: Returns encoder last direction of rotation. Read-only.

Return Value: 1 – encoder rotated clockwise; -1 – encoder rotated counterclockwise; 0 – position changed by API call (no physical rotation). Note that return value reflects direction of rotation, and not encoder position change. For example, while rotating clockwise, the encoder position may flip over the range boundary (e.g. from +127 to -128), or saturate at the **upper_bound**, yet the **Direction** value will stay 1.

unt8 Decoder_PositionChanged

Description: Flag indicating change of encoder position. Read-only. Check this flag in the main() loop to detect encoder position change event. Once checked, the flag automatically resets to 0.

Return Value: 1 – position changed, otherwise return value is 0.

unt8 Decoder_BtnPressed

Description: Flag indicating button pressed event. Read-only. Check this flag in the main() loop to detect button pressed event. The flag will rise after debouncing time has elapsed, which adds delay of 50 clock cycles (50 ms at 1 kHz) after the button was actually pressed. Once checked, the flag automatically resets to 0.

Return Value: 1 – button pressed, otherwise return value is 0.

uint8 Decoder_Initialized

Description: Returns Decoder initialized state. Read-only.

Return Value: 1 – decoder started, 0 – decoder stopped.

uint8 Decoder_Enabled

Description: Reads/writes parameter controlling decoder state machine operation. Assign 1- to enable, 0 - to disable decoder state machine. When disabled, the flag **PositionChanged** shall not raise. Unlike the Stop() procedure, disabling the state machine won't free interrupts nor alter the pins drive mode. This parameter doesn't affect button switch detection, and the B**uttonPressed** flag shall rise normally. This can be used, for example, to enable/disable encoder by pressing the button.

Return Value: 1 – decoder enabled, 0 – decoder disabled.

er_t Decoder_Increment

Description: Returns position increment step. Read-only.

Return Value: increment step value.

er_t Decoder_LowerBound

Description: Returns position lower limit. Read-only.

Return Value: lower bound value.

er_t Decoder_UpperBound

Description: Returns position upper limit. Read-only.

Return Value: upper bound value.

uint8 Decoder_CheckBounds

Description: Returns **check_bounds** parameter. Read-only.

Return Value: 1 – bounds check enabled, 0 – bounds check disabled.

Functional Description

Basic rotary encoder switch is a mechanical device utilizing a pair of contacts operating in quadratures when shaft is rotated [2]. Encoders come from variety of manufactures and available with or without breakout board (Figure 3); the Decoder component can be configured to operate with both types. Having breakout board has benefits for prototyping purposes as it can be directly plugged into a protoboard or a ribbon cable, needs only four wires for connection, and optional decoupling capacitors could be directly soldered to the board.

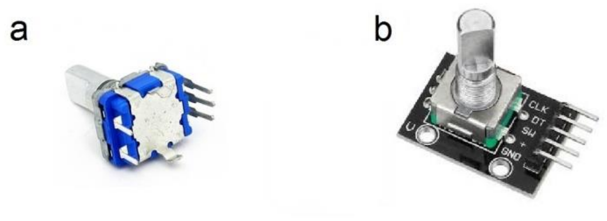


Figure 3. Rotary encoder examples: (a) without breakout board, (b)- with KY-040 breakout board[*].

Encoder connection to PSoC is shown on Figure 4. Traditional approach requires a pair of external pullup resistors to interface encoder to microcontroller pins configured to operate in the high impedance digital input mode (Figure 4a). By enabling pins internal pullup resistors the encoder hook-up simplifies, so that no external parts are necessary (Figure 4b). In this case the Decoder input mode must be configured as resistive pull up. Encoder rotation will produce quadrature signals on PSoC digital input pins, which can be captured and processed by the state machine. Examples of encoder interfacing to the PSoC are described in the **Appendix 1**.

