A New Generation of Hall Sensors Including Delta-Sigma Modulators

80% of all current measurements within motor control are done with a shunt resistor. The voltage drop across the shunt is converted to a digital signal with a delta-sigma modulator. Hall sensors are mainly used in high current applications, where the power consumption inside the shunt resistor is getting too big. To generate the lowest overhead in development, the shunt and hall module should just be exchangeable. Therefore, the hall sensor should provide a bit-stream output of a delta-sigma modulator by maintaining low noise at a low price. The delta-sigma modulator ADS1208 from TI makes this possible.

In motor control, up to 10 signals need to be monitored. Therefore, it is most important to keep the costs for the sensors and their analog-to-digital conversion low. The cheapest method to measure currents is adding a resistor (shunt) into the current path and to measure the voltage drop across the resistor. A delta-sigma modulator is used to convert this voltage drop into a bit-stream. There are several reasons to use modulators instead of conventional analog-to-digital converters (ADC).

First of all, the voltage drop needs to remain as small as possible (typically +/-250mV) to minimize the power loss (P=I*V) in the shunt and delta-sigma modulators are very robust in respect to noise and offset. Even such low voltages can be converted to high resolutions. Also, the shunt and the modulator are often at a floating potential, so that the digital output (bit-stream) of the modulator must be galvanically isolated. The bit-stream is a two wire interface, a data and a clock signal, and only one wire if Manchester encoding is used. Therefore, its isolation is most cost effective. Finally, the bit-stream needs to be decimated with a digital filter to receive a higher resolution output at a lower data rate. The filter structure can be adjusted to the applications needs in respect of resolution and speed. It can include over-current protection or a pure integrator to receive the integral of the current that was applied to the motor during one cycle of the control loop. The filter is usually implemented inside a FPGA or an ASIC. To make the use of modulators easier, TI is currently developing a flexible filter structure (AMC1204).
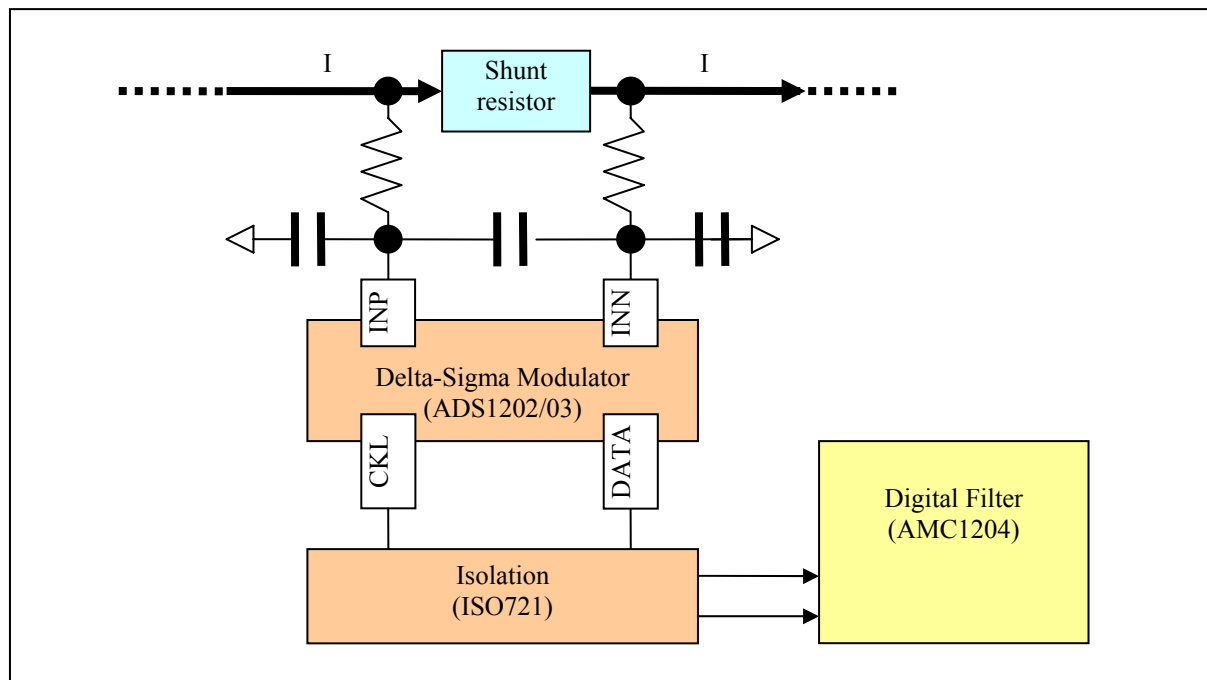

