Application Note: AN-202

CPC1590 Application Technical Information

1 Using the CPC1590 Isolated Gate Driver IC

The CPC1590 is an excellent choice for remote switching of DC and low frequency loads where isolated power is unavailable. The device uses external components to satisfy design switching requirements, which enables the designer to choose from a great number of MOSFETs. The designer also has several options when designing over-voltage protection circuitry. The case studies look at only two of many methods, but each has unique constraints that should prove useful to many other designs.

Figure 1 shows a typical application circuit for using the CPC1590 gate driver. The part allows the user to turn on the gate of a MOSFET, and keep it on until the LED current is turned off. The application circuit uses a boot-strap diode (internal to the part) and storage capacitor (C_{ST}) to provide the charge needed for fast turn-on switching of an external MOSFET device. When the MOSFET is on, the photo current from the LED keeps the MOSFET gate biased to the rated voltage continuously.

The CPC1590 uses charge from the load voltage when turning off to restore the MOSFET gate's switching charge for the next turn-on event. The part will turn on even without this restoration of charge (in the case of no load voltage), although the turn-on will be much slower because the photo current will be charging the gate. This feature can be exploited during system startup.

2 Application Component Selection

2.1 Storage Capacitor Selection C_{ST}

The storage capacitor (C_{ST}) enables the part to turn on quickly by holding a reservoir of charge to be transferred to the gate of the MOSFET. The turn-off cycle does not depend on the storage capacitor.

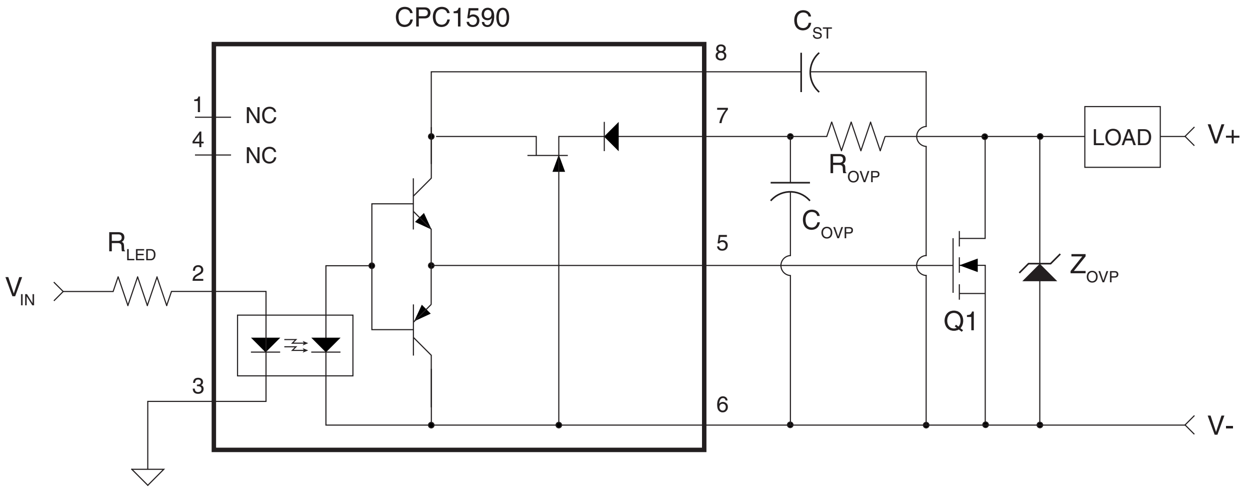
Equation 1: Charge Storage Capacitor Calculation:

$$C_{ST} \geq \frac{Q_G}{0.5V} \qquad \text{(FARADS)}$$

Q_G is the total gate charge. Equation 1 shows that the storage capacitor needs to deliver enough charge to the gate while only dropping 0.5V. The CPC1590 can deliver 32nC at the rated operating speed and will operate with much larger loads (<4uF) with a slower turn-on and turn-off time.

> ***Note:*** *Care must be taken to minimize any leakage current path from the capacitor to ground, between pins 7 and 8, MOSFET gate current, and between pins 5 and 6. Leakage currents will discharge the storage capacitor and, even though the device is already on, will become a load to the photo current that keeps the gate voltage on. The gate voltage will be reduced if >500nA of leakage is present. Therefore, the combined impedance from pin 8 to pin 7, pin 5 and pin 6, capacitor current, and MOSFET current must be >20MΩ over the temperature rating of the part.*

Figure 1 **CPC1590 Application Circuit Diagram with Over-Voltage Protection**



2.2 Transistor Selection

The CPC1590 charges and discharges an external MOSFET transistor. The selection of the MOSFET is determined by the user to meet the specific power requirements for the load. The CPC1590 output voltage is listed in the specification, but, as mentioned earlier, there must be little or no gate leakage.

Another parameter that plays a significant role in the determination of the transistor is the gate drive voltage available from the part. The CPC1590 uses photovoltaic cells to collect the optical energy generated by the LED, and, to generate more voltage, the photovoltaic diodes are stacked. As such, the voltage of the photovoltaic stack reduces with increased temperature. The user must select a transistor that will maintain the load current at the maximum temperature, given the V_{GS} in the CPC1590 specification.

The case studies below use "logic-level" MOSFETs for each design to maintain the load described.

2.2.1 Transistor Switching Characteristics

The primary characteristics of the application's switching behavior are t_{ON}, t_{OFF}, t_{RISE}, t_{FALL}, and the recovery time of the storage capacitor, t_{CHG}. These parameters are dependent on the MOSFET selection and need to be reviewed in light of the application requirements.

The CPC1590 turns on the MOSFET to the datasheet V_{GS} after the t_{ON} delay. Similarly the t_{OFF} delay is the amount of time until the LED is turned off and the capacitive load discharges to the level in the CPC1590 specification. For MOSFETs with larger or smaller required gate charge the t_{ON} and t_{OFF} will be proportionately faster or slower, but it is not a linear relationship.

The approximate rise and fall times of the transistor's drain voltage is:

Equation 2: Rise Time Calculation:

$$t_{RISE,VD} \approx \frac{V_{LOAD} \bullet C_{RSS}}{I_{G\_SINK}} \qquad \text{(SECONDS)}$$

Equation 3: Fall Time Calculation:

$$t_{FALL,VD} \approx \frac{V_{LOAD} \bullet C_{RSS}}{I_{G\_SOURCE}} \qquad \text{(SECONDS)}$$

Where C_{RSS} is the MOSFET gate-drain capacitance (averaged over the switching voltage range) found in the MOSFET datasheet, and I_{G_SINK} is the gate sinking current of the CPC1590, and I_{G_SOURCE} is the gate driving ability.

For a significant number of applications, the rise time will likely be dominated by the CPC1590's internal discharge time. This can alter the amount of dissipated energy in the MOSFET during switching so the user must review the application carefully as shown in the design examples.

The value for the charge time, t_{CHG} is due to external component selection.

To calculate the value for the charge time, t_{CHG}, which is due to external component selection:

Equation 4: Storage Capacitor Charge Recovery Time (seconds):

$$t_{CHG} \approx 5 \bullet 300\Omega \bullet C_{ST}$$

Note:*The CPC1590 is ideal to use where remote power is otherwise unavailable. If the LED is also powered remotely, care must be taken to ensure that parasitic transient signals are reliably filtered from the input control signal. Large transient currents will mutually couple energy between cables, and a simple R-C filtering of the CPC1590 input may be sufficient to suppress false turn-on.*

3 Application Switching Losses

During the transition intervals, the application and load components change energy states, and during the process incur switching losses. These losses are manifested as heat in the application circuit, and must be addressed by the designer to ensure that no one component exceeds its power rating. The designer must understand the details of load behavior in order to adequately size and protect the application circuit. There are three general cases to observe: (1) purely resistive loads, (2) inductive/resistive loads, and (3) loads with significant capacitance. Inductors and capacitors are energy storage elements that require special consideration for switching.

The energy stored in the load inductor is discharged through the switching MOSFET, load capacitance and the over-voltage-protection circuitry.

During the turn-on interval, the inductor energy is zero, and so the capacitive energy in the load and parasitic elements of the switching application must be dissipated by the MOSFET in order for the load to change state.

Equation 5: Stored Inductive Energy (Joules):

$$E_L = \frac{1}{2} \bullet L \bullet I_{LOAD}^2$$

3.1 Resistive Load Losses: The Ideal Case

For purely resistive loads, the energy dissipated by changing states occurs primarily in the MOSFET. The equation describing MOSFET energy dissipation is:

Equation 6: MOSFET Energy: E_{RISE} (Joules):

$$E_{MOSFET} \geq V_{LOAD}^2 \bullet \frac{C_{RSS}}{I_{G\_SINK}} \bullet \frac{I_{LOAD}}{6} = \frac{P_{LOAD}}{6} \bullet t_{RISE}$$

The average power of the MOSFET for any load type is:

Equation 7: MOSFET Average Power (Watts):

$$P_{AVG} = I_{LOAD}^2 \bullet R_{DSAT} \bullet D + f_{SWITCH} \bullet (E_{RISE} + E_{FALL})$$

Where f_{SWITCH} is the application switching frequency, R_{DSAT} is the MOSFET's on-resistance, and D is the switch's operational duty cycle: $D = t_{ON}/(t_{ON}+t_{OFF})$. E_{RISE} and E_{FALL} represent the energy dissipated by the MOSFET during rise and fall, in Joules.

3.2 Inductive/Resistive Loads

If the load is resistive and inductive, and the inductance doesn't saturate, then the load current during turn off is described by:

Equation 8: Resistive/Inductive Load Current during t_{RISE} (Amps):

$$I_{LOAD}(t) = \frac{V_{LOAD}}{R_{LOAD}} - \frac{I_{G\_SINK}}{L_{LOAD} \bullet C_{RSS}} \bullet \left(\frac{L_{LOAD}}{R_{LOAD}}\right)^2 \bullet \left[\frac{R_{LOAD}}{L_{LOAD}} \bullet t - 1 + e^{\frac{-R_{LOAD}}{L_{LOAD}} \bullet t}\right]$$

The drain voltage during turn off is:

Equation 9: MOSFET Drain Voltage during t_{RISE} (V):

$$V_{DRAIN}(t) = \frac{I_{G\_SINK}}{C_{RSS}} \bullet t$$

The instantaneous power in the MOSFET will be the product of the two equations, and the energy will be the integral of the power over time.

3.3 Capacitive Loads

The energy absorbed by the MOSFET for loads that are more capacitive in nature occurs during the MOSFET turn-on as opposed to the turn-off. The energy absorbed by the MOSFET will be a function of the load, the Transient Voltage Suppressor TVS (or other protector) and the MOSFET drain capacitance.

Equation 10: MOSFET Energy: E_{FALL} (Joules):

$$E_{FALL} = \frac{1}{2} \bullet (C_{TVS} + C_{OSS} + C_{LOAD}) \bullet V_{LOAD}^2$$

C_{OSS} is the MOSFET output capacitance found in the datasheet. As mentioned earlier, the MOSFET switching losses occur at different times, either rising or falling, so loads with a combination of inductance and capacitance can also be calculated by the energy equations described above.

The MOSFET can dissipate repeated avalanche energy, found in the datasheet, however that energy must be reduced for increased ambient temperature. For a 150°C MOSFET, the energy reduction at $T_{J,MAX}$ is:

Equation 11: MOSFET Energy Adjustment for Operating conditions (Joules):

$$E(T_{J,MAX}) \le E(25^{\circ}C) \bullet \frac{(150^{\circ}C - T_{J,MAX})}{(150^{\circ}C - 25^{\circ}C)}$$

$T_{J,MAX}$ is the junction temperature of the die, so it must include the temperature increase caused by power dissipation of the load and the thermal impedance of the package/application. E(25°C) is the repetitive avalanche energy, E_{AR}, in the MOSFET datasheet at 25°C.

3.4 dV/dt Characteristics

The application shown in **Figure 1** and the detailed design of **Case 1** (**See "Case 1: 180V Application Circuit" on page 7**), dissipates significant energy caused by large dV/dt events. Fault voltages across the MOSFET will turn it on for the same reason that the part turns off slowly. For dV/dt events > I_{G_SINK}/C_{RSS} (from Equation 2) the application circuit will dissipate energy proportional to the C_{RSS} and g_{FS} (forward conductance) of the selected transistor. C_{RSS} is a function of the transistor's on-resistance and current/power capability, so higher load-power designs are more sensitive.

The CPC1590 provides an internal clamp to protect the gate of the MOSFET from damage during such an event. The part can withstand 100mA for short periods, such as dV/dt transients.

> ***Note:*** *The CPC1590 is ideal to use where remote power is otherwise unavailable. If the LED is also powered remotely, care must be taken to ensure that parasitic transient signals are reliably filtered from the input control signal. Large transient currents will mutually couple energy between cables, and a simple R-C filtering of the CPC1590 input may be sufficient to suppress false turn-on.*

4 Design Switching Frequency

The over-voltage protection and storage capacitor play a significant role in determining the switching frequency. The maximum switching frequency is a function of the Gate charge of the MOSFET, the storage capacitor (C_{ST}), and R_{OVP}. The maximum switching frequency relationship is:

Equation 12: Maximum Switch Operation (Hz):

$$f_{MAX} \le \frac{1}{M} \bullet (t_{ON} + t_{OFF} + (t_{RISE,VD} \mid t_{CHG}) + t_{FALL,VD})^{-1}$$

where M=3 and is a multiplication factor for temperature and process variations; t_{ON} and t_{OFF} are CPC1590 datasheet parameters; $t_{RISE,VD}$ is the rise time of the drain voltage and t_{CHG} is the charge time of the storage capacitor, C_{ST}, and overvoltage protection circuitry; $t_{FALL,VD}$ is the fall time across the transistor. For calculation, choose the greater of $t_{RISE,VD}$ or t_{CHG}.

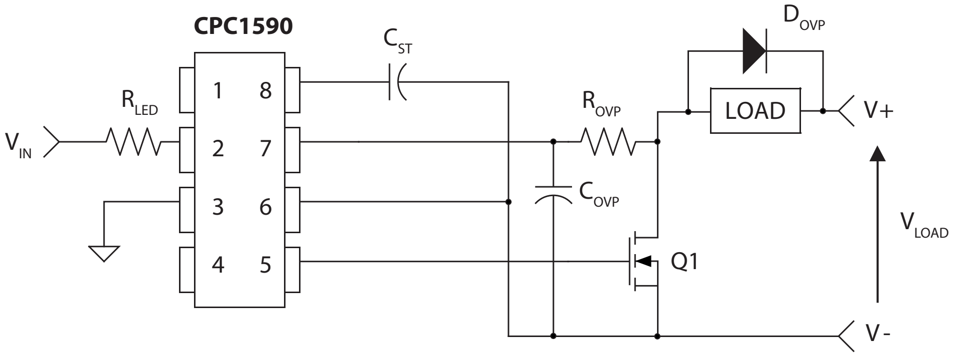
There is no minimum switching frequency because the CPC1590 uses photovoltaic diode current to keep the output charged as long as LED current flows.

5 CPC1590 Over-Voltage Protection

Over-voltage protection is generally required for the CPC1590 because of parasitic inductance in the load, wires, board traces, and axial leads of protectors. Purely resistive loads, or loads with low voltage switching, may be able to rely on the transistor to handle any parasitic energy, and thereby not require protection for the CPC1590. For very low inductance loads and traces, over-voltage suppression may be handled with a simple R-C filter consisting of R_{OVP} and C_{OVP} , or by use of a free-wheeling diode. For more moderate load inductance, or for remote switching of a load (i.e. through a long cable) a voltage suppressor can be used. For heavily inductive loads, only a free-wheeling diode, D_{OVP} , connected across the load element is recommended, see **Figure 2**.

The energy not consumed in switching losses must be absorbed by the over-voltage protection element. Most protective devices are designed to withstand certain peak power as in the case of a TVS, or maximum avalanche energy in the case of a MOSFET. The energy not consumed in switching losses must be absorbed by the over-voltage protection element. Most protective devices are designed to withstand certain peak power in the case of a TVS, or maximum avalanche energy in the case of a MOSFET. To reduce the amount of stored inductive energy, a larger capacitor can be added in parallel with the gate-drain connection of the MOSFET.However care must be taken so that the rise time and peak current do not exceed the Safe Operating Area (SOA) rating of the transistor. The consequence of increasing the gate-drain effective capacitance is reduced dV/dt tolerance.

Figure 2 CPC1590 Over-Voltage Protection for Inductive Loads



5.1 Other Protection Techniques

For applications in which higher inductance loads are switched, the designer must consider other circuit techniques, device ratings, or protector types. Of paramount importance is that the designer know the characteristics of the load being switched.

An excellent source describing power electronic devices and switching behavior is: *Power Semiconductor Devices,* by B. Jayant Baliga, ISBN 0-543-94098-6

For more over-voltage protection circuit techniques consult: *Switchmode Power Supply Handbook*, 2nd *Edition*, Keith Billings, ISBN 0-07-006719-8, or *Power MOSFET Design*, B. E. Taylor, ISBN 0-471-93802-5.

6 Design Examples

Table 1: Sample Application Components

Table 1 shows two sample application component selections for two different voltage ratings.

Device	180V/1A Value/Rating	48V/5A Value/Rating	Comment
Q1	FDD18N20LZ [1]	FQP20N06L [1]	MOSFETS
C_{ST}	>0.1µF/100V	>0.01µF/100V	5% Capacitor
Z_{OVP}	Not Used	SA48A [1]	TVS-style protector
R_{OVP}	1KΩ	5.1KΩ	5%, 1/8 Watt (60Hz Switching Frequency or less)
C_{OVP}	0.001µF, 400V	0.001µF, 100V	5% Capacitor
R_{LED}	680Ω	680Ω	5V Switching

[1] Use of the FDD18N20LZ, FQP20N06L and SA48A product datasheets is necessary to completely understand the examples given.

6.1 Case 1: 180V Application Circuit

The application circuit selected uses a 200V MOSFET (Q1) as shown in Table 1 in conjunction with the CPC1590. The operating voltage allows 20V B_{VDSS} breakdown reduction for low temperature operation (-40°C). This sample application does not include an over-voltage protector, so the parasitic inductance and load current will need to be less than the repetitive avalanche energy of the MOSFET, derated for high temperature according to following equation:

$$E(T_{J,MAX}) \le E(25°C) \bullet \frac{(150°C - T_{J,MAX})}{(150°C - 25°C)}$$

The repetitive avalanche energy $E_{AR}(25°C)$ specification of the MOSFET (Q1) is listed as 8.9mJ.

Therefore, if derated for higher temperatures (e.g. $T_{J,MAX} = 110°C$):

$E(T_{J,MAX}) \le 8.9mJ \bullet (0.32) = 2.84mJ$

Use the following equations, shown previously,

$$t_{RISE,VD} \approx \frac{V_{LOAD} \bullet C_{RSS}}{I_{G\_SINK}} \qquad \text{(SECONDS)}$$

$$t_{FALL,VD} \approx \frac{V_{LOAD} \bullet C_{RSS}}{I_{G\_SOURCE}} \qquad \text{(SECONDS)}$$

$$E_{MOSFET} \ge V_{LOAD}^2 \bullet \frac{C_{RSS}}{I_{G\_SINK}} \bullet \frac{I_{LOAD}}{6} = \frac{P_{LOAD}}{6} \bullet t_{RISE}$$

with these specifications from the CPC1590 DataSheet:

$I_{G\_SINK} = 3.3$ mA

$I_{G\_Source} = 3.3$ mA

and from the MOSFET (Q1) datasheet:

$C_{RSS} = 30pF$

$Q_G = 30nC$

With $V_{LOAD} = 180V$ and $I_{LOAD} = 1A$, the calculated values are:

$t_{RISE} = 1.64\mu s$

$t_{FALL} = 1.64\mu s$

$E_{MOSFET} = 49\mu J$.

(Note: The energy dissipated during t_{FALL} is negligible)

$$C_{ST} \ge \frac{Q_G}{0.5V} \qquad \text{(FARADS)}$$

Selecting a 0.1uF for C_{ST} with a gate charge Q_G=30nC, the voltage drop of the storage capacitor would equal 300mV, which is within the 0.5 V requirement above.

