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Fast, Simple Solenoid Driver Saves Power In Industrial Applications

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Solenoids are widely used in different areas of industrial automation as actuators of valves and plungers. In many cases the required solenoid activation repetition rate is so fast there's a need to shorten the natural solenoid inductor recuperation time. This means the energy stored in the solenoid inductor must be dissipated fast enough to allow the fast repetition rate and that, in turn, requires the inductor current decay time to be shortened.

Usually, the solenoids are controlled by drivers with a pulse-width modulated (PWM) signal that operates a switch, which manages the current through the solenoid. This PWM method ensures low power dissipation in the driver's components, as well as a good controllability of the plunger trajectory. Fig. 1 shows the schematic of this type of conventional solenoid driver, while Fig.2 shows the current decay timing waveform for this driver.

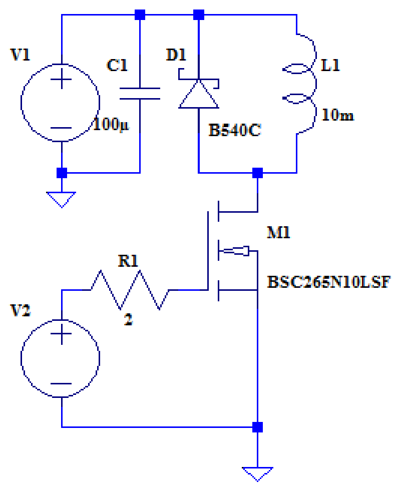

Fig.1. A conventional solenoid driver.

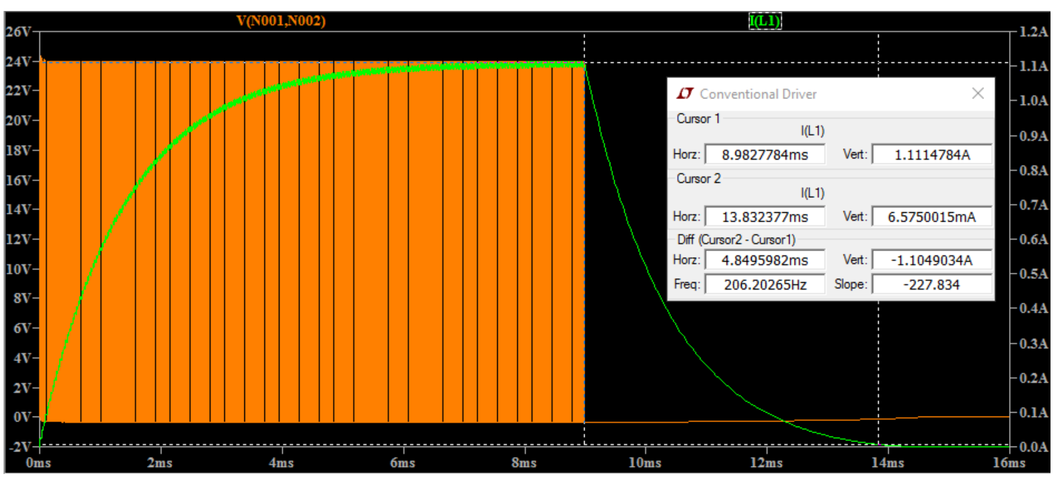

Fig. 2. Current ramp up and decay of the solenoid drive depicted in Fig. 1. The green trace is the L1 inductor current, while the orange trace is the voltage between the supply rail and M1 drain.

Conventional solenoid drivers have uncontrollable current decay arrangements. If a fast current decay is required, a higher supply voltage is used, which results in high power dissipation. Alternatively, an extra Zener diode may be connected in series with the solenoid recuperating diode.

In that case a special external signal clamps the Zener diode during the driver active mode and releases it when its operation is necessary. Typically, a microcontroller is needed to control the Zener, which adds complexity. Or, if the Zener diode is connected on a permanent basis, the solenoid operates in a discontinuous conduction mode—this approach also dissipates a lot of power, creating heat and substantial electromagnetic interference.

To overcome these limitations, a new solenoid driver arrangement is proposed. This circuit uses just the driving signal for shorting the Zener diode in the active phase of its operation and engages it quickly when the solenoid is de-energized and a fast current decay is required.

Fig. 3 shows the schematic for the new Fast Solenoid Driver, while Fig. 4 shows a simulation of this circuit's current decay.

