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DC Solid State Power Controller Module

Description:
The Solid State Power Controller (SSPC) Module is a 40 Amp microcontroller-based Solid State Relay designed to be used in hi-rel 28V DC applications. This module has integrated current sensing with no derating over the full operating temperature range. The module is the electronic equivalent to an electromechanical circuit breaker with isolated control and status.

Compliant Documents & Standards:

MIL-STD-1275B, Notice1	Characteristics of 28 Volt DC Electrical Systems in Military Vehicles – 20 April 2004
MIL-STD-704F	Aircraft Electrical Power Characteristics - 12 March 2004
MIL-STD-217F, Notice 2	Reliability Prediction of Electronic Equipment - 28 Feb 1995

Module Features:
- Epoxy Shell Construction
- Solid State Reliability; Low Weight (20 gms) - High Power Density
- Same Pin Out as Industry Standard SSPCs in a Smaller Outline
- Extremely Low Power, No Derating Over the Full Temperature Range

Electrical Features:
- 28VDC Input: Current Rating of 40A with Very Low Drop; 24mV, typ.
- True I^2t Protection from 50A to 400A with Nuisance Trip Suppression
- Instant Trip Protection (50 μsec typ) for Loads Above 400A
- Unlimited Interrupt Capability; Repetitive Fault Handling Capability
- Thermal Memory
- Internally Generated Isolated Supply to Drive the Switch
- Low Bias Supply Current: 20 mA typ @ 5V DC
- High Control Circuit Isolation: 750V DC Control to Power Circuit
- Soft Turn-On to Reduce EMC Issues
- EMI Tolerant
- Module Reset with a Low Level Signal; Trip Reset Circuit is Trip-Free
- TTL/CMOS Compatible, Optically Isolated, Input and Outputs
- Schmitt-Trigger Control Input for Noise Immunity

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Table 1 - Electrical Characteristics (at 25 °C and V_{bias} = 5.0V DC unless otherwise specified)

Control & Status (TTL/CMOS Compatible)	
BIAS (Vcc)	5.0V DC Nominal, 6.5V DC Absolute Maximum 4.5V to 5.5 VDC
BIAS (Vcc) Current	20 mA typ 25 mA, max
GATE Status, Load Status Signals	V_{oh}=3.7V, min, at I_{oh}=-20mA V_{ol}=0.4V, max, at I_{ol}=20mA
CONTROL Signal V_{T+} (Positive-going input threshold voltage) V_{T-} (Negative-going input threshold voltage) ΔV_T Hysteresis (V_T+ V_T−)	 2.0V, min, 3.5V, max 1.2V, min, 2.3V, max 0.6V, min, 1.4V, max
Reset	Cycle CONTROL Signal

Power	
Input Voltage – Continuous – Transient	0 to 40V DC, 50V DC Absolute Maximum +600V or –600V Spike (≤ 10 uS)
Power Dissipation	< 0.7W typ @ 25A @ 25°C < 1.75W max @ 40A @ 25°C < 2.55W max @ 40A @ 100°C
Current	40A Continuous See Trip Curve
Max Voltage Drop	24 mV typ @ 25A, T_A = 25 °C 40 mV max @ 40A, T_A = 25 °C 60 mV max @ 40A, T_A = -55 °C ~ 100 °C
Max current without tripping	44A DC, min
Trip time	See Trip Curve
Output Rise Time (turn ON)	110 µsec typ
Output Fall Time under normal turn-off	110 usec typ
Output Fall Time under Fault	50 usec typ
Min Load Requirement	Nil

Protection	
Short Circuit Protection	Unlimited
Instant Trip	800%, min; 1200%, max

Physical Characteristics

Temperature	
Operating Temperature	T_A = -55 °C to +100 °C
Storage Temperature	T_A = -55 °C to +125 °C

Environmental	
Altitude	Up to 30,000 ft Can be installed in an unpressurized area
Case Dimensions	1.825"L x 1.25"W x 0.38"H
Operating Orientation	Any
Weight	20 grams typ
MTBF (Estimate: MIL STD 217F)	1.1 Mhrs at 25°C Full load