Figure 3 Voltage Drop on C_{ST}

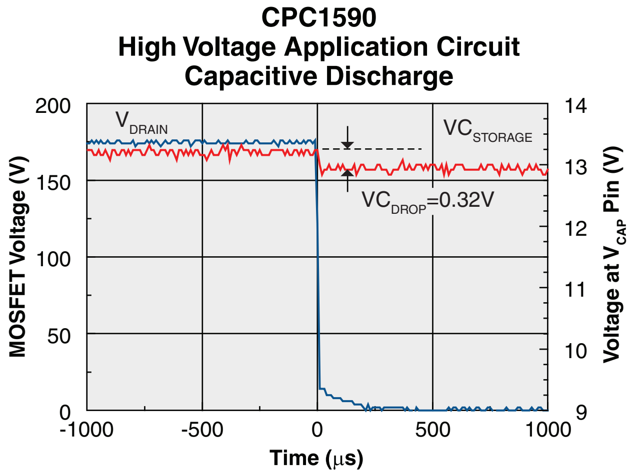


Figure 4 CPC1590 Application During Turn-Off

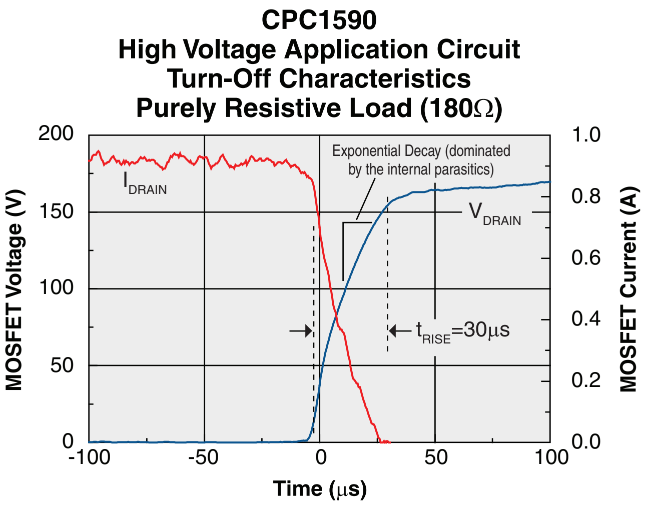


Figure 5 CPC1590 Application During Turn-On

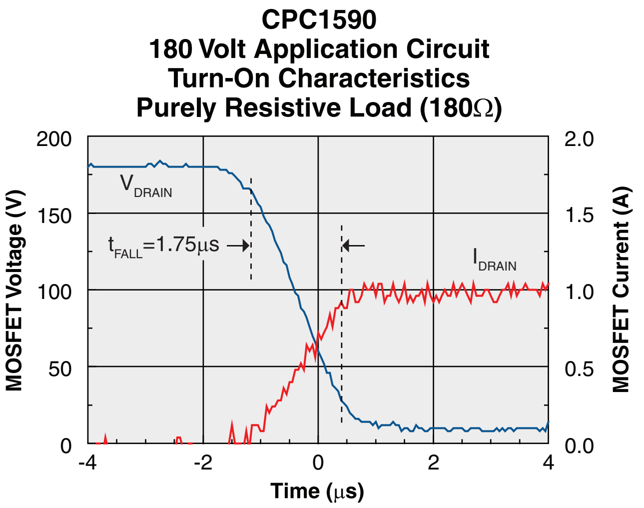


Figure 6 MOSFET Power and Energy

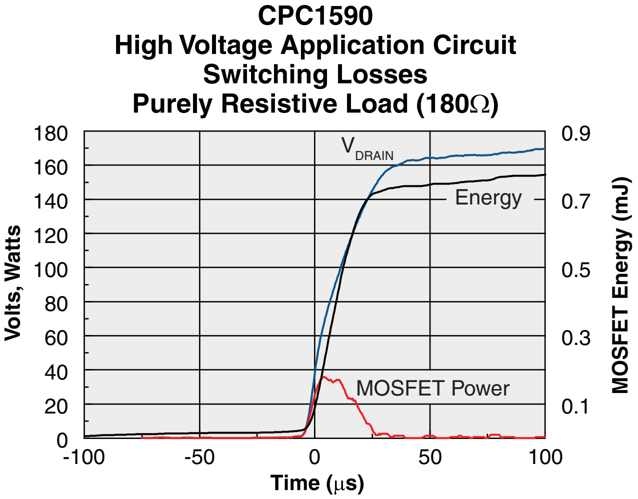
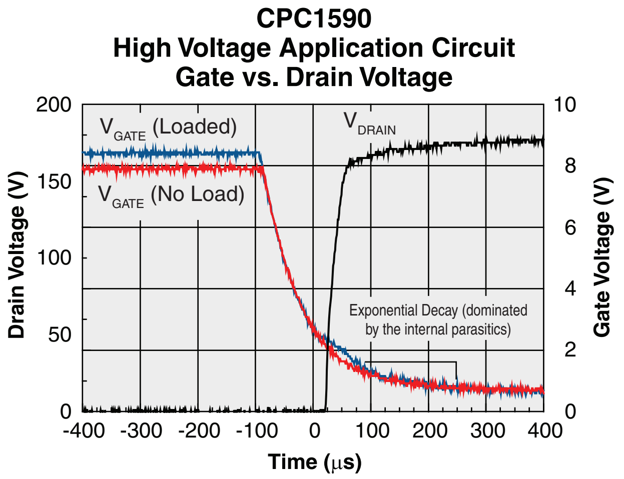


Figure 7 CPC1590 Gate Drive Parasitic Behavior



6.2 Case 1: (Continued)

The load was modified by adding 630µH of inductance in series with the load resistor. The purpose is to emulate a leakage inductance or mutual inductance that may represent a load characteristic. **Figure 8** shows the turn-on behavior, and **Figure 9** shows the turn-off behavior with the load.

While **Figure 9** shows a small amount of peaking as the switch turns off, it is clear that avalanche breakdown is avoided. This is further demonstrated by the energy dissipated in the MOSFET exceeding the energy stored in the magnetic inductance.

Figure 10 shows how much power is dissipated in the MOSFET during turn-off, and the energy absorbed during the turn-off event. From the graph the user can see 750µJ is absorbed in the MOSFET while only 315µJ was stored in the inductor.

A final design will characterize t_{RISE} of the entire application at the maximum operating temperature and derate the avalanche energy (E_{AR} in the datasheet,) accordingly.

Figure 8 630µH Turn-On

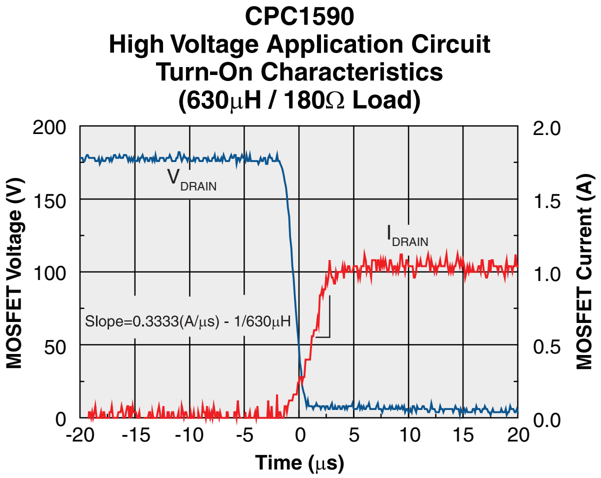


Figure 9 630µH Turn-Off

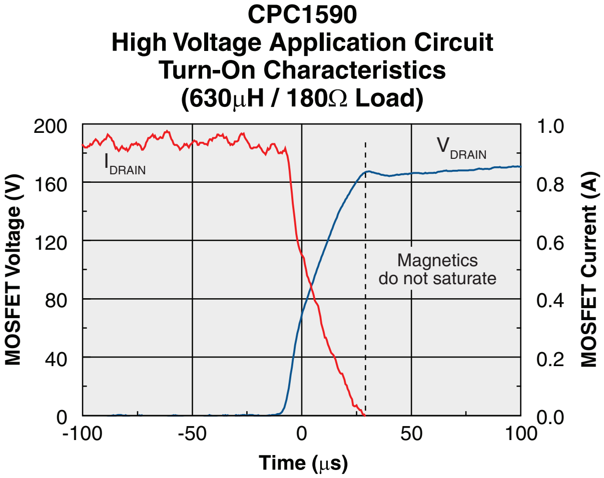
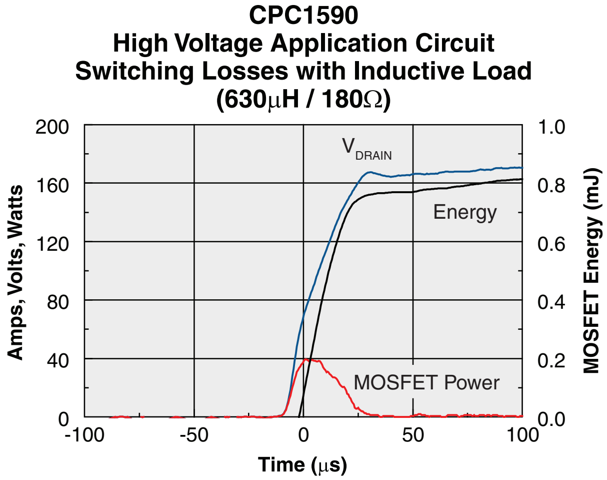


Figure 10 630µH MOSFET Power and Energy



6.3 Case 2: 48V Application Circuit

The CPC1590 can be used over a wide range of load voltages, some as low as 15V. An identical application circuit was used with the CPC1580, so for comparison the application circuit was adjusted for the CPC1590. The results are essentially identical for all factors between the CPC1590 and CPC1580 at 48V.

Figure 11 CPC1590 48V t_{FALL}

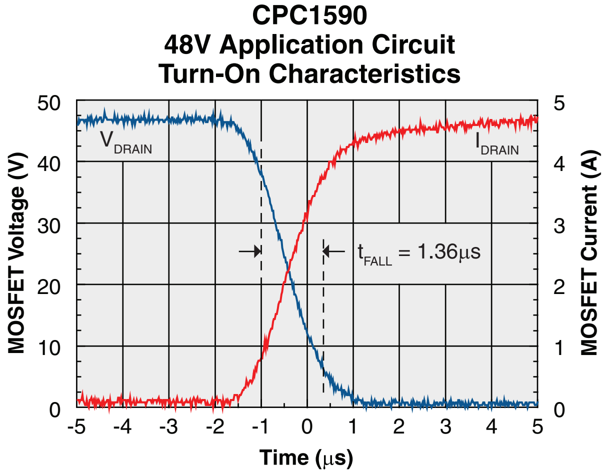
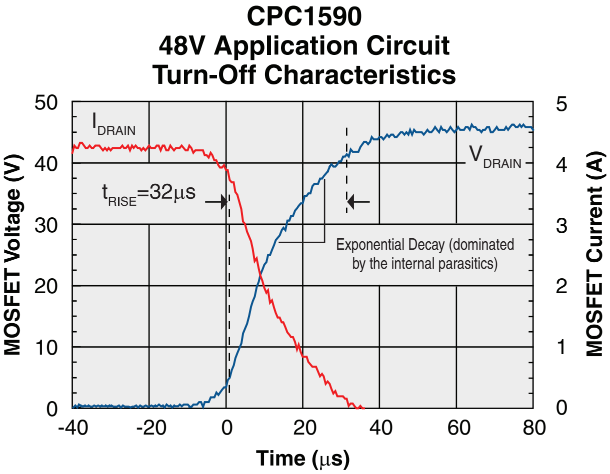


Figure 12 CPC1590 48V t_{RISE}



Rise and fall times shown in **Figure 11** and **Figure 12** which are limited by decay times internal to the part (shown in **Figure 13**). The peak power and energy shown in **Figure 14** are well below the peak energy and power restrictions shown in the MOSFET datasheet.

Figure 13 CPC1590 48V Gate Discharge

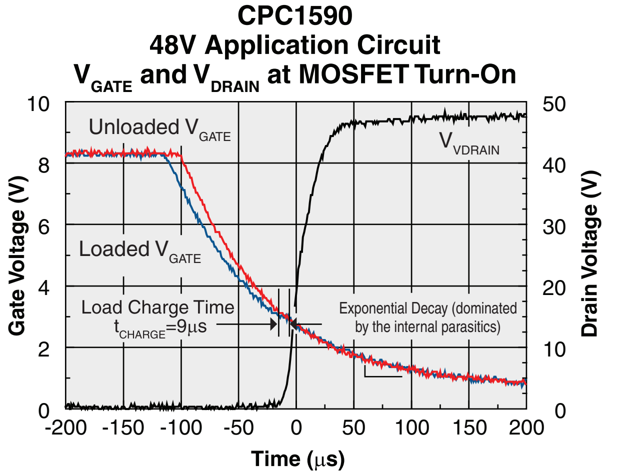
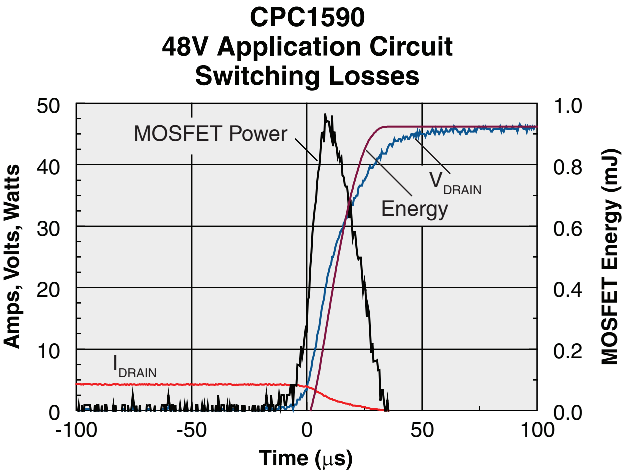


Figure 14 48V MOSFET Power and Energy

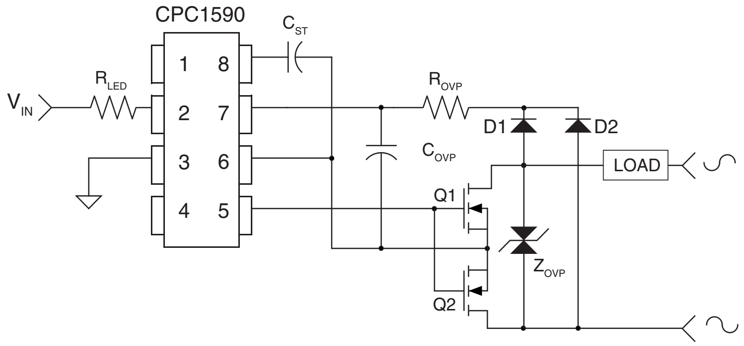


6.4 AC Relay Application Circuit

The CPC1590 can be used in other configurations. One typical configuration, an “AC Switch,” is shown in **Figure 15**. “AC Switch” simply means that either terminal can be positive or negative. This configuration requires a second MOSFET (Q2) and two rectifying diodes (D1 and D2).

The design considerations are identical for this application. Diodes D1 and D2 must have a voltage rating greater than the peak load voltage.

Figure 15 CPC1590 AC Relay Application Circuit



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Specification: AN-202-R01

8/1/2014

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1 Using the CPC1580 Isolated Gate Driver IC

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Figure 1 shows a typical DC application circuit for using the CPC1580 gate driver. The driver allows the user to turn on the gate of a MOSFET and keep it on until the LED current is turned off. The application circuit uses a bootstrap diode (internal to the part) and storage capacitor (C_{ST}) to provide the charge needed for fast turn-on switching of an external MOSFET device. When the MOSFET is on, the photo current from the LED keeps the MOSFET gate biased to the device's specified gate to source voltage (V_{GS}) continuously.

The CPC1580 uses charge from the load voltage when turning off to recover the MOSFET gate switching charge for the next turn-on event. The transistor will turn on even without this recovery of charge (in the case of no load voltage), although the turn-on will be much slower because only internal photo current will be charging the gate of the MOSFET. This feature can be exploited during system startup.

2 Application Component Selection

2.1 Storage Capacitor Selection C_{ST}

The storage capacitor (C_{ST}) enables the part to turn on quickly by holding a reservoir of charge to be transferred to the gate of the MOSFET. The turn-off cycle doesn't depend on the storage capacitor.

Equation 1: Charge Storage Capacitor Calculation:

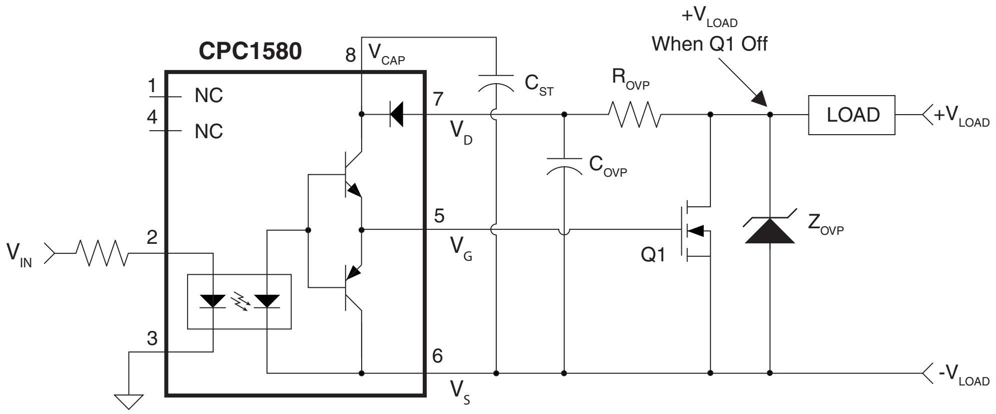
$$C_{ST} \geq \frac{Q_G}{V_{LOAD} - V_{CAP}} \qquad \text{(FARADS)}$$

Q_G is the MOSFET's total gate charge; $V_{CAP} \geq 15V$.

Equation 1 shows that the storage capacitor needs to deliver enough charge to the gate without going below the 15V required for switching the MOSFET. The CPC1580 can deliver adequate peak current to drive 32nC total gate charge at the rated operating speed, and will operate with much higher capacitive loads (<4µF), or larger gate charge, with a slower turn-on and turn-off time.

> ***Note:*** *Care must be taken to minimize any capacitor-to-ground leakage current path between pins 7 and 8, MOSFET gate current, and between pins 5 and 6. Leakage currents will discharge the storage capacitor, and, even though the device is already on, will become a load to the photocurrent which keeps the gate voltage on. The gate voltage will be reduced if >500nA of leakage is present, therefore the combined impedance from pin 8 to pin 7, pin 5 and pin 6, capacitor current, and MOSFET current must be >20MΩ over the temperature rating of the part.*

Figure 1 **CPC1580 DC Application Circuit Diagram with Over-Voltage Protection**



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Another parameter that plays a significant role in the determination of the transistor is the gate drive voltage available from the part. The CPC1580 uses photovoltaic cells to collect the optical energy generated by the LED, and, to generate more voltage, the photovoltaic diodes are stacked. As such, the voltage of the photovoltaic stack reduces with increased temperature. The user must select a transistor that will maintain the load current at the maximum temperature, given the V_{GS} in the CPC1580 specification.

The case studies below use "logic-level" MOSFETs for each design to maintain the load described.

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The primary characteristics of the application switching are t_{ON}, t_{OFF}, t_{RISE}, t_{FALL}, and the recovery time of the storage capacitor, t_{CHG}. These parameters are dependent on the MOSFET selection and need to be reviewed in light of the application requirements.

The CPC1580 turns on the MOSFET to the datasheet V_{GS} after the t_{ON} delay. Similarly the t_{OFF} delay is the amount of time until the LED is turned off and the capacitive load discharges to the level in the CPC1580 specification. For MOSFETs with larger or smaller required gate charge the t_{ON} and t_{OFF} will be proportionately faster and slower, but it is not a linear relationship.

To calculate the nominal rise and fall times of the MOSFET's drain voltage:

Equation 2: Rise Time Calculation

$$t_{RISE,VD} \approx \frac{V_{LOAD} \bullet C_{RSS}}{I_{G\_SINK}} \qquad \text{(SECONDS)}$$

Equation 3: Fall Time Calculation

$$t_{FALL,VD} \approx \frac{V_{LOAD} \bullet C_{RSS}}{I_{G\_SOURCE}} \qquad \text{(SECONDS)}$$

Where C_{RSS} is the MOSFET gate-drain capacitance (averaged over the switching voltage range) found in the MOSFET datasheet, I_{G_SINK} is the gate sinking current of the CPC1580, and I_{G_SOURCE} is the gate driving ability. The maximum value of t_{RISE} is limited by the CPC1580 unloaded discharge characteristic, and should be reviewed in light of the final application component selections, if critical.

To calculate the value for the charge time, t_{CHG}, which is due to external component selection:

Equation 4: Storage Capacitor Charge Recovery Time (seconds):

$$t_{CHG} \approx -(400 + R_{OVP}) \bullet (C_{ST} + C_{OVP}) \bullet \ln\left(\frac{(V_{LOAD} - V_{FINAL}) \bullet C_{ST}}{Q_G}\right)$$

where $(V_{LOAD} - V_{FINAL})$ is the difference in voltage between the required load voltage and the potential the capacitor will charge up to. The voltage at the storage capacitor is $V_{LOAD} - (Q_G/C_{ST})$ when the MOSFET is on, where charge, Q_G, is the amount of charge required to switch the MOSFET gate from 0V to the final voltage out of the CPC1580 (V_{GS} specification). V_{FINAL} is the capacitor voltage when it charges back up from when the MOSFET is off.

R_{OVP} and C_{OVP} form the overvoltage protection RC filter. The RC filter is used to reduce the peak power dissipation in the MOSFET by controlling the rate of rise of the drain voltage. Note that the RC circuit will reduce the switching speed of the MOSFET.

> ***Note:*** *Obviously, the logarithm doesn't work if $V_{FINAL} = V_{LOAD}$ because of the exponential nature of R-C charging. That subsequently affects the next cycle, so C_{ST} is more critical and should be larger if the switching frequency is faster. Selecting the term inside the logarithm to be 0.05 yields 3τ equivalent time-constants.*

Using this information, the maximum switching frequency will be calculated in each application case study below.

> ***Note:*** *The CPC1580 is ideal to use where remote power is otherwise unavailable. If the LED is also powered remotely, care must be taken to ensure that parasitic transient signals are reliably filtered from the input control signal. Large transient currents will mutually couple energy between cables and a simple R-C filtering of the CPC1580 input may be sufficient to suppress false turn-on.*

3 Application Switching Losses

During the transition intervals, the application and load components change energy states and during the process incur switching losses. These losses are manifested as heat in the application circuit, and must be addressed by the designer to ensure that no one component exceeds its power rating. The designer must understand the details of load behavior in order to adequately size and protect the application circuit. There are three general cases to observe: (1) purely resistive loads, (2) inductive/resistive loads, and (3) loads with significant capacitance. Inductors and capacitors are energy storage elements that require special consideration for switching.

During switching periods, the energy stored in the load inductor is discharged through the switching MOSFET, load capacitance and the over-voltage-protection circuitry.

At turn-on, the inductor energy is zero, and so the capacitive energy in the load and parasitic elements of the switching application must be dissipated by the MOSFET in order for the load to change state.

Equation 5: Stored Inductive Energy (Joules)

$$E_L = \frac{1}{2} \bullet L \bullet I_{LOAD}^2$$

3.1 Resistive Load Losses: The Ideal Case

For purely resistive loads, the energy dissipated by changing states occurs primarily in the MOSFET. The equation describing MOSFET energy dissipation is:

Equation 6: MOSFET Energy: E_{RISE} (Joules)

$$E_{MOSFET} \geq V_{LOAD}^2 \bullet \frac{C_{RSS}}{I_{G\_SINK}} \bullet \frac{I_{LOAD}}{6} = \frac{P_{LOAD}}{6} \bullet t_{RISE,VD}$$

The average power of the MOSFET for any load type is:

Equation 7: MOSFET Average Power (Watts)

$$P_{AVG} = I_{LOAD}^2 \bullet R_{DSAT} \bullet D + f_{SWITCH} \bullet (E_{RISE} + E_{FALL})$$

Where f_{SWITCH} is the application switching frequency, R_{DSAT} is the MOSFET's on-resistance, D is the switch's operational duty cycle: $D = t_{ON}/(t_{ON}+t_{OFF})$. E_{RISE} and E_{FALL} are the energy dissipated during the rise and fall times.