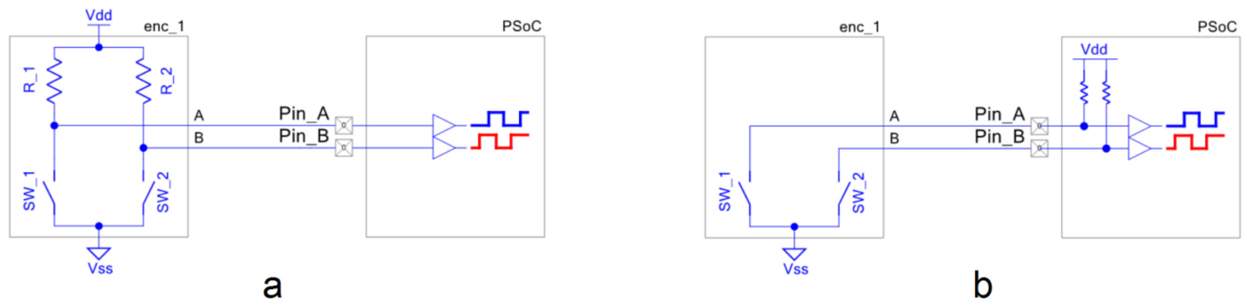


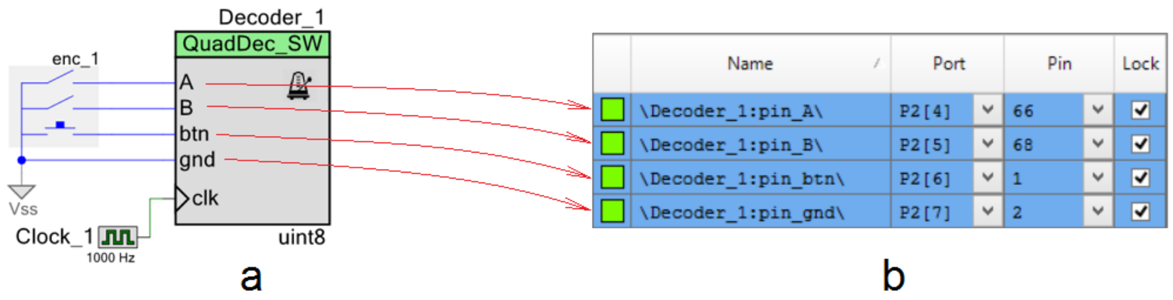
Figure 4. Encoder connection schematic using: (a) external pullup resistors, (b) internal pullup resistors.

[*] Keyes KY-040 rotary encoder with breakout board [3]

Input pins configuration

To parse encoder state, the Decoder component utilizes buried pins. Component configures pins automatically according to options selected; only job left to user is to assign inputs in the Pin Configuration window, which looks differently in polling and interrupt mode.

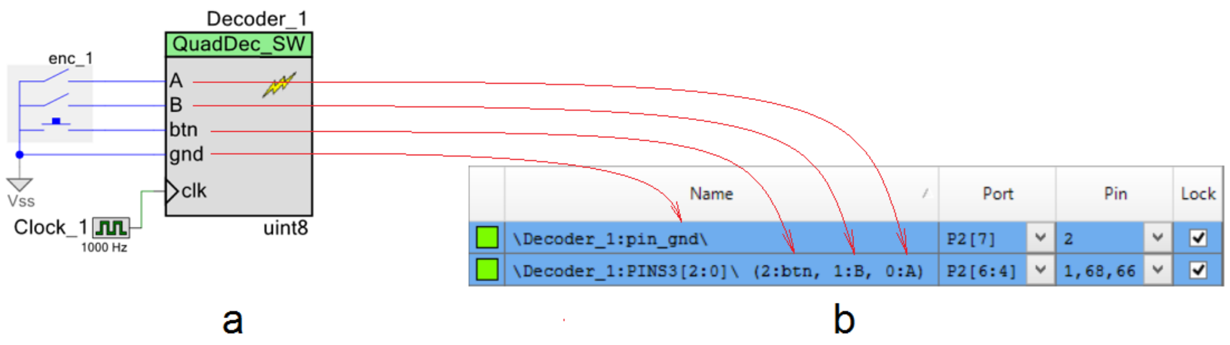
Decoder pins configuration in the polling mode is shown on Figure 5. In polling mode the pin assignment is arbitrary, and any available pins can be selected for lines **A**, **B, btn** and **gnd**. External clock (Clock_1) is required here both for encoder polling and button operation. The off-chip encoder component (enc_1) is provided merely for annotation purpose; its presence on the schematic does not affect operation of the Decoder component.



