CURRENT SENSING IN MOTOR DRIVES

INTRODUCTION TO CURRENT SENSING ARCHITECTURES IN MOTOR DRIVES

One of the more popular uses of the current sensor is the broad application of motor drives. Motors are electro-mechanical systems, converting electrical energy (voltage and current) into mechanical energy (torque and speed). Proper operation of a motor requires a well-controlled electrical drive, and this requires an accurate measurement of the current flowing through the one or many coils of the motor.

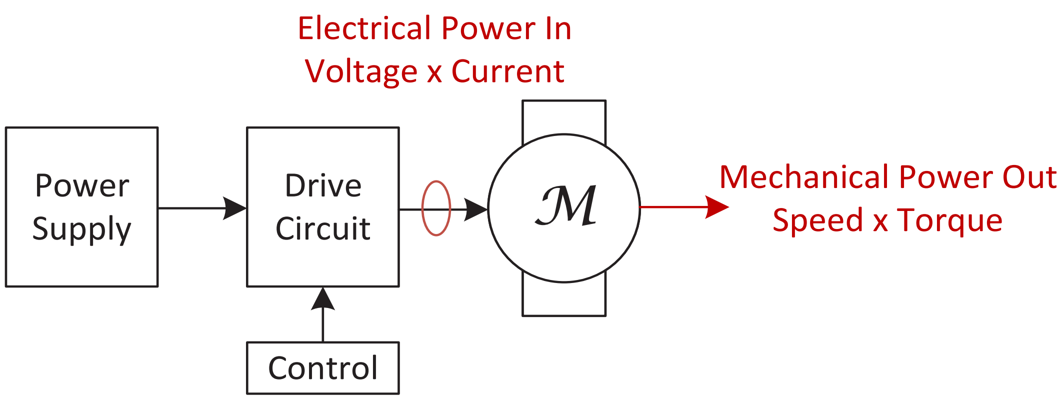


Figure 1: General diagram of current sensing in motors

Classically, motors can be divided into several categories based on their type. Motors range from one phase (or motor coil) up to three in a typical motor, with even higher phase counts possible for motor types like stepper and brushless-DC. Different motor types will require a different power driver circuit and preferred current sensing scheme.

Category	Brushed-DC (BDC)	Universal	Unidirectional stepper	Bidirectional stepper	Brushless-DC (BLDC)	Switched reluctance (SRM)	AC Induction (ACIM)
Commutation	Mechanical	Mechanical	Electrical	Electrical	Electrical	Electrical	Electrical
Input Control	DC	AC or DC	AC	AC	AC	AC	AC
Typical number of phases	1	1	2 (center-tapped)	2	Single-phase: 1 Three-phase: 3	3	1 or 3
Typical power driver circuit	Low-side/high-side MOSFET or H-Bridge (two ½-H bridges)	TRIAC	Four low-side MOSFETs with recirculation diodes	Two H-bridges (four ½-H bridges)	Single phase: H-Bridge (two ½-H bridges) Three phase: three ½-H bridges	Three-phase Asymmetric Bridge or three-phase Miller Inverter	TRIAC(s) or three-phase variable frequency drive (rectifier & three ½-H bridges)
Typical current sensing schemes	1× high-side/ low-side or 1× in-line	1× isolated in-line or 1× low-side	4× low-side	2× high-side/ low-side or 2× in-line	1×, 2×, or 3× high-side/low-side or 2×/3× in-line (maybe isolated)	3× high-side/ low-side or 3× in-line	2×/3× low-side or 2×/3× isolated in-line

Brushed-DC and Universal motors feature mechanical commutation and will spin whenever a DC voltage is applied. For these motor types, any current sensing is used to determine the motor load (torque output) or to detect any fault conditions (for example, a winding short on the motor). One unique current sensing application for Brushed-DC and Universal motors is Ripple Counting, which accurately measures the motor current to detect current ripple due to the commutator motion and measure the motor speed.

The other motor types require electrical commutation, and that means the system controller must be measuring the motor conditions (voltage, current, rotor position) to determine how to drive the motor. The current sensing therefore must perform same functions from the Brushed-DC case but additionally measure the current in each motor coil in real time to properly commutate the motor and keep it spinning. Brushless-DC motor control algorithms, for example, can require current sensor feedback to commutate the motor. These motor types typically require a high enough bandwidth current sensor to measure the phase current, perform a calculation, and then apply a new output to the power driver circuit. This real-time control loop needs to operate at a rate high enough and a total delay time low enough to support the motor performance goals.

In addition to these considerations, motor driver circuits have multiple possible configurations for a current sensor inside the power driver circuit. For example, a brushed-DC motor driver circuit is an H-bridge, and the motor current can be measured in one (or several) of many different places. A low-side ("LS") measurement occurs on the "bottom leg" of the ½-H bridge, or as one summed measurement combining both H-bridge legs. The high-side ("HS") measurement can be similarly made at the top of the ½-H bridge per leg or as a summed high-side. A single in-line ("IL") current measurement can be used in series with the motor because it only has one phase.

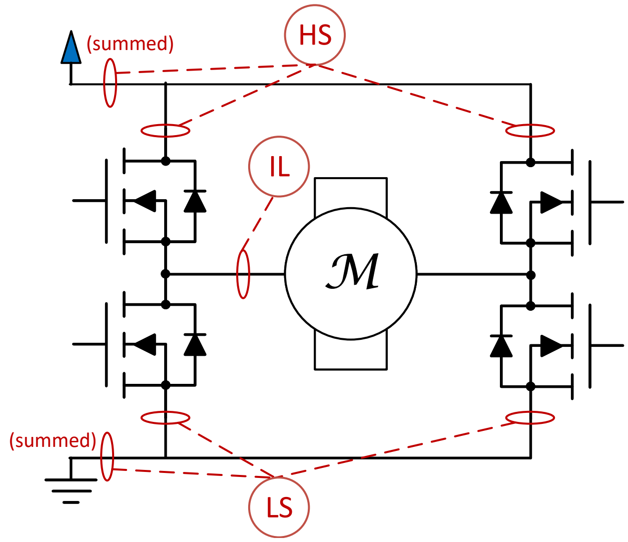


Figure 2: Brushed DC motor driver circuit

A three-phase brushless motor driver circuit is like the brushed-DC case, but now there are more potential points at which one can measure current. Instead of two ½-H bridges, there are three. An in-line current measurement can occur at the three motor phases, although using math it is possible to get away with measuring only two out of the three ($I_A + I_B + I_C = 0$) based on Kirchhoff's Current Law.