3.2 Inductive/Resistive Loads

If the load is resistive and inductive, and the inductance doesn't saturate, then the load current during turn-off is described by:

Equation 8: Resistive/Inductive Load Current during t_{RISE} (Amps)

$$I_{LOAD}(t) = \frac{V_{LOAD}}{R_{LOAD}} - \frac{I_{G\_SINK}}{L_{LOAD} \bullet C_{RSS}} \bullet \left(\frac{L_{LOAD}}{R_{LOAD}}\right)^2 \bullet \left[\frac{R_{LOAD}}{L_{LOAD}} \bullet t - 1 + e^{\frac{-R_{LOAD}}{L_{LOAD}} \bullet t}\right]$$

The drain voltage during turn-off is:

Equation 9: MOSFET Drain Voltage during t_{RISE} (V)

$$V_{DRAIN}(t) = \frac{I_{G\_SINK}}{C_{RSS}} \bullet t$$

The instantaneous power in the MOSFET will be the product of the two equations and the energy will be the integral of the power over time.

3.3 Capacitive Loads

The energy absorbed by the MOSFET for loads that are more capacitive in nature occurs during the MOSFET turn-on as opposed to the turn-off. The energy absorbed by the MOSFET will be a function of the load, the Transient Voltage Suppressor (TVS) or other protector, and the MOSFET drain capacitance.

Equation 10: MOSFET Energy: E_{FALL} (Joules)

$$E_{FALL} = \frac{1}{2} \bullet (C_{TVS} + C_{OSS} + C_{LOAD}) \bullet V_{LOAD}^2$$

C_{OSS} is the MOSFET output capacitance found in the datasheet. As mentioned earlier, the MOSFET switching losses occur at different times, either rising or falling, so loads with a combination of inductance and capacitance can also be calculated by the energy equations described above.

The MOSFET can dissipate the repeated avalanche energy, (E_{AR}), as specified in the datasheet. However that energy must be reduced for increased ambient temperature. For a 150°C MOSFET, the energy reduction at $T_{J,MAX}$ is:

Equation 11: MOSFET Energy Adjustment for Operating conditions (Joules):

$$E(T_{J,MAX}) \leq E(25°C) \bullet \frac{(150°C - T_{J,MAX})}{(150°C - 25°C)}$$

$T_{J,MAX}$ is the junction temperature of the die, so it must include the temperature increase caused by power dissipation of the load and the thermal impedance of the package/application. E(25°C) is the E_{AR} specification found in the MOSFET datasheet at 25°C.

3.4 dV/dt Characteristics

The application shown in **Figure 1** and described in section **6.1** "**Case 1: 24 V Loading Application**" dissipates significant energy caused by large dV/dt events. Fault voltages across the MOSFET will turn it on for the same reason the part turns off slowly.

For dV/dt events > I_{G_SINK}/C_{RSS} (from Equation 2) the application circuit will dissipate energy proportional to the C_{RSS} and g_{FS} (forward conductance) of the selected transistor. C_{RSS} is a function of the transistor's on-resistance and current/power capability, so higher load designs are more sensitive.

The CPC1580 provides an internal clamp to protect the gate of the MOSFET from damage during such an event. It can withstand 100mA for short periods, for instance, during dV/dt transients.

> ***Note:****The CPC1580 is ideal to use where remote power is otherwise unavailable. If the LED is also powered remotely, care must be taken to ensure that parasitic transient signals are reliably filtered from the input control signal. Large transient currents will mutually couple energy between cables and a simple R-C filtering of the CPC1580 input may be sufficient to suppress false turn-on.*

4 Design Switching Frequency

The over-voltage protection and storage capacitor play a significant role in determining the switching frequency. The maximum switching frequency is a function of the gate charge of the MOSFET, the storage capacitor (C_{ST}), and R_{OVP}. The maximum switching frequency relationship is:

Equation 12: Maximum Switch Operation (Hz)

$$F_{MAX} \leq \frac{1}{M} \bullet (t_{ON} + t_{OFF} + t_{RISE,VD} \mid t_{CHG} + t_{FALL,VD})^{-1}$$

where M=3 (a multiplication factor for temperature and process variations); t_{ON} and t_{OFF} are CPC1580 datasheet parameters; $t_{RISE,VD}$ is the rise time of the drain voltage; t_{CHG} is the charge time of the storage capacitor (C_{ST}) and over-voltage protection circuitry (C_{OVP} and R_{OVP}); and $t_{FALL,VD}$ is the fall time across the transistor. For this calculation, choose the greater of $t_{RISE,VD}$ or t_{CHG}.

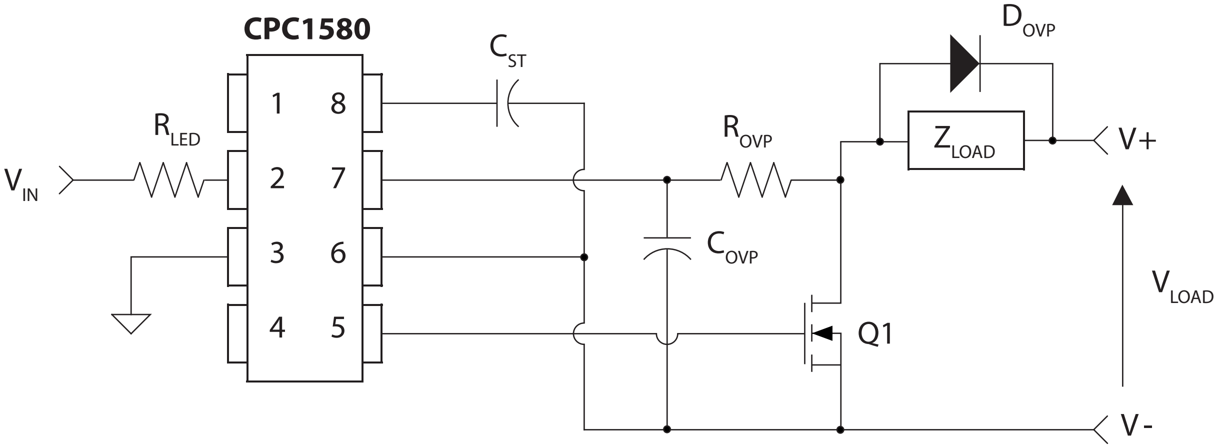
There is no minimum switching frequency because the CPC1580 uses photovoltaic diode current to keep the output charged as long as LED current flows.

5 CPC1580 Over-Voltage Protection

Over-voltage protection is generally required for the CPC1580 because of parasitic inductance in the load, wires, board traces, and axial leads of protectors. Purely resistive loads or loads with low voltage switching may be able to rely on the transistor to handle any parasitic energy and thereby not require protection for the CPC1580. For very low-inductance loads and traces, over-voltage suppression may be handled with a simple RC filter consisting of R_{OVP} and C_{OVP}, or by use of a free-wheeling diode. For more moderate load inductance, or remote switching of a load (i.e. through a long cable) a voltage suppressor can be used. For heavily inductive loads only a free-wheeling diode, D_{OVP}, connected across the load element is recommended, see **Figure 2**.

The energy not consumed in switching losses must be absorbed by the over-voltage protection element. Most protective devices are designed to withstand certain peak power in the case of a TVS, or maximum avalanche energy in the case of a MOSFET. To reduce the amount of stored inductive energy, a larger capacitor can be added in parallel with the gate-drain connection of the MOSFET. However care must be taken so that the rise time and peak current do not exceed the Safe Operating Area (SOA) rating of the transistor. A consequence of increasing the gate-drain effective capacitance is reduced dV/dt tolerance.

Figure 2 CPC1580 Over-Voltage Protection for Inductive Loads



5.1 Other Protection Techniques [1, 2]

For applications in which higher inductance loads are switched, the designer must consider other circuit techniques, device ratings, or protector types. Of paramount importance is that the designer know the characteristics of the load being switched.

[1] An excellent source describing power electronic devices and switching behavior is: *Power Semiconductor Devices,* by B. Jayant Baliga, ISBN 0-543-94098-6

[2] For more over-voltage protection circuit techniques consult: *Switchmode Power Supply Handbook*, *2nd Edition*, Keith Billings, ISBN 0-07-006719-8, or *Power MOSFET Design*, B. E. Taylor, ISBN 0-471-93802-5.

6 Design Examples

Table 1: shows two sample application component selections each with different over-voltage protection strategies.

Table 1: Sample Application Components

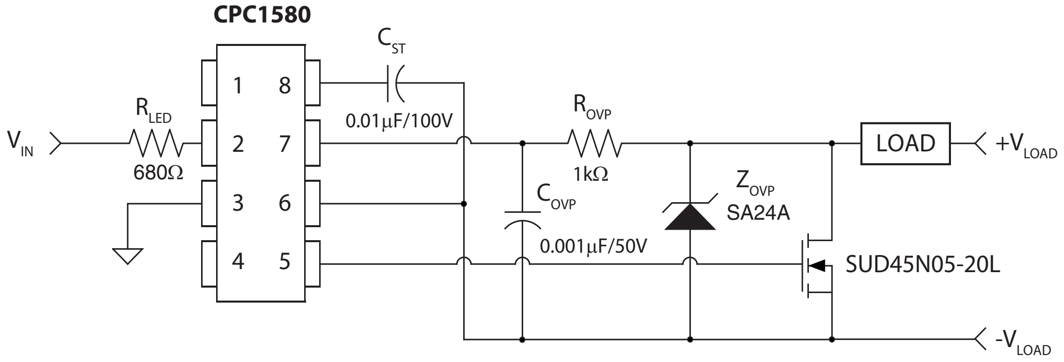
Device	Case 1: 24V/10A Value/Rating	Case 2: 48V/5A Value/Rating	Comment
Q1	SUD45N05-20L [3]	SUD23N06-31L [3]	MOSFET
C_{ST}	>0.01µF/100V	>0.01µF/100V	5% Ceramic Disk
Z_{OVP}	SA24A [3]	SA48A [3]	Littelfuse TVS-style protector
R_{OVP}	1KΩ	5.1KΩ	5%, 1/8 Watt (60Hz Switching Frequency or less)
C_{OVP}	0.001µF, 50V	0.001µF, 100V	5% Ceramic Disk
R_{LED}	680Ω, 1/8 Watt	680Ω, 1/8 Watt	0 - 5V Switching

[3] Use of the SUD45N05-20L, SUD23N06-31L, SA24A, and SA48A product datasheets is necessary to completely understand the examples given.

6.1 Case 1: 24V Load Switching

In this example, the over-voltage protection circuitry is quite simple. The CPC1580 is guaranteed for 60V operation and the protector is rated for 45.4V @ 11.2A peak pulse current, well below the 60V. The transistor (Q1) is a 50V MOSFET, which guarantees the TVS clamps before the transistor breakdown. Assuming there will be load inductance in both the V_{LOAD+} and V_{LOAD-} traces, a TVS is selected to clamp the residual 10A not otherwise dissipated in the turn-off of the MOSFET and parasitic TVS capacitance. R_{OVP} and C_{OVP} are optional for this load condition; however, their inclusion will ease layout and critical placement of the CPC1580.

Figure 3 Case 1 Application Circuit



For this test case, the maximum switching frequency for the design is $F_{MAX} = 0.333 \bullet (40\mu s + 600\mu s + (40\mu s \mid 42\mu s) + 0.87\mu s)^{-1} < \sim 475Hz$. The components selected were used for in-lab testing. Other components with smaller package sizes and wattage will also work, if calculations are performed to meet component specifications.

Example:

- R_{LED}=680Ω
- Minimum voltage drop across the LED is 1.0V
- Switching voltage, SwV_{ON}, when on, is 5V
- I_F=Forward current of the LED

$$I_F = \frac{SwV_{ON} - \text{Min LED Volt}}{R_{LED}}$$

$$I_F = \frac{5V - 1V}{680\Omega}$$

$$I_F = 0.005882A = 5.9mA$$

The recommended I_F is between 2mA and 10mA. The I_F calculated above meets this requirement.

The power dissipated, P_D, is:

$$P_D = I_F^2 \bullet R$$

$$P_D = (5.9\text{mA})^2 \bullet (680\Omega)$$

$$P_D = 0.024\text{W} = 24\text{mW}$$

These calculations show that a 0603 resistor, which is 1/16 Watt, can be selected. The 1/16 Watt still provides an adequate design margin: 0.0625W where only 0.024W is required.

6.1.1 Measured Results

Figure 4 shows the discharge of the storage capacitor due to the gate switching on. The calculated voltage drop (V_{LOAD} - V_{CAP}) using C_{ST} = 10 nF and (Q_G = 43nC from the Q1 datasheet) from **Equation 1** is 4.3 Volts.

From Equation 1: Charge Storage Capacitor Calculation:

$$C_{ST} \geq \frac{Q_G}{V_{LOAD} - V_{CAP}} \qquad \text{(FARADS)}$$

From Equation 2: Rise Time Calculation

$$t_{RISE,VD} \approx \frac{V_{LOAD} \bullet C_{RSS}}{I_{G\_SINK}} \qquad \text{(SECONDS)}$$

t_{RISE} ~ (24V-5V) • 190pF/.0036 A ~ 1µS

From Equation 3: Fall Time Calculation

$$t_{FALL,VD} \approx \frac{V_{LOAD} \bullet C_{RSS}}{I_{G\_SOURCE}} \qquad \text{(SECONDS)}$$

t_{FALL} ~ (24V-5V) • 190pF/0.00022 A ~ 16µS

All other calculated / measured data is summarized in **Table 2:**

Table 2: 24 Volt Load Switching Data

Parameter	Calculated	Measured
Voltage Drop C_{ST}	4.3V	3.7V
t_{FALL} **Figure 5**	16µS	2µS
t_{RISE} **Figure 8**	1µS	38µS [4]
t_{ON} **Figure 6**	16µS (**1580 spec**)	7.3µS
t_{OFF} **Figure 7**	175µS (**1580 spec**)	189µS

The energy in **Figure 9** rises to 3.3mJ, and the switching frequency can be as high as >475Hz which would make the average power $(12\text{A})^2 \bullet 0.02\Omega + 475/\text{s} \bullet 3.3\text{mJ} = 4.5$ Watts, assuming very high operational duty cycles.

This circuit load was modified to include an 800µH inductor that saturates at ~0.5A. This load condition may not represent the user's load but does serve to illuminate more about the switching characteristics of a non-linear load.

Again this assumes that the magnetics do not saturate, however for the graphs shown in **Figure 10** and **Figure 11**, the current equation above only applies after the magnetic flux leaves saturation and becomes inductive again. As such, the load current is dominated by V_{LOAD} and R_{LOAD} in **Figure 10**.

The power absorbed by the TVS can be calculated from the characteristic of the waveform shown in **Figure 10**:

$$\text{Energy} = ½\, L \bullet I^2 = [(V_{TVS} - V_{LOAD}) \bullet t_{DSCHG}]^2/(2 \bullet L)$$

which is ½ • 800µH • $(0.45\text{A})^2$ = 81µJ. This current (0.45A) agrees well with the turn-off characteristic shown in the graph where the magnetics leave saturation at ~0.5A.

The example listed demonstrates the need to have an accurately characterized load so that the energy due to the switching event does not exceed the rating of the MOSFET or TVS protector.

[4] The calculated rise time relies on the manufacturer supplied graphs for C_{RSS}. The actual rise time during the interval shown in **Figure 8** is longer due to the non-linear nature of the capacitance C_{RSS}. From the datasheet graphs, the average capacitance is 190pF over the interval of $5\text{V} < V_{DS} < 25\text{V}$. During the initial turn-off the capacitance is much larger, affecting the total energy by ~30%. A second-order effect not used in Equation 2 is due to the gate-source capacitance C_{ISS}. That additional capacitance divided by the transistor's conductance and load resistance causes an additional delay of 5µs-10µs, so the calculated rise time is closer to 35µs.