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Figure 1 - Trip Curve

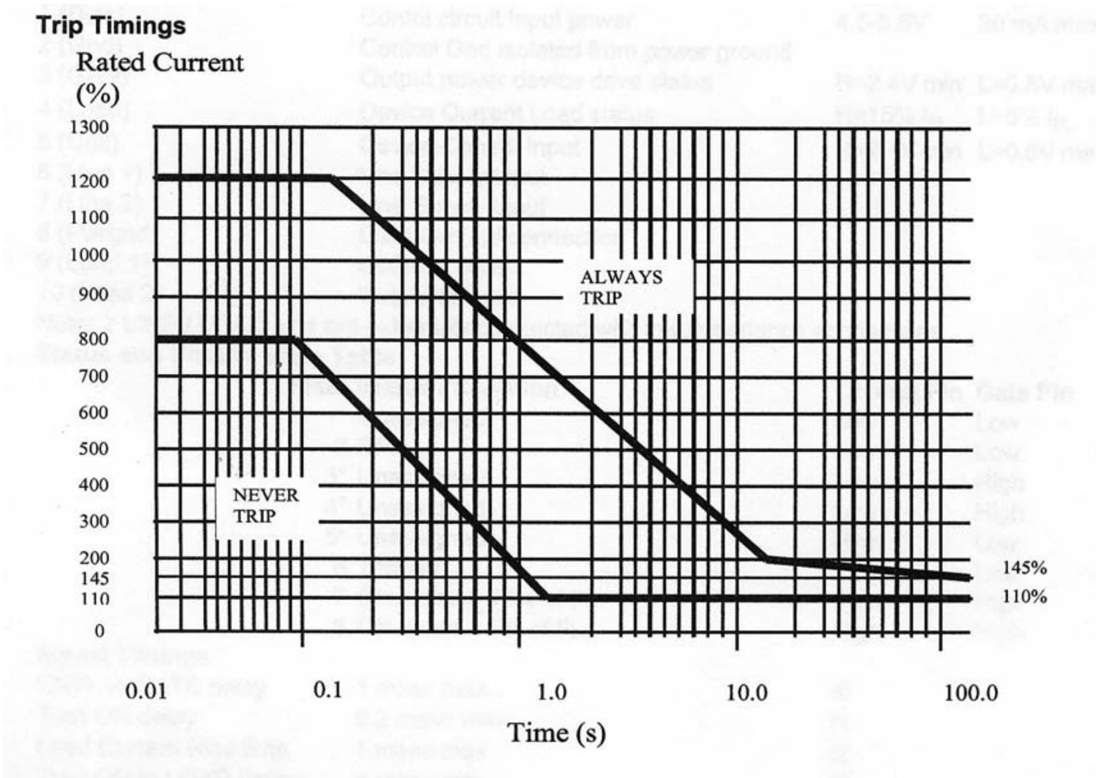

Figure 2 - Timing Diagram

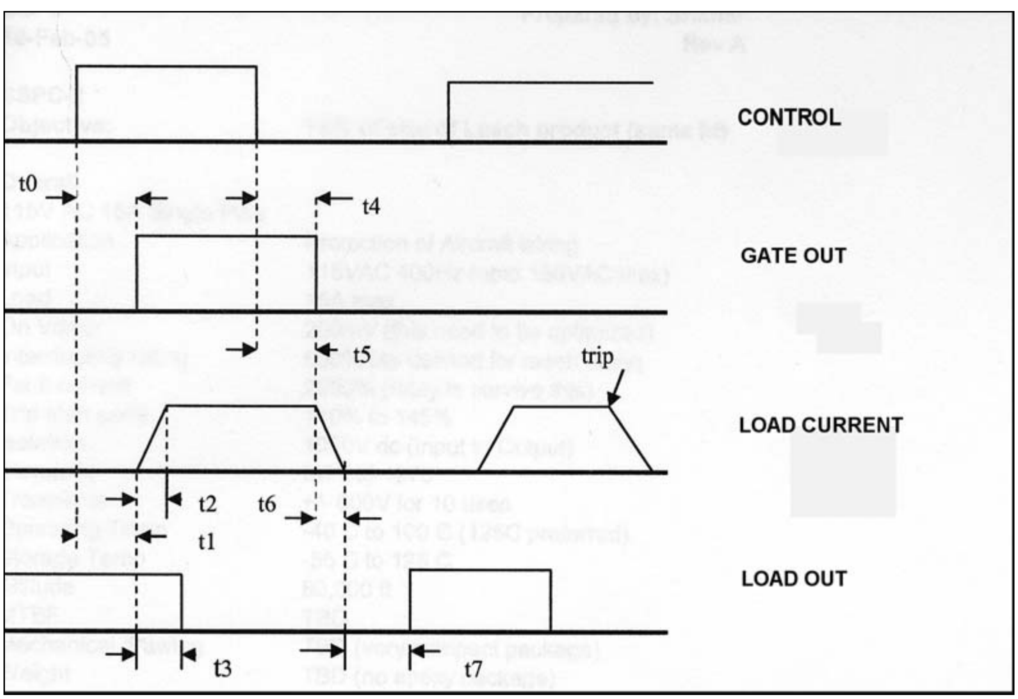

Table 2 - Signal Timing – (-55 °C to 100 °C @ LINE = 28V DC)

