TMR vs. Shunt Sensors: How the Tables Have Turned

Supply Chain and Accuracy Concerns Make TMR the Safe Bet

There was a time shunt solutions were considered the safe choice in sensor technology. But the world has changed. The days of trying to piece together inexpensive shunt architectures is over. As accuracy requirements continue to increase, traditional shunt solutions lose cost-effectiveness, as total solution costs increase dramatically.

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The Snag with Shunt

In addition, shunt designers are routinely faced with a balancing act to select the correct combination of resistor, operational amplifier, and implementation topology. Designing an accurate and cost-effective shunt based current sensing solution requires a substantial engineering effort.

For instance, using a shunt-resistor in high voltage systems for measuring high-side current requires an isolated op-amp which complicates and increases cost. On the other hand, the Crocus XtremeSense™ TMR architecture simplifies the circuit design while providing built-in galvanic isolation. Its construction provides inherent isolation, because the active circuitry on the die does not electrically connect outside of the molded package.

Another concern with shunt is the supply chain, which is driving new ways to meet current sense requirements. Supply chain issues mean a complicated architecture like shunt incurs significant risk. As an example, many of the zero-drift amplifiers needed for the shunt solution now take a year to acquire. Whereas, Crocus XtremeSense™ TMR architecture – with significantly fewer parts – takes about 12 weeks. Simply put, more parts = more things to go wrong = more reliance on the supply chain = more risk. With Crocus XtremeSense™, with reduced component count and a simpler supply chain response, delivers a safer solution.

Besides less risk, proven tunnel magneto resistive technology also delivers higher sensitivity, accuracy, and inherent galvanic isolation when compared to shunt resistors. The Crocus XtremeSense™ CT45x, for example, allows manufacturers to eliminate costly shields, concentrators or magnetic cores. The CT452 and CT453 offers contactless 0.7% accuracy, 1 MHz bandwidth, and better than -50 dB immunity to external magnetic fields without additional mechanical components. This combination of performance and accuracy enables customers to reduce their overall Bill-of-Materials (BOM), product size and weight which enables them to replace large and costly current sense modules with a small and simple solution.

TMR vs. Shunt

In shunt-based sensing, a small-value shunt resistor (typically less than one Ohm) is placed in series with the load. Per Ohm's Law, a small voltage on two sides of the shunt is proportional to the current draw of the load. As the max current increases, the shunt resistive value must decrease to minimize the excessive power losses due to heat dissipation and temperature rise.

The small voltage needs to be amplified in many cases to provide enough resolution, SNR and accuracy (Figure 1.) However, low-price shunt sensors suffer from power dissipation, error over temperature due to TCR and low output range. Hence, a good resistor and an isolated zero-drift amplifier will no longer be the most cost-effective, nor simplest solution.

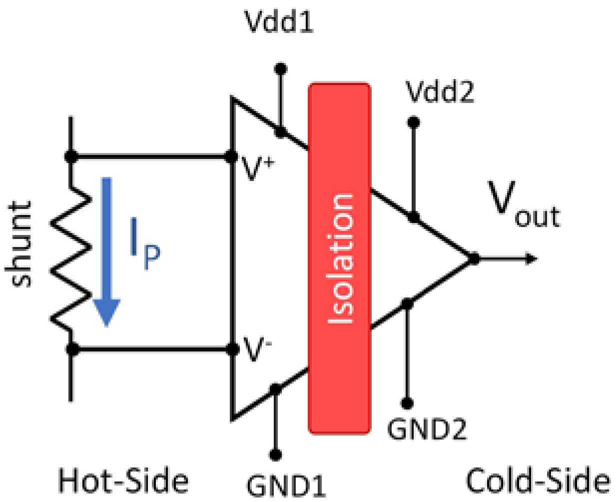


Figure 1: An isolated shunt amplifier

Head-to-head in high performance applications, Shunt performs well in some categories (bandwidth), and poorly in others (noise), while Crocus' CT430 performs well across the board. (Figure 2.)

	Shunt Based Current Sensors	CT430
Total FS Error	±0.5%-5%	±0.5%-1%
Temperature FS Error	±0.21% - ±1.19%	±0.5%
Non-Linearity FS error	±0.03% - ±0.3%	0.1%
Offset Error	0.06A-2.3A	0.083A
THD	-34 to -50dB	-46dB
SNR	14–31dB	31dB
Application Noise StdDev	2.6 – 16.3	2.53
CMRR FS Error	0.02% to ± 2.5%	N/A
Bandwidth	50kHz-1.7MHz	1MHz

Figure 2: CT430 TMR vs. Shunt

In addition to superior performance, Crocus XtremeSense™ TMR also features a drastically simpler architecture in isolated applications compared to shunt-based systems (Figure 3.)