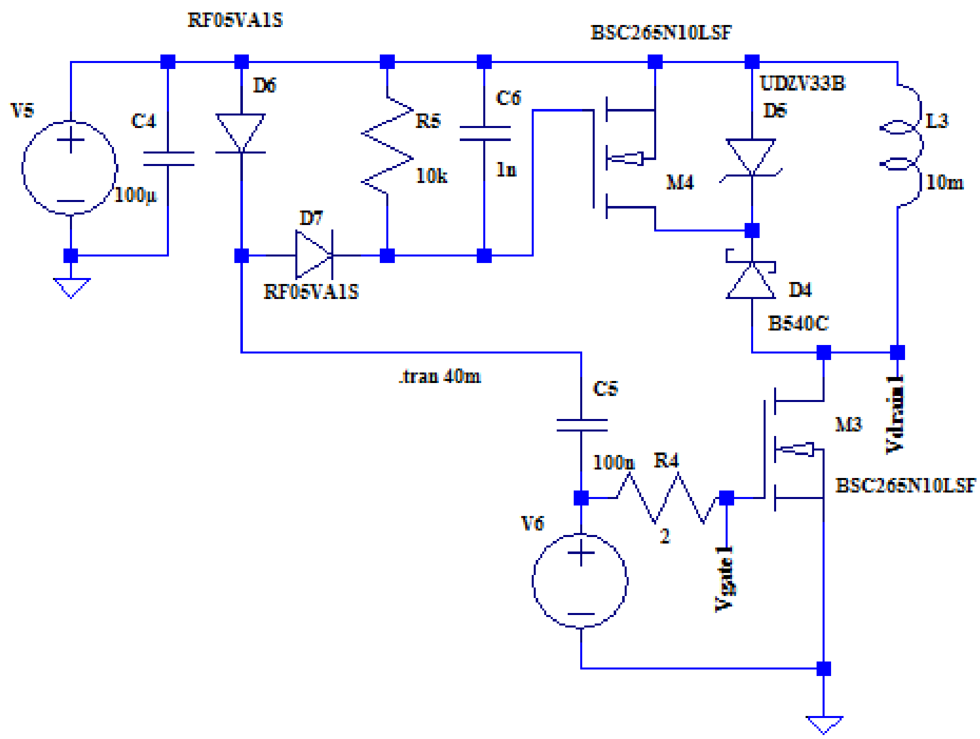

Fig. 3. The Fast Solenoid Driver adds a Zener diode and a simple charge pump circuit to the conventional solenoid driver for the purpose of ensuring fast current decay in the solenoid coil L3.