Figure 1: Current Measurement using the ADS1202 or ADS1203 type modulators

Unfortunately, the shunt measurement is not usable in all applications. The power loss (P=I*V) inside the shunt, will heat up the resistor and cause a drift of its value causing gain and linearity errors. Therefore, the hall sensor is mostly used in high current applications.

Figure 2 shows a typical solution for the electronics inside a hall sensor. A current source, which can be implemented with a reference voltage and an operational amplifier, is used to apply a DC current to the hall element. An external magnetic field is generating a hall voltage V_H, which is in the range of +/-100mV. This voltage needs to be corrected in offset, gained up and shifted to a common mode voltage, so that the output fits to a standard voltage range (for example a bipolar input range of +/-2.5V around common mode voltage of 2.5V: 2.5V+/-2.5V). The user can now add a delta-sigma modulator in his application (ADS1204 from TI) to transfer the output of the sensor into a bit-stream that interfaces to the digital filter of the shunt solution.
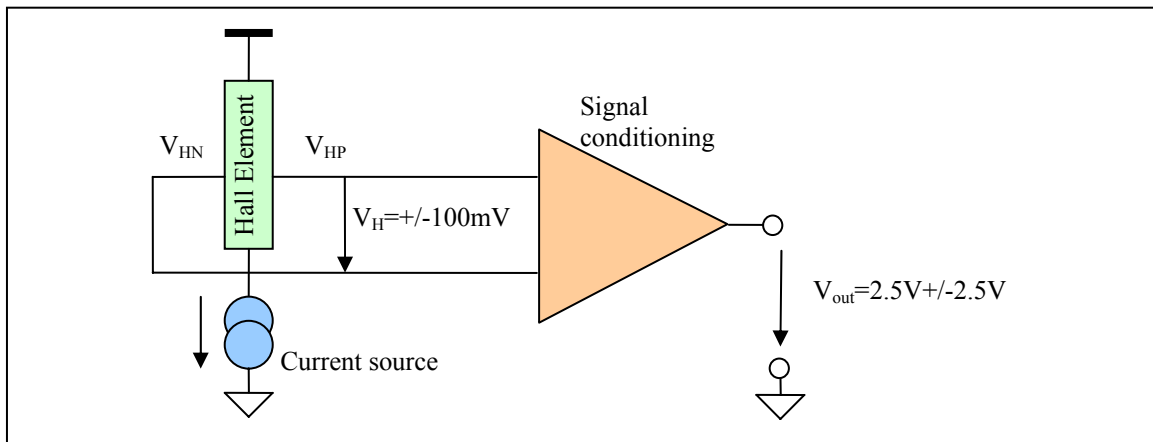
Figure 2: Possible electronic circuit of a hall sensor

All these necessary components of the hall sensor add up in price. While a shunt solution can be implemented with approximately $3-4, the hall solution would cost around $6-7 (including the modulator). The new modulator ADS1208 is optimized to reduce the count of components and therefore the costs by improving the performance.

