Application Note AN2301

Tachometer using a Switched Reluctance Rotation Sensor

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Associated Project: Yes
Associated Part Family: CY8C24xxxA, CY8C27xxx, CY8C29xxx
PSoC Designer Version: 4.2 SP2
Associated Application Notes: AN2044, AN2099, AN2156, AN2249

Abstract

This Application Note describes a tachometer using a switched reluctance rotation sensor. Besides providing information about rotational speed, the tachometer separates the marker signal, which is intended to measure shaft absolute angle. The device can be used in vehicles to measure engine rotation speed and detect the top dead-center position of the crank/camshaft.

Introduction

Several types of sensors can be used to measure shaft rotational speed. Sensor types include mechanical, optical, magnetoresistive, and switched reluctance. Mechanical sensors have mechanical contacts and their operational life is limited to contact life. Optical sensors use light (visible or infrared) modulation by using a rotation disc with holes or slots. Optical sensors are widely used in applications where there is no dust or other components that can prevent light penetration. Magnetoresistive and switched reluctance sensors are intended for harsh environments including dust, dirt, and temperature transients. Magnetoresistive sensor operation is based on changing the sensor resistance in a magnetic field.

Switched reluctance sensors use reluctance modulation. It consists of a coil with a permanent magnet core (see Figure 1). The ferromagnetic material pinion is placed near the core. When the wheel rotates, the distance between the wheel cogs and the permanent magnet core changes and modulates the reluctance. This reluctance modulation causes the magnetic induction to change in the core.

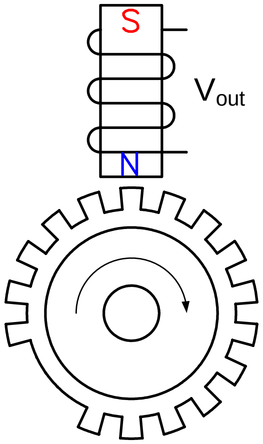


Figure 1. Switched Reluctance Rotation Sensor

The frequency of this signal is proportional to the number of wheel cogs that pass the sensor core within a period of time, or in other words, the wheel rotational speed. In addition to determining rotational speed, the sensor can be used to determine absolute angle positions. This is achieved by varying the distance between some of the wheels' cogs, as for example, by skipping several cogs in the wheel, forming a special marker.

The marker position can easily be detected by measuring and analyzing the time intervals between neighboring cogs that pass the sensor. This feature is useful in vehicle engines to find the top dead-center position of the crank/camshaft (see Figure 2).

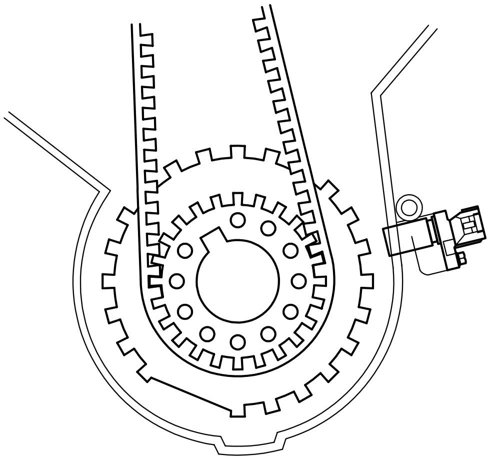


Figure 2. Switched Reluctance Sensor in Vehicle Engine

This Application Note demonstrates how to process switched reluctance sensors using a PSoC™ device to build a simple tachometer. The associated project measures the rotational speed in revolutions per minute (RPM) and transmits this data via a UART. Instead of a UART, the LIN bus protocol can be used for integration in vehicle networks. The marker signal is also separated and routed to an external pin. This signal can be used by the ignition system, for example.

Technical specifications for the device are given in Table 1.

Table 1. Tachometer Specifications

Item	Value
Input Signal Frequency	50 Hz – 10 kHz
Input Signal Level (Peak-to-Peak)	100 mV – 50V
Output Data	Rotation Speed, RPM, Marker Pass
Supply Value	3.3V – 5V

Tachometer Operation

Various techniques can be used to process the switched reluctance sensor signal. The induced voltage is proportional to the rate of change in the magnetic field and the sensor output voltage is proportional to the rotation speed. This results in the output voltage varying over a large range. For example, a vehicle engine can operate from 60 RPM at startup or idle to 6000 RPM at maximum speed.

This design uses an adjustable hysteresis comparator to process the sensor signal with the hysteresis comparator proportional to the input voltage level. This solution handles sensor signals in wide signal range and improves noise immunity. Vehicle electrical systems are an excellent noise source!