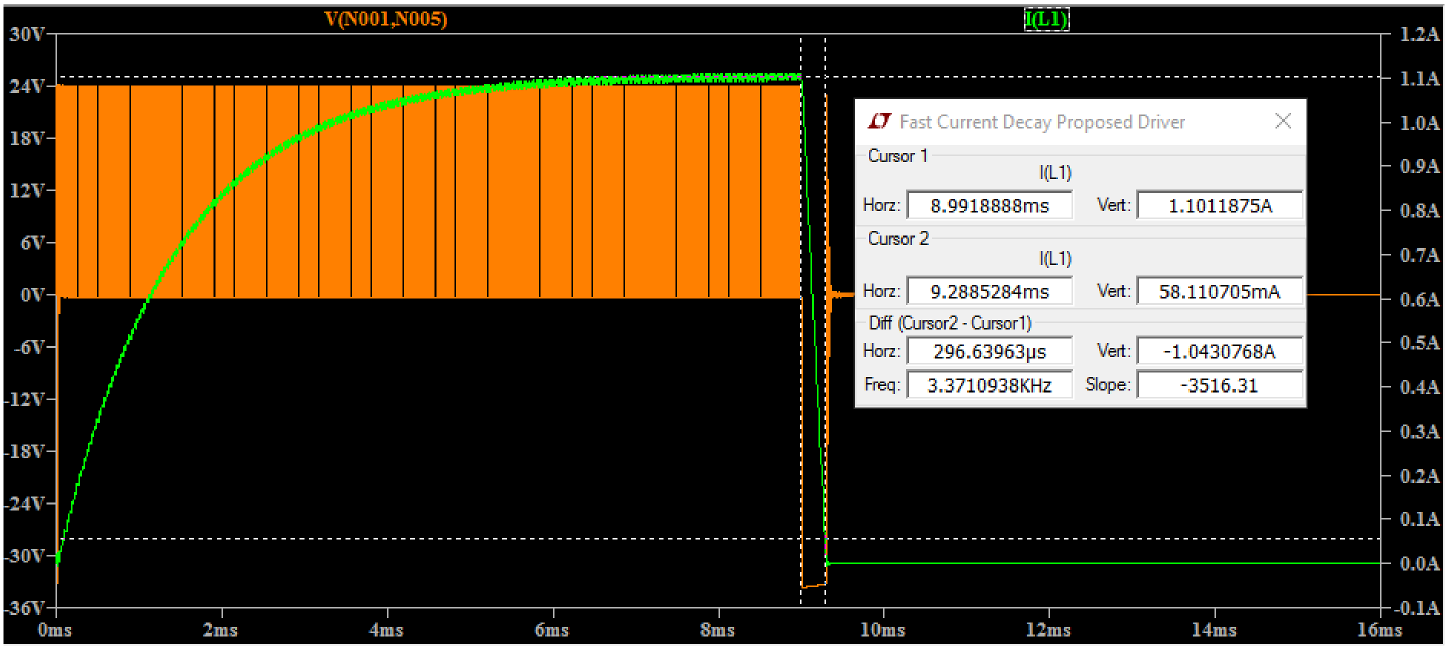

Fig. 4. Solenoid current decay provided by the Fast Solenoid Driver. The green trace is the L3 inductor current and the orange trace is the voltage between the supply rail and M3 drain.

The fast current decay is ensured by adding the Zener diode D5 per Fig. 3 in series with the recuperating diode D4 when the control signal, coming to the gate of the switch M3, interrupts. As the solenoid L3 decaying current sees a higher voltage across Zener D5, the decay time goes down since the volt-second integral must remain the same.

If we were to allow this Zener diode Z5 to remain continuously active in the circuit, it would cause the solenoid to operate in a discontinuous conduction mode. As noted above, this would result in high emissions and high power dissipation in the components. Besides that, a significant reduction in solenoid inductance would be required in this case, which is practically impossible. Fortunately, the proposed Fast Solenoid Driver does not leave Z5 continuously active, but rather shorts it out when not needed using MOSFET M3.

At start-up, the control signal comes to the gate of switch M3 and, at the same time, to the charge pump consisting of diodes D6, D7, resistor R5 and capacitor C6. This charge pump keeps the switch M4 continuously on while the control signal is present, and this switch shorts out the Zener diode D5. This maintains a continuous conduction mode in the solenoid inductor L3, which keeps power dissipation in other components low.

When the input signal interrupts to deactivate the solenoid and associated plunger or valve, the charge pump capacitor C6 discharges quickly through resistor R5, engaging the Zener diode D5 through a fast turn-off of switch M4. Engaging D5 allows for the fast solenoid current decay.

To illustrate the operation of the conventional and the proposed solenoid drivers, oscillograms were taken of the two solenoid drivers utilizing a 25-mH off-the-shelf inductor with a winding resistance of 7 Ω. Fig. 5 shows an oscillogram of the power supply minus M1 drain voltage (yellow trace) and inductor L1 current (green trace) for the case of where the Fig. 1 circuit was used. Fig. 6 depicts an oscillogram of the power supply minus M3 drain voltage (yellow) and inductor L3 current (green) for the case where the Fig. 3 circuit was used. As the simulations reveal, inductor current decay in the proposed arrangement is four times shorter than in the conventional one.