Parameter	Symbol	Min	Max	Units
CONTROL to GATE Status Delay for Turn On	t0		1	mS
Turn ON Delay	t1		200	µS
Load Current Rise Time	t2	50	200	µS
Turn ON to LOAD Status Delay	t3		1	mS
CONTROL to GATE Status Delay for Turn Off	t4		1	mS
Turn OFF Delay	t5		200	µS
Load Current Fall Time	t6	50	200	µS
Turn OFF to LOAD Delay	t7		1	mS

Note: Current Fall Time from trip dependent on magnitude of overload

Figure 3 - Mechanical Dimensions

All Dimensions are in Inches

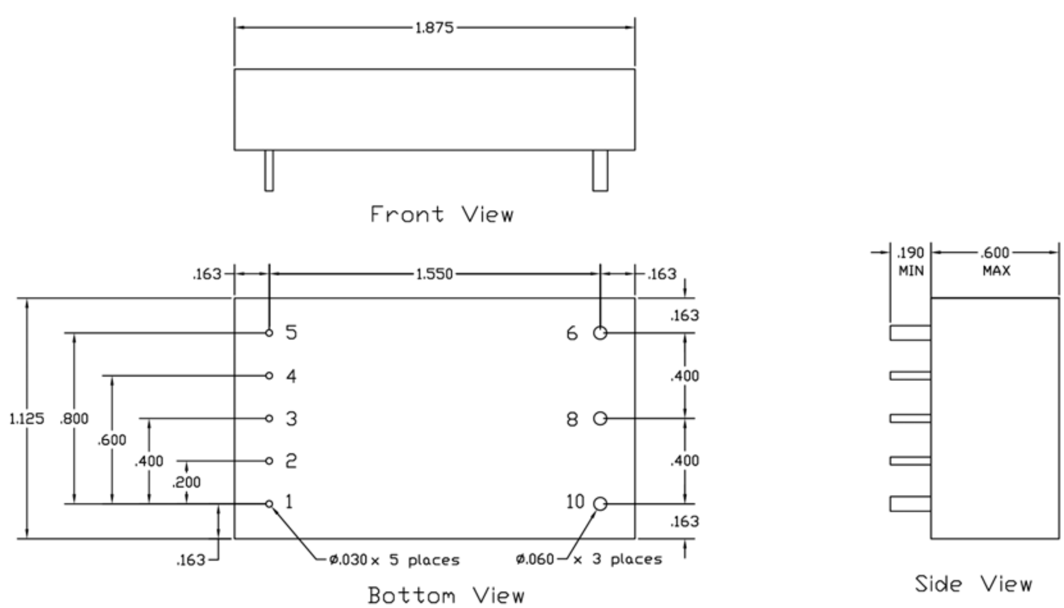

Table 3 - Pin Definitions

Pin Number	Pin Name	Function
1	BIAS	+5V DC Supply
2	GND	5V Return
3	GATE Status	Switch Status
4	LOAD Status	Load Current Detection
5	CONTROL Input	On/Off Control
6	LINE	+28V DC Supply
7	---	No Pin
8	PWRGND	28V Return
9	---	No Pin
10	LOAD	Load Connection

