A New Rotational Speed Sensor Interface Circuit with Improved EMC Immunity

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Abstract: - This paper presents a new circuit concept for interfacing current feedback rotational speed sensors to a microcontroller digital input. The circuit meets the high EMC immunity requirements of automotive applications due to the adaptive voltage threshold generator circuit, threshold used as reference voltage for the output level shifting comparator circuit. Simulation and experimental results are provided to prove the circuit concept validity and performance.

Key-Words: - Hall sensor, Rotational speed sensor, Automotive applications;

1 Introduction

Today's modern cars are equipped with several driver assisting units creating a more comfortable and safe driving. Among of these electronic units are the ABS (Anti-lock Braking System), TCU (Transmission Control Unit), XCU (4 wheel drive Control Unit), ECU (Engine Control Unit), TCS (Traction Control System), ESP (Electronic Stability Program). These systems are connected to several external or internal sensors which provide continuous information's about the car parameters, driving conditions, inputs from the driver etc. One of the most important sensors for these systems is the position and speed sensors. This provides vital information's about position, rotating speed of different wheels/shafts in the car, based on which the electronic control units assist the driver.

There are several types of speed and position sensors where developed in the last years, mainly based on the following technologies: optical speed sensors, inductive speed sensors and magnetic (Hall effect) speed sensors;

The optical sensors are based a light sensitive unit (photodiode or phototransistor) which is masked from a light source (infrared LED) by a slotted disk [1]. The inductive speed sensors are based on a pick up coil exited by magnets placed on the rotating wheel [2]. The magnetic speed and position sensors based on Hall sensor technology are the highest performance speed sensor types [3], [4], [5].

2 Classical interface circuit

Today trend in wheel speed sensors is the usage of Hall effect based sensors which gives encodes the speed information in the supply current of the sensors itself. In this way the wiring connections to the sensor is minimized to two wires [4]. Fig.1. presents a connection example for these sensor types. The speed information's is encoded in current pulses in the sensor supply line, using of 7-14mA current levels. This current is feed to a shunt resistor at the receiver unit, which then compares the compares the voltage drop on the resistor with a reference voltage to detect the pulses. The Infineon TLE4953 series differential two-wire Hall Effect sensor IC (Integrated Circuit) using active target wheel generates a current pulse on its supply line each time a magnetic field transition occurs (see Fig.2.) [5]. In addition the sensor can sense the

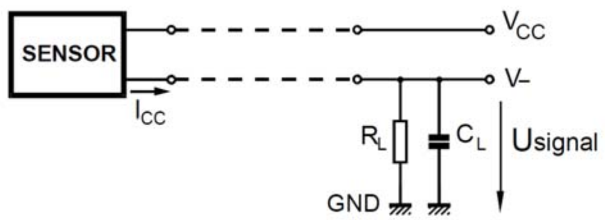

Fig. 1. Two wire speed sensor interconnecting diagram

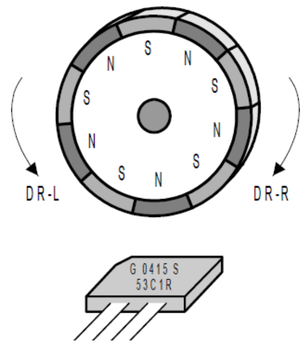

Fig. 2. Infineon speed sensor concept

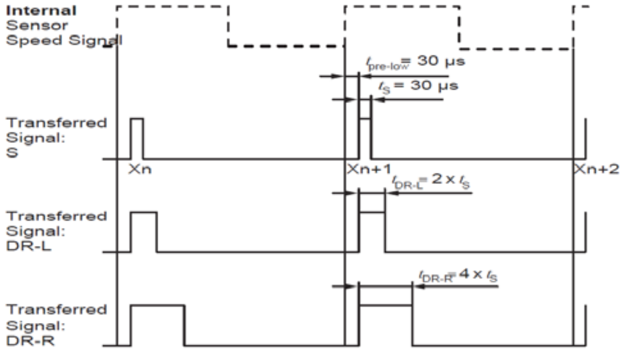

Fig. 3. Output signal and direction encoding

Table 1.
Typical speed sensor supply current limits

Parameter	Symbol	Limit Values			Unit
		min.	typ.	max.	
Supply current	I_{Low}	5.9	7	8.4	mA
Supply current	I_{High}	11.8	14	16.8	mA
Supply current ratio	I_{High}/I_{Low}	1.9	–	–	

rotation direction, encoded in the generated pulse duration (see Fig.3.).

