



## **Didactic System For Teaching Microcontrollers - Case Study: Design Of A Digital Tachometer**

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### **Abstract**

This document presents in a didactic way the development of a digital tachometer that can measure speeds up to 800 RPMs (Revolutions Per Minute), using a PSoC5LP, which includes an alphanumeric LCD, an optical sensor, a DC motor and the additional components required for its operation. For the visualization of the information generated by the system, the alphanumeric LCD of 2x16 characters is used. PSoC5LP interrupts are used to measure the motor speed generated by the optical sensor and the data is updated on the LCD every three seconds. The measurements captured by selecting different engine speeds were verified and compared practically. With the above, the objective of showing in a practical way the use of the concept of interruption and various elements associated with the teaching of microcontrollers and specifically the PSoC5LP would be fulfilled.

**Keywords:** Interruption; LCD; optical sensor; PSoC5LP; slotted disk

## **1. Introduction**

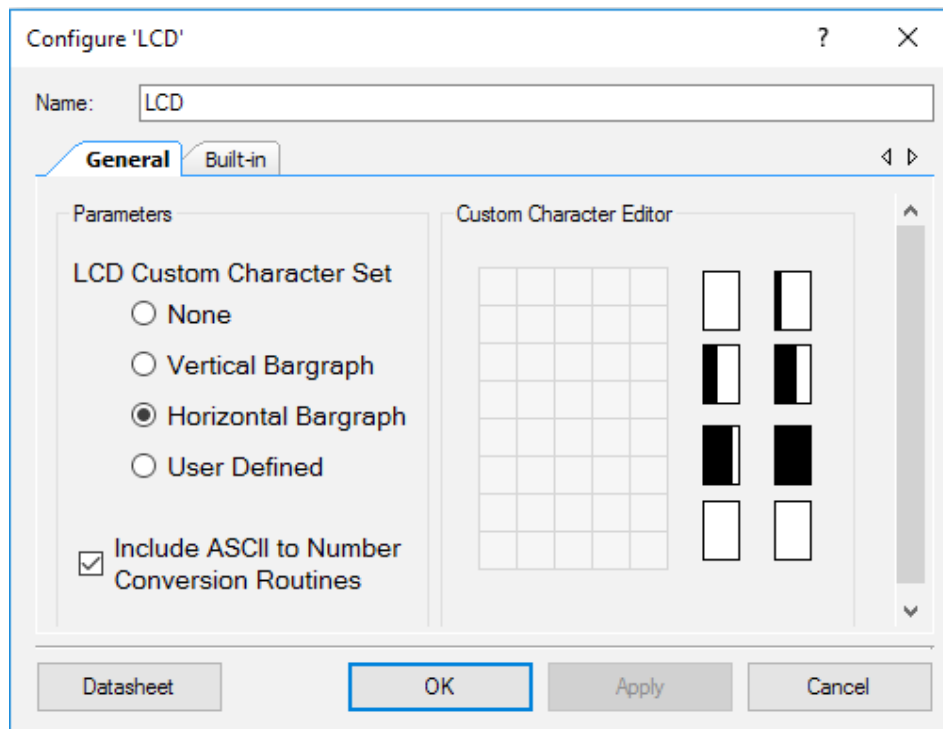
With the purpose of showing the operation of the visualization through the LCD block and the interruptions offered by the PSoC5LP, this document shows the design of a system for measuring the speed of a DC motor (digital tachometer), since the system is of didactic type, the motor used was recycled from a toy in bad condition, in which it is also necessary the use of external elements such as an optical sensor type horseshoe and a slotted disc of 20 slots.

### *1.1. Character LCD*

It is a component that implements the industry standard Hitachi HD44780 display LCD (Camargo & Perdomo, 2016). This component contains a set of library routines that enable the use of one-, two-, or four-line LCD modules that implement the Hitachi 44780 4-bit standard (Infineon Technologies AG, 2018).

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In Figure 1 you can see the configuration made in the LCD, selecting the option LCD Custom Character Set Horizontal Bargraph (used to generate an animation with a horizontal bar that increases or decreases proportional to the motor speed), Include ASCII to Number Conversion Routines selected.