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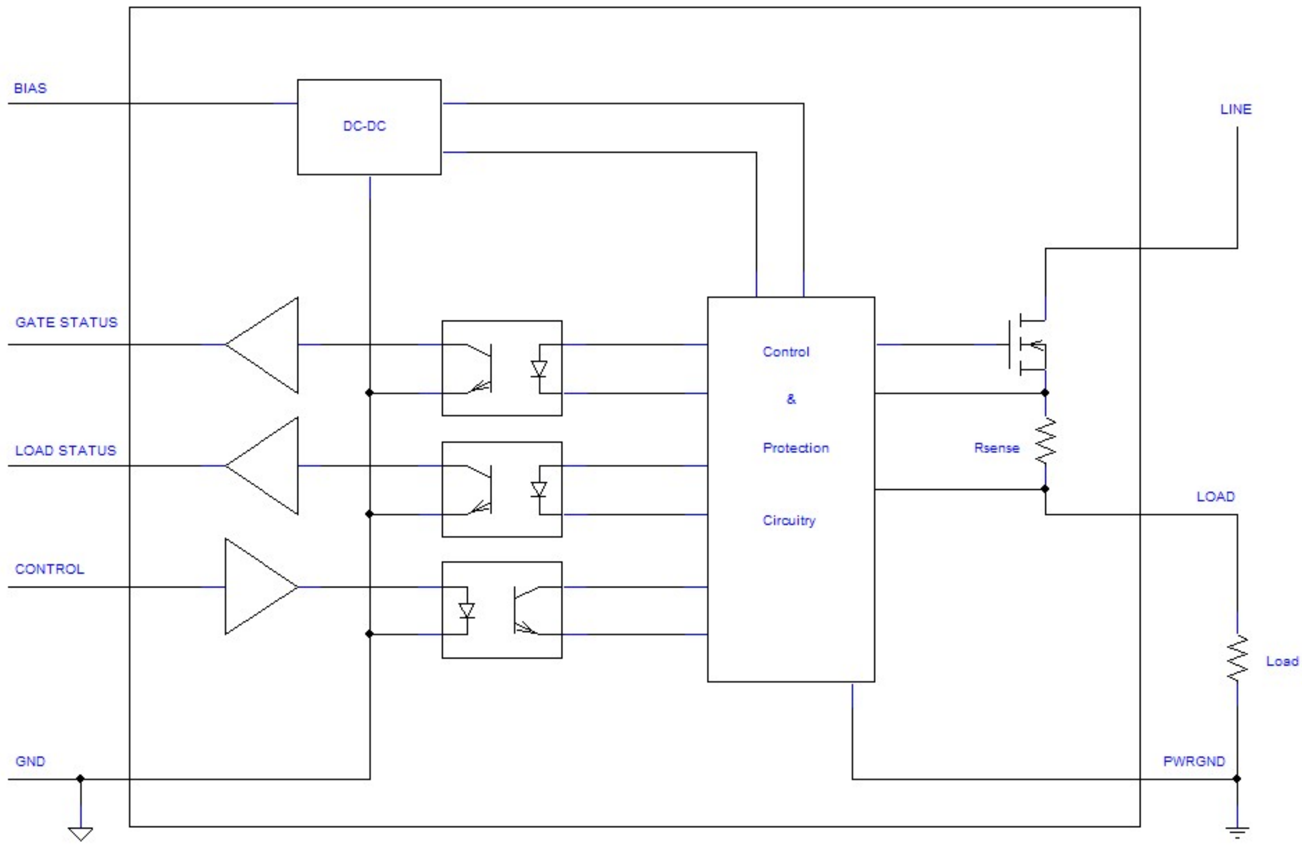

Figure 4 - Electrical Block Diagram

Description

Figure 4 shows the block diagram of the SPD40D28. It uses a SN74LVC3G14 device for digital I/O. This TTL compatible device has a Schmitt-Trigger input to minimize the effects of noise on the input. Its outputs can each drive more than 10 standard TTL loads. It's also compatible with CMOS inputs and outputs. The SN74LVC3G14 is isolated from the remainder of the module circuitry by three optocouplers.

The block labeled "Control & Protection Circuitry" gets power from the DC-DC converter and is referenced to the output of the SPD40D28. This block contains an amplifier to gain up the voltage developed across the sense resistor. It also contains a microcontroller with on-board timers, A/D converter, clock generator and independent watchdog timer. The microcontroller implements a precision I^2t protection curve as well as an Instant Trip function to protect the wiring and to protect itself. It performs all of the functions of multiple analog comparators and discrete logic in one high-reliability component.

The code programmed in the microcontroller acquires the output of the internal A/D converter, squares the result and applies it to a simulated RC circuit. It checks the output of the simulated circuit to determine whether or not to trip (turn off the power Mosfets). Because the microcontroller simulates an analog RC circuit, the SSPC has 'thermal memory'. That is, it trips faster if there had been current flowing prior to the overload than if there hadn't been current flowing. This behavior imitates thermal circuit breakers and better protects the application's wiring since the wiring cannot take as much an overload if current had been flowing prior to the overload.

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The watchdog timer operates from its own internal clock so a failure of the main clock will not stop the watchdog timer. The code programmed in the microcontroller will periodically reset the watchdog timer preventing it from timing out. If the code malfunctions for any reason, the watchdog timer is not reset and it times out. When the watchdog timer times out, it resets the microcontroller. Since the code is designed to detect levels and not edges, the output of the module, and therefore the output of the SPD40D28, immediately reflects the command on its input.

The Power Mosfets used in the SPD40D28 have been selected for very low $R_{ds(on)}$ and results in low voltage drop and low power dissipation. In most applications, the SPD40D28 will be operated at 50 – 60% of rated current to provide a safety margin. As can be seen in Table 1, when the SPD40D28 is operated at 25 Amps, 62.5% of rated current, it only dissipates 0.7 Watt at room temperature. No heatsinking is required for this condition. However, if the SPD40D28 is to be operated at maximum rating and/or at elevated temperatures, the dissipation can exceed 2.5 watts and heatsinking may be required. Some heatsinking can be accomplished by adding copper area to the LINE and LOAD pins, a heatsink can be epoxied to the surface of the module or a flat copper or aluminum heatsink can be sandwiched between the SPD40D28 and the printed circuit board using a thermal pad to maximize heat transfer. Each application should be evaluated at maximum expected constant current.