Figure 4 Discharge from Gate Turning On

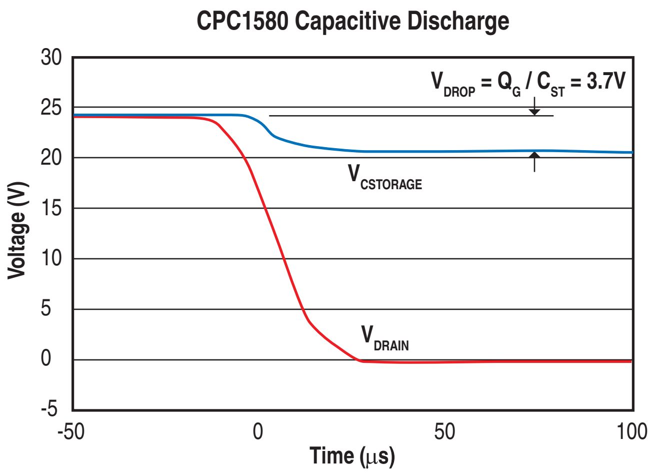


Figure 5 Load Current and t_{FALL}

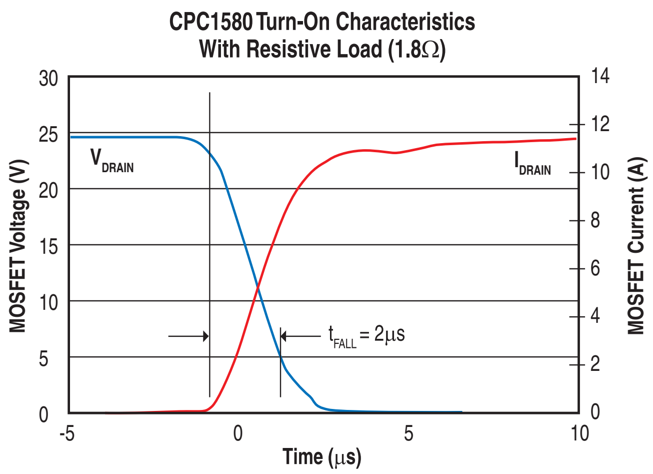


Figure 6 Turn-On Delay

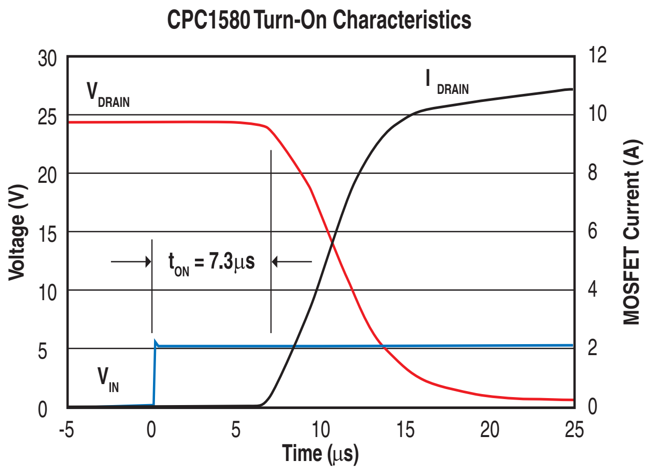


Figure 7 Turn-Off Delay

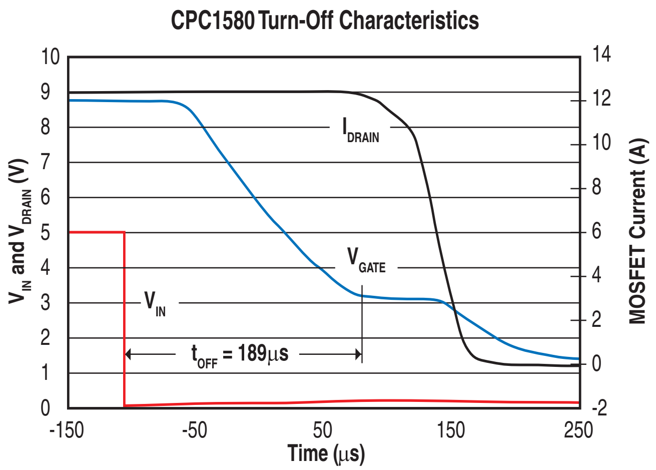


Figure 8 Load Current and t_{RISE}

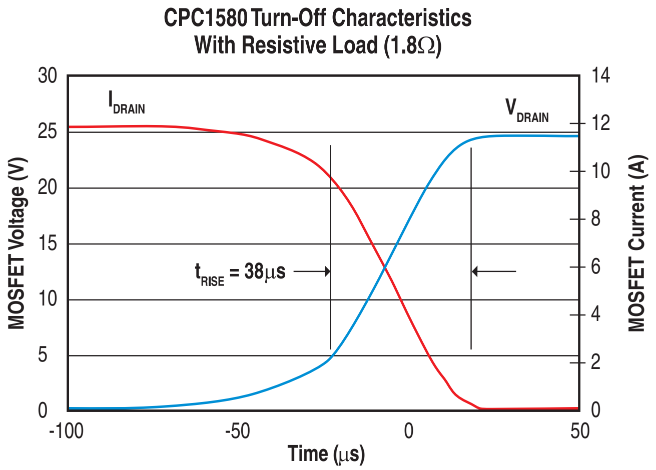


Figure 9 Discharge Power and Energy

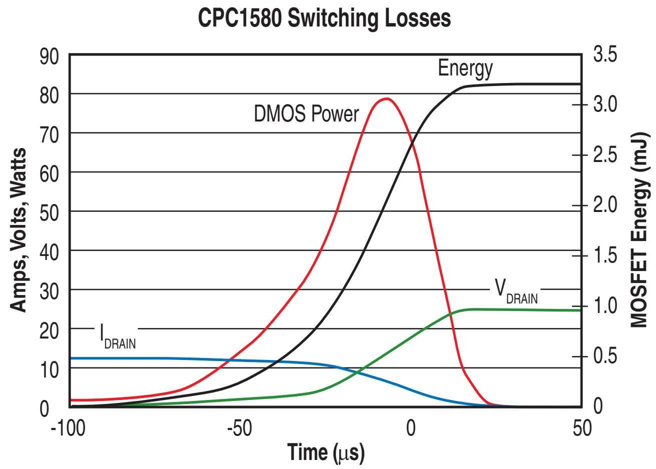


Figure 10 Moderate Inductive Current and t_{RISE}

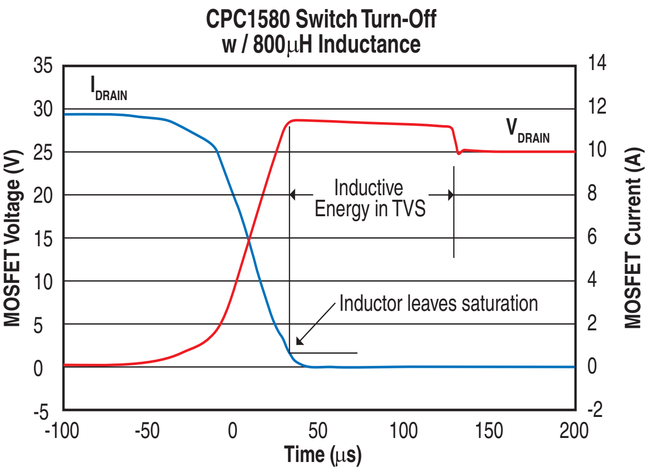


Figure 11 Inductive Turn-On

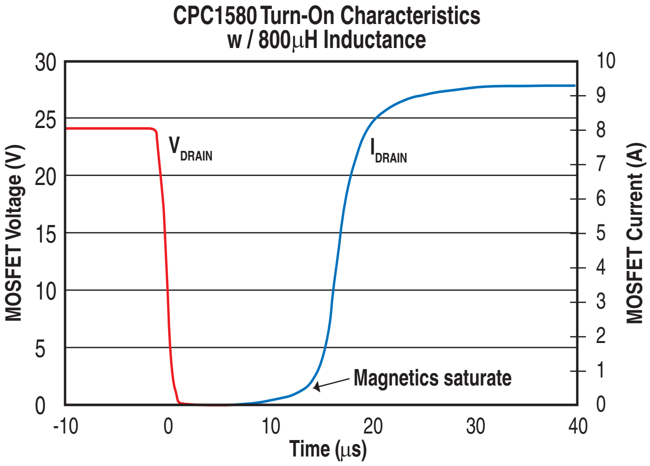


Figure 12 Turn-On with Modified Load

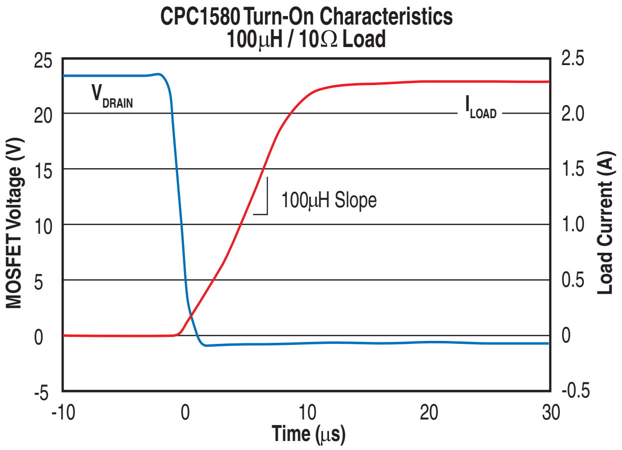
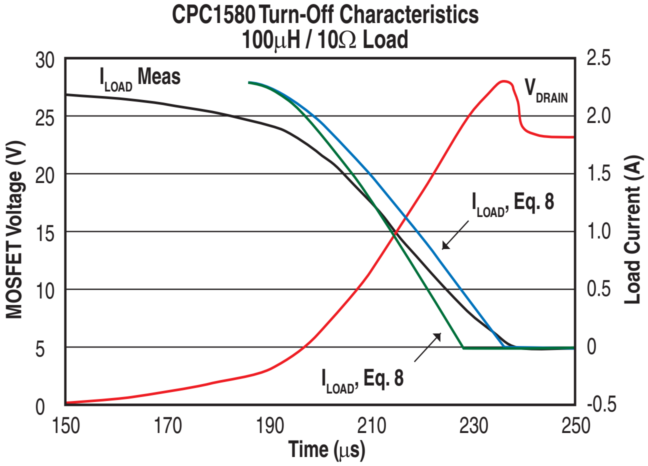


Figure 13 Turn-Off with Modified Load



The load was modified to avoid saturating the magnetics allowing comparison of the expected load current (from Equation 8) versus the measured load current. The circuit changes were to increase the resistance to 10.2 Ohms and change the magnetic inductance to 113µH.

As seen in the turn-on characteristic is almost perfectly inductive where the di/dt forms a non-saturating V/L curve. The voltage applied remains at 24V.

Figure 13 shows the inductive nature of the turn-off as seen in the overshoot. In this case **Equation 8** was fit to the time-base and the resistance, inductance, and capacitance were plugged in. The slope of the line is steeper than expected, which is what has been observed in the previous example. **Equation 8** was then modified to include the C_{ISS} factor $(C_{RSS} + C_{ISS}/(g_{FS} \bullet R_{LOAD}))$ and the resultant slope better approximates the actual slope as expected. It is worth restating that the slow change at the beginning of the transition is due to the large non-linearity in capacitance vs. voltage. While this interval is an important component of the total energy (~30%) the calculation is more complicated and not readily available from the component datasheets. Analysis described in the references listed will improve the characteristic to within 10%.

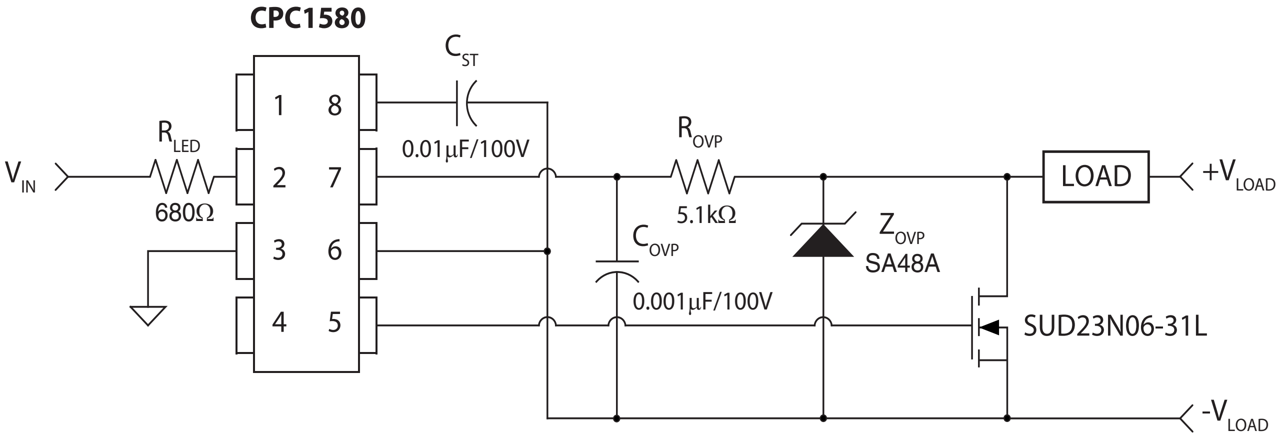
Equation 8 proves to be an accurate model for load current during the turn-off time, which can be subsequently used to consume inductive energy during the turn-off event. The equation can include second-order terms to more accurately model the transition region of switching.

6.2 Case 2: 48V Load Switching

Voltages closer to the peak operating voltage of the CPC1580 can also be accommodated, but the over-voltage protection becomes more important. **Table 1:** shows a sample over-voltage protection component selection for a 48V/5A design requirement.

The design criteria are more complicated because the peak voltage at 5A for the TVS component is 77V which exceeds the voltage rating for the CPC1580 and MOSFET of 60 volts maximum. Two conditions must be met for using such a protector: (1) protecting the CPC1580 from going above it's maximum voltage, and (2) ensuring the avalanche energy of the MOSFET is not exceeded. Since the MOSFET breakdown voltage will be nominally higher than the specification, (or if the user selects a higher voltage MOSFET), then C_{OVP} should be replaced with a zener diode/TVS to keep the voltage at pin 7 (V_D) to less than 60V but greater than 48V. (Until the parasitic inductance discharges to 1mA at which the TVS voltage is 59V.)

Figure 14 Case 2 Application Circuit



6.2.1 Measured Results

The design for Case 2 was implemented and the following characteristics observed. **Figure 15** shows the fall time for a resistive load. The calculated fall time is ~1µS. The rise time is shown in **Figure 16**. The calculated value is 34µS in the linear region shown on the graph. The peak energy during the transient is shown in **Figure 17**. The calculated Peak Energy, from Equation 6 is 1.36mJ. This value is consistent with the linear-region switching losses. The additional energy dissipation is due to the large non-linear capacitance at the beginning of the transition.

Figure 18 and **Figure 19** demonstrate the response with the inclusion of the inductive load. For the case shown, the MOSFET energy dissipation exceeds the stored inductive energy of 160µJ, so no energy is transferred to the TVS.

The charge time plays a significant role in the calculation of the maximum switching frequency for this case study. However, the charging voltage is very small so the resulting charge time can be reduced, knowing that the voltage dropped across R_{OVP} will increase proportionally. The maximum switching frequency of the example in **Table 1:** is $F_{MAX} = 0.333 \bullet (40\mu s + 600\mu s + (34\mu s \mid 181\mu s) + 2\mu s)^{-1} < {\sim}400Hz$.

Figure 15 48V Case Study t_{FALL}

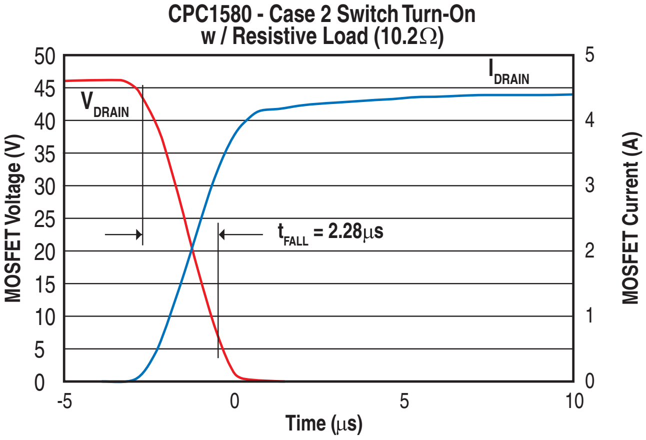


Figure 16 48V Case Study t_{RISE}

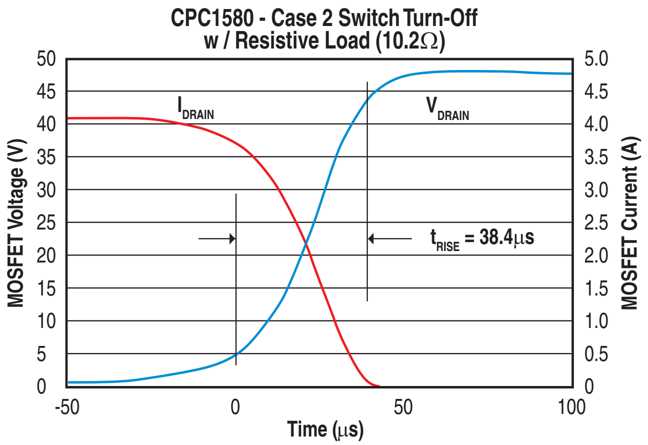


Figure 17 48V Case Study Peak Power and Energy

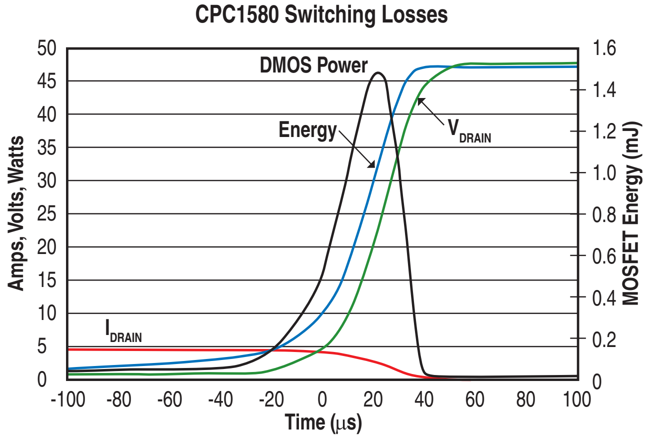


Figure 18 Inductive Turn-On Transition

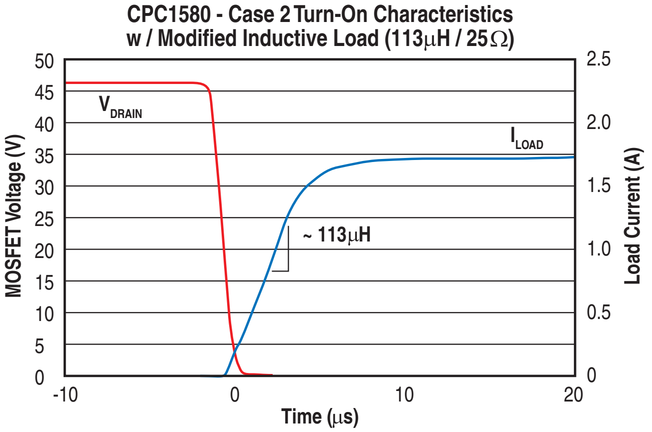
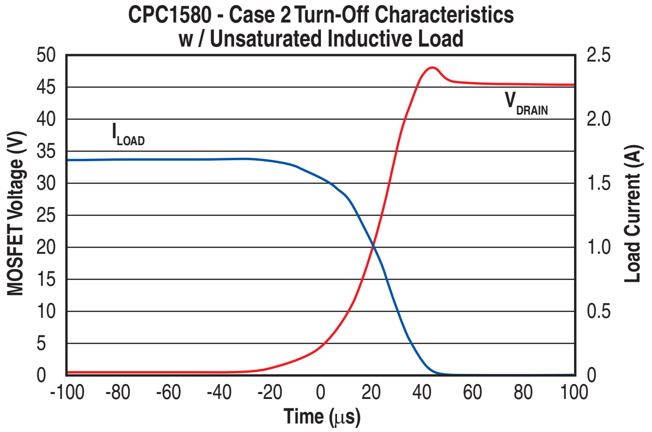


Figure 19 Inductive Turn-Off Transition



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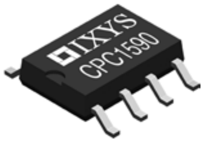


CPC1590
Optically Isolated Gate Driver

Driver Characteristics

Parameter	Rating	Units
Input Current	2.5	mA
Switching Speed (I_F=5mA, MOS Input Capacitance=4nF)		
$t_{d(on)}$	12	µs
$t_{d(off1)}$ (V_{GS}=2V)	125	
$t_{d(off2)}$ (V_{GS}=1V)	210	

Features

- 3750V_{rms} Input-to-Output Isolation
- Drives External Power MOSFET
- Low LED Current (2.5mA)
- Requires No External Power Supply
- Load Voltages up to 200V
- High Reliability
- Small 8-pin Surface Mount Flatpack Package
- Machine Insertable, Wave Solderable
- Tape and Reel Version Available
- Flammability Rating UL 94 V-0

Applications

- Industrial Controls
- Instrumentation
- Medical Equipment Isolation
- Electronic Switching
- I/O Subsystems
- Appliances

Pb RoHS e3

Description

The CPC1590 is a MOSFET Gate Driver that requires no external power supply: it regulates the input voltage drawn from the load (up to 200V), down to 12.2V for internal use. It is specifically designed for low duty cycle switching applications that drive up to 4nF of gate capacitance.

The CPC1590 accomplishes very fast MOSFET turn-on by supplying stored charge, from an external capacitor, to the MOSFET gate when input control current is applied to the device's LED. After the MOSFET is turned on, photocurrent from the input optocoupler keeps it on for as long as sufficient input control current flows, so there is no low-frequency operating limit. When the MOSFET is turned off, the storage capacitor charges from the device's regulated internal voltage in preparation for the next turn-on.

Because it is provided in a small, 8-pin Flatpack package and requires no separate power supply, the CPC1590 provides a flexible design solution that consumes the least amount of PCB land area.

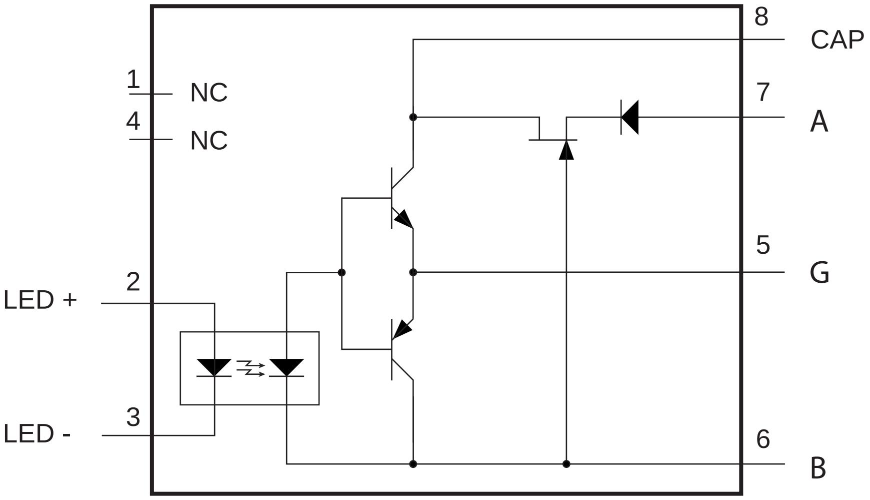
Approvals

- UL Recognized Component: File E76270

Ordering Information

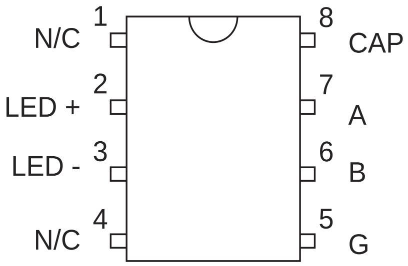
Part	Description
CPC1590P	8-Pin Flatpack (50/Tube)
CPC1590PTR	8-Pin Flatpack (1000/Reel)

Figure 1. CPC1590 Block Diagram



1. Specifications

1.1 Package Pinout



1.2 Pin Description

Pin#	Name	Description
1	-	Not connected
2	LED +	Positive input to LED
3	LED -	Negative input to LED
4	-	Not connected
5	V_G	Output, MOSFET Gate Control
6	V_{L2}	-Load Voltage DC, ±Load Voltage AC
7	V_{L1}	+Load Voltage DC, ±Load Voltage AC
8	V_{CAP}	Storage Capacitor Voltage

1.3 Absolute Maximum Ratings

Parameter	Rating	Units
Blocking Voltage (V_{DS})	200	V_P
Reverse Input Voltage	5	V
Input Control Current	50	mA
Peak (10ms)	1	A
Input Power Dissipation	20	mW
Total Package Dissipation	200	mW
Isolation Voltage (Input to Output)	3750	V_{rms}
Operational Temperature	-40 to +110	°C
Storage Temperature	-40 to +125	°C

Absolute maximum electrical ratings are at 25°C

Absolute maximum ratings are stress ratings. Stresses in excess of these ratings can cause permanent damage to the device. Functional operation of the device at conditions beyond those indicated in the operational sections of this data sheet is not implied.

1.4 ESD Rating

ESD Rating (Human Body Model)
1000 V

1.5 Recommended Operating Conditions

Parameter	Symbol	Min	Max	Units
Load Voltage	V_L	15	200	V
Input Control Current	I_F	2.5	10	mA
Forward Voltage Drop	V_F	1	1.5	V
Operating Temperature	T_A	-40	+110	°C

1.6 General Conditions

Unless otherwise specified, minimum and maximum values are guaranteed by production testing.

Typical values are characteristic of the device at 25°C and are the result of engineering evaluations. They are provided for informational purposes only and are not part of the manufacturing testing requirements.

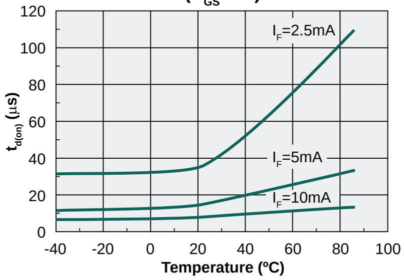
Unless otherwise noted, all electrical specifications are listed for T_A=25°C.