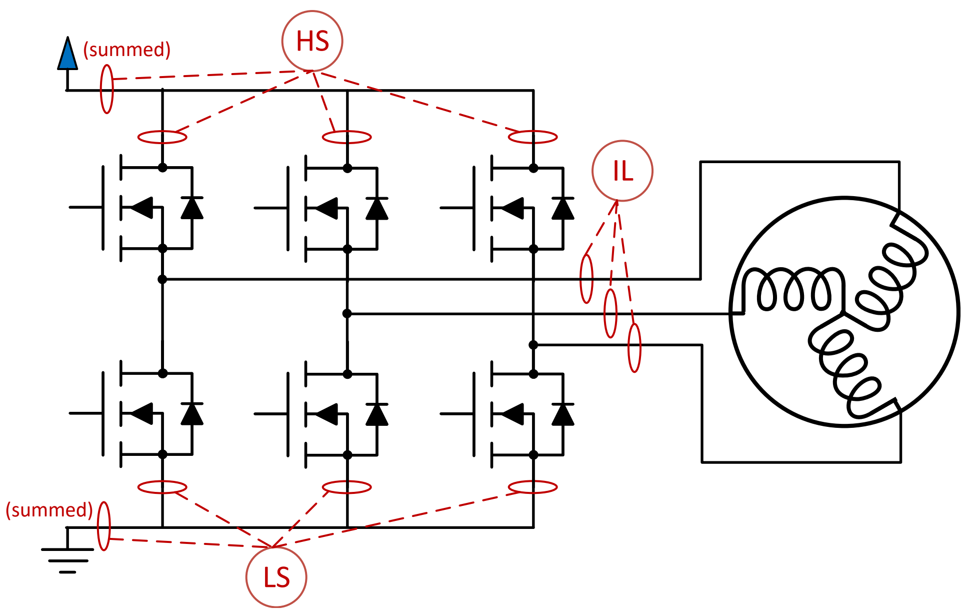


Figure 3: Brushless DC motor driver circuit

Low-side current sensing

Low-side current sensing is considered the most popular method for many motor types. Cost-sensitive applications tend to use low-side current sensing, for example in brushed-DC motor applications. The low-side current sensor can be configured to sense either the current through each ½-H bridge leg or phase, or as a single summed current. The low-side current sensing method is the lowest cost option from a component standpoint but presents some system-level challenges to the designer.

Low-side current sensing has a few distinct advantages:

- The common mode voltage at the sensor location is low, or close to ground
- The sensor can have a low voltage rating and may not require isolation
- The sensor can be used to detect system shorts to the battery when the low-side MOSFET is ON

However, there are some key disadvantages:

- The sensor cannot detect system shorts to ground
- The sensor can only measure current when the corresponding low-side MOSFET is ON
- The controller needs to carefully synchronize the sensor reading with the PWM
- The sensor needs a higher bandwidth to sample during the PWM

System shorts to ground are classically the most common failure mechanisms to occur, for example a loose wire contacting a chassis, and a low-side current sensor cannot detect it. A short to ground on the motor terminals results in a current path that bypasses any low-side current sensor. If this failure is a key consideration for a system designer, a low-side current sensor is not a good solution to protect the system.

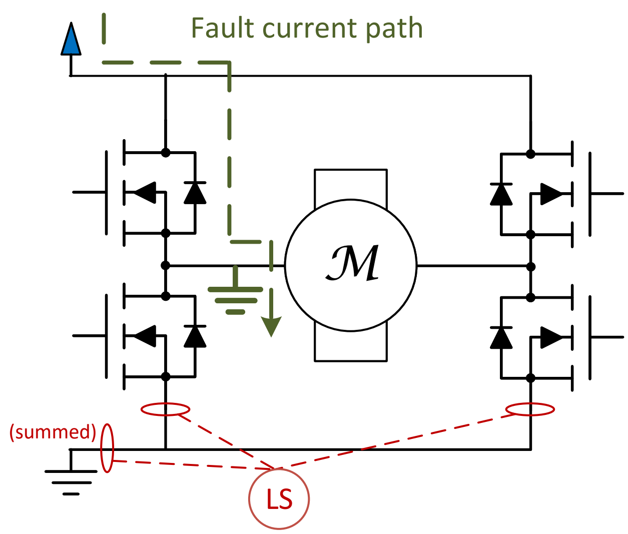


Figure 4: Fault current path using low-side current sensing

When using a low-side current sense scheme, the motor current is only available to measure during certain operating modes of the driver, depending on the position of the current sensor. Using the brushed-DC motor as an example case, the drive current into the motor results in current flowing through one leg as well as the common ground; either can detect the current. However, in a brake mode where both low-side MOSFETs are ON the current will be recirculating between both low-side MOSFETs without returning to the common ground. Individual low-side sensors for the ½-H bridge legs will detect this current, but a summed low-side current sensor will not. If the brake mode must be implemented on the two high-side MOSFETs rather than the two low-side MOSFETs, the low-side current sensor cannot detect the current. Recirculating current may be important to measure in systems where the motor can be externally rotated, effectively acting as a generator.