For overloads, no heatsinking is required providing the SPD40D28 is allowed some time to cool down. The SPD40D28 has sufficient thermal mass that the temperature will rise only a few degrees under the worst-case overload. Repetitive overloads should be avoided. When the SPD40D28 reports a trip condition, the controller driving the SPD40D28 should allow no more than four repetitions and then allow a few minutes to cool down before trying to turn on again.

The SPD40D28 will trip on overloads in the ALWAYS TRIP region shown in Figure 1 and will never trip when in the NEVER TRIP region. The SPD40D28 can be reset by bringing the CONTROL pin to a logic low. When the CONTROL pin is brought back to a logic high, the SPD40D28 will turn back on. If the overload is still present, the SPD40D28 will trip again. Cycling the 5 Volt BIAS power will also reset the SPD40D28. If the CONTROL pin is at a logic high when the BIAS power is cycled, the SPD40D28 will turn back on when the BIAS power is re-applied.

Status Outputs
The LOAD and GATE status outputs of the SPD40D28 show whether or not the load is drawing current and whether or not the SPD40D28 Power Mosfet switch is on. A logic high on the LOAD status output shows that the load draws $\leq$ 5% of rated load and a logic low shows that the load draws $\geq$ 15% of rated current. A load that draws between 5% and 15% of rated current could result in either a high or low logic level on the LOAD status output. A logic high on the GATE output indicates that the Power Mosfet switch is on while a logic low indicates that the switch is off.

As can be seen in Table 4, of the 8 possible states for the combination of CONTROL, LOAD and GATE, only 3 states represent valid SSPC operation. The other 5 states indicate either a failed SSPC or, more likely, a short to ground or a short to the BIAS supply of one of the logic outputs. By comparing the CONTROL input with the LOAD and GATE outputs, the user can determine whether or not the load is supposed to be on (GATE), whether or not it's drawing current (GATE) and whether or not the LOAD and GATE outputs are valid responses to the CONTROL input.

State	CONTROL	LOAD	GATE	Comments
1	L	L	L	SSPC failure or shorted LOAD output to ground
2	L	L	H	SSPC failure
3	L	H	L	Normal OFF condition
4	L	H	H	SSPC failure or shorted GATE output to BIAS supply
5	H	L	L	SSPC failure or shorted GATE output to ground
6	H	L	H	Normal ON condition with load current > 15% rated current
7	H	H	L	Tripped
8	H	H	H	Normal ON condition with load current < 5% rated current

Table 4 – CONTROL, LOAD & GATE Truth Table

Wire Size

MIL-W-5088L has a chart the shows wire size as a function of wire temperature and current. This chart is for a single copper wire in free air. For an ambient temperature of 70 ^{o}C, the chart allows an 14-gauge wire to handle 40 Amps continuously at a wire temperature of 200 ^{o}C – a wire temperature rise of 130 ^{o}C. For a wire temperature limited to 150 ^{o}C, the chart requires a 12-gauge wire and for a wire temperature of 105 ^{o}C, the chart requires a 10-gauge wire.

Amendment 1 of MIL-W-5088L has a table for copper wire in a bundle, group or harness with conditions on the number of wires, percent of total harness capacity, etc. This table shows that a 8-gauge wire is necessary for 200 ^{o}C operation, 8 gauge for 150 ^{o}C and 6 gauge for 105 ^{o}C.

MIL-W-5088L has various figures showing derating for harnesses as a function of the number of current carrying conductors and for altitude. MIL-W-5088L only specifies wire for DC or RMS AC conditions, not for transient or overload conditions.

For transient or overload conditions, the transient or overload happens so quickly that heat is not transferred from the wire to the surroundings. The heat caused by the I^2R heating of the wire causes the temperature to rise at a linear rate controlled by the heat capacity of the wire. The equation for this linear rise in temperature, with respect to time, can be solved as: I^2t = constant. Every wire has an I^2t rating that's dependent on the temperature rise allowed and the diameter of the wire. If the I^2t rating of the SSPC or circuit breaker is less than the I^2t rating of the wire, then the SSPC or circuit breaker can protect the wire. The maximum I^2t rating for the SPD40D28 is 19.1 x 10^3 Amp^2-Seconds. Every wire size in the paragraphs above has an I^2t rating that exceeds the SPD40D28 I^2t rating for the temperature rises stated. Therefore, to select a wire size, it's simply a matter of determining the maximum temperature rise of the application and deciding whether or not the wire will be in a bundle and use the information above.

Application Connections

The SPD40D28 may be configured as a high-side or low-side switch and may be used in positive or negative supply applications. Figure 5 shows the connections as a high-side switch with a positive power supply.