1.7 Electrical Specifications

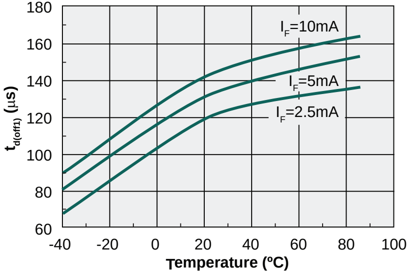
Parameter	Conditions	Symbol	Min	Typ	Max	Units
Load Side Characteristics						
Gate Voltage	I_F=2.5mA	V_{GS}	7.0	7.3	12	V
	I_F=5mA		7.5	8.0		
	I_F=10mA			8.4		
	I_F=2.5mA -40°C<T_A<110°C		4.2	-	14.4	
Capacitor Voltage	10V<V_{DS}<200V	V_{CAP}	10	12.2	16	V
Gate Drive Capability	I_F=2.5mA, V_{GS}=0V, V_{CAP}=15V	I_{G_source}	2	3.3	7	mA
	I_F=0mA, V_{GS}=8V, V_{CAP}=8V	I_{G_sink}	4.0	9.0	14	
	I_F=0mA, V_{GS}=4V, V_{CAP}=4V		1.5	3.3	6	
	I_F=0mA, V_{GS}=2V, V_{CAP}=2V		0.5	1.2	2	
Turn-On Delay	V_{DS}=48V, V_{GS}=4V, C_{VG}=4nF	t_{on}				µs
	I_F=2.5mA		1	40	140	
	I_F=5mA			12	40	
	I_F=10mA			5	20	
Turn-Off Delay	V_{DS}=48V, V_{GS}=2V, C_{VG}=4nF	t_{off1}				µs
	I_F=2.5mA		40	110	400	
	I_F=5mA			125		
	I_F=10mA			130		
	V_{DS}=48V, V_{GS}=1V, C_{VG}=4nF	t_{off2}				
	I_F=2.5mA		40	200	600	µs
	I_F=5mA			210		
	I_F=10mA			220		
Off-State Leakage Current	V_{DS}=200V	I_{DS}	-	-	1	µA
LED Characteristics						
Forward Voltage Drop	I_F=5mA	V_F	1	1.27	1.5	V
Input Dropout Current	V_{GS}=1V	I_F	0.2	0.75	1	mA
Reverse Bias Leakage Current	V_R=5V	I_R	-	-	10	µA
Common Characteristics						
Input to Output Capacitance	-	C_{IO}	-	3	-	pF

1.8 Performance Data*

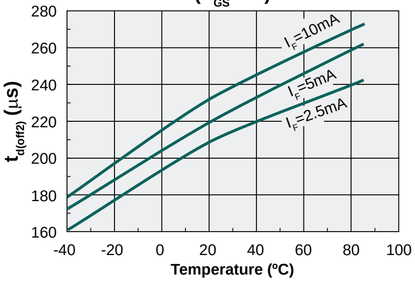
$t_{d(on)}$ vs. Temperature (V_{GS}=4V)



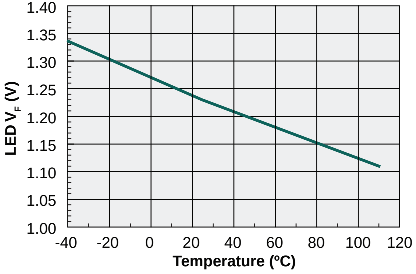
$t_{d(off1)}$ vs. Temperature (V_{GS}=2V)



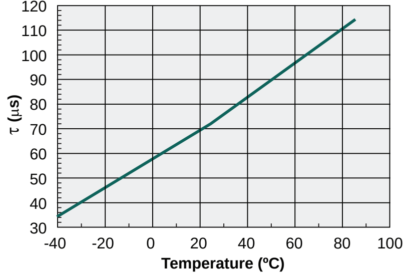
$t_{d(off2)}$ vs. Temperature (V_{GS}=1V)



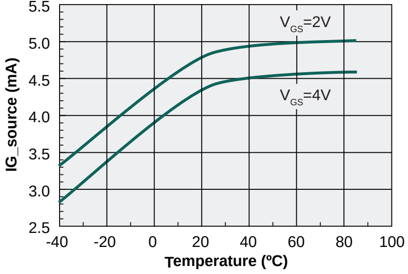
LED Forward Voltage Drop vs. Temperature (I_F=5mA)



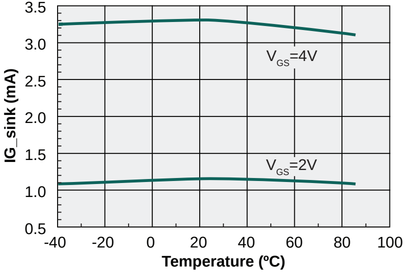
Time Constant (τ) vs. Temperature (I_F=5mA)



Gate Source Current vs. Temperature (I_F=5mA, V_{CAP}=15V)



Gate Sink Current vs. Temperature (I_F=0mA, V_{GS}=V_{CAP})



* Unless otherwise noted, data presented in these graphs is typical of device operation at 25ºC. For guaranteed parameters not indicated in the written specifications, please contact our application department.

2. Introduction

The CPC1590 is a MOSFET Gate Driver that requires no external power supply. It can regulate an input voltage, up to 200V, down to 12.2V for internal use. It is specifically designed for low-duty-cycle switching frequencies that drive 4nF of gate capacitance.

3. Functional Description

The CPC1590 is used in conjunction with a single MOSFET transistor for remote switching of DC loads (**Figure 2**), and two MOSFETS and a diode for remote switching of low-frequency AC loads (**Figure 3**) where isolated power is unavailable.

The device uses external components, most notably a charge storage capacitor, to satisfy design switching and over-voltage protection requirements. Because of this design flexibility, the designer may choose a great number of MOSFETs for use in a wide variety of applications. The designer simply needs to know the MOSFET total gate charge (Q_G), and with this information a capacitor can be chosen. The capacitance of the storage capacitor should be greater than, or equal to, Q_G/0.5V.

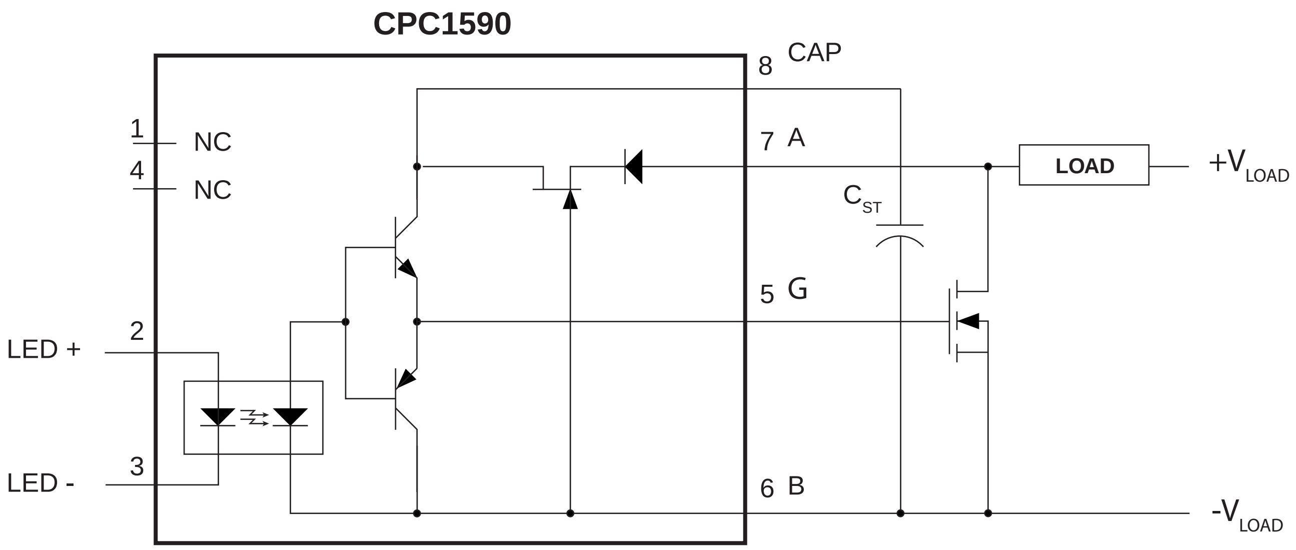
The CPC1590 has two states of operation:
(1) sufficient input control current is flowing, the LED is turned on, and the gate current is being applied. The light from the LED is being reflected onto the photovoltaic, which then produces a photocurrent that turns on the NPN bipolar transistor and provides the charge (I x t = Q), or the gate current that is being applied to turn on the MOSFET. (2) Sufficient input control current is not flowing, the LED is turned off, and gate current is not flowing. The LED is off because V_F << the minimum forward voltage required, and not enough current is being applied. This turns on the PNP bipolar transistor, providing a path for gate current to discharge to V_{L2}.

When V_{LOAD} is first applied, the external storage capacitor begins to charge. The charge is sent through a bootstrap diode to prevent the charge from escaping and discharging through a turned-on MOSFET. The J-FET then regulates the voltage between 10V and 16V. The input control current is applied, then the charge is transferred from the storage capacitor through the NPN bipolar transistor, along with the charge from the photovoltaic, to the MOSFET gate to accomplish a rapid turn-on. After the capacitor has discharged and the MOSFET has turned on, the photocurrent from the input optocoupler continues to flow into the gate to keep the MOSFET turned on.

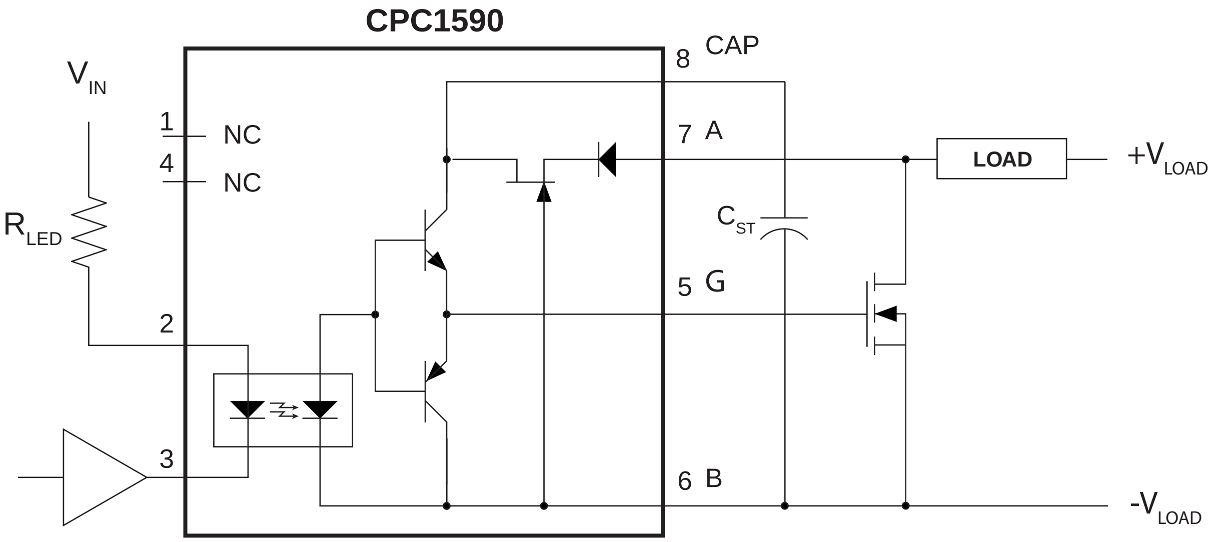
When the input control current is removed, the gate current stops flowing and the PNP bipolar transistor is on and is discharging the MOSFET gate. The MOSFET is now off. At this point the capacitor begins to recharge for the next turn on cycle.

The circuit below does not include over-voltage protection.

Figure 2. CPC1590 DC Application Circuit



4. Device Configuration



4.1 LED resistor

The input resistor is required to limit LED current to a value set by Recommended Operating Conditions in **"Recommended Operating Conditions" on page 3**. In some cases, higher LED operating current would improve driver speed; however, this higher current could also reduce LED lifespan, which would cause reliability issues.

The general equation used to calculate the resistor value is:

$$R_{LED} = \frac{V_{IN} - (V_F + V_{OL})}{I_F}$$

- I_F = Input Control Current
- V_{OL} = Low-level output of the driving logic gate or the collector-emitter voltage of the driving logic transistor. (This parameter is provided in the manufacturer's data sheet.)
- V_{IN} = Input Power Source
- V_F = Forward Voltage Drop of LED
- R_{LED} = Input Resistor

When calculating the resistor value, the designer should take into consideration power-supply variations, which can range about ±10%, temperature variations from -40°C to +85°C, LED forward voltage drop over the temperature range, and the resistor's tolerance and temperature stability rating.

When the LED resistor value is selected by the above formula, the R_{LED} power dissipation, P_D, can be obtained from the following equation:

$$P_D = I_F^2 \bullet R_{LED}$$

With power dissipation calculated, it is now possible to select an appropriate resistor size that can be used in the particular application circuit. It is recommended that a resistor with at least twice the calculated power rating should be selected.

4.2 Storage Capacitor

The storage capacitor (C_{ST}) enables the gate driver to turn on a power MOSFET faster by delivering a reservoir of charge to the gate. Selection of the storage capacitor is given by the following equation:

$$C_{ST} \geq Q_G / 0.5V$$

This equation shows that the storage capacitor needs to deliver enough charge to the gate while only dropping 0.5V. The CPC1590 can deliver 32nC of charge at rated operating speed, and will operate with much larger loads, >4nF, with slower turn-on and turn-off times.

The CPC1590 has an internal J-FET, which is used to regulate the voltage applied to the storage capacitor. The voltage applied to the storage capacitor will be between 10V and 16V. The capacitor's voltage rating should be two to three times this range.

The designer should select the storage capacitor based on the particular application requirements. If the final product requires operating at a higher ambient temperature range of -40°C to +110°C, then it is better to select COG/NPO capacitors in order to meet minimum capacitance requirements.

4.3 Transistor Selection

The CPC1590 charges and discharges an external MOSFET transistor. The selection of the MOSFET is determined by the user to meet the specific power requirements for the load. The CPC1590 output voltage is listed in the specification, but, as mentioned earlier, there must be little or no gate leakage.

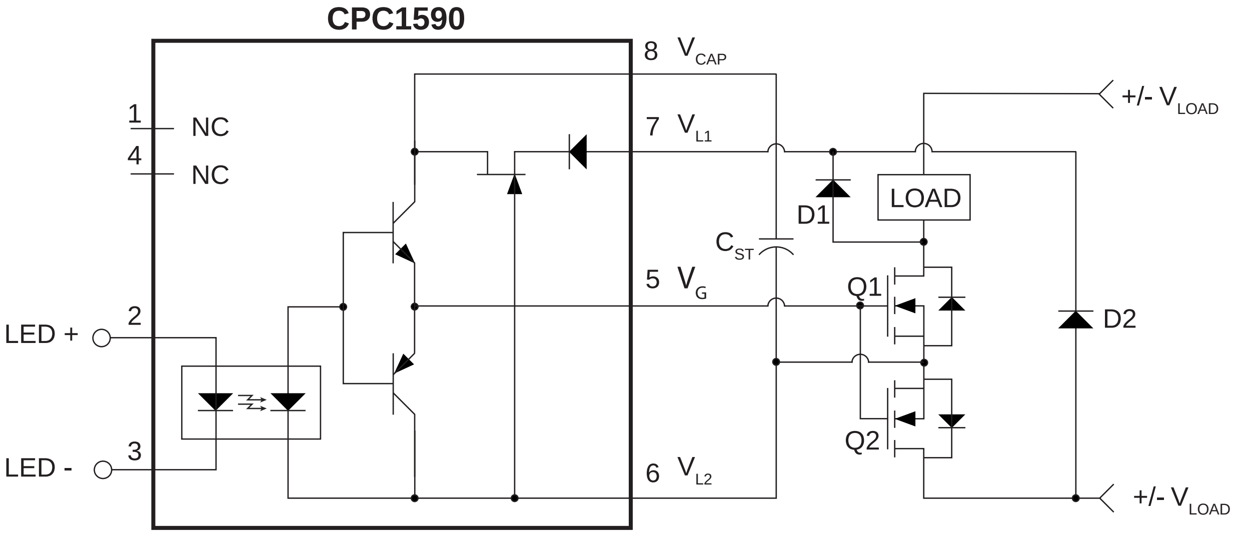
Another parameter that plays a significant role in the selection of the transistor is the gate drive voltage available from the part. The CPC1590 uses photovoltaic cells to collect the optical energy generated by the internal LED; to generate more voltage, the photovoltaic diodes are stacked. As such, the voltage of the photovoltaic stack reduces with increased temperature. The user must select a transistor that will maintain the load current at the maximum temperature, given the V_{GS} in the CPC1590 specifications.

5. CPC1590 Used as an AC Switch

The CPC1590 can be used in other configurations. One typical configuration is shown in **Figure 3**, which is called an AC Switch. This simply means that either terminal can be positive or negative. This configuration requires a second MOSFET (Q2) and two rectifying diodes (D1 and D2).

The design considerations are identical for this application. Diodes D1 and D2 must have voltage ratings greater than the breakdown voltage of the MOSFETs.

Figure 3. Application Circuit for Using the CPC1590 as an AC Switch



6. Conclusion

See IXYS Integrated Circuits' Application Note, AN-202, for a thorough discussion, and for examples of device usage, component selection, and over-voltage protection circuitry.

7. Manufacturing Information

7.1 Moisture Sensitivity

All plastic encapsulated semiconductor packages are susceptible to moisture ingression. IXYS Integrated Circuits classifies its plastic encapsulated devices for moisture sensitivity according to the latest version of the joint industry standard, **IPC/JEDEC J-STD-020**, in force at the time of product evaluation. We test all of our products to the maximum conditions set forth in the standard, and guarantee proper operation of our devices when handled according to the limitations and information in that standard as well as to any limitations set forth in the information or standards referenced below.

Failure to adhere to the warnings or limitations as established by the listed specifications could result in reduced product performance, reduction of operable life, and/or reduction of overall reliability.

This product carries a **Moisture Sensitivity Level (MSL)** classification as shown below, and should be handled according to the requirements of the latest version of the joint industry standard **IPC/JEDEC J-STD-033**.

Device	Moisture Sensitivity Level (MSL) Classification
CPC1590P	MSL 1

7.2 ESD Sensitivity

This product is **ESD Sensitive**, and should be handled according to the industry standard **JESD-625**.

7.3 Reflow Profile

Provided in the table below is the Classification Temperature (T_C) of this product and the maximum dwell time the body temperature of this device may be (T_C - 5)ºC or greater. The classification temperature sets the Maximum Body Temperature allowed for this device during lead-free reflow processes. For through-hole devices, and any other processes, the guidelines of **J-STD-020** must be observed.

Device	Classification Temperature (T_C)	Dwell Time (t_p)	Max Reflow Cycles
CPC1590P	260°C	30 seconds	3

7.4 Board Wash

IXYS Integrated Circuits recommends the use of no-clean flux formulations. Board washing to reduce or remove flux residue following the solder reflow process is acceptable provided proper precautions are taken to prevent damage to the device. These precautions include but are not limited to: using a low pressure wash and providing a follow up bake cycle sufficient to remove any moisture trapped within the device due to the washing process. Due to the variability of the wash parameters used to clean the board, determination of the bake temperature and duration necessary to remove the moisture trapped within the package is the responsibility of the user (assembler). Cleaning or drying methods that employ ultrasonic energy may damage the device and should not be used. Additionally, the device must not be exposed to flux or solvents that are Chlorine- or Fluorine-based.

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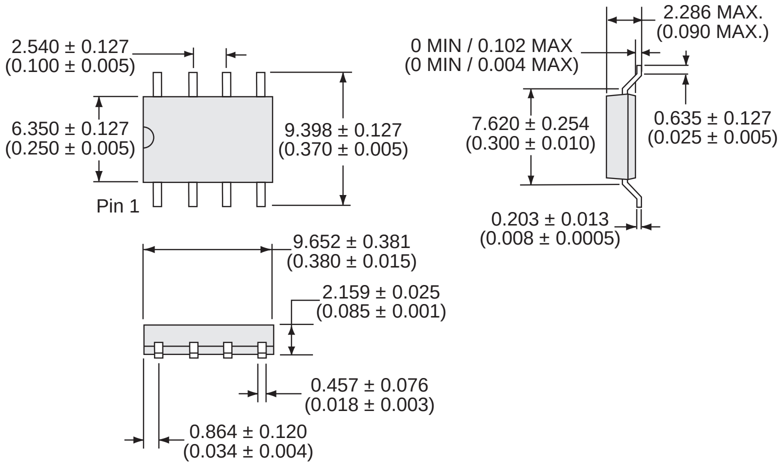
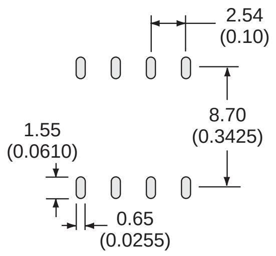
7.5 Mechanical Dimensions

7.5.1 CPC1590P 8-Pin Flatpack Package

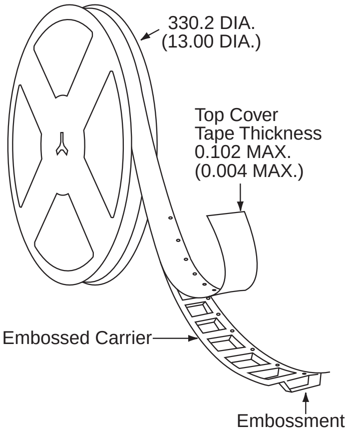


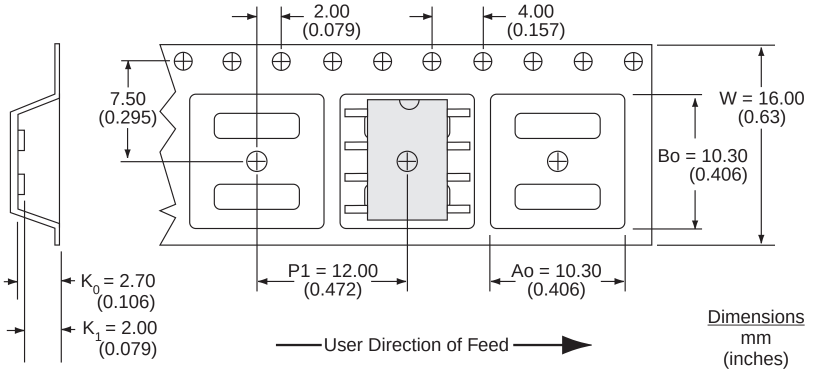
PCB Land Pattern



Dimensions
mm
(inches)

7.5.2 CPC1590PTR Tape & Reel





Dimensions
mm
(inches)

NOTES:
1. All dimensions carry tolerances of EIA Standard 481-2
2. The tape complies with all “Notes” for constant dimensions listed on page 5 of EIA-481-2

For additional information please visit www.ixysic.com

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Specification: DS-CPC1590-R02

6/18/2018

The information below supercedes any previously presented material.