In Table 1 are listed the supply current limits of this speed sensor types according to suppliers specifications [5].

The speed measurement itself is done by the system microcontroller, counting the number of pulses during a defined time unit or measuring the time interval between two consecutive pulses.

In order that the microcontroller to be able to count this pulses an interfacing circuit is necessary which converts the input current signal levels to TTL or CMOS logic levels interpretable by the microcontroller digital inputs. The basic circuit for this is using the voltage drop on the input shunt resistor feed to a voltage comparator input, having a threshold voltage in the middle of the input voltage scale. The optimum threshold voltage can be expressed as follows:

$$V_{TH} = \frac{(I_{LO} + I_{HI}) \cdot R_S}{2} \qquad (1)$$

Where:

- V_{TH} – optimal threshold voltage;
- I_{LO}, I_{HI} – current high and low levels;
- R_S – shunt resistor;

Fig.4. presents a typical application circuit example for the interface circuit between the speed sensor and the microcontroller digital input [4].

The voltage drop on the shunt resistor R_S filtered by Rf and Cf is feed into a voltage comparator which have its reference voltage given by the voltage divider formed with Rd1 and Rd2. Fig.5.

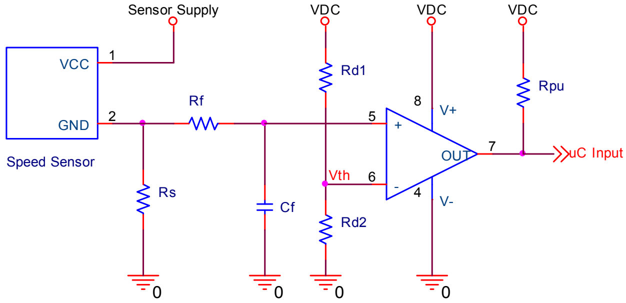

Fig. 4. Typical interface circuit example

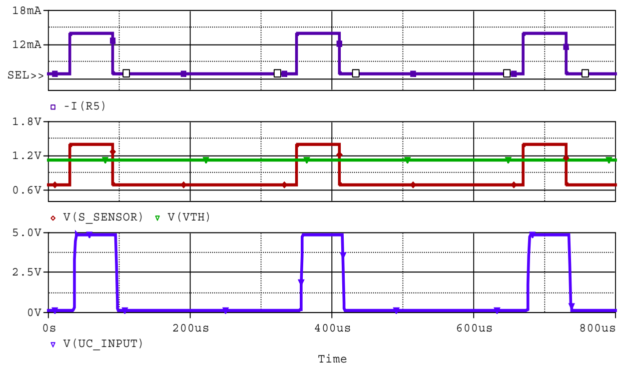

Fig. 5. Typical interface circuit behavior

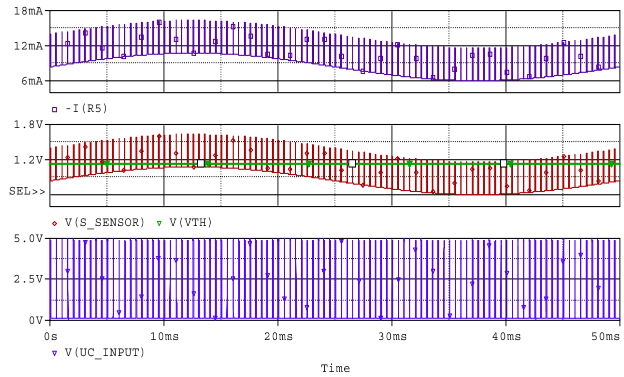

Fig. 6. Typical circuit behavior at sensor supply current limit ranges of a typical speed sensor.

presents the circuit behavior in typical conditions. Fig.6. presents the circuit behavior at sensor supply current limits of a typical speed sensor. It can be observed that at the sensor supply current limits the static threshold voltage V_{th} is very close to the drop voltage amplitude on the shunt resistance thus making it very sensitive to input signal noises.