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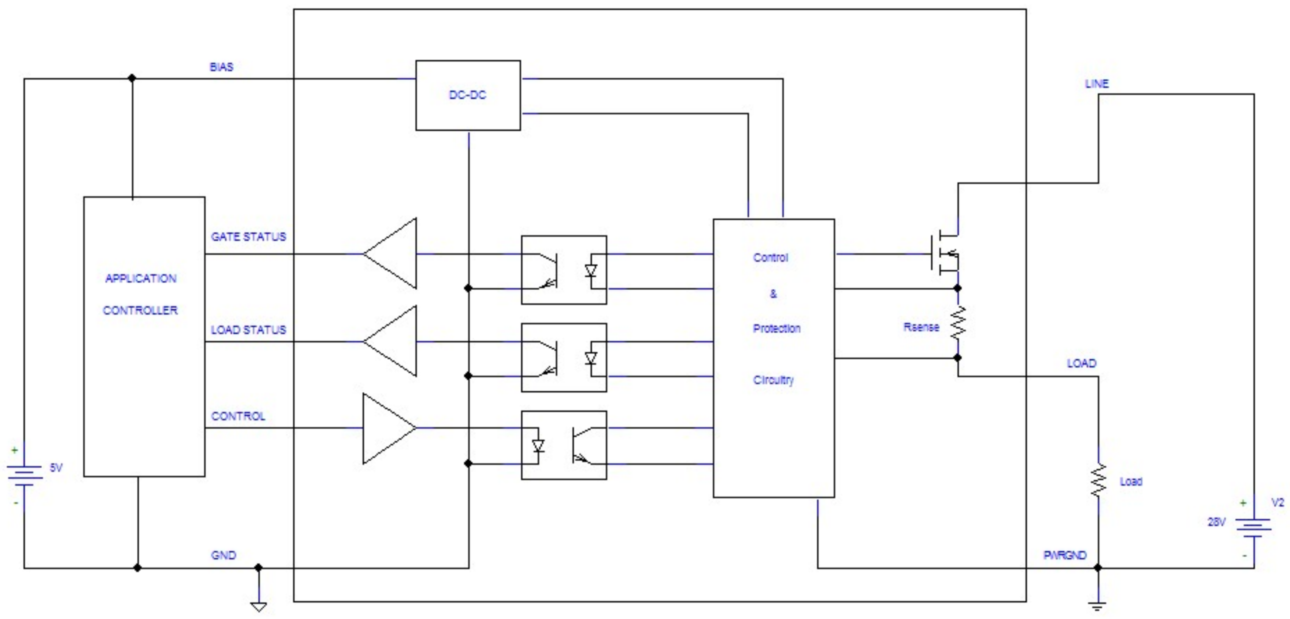

Figure 5 – High-Side Switch, Positive Supply

Figure 6 shows a low-side switch with a negative power supply. Note that the PWRGND pin is now connected to the LINE pin (see Rise/Fall Time paragraph below for more information on the PWRGND pin).

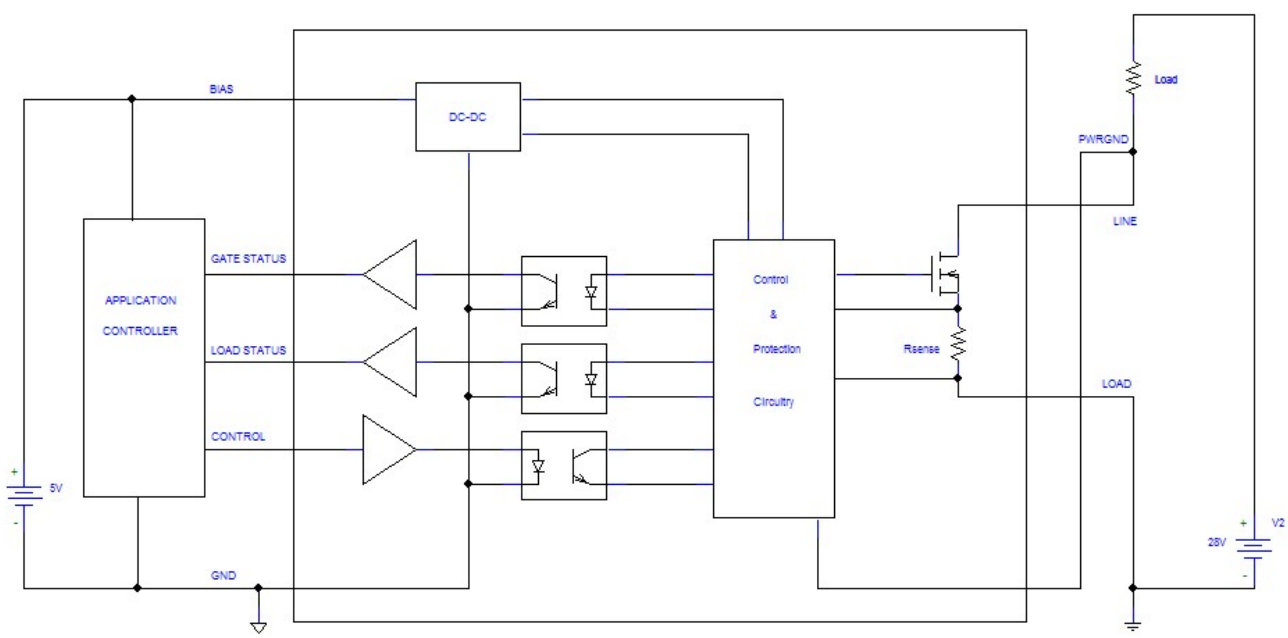

Figure 6 – Low-Side Switch, Positive Supply

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Figure 7 and Figure 8 show negative supply high-side switch and low-side switch implementations. Again, note the connection of the PWRGND pin.