The tachometer block diagram is shown in Figure 3. The sensor is implemented by using a combination of hardware and software resources.

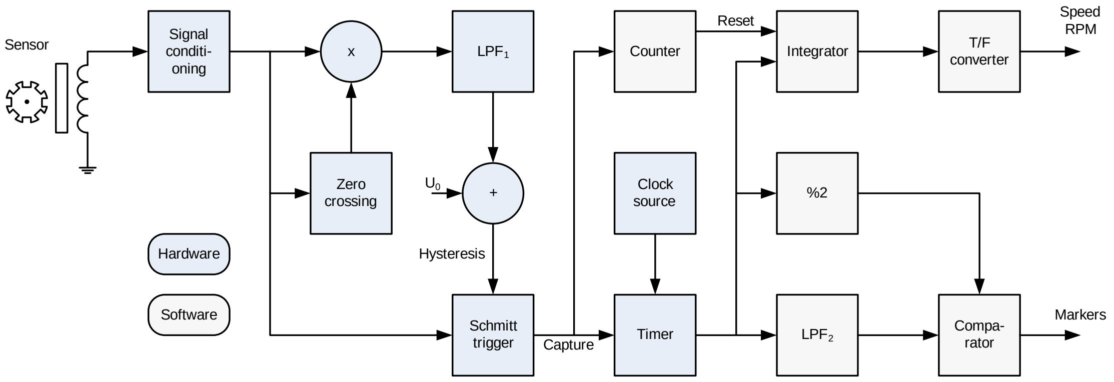


Figure 3. Device Block Diagram

The sensor signal passes through a signal-conditioning circuit, which protects the device inputs against transients and high-voltage spikes. The sensor signal is then passed through a Schmitt trigger signal input. The trigger output generates the capture signal for a timer, which is used to count the time interval between adjacent wheel cogs.

This project uses a programmable hysteresis comparator (Schmitt trigger), described in AN2156 “A Switched Capacitor Comparator with Programmable Hysteresis.” The advantage of this comparator is the flexible settings to vary the hysteresis input voltage or ACap value in the switching capacitor module.

To form the adjustable Schmitt trigger hysteresis, the sensor signal is synchronously rectified using a zero-crossing detector, together with the PSoC analog modulator. The rectified signal is filtered using the low pass filter (LPF). The filtered signal is summed with a constant voltage (to set the minimum hysteresis level in order to prevent false triggers when there is no rotation) and fed into the hysteresis input of a Schmitt trigger. Therefore, the Schmitt trigger hysteresis is proportional to the input signal level, providing a dynamically adjustable trigger threshold. One advantage of this solution is constant triggering angle, which allows a more precise dead-center position over a wide speed range. The second advantage is the suppression of ringing. The amplitude of the ringing is proportional to the sensor peak voltage, therefore a constant threshold comparator is not adequate. For these systems, additional blanking time can be provided by using the one-shot module described in AN2249 “PRS User Module as a One-Shot Pulse Width Discriminator and Debouncer.”

The interval timer capture events are handled in software to calculate the rotation speed (in RPM) and detect marker signals. Rotational speed measurement uses a resetable integrator. The time interval between a predefined number of cogs is calculated. This time is inversely proportional to the rotation speed, so scaling and conversion is implemented in software. Also, the no-rotation state is analyzed and detected using an additional PSoC sleep timer. This timer resets the integrator and internal state machine to prevent false readings when the next rotation cycle begins.

Marker detection is implemented by comparing each cog interval pass using a software threshold comparator. The comparator reference is set by using a first order IIR low pass filter (described in AN2099 “Single-Pole IIR Filters”) to estimate the average interval between neighboring cogs. The comparator increases its reference level when the measured voltage is greater than two times the filter average. This technique provides a flexible mechanism for various rotational speeds.

The Schematic

The complete device schematic is shown in Figure 4. Most analog and digital signal processing is implemented inside the PSoC, only a few external components are required.