For automotive application the EMC performance of these circuits is very important, especially because often these sensors are placed far away from the electronic control unit and the connecting wires can act as an antenna picking up a lot of perturbations.

From this EMC point of view the performance of the typical application circuit is quiet poor. To improve the immunity against EMC perturbations of the circuit the comparator is designed with hysteresis.

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The amount of hysteresis that can be applied is limited by the threshold voltage V_{th} accuracy, the shunt resistor accuracy and the I_{HI}, I_{LO} amplitude of the currents given by this sensor types.

The typical hysteresis than can be applied can be expressed as follows:

$$V_{hyst\_TYP} = (I_{HI} - I_{LO}) \cdot R_S \quad (2)$$

For example if we use a shunt resistor with a typical value of 100Ω, a threshold voltage for the comparator V_{th}=1,05V (resulted from equation (1) using limits from Table 1) and taking into account the speed sensor typical supply current limits presented in Fig.7., the maximum hysteresis than can be applied according to equation (2) will be: **V_{hyst_TYP} < 700mV**.

If we take into account the speed sensor supply current worst case limits, listed in Table 1, the hysteresis limits for the comparator according to equation (3) will be:
V_{hyst} < 340mV.

$$V_{hyst} = (I_{HI_{MIN}} - I_{LO_{MAX}}) \cdot R_S \quad (3)$$

Considering the other components tolerances of the interface circuit, like 1% precision for the shunt resistor and the threshold voltage divider resistors, 1% accuracy of the supply voltage (V_{DC} = 5V), using equations (4) the resulted worst case maximum hysteresis will be: **V_{hystWC} < 336,5mV**.

$$V_{hystWC} = (I_{HI_{MIN}} - I_{LO_{MAX}}) \cdot R_{S_{MIN}} - \Delta V_{th} \quad (4)$$

$$\Delta V_{th} = \frac{R_{d2MAX}}{R_{d2MAX} + R_{d1MIN}} \cdot V_{DC_{MAX}} - \frac{R_{d2MIN}}{R_{d2MIN} + R_{d1MAX}} \cdot V_{DC_{MIN}}$$

In case of a real automotive application even this resulted V_{hystWC} is not practical to use because the temperature and aging effect of the components is not taken into consideration. However these parameters depend on the chosen components quality and performances. Nevertheless out of the above calculations we can conclude that the main restriction for the comparator hysteresis and the input circuitry performance limitation is given by the speed sensor supply current limits itself.

3 Proposed interface circuit

The interface circuit comparator threshold voltage and hysteresis amplitude is mainly dependent on the speed sensor supply current limits as demonstrated in the last section. The worst case supply current limits given by the sensor suppliers are quiet large, however a minimum ration between I_{HI} and I_{LO} is guaranteed by the suppliers. This means that if the I_{LO} limit goes to higher values also I_{HI} goes to higher values to keep the minimum I_{HI}/I_{LO} ratio of 1,9 (listed in Table 1.). The circuit proposed in this paper is based on this supply current ratio, setting the voltage comparator threshold voltage dynamically according to the actual I_{LO} current value. Fig.7. presents the block diagram of the proposed circuit.

In addition to the classical method this circuit contains a minimum value detector block which maintains the input signal minimum value. To this minimum value a reference voltage is added. The typical reference voltage required can be expressed with the following formula:

$$Vref_{TYP} = \frac{(I_{HI} - I_{LO}) \cdot R_S}{2} \quad (5)$$

Taking into consideration the worst case supply current limits of the speed sensor, which should be used in the implemented application circuit, the equation will be:

$$Vref = \frac{(I_{HI_{MIN}} - I_{LO_{MIN}}) \cdot R_S}{2} \quad (6)$$

The amount of hysteresis for this new concept circuit than can be applied to the comparator in order to increase the EMC immunity of the interface circuit can be expressed as follows:

$$V_{hyst\_enh} = (I_{HI_{MIN}} - I_{LO_{MIN}}) \cdot R_S \quad (7)$$

Considering the conditions within the example from the last chapter the amount of hysteresis according to equation (7) will be: **V_{hyst_enh} = 590mV**. Comparing to the maximum applicable hysteresis of the classical interface circuit (**V_{hyst} = 340mV**) with this concept the resulted maximum applicable hysteresis can be higher with 250mV.

