Protecting Industrial Digital Control Outputs Using Intelligent MOSFETS

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ABSTRACT

Digital outputs in industrial applications often must implement some type of protection measure. The integrity of the signal, transmitted over a distance of several meters, can suffer due to fault conditions like a short circuit or an over current, either of which can damage the device driving the signal. To prevent electromagnetic compatibility problems, it may also be necessary to slow down the signal slopes by reducing the rise and fall times of the signal to a moderate level. This application report shows how a high-side, power-distribution switch from Texas Instruments safely drives small resistive, capacitive, and inductive loads.

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Design Problem

In industrial control environments there are many signals that need to be transmitted from one machine or system to another, to signal faults, or to initiate the next operating stage. These signals are often driven by PLCCs or other digital controllers, which may have the ability to drive small resistive, capacitive, or inductive loads over a long cable run. They may not have the ability to withstand a fault and continue to operate normally.

When driven by a PLCC or other digital controller, these same signals may have very rapid slew rates and sharp signal edges. When driven down a long cable, a transmission line generating potentially large EMI noise is created.

Both of these conditions reduce the integrity and reliability of the industrial control system. Many of these problems are symptoms seen in the system that appear to be hard to find anomalies.

Solution

The solution consists of driving the /EN pin of the TPS202x family or the EN pin of the TPS203x family power distribution switch with the controller's digital signal, and using the device intelligent MOSFET to drive the load. The high-side switches can switch loads within a voltage range of 2.7 V to 5.5 V and have a maximum continuous output current of up to 2 A. The high-side switches contain features like short circuit, thermal, and over current protection. The devices are tested with different types of loads (resistive, capacitive, RC, DC motor, relay, lamp) connected to the switch via a cable 2 meters in length (see Figure 1). Test conditions are shown in Figure 1, omitting the 22 µF capacitor. V_I is 5 V and /EN is tied to GND. A high value electrolytic capacitor at the input and output reduces power supply transients when the output load is heavy.

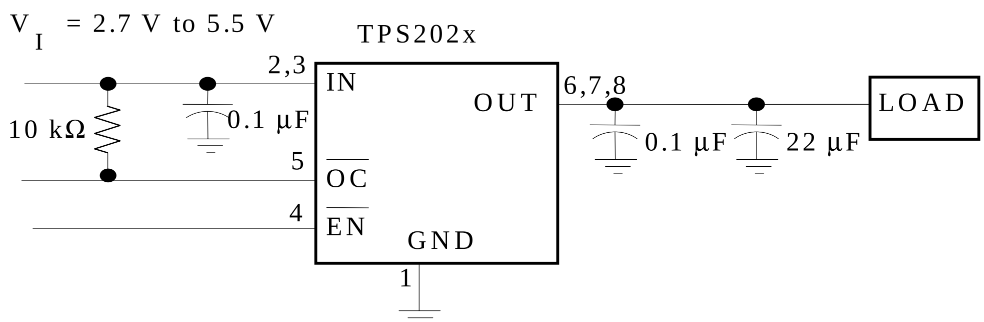


Figure 1. Typical Implementation With the TPS202X

A small ceramic capacitor (0.01 µF to 0.1 µF) at the input is recommended for helping with ESD immunity as well as the immunity of the device to short-circuit transients. A 10 kΩ pullup resistor should be connected to the /OC pin for proper operation of the open-drain pulldown circuit (see data sheet for more information).

In terms of rise time, fall time, propagation delay time, current limit, and short circuit, the typical test results are as shown in Table 1. Measured values may differ within a certain range due to changes in load characteristics, variation in temperature, or other conditions.

Table 1. Rise- and Fall Time, Propagation Delay for V_{IN} = 5 V

	Resistor	Lamp 0.6 W	R□C (22 µF)	5 V relay	DC Motor
Rise time, t_r	6.5 ms	6.5 ms	6.5 ms	6.5 ms	~300 ms
Fall time, t_f	0.03 ms	0.03 ms	2 ms	0.03 ms	~300 ms
Prop delay, t_{pd}	1.7 ms	1.7 ms	1.7 ms	1.7 ms	40- ms

Loads that are not capacitive have a rise time (t_r) of approximately 6.5 ms, a fall time (t_f) of approximately 30 µs, and a propagation delay (t_{pd}) time between V_I and V_O of approximately 1.7 ms. The 22 µF output capacitor mainly influences fall time. The times for the motor are much larger because of its large and varying inductance, especially during start-up and stop phases. The typical rise time of 6.5 ms diminishes steep signal slopes and increases the electromagnetic compatibility of the application.

In the case of an over current or a short-circuit condition, the device maintains a constant output current while the output voltage is reduced accordingly (see t_1 in Figure 2). If the fault condition lasts for an extended period of time and the device is not disabled using the /EN pin, the device shuts down thermally (see t_2). After the die cools approximately 20°C, the device turns on again. Testing this behavior with a resistive load of 3.3 Ω on the TPS2020 shows that the device limits the output current to 300 mA. The output voltage initially decreases from 5 V down to 1 V.

