

DC Solid State Power Controller Module

Description:

The Solid State Power Controller (SSPC) Module is a microcontroller-based Solid State Relay rated upto 25A designed to be used in Army, Air force and Navy in 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.

This series is supplied in 3 product families covering 9 current ranges:

SPD5D28 Family:

- SPD5D28-1: 1A
- SPD5D28-3: 3A
- SPD5D28-5: 5A

SPD15D28 Family:

- SPD14D28-7: 7A
- SPD14D28-10: 10A
- SPD14D28-14: 14A

SPD25D28 Family:

- SPD25D28-15: 15A
- SPD25D28-20: 20A
- SPD25D28-25: 25A

Compliant Documents & Standards:

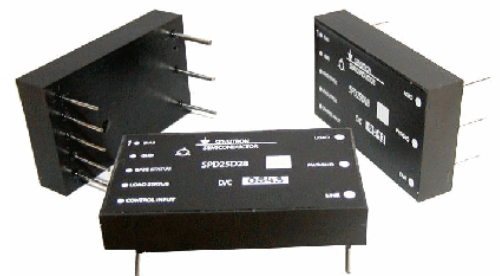
MIL-STD-1275B, Notice 1	Characteristics of 28 Volt DC Electrical Systems in Military Vehicles-4/20/04
MIL-STD-704F	Aircraft Electrical Power Characteristics 12 March 2004
MIL-STD-217F, Notice 2	Reliability Prediction of Electronic Equipment 28 Feb 1995

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 (SPDXXD28 Series):

- 28VDC Input with Very Low Voltage Drop; 60mV, typ. @15A
- True I^2t Protection from 32A to 250A with Nuisance Trip Suppression
- Instant Trip Protection (50 μ sec typ) for Loads Above 250A
- 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; 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 (V_{cc})	5.0V DC Nominal, 6.5V DC Absolute Maximum 4.5V to 5.5 VDC
BIAS (V_{cc}) 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 ($\leq 10 \mu s$)
Power Dissipation	See Table 4
Current	See Table 4 See Trip Curve
Max Voltage Drop	See Table 4
Max current without tripping	110% min

Trip time	See Trip Curve
Output Rise Time (turn ON)	110 μs typ
Output Fall Time under normal turn-off	110 μs typ
Output Fall Time under Fault	50 μs typ
Min Load Requirement	Nil

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

Physical Characteristics

Temperature	
Operating Temperature	$T_A = -55^\circ C$ to $+100^\circ C$
Storage Temperature	$T_A = -55^\circ C$ to $+125^\circ C$