Design Considerations

Historically, Hall effect sensing has been considered an alternative to shunt, but due to inferior temperature performance, linearity errors and offset errors, it was not a viable alternative.

Here's how they stack up:

Magnetic - Hall Effect

Operation relies on the Hall effect, shown in Figure 4(a) where current (I) flowing through a conductor in the presence of an applied magnetic field (B) generates a transverse Hall voltage (UH) that is a function of the current, the magnetic field, the thickness of the conductor and the charge carrier density.

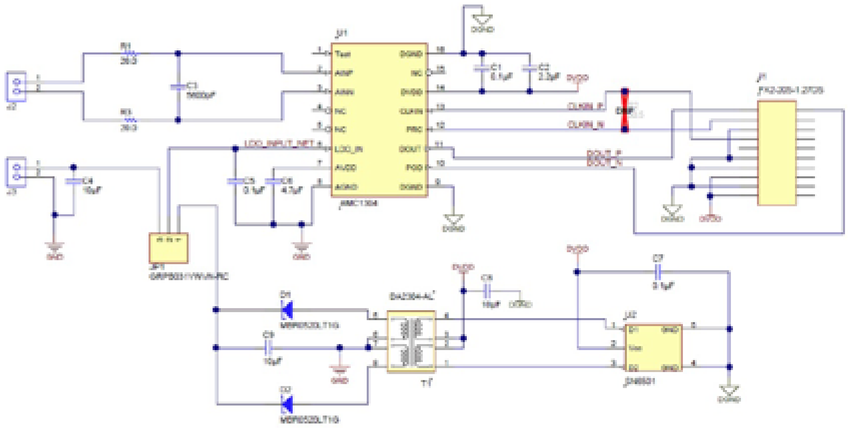
Figure 5 shows a typical EV or HEV arrangement where the shunt is placed in the battery return path. The shunt resistor is part of a module that also includes a battery management IC to measure the voltage across the shunt and communicates with the vehicle network over the industry-standard CAN bus. Note that the current flow can be positive or negative.

The resistance of an "ideal" shunt resistor does not change with time, current or operating temperature; this is not true for a real-world device. For example, any resistor dissipates power according to the equation P = I2R. As I increases, so too does the temperature. In a real component, a change in temperature causes a change in the value of R, characterized in a resistor data sheet as the temperature coefficient of resistance (TCR). Additionally, component aging causes the resistance to change over time, and a real-world device also exhibits parasitic inductance and capacitance. At low currents, error may occur due to thermal electromotive force (EMF) — a voltage in the microvolt (µV) range caused by temperature variations across the shunt resistor.

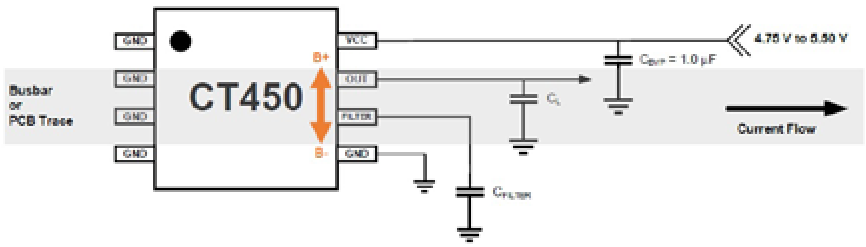
Hall effect versus shunt resistor

Hall effect sensors can measure both DC and AC current, have inherent galvanic insulation, low power loss and thermal decoupling from the power electronics, yet their historic weaknesses: low bandwidth; output drift and non-linearity over temperature; and self-heating at high currents that leads to a low overcurrent capability. The magnetic core exhibits hysteresis, and saturation leads to non-ideal offset and linearity characteristics. Additionally, the core contributes to a comparatively large size and weight.

On the other hand, a shunt-resistor system can feature high bandwidth, good performance under overcurrent conditions. They also can measure both AC and DC currents. Since there's no magnetic core, they are lightweight, saturation and hysteresis do not occur, and it's less prone to noise in the signal caused by EMI. A shunt-based system has more robustness to vibration in applications such as electric vehicles.