**Figure 1.** Character LCD Component Configuration

## 1.2. Interruptions

They are resources or mechanisms of the microcontroller to respond to events immediately, allowing to temporarily suspend the execution of the main program to run an interrupt service subroutine ISR (Interrupt Service Routine), when it ends it resumes the execution of the main program (Infineon Technologies AG, 2020).

These interrupts are generated when peripheral devices connected to the PSoC5LP, generates a state change in its terminals or generates a signal by software indicating that it wants to send information to the microcontroller, this can occur asynchronously (Reyes & Cid, 2015).

An interrupt can be defined as a signal generated by the hardware or a software instruction that forces the CPU of the device used, to stop the execution of the program being executed (main program), to execute a routine, procedure or function that is considered as a priority and whose execution must be performed at the time the request is made (Camargo, 2013).

The PSoC5LP has the following types of interrupts:

- External HW: they are asynchronous to CPU execution, they are tied to input or output devices, such as an input/output pin.
- Internal HW: they are linked to internal devices of the PSoC5LP, such as timer-generated interrupts.
- SW: Software interrupts, they are generated by a running program, i.e. being able to "call" the interrupt during the execution of an algorithm.

### 1.3. Transmissive Optical Sensor with Phototransistor Output

The TCST2103 is transmissive sensors that include an infrared emitter and phototransistor, located face-to-face on the optical axes in a leaded package which blocks visible light. These part numbers include options for aperture width (Vishay Semiconductors, 2022).

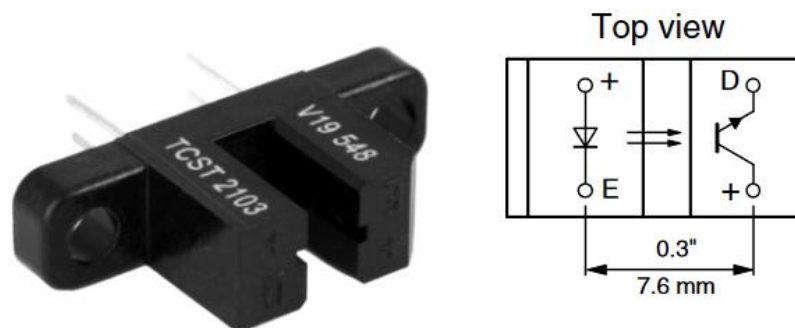
Features:

- Package type: leaded
- Detector type: phototransistor
- Dimensions (L x W x H in mm): 24.5 x 6.3 x 10.8
- Gap (in mm): 3.1
- Typical output current under test:  $I_C = 4 \text{ mA}$
- Daylight blocking filter
- Emitter wavelength: 950 nm
- Lead (Pb)-free soldering released
- Compliant to RoHS directive 2002/95/EC and in accordance to WEEE 2002/96/EC

Applications:

- Optical switch
- Photo interrupter
- Counter
- Encode

Figure 2 shows the image of the low-cost commercial optical sensor reference TCST2103 (Digi-Key, 2022), where the optical emitter and receiver are clearly separated.



**Figure 2.** Transmissive Optical Sensor with Phototransistor Output with reference TCST2103

### 1.4. Slotted Disc

For speed measurement, a 20-slotted plastic disk is used (manufactured in a 3D printer available at the University) that allows performing the speed count without having to wait a minute to have the scale in RPMs, the disk is coupled to the motor shaft, allowing the measurement of RPMs every three seconds, having only to multiply x3 the count value performed in the algorithm, in Figure 3 can be seen an image of the manufactured disk (Camargo, Perdomo & Bermudez, 2019).



**Figure 3.** Slotted disc used for design solution

## 2. Formulation of the Problem

For the development of the didactic application it is required to design a digital tachometer (Oyelami, Azeez & Abioye, 2019), (Zhang, 2010) that performs the measurement of the speed in RPMs of a DC motor whose maximum speed is 800RPMs, displaying the information on an alphanumeric LCD.