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

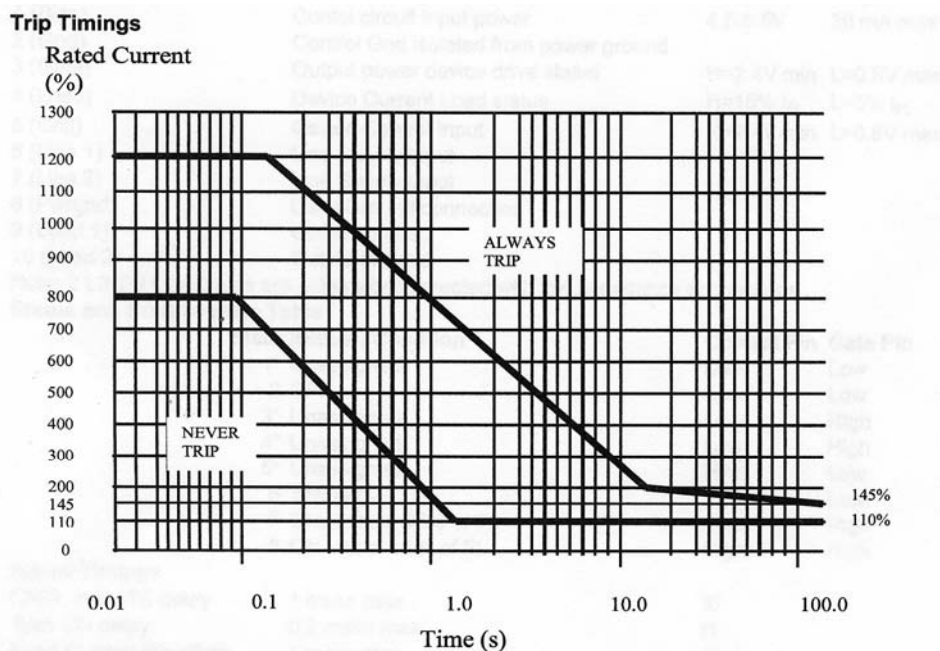
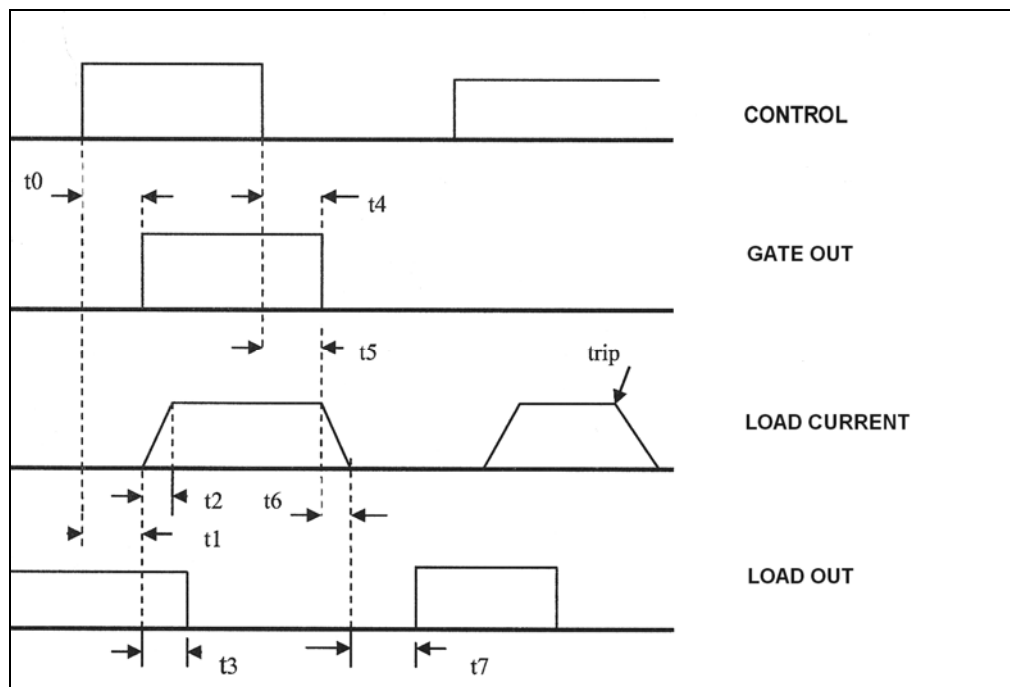


Figure 2 - Timing Diagram



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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