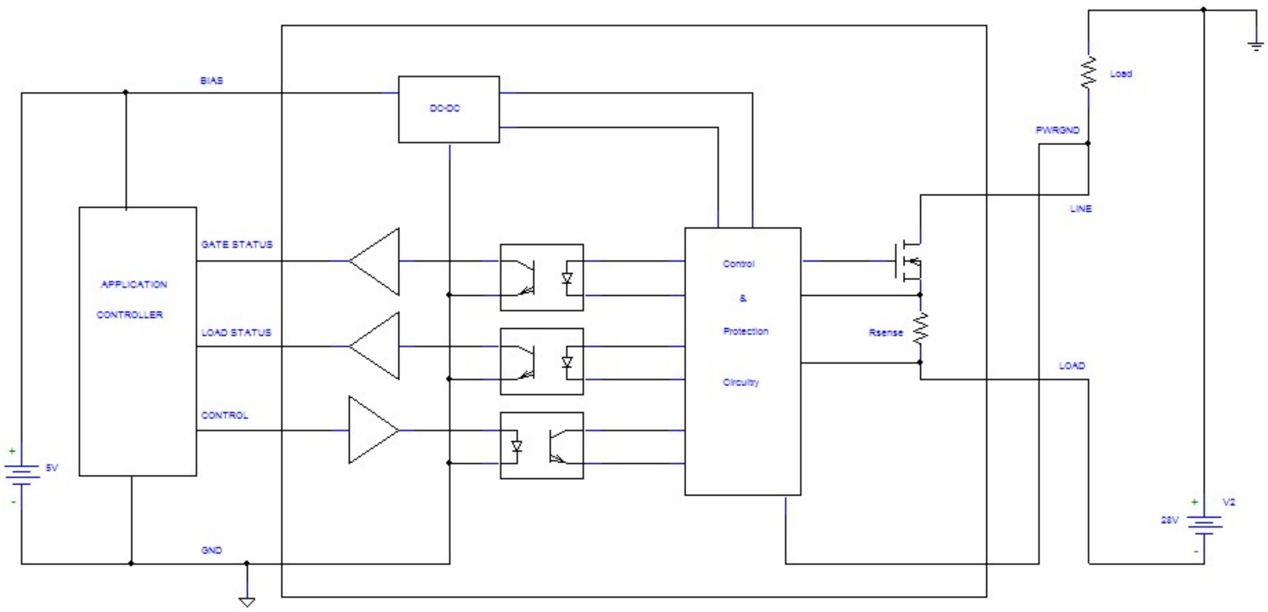

Figure 7 – High Side Switch, Negative Supply

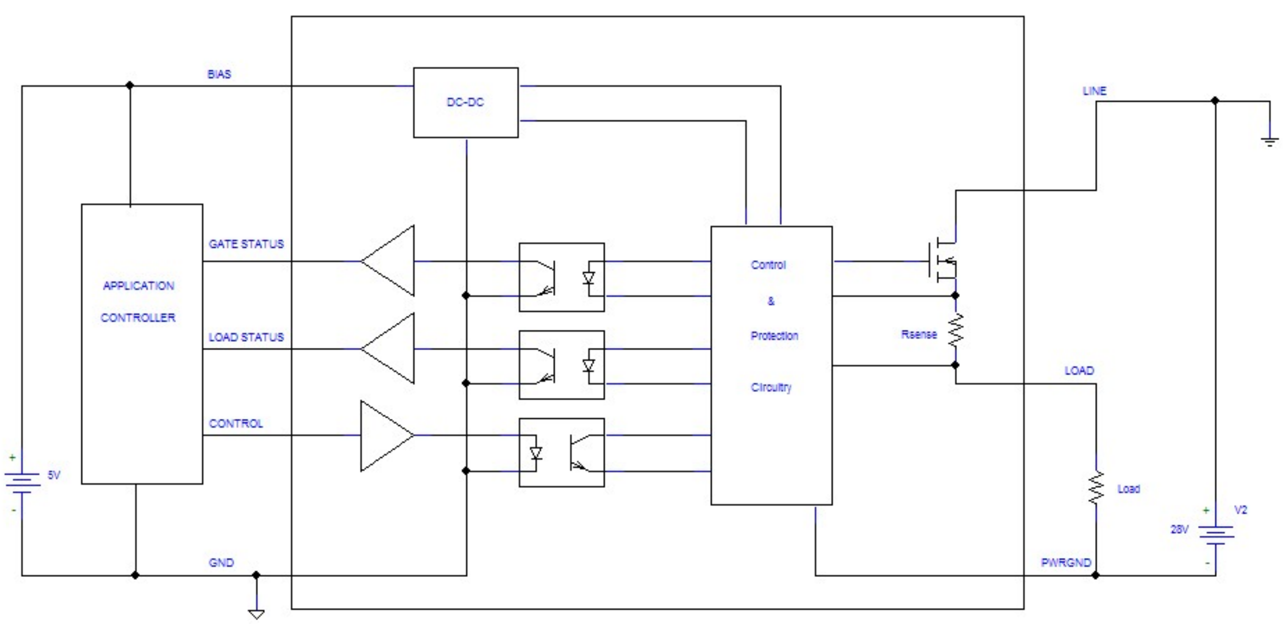

Figure 8 – Low Side Switch, Negative Supply

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Rise Time & Fall Time
The rise and fall times of the SPD40D28 is pre-set at the factory for a nominal 100uS with a LINE supply of 28VDC (see Table 2 for min/max limits). The rise and fall times will vary linearly with supply voltage. The PWRGND pin is used to control the rise and fall times. If the PWRGND pin is left open, the rise and fall times will be about 50uS. Leaving the PWRGND pin open can be useful when a faster rise or fall time is desirable.

With the PWRGND pin connected as in Figures 5 through 8, the SPD40D28 can turn on into a capacitive load of 700uF, min, 1400uF, typ, without tripping for any power supply voltage within the ratings.

Wiring and Load Inductance
Wiring inductance can cause voltage transients when the SPD40D28 is switched off due to an overload. Generally, these transients are small but must be considered when long wires are used on either the LINE or LOAD pins or both. A 10 foot length of wire in free air will cause a transient voltage of about 16 Volts when the SPD40D28 trips at an Instant Trip level of 400 Amps. At the rated load current of 40 Amps, the voltage transient will be less than 2 Volts. If longer wire lengths are used, a transient suppressor may be used at the LINE pin and a power diode may be used at the LOAD pin so that the total voltage between the LINE and LOAD pins is less than 50 Volts.

When powering inductive loads, the negative voltage transient at the LOAD pin can cause the voltage between LINE and LOAD to exceed the SPD40D28 rating of 50 Volts and a power diode from the LOAD pin to ground must be used. The cathode of the power diode is connected to the LOAD pin with the anode connected to ground. The power diode must be able to carry the load current when the SPD40D28 switches off.

Paralleling