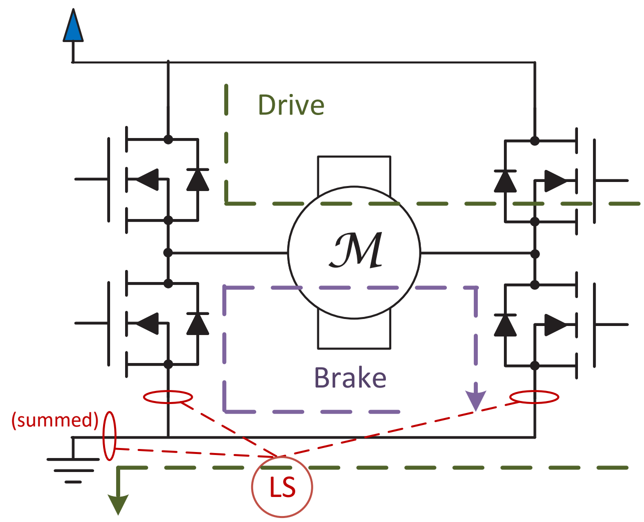


Figure 5: Direction of current during drive and brake modes implementing a low-side sensor

The strategy to sample the motor current is also impacted by the choice of a low-side current sensor. The system controller needs to carefully time the measurements with the motor drive pulse width modulation (PWM) because the sensor can only detect current whenever the corresponding low-side MOSFET is ON. This can present timing concerns when the PWM frequency is very high, or the PWM duty cycle is very high. Both situations can lead to very short low-side MOSFET ON times and therefore a very short window to capture the true motor current. The current sensor bandwidth needs to be high enough to properly sample the current inside this window, and the current sensor settling time will also significantly impact how much time in the window is useable.

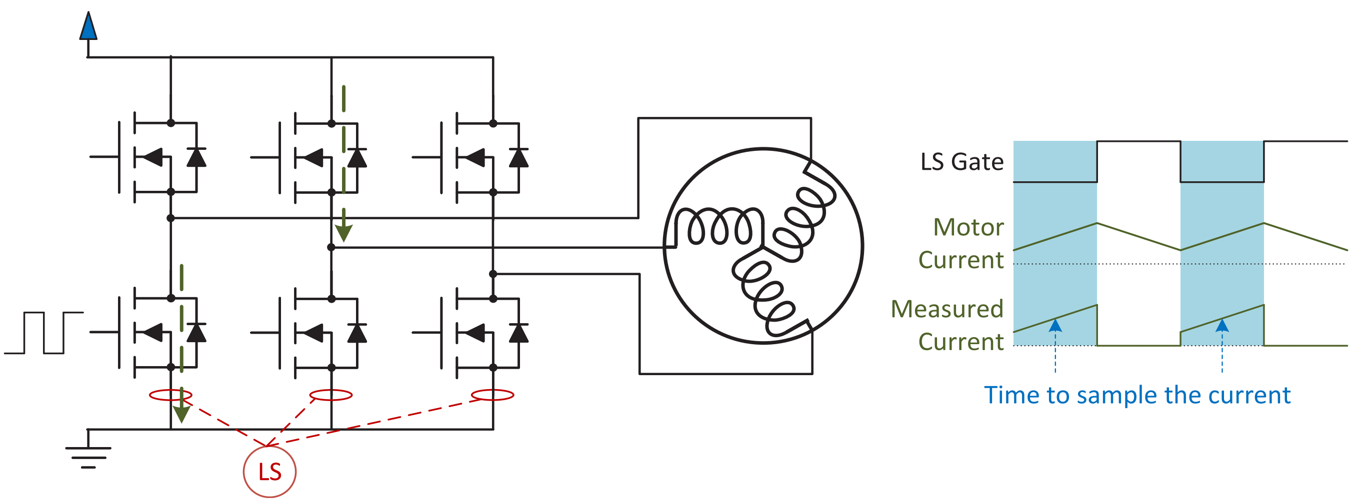


Figure 6: Current sampling with low-side current sensors in a brushless-DC motor driver circuit

Implementing low-side current sensing using a magnetic current sensor presents a few advantages over a sense-resistor-based solution. Magnetic sensors can have a smaller solution size compared to a current shunt resistor and current shunt amplifier and can therefore shrink the board size. In the event of extreme overcurrent, a sense resistor may fail open resulting in the full supply voltage presenting across the current sense amplifier inputs. This event would cause a cascading failure into the current sense amplifier, and possibly into further circuits on the board. A magnetic sensor is nonconducting and therefore provides additional isolation in the case of the conductor fusing into an open state.

When selecting a magnetic current sensor for a low-side current sensing application, there are several parameters that need to be considered: range of current to be sensed, sensing polarity, and bandwidth.

A current sensor polarity can be either unidirectional or bidirectional. A unidirectional sensor has an optimized dynamic range for measuring current flowing in one direction, while a bidirectional output can measure current flowing in either direction. Many systems implementing a low-side current sensor can use a unidirectional output because the nominal drive current to measure is only flowing in one direction: down to the common ground. However, some systems may opt to use a bidirectional current sensing scheme to also measure the current when operating in a recirculation state (coast or brake) where current is flowing in the reverse direction. A bidirectional sensor may be used in a unidirectional sensing system at the expense of sacrificing about half of the output dynamic range. Most microcontroller ADC resources have significantly higher resolution than magnetic current sensor outputs, and so the system accuracy is often not affected by the choice of a bidirectional sensor over a unidirectional sensor.

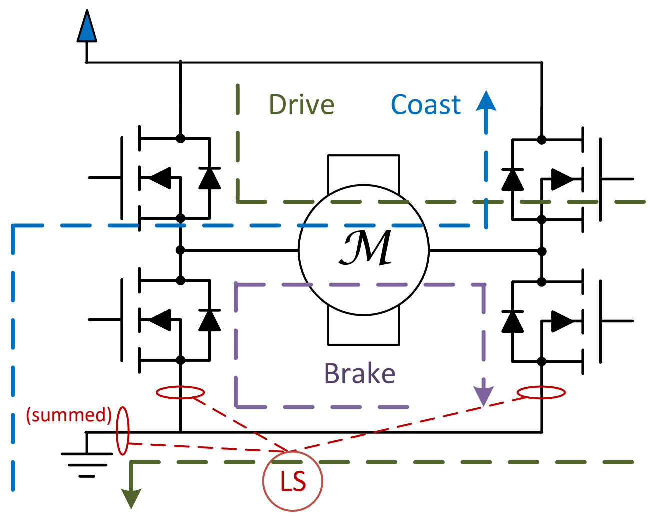


Figure 7: Low-side current sensing during the operating modes of the motor

When using a low-side current sensor, the bandwidth must be chosen so that the sensor can react fast enough to respond to the driver stage turning ON and OFF during PWM. The real motor current may not actually have such a high bandwidth, since a motor acts as a large low-pass filter for the current. However, to properly measure the current during the PWM period where the low-side MOSFET is ON, the current sensor must have a bandwidth significantly higher than the PWM frequency - for example >2×, although this will depend on the specific design requirements.