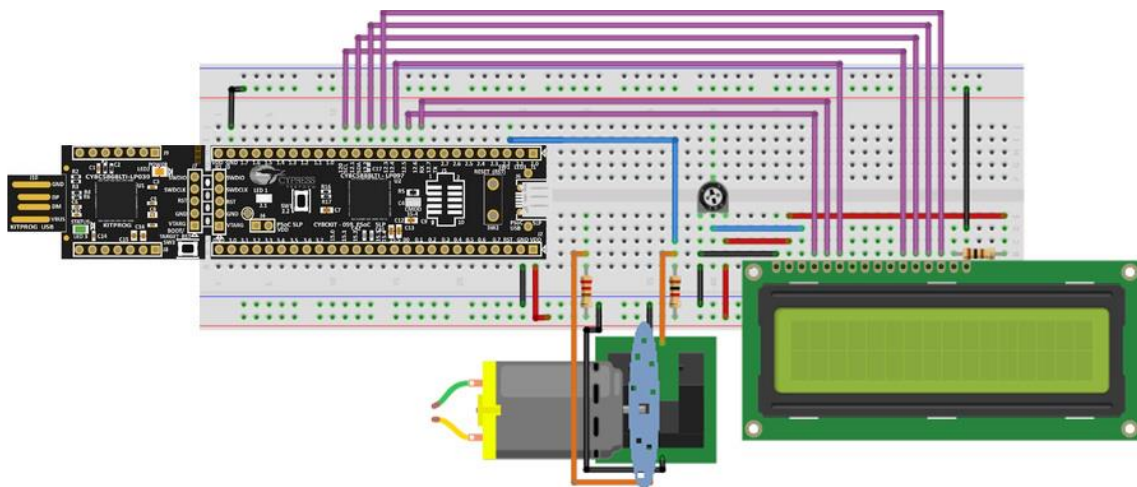
The speed data should be displayed as a numerical value and, in addition, in a horizontal bar representing the corresponding range, these values should be updated on the LCD at least every 5 seconds (Masud, Sahabuddin & Shourov, 2016), (Ehikhamenle & Omijeh, 2017).

## 3. Design and Solution Model

### 3.1. Hardware

In order to solve the problem, we start by analyzing the necessary hardware and software components. Thus, if we have a 16x2 LCD, it is evident the use of the LCD block of the PSoC5LP that allows its configuration. The optical sensor used to generate pulses along with the slotted disk that finally, are used to count the pulses generated by interrupts in the PSoC5LP.

Figure 4 shows the circuit diagram and protoboard connections of the peripherals used with the proposed solution.



**Figure 4.** Connection diagram

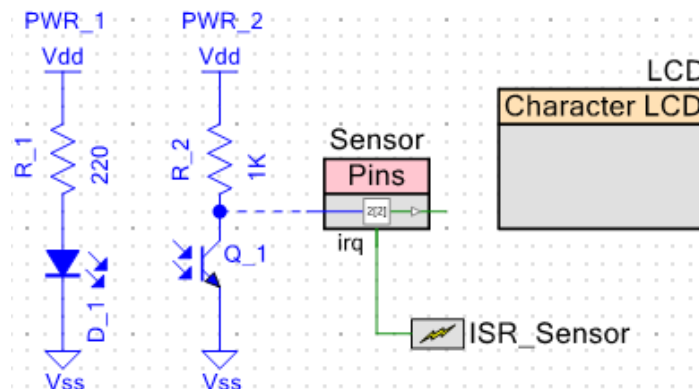
Table 1 below lists all the components used for the solution of the problem:

**Table 1.** List of components of the problem posed

Name	Reference	Value
	PSoC5LP development board	CY8CKIT-059
R_1	Resistance	220 $\Omega$
R_2	Resistance	1k $\Omega$
	Resistance	100 $\Omega$
	Potentiometer	10k $\Omega$
LCD	Alphanumeric LCD	2x16
Sensor	Optical transmitter-receiver pair	TCST2103
	Slotted disc	20 slots
	D.C. motor	5v

### 3.2. Software

The algorithm to solve the problem is implemented in the PSoC5LP memory, it is based on the circuit diagram in Figure 5, generated by the PSoC Creator, which is the development environment where PSoC5LP works.