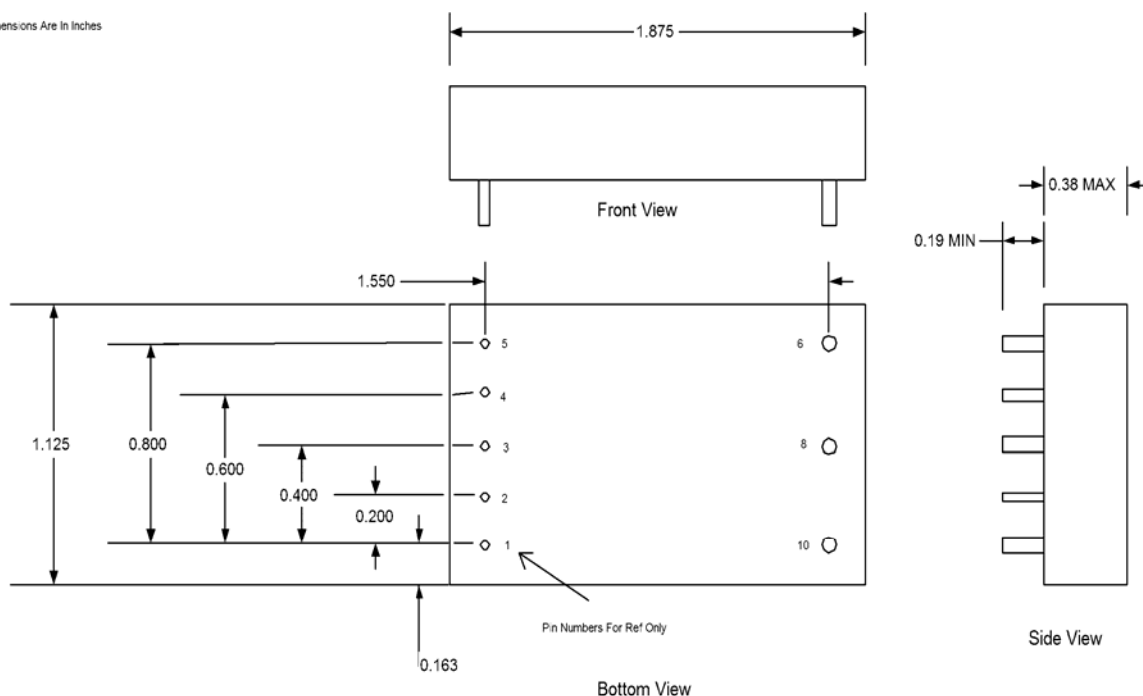


Table 3 - Pin Definitions

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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Table 4 – Individual Model Ratings

SPD5D28 Family

Model	SPD5D28-1	SPD5D28-3	SPD5D28-5
Current Rating @ 100°C	1A	3A	5A
Power Dissipation	0.01W typ @ 0.6A 25°C 0.035W max @ 1A 25°C 0.04W max @ 1A 100°C	0.04W typ @ 1.8A 25°C 0.14W max @ 3A 25°C 0.16W max @ 3A 100°C	0.09W typ @ 3A 25°C 0.30W max @ 5A 25°C 0.36W max @ 5A 100°C
Max Voltage Drop	18mV typ @ 0.6A 25°C 35mV max @ 1A 25°C 40mV max @ 1A 100°C	23mV typ @ 1.8A 25°C 46mV max @ 3A 25°C 53mV max @ 3A 100°C	30mV typ @ 3A 25°C 60mV max @ 5A 25°C 71mV max @ 5A 100°C

SPD14D28 Family

Model	SPD14D28-7	SPD14D28-10	SPD14D28-14
Current Rating @ 100°C	7A	10A	14A
Power Dissipation	0.15W typ @ 4.2A 25°C 0.49W max @ 7A 25°C 0.60W max @ 7A 100°C	0.26W typ @ 6A 25°C 0.87W max @ 10A 25°C 1.10W max @ 10A 100°C	0.48W typ @ 8.4A 25°C 1.61W max @ 14A 25°C 2.06W max @ 14A 100°C
Max Voltage Drop	35mV typ @ 4.2A 25°C 70mV max @ 7A 25°C 86mV max @ 7A 100°C	43mV typ @ 6A 25°C 87mV max @ 10A 25°C 110mV max @ 10A 100°C	57mV typ @ 8.4A 25°C 115mV max @ 14A 25°C 147mV max @ 14A 100°C

SPD25D28 Family

Model	SPD25D28-16	SPD25D28-20	SPD25D28-25
Current Rating @ 100°C	16A	20A	25A
Power Dissipation	0.41W typ @ 9.6A 25°C 1.44W max @ 16A 25°C 1.73W max @ 16A 100°C	0.60W typ @ 12A 25°C 2.11W max @ 20A 25°C 2.56W max @ 20A 100°C	0.90W typ @ 15A 25°C 3.15W max @ 25A 25°C 3.86W max @ 25A 100°C
Max Voltage Drop	43mV typ @ 9.6A 25°C 90mV max @ 16A 25°C 108mV max @ 16A 100°C	50mV typ @ 12A 25°C 105mV max @ 20A 25°C 128mV max @ 20A 100°C	60mV typ @ 15A 25°C 126mV max @ 25A 25°C 154mV max @ 25A 100°C