	Name	Port	Pin	Lock
🟩	\Decoder_1:pin_A\	P2[4]	66	✓
🟩	\Decoder_1:pin_B\	P2[5]	68	✓
🟩	\Decoder_1:pin_btn\	P2[6]	1	✓
🟩	\Decoder_1:pin_gnd\	P2[7]	2	✓

Figure 5. Pins configuration in polling mode: (a)- component appearance on schematic, (b)- pins configuration (individual pin assignment is arbitrary).

When Decoder is set to operate in interrupt mode, the pins assignment looks different and has some constrains (Figure 6). It requires pins **A**, **B** and **btn** to be contiguous (belong to same port and be consecutive), as they share same port interrupt. Optional pin **gnd** can be assigned to any available pin as it needs no interrupt. In this mode external clock (Clock_1) is required for button switch debouncing only, no clock required if button disabled.

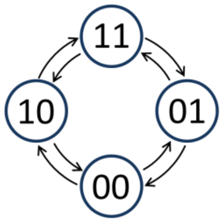


	Name	Port	Pin	Lock
🟩	\Decoder_1:pin_gnd\	P2[7]	2	✓
🟩	\Decoder_1:PINS3[2:0]\ (2:btn, 1:B, 0:A)	P2[6:4]	1,68,66	✓

Figure 6. Pins configuration in interrupt mode: (a)- component appearance on schematic, (b)- pins configuration (pins A, B and gnd assignment is contiguous).

Implementation

Component implements a state machine using established algorithm [1]. It utilizes buried pins which state is being parsed by CPU either on timer or pin interrupt. The component consumes neither UDB Datapath nor PLD resources, performing all operation entirely by CPU. CPU clock consumption is given in **Performance** section, typically taking about 50 CPU clocks to process single interrupt or polling event. During that time CPU is unavailable to other task.



The state machine has 4 sequential pin states (11), (01), (00), (10), therefore Decoder must correctly identify all 4 consecutive transitions (micro-steps) in order to detect encoder single step(*). In interrupt mode, any state change on digital lines A and B is captured and processed using port interrupt. It will take at least 4 interrupt events to detect encoder rotation. The drawback of using port interrupt is that in current implementation only a single encoder can be connected to PSoC port(†); having several encoders in the project will occupy several ports.

In the polling mode, pin state is being checked on each clock rising edge. To catch the transition, polling must occur faster than encoder lines A and B are switching states. Typically, polling rate of 1 kHz to 2 kHz is sufficient for normal hand operation of shaft encoder with 20 detents per revolution. Faster polling rate reduces error rate, but increases CPU load, which may become essential if many encoders are attached to PSoC.

In the main loop the **PositionChanged** flag is evaluated based on encoder rotation direction and boundary limits (if set) and new encoder position is calculated. Having encoder position incremented in the main loop instead of inside interrupt routine reduces amount of CPU clocks spent in the interrupt, but may not fit application with heavy CPU load. The Decoder component is best suited for non-critical task (such as update of the audio volume, etc.).

Button press detection implemented using either polling or interrupt (according to state check option selected), followed by a debouncing time interval. On button pressed event a counter is set, starting a countdown for debouncing time delay. Elapsed time is counted on each input clock. Default debouncing time is set to 50 clocks (50 ms using 1 kHz clock), defined by the SW_DEBOUNCE_TIME in the API header file. When countdown expires, the state of the **Btn** line is checked again, and, depending on the outcome, the **ButtonPressed** flag is raised for further processed in the main loop.

Comparison of polling vs. interrupt modes is provided in the **Performance** section.