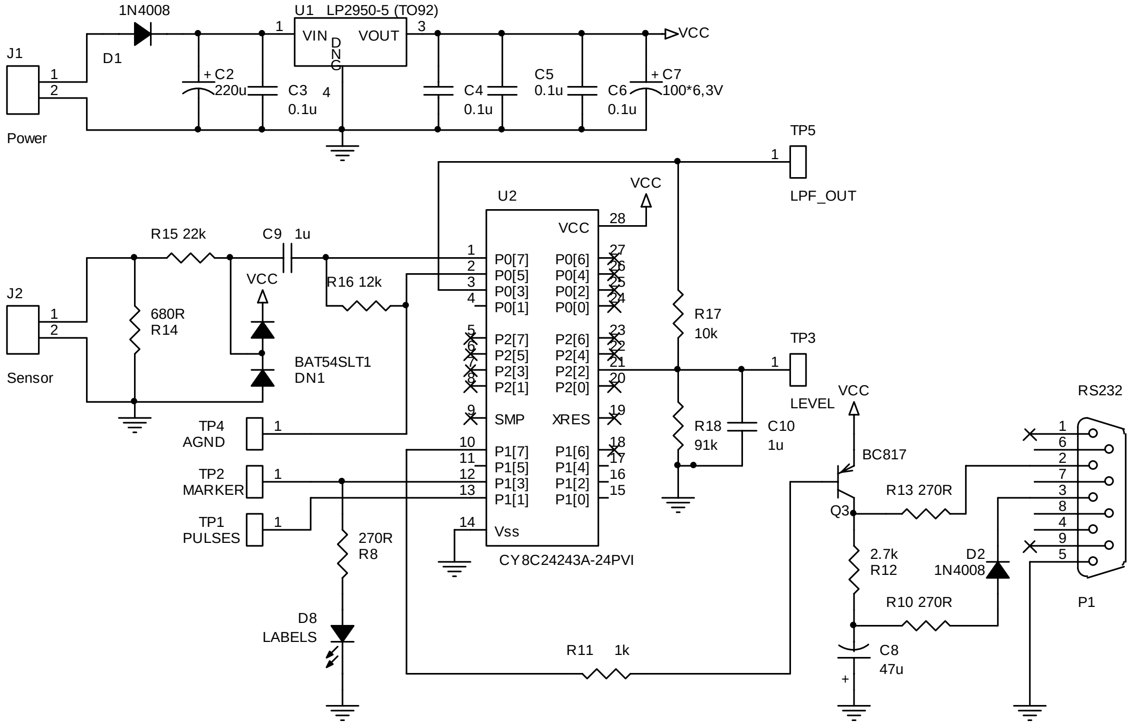


Figure 4. Device Schematic

The DN$_1$, voltage limiter, and C$_9$R$_{16}$, high pass filter, are intended for sensor signal centering around AGND. AGND is routed to TP$_4$. The synchronous rectifier LPF output is routed to TP$_5$ and via additional filter/bias network R$_{17}$R$_{18}$C$_{10}$ is routed to the hysteresis input of a Schmitt trigger. R$_{18}$ provides bias voltage to set the initial hysteresis comparator. Note that the voltage on the hysteresis input of a Schmitt trigger is relative to AGND.

The trigger output is routed to TP$_1$ for scope observation. The software interval threshold comparator output is routed to TP$_2$ to show the marker pass. The speed value in RPM is sent via a low-cost RS232 level translator, built around Q$_3$. The device can be powered from a 6-15-V DC supply. U$_1$ provides the stable 5V supply. Note that the R$_{14}$, R$_{16}$, and R$_{18}$ values can be adjusted to work with different inductive sensors.

PSoC Device's Internals

Digital and analog user module placement is shown in Figure 5.