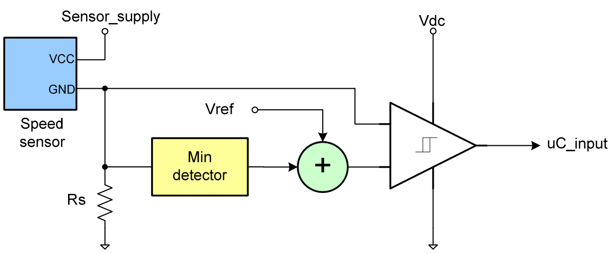


Fig. 7. Proposed circuit block diagram

The second advantage of this concept is that the comparator threshold voltage never gets too close to the input voltage limits. Compared with the behavior of the typical circuit presented in Fig.6., the threshold voltage of the proposed circuit is always a least with a Vref (=295mV worst case) voltage difference from the input voltage levels.

4 Simulation and experimental results

To validate the proposed concept the circuit was designed, simulated than built up for experimental evaluation. The following sections present the simulation and experimental measurement results.

For the simulations and experimental laboratory measurements as input parameters the Infineon speed sensor TLE4953 series supply current limits were applied.

4.1 Simulation results

The simulation of the circuit was performed using OrCad PSpice V16.0.

The evaluation of the proposed concept was done using the circuit presented in Fig.8.

The speed sensor GND pin is connected to the S_SENSOR signal which is connected to the shunt resistor R5. The minimum voltage detector circuit is formed with U1A operational amplifier and the surrounding components. The voltage comparator with the hysteresis is formed with U1B operation amplifier and the surrounding components. The Minimum detector circuit provides the adaptive threshold voltage at C4 terminal (Vth net).

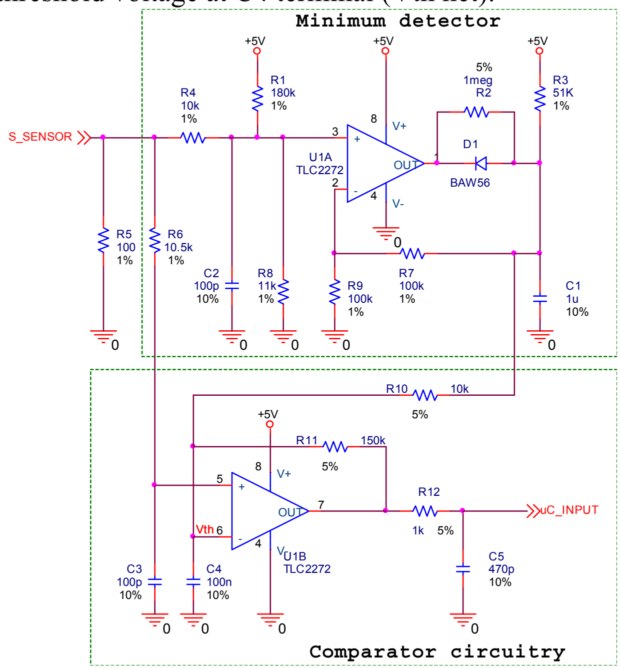
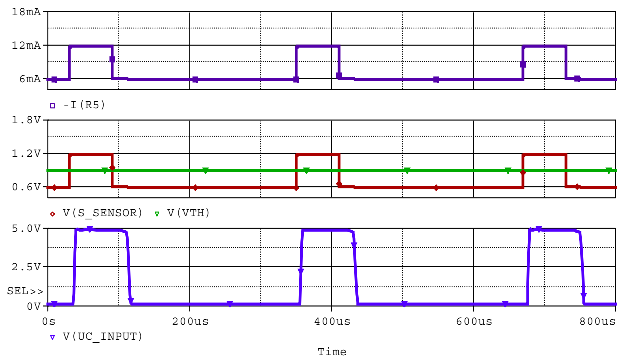
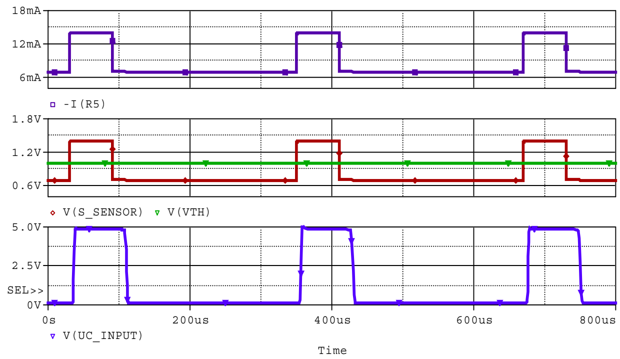