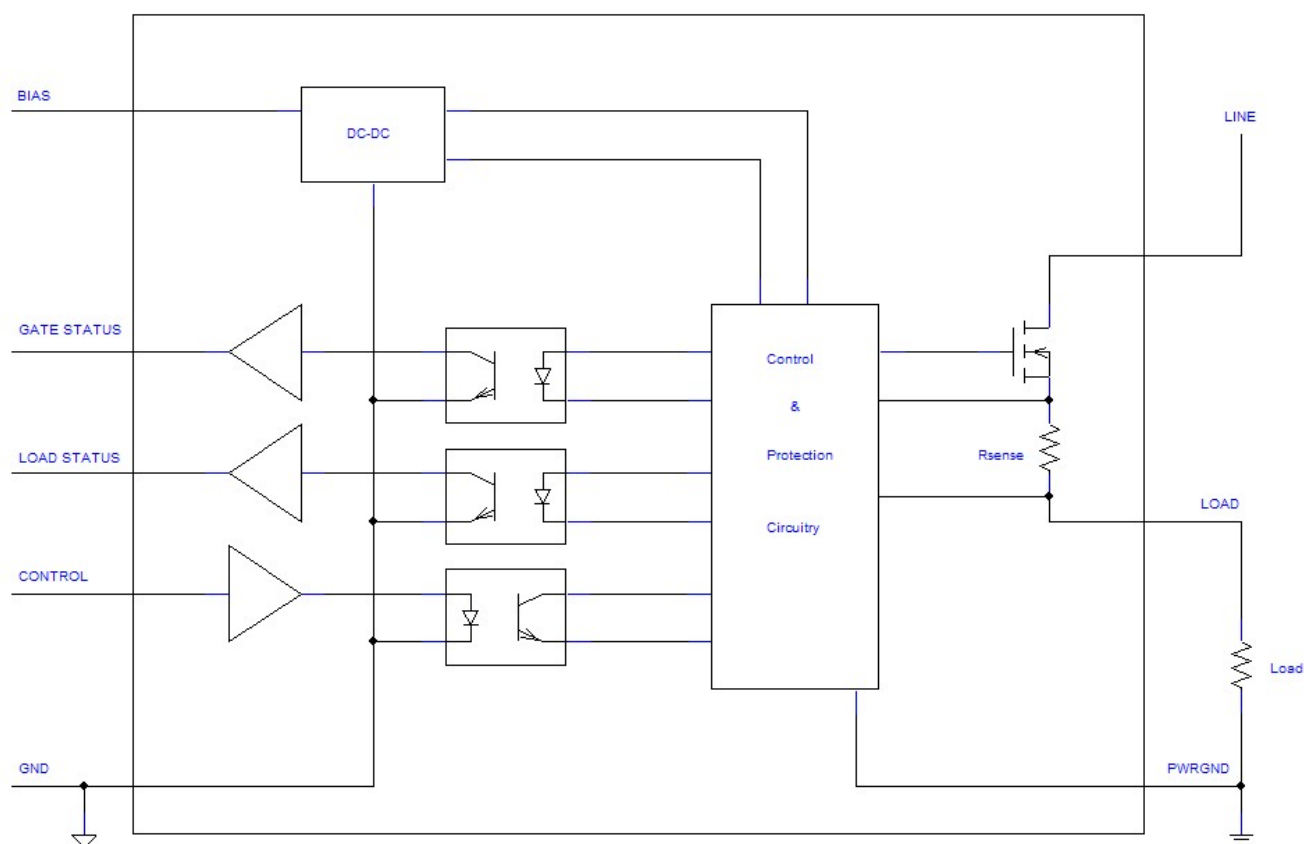
TECHNICAL DATA
DATASHEET 4310, Rev B**Figure 4 - Electrical Block Diagram****Description**

Figure 4 shows the block diagram of the SPDXXD28 SSPC Series. 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 SSPC. 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 SPDXXD28, immediately reflects the command on its input.

The Power Mosfets used in the SPDXXD28 Series have been selected for very low $R_{ds(on)}$ and results in low voltage drop and low power dissipation. In most applications, the SPDXXD28 will be operated at 50 – 60% of rated current to provide a safety margin. As can be seen in Table 1, when the SPD25D28 is operated at 15 Amps, 60% of rated current, it only dissipates 1.0 Watt at room temperature. No heatsinking is required for this condition. However, if the SPD25D28 is to be operated at maximum rating and/or at elevated temperatures, the dissipation can exceed 4 Watts and heatsinking is 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 SPD25D28 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 provided the SPDXXD28 Series is allowed some time to cool down. The SPDXXD28 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 SPDXXD28 reports a trip condition, the controller driving the SPDXXD28 should allow no more than four repetitions and then allow thirty seconds to cool down before trying to turn on again.

The SPDXXD28 will trip on overloads in the ALWAYS TRIP region shown in Figure 1 and will never trip when in the NEVER TRIP region. The SPDXXD28 can be reset by bringing the CONTROL pin to a logic low. When the CONTROL pin is brought back to logic high, the SPDXXD28 will turn back on. If the overload is still present, the SPDXXD28 will trip again. Cycling the 5 Volt BIAS power will also reset the SPDXXD28. If the CONTROL pin is at logic high when the BIAS power is cycled, the SPDXXD28 will turn back on when the BIAS power is re-applied.