* The algorithm used does not detect half-steps.

† There are no formal restrictions to have several encoders per port operating in interrupt mode, being only a matter of customizer implementation to cover various pins arrangements.

Performance

Component was tested using PSoC5LP (CY8KIT-059) and PSoC4 (CY8CKIT-042 Pioneer Kit). The component consumes neither UDB Datapath nor PLD resources, performing all operation entirely by CPU. The state machine takes about 50 CPU clocks to process a single interrupt event. Typical results for PSoC5LP are shown. Results for PSoC4 are about 20% slower.

Table 1. PSoC5LP typical CPU clocks consumption by state machine processing a single transition (micro-step).

Option	Polling		Interrupt	
	w/o button	w/ button	w/o button	w/ button
debug(*)	51	68	55-57	58-60
release(†)	43	57	44-46	49

(*) data collected in debug mode with compiler optimization turned off

(†) data collected in release mode with compiler optimization set to speed

Table 2. Comparison of polling vs. interrupt mode.

Polling mode	Interrupt mode
Number of encoders in the project is limited by amount of available pins and interrupts	Number of encoders in the project is limited by amount of available ports
Up to 4 encoders per physical port	Only 1 encoder per physical port
Pins assignment is arbitrary	Pins assignment is contiguous
Continuous polling drains CPU resources	CPU engages when encoder activity detected
Needs external clock	External clock needed only when button enabled
Debouncing time linked to polling rate	Debouncing time defined by input clock
Low differential error rate	Low integral error rate
Error rate depends on clock frequency	Error rate does not depend on clock frequency

Resources

Component resources consumption is provided below. The component does not consume UDB resources. Component does not have built-in DMA capabilities.

Table 3. Resources consumption.

Resource	Polling(*)		Interrupt	
	w/o button	w/ button	w/o button	w/ button
interrupts	1	1	1	2
clocks	1	1	-	1

(*) using internal interrupt

Sample Firmware Source Code

Basic application example shows Decoder operation in interrupt mode (Figure 7). Several demo projects are provided along with the Application Note showing various use of the component.

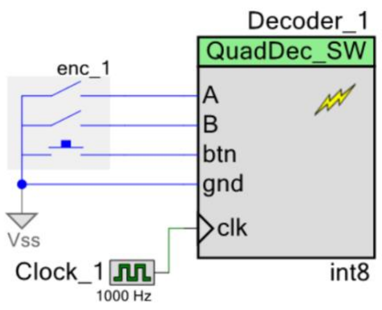


Figure 7. Basic application example showing Decoder operating in interrupt mode.

Component Changes

Version	Description of changes	Reason for changes/impact
0.2	Schematic update – the Dedicated Pin Interrupt checkbox is explicitly checked out	Previous version didn't compile with PSoC4M as the Dedicated Pin Interrupt checkbox is not explicitly checked out for PSoC4M
0.1	Updated validator definition for increment field.	Validator error when selected encoder_range is double and increment value is in range]0, 1[.
	Added instance name prefix to the encoder range type (er_t)	Multiple instances of the Decoder with different encoder range types gives warning message of type re-definition.
0.0	Version 0.0 is the first beta release of the QuadDec_SW component	

References

1. M. Kellett, Interfacing Micro-controllers with Incremental Shaft Encoders. http://www.mkesc.co.uk/ise.pdf
2. Wikipedia. https://en.wikipedia.org/wiki/Rotary_encoder
3. Keyes rotary encoder user manual

Appendix 1

Breakout board connection

The Keyece KY-040 breakout board schematic is shown on Figure 8. Original board provides external pull-up resistors which require pull-up voltage (Vdd). Using PSoC built-in pull-up resistors, the encoder hook-up simplifies, no longer requiring external pull-up voltage. Pull-up resistors on the breakout board can be left in place (Fig. 8a) or removed (Fig. 8b). Leaving resistors in-place causes some crosstalk between encoder channels, which does not affect performance. Partial hardware debouncing can be achieved by replacing onboard resistors with 0.1 uF capacitors (Fig 8c). Such modification debounces low-to-high transition only.