Putting two SPD40D28s in parallel will not double the rating to 80 Amps. Due to differences in the $R_{ds(on)}$ of the Power Mosfets in the SPD40D28s, the current will not share equally. In addition, there are unit-to-unit differences in the trip curves so that two SPD40D28s in parallel may possibly trip at 55 Amps. Also, both SPD40D28s will not trip together; the SPD40D28 carrying the higher current will trip first followed by the other SPD40D28. Multiple SPD40D28s may be used in parallel as long as these complexities are appreciated.

Board Layout
The current-carrying power circuit should be kept well away from the control circuit and other low-level circuits in the system. It's unlikely, but possible, that magnetic coupling could affect the control circuit when turning normal loads on and off. However, in the case of an overload, the magnetic coupling could be 10 times greater than with normal loads. Effects of such coupling could cause 'chattering' when turning on and off, oscillation, and the possibility of turning the SPD40D28 back on after an overload. The SPD40D28 is a Trip-Free device. Once tripped it will not turn back on until reset and commanded on again. Reset is accomplished by bringing the CONTROL pin low and turning the SPD40D28 back on is accomplished by bringing the CONTROL pin high. Sufficient magnetic coupling between the current-carrying power circuit and the control circuit can negate the Trip-Free characteristic.

MIL-STD-704F and MIL-STD-1275B
These standards cover the characteristics of the electrical systems in Military Aircraft and Vehicles. The SPD40D28 meets all of the requirements of MIL-STD-704F including Normal, Emergency, Abnormal and Electric Starting conditions with the Ripple, Distortion Factor and Distortion Spectrum defined in the standard. The SPD40D28 also meets all of the requirements of MIL-STD-1275B including operation with Battery and Generator, Generator Only and Battery Only for all of the conditions described in the standard including Cranking, Surges, Spikes and Ripple.

In addition, the SPD40D28 can withstand $\pm$ 600 V spikes for 10uS. This capability is beyond that required by the standards cited above.

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