Here are some low-side current sensing device selection examples:

Input Parameters	Case 1	Case 2
Current sensing range (A)	9 A	9 A
Sensing polarity	Bidirectional	Unidirectional
PWM frequency (Hz)	20 kHz	60 kHz
Target device	ACS71240	ACS730
Justification	Can choose either bi- or unidirectional, supports 10 A current range (next highest option), bandwidth is 120 kHz which is >> 20 kHz	Bidirectional, 20 A current range (next highest option), bandwidth is 1 MHz which is >> 60 kHz
Alternative device	ACS711	–
Justification	Bidirectional, supports 10 A current range (next highest option), bandwidth is 100kHz which is >> 20 kHz	–

High-side current sensing

High-side current sensing is an alternative method to sense the motor current. The high-side current sensor can be configured to sense either the current through each ½-H bridge leg or phase, or as a single summed current like the low-side case. The high-side current sensing method typically presents a higher component cost than low-side, yet may be slightly lower than an in-line current sense.

High-side current sensing has a one key advantage over low-side sensing:

- The sensor can detect system shorts to ground when the high-side MOSFET is ON

However, there are several disadvantages:

- The sensor requires a high common mode voltage rating or isolation
- The sensor cannot detect system shorts to supply
- The sensor can only measure current when the corresponding high-side MOSFET is ON
- The controller needs to carefully synchronize the sensor reading with the PWM

The high-side current sensor is primarily used when a customer must detect a system-level short to ground. As mentioned previously, this can be the most common failure mechanism to occur. In the low-side sensing case, the fault current path bypasses the sensor. When a high-side current sensor is used, the fault current flows through the current sensor and this fault mode can be properly detected so that the system can act.

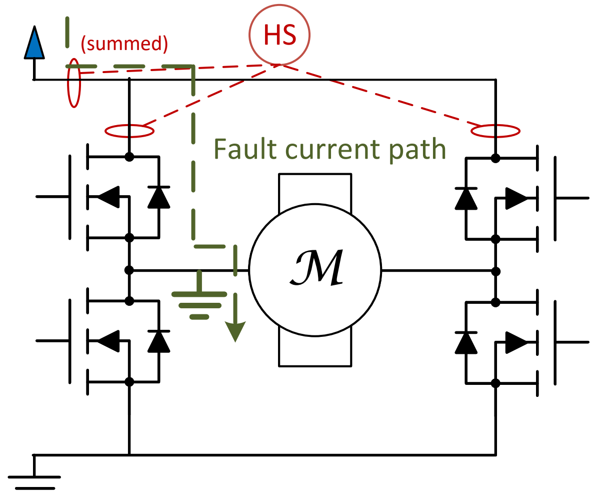


Figure 8: Fault current path using high-side current sensing

Unlike the low-side current sensor, the high-side current sensor requires a high common mode of operation. The sensor is referenced to the supply or battery, rather than to ground. If the supply voltage is high enough, an isolated current sensor will be a good choice. This higher voltage range typically results in a more expensive component compared to the low-side current sensor.

The high-side current sensor allows for motor current measurement only during certain operating modes of the driver, like the low-side case. Again, using the brushed-DC motor, the drive current into the motor results in current flowing through the common supply as well as one leg; either can detect the current. However, in a brake mode where both high-side MOSFETs are ON the current will be recirculating between both high-side MOSFETs without returning to the common ground. Individual high-side sensors for the ½-H bridge legs will detect this current, but a summed high-side current sensor will not. If the brake mode must be implemented on the two low-side MOSFETs rather than the two high-side MOSFETs, the high-side current sensor cannot detect the current.

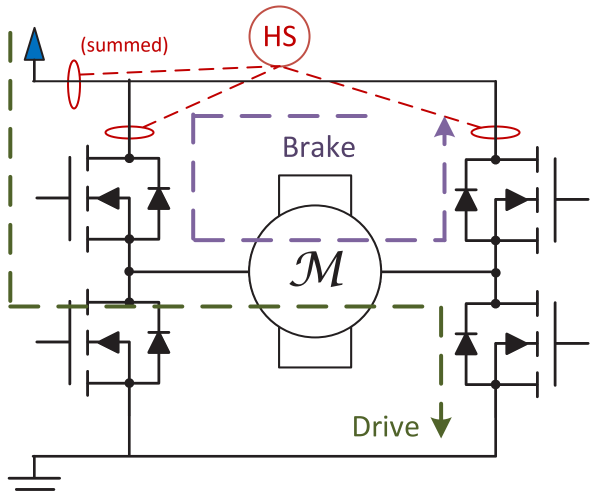


Figure 9: Direction of current during drive and brake modes implementing a high-side sensor

The current sense measurement is impacted by the choice of a high-side current sensor: PWM synchronization is required. The high-side sensor can only detect current whenever the corresponding high-side MOSFET is ON. This can present timing concerns when the PWM frequency is very high, or the PWM duty cycle is very low. Both situations can lead to very short high-side MOSFET ON times and therefore a very short window to capture the true motor current.