Item	Quantity	Designator	Description	Manufacturer	PartNumber
1	1	!PCB1	Printed Circuit Board	Any	AMC1304EVM - TIPD
2	3	C1, C5, C7	CAP, CERM, 0.1uF, 25V, +/-5%, C0G/NP0, 1206	TDK	C3216C0G1E104J
3	1	C2	CAP, CERM, 2.2uF, 16V, +/-10%, X7R, 0805	Taiyo Yuden	EMK212B7225KG-T
4	1	C3	CAP, CERM, 5600pF, 25V, +/-5%, C0G/NP0, 0805	TDK	C2012C0G1E562J
5	3	C4, C8, C9	CAP, CERM, 10uF, 16V, +/-10%, X5R, 0805	Taiyo Yuden	EMK212BJ106KG-T
6	1	C6	CAP, CERM, 4.7uF, 10V, +/-10%, X5R, 0805	Kemet	C0805C475K8PACTU
7	2	D1, D2	Diode, Schottky, 20V, 0.5A, SOD-123	ON Semiconductor	MBR0520LT1G
8	3	FID1, FID2, FID3	Fiducial mark. There is nothing to buy or mount.	N/A	N/A
9	1	J1	1.27mm Pitch Multi-function Two Piece Connector	Hirose	FX2-20S-1.27DS
10	2	J2, J3	Conn Term Block, 2POS, 3.5mm, TH	Phoenix Contact	1751248
11	1	JP1	Header, 3-Pin	Sullins Connector Solutions	
12	2	R1, R3	RES, 20.0 ohm, 0.1%, 0.1W, 0603	Yageo America	RT0603BRD0720RL
13	1	SH-J1	Shunt, 1.27 mm	Harwin Inc	M50-2000005
14	1	T1	1:2.2 Isolation Transformer	Coilcraft	DA2304-AL
15	1	U1	AMC1304Mx in 16-pin DW (SOIC) package	Texas Instruments	AMC1304
16	1	U2	SN6501 transformer driver	Texas Instruments	SN6501
17	0	R2	RES, 50.5 ohm, 0.1%, 0.1W, 0603	Yageo America	RT0603BRD0750R5L



Component	Description	Vendor & Part Number	Parameter	Min.	Typ.	Max.	Unit
C_{BYP}	1.0 µF, X5R or Better	Murata GRM155C81A105KA12	C1		1.0		µF
C_{FILTER}	Various, X5R or Better	Murata	C2		. Figure 27		pF

Figure 3: Shunt based design vs. Crocus CT45x TMR Design, including bill of materials.

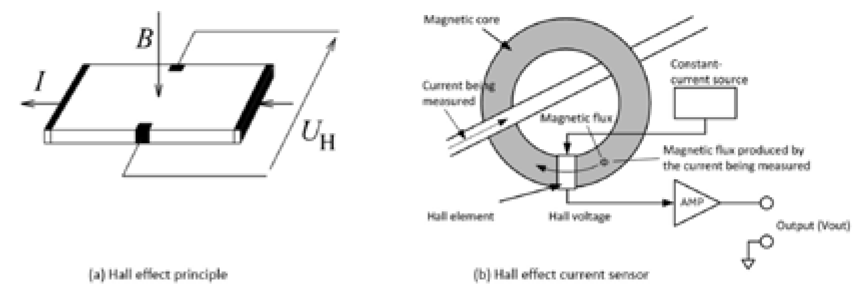


Figure 4: The Hall effect (a) and a Hall effect current sensor (b). Source: Isabellenhütte

The Hall effect forms the basis of a current sensor, shown in Figure 4(b). A Hall element is mounted in the gap in a ferrite magnetic core placed around the current conductor. The Hall voltage indicates the DC magnetic flux, leading to a measurement of the DC current in the conductor.

Shunt-based sensing technology can be an efficient solution for vehicular and stationary applications. Hall effect magnetic components have their place, but shunt-based solutions are preferable where precise performance over a wide temperature range is a priority.

Figure 6 illustrates the shunt-based system's accuracy over temperature versus a Hall-effect system.