Status Outputs

The LOAD and GATE status outputs of the SPDXXD28 show whether or not the load is drawing current and whether or not the SPDXXD28 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 (LOAD) and whether or not the LOAD and GATE outputs are valid responses to the CONTROL input.

Table 4 – CONTROL, LOAD & GATE Truth Table

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

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DATASHEET 4310, Rev B**Wire Size**

MIL-W-5088L has a chart that 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 °C, the chart allows an 18-gauge wire to handle 25 Amps continuously at a wire temperature of 200 °C – a wire temperature rise of 130 °C. For a wire temperature limited to 150 °C, the chart requires a 16-gauge wire and for a wire temperature of 105 °C, the chart requires a 14-gauge wire.

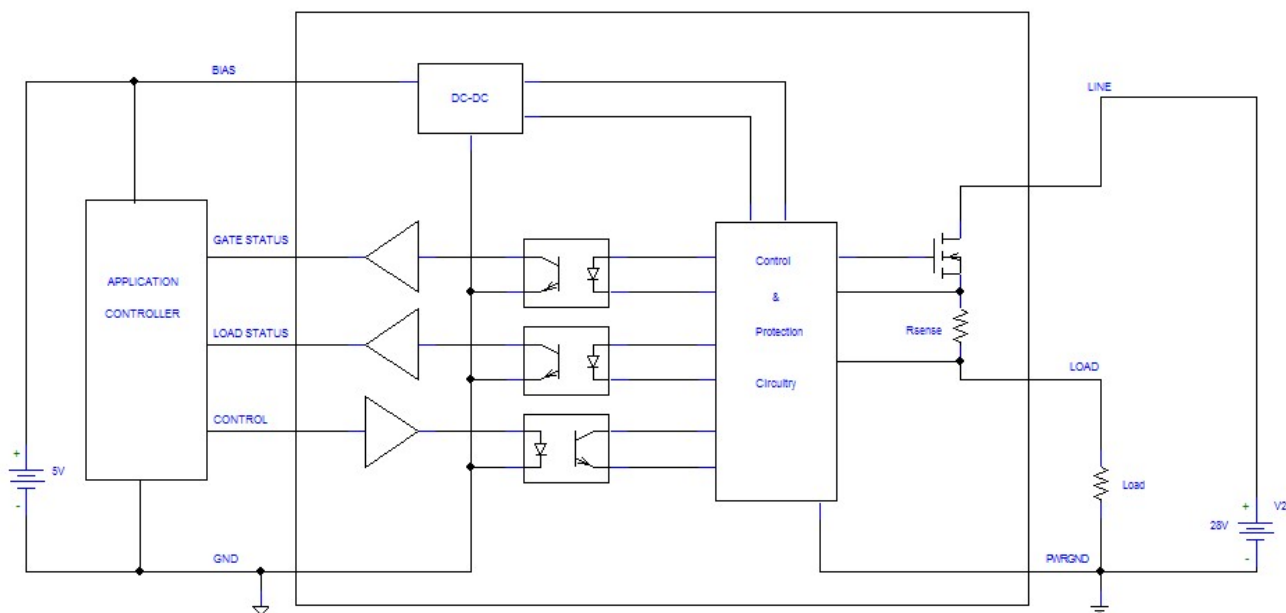
Amendment 1 of MIL-W-5088L has a table for copper wire in a bundle, group or harness with conditions on the number of wires, percent of total harness capacity, etc. This table shows that a 12 gauge wire is necessary for 200 °C operation, 10 gauge for 150 °C and 8 gauge for 105 °C.

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: $I^2t = \text{constant}$. 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 SPD25D28 is 7.45 Amp²-Seconds. Every wire size in the paragraphs above has an I^2t rating that exceeds the SPD25D28 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 SPDXXD28 Series 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.

**Figure 5 – High-Side Switch, Positive Supply**

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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).