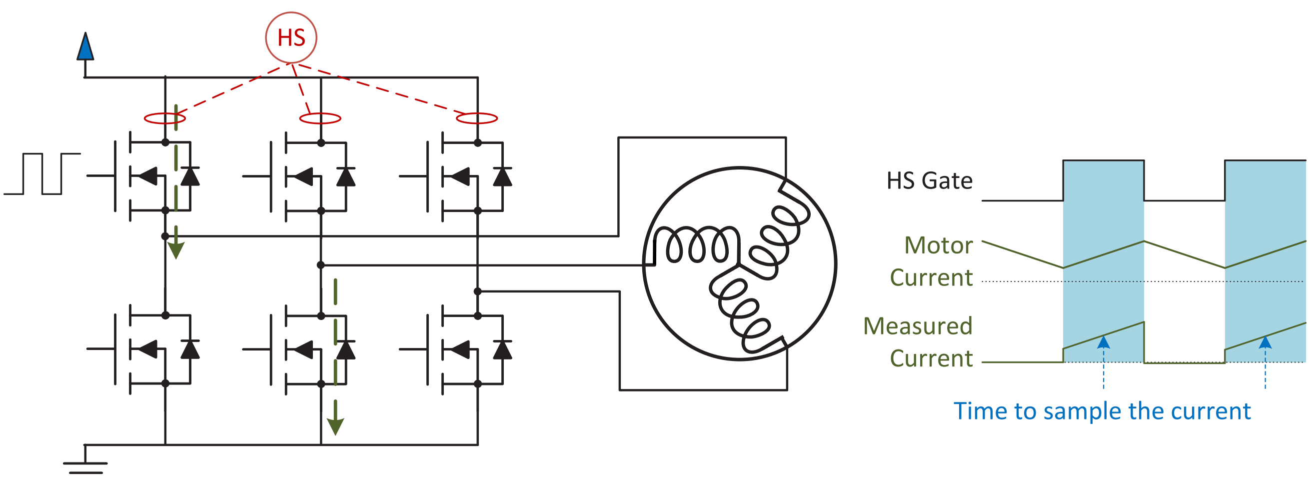


Figure 10: Current sampling with high-side current sensors in a brushless-DC motor driver circuit

Again, implementing a high-side current sensing using a magnetic current sensor presents a few advantages over a sense-resistor-based solution. The magnetic sensor can be smaller than a sense resistor and external shunt amplifier. Many magnetic current sensors also include built-in basic or reinforced isolation to support the high supply voltage, and this further reduces the need for components on the board.

When selecting a magnetic current sensor for a high-side current sensing application, the designer must consider the current, sensing polarity, and bandwidth in addition to the working voltage rating.

Just as in the case of the low-side current sensor, the high-side current sensor may be unidirectional or bidirectional. A system may implement a unidirectional output to maximize the dynamic range of the output when driving current into the motor. Alternatively, using a bidirectional current sensor allows for the system to measure the current in a recirculation mode (brake or coast). Again, a bidirectional sensor may be used in a unidirectional sensing system at with a reduced dynamic range.

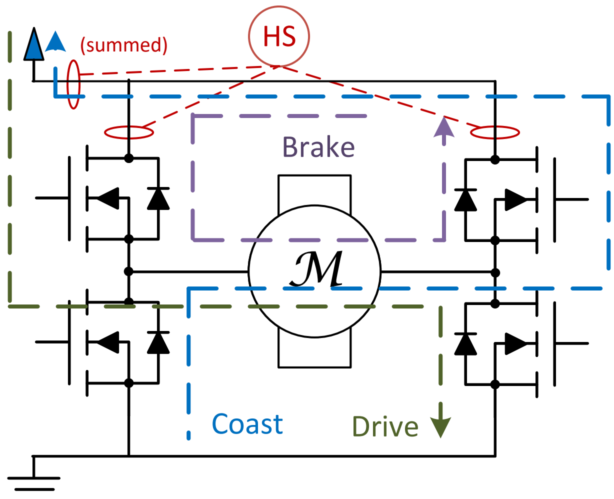


Figure 11: High-side current sensing during the operating modes of the motor

The sensor bandwidth for a high-side current sense must be considered in a similar fashion to the low-side current sense. The bandwidth of the sensor should be significantly higher than the PWM frequency because the system can only measure the motor current when the high-side MOSFET is ON.

In the case of the high-side magnetic current sensor, the device is expected to withstand the full system supply voltage. The working voltage rating of the part should be selected to provide adequate margin for any supply fluctuations during normal & abnormal operation of the motor. Many high-voltage systems will have a requirement for functional, basic, or reinforced isolation and that needs to be considered in the devices chosen.

Here are some high-side current sensing device selection examples:

Input Parameters	Case 1	Case 2
Current sensing range (A)	9 A	9 A
Sensing polarity	Bidirectional	Unidirectional
PWM frequency (Hz)	20 kHz	60 kHz
Supply voltage absolute maximum (V)	24 V Battery 55 VDC absmax	240 V AC
Target device	ACS711LC	ACS730LC
Justification	100 V isolation voltage covers 55 V abs max, bidirectional, supports 10 A current range, bandwidth is 100 kHz which is >> 20 kHz	2500 V_P (1767 V_{RMS}) isolation voltage, bidirectional, 20 A current range (next highest option), bandwidth is 1 MHz which is >> 60 kHz, Over Voltage Category (OVC) II
Alternative device	ACS71240LC	ACS732LA/MA
Justification	100 V isolation voltage covers 55 V abs max, bidirectional, supports 10 A current range, bandwidth is 120 kHz which is >> 20 kHz	6000 V_P (4242 V_{RMS}) isolation voltage covers 240 V AC, can choose either bi- or unidirectional, supports 20 A current range, bandwidth is 1MHz which is >> 60 kHz, Over Voltage Category (OVC) IV

In-line Current Sensing

In-line current sensing is the third choice for the motor drive circuit. In-line current sensing solves some of the disadvantages with both low-side and high-side sensing by measuring the current in series with the motor windings. The in-line current sensing method typically presents a higher component cost than both the low-side or high-side current sense, especially when using sense-resistor-based current sensing methods.

In-line current sensing has several big advantages over low-side and high-side sensing:

- The sensor can measure current irrespective of the state of the power MOSFETs
- The controller does not need to synchronize the sensor reading with the PWM
- The sensor can detect system shorts to ground when the high-side MOSFET is ON
- The sensor can be used to detect system shorts to the battery when the low-side MOSFET is ON

However, there are some key disadvantages:

- The sensor requires a high common mode voltage rating or isolation
- The sensor requires a very high common mode rejection ratio
- There is no way to have a single "summing" in-line current sensor

An in-line current sensor can be used to detect either a system-level short to ground or supply, making it the most useful for system diagnostics and determining if one of these two failure modes has occurred. For customers requiring detection of both failure modes, in-line current sensing is the better alternative to using both a low-side and high-side current sensor in the system.