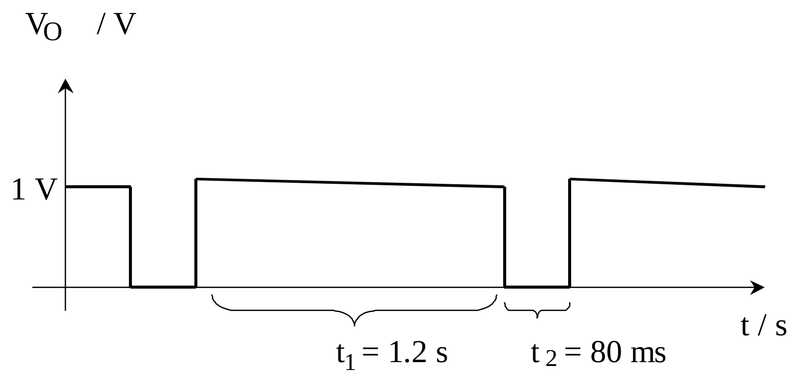


Figure 2. Over Current Protection and Thermal Shutdown for 3.3-Ω Load (TPS2020)

Figure 3 shows the output voltage when a 5-V relay is connected to the output. The waveform is identical with or without an external clamping diode. The reason they are identical is that the internal ESD structures of the power switch device functions as clamping diodes. To ensure that the device meets the absolute maximum ratings as indicated in the data sheet; it is recommended that an external clamping Schottky diode and additional bypass capacitors be connected when switching inductive loads.

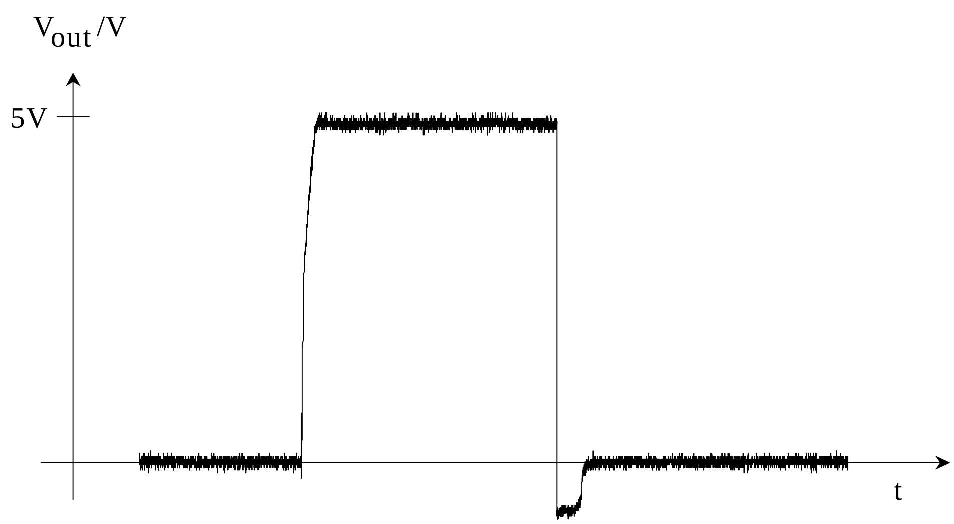


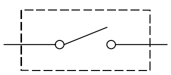
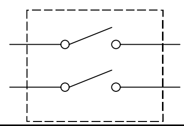
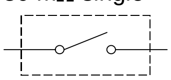
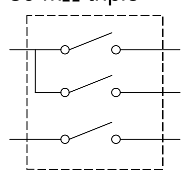
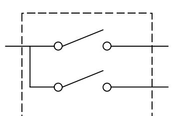
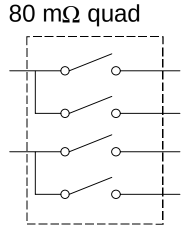
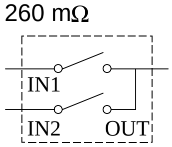
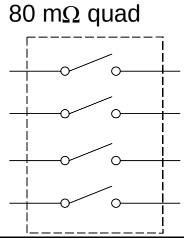
Figure 3. Output Voltage of a TPS2020 Driving a 5-V Relay

Another feature of the TPS20xx is undervoltage lockout. The device goes into shutdown mode when the input voltage is below approximately 2 V. When the input voltage exceeds this value by a hysteresis voltage of approximately 100 mV, the device is activated again. This allows the design of hot-swap systems to ensure correct power supplies.

Conclusion

Power distribution switches of families TPS202x and TPS203x are a good solution for protecting industrial digital control outputs within a supply voltage range of 2.7 V to 5.5 V. Integrated protection features such as over-current protection, thermal shutdown, and undervoltage lockout make them well suited to the application. Reducing slew rates and the sharpness of signal edges improves the EMC of the application. It must be taken into consideration that large capacitive or inductive loads may influence the rise- and fall-time of the output signal. See Table 2 for a general switch catalog.

Table 2. General Switch Catalog

33 mΩ single 	TPS201xA TPS202x TPS203x	0.2A – 2A 0.2A – 2A 0.2A – 2A	80 mΩ dual 	TPS2080/1/2 TPS2090/1/2	500 mA 250 mA
80 mΩ single 	TPS2014 TPS2015 TPS2041 TPS2051 TPS2045 TPS2055	600 mA 1A 500 mA 500 mA 250 mA 250 mA	80 mΩ triple 	TPS2043 TPS2053 TPS2047 TPS2057	500 mA 500 mA 250 mA 250 mA
80 mΩ dual 	TPS2042 TPS2052 TPS2046 TPS2056	500 mA 500 mA 250 mA 250 mA	80 mΩ quad 	TPS2044 TPS2054 TPS2048 TPS2058	500 mA 500 mA 250 mA 250 mA
260 mΩ 	TPS2100/1 TPS2102/3/4/5	IN1 500 mA IN2 10 mA IN1 500 mA IN2 100 mA	80 mΩ quad 	TPS2085/6/7 TPS2095/6/7	500 mA 250 mA

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