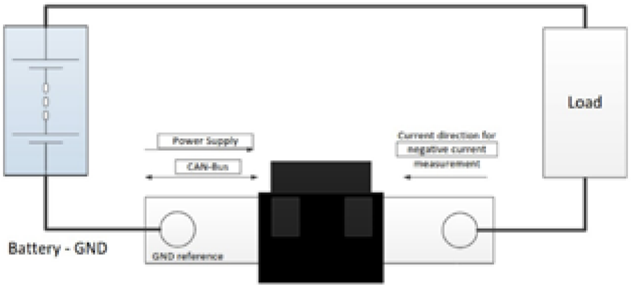


Figure 5: Shunt current measurement. Source: Isabellenhütte

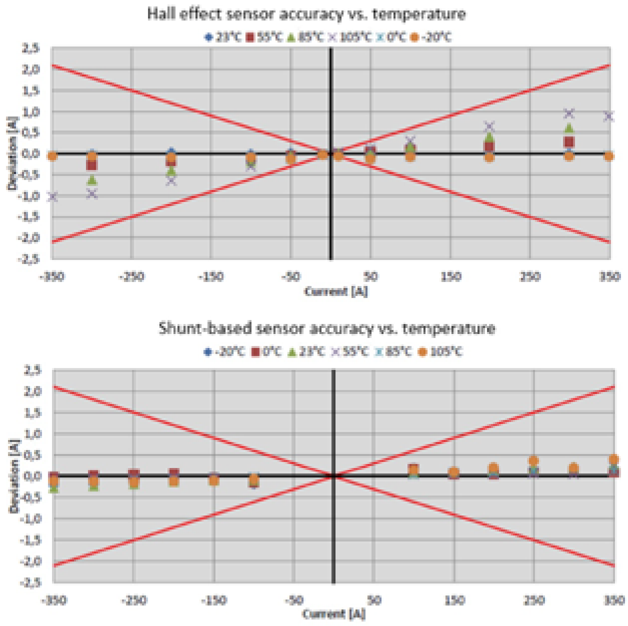


Figure 6: Accuracy comparison versus temperature.
Source: Isabellenhütte

TMR: A Better Alternative

TMR technology has tremendous advantages over both Shunt Resistor (with added amplifiers and digital isolators), and Hall Effect based sensing solutions, especially for battery-powered systems. TMR also offers lower power consumption, better thermal stability, better resolution and higher sensitivity.

Amazingly, TMR provides 1000 times more sensitivity than Hall effect while consuming only a few micro ampere current. With its uniquely positive features, the TMR sensor has the potential to replace Hall effect sensors in most applications. Engineers who have been using a Hall-based sensor for current sensing, are now seeing that it can offer a significant advantage for their system on accuracy, bandwidth, latency, and overall efficiency.

For instance, Crocus' XtremeSense™ TMR sensors enables a no-compromise design solution by combining high bandwidth response and high accuracy. This technology detects extremely small variations in AC or DC currents while achieving an unprecedented total output error of less than 0.7%. In addition, the CT43x has robust built-in immunity to common-mode fields which allows the device to reject > 99% of stray fields without the need for external shielding. The Crocus proprietary TMR technology inherently offers very high signal-to-noise ratio (SNR) which allow for high resolution measurements required for precision control or monitoring applications. The linear error and offset performance are intrinsically more accurate permitting the elimination of system level calibration normally done with an external voltage reference or temperature sensor, thus freeing up processor time and simplifying system design.

Current-sensing solutions, based on shunt resistors, amplifiers, and digital isolators, are showing several limitations that can be overcome by using TMR sensors, shrinking the footprint on the PCB by 2× to 5×.

Main advantages over Hall and Shunt based solutions include:
- High SNR (5-mA resolution in current sensors)
- Low power consumption
- Temperature stability (less than 40ppm/°C)
- Programmable overcurrent detection and fault pin to provide current information to the MCU
- Measure of both positive and negative current with bidirectional sensing

Figure 7 shows a waveform comparison of a Hall Sensor and TMR Sensor under the same application conditions. You can see the TMR waveform is clean and accurate to the peak measurement levels. The Hall Sensor provides a noisy signal with less accurate measurements.

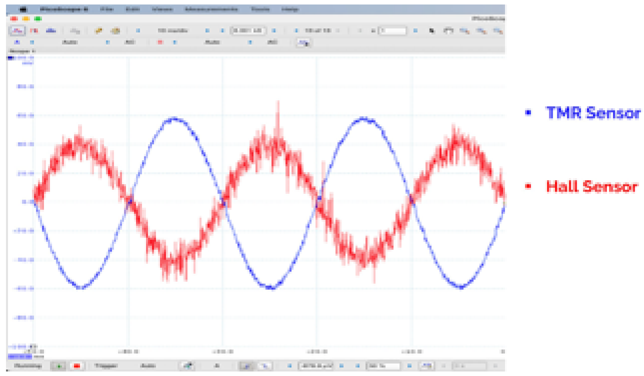


Figure 7: TMR sensor vs. Hall-based sensor (Source: Crocus Technology)

Conclusion

Clearly, Hall effect sensors can no longer meet current standards of low power consumption, sensitivity, accuracy and cost.

TMR, on the other hand, is less susceptible to temperature changes and boasts low power consumption, high signal to noise ratio, better linearity, and needs no additional flux concentrator structure. The output of TMR sensors is 1000 times higher than that of a Hall element.

While shunt is preferable to the Hall Effect, when accuracy is paramount, shunt based current sensors tend to suffer from CMRR error. Luckily, reliable Crocus XtremeSense™ sensors replace shunt with a smaller, more efficient solution – one that easily handles today's accuracy requirements. TMR coreless current sensors are not only smaller in size and simpler to design than shunt, but they also provide 99% immunity to stray magnetic fields, dramatically improving accuracy.

And with shunt resistors, you still are faced with a tradeoff of precision and dissipated power, and you'll experience voltage drops that may not be acceptable for very low voltage, high current applications.

Finally, the complicated architectures of shunt and Hall effect, leave you open to supply chain issues, leading to significant risk. With Crocus XtremeSense™, with reduced component count and a simpler supply chain response, delivers a safer solution.

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