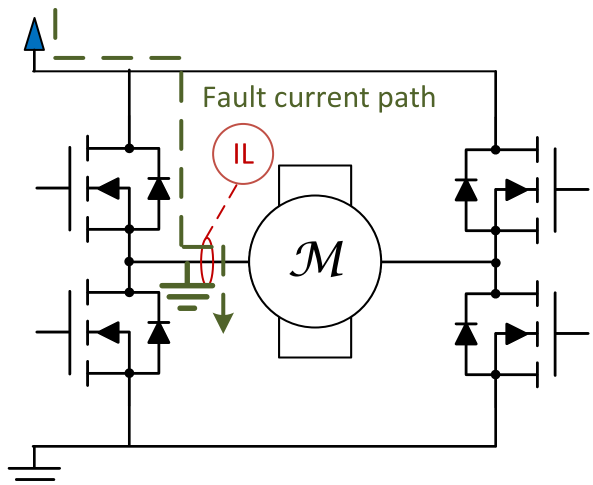


Figure 12: Fault current path using in-line current sensing

Like the high-side current sensor, the in-line current sensor requires a high common mode of operation. This requires the sensor to support a high voltage or have built-in isolation. However, the in-line current sensor must also reject the common mode very well.

As the motor driver applies a PWM to the motor, the phases will be alternating between low (close to ground) and high (close to the supply). The in-line current sensor is "riding" on top of the PWM. Any sensor used for in-line current sensing must have a very strong common mode rejection ratio (CMRR) or the sensor output will be significantly affected every time the output switches.

In-line current sensing greatly simplifies the conditions when the sensor output is properly reflecting the actual motor current. In the low-side and high-side current sensor cases, the corresponding MOSFET must be on and conducting to direct the motor current through the current sensor and produce an output. However, the in-line current sensor does not have any such restriction. The in-line current sensor is measuring current in series with the motor windings, which is always representative of the motor current, regardless of the state of the power MOSFETs in the drive circuit. Current may be properly measured in drive, coast, high-side brake, or low-side brake.

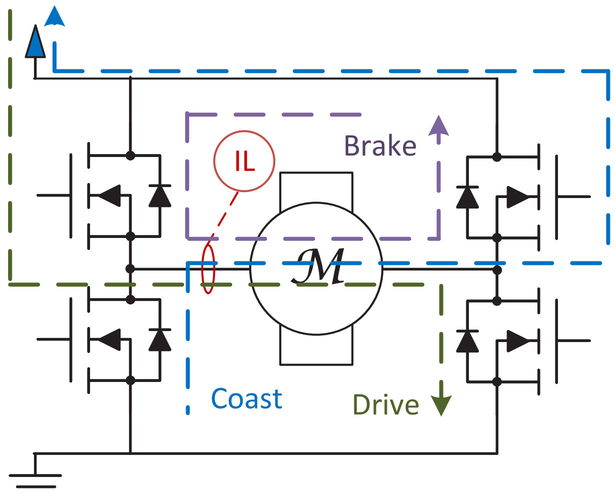


Figure 13: In-line current sensing during the operating modes of the motor

In-line current sensing greatly simplifies the method for the controller to sample the motor current. The controller may sample the sensor output at any time, regardless of the PWM being applied because the current sensor output is always representative of the motor current.. In-line current sensing becomes an obvious choice in systems where the PWM frequency is very high, or the system requires a very high or very low duty cycle because low-side and high-side current sensors can present timing concerns when trying to capture the sensor output at the right time. In-line current sensing allows for a much easier averaging of the motor current over a long period of time. This is not simple to do using a low-side or high-side current sensor.

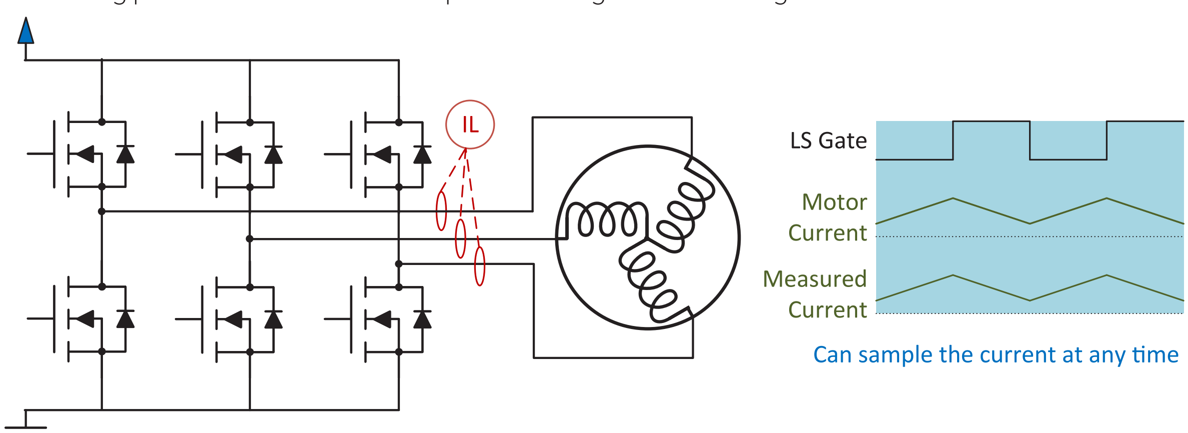


Figure 14: Current sampling with in-line current sensors in a brushless-DC motor driver circuit

In-line current sensing using a magnetic sensor presents some notable advantages over a sense-resistor-based solution. As in the low-side and high-cases, magnetic sensors have a smaller total solution size, additional protection in the case of overcurrent, and has built-in isolation. In-line current sensing also presents a system level benefit for magnetic sensors that can improve the common mode rejection ratio. A sense-resistor based solution is measuring the current via the voltage drop across a sense resistor. When a PWM is being applied to the motor, the sense resistor voltage and amplifier common mode will experience that change in voltage and need to reject it. A magnetic sensor does not measure the voltage to determine the current, it measures the magnetic field generated by the current. Because of this, the magnetic sensor is much more immune to the PWM.

When selecting a magnetic current sensor for an in-line current sensing application, there are four parameters that need to be considered: current, sensing polarity, bandwidth, and working voltage rating.

Due to the in-line current sensor's position, the sensing polarity of bidirectional is most useful. Current may be flowing in either direction in the motor winding, and therefore a bidirectional sensing scheme is needed.