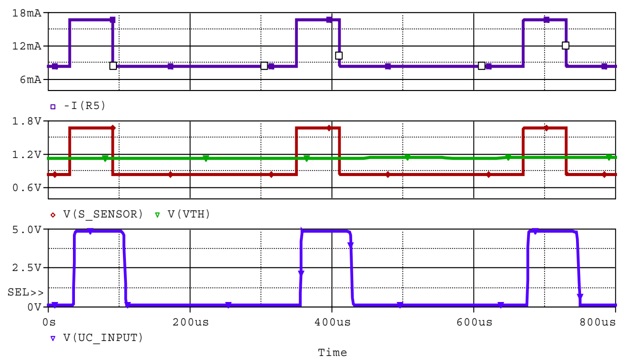
Fig. 8. Proposed interface circuit schematic



(a) I_{LO} = 5,9mA; I_{HI} = 11,8mA; Vth = 882mV



(b) I_{LO} = 7mA; I_{HI} = 14mA; Vth = 994mV



(c) I_{LO} = 8,4mA; I_{HI} = 16,8mA; Vth = 1,135V

Fig. 9. Sensor supply current limit simulation results

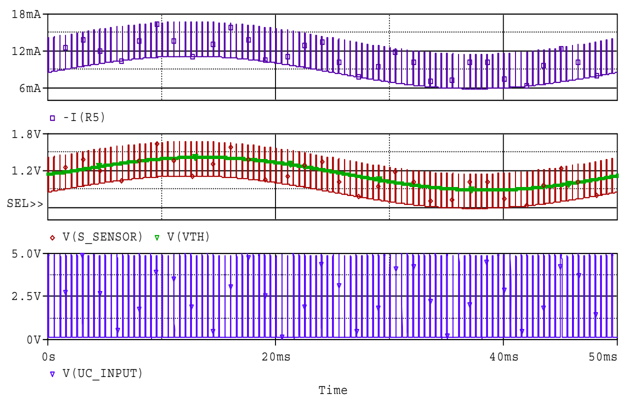


Fig.10. Proposed circuit threshold adapting behavior simulation

Fig.9. presents the simulation results for the different supply current limits of the speed sensor as follows:

(a) – simulation at minimum supply current limits;

(b) – simulation for typical supply currents;

(c) – simulation at maximum supply current limits;

To simulate the speed sensor supply current limits change over temperature and lifetime, under worst case conditions according to the sensor supplier datasheet and the dynamic threshold behavior a sinusoidal offset current is added to the signal generated by the speed sensor with 20Hz frequency. The simulation result is presented in Fig.10.

4.2 Experimental evaluation results

In Fig.11. are presented the measurement results for different speed sensor supply current limits. For the measurements the Infineon TLE4953 speed sensor current limits where applied at the circuit input, supplied from a programmable signal generator.

The measurement results show similar results with the simulations, proving the concept validity and good performance.

5 Conclusions

In the paper a new interface circuit was presented for current feedback rotational speed sensors with improved EMC immunity due to the self adaptive comparator threshold voltage.