**Figure 5.** Circuit diagram with proposed solution to the problem

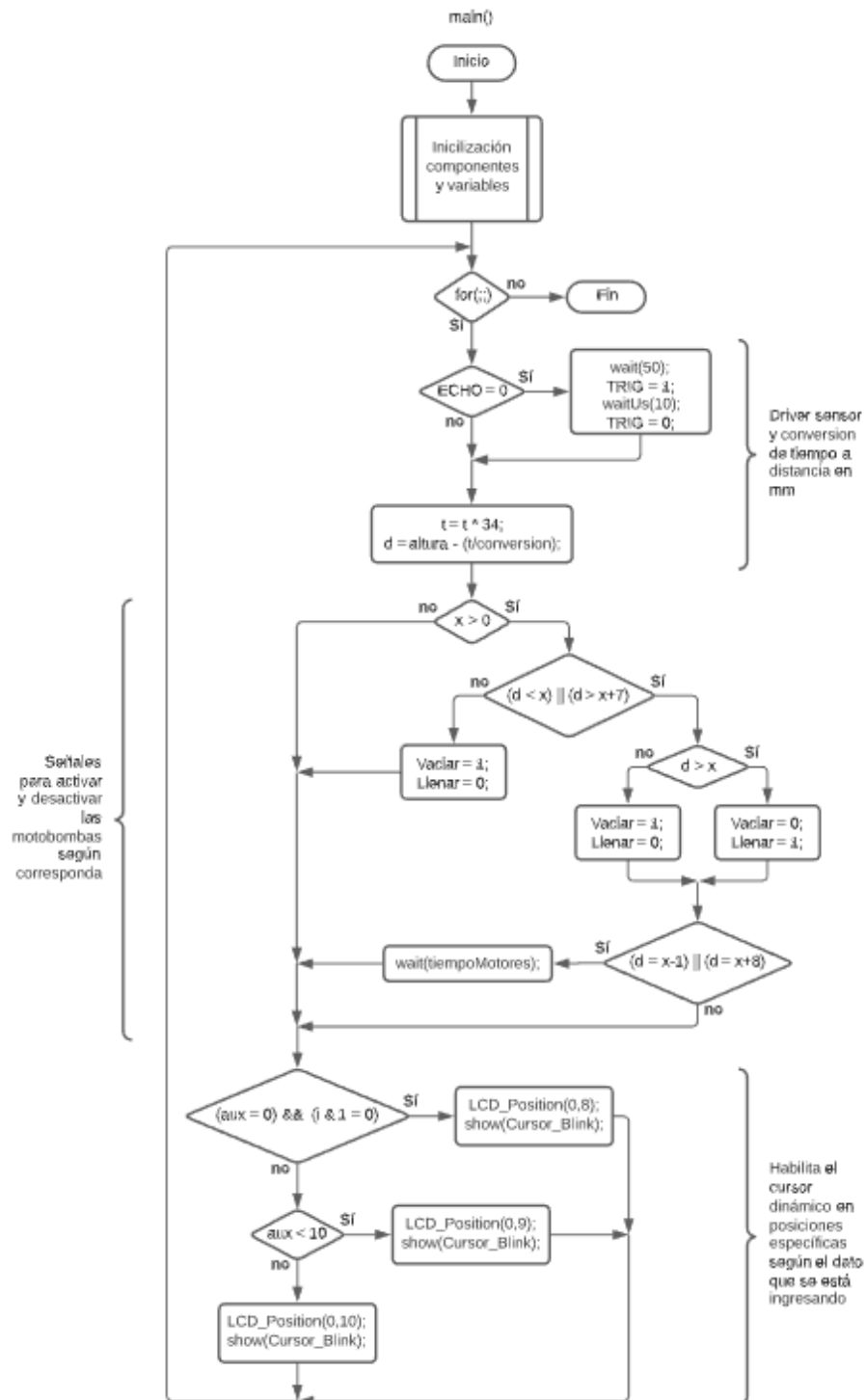
The LCD Character block with LCD name uses the following configuration: LCD Custom Character Set Horizontal Bargraph, Include ASCII to Number Conversion Routines selected.

The second and last block corresponds to a one bit Pins block, configured as input with the name Sensor with the following configuration: Number of pins 1, HW connection disabled, External terminal enabled and Drive mode with the Resistive pull up option selected. For the Input tab, the Rising edge option associated with the Interrupt function is selected, which will determine when the sensor changes state (the slot cuts the light beam).