The ADS1208 has the current source already included, which is sourced out of the pin I_OUT (see figure 3). The voltage between the supply pin AVDD and the I_ADJ pin is internally regulated to the voltage at the REFOUT pin divided by 5 (equals 0.5V). The current is defined to this voltage divided by the resistor value of R_1. Therefore in the application, the current can be adjusted to a required value:

$$I_{out} = \frac{v_{refout}(T)}{5 * R_1(T)}$$

This current at I_OUT is applied to the Hall element. The resistor R_1 can also be chosen to have a certain temperature characteristic to compensate drifts of the hall element itself, which are expressed with a(T) in equation (1). The actual Hall voltage (V_{HP}-V_{HN}) is directly proportional to the applied current and to the magnetic field that should be sensed:

$$V_H = V_{HP} - V_{HN} = B * \frac{x * v_{refout}(T)}{R_1(T)} * a(T) \qquad (1)$$

Finally, the hall voltage is converted into a digital bit stream with a delta-sigma modulator that is included inside the ADS1208. The analog input range of the ADS1208 is adjusted to the typical output voltage of a hall element (+/-125mVwith REFIN=2.5V). Gaining up the input signal with internal or external amplifiers would cause additional noise. Especially the common mode noise, which is very essential in motor control

systems, could affect the signal. Delta-sigma modulators have the ability to convert low voltage inputs with high accuracy and low noise. Therefore, the ADS1208 can achieve above 80dB in SNR with no missing codes.
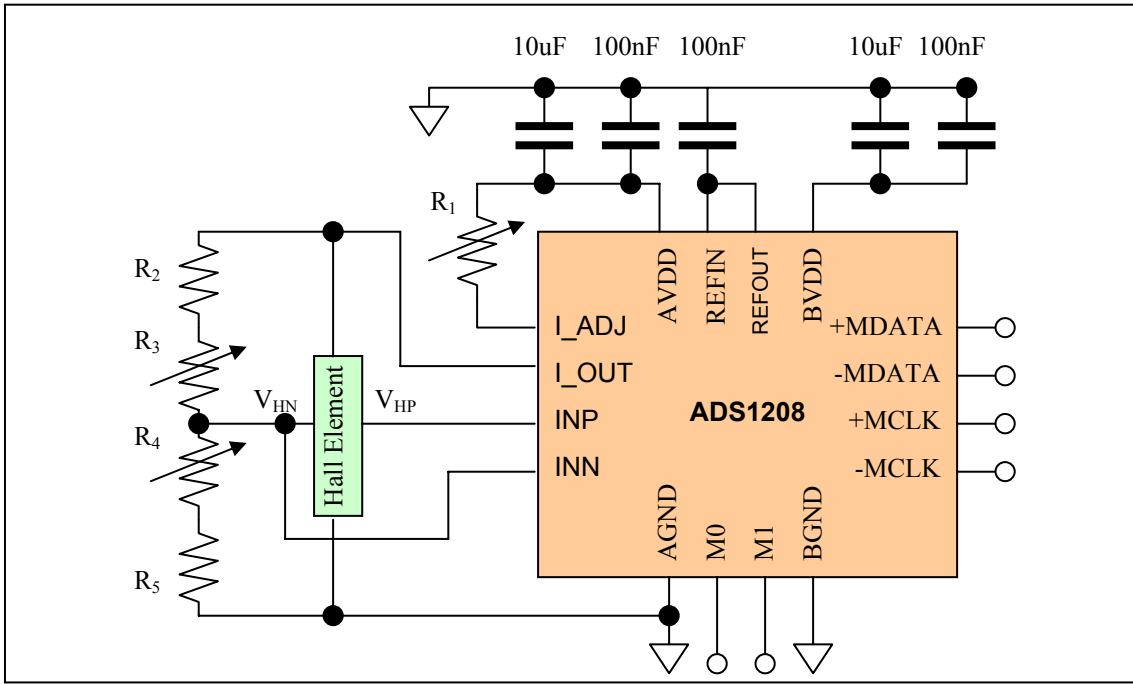
Figure 3: Hall module using the ADS1208