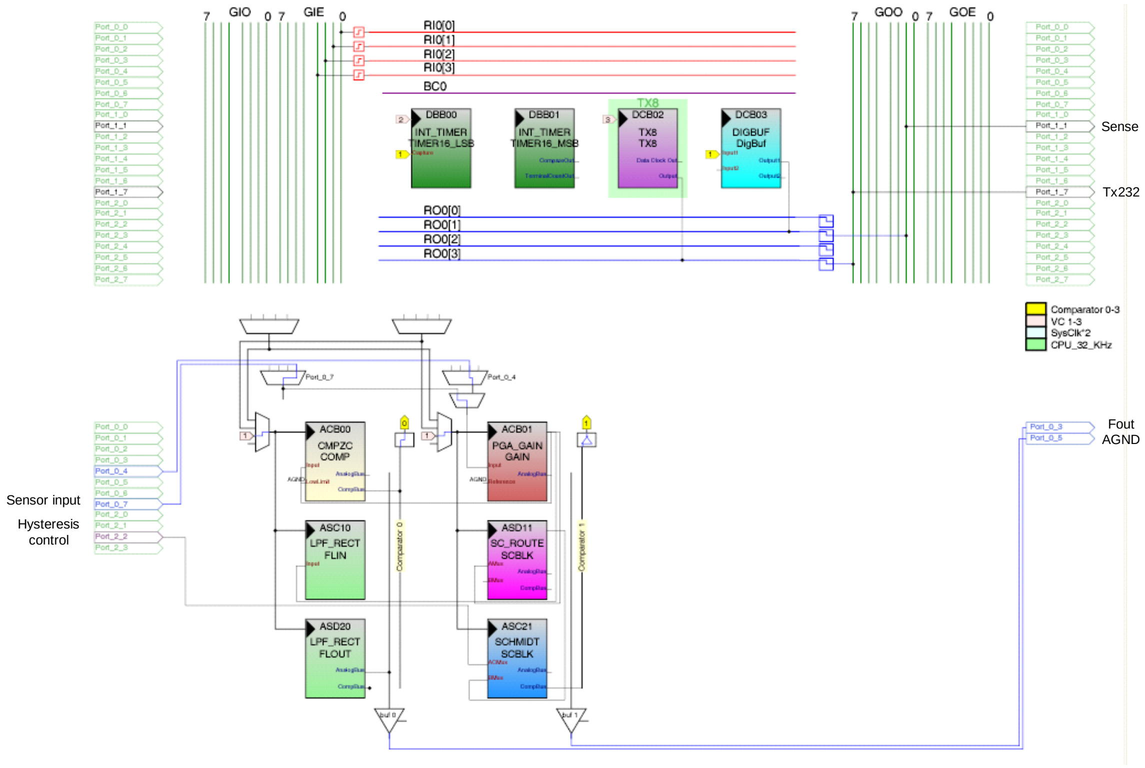


Figure 5. PSoC Internal User Module Configuration

The input sensor signal is buffered via a unity gain PGA, placed in ACB01. The buffered signal is rectified using the analog modulator of ASC10. The Schmitt trigger is placed in ASC21. The analog buffer in ASD11 is used to route the PGA output signal to the Schmitt trigger signal input. The hysteresis input is connected to port P2[2]. In some applications, the external filter is not required and the hysteresis input can be connected to the low pass filter output directly to ASD20.

The zero-crossing comparator to generate the synchronous rectifier reference signal is placed in ACB00. The comparator is reconfigured manually in code to connect one input to the PGA output and the second to AGND. AGND is routed to P0[5] using the column analog buffer and ACB01 test multiplexer, which is manually enabled in code.

The Schmitt trigger output is connected to Comparator Bus 1. This signal is routed to an external pin using the digital buffer in DCB03. This module is optional and can be omitted when the conditioned sensor pulse signal is not required. The 16-bit interval timer is placed in DBB00 and DBB01. The UART serial transmitter is placed in DCB02 with the VC3 source used as baud rate clock. The transmitter sends data at 19200 bps without parity (N81). End applications can use other interfaces including SPI, I2C, or LIN bus (porting to larger devices (CY8C27xxx family) might be required in some cases).

Prototype Testing

To investigate and debug project operation, a special testbench was been developed and implemented. The testbench consists of the DC brushed motor, flexible coupler, wheel with cogs, and switched reluctance sensor from a vehicle motor. The photograph in Figure 6 shows the prototype.

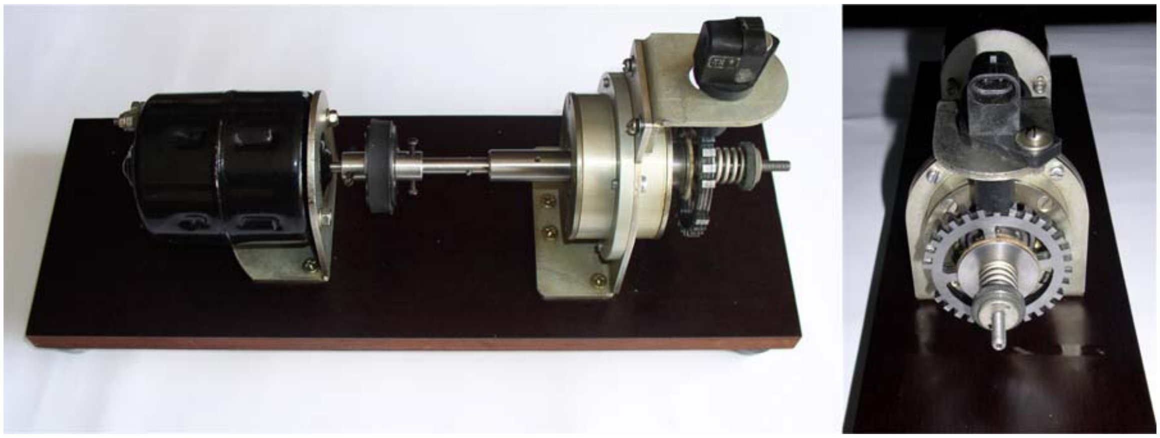


Figure 6. Testbench Photographs, Left – Complete Assembly, Right – Sensor and Wheel

Figure 7 shows the signals from the sensor after processed by PSoC.