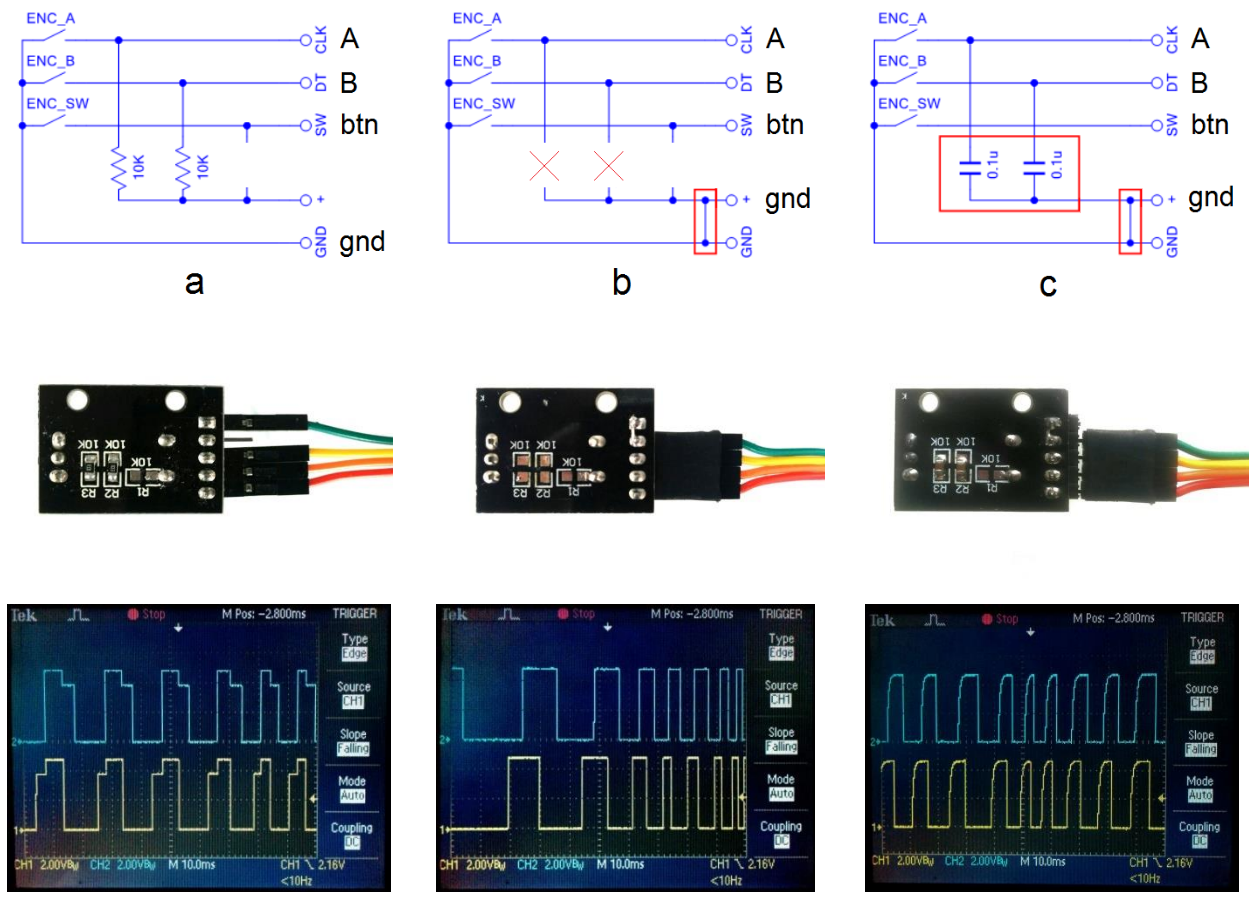
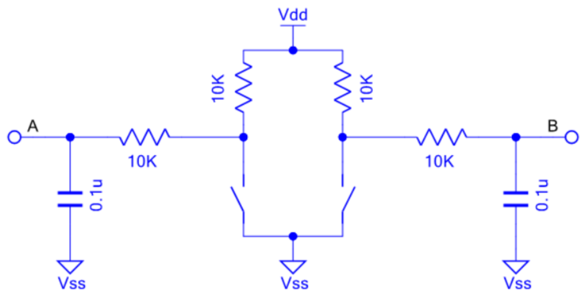