When using an in-line current sensor the sensor bandwidth does not need to exceed the PWM frequency as was the case with the low-side and high-side current sensor. The in-line current sensor can have a bandwidth that is tuned for the motor current bandwidth, much lower than the PWM frequency.

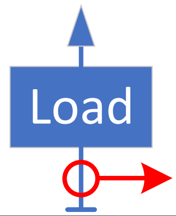
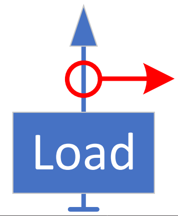
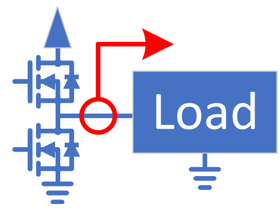
The in-line magnetic current sensor needs to withstand the same voltages as the high-side magnetic current sensor. The working voltage rating of the part should be selected to provide adequate margin for any supply fluctuations during normal & abnormal operation of the motor. Again, many systems will have a requirement for isolation and that needs to be considered in the devices chosen by the designer.

Here are some in-line current sensing device selection examples:

Input Parameters	Case 1	Case 2
Current sensing range (A)	9 A	9 A
Sensing polarity	Bidirectional	Bidirectional
PWM frequency (Hz)	20 kHz	60 kHz
Supply voltage absolute maximum (V)	24 V Battery 55 V DCabsmax	120 V AC
Target device	ACS711	ACS724/25 LC
Justification	100 V isolation voltage covers 55 V abs max, bidirectional, supports 10 A current range, bandwidth is 100 kHz which is >> 10 kHz	2500 V_P basic isolation voltage covers 120 V AC, bidirectional option, supports 20 A current range, bandwidth is 120 kHz which is >> 10 kHz
Alternative device	ACS71240 (QFN)	ACS71240 (SOIC)
Justification	100 V isolation voltage (QFN) covers 55 V abs max, bidirectional, supports 10 A current range, bandwidth is 120 kHz which is >> 10 kHz	2400 V isolation voltage (SOIC) covers 120 V AC, bidirectional, supports 10 A current range, bandwidth is 120 kHz which is >> 10 kHz

Magnetic current sensing in low-side, high-side, and in-line current sensing

After covering case-by-case examples of using magnetic current sensors, now it is possible to compare them side-by-side:

Type	Low-side		High-side		In-line
Picture					
Detects short to GND	✗		✓		✓
Detects short to supply	✓		✗		✓
Asynch with PWM	✗		✗		✓
Voltage rating	Low (<20 V)		High, depends on supply		High, depends on supply
Bandwidth required	Higher than PWM		Higher than PWM		Higher than motor
Polarity	Unidirectional or Bidirectional		Unidirectional or Bidirectional		Bidirectional only
Possible configurations	1 per 1/2-H	1 summing	1 per 1/2-H	1 summing	1 per 1/2-H bridge
Measures LS brake	✓	✗	✗		✓
Measures HS brake	✗		✓	✗	✓
Measures in coast	✓ (bidirectional only)		✓ (bidirectional only)		✓
Measures in drive	✓		✓		✓
Magnetic solution comparison to shunt-based current sensing	Smaller solution size Fail open, protect from overvoltage stress		Smaller solution size Basic or reinforced isolation built-in		Smaller solution size Basic or reinforced isolation built-in PWM rejection
Example devices	Low voltage: <100 V Bidirectional: ACS711 (SOIC/QFN) ACS71240EX (QFN) ACS730 (SOIC) ACS724/25LC (SOIC) Unidirectional: ACS71240EX (QFN)		Low voltage: <100 V Bidirectional: ACS711, ACS71240EX Unidirectional: ACS71240EX High voltage: >100 V 2.5 kV$_P$: ACS724/25LC 6 kV$_P$: ACS37002LA 4 kV$_P$: ACS724/5MA		Low voltage: <100 V ACS711, ACS71240EX High voltage: >100 V 2.5 kV$_P$: ACS724/25LC 6 kV$_P$: ACS37002LA 4 kV$_P$: ACS724/5MA

While most shunt-resistor-based current sensing schemes today use a low-side current sensing architecture, magnetic current sensors provide potential benefits in moving directly to an in-line architecture. For low-voltage systems (i.e. < 100 V), the same component (i.e. ACS711) can be used for either a low-side current sensor, a high-side current sensor, or an in-line current sensor because the devices listed in the table above support voltage ratings of at least 100 V. With this conversion, designers can have a more robust motor current measurement that can be sensed during any driving state of the power stage.

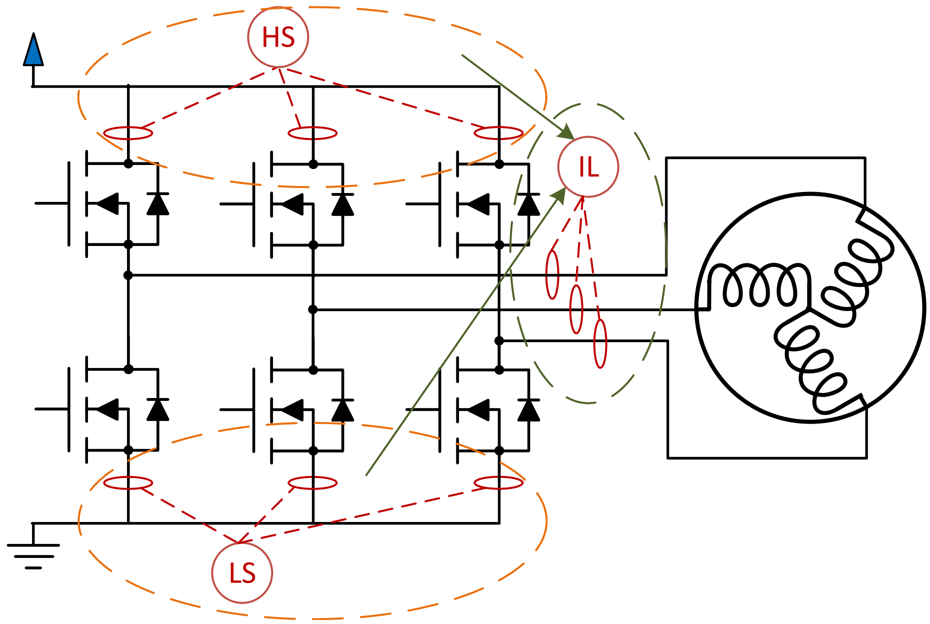


Figure 15: Current sensing options in a brushless-DC motor driver

Customers will opt not to move to in-line architectures in cases of brushless-DC or other multi-phase motors where only a single low-side or high-side current sense is required. Moving to an in-line current sense scheme would require at least 2 current sensors compared to the single summing current sensor, and that does add significantly to the total component count of the system. In these cases, using a single low-voltage magnetic current sensor may still be a valuable design option to reduce the solution size of the system by removing the sense resistor. The magnetic current sensor also gives the sensor increased robustness against cascading damage due to the sensing element failing open, as mentioned previously.