This threshold voltage is automatically changing with the change of the sensor supply parameters over initial tolerance, temperature and aging, in order to obtain good performances and high immunity against EMC perturbations.

The validity of the concept was proven by PSpice simulations and practical laboratory evaluations.

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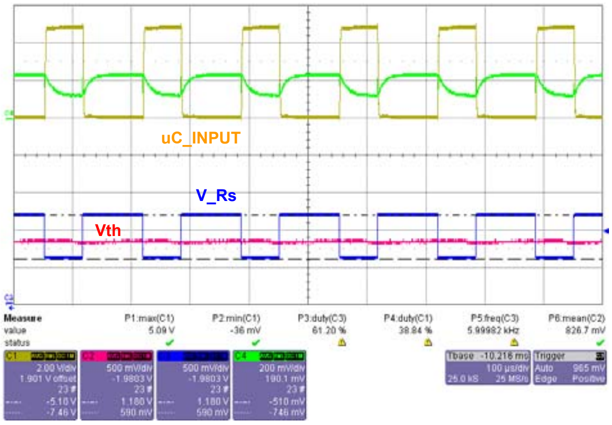
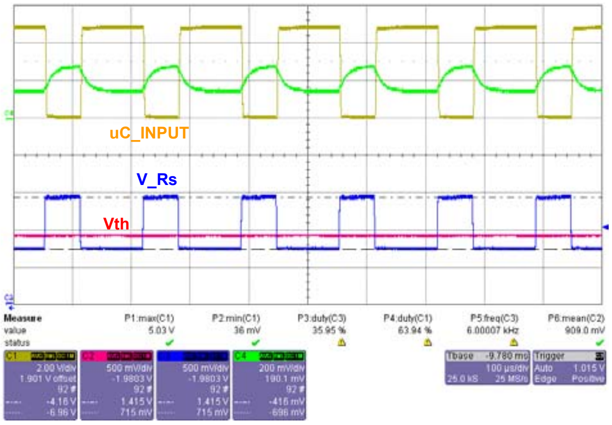
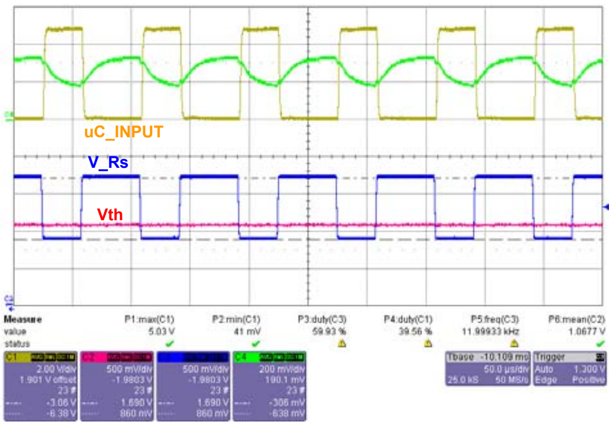


(a) I_{LO} = 5,9mA; I_{HI} = 11,8mA; Vth = 826mV



(b) I_{LO} = 7mA; I_{HI} = 14mA; Vth = 910mV



(c) I_{LO} = 8,4mA; I_{HI} = 16,8mA; Vth = 1,068V

Fig. 11. Sensor supply current limit measurement results
Note: CH1 is in inverted mode.

References:

[1] Kenneth W. Padgitt, Rotational Speed Sensor, *US Patent* 3,725,668, Apr. 1973

[2] Nicola V. Kirianaki, Sergey Y. Yurish, High Precision, Wide Speed Range Rotation Sensing with UFDC-1, *Sensors & Transducers (S&T e-Digest)* Vol.59, Issue 9, pp. 426-431, Sept 2005

[3] C.P.O Treutler, Robert Bosch Gmbh, *Magnetic sensors for automotive applications*, Elsevier, Sensors and Actuators A 91 (2001) 2-6

[4] Philips Semiconductors, *Rotational Speed Sensors,* Application note AN98097, 1999

[5] Infineon Technologies, *Differential Two-Wire Hall Effect Sensor IC,* Component datasheet TLE4953, Feb. 2008