ENC_A
ENC_B
ENC_SW
CLK
DT
SW
GND
A
B
btn
gnd
10K
0.1u
a
b
c
CH1 2.00V CH2 2.00V M 10.0ms
TRIGGER Type Edge Source CH1 Slope Falling Mode Auto Coupling DC

Figure 8. KY-040 breakout board schematic, connector pinout and scope traces for the channels A and B: (a) original, (b) pullup resistors removed, (c) resistors are replaced with capacitors. Connector wire pinout: A (red), B (orange), Btn (yellow), Gnd (green). Unused pin on breakout board (b, c) is removed.

Traditional encoder connection

Traditional encoder connection to controller with hardware debouncing is shown on Figure 9. It uses external pullup resistors with additional RC-circuit for debouncing. Such connection requires Decoder component operation in high impedance input mode. Hardware debouncing is achieved by using RC-circuits, which debouncing both low- and high- transitions. Its drawback is larger external parts count, but resulting input signals are nicely clean.



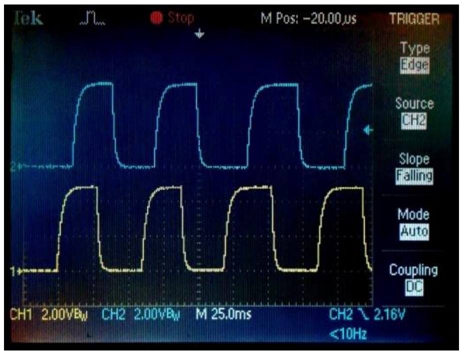
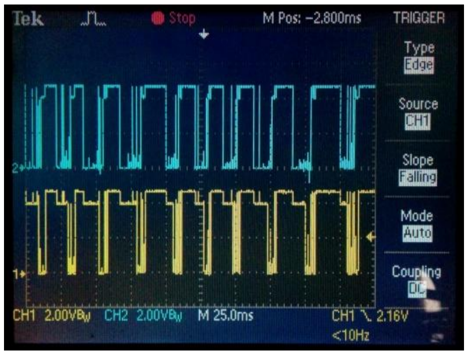


Figure 9. Encoder connection using external pullup resistors with hardware debouncing. Right: oscilloscope traces at points A and B.

Sub-standard quality encoders

Some batches of the KY-040 appear of inferior quality (Figure 10). Intermittent contact of the slider electrode with the ground is likely culprit. Decoder component state machine filters out most of the noise, yet about 1% position error rate feeds through. Always check new encoder for output signal integrity and discard the faulty units.



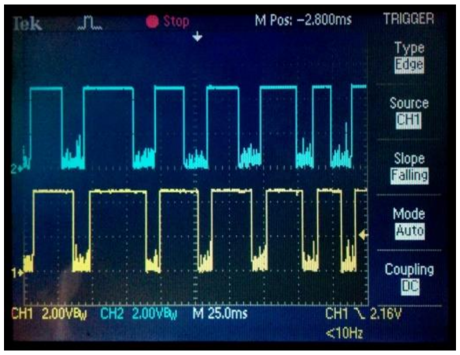


Figure 10. Examples of signal traces from faulty encoders (same batch).

Appendix 2

Encoder off-chip annotation components

The Decoder component is accompanied with few off-chip Encoder components (Figure 11). They are optional annotation components, designed to improve visibility of the Decoder component settings. Dialog options can set visibility of the name, labels and button switch.