For additional information please visit our website at: https://www.littelfuse.com

IXYS
A Littelfuse Technology

CPC1590 Application
Technical Information

1 Using the CPC1590 Isolated Gate Driver IC

The CPC1590 is an excellent choice for remote switching of DC and low frequency loads where isolated power is unavailable. The device uses external components to satisfy design switching requirements, which enables the designer to choose from a great number of MOSFETs. The designer also has several options when designing over-voltage protection circuitry. The case studies look at only two of many methods, but each has unique constraints that should prove useful to many other designs.

Figure 1 shows a typical application circuit for using the CPC1590 gate driver. The part allows the user to turn on the gate of a MOSFET, and keep it on until the LED current is turned off. The application circuit uses a boot-strap diode (internal to the part) and storage capacitor (C_{ST}) to provide the charge needed for fast turn-on switching of an external MOSFET device. When the MOSFET is on, the photo current from the LED keeps the MOSFET gate biased to the rated voltage continuously.

The CPC1590 uses charge from the load voltage when turning off to restore the MOSFET gate's switching charge for the next turn-on event. The part will turn on even without this restoration of charge (in the case of no load voltage), although the turn-on will be much slower because the photo current will be charging the gate. This feature can be exploited during system startup.

2 Application Component Selection

2.1 Storage Capacitor Selection C_{ST}

The storage capacitor (C_{ST}) enables the part to turn on quickly by holding a reservoir of charge to be transferred to the gate of the MOSFET. The turn-off cycle does not depend on the storage capacitor.

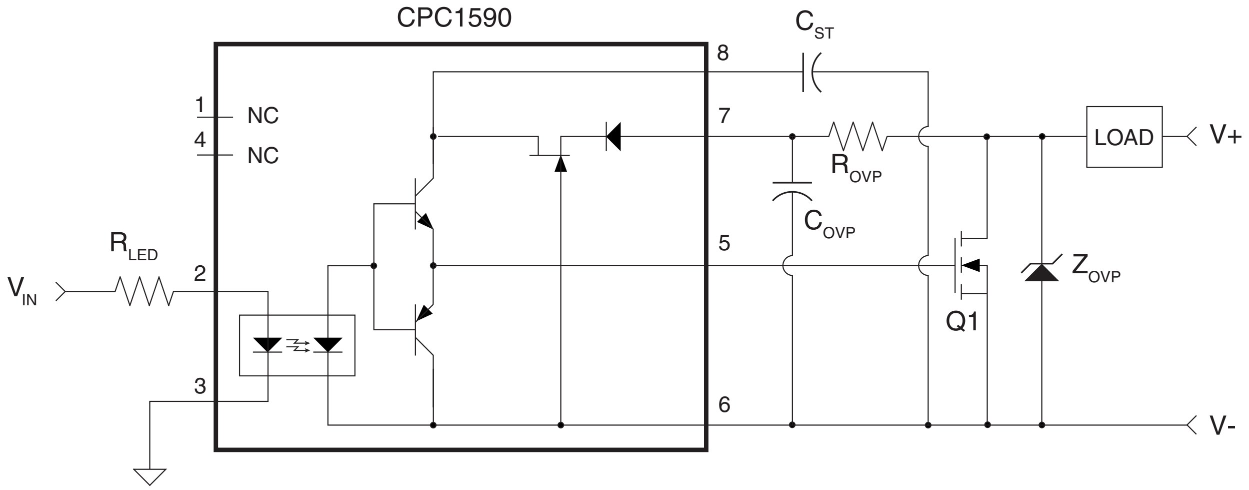
Equation 1: Charge Storage Capacitor Calculation:

$$C_{ST} \geq \frac{Q_G}{0.5V} \qquad \text{(FARADS)}$$

Q_G is the total gate charge. Equation 1 shows that the storage capacitor needs to deliver enough charge to the gate while only dropping 0.5V. The CPC1590 can deliver 32nC at the rated operating speed and will operate with much larger loads (<4uF) with a slower turn-on and turn-off time.

> ***Note:*** *Care must be taken to minimize any leakage current path from the capacitor to ground, between pins 7 and 8, MOSFET gate current, and between pins 5 and 6. Leakage currents will discharge the storage capacitor and, even though the device is already on, will become a load to the photo current that keeps the gate voltage on. The gate voltage will be reduced if >500nA of leakage is present. Therefore, the combined impedance from pin 8 to pin 7, pin 5 and pin 6, capacitor current, and MOSFET current must be >20MΩ over the temperature rating of the part.*

Figure 1 CPC1590 Application Circuit Diagram with Over-Voltage Protection



2.2 Transistor Selection

The CPC1590 charges and discharges an external MOSFET transistor. The selection of the MOSFET is determined by the user to meet the specific power requirements for the load. The CPC1590 output voltage is listed in the specification, but, as mentioned earlier, there must be little or no gate leakage.

Another parameter that plays a significant role in the determination of the transistor is the gate drive voltage available from the part. The CPC1590 uses photovoltaic cells to collect the optical energy generated by the LED, and, to generate more voltage, the photovoltaic diodes are stacked. As such, the voltage of the photovoltaic stack reduces with increased temperature. The user must select a transistor that will maintain the load current at the maximum temperature, given the V_{GS} in the CPC1590 specification.

The case studies below use "logic-level" MOSFETs for each design to maintain the load described.

2.2.1 Transistor Switching Characteristics

The primary characteristics of the application's switching behavior are t_{ON}, t_{OFF}, t_{RISE}, t_{FALL}, and the recovery time of the storage capacitor, t_{CHG}. These parameters are dependent on the MOSFET selection and need to be reviewed in light of the application requirements.

The CPC1590 turns on the MOSFET to the datasheet V_{GS} after the t_{ON} delay. Similarly the t_{OFF} delay is the amount of time until the LED is turned off and the capacitive load discharges to the level in the CPC1590 specification. For MOSFETs with larger or smaller required gate charge the t_{ON} and t_{OFF} will be proportionately faster or slower, but it is not a linear relationship.

The approximate rise and fall times of the transistor's drain voltage is:

Equation 2: Rise Time Calculation:

$$t_{RISE,VD} \approx \frac{V_{LOAD} \bullet C_{RSS}}{I_{G\_SINK}} \qquad \text{(SECONDS)}$$

Equation 3: Fall Time Calculation:

$$t_{FALL,VD} \approx \frac{V_{LOAD} \bullet C_{RSS}}{I_{G\_SOURCE}} \qquad \text{(SECONDS)}$$

Where C_{RSS} is the MOSFET gate-drain capacitance (averaged over the switching voltage range) found in the MOSFET datasheet, and I_{G_SINK} is the gate sinking current of the CPC1590, and I_{G_SOURCE} is the gate driving ability.

For a significant number of applications, the rise time will likely be dominated by the CPC1590's internal discharge time. This can alter the amount of dissipated energy in the MOSFET during switching so the user must review the application carefully as shown in the design examples.

The value for the charge time, t_{CHG} is due to external component selection.

To calculate the value for the charge time, t_{CHG}, which is due to external component selection:

Equation 4: Storage Capacitor Charge Recovery Time (seconds):

$$t_{CHG} \approx 5 \bullet 300\Omega \bullet C_{ST}$$

Note:*The CPC1590 is ideal to use where remote power is otherwise unavailable. If the LED is also powered remotely, care must be taken to ensure that parasitic transient signals are reliably filtered from the input control signal. Large transient currents will mutually couple energy between cables, and a simple R-C filtering of the CPC1590 input may be sufficient to suppress false turn-on.*

3 Application Switching Losses

During the transition intervals, the application and load components change energy states, and during the process incur switching losses. These losses are manifested as heat in the application circuit, and must be addressed by the designer to ensure that no one component exceeds its power rating. The designer must understand the details of load behavior in order to adequately size and protect the application circuit. There are three general cases to observe: (1) purely resistive loads, (2) inductive/resistive loads, and (3) loads with significant capacitance. Inductors and capacitors are energy storage elements that require special consideration for switching.

The energy stored in the load inductor is discharged through the switching MOSFET, load capacitance and the over-voltage-protection circuitry.

During the turn-on interval, the inductor energy is zero, and so the capacitive energy in the load and parasitic elements of the switching application must be dissipated by the MOSFET in order for the load to change state.

Equation 5: Stored Inductive Energy (Joules):

$$E_L = \frac{1}{2} \bullet L \bullet I_{LOAD}^2$$

3.1 Resistive Load Losses: The Ideal Case

For purely resistive loads, the energy dissipated by changing states occurs primarily in the MOSFET. The equation describing MOSFET energy dissipation is:

Equation 6: MOSFET Energy: E_{RISE} (Joules):

$$E_{MOSFET} \geq V_{LOAD}^2 \bullet \frac{C_{RSS}}{I_{G\_SINK}} \bullet \frac{I_{LOAD}}{6} = \frac{P_{LOAD}}{6} \bullet t_{RISE}$$

The average power of the MOSFET for any load type is:

Equation 7: MOSFET Average Power (Watts):

$$P_{AVG} = I_{LOAD}^2 \bullet R_{DSAT} \bullet D + f_{SWITCH} \bullet (E_{RISE} + E_{FALL})$$

Where f_{SWITCH} is the application switching frequency, R_{DSAT} is the MOSFET's on-resistance, and D is the switch's operational duty cycle: $D = t_{ON}/(t_{ON}+t_{OFF})$. E_{RISE} and E_{FALL} represent the energy dissipated by the MOSFET during rise and fall, in Joules.

3.2 Inductive/Resistive Loads

If the load is resistive and inductive, and the inductance doesn't saturate, then the load current during turn off is described by:

Equation 8: Resistive/Inductive Load Current during t_{RISE} (Amps):

$$I_{LOAD}(t) = \frac{V_{LOAD}}{R_{LOAD}} - \frac{I_{G\_SINK}}{L_{LOAD} \bullet C_{RSS}} \bullet \left(\frac{L_{LOAD}}{R_{LOAD}}\right)^2 \bullet \left[\frac{R_{LOAD}}{L_{LOAD}} \bullet t - 1 + e^{\frac{-R_{LOAD}}{L_{LOAD}} \bullet t}\right]$$

The drain voltage during turn off is:

Equation 9: MOSFET Drain Voltage during t_{RISE} (V):

$$V_{DRAIN}(t) = \frac{I_{G\_SINK}}{C_{RSS}} \bullet t$$

The instantaneous power in the MOSFET will be the product of the two equations, and the energy will be the integral of the power over time.

3.3 Capacitive Loads

The energy absorbed by the MOSFET for loads that are more capacitive in nature occurs during the MOSFET turn-on as opposed to the turn-off. The energy absorbed by the MOSFET will be a function of the load, the Transient Voltage Suppressor TVS (or other protector) and the MOSFET drain capacitance.

Equation 10: MOSFET Energy: E_{FALL} (Joules):

$$E_{FALL} = \frac{1}{2} \bullet (C_{TVS} + C_{OSS} + C_{LOAD}) \bullet V_{LOAD}^2$$

C_{OSS} is the MOSFET output capacitance found in the datasheet. As mentioned earlier, the MOSFET switching losses occur at different times, either rising or falling, so loads with a combination of inductance and capacitance can also be calculated by the energy equations described above.

The MOSFET can dissipate repeated avalanche energy, found in the datasheet, however that energy must be reduced for increased ambient temperature. For a 150°C MOSFET, the energy reduction at $T_{J,MAX}$ is:

Equation 11: MOSFET Energy Adjustment for Operating conditions (Joules):

$$E(T_{J,MAX}) \leq E(25°C) \bullet \frac{(150°C - T_{J,MAX})}{(150°C - 25°C)}$$

$T_{J,MAX}$ is the junction temperature of the die, so it must include the temperature increase caused by power dissipation of the load and the thermal impedance of the package/application. E(25°C) is the repetitive avalanche energy, E_{AR}, in the MOSFET datasheet at 25°C.

3.4 dV/dt Characteristics

The application shown in **Figure 1** and the detailed design of **Case 1** (**See "Case 1: 180V Application Circuit" on page 7**), dissipates significant energy caused by large dV/dt events. Fault voltages across the MOSFET will turn it on for the same reason that the part turns off slowly. For dV/dt events > I_{G_SINK}/C_{RSS} (from Equation 2) the application circuit will dissipate energy proportional to the C_{RSS} and g_{FS} (forward conductance) of the selected transistor. C_{RSS} is a function of the transistor's on-resistance and current/power capability, so higher load-power designs are more sensitive.

The CPC1590 provides an internal clamp to protect the gate of the MOSFET from damage during such an event. The part can withstand 100mA for short periods, such as dV/dt transients.

> ***Note:****The CPC1590 is ideal to use where remote power is otherwise unavailable. If the LED is also powered remotely, care must be taken to ensure that parasitic transient signals are reliably filtered from the input control signal. Large transient currents will mutually couple energy between cables, and a simple R-C filtering of the CPC1590 input may be sufficient to suppress false turn-on.*

4 Design Switching Frequency

The over-voltage protection and storage capacitor play a significant role in determining the switching frequency. The maximum switching frequency is a function of the Gate charge of the MOSFET, the storage capacitor (C_{ST}), and R_{OVP}. The maximum switching frequency relationship is:

Equation 12: Maximum Switch Operation (Hz):

$$f_{MAX} \leq \frac{1}{M} \bullet (t_{ON} + t_{OFF} + (t_{RISE,VD} \mid t_{CHG}) + t_{FALL,VD})^{-1}$$

where M=3 and is a multiplication factor for temperature and process variations; t_{ON} and t_{OFF} are CPC1590 datasheet parameters; $t_{RISE,VD}$ is the rise time of the drain voltage and t_{CHG} is the charge time of the storage capacitor, C_{ST}, and overvoltage protection circuitry; $t_{FALL,VD}$ is the fall time across the transistor. For calculation, choose the greater of $t_{RISE,VD}$ or t_{CHG}.

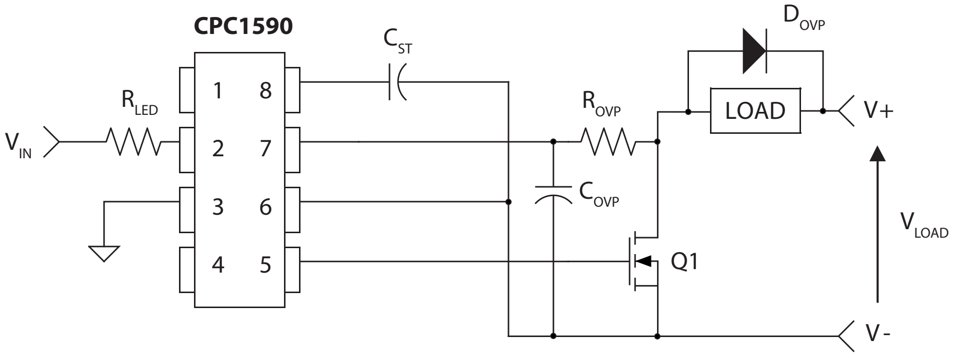
There is no minimum switching frequency because the CPC1590 uses photovoltaic diode current to keep the output charged as long as LED current flows.

5 CPC1590 Over-Voltage Protection

Over-voltage protection is generally required for the CPC1590 because of parasitic inductance in the load, wires, board traces, and axial leads of protectors. Purely resistive loads, or loads with low voltage switching, may be able to rely on the transistor to handle any parasitic energy, and thereby not require protection for the CPC1590. For very low inductance loads and traces, over-voltage suppression may be handled with a simple R-C filter consisting of R_{OVP} and C_{OVP} , or by use of a free-wheeling diode. For more moderate load inductance, or for remote switching of a load (i.e. through a long cable) a voltage suppressor can be used. For heavily inductive loads, only a free-wheeling diode, D_{OVP} , connected across the load element is recommended, see **Figure 2**.

The energy not consumed in switching losses must be absorbed by the over-voltage protection element. Most protective devices are designed to withstand certain peak power as in the case of a TVS, or maximum avalanche energy in the case of a MOSFET. The energy not consumed in switching losses must be absorbed by the over-voltage protection element. Most protective devices are designed to withstand certain peak power in the case of a TVS, or maximum avalanche energy in the case of a MOSFET. To reduce the amount of stored inductive energy, a larger capacitor can be added in parallel with the gate-drain connection of the MOSFET.However care must be taken so that the rise time and peak current do not exceed the Safe Operating Area (SOA) rating of the transistor. The consequence of increasing the gate-drain effective capacitance is reduced dV/dt tolerance.

Figure 2 CPC1590 Over-Voltage Protection for Inductive Loads



5.1 Other Protection Techniques

For applications in which higher inductance loads are switched, the designer must consider other circuit techniques, device ratings, or protector types. Of paramount importance is that the designer know the characteristics of the load being switched.

An excellent source describing power electronic devices and switching behavior is: *Power Semiconductor Devices,* by B. Jayant Baliga, ISBN 0-543-94098-6

For more over-voltage protection circuit techniques consult: *Switchmode Power Supply Handbook*, 2^{nd} *Edition*, Keith Billings, ISBN 0-07-006719-8, or *Power MOSFET Design*, B. E. Taylor, ISBN 0-471-93802-5.

6 Design Examples

Table 1: Sample Application Components

Table 1 shows two sample application component selections for two different voltage ratings.

Device	180V/1A Value/Rating	48V/5A Value/Rating	Comment
Q1	FDD18N20LZ [1]	FQP20N06L [1]	MOSFETS
C_{ST}	$>0.1\mu F/100V$	$>0.01\mu F/100V$	5% Capacitor
Z_{OVP}	Not Used	SA48A [1]	TVS-style protector
R_{OVP}	1KΩ	5.1KΩ	5%, 1/8 Watt (60Hz Switching Frequency or less)
C_{OVP}	0.001µF, 400V	0.001µF, 100V	5% Capacitor
R_{LED}	680Ω	680Ω	5V Switching

[1] Use of the FDD18N20LZ, FQP20N06L and SA48A product datasheets is necessary to completely understand the examples given.

6.1 Case 1: 180V Application Circuit

The application circuit selected uses a 200V MOSFET (Q1) as shown in Table 1 in conjunction with the CPC1590. The operating voltage allows 20V B_{VDSS} breakdown reduction for low temperature operation (-40°C). This sample application does not include an over-voltage protector, so the parasitic inductance and load current will need to be less than the repetitive avalanche energy of the MOSFET, derated for high temperature according to following equation:

$$E(T_{J,MAX}) \le E(25°C) \bullet \frac{(150°C - T_{J,MAX})}{(150°C - 25°C)}$$

The repetitive avalanche energy $E_{AR}(25°C)$ specification of the MOSFET (Q1) is listed as 8.9mJ.

Therefore, if derated for higher temperatures (e.g. $T_{J,MAX} = 110°C$):

$E(T_{J,MAX}) \le 8.9mJ \bullet (0.32) = 2.84mJ$

Use the following equations, shown previously,

$$t_{RISE,VD} \approx \frac{V_{LOAD} \bullet C_{RSS}}{I_{G\_SINK}} \qquad \text{(SECONDS)}$$

$$t_{FALL,VD} \approx \frac{V_{LOAD} \bullet C_{RSS}}{I_{G\_SOURCE}} \qquad \text{(SECONDS)}$$

$$E_{MOSFET} \ge V_{LOAD}^2 \bullet \frac{C_{RSS}}{I_{G\_SINK}} \bullet \frac{I_{LOAD}}{6} = \frac{P_{LOAD}}{6} \bullet t_{RISE}$$

with these specifications from the CPC1590 DataSheet:

$I_{G\_SINK} = 3.3\ mA$

$I_{G\_Source} = 3.3\ mA$

and from the MOSFET (Q1) datasheet:

$C_{RSS} = 30pF$

$Q_G = 30nC$

With V_{LOAD} = 180V and I_{LOAD} = 1A, the calculated values are:

$t_{RISE} = 1.64\mu s$

$t_{FALL} = 1.64\mu s$

$E_{MOSFET} = 49\mu J.$

(Note: The energy dissipated during t_{FALL} is negligible)

$$C_{ST} \ge \frac{Q_G}{0.5V} \qquad \text{(FARADS)}$$

Selecting a 0.1uF for C_{ST} with a gate charge Q_G=30nC, the voltage drop of the storage capacitor would equal 300mV, which is within the 0.5 V requirement above.