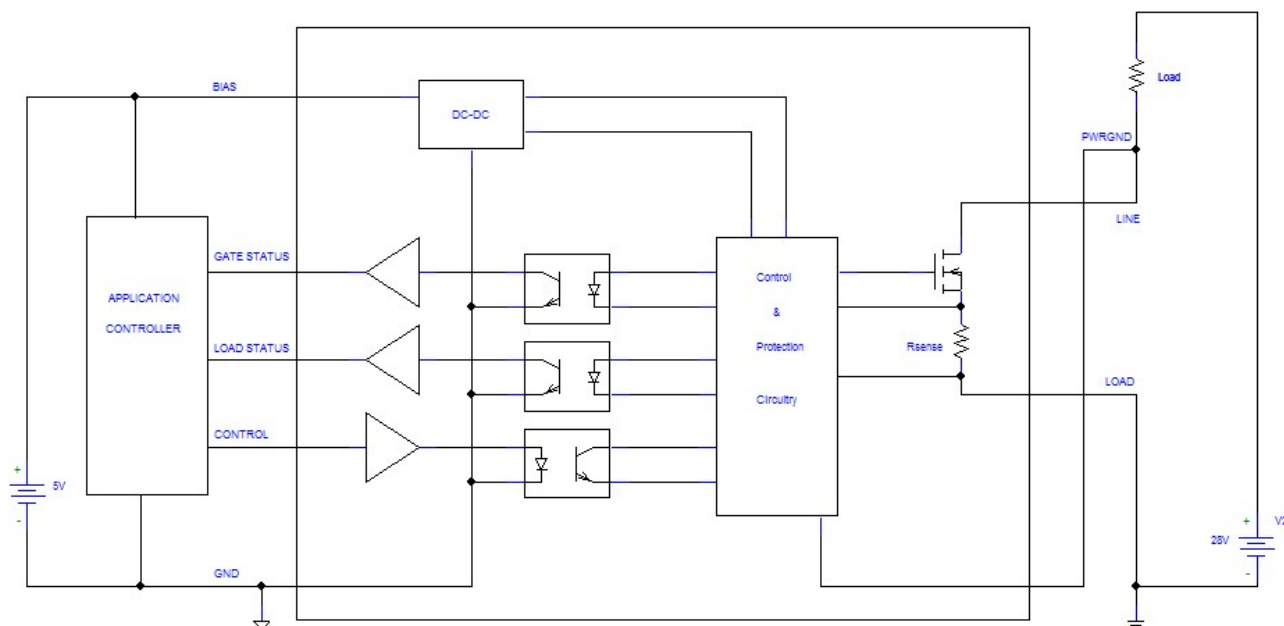


Figure 6 – Low-Side Switch, Positive Supply

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

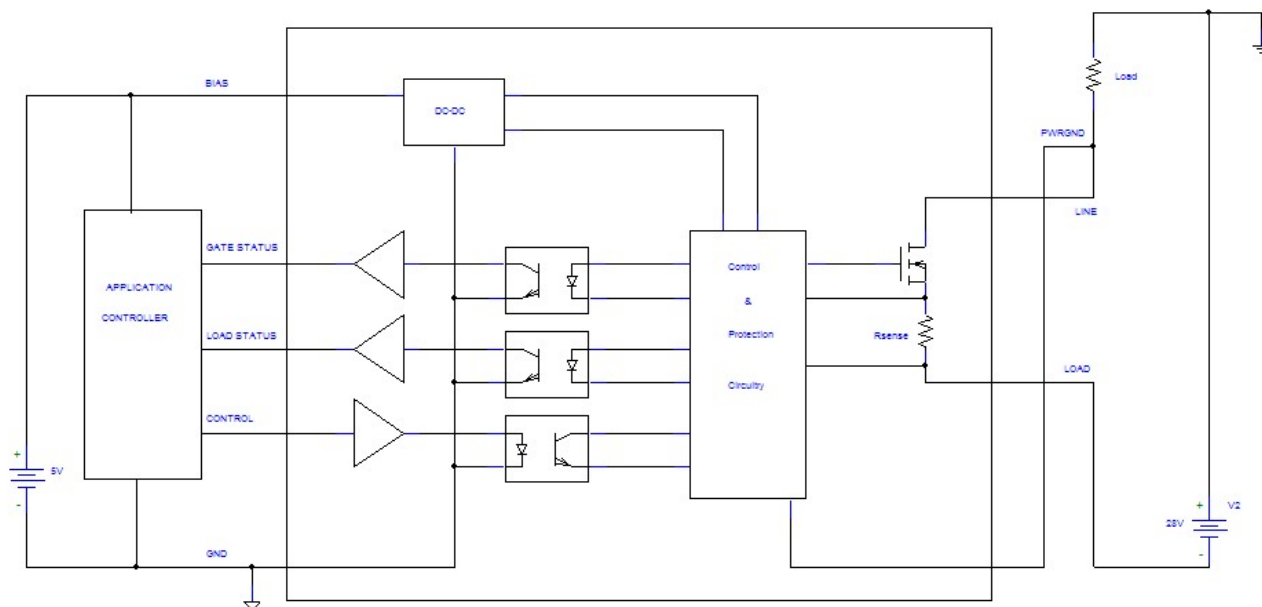


Figure 7 – High Side Switch, Negative Supply

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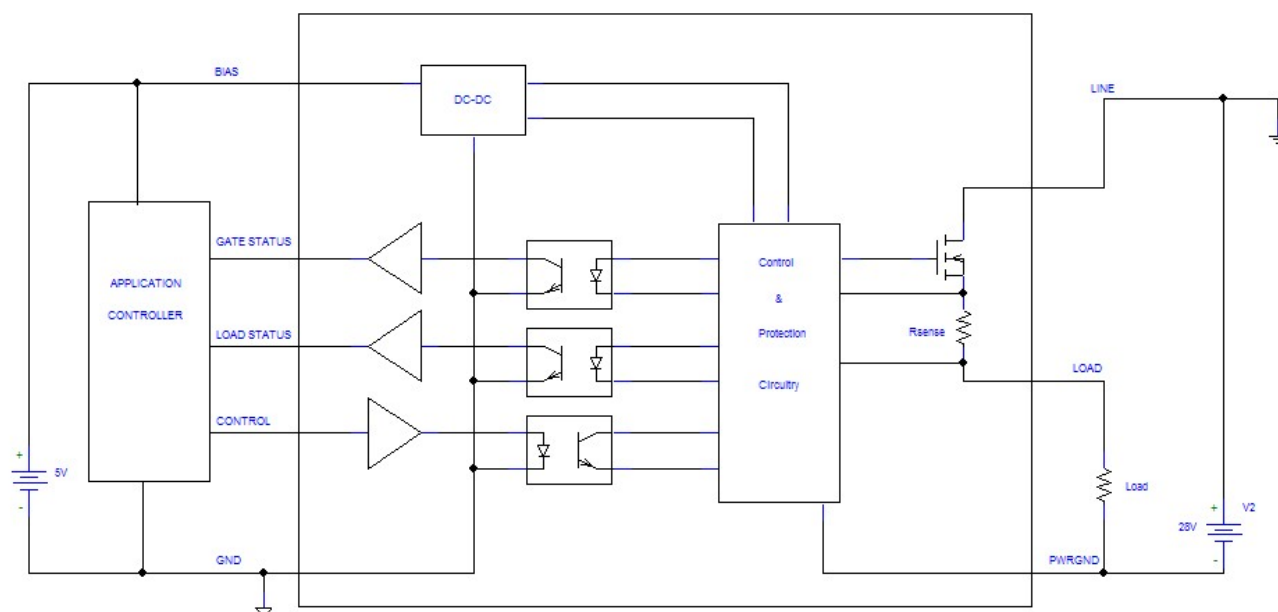


Figure 8 – Low Side Switch, Negative Supply

Rise Time & Fall Time

The rise and fall times of the SPDXXD28 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 SPDXXD28 can turn on into a capacitive load of 440uF, min, 880uF, typ, without tripping for any power supply voltage within the ratings.

Wiring and Load Inductance

Wiring inductance can cause voltage transients when the SPDXXD28 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 10 Volts when the SPD25D28 trips at an Instant Trip level of 250 Amps. At the rated load current of 25 Amps, the voltage transient will be about 1 Volt. 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 SPDXXD28 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 SPDXXD28 switches off.

Paralleling

For example, putting two SPD25D28s in parallel will not double the rating to 50 Amps. Due to differences in the $R_{ds(on)}$ of the Power Mosfets in the SSPCs, the current will not share equally. In addition, there are unit-to-unit differences in the trip curves so that two SPD25D28s in parallel may possibly trip at 35 Amps. Also, both SPD25D28s will not trip together; the SPD25D28 carrying the higher current will trip first followed by the other SPD25D28. Multiple SPD25D28s may be used in parallel as long as these complexities are appreciated.

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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 SPDXXD28 back on after an overload. The SPDXXD28 Series 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 SSPC 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 SPDXXD28 Series 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 SPDXXD28 Series 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 SPDXXD28 Series can withstand ± 600 V spikes for 10uS. This capability is beyond that required by the standards cited above.

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