TI TechNotes

High-Side Drive, High-Side Solenoid Monitor With PWM Rejection

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A solenoid is an electromechanical device that is made up of a coil wound around a movable iron material, also called an armature or plunger. When an electric current is passed through the coil a magnetic field is generated causing the armature to travel over a fixed range. Figure 1 shows an illustration of an electromechanical solenoid. Solenoids are often designed for simple ON - OFF applications like relays that require only two states of operation. These solenoids can be also be designed for linear operation where the current is proportional to the position of the armature. Linear solenoids are used in several applications where pressure, fluid or air is precisely regulated. In automotive applications, linear solenoids are used in fuel injectors, transmission, hydraulic suspension and also for haptic effects. Linear solenoids are seen in critical medical applications that requires precise air flow control as well in industrial applications that redirect and control fluid flow.

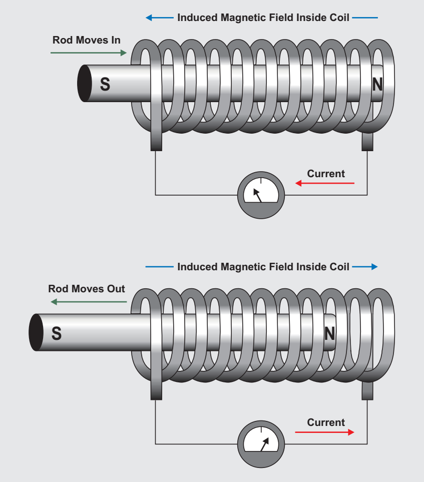

Figure 1. Electromechanical Solenoid Construction

There are multiple configurations for connecting and driving solenoids. One common approach to driving solenoids uses a high-side driver configuration. In this configuration the current sense amplifier is connected between high-side switch and the solenoid as shown in Figure 2. One benefit to this configuration is the solenoid is isolated from the battery voltage when the high side switch is turned off. Eliminating the solenoid's continuous connection to the battery voltage reduces solenoid degradation and early lifetime failures.

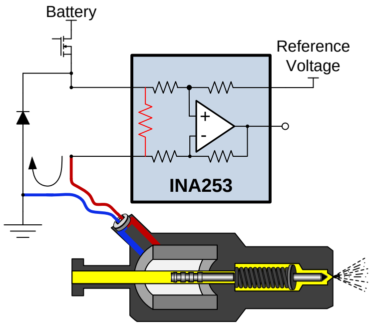

Figure 2. High-Side Drive With High-Side Current Sense

The current sense amplifier shown in Figure 2 must be able to reject high common mode dv/dt signals as well as support common mode voltages that fall below ground. In the above configuration when the high side switch is turned on the solenoid is energized by the current flowing from the battery. The duty cycle of the high-side switch determines the current flowing through the solenoid, which inturn, controls the travel range of the plunger. At the time when the high-side switch is turned off, the current flows through the flyback diode forcing the common voltage to drop one diode drop below ground.

Solenoids and valves are highly inductive in nature. The effective impedance of solenoid can be simplified as resistance and inductance. The coil is constructed using copper (4000ppm/°C) and the effective resistance varies on the type of solenoids from 1Ω for haptic applications to 10Ω for a linear or positional valve systems. The inductance for all of the solenoids ranges from 1mH to 10mH. Figure 3 shows example of current profile of a solenoid driver in open loop mode at 25°C and 125°C. Over a 100°C rise in ambient temperature without compensating for Cu resistance the plunger travel distance accuracy is around 40%.

The solenoid current flow directly controls the plunger's travel distance. If the ambient temperature changes, the plunger's travel distance changes impacting the output control which could be regulating pressure, fluid or air.

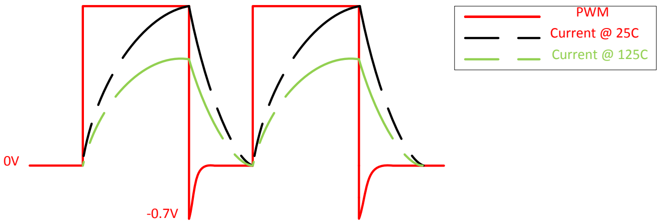

Figure 3. Solenoid Current Profile Across Temperature

Measuring current in solenoid and valve applications provides the capability to detect changes in a solenoid's operating characteristics. Current measurement can identify the effects of a decrease in the magnetic field of an aging solenoid to detect faulty components before they fail. In an open-loop solenoid control system the variation of effective impedance can drift 40% for a 100°C rise in temperature from the copper windings. Current measurement used in a current control feedback loop can reduce the solenoid's impedance variation over temperature from 40% down to 0.2% using the INA253 current sense amplifier.

The INA253 is a high-side, bi-directional current sense amplifier with an integrated 2mΩ low inductive shunt that can support large common mode voltages ranging from –4V to +80V. The integrated shunt is factory calibrated to provide <0.1% total system accuracy with a gain error temperature drift of <15ppm/°C. The INA253 is specifically designed to operate within PWM applications where high dv/dt transients needs to be suppressed. INA253 is designed with circuitry to suppress dv/dt signals. This features lowers blanking time enabling accurate PWM current measurements at lower duty cycle. The device's low offset voltage, drift, gain and high bandwidth of 400kHz enables accurate in-line current measurements for PWM applications. Valve applications requiring precision control of fluid, air and pressure all benefit from the accuracy and temperature stability in the current measurement by using the INA253. The integrated precision shunt of the INA253 can provide high accuracy position control of <0.2% across temperature with eliminating the need for current measurement calibration across temperature.

Alternate Device Recommendations

The INA240 is a high-side, bi-directional current sense amplifier that can support large common mode voltages ranging from –4V to +80V. The INA240 is specifically designed to operate within PWM applications where high dv/dt transients needs to be suppressed. The device's low offset voltage of 25µV (max), drift of 250nV/°C (max), gain (0.2%) and high bandwidth of 400kHz enables accurate in-line current measurements for PWM applications.

The LMP8601 is device that can also be used in this type system if lower negative common-mode voltages are required. The –22V input range allows for sufficient margins if larger solenoid kickback voltages are present. One of the drawbacks of LMP8601 is the PWM glitch rejection and its response to quickly settle for high dv/dt signals.

The LMP8640HV is another good example of a current sense amplifier capable of supporting the requirements of this high-side drive configuration. For applications requiring higher signal bandwidths with low input offset voltage drifts, the LMP8640HV can be used..

The LMP8278Q is also another device that can also be used in PWM applications. LMP8278 is AEC-Q100 qualified guaranteeing device specifications over full ambient temperature range from –40°C to +125°C. With V_{cm} operation from –2V to +40V, the LMP8278 can be used in powertrain applications if a solenoid needs to be precisely controlled inside the chassis.

Table 1. Alternate Device Recommendations

Device	Optimized Parameter	Performance Trade-Off
INA240	PWM settling time: 2uS, V_{os}: 25µV	Package: TSSOP
LMP8601	V_{cm} range: -22V to +60V	Bandwidth, Accuracy
LMP8640HV	Bandwidth: 950kHz	Slew rate, Longer step response settling
LMP8278Q	V_{cm} range: -2V to +40V, CMRR	Slew rate

Table 2. Related TI TechNotes

SBOA189	Precision Brightness and Color Mixing in LED Lighting Using Discrete Current Sense Amplifiers
SBOA161	Low-Drift, Low-Side Current Measurements for ThreePhase Systems
SBOA163	High-Side Motor Current Monitoring for Over-Current Protection
SBOA193	Safety and Protection for Discrete Digital Outputs in a PLC System Using Current Sense Amplifiers

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