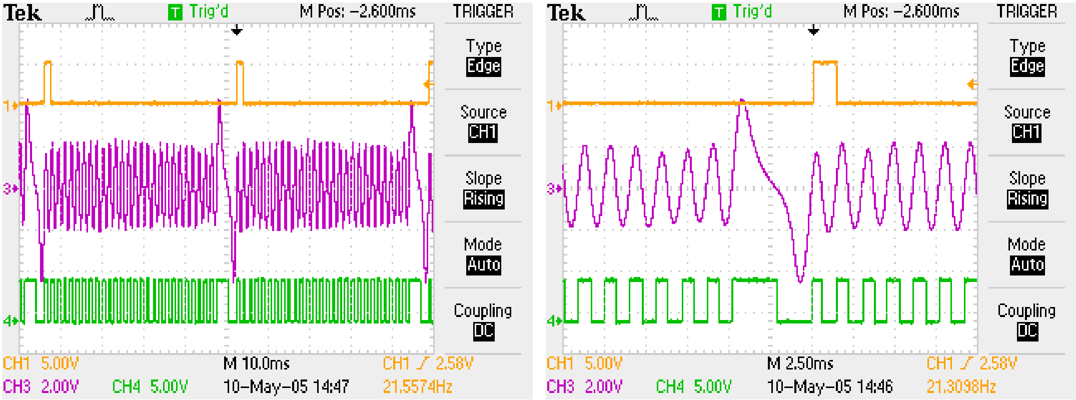
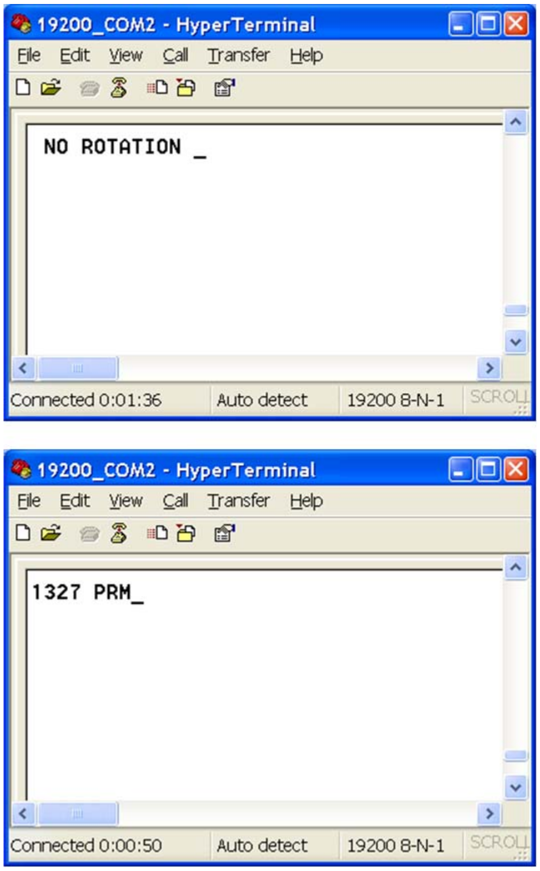


Figure 7. Test Setup Scope Images
Upper – Marker Signal, Middle – Analog Sensor Signal, Bottom – Schmitt Trigger Output

The measured speed data is sent to the PC using a Hyperterminal. The screen shots are shown in Figure 8.



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NO ROTATION _
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1327 PRM_
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Figure 8. Hyperterminal Screen Shoots

Conclusion

This Application Note demonstrates switched reluctance sensor signal processing with PSoC. The described technique can be used in various vehicle and industrial applications, for example, combined with a gauge driver in the vehicle tachometer.

About the Author

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Background: Victor earned his radiophysics diploma in 1996 from Ivan Franko National Lviv University, his PhD degree in Computer Aided Design systems in 2000, and is presently working as Associate Professor at National University "Lvivska Polytechnika" (Lviv, Ukraine). His interests involve the full cycle of embedded systems design including various processors, operation systems and target applications.
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