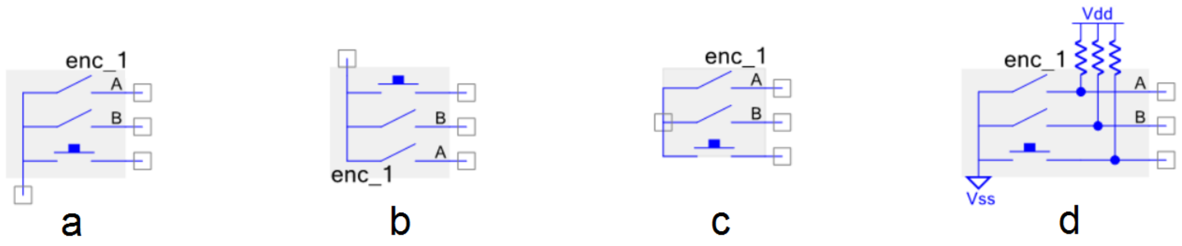


Figure 11. Encoder off-chip annotation components: (a) standard; (b) upside down configuration; (c) compact; (d)-with external pullup resistors.

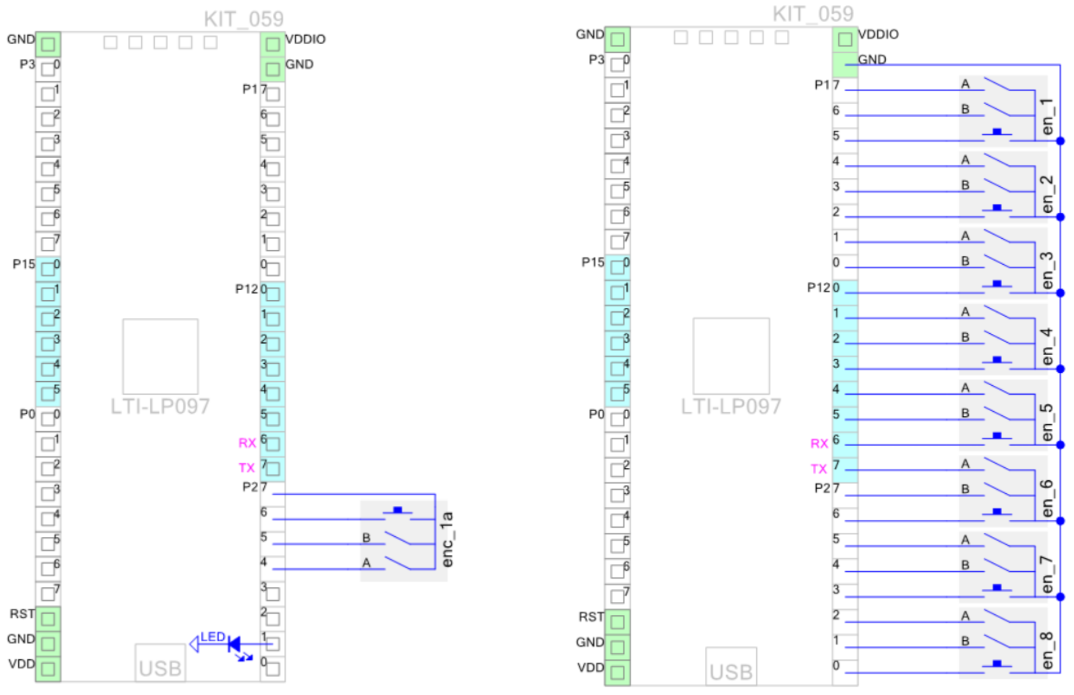


Figure 12. Examples of schematic using CY8KIT-059 off-chip annotation library[*] and the Encoder component.