Figure 3 Voltage Drop on C_{ST}

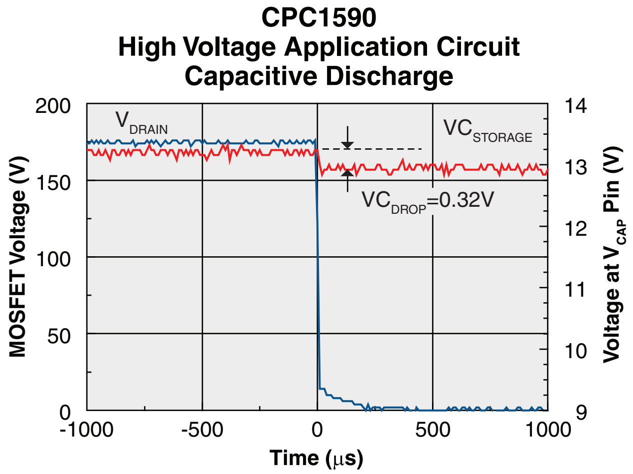


Figure 4 CPC1590 Application During Turn-Off

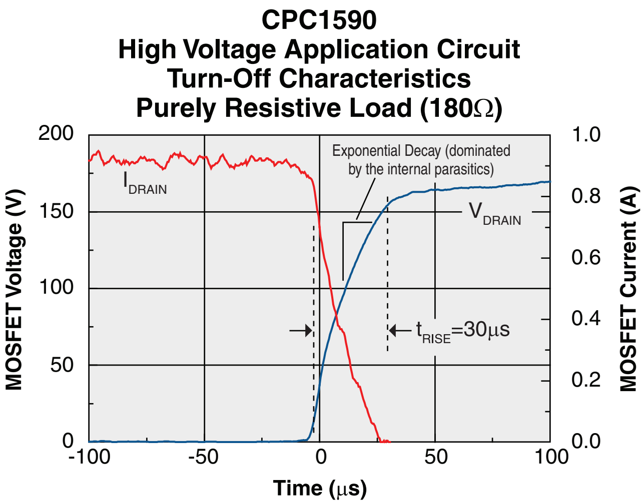


Figure 5 CPC1590 Application During Turn-On

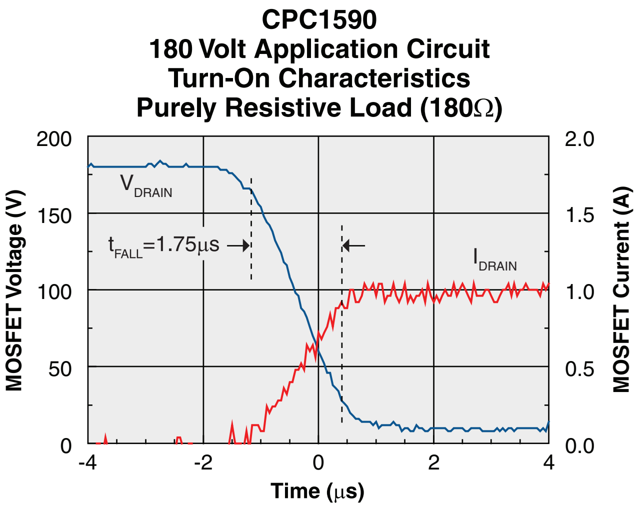


Figure 6 MOSFET Power and Energy

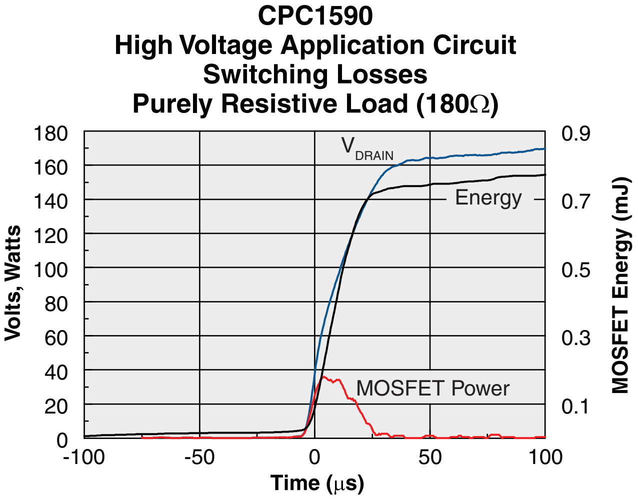
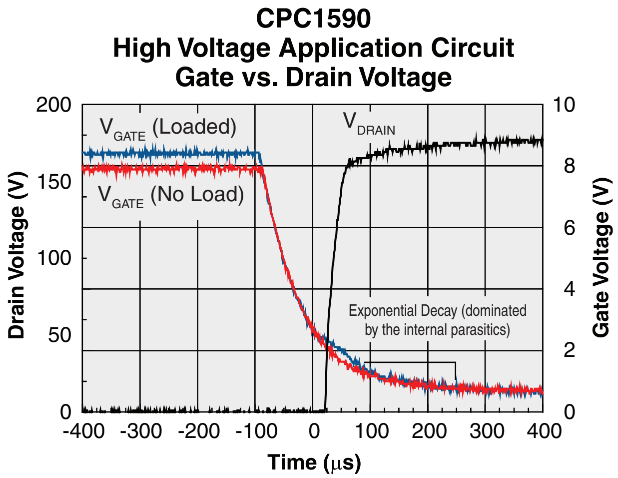


Figure 7 CPC1590 Gate Drive Parasitic Behavior



6.2 Case 1: (Continued)

The load was modified by adding 630µH of inductance in series with the load resistor. The purpose is to emulate a leakage inductance or mutual inductance that may represent a load characteristic. **Figure 8** shows the turn-on behavior, and **Figure 9** shows the turn-off behavior with the load.

While **Figure 9** shows a small amount of peaking as the switch turns off, it is clear that avalanche breakdown is avoided. This is further demonstrated by the energy dissipated in the MOSFET exceeding the energy stored in the magnetic inductance.

Figure 10 shows how much power is dissipated in the MOSFET during turn-off, and the energy absorbed during the turn-off event. From the graph the user can see 750µJ is absorbed in the MOSFET while only 315µJ was stored in the inductor.

A final design will characterize t_{RISE} of the entire application at the maximum operating temperature and derate the avalanche energy (E_{AR} in the datasheet,) accordingly.

Figure 8 630µH Turn-On

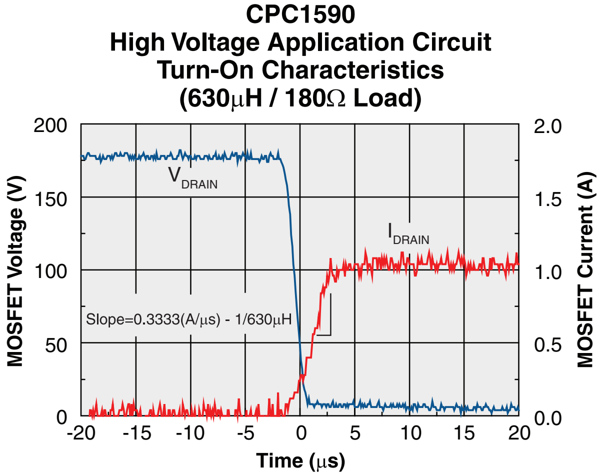


Figure 9 630µH Turn-Off

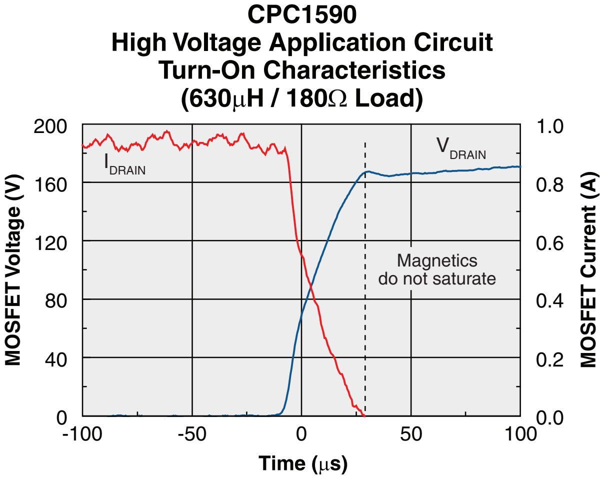
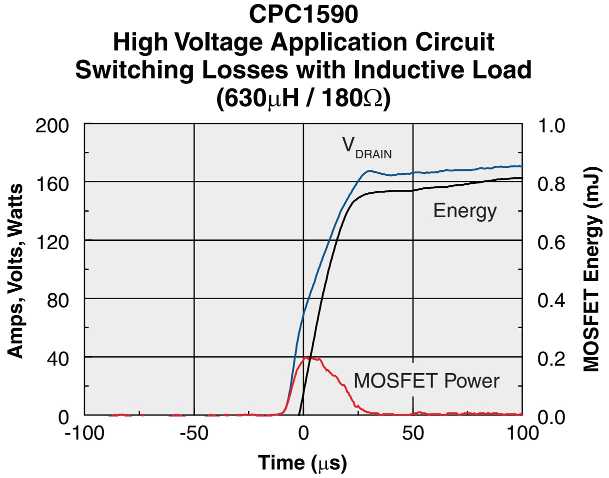


Figure 10 630µH MOSFET Power and Energy



6.3 Case 2: 48V Application Circuit

The CPC1590 can be used over a wide range of load voltages, some as low as 15V. An identical application circuit was used with the CPC1580, so for comparison the application circuit was adjusted for the CPC1590. The results are essentially identical for all factors between the CPC1590 and CPC1580 at 48V.

Rise and fall times shown in **Figure 11** and **Figure 12** which are limited by decay times internal to the part (shown in **Figure 13**). The peak power and energy shown in **Figure 14** are well below the peak energy and power restrictions shown in the MOSFET datasheet.

Figure 11 CPC1590 48V t_{FALL}

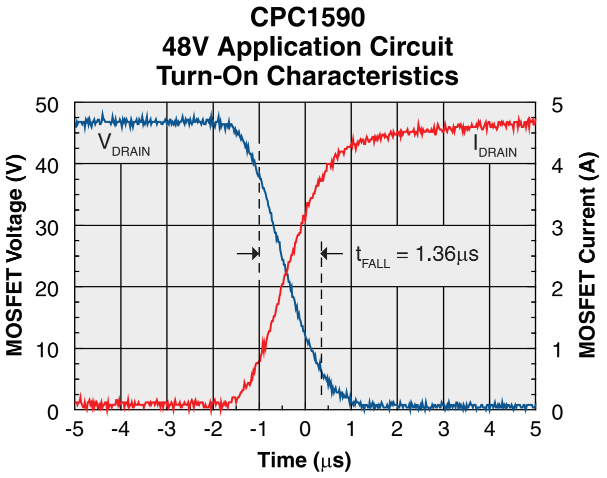


Figure 12 CPC1590 48V t_{RISE}

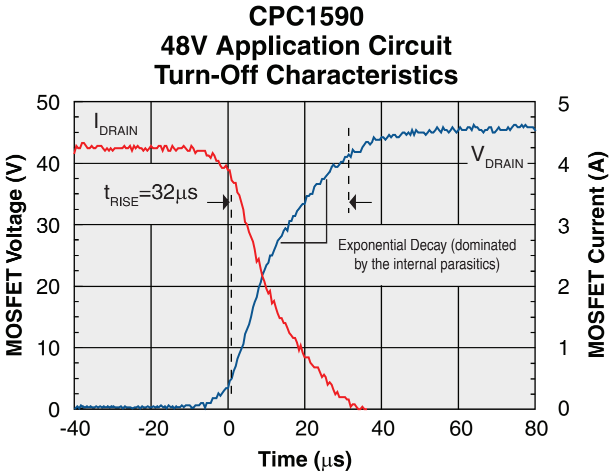


Figure 13 CPC1590 48V Gate Discharge

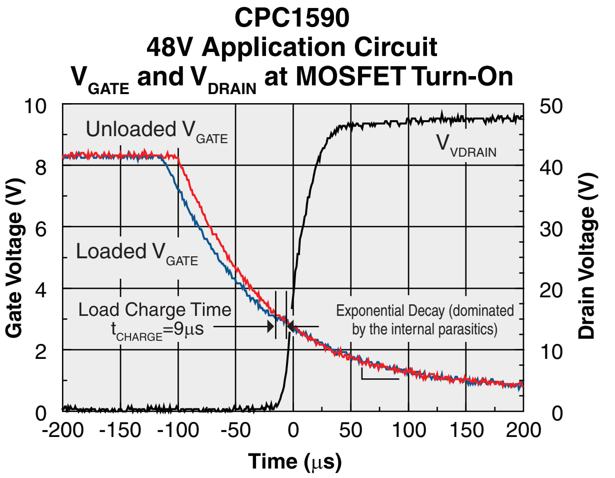
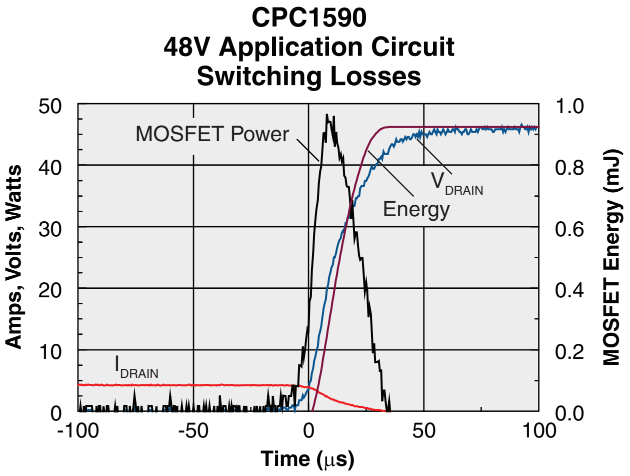


Figure 14 48V MOSFET Power and Energy

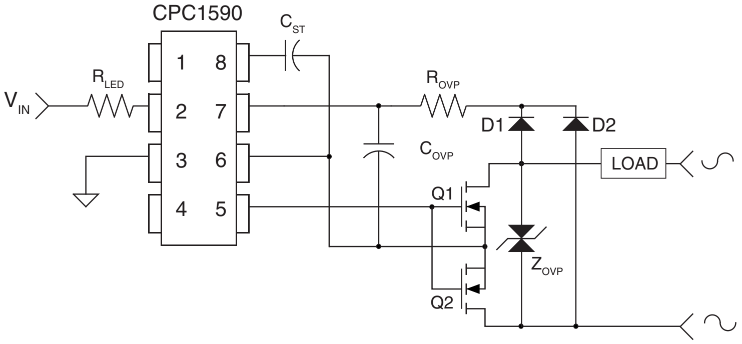


6.4 AC Relay Application Circuit

The CPC1590 can be used in other configurations. One typical configuration, an “AC Switch,” is shown in **Figure 15**. “AC Switch” simply means that either terminal can be positive or negative. This configuration requires a second MOSFET (Q2) and two rectifying diodes (D1 and D2).

The design considerations are identical for this application. Diodes D1 and D2 must have a voltage rating greater than the peak load voltage.

Figure 15 CPC1590 AC Relay Application Circuit



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Specification: AN-202-R01

8/1/2014

Application Note: AN-201

CPC1580 Application Technical Information

1 Using the CPC1580 Isolated Gate Driver IC

The CPC1580 is an excellent choice for remote switching of DC and low frequency loads where isolated power is unavailable. The device uses external components to satisfy design switching requirements, which enables the designer to choose from a great number of MOSFETs. The designer also has several options when designing over-voltage protection circuitry. The case studies look at only two of many methods, but each has unique constraints that should prove useful to many other designs.

Figure 1 shows a typical DC application circuit for using the CPC1580 gate driver. The driver allows the user to turn on the gate of a MOSFET and keep it on until the LED current is turned off. The application circuit uses a bootstrap diode (internal to the part) and storage capacitor (C_{ST}) to provide the charge needed for fast turn-on switching of an external MOSFET device. When the MOSFET is on, the photo current from the LED keeps the MOSFET gate biased to the device's specified gate to source voltage (V_{GS}) continuously.

The CPC1580 uses charge from the load voltage when turning off to recover the MOSFET gate switching charge for the next turn-on event. The transistor will turn on even without this recovery of charge (in the case of no load voltage), although the turn-on will be much slower because only internal photo current will be charging the gate of the MOSFET. This feature can be exploited during system startup.

2 Application Component Selection

2.1 Storage Capacitor Selection C_{ST}

The storage capacitor (C_{ST}) enables the part to turn on quickly by holding a reservoir of charge to be transferred to the gate of the MOSFET. The turn-off cycle doesn't depend on the storage capacitor.

Equation 1: Charge Storage Capacitor Calculation:

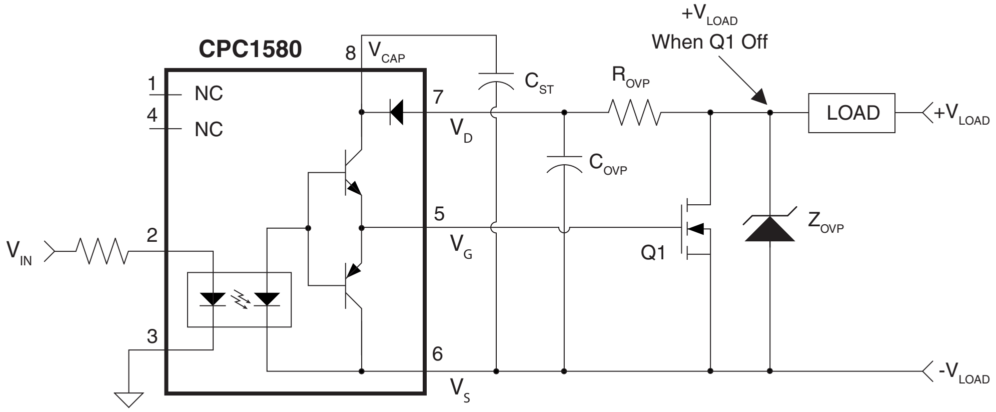
$$C_{ST} \geq \frac{Q_G}{V_{LOAD} - V_{CAP}} \qquad \text{(FARADS)}$$

Q_G is the MOSFET's total gate charge; $V_{CAP} \geq 15V$.

Equation 1 shows that the storage capacitor needs to deliver enough charge to the gate without going below the 15V required for switching the MOSFET. The CPC1580 can deliver adequate peak current to drive 32nC total gate charge at the rated operating speed, and will operate with much higher capacitive loads (<4µF), or larger gate charge, with a slower turn-on and turn-off time.

> ***Note:*** *Care must be taken to minimize any capacitor-to-ground leakage current path between pins 7 and 8, MOSFET gate current, and between pins 5 and 6. Leakage currents will discharge the storage capacitor, and, even though the device is already on, will become a load to the photocurrent which keeps the gate voltage on. The gate voltage will be reduced if >500nA of leakage is present, therefore the combined impedance from pin 8 to pin 7, pin 5 and pin 6, capacitor current, and MOSFET current must be >20MΩ over the temperature rating of the part.*

Figure 1 CPC1580 DC Application Circuit Diagram with Over-Voltage Protection



2.2 Transistor Selection

The CPC1580 charges and discharges an external MOSFET transistor. The selection of the MOSFET is determined by the user to meet the specific power requirements for the load. The CPC1580 output voltage is listed in the specification, but, as mentioned earlier, there must be little or no gate leakage.

Another parameter that plays a significant role in the determination of the transistor is the gate drive voltage available from the part. The CPC1580 uses photovoltaic cells to collect the optical energy generated by the LED, and, to generate more voltage, the photovoltaic diodes are stacked. As such, the voltage of the photovoltaic stack reduces with increased temperature. The user must select a transistor that will maintain the load current at the maximum temperature, given the V_{GS} in the CPC1580 specification.

The case studies below use "logic-level" MOSFETs for each design to maintain the load described.

2.2.1 Transistor Switching Characteristics

The primary characteristics of the application switching are t_{ON}, t_{OFF}, t_{RISE}, t_{FALL}, and the recovery time of the storage capacitor, t_{CHG}. These parameters are dependent on the MOSFET selection and need to be reviewed in light of the application requirements.

The CPC1580 turns on the MOSFET to the datasheet V_{GS} after the t_{ON} delay. Similarly the t_{OFF} delay is the amount of time until the LED is turned off and the capacitive load discharges to the level in the CPC1580 specification. For MOSFETs with larger or smaller required gate charge the t_{ON} and t_{OFF} will be proportionately faster and slower, but it is not a linear relationship.

To calculate the nominal rise and fall times of the MOSFET's drain voltage:

Equation 2: Rise Time Calculation

$$t_{RISE,VD} \approx \frac{V_{LOAD} \bullet C_{RSS}}{I_{G\_SINK}} \qquad \text{(SECONDS)}$$

Equation 3: Fall Time Calculation

$$t_{FALL,VD} \approx \frac{V_{LOAD} \bullet C_{RSS}}{I_{G\_SOURCE}} \qquad \text{(SECONDS)}$$

Where C_{RSS} is the MOSFET gate-drain capacitance (averaged over the switching voltage range) found in the MOSFET datasheet, I_{G_SINK} is the gate sinking current of the CPC1580, and I_{G_SOURCE} is the gate driving ability. The maximum value of t_{RISE} is limited by the CPC1580 unloaded discharge characteristic, and should be reviewed in light of the final application component selections, if critical.

To calculate the value for the charge time, t_{CHG}, which is due to external component selection:

Equation 4: Storage Capacitor Charge Recovery Time (seconds):

$$t_{CHG} \approx -(400 + R_{OVP}) \bullet (C_{ST} + C_{OVP}) \bullet \ln\left(\frac{(V_{LOAD} - V_{FINAL}) \bullet C_{ST}}{Q_G}\right)$$

where $(V_{LOAD} - V_{FINAL})$ is the difference in voltage between the required load voltage and the potential the capacitor will charge up to. The voltage at the storage capacitor is $V_{LOAD} - (Q_G/C_{ST})$ when the MOSFET is on, where charge, Q_G, is the amount of charge required to switch the MOSFET gate from 0V to the final voltage out of the CPC1580 (V_{GS} specification). V_{FINAL} is the capacitor voltage when it charges back up from when the MOSFET is off.

R_{OVP} and C_{OVP} form the overvoltage protection RC filter. The RC filter is used to reduce the peak power dissipation in the MOSFET by controlling the rate of rise of the drain voltage. Note that the RC circuit will reduce the switching speed of the MOSFET.

> ***Note:*** *Obviously, the logarithm doesn't work if $V_{FINAL} = V_{LOAD}$ because of the exponential nature of R-C charging. That subsequently affects the next cycle, so C_{ST} is more critical and should be larger if the switching frequency is faster. Selecting the term inside the logarithm to be 0.05 yields 3τ equivalent time-constants.*

Using this information, the maximum switching frequency will be calculated in each application case study below.

> ***Note:*** *The CPC1580 is ideal to use where remote power is otherwise unavailable. If the LED is also powered remotely, care must be taken to ensure that parasitic transient signals are reliably filtered from the input control signal. Large transient currents will mutually couple energy between cables and a simple R-C filtering of the CPC1580 input may be sufficient to suppress false turn-on.*

3 Application Switching Losses

During the transition intervals, the application and load components change energy states and during the process incur switching losses. These losses are manifested as heat in the application circuit, and must be addressed by the designer to ensure that no one component exceeds its power rating. The designer must understand the details of load behavior in order to adequately size and protect the application circuit. There are three general cases to observe: (1) purely resistive loads, (2) inductive/resistive loads, and (3) loads with significant capacitance. Inductors and capacitors are energy storage elements that require special consideration for switching.

During switching periods, the energy stored in the load inductor is discharged through the switching MOSFET, load capacitance and the over-voltage-protection circuitry.

At turn-on, the inductor energy is zero, and so the capacitive energy in the load and parasitic elements of the switching application must be dissipated by the MOSFET in order for the load to change state.