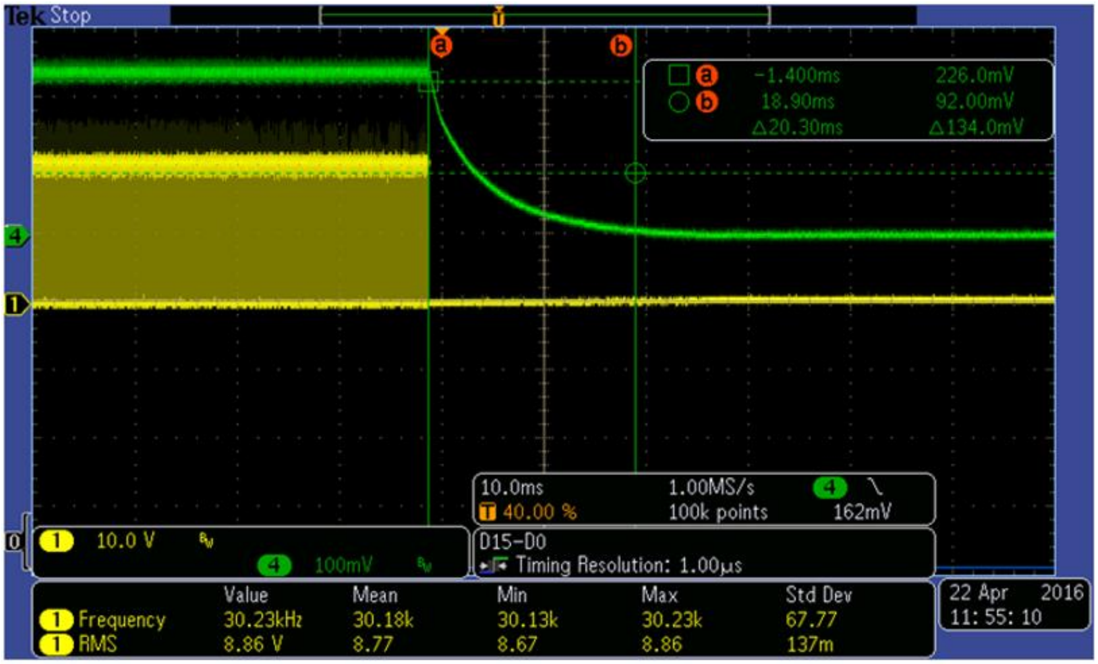

Fig. 5. The power supply voltage minus M1 drain voltage (yellow trace) and inductor L1 current (green trace) for the solenoid driver in Fig. 1. The decay time measured between points a and b is 20.3 ms.

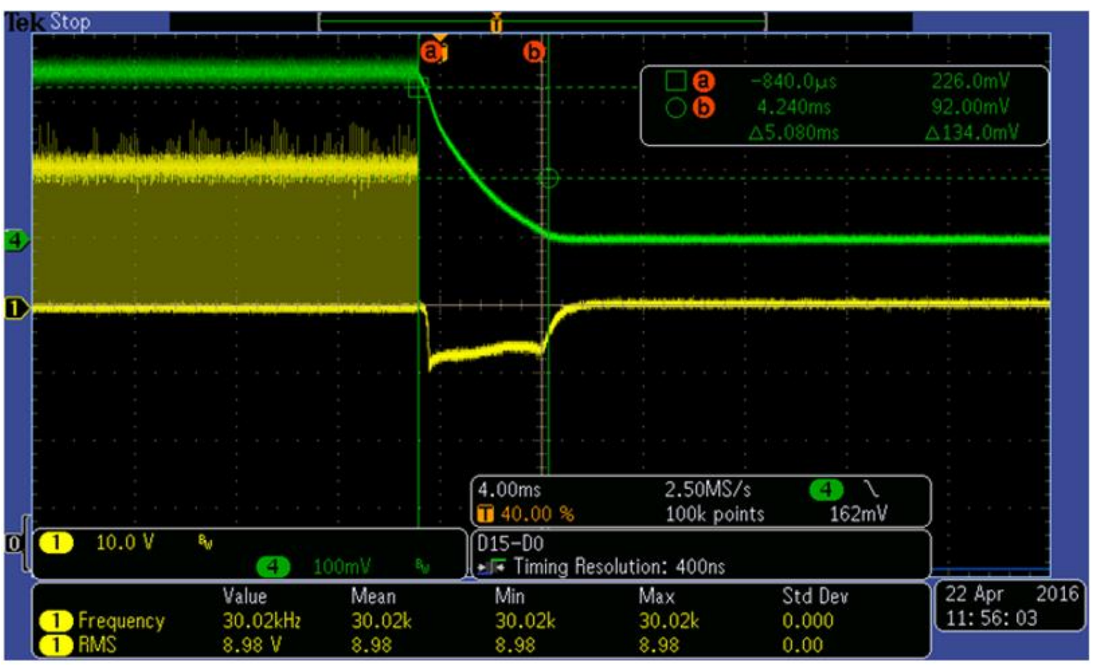

Fig. 6. The power supply voltage minus M1 drain voltage (yellow trace) and inductor L1 current (green trace) for the proposed Fast Solenoid Driver in Fig. 3. In this case, the decay time measured between points a and b is just 5.08 ms.

About The Author

Gregory Mirsky is a senior electrical engineer with Continental Automotive Systems in Deer Park, Ill., which he joined in March 2015. In his current role, Gregory performs design verification on various projects, designs and implements new methods of electronic circuit analysis, and runs workshops on MathCAD 15 usage for circuit design and verification.

He obtained a Ph.D. degree in physics and mathematics from the Moscow State Pedagogical University, Russia. During his graduate work, Gregory designed hardware for the high-resolution spectrometer for research of highly compensated semiconductors and high-temperature superconductors. He also holds an MS degree from the Baltic State Technical University, St. Petersburg, Russia where he majored in missile and aircraft electronic systems.

Gregory holds numerous patents and publications in technical and scientific magazines in Great Britain, Russia and the United States. Outside of work, Gregory's hobby is traveling, which is associated with his wife's business as a tour operator, and he publishes movies and pictures about his travels online.