The input voltage range of the delta-sigma modulator is proportional to the voltage at the pin REFIN, which is normally shorted to REFOUT. The bit-stream output of the ADS1208 needs to be filtered with an external digital low pass filter to receive a low noise, higher resolution digital output word, which is here called F_{data}. The value of F_{data} is proportional to the input voltage divided by the voltage v_{refin}.

$$F_{DATA} = y * \frac{v_{INP} - v_{INN}}{v_{refin}} = y * \frac{v_{INP} - v_{INN}}{v_{refout}} \qquad (2)$$

With the hall sensor being directly connected to the modulators input, 'v_{inp}-v_{inn}' is equal to V_H in formula (1). Therefore:

$$F_{DATA} = \frac{y}{v_{refout}(T)} * \frac{B * x * V_{refout}(T)}{R_1(T)} * a(T) = B * \frac{y * x * a(T)}{R_1(T)} \qquad (3)$$

Formula (3) shows that the reference drift is canceled out ($V_{refout}(T)$). In case that the Hall element itself has also a temperature drift a(t), a combination of resistor and thermistor can be chosen for $R_1(T)$ to cancel out that temperature dependency.

The absolute accuracy of modulators is usually described with the (integral) linearity, the offset and the gain. While the non-linearity is usually in the range of 0.01-0.02% of the full-scale range (%FSR) and the offset around 0.15-0.3%FSR, the gain error is much higher (1-3%FSR). Also the drift of the gain error is very significant (typically 0.4%FSR, -40°C to 85°C).

The above equations show that the ADS1208 is increasing the system performance by reducing the gain error (trimming R1) and the gain error drift (cancellation of the reference drift, compensation of the hall element's drift with a thermistor for R1). In addition, the offset can be calibrated at room temperature by trimming the resistors R_3 and R_4.

A sigma delta modulator is usually implemented in a switched capacitor design. These designs are pre-charging an input capacitor C_{samp} (also called sampling capacitor) to the input voltage, disconnect the input from the capacitor and are then processing the charge to further capacitors with the help of operational amplifiers. The sampling capacitor is then discharged and reconnected to the input. This cycle is repeated with every system clock (the ADS1208 has an internal clock generator, but can also run with an external clock).

$$C_{samp} = \frac{\Delta Q}{\Delta V} = \frac{I_{in} * \Delta t}{\Delta V} \qquad (4)$$

Formula (4) takes into account that recharging the input capacitor with every clock cycle (cycle time $\Delta t = 1/f_{clk}$) from 0V to the input voltage (=$\Delta V = v_{in} - 0V$) will require an average current I_{in}. In other words, the equivalent input impedance of the modulator is:

$$R_{in} = \frac{V_{in}}{I_{in}} = \frac{1}{f_{clk} * C_{samp}}$$

The high output impedance R_H (several kOhms) of hall sensors has two effects. First, the output impedance of the hall sensor and the equivalent input resistance from the modulator form a voltage divider $R_H/(R_H * R_{in})$ causing an essential gain error that can drift with frequency and temperature. Furthermore, the bandwidth that is formed by the output impedance of the hall element and the input capacitor of the modulator is limited, so that the capacitor cannot be fully recharged within the sampling time (typically one half of a clock cycle). This generates a significant non-linearity.

To overcome these problems and to make the above gain adjustment effective, operational amplifiers are added to the inputs inside the ADS1208. These amplifiers work in a unity gain configuration to avoid common mode effects. They are also calibrated in offset to keep the offset specification tight (including drift).

Contact you local Texas Instrument's sales office or go to www.ti.com for more information.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DSP	dsp.ti.com	Broadband	www.ti.com/broadband
Interface	interface.ti.com	Digital Control	www.ti.com/digitalcontrol
Logic	logic.ti.com	Military	www.ti.com/military
Power Mgmt	power.ti.com	Optical Networking	www.ti.com/opticalnetwork
Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
		Telephony	www.ti.com/telephony
		Video & Imaging	www.ti.com/video
		Wireless	www.ti.com/wireless

Mailing Address: Texas Instruments
                               Post Office Box 655303 Dallas, Texas 75265