For the selection of pins used in the PSoC5LP, the following choices are made: for the connection of the 4 bits of the data bus and LCD control, pin array P12[6:0] was used and for the optical sensor, pin P2.2 was used.

Finally, the algorithm implemented for this project is divided into two processes: the first one is in charge of detecting the pulse generated by the sensor each time it passes through a disk slot, the second process is performed in the main program where a time delay is generated to update the reading of the value counted in the first process.

The flowchart in Figure 6 presents the general algorithm with the solution proposed for the case study.



**Figure 6.** General flow diagram

The interruption routine named INT\_Sensor() is in charge of detecting the cut of the light beam of the sensor generated by the selected slotted disk updating a counter, the counting is done for three seconds, after this time the data generated by the counter is used in the main routine.

In the main program, after configuring the peripherals and initializing the counting variable used in the process, a waiting cycle of three seconds is generated, at the end of the cycle the interruption generated by the sensor is disabled to efficiently stop the counting, then the counting is adjusted by performing a multiplication x3 since the disk has 20 slots, thus generating the measurement in revolutions per minute,

the adjusted value is displayed as a number value finally it is adjusted to be displayed graphically using a horizontal bar, this bar uses each of the five columns that has a character of the LCD matrix, for a 2x16 character LCD the bar can represent up to 80 values (16 characters x 5 columns per character), so the adjustment is given by a division x 10 to take the maximum range of 800RPMs and represent it in each column of the LCD line where it is plotted as a value of approximately 10RPMs per column.

To plot the horizontal bar we use the API function associated with the LCD block called `LCD_DrawHorizontalBG(row,column,n_car,n_colum)`, this is responsible for drawing on the LCD one character, out of the five possible that represents a part of a horizontal bar. The function uses four input parameters: row corresponding to an 8-bit unsigned integer value, column corresponding to an 8-bit unsigned integer value, these two values represent the row-column location where you want to place the start of the horizontal bar, the next parameter (`n_car`) determines the maximum amount of characters used by the horizontal bar per row is an 8-bit unsigned integer value (typical value is the amount of characters per row), the last parameter (`n_colum`) determines the amount of columns-pixel drawn, this value should not exceed the maximum amount of characters per row 4 (Camargo & Perdomo, 2016).

#### 4. Results

Different tests were performed by modifying with the potentiometer the supply voltage of the D.C. motor, in all cases a commercial digital tachometer reference PM6208A manufactured by PEAKMeter was used to compare it with the measurement made by the implemented circuit.

Figure 7 shows a real image of the result obtained by executing the algorithm explained using the assembly shown in Figure 4. In this case the number 228 representing the measured speed of the motor is displayed graphically in 22 columns of the horizontal bar.



**Figure 7.** Result of running the algorithm that solves the problem posed

Table 2 shows the results obtained from the various levels selected for testing.

**Table 2.** Results obtained from motor speed measurement

Instrument measurement (RPM)	Measurement with circuit (PRM)	Error (%)
25	29	16
51	55	7.84
77	80	3.89
104	108	3.84
225	228	1.33
274	279	1.82
386	390	1.03
517	522	0.95
625	631	0.96
748	753	0.66

As can be seen, the accuracy of the system improves notably as the motor speed increases, presenting an error of much less than 2%.

## 5. Conclusions

The digital tachometer and all that this entails are obtained, each of the requirements is fulfilled and the operation of each component used is internalized, thus fulfilling the initial objective of showing in a didactic way the design and implementation of this type of digital systems.

Regarding the measurements obtained, a quite accurate system is obtained, which meets the requirements set out in the initial problem, because if the respective parallel between the measurements captured by the optical sensor and the real measurements is elaborated, errors ranging from 0.6% to 1.3% are obtained, for speeds greater than 200RPMs. For lower values, the increase in the measurement error is notorious, presenting an error that varies from 3.8% to 16%. However, this does not mean that the system is working incorrectly. These error values can be supported, among many other causes, to the temperature and the way of measurement; to irregularities in the disk, which could influence the data acquisition by the sensor.

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