[*] CY8KIT-059 Annotation Library v1.0: https://community.infineon.com/t5/Code-Examples/PSoC-Annotation-Library-v1-0/td-p/62657

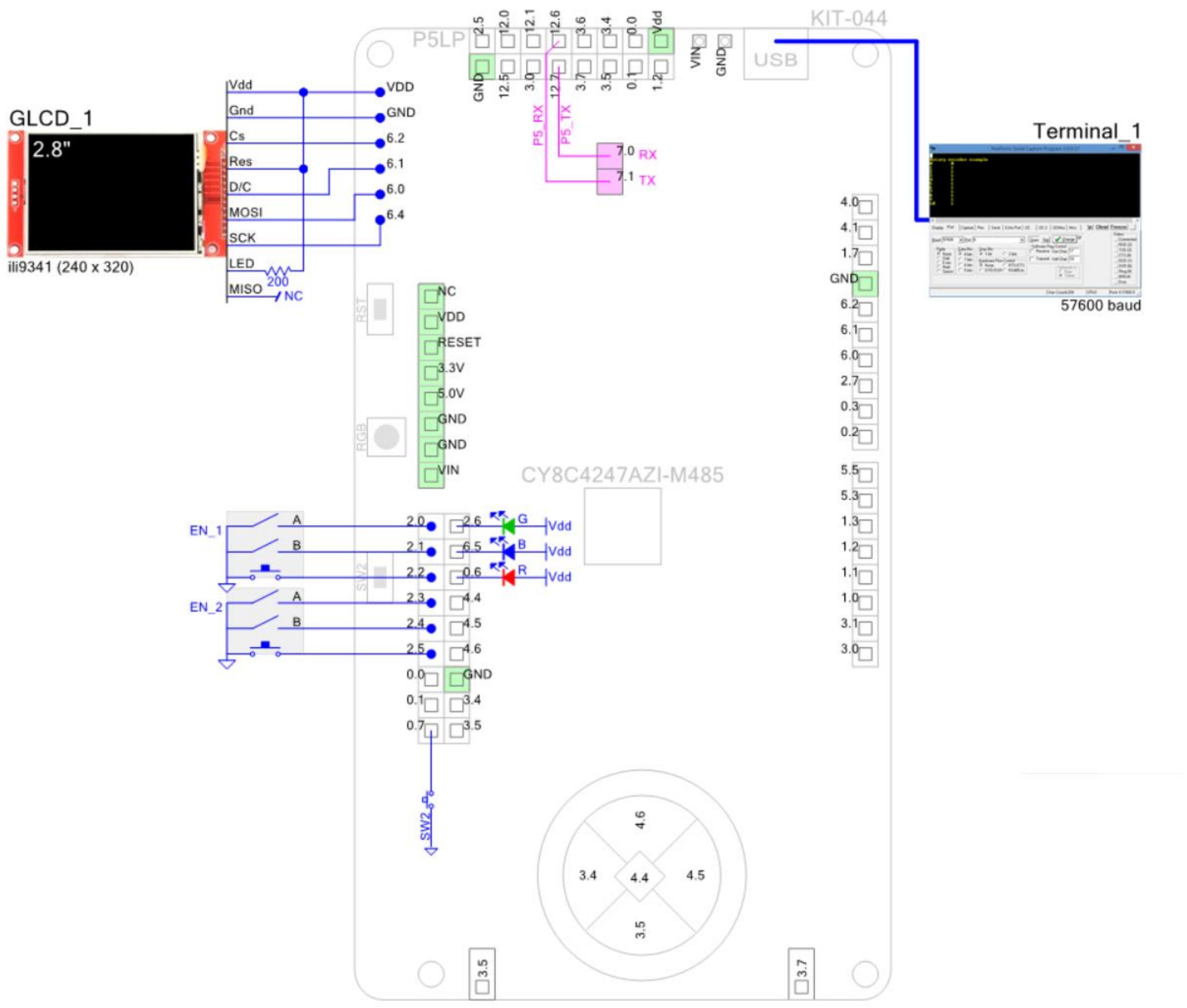


Figure 13. Examples of using rotary encoders alongside with CY8CKIT-044 Pioneer Kit, and project annotation using KIT-044 off-chip Annotation Library[*] and the Encoder component.

[*] CY8KIT-044 Annotation Library v0.2: https://community.infineon.com/t5/Code-Examples/KIT-044-annotation-component-for-CY8CKIT-044-PSoC4M-Pioneer-Kit/td-p/44982