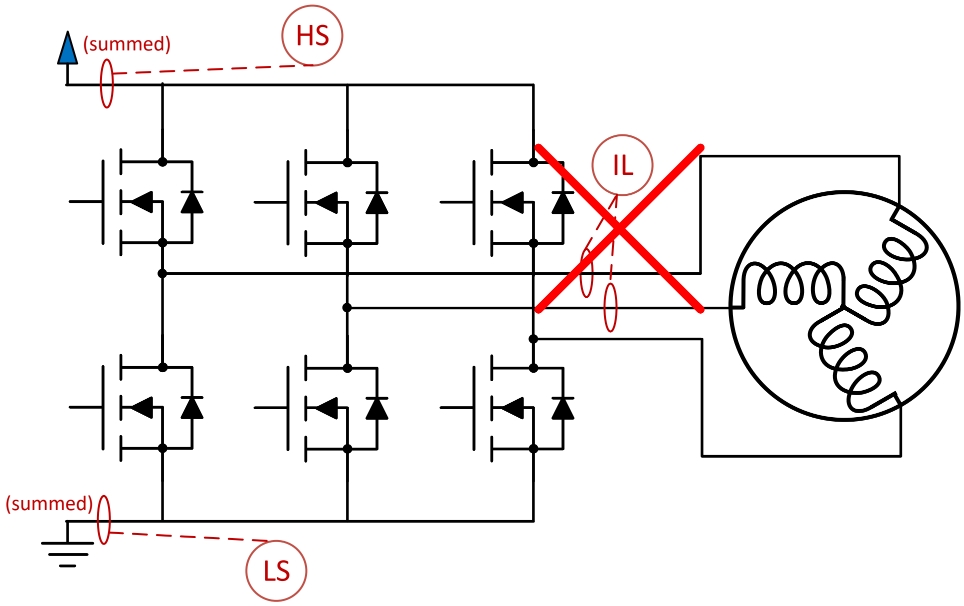
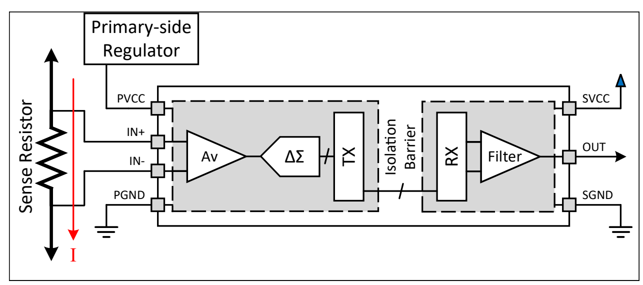
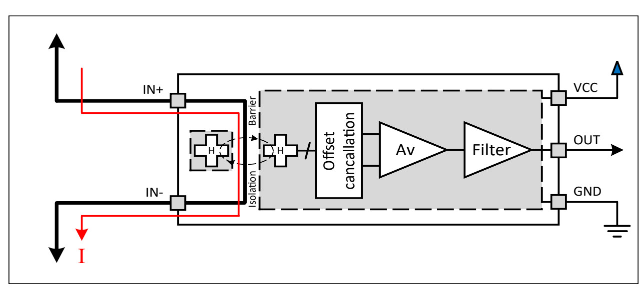


Figure 16: Using a summed current sensor in a brushless-DC motor driver

In high-voltage systems, the magnetic current sensor's integrated basic or reinforced isolation makes it invaluable in achieving performance requirements for high-side or in-line current sensing. A typical sense-resistor-based approach requires an external sense resistor, an amplification stage, digitization, communication over an isolation barrier, and re-construction of the signal. The primary (high-voltage) side of the circuit requires some supply voltage to power the input circuitry. It is possible to contrast this with the magnetic current sensor, which has no active circuitry on the primary side and therefore has a lower total component count as a system solution.

Circuit Type	Circuit Diagram
Isolated Sense Amplifier	
Magnetic Current Sensor	

CONCLUSION

After reviewing the purpose of current sensors in motor drive applications and discussing potential system architecture choices for designers, it is possible to cover several best practices when selecting a magnetic current sensor for a motor drive system:

1. Magnetic current sensors provide the largest benefit when currently using or transitioning to in-line current sensing. Consider using in-line current sensing to simplify the output sampling, measure in any motor drive state, detect short-to-GND conditions, and lower sensor bandwidth requirements.
2. Choose the magnetic current sensor isolation voltage rating to be significantly higher (i.e. at least +20%) than the maximum possible supply voltage that the system can see when in regular operation and when encountering faults like overcurrent.
3. Make sure that the magnetic current sensor device bandwidth has adequate margin (i.e. > 2×) above the PWM frequency for low-side and high-side applications, and adequate margin above the motor current bandwidth for in-line applications. In-line applications can often use devices with lower bandwidth compared to high-side and low-side.
4. Choose the magnetic current sensor current measurement range to most closely cover the target motor current range to be sensed. For example, if the motor is rated at 5A RMS and 10A peak, select a current sensor with at least 10A current measurement range.
5. The most common output polarity is bidirectional, however using a unidirectional polarity can effectively double the output signal in some low-side and high-side applications where the reverse current does not need to be measured. Most microcontroller ADC resources have significantly higher resolution than magnetic current sensor outputs, and so the system accuracy is often not effected by the choice of a bidirectional sensor over a unidirectional one.

Revision History

Number	Date	Description	Responsibility
–	March 29, 2023	Initial release	Tyler Hendrigan