Equation 5: Stored Inductive Energy (Joules)

$$E_L = \frac{1}{2} \bullet L \bullet I_{LOAD}^2$$

3.1 Resistive Load Losses: The Ideal Case

For purely resistive loads, the energy dissipated by changing states occurs primarily in the MOSFET. The equation describing MOSFET energy dissipation is:

Equation 6: MOSFET Energy: E_{RISE} (Joules)

$$E_{MOSFET} \geq V_{LOAD}^2 \bullet \frac{C_{RSS}}{I_{G\_SINK}} \bullet \frac{I_{LOAD}}{6} = \frac{P_{LOAD}}{6} \bullet t_{RISE,VD}$$

The average power of the MOSFET for any load type is:

Equation 7: MOSFET Average Power (Watts)

$$P_{AVG} = I_{LOAD}^2 \bullet R_{DSAT} \bullet D + f_{SWITCH} \bullet (E_{RISE} + E_{FALL})$$

Where f_{SWITCH} is the application switching frequency, R_{DSAT} is the MOSFET's on-resistance, D is the switch's operational duty cycle: $D = t_{ON}/(t_{ON}+t_{OFF})$. E_{RISE} and E_{FALL} are the energy dissipated during the rise and fall times.

3.2 Inductive/Resistive Loads

If the load is resistive and inductive, and the inductance doesn't saturate, then the load current during turn-off is described by:

Equation 8: Resistive/Inductive Load Current during t_{RISE} (Amps)

$$I_{LOAD}(t) = \frac{V_{LOAD}}{R_{LOAD}} - \frac{I_{G\_SINK}}{L_{LOAD} \bullet C_{RSS}} \bullet \left(\frac{L_{LOAD}}{R_{LOAD}}\right)^2 \bullet \left[\frac{R_{LOAD}}{L_{LOAD}} \bullet t - 1 + e^{\frac{-R_{LOAD}}{L_{LOAD}} \bullet t}\right]$$

The drain voltage during turn-off is:

Equation 9: MOSFET Drain Voltage during t_{RISE} (V)

$$V_{DRAIN}(t) = \frac{I_{G\_SINK}}{C_{RSS}} \bullet t$$

The instantaneous power in the MOSFET will be the product of the two equations and the energy will be the integral of the power over time.

3.3 Capacitive Loads

The energy absorbed by the MOSFET for loads that are more capacitive in nature occurs during the MOSFET turn-on as opposed to the turn-off. The energy absorbed by the MOSFET will be a function of the load, the Transient Voltage Suppressor (TVS) or other protector, and the MOSFET drain capacitance.

Equation 10: MOSFET Energy: E_{FALL} (Joules)

$$E_{FALL} = \frac{1}{2} \bullet (C_{TVS} + C_{OSS} + C_{LOAD}) \bullet V_{LOAD}^2$$

C_{OSS} is the MOSFET output capacitance found in the datasheet. As mentioned earlier, the MOSFET switching losses occur at different times, either rising or falling, so loads with a combination of inductance and capacitance can also be calculated by the energy equations described above.

The MOSFET can dissipate the repeated avalanche energy, (E_{AR}), as specified in the datasheet. However that energy must be reduced for increased ambient temperature. For a 150°C MOSFET, the energy reduction at $T_{J,MAX}$ is:

Equation 11: MOSFET Energy Adjustment for Operating conditions (Joules):

$$E(T_{J,MAX}) \leq E(25°C) \bullet \frac{(150°C - T_{J,MAX})}{(150°C - 25°C)}$$

$T_{J,MAX}$ is the junction temperature of the die, so it must include the temperature increase caused by power dissipation of the load and the thermal impedance of the package/application. E(25°C) is the E_{AR} specification found in the MOSFET datasheet at 25°C.

3.4 dV/dt Characteristics

The application shown in **Figure 1** and described in section **6.1** "**Case 1: 24 V Loading Application**" dissipates significant energy caused by large dV/dt events. Fault voltages across the MOSFET will turn it on for the same reason the part turns off slowly.

For dV/dt events > I_{G_SINK}/C_{RSS} (from Equation 2) the application circuit will dissipate energy proportional to the C_{RSS} and g_{FS} (forward conductance) of the selected transistor. C_{RSS} is a function of the transistor's on-resistance and current/power capability, so higher load designs are more sensitive.

The CPC1580 provides an internal clamp to protect the gate of the MOSFET from damage during such an event. It can withstand 100mA for short periods, for instance, during dV/dt transients.

> ***Note:*** *The CPC1580 is ideal to use where remote power is otherwise unavailable. If the LED is also powered remotely, care must be taken to ensure that parasitic transient signals are reliably filtered from the input control signal. Large transient currents will mutually couple energy between cables and a simple R-C filtering of the CPC1580 input may be sufficient to suppress false turn-on.*

4 Design Switching Frequency

The over-voltage protection and storage capacitor play a significant role in determining the switching frequency. The maximum switching frequency is a function of the gate charge of the MOSFET, the storage capacitor (C_{ST}), and R_{OVP}. The maximum switching frequency relationship is:

Equation 12: Maximum Switch Operation (Hz)

$$F_{MAX} \leq \frac{1}{M} \bullet (t_{ON} + t_{OFF} + t_{RISE,VD} \mid t_{CHG} + t_{FALL,VD})^{-1}$$

where M=3 (a multiplication factor for temperature and process variations); t_{ON} and t_{OFF} are CPC1580 datasheet parameters; $t_{RISE,VD}$ is the rise time of the drain voltage; t_{CHG} is the charge time of the storage capacitor (C_{ST}) and over-voltage protection circuitry (C_{OVP} and R_{OVP}); and $t_{FALL,VD}$ is the fall time across the transistor. For this calculation, choose the greater of $t_{RISE,VD}$ or t_{CHG}.

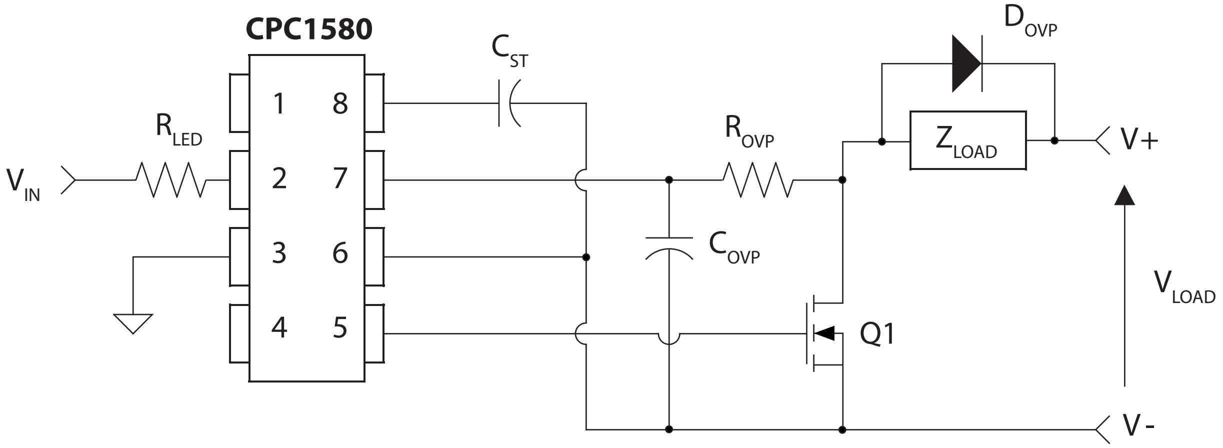
There is no minimum switching frequency because the CPC1580 uses photovoltaic diode current to keep the output charged as long as LED current flows.

5 CPC1580 Over-Voltage Protection

Over-voltage protection is generally required for the CPC1580 because of parasitic inductance in the load, wires, board traces, and axial leads of protectors. Purely resistive loads or loads with low voltage switching may be able to rely on the transistor to handle any parasitic energy and thereby not require protection for the CPC1580. For very low-inductance loads and traces, over-voltage suppression may be handled with a simple RC filter consisting of R_{OVP} and C_{OVP}, or by use of a free-wheeling diode. For more moderate load inductance, or remote switching of a load (i.e. through a long cable) a voltage suppressor can be used. For heavily inductive loads only a free-wheeling diode, D_{OVP}, connected across the load element is recommended, see **Figure 2**.

The energy not consumed in switching losses must be absorbed by the over-voltage protection element. Most protective devices are designed to withstand certain peak power in the case of a TVS, or maximum avalanche energy in the case of a MOSFET. To reduce the amount of stored inductive energy, a larger capacitor can be added in parallel with the gate-drain connection of the MOSFET. However care must be taken so that the rise time and peak current do not exceed the Safe Operating Area (SOA) rating of the transistor. A consequence of increasing the gate-drain effective capacitance is reduced dV/dt tolerance.

Figure 2 CPC1580 Over-Voltage Protection for Inductive Loads



5.1 Other Protection Techniques [1, 2]

For applications in which higher inductance loads are switched, the designer must consider other circuit techniques, device ratings, or protector types. Of paramount importance is that the designer know the characteristics of the load being switched.

[1] An excellent source describing power electronic devices and switching behavior is: *Power Semiconductor Devices,* by B. Jayant Baliga, ISBN 0-543-94098-6

[2] For more over-voltage protection circuit techniques consult: *Switchmode Power Supply Handbook*, *2nd Edition*, Keith Billings, ISBN 0-07-006719-8, or *Power MOSFET Design*, B. E. Taylor, ISBN 0-471-93802-5.

6 Design Examples

Table 1: shows two sample application component selections each with different over-voltage protection strategies.

Table 1: Sample Application Components

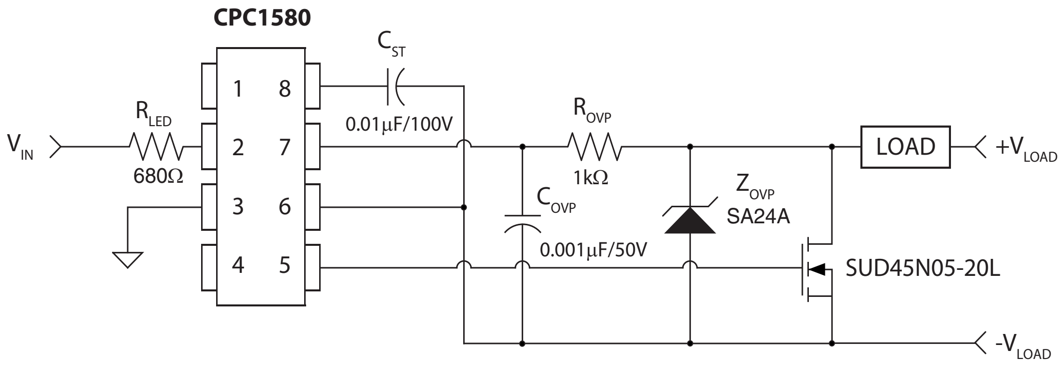
Device	Case 1: 24V/10A Value/Rating	Case 2: 48V/5A Value/Rating	Comment
Q1	SUD45N05-20L [3]	SUD23N06-31L [3]	MOSFET
C_{ST}	>0.01µF/100V	>0.01µF/100V	5% Ceramic Disk
Z_{OVP}	SA24A [3]	SA48A [3]	Littelfuse TVS-style protector
R_{OVP}	1KΩ	5.1KΩ	5%, 1/8 Watt (60Hz Switching Frequency or less)
C_{OVP}	0.001µF, 50V	0.001µF, 100V	5% Ceramic Disk
R_{LED}	680Ω, 1/8 Watt	680Ω, 1/8 Watt	0 - 5V Switching

[3] Use of the SUD45N05-20L, SUD23N06-31L, SA24A, and SA48A product datasheets is necessary to completely understand the examples given.

6.1 Case 1: 24V Load Switching

In this example, the over-voltage protection circuitry is quite simple. The CPC1580 is guaranteed for 60V operation and the protector is rated for 45.4V @ 11.2A peak pulse current, well below the 60V. The transistor (Q1) is a 50V MOSFET, which guarantees the TVS clamps before the transistor breakdown. Assuming there will be load inductance in both the V_{LOAD+} and V_{LOAD-} traces, a TVS is selected to clamp the residual 10A not otherwise dissipated in the turn-off of the MOSFET and parasitic TVS capacitance. R_{OVP} and C_{OVP} are optional for this load condition; however, their inclusion will ease layout and critical placement of the CPC1580.

Figure 3 Case 1 Application Circuit



For this test case, the maximum switching frequency for the design is $F_{MAX} = 0.333 \bullet (40\mu s + 600\mu s + (40\mu s \mid 42\mu s) + 0.87\mu s)^{-1} < \sim 475Hz$. The components selected were used for in-lab testing. Other components with smaller package sizes and wattage will also work, if calculations are performed to meet component specifications.

Example:

- R_{LED}=680Ω
- Minimum voltage drop across the LED is 1.0V
- Switching voltage, SwV_{ON}, when on, is 5V
- I_F=Forward current of the LED

$$I_F = \frac{SwV_{ON} - \text{Min LED Volt}}{R_{LED}}$$

$$I_F = \frac{5V - 1V}{680\Omega}$$

$$I_F = 0.005882A = 5.9mA$$

The recommended I_F is between 2mA and 10mA. The I_F calculated above meets this requirement.

The power dissipated, P_D, is:

$$P_D = I_F^2 \bullet R$$

$$P_D = (5.9\text{mA})^2 \bullet (680\Omega)$$

$$P_D = 0.024\text{W} = 24\text{mW}$$

These calculations show that a 0603 resistor, which is 1/16 Watt, can be selected. The 1/16 Watt still provides an adequate design margin: 0.0625W where only 0.024W is required.

6.1.1 Measured Results

Figure 4 shows the discharge of the storage capacitor due to the gate switching on. The calculated voltage drop (V_{LOAD} - V_{CAP}) using C_{ST} = 10 nF and (Q_G = 43nC from the Q1 datasheet) from **Equation 1** is 4.3 Volts.

From Equation 1: Charge Storage Capacitor Calculation:

$$C_{ST} \geq \frac{Q_G}{V_{LOAD} - V_{CAP}} \qquad \text{(FARADS)}$$

From Equation 2: Rise Time Calculation

$$t_{RISE,VD} \approx \frac{V_{LOAD} \bullet C_{RSS}}{I_{G\_SINK}} \qquad \text{(SECONDS)}$$

t_{RISE} ~ (24V-5V) • 190pF/.0036 A ~ 1µS

From Equation 3: Fall Time Calculation

$$t_{FALL,VD} \approx \frac{V_{LOAD} \bullet C_{RSS}}{I_{G\_SOURCE}} \qquad \text{(SECONDS)}$$

t_{FALL} ~ (24V-5V) • 190pF/0.00022 A ~ 16µS

All other calculated / measured data is summarized in **Table 2:**

Table 2: 24 Volt Load Switching Data

Parameter	Calculated	Measured
Voltage Drop C_{ST}	4.3V	3.7V
t_{FALL} **Figure 5**	16µS	2µS
t_{RISE} **Figure 8**	1µS	38µS [4]
t_{ON} **Figure 6**	16µS (**1580 spec**)	7.3µS
t_{OFF} **Figure 7**	175µS (**1580 spec**)	189µS

The energy in **Figure 9** rises to 3.3mJ, and the switching frequency can be as high as >475Hz which would make the average power $(12\text{A})^2 \bullet 0.02\Omega + 475/\text{s} \bullet 3.3\text{mJ} = 4.5$ Watts, assuming very high operational duty cycles.

This circuit load was modified to include an 800µH inductor that saturates at ~0.5A. This load condition may not represent the user's load but does serve to illuminate more about the switching characteristics of a non-linear load.

Again this assumes that the magnetics do not saturate, however for the graphs shown in **Figure 10** and **Figure 11**, the current equation above only applies after the magnetic flux leaves saturation and becomes inductive again. As such, the load current is dominated by V_{LOAD} and R_{LOAD} in **Figure 10**.

The power absorbed by the TVS can be calculated from the characteristic of the waveform shown in **Figure 10**:

$$\text{Energy} = \tfrac{1}{2} L \bullet I^2 = [(V_{TVS} - V_{LOAD}) \bullet t_{DSCHG}]^2/(2 \bullet L)$$

which is ½ • 800µH • $(0.45\text{A})^2$ = 81µJ. This current (0.45A) agrees well with the turn-off characteristic shown in the graph where the magnetics leave saturation at ~0.5A.

The example listed demonstrates the need to have an accurately characterized load so that the energy due to the switching event does not exceed the rating of the MOSFET or TVS protector.

[4] The calculated rise time relies on the manufacturer supplied graphs for C_{RSS}. The actual rise time during the interval shown in **Figure 8** is longer due to the non-linear nature of the capacitance C_{RSS}. From the datasheet graphs, the average capacitance is 190pF over the interval of $5\text{V} < V_{DS} < 25\text{V}$. During the initial turn-off the capacitance is much larger, affecting the total energy by ~30%. A second-order effect not used in Equation 2 is due to the gate-source capacitance C_{ISS}. That additional capacitance divided by the transistor's conductance and load resistance causes an additional delay of 5µs-10µs, so the calculated rise time is closer to 35µs.

Figure 4 Discharge from Gate Turning On

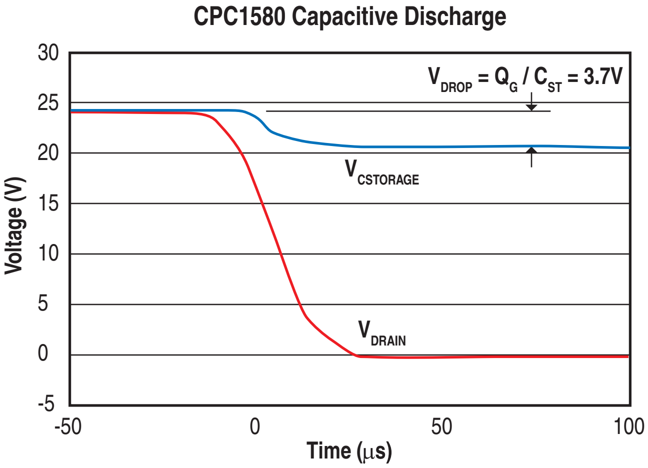


Figure 5 Load Current and t_{FALL}

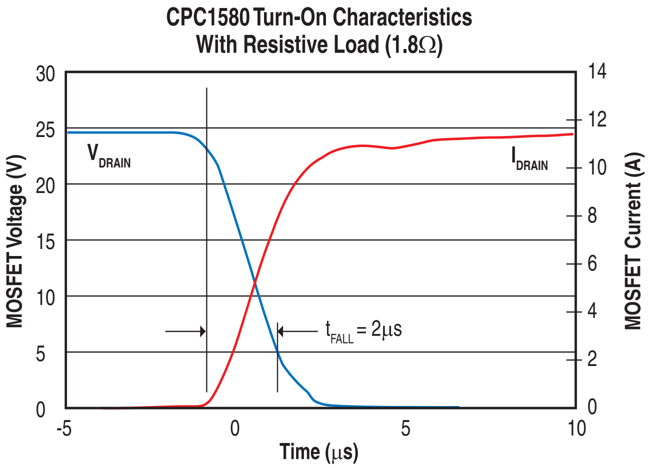


Figure 6 Turn-On Delay

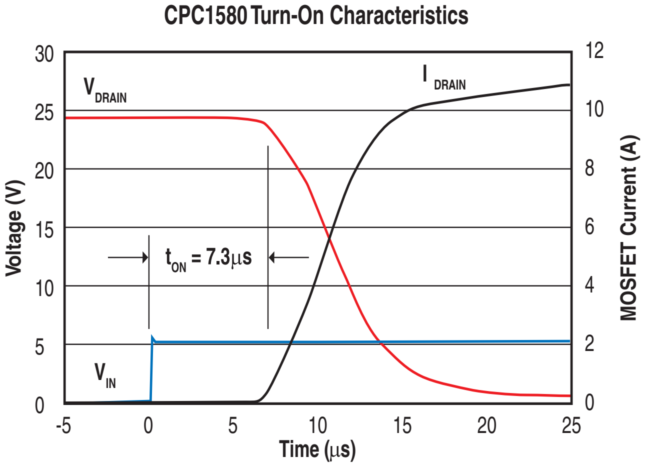


Figure 7 Turn-Off Delay

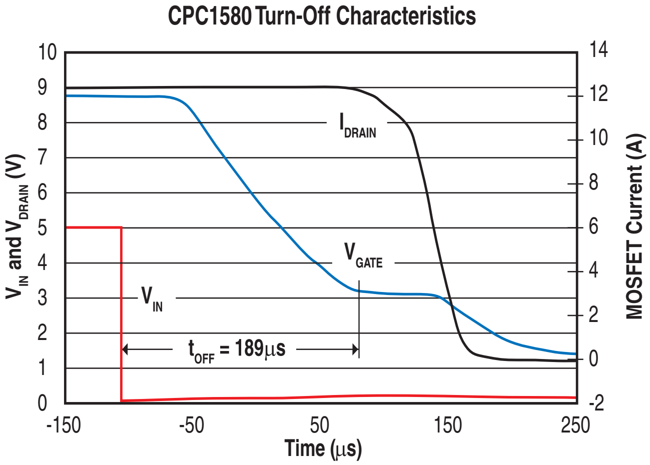


Figure 8 Load Current and t_{RISE}

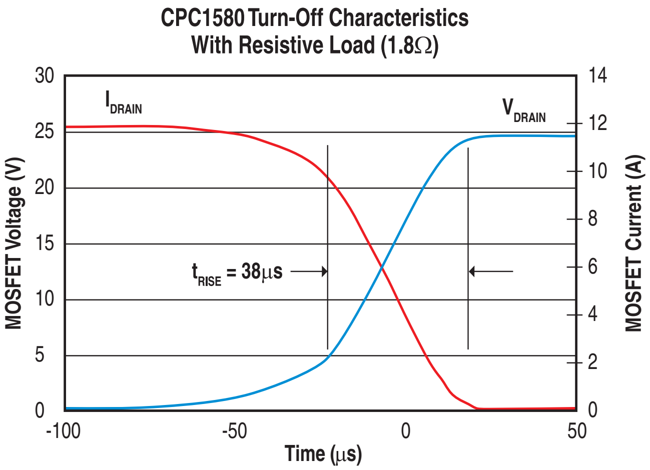


Figure 9 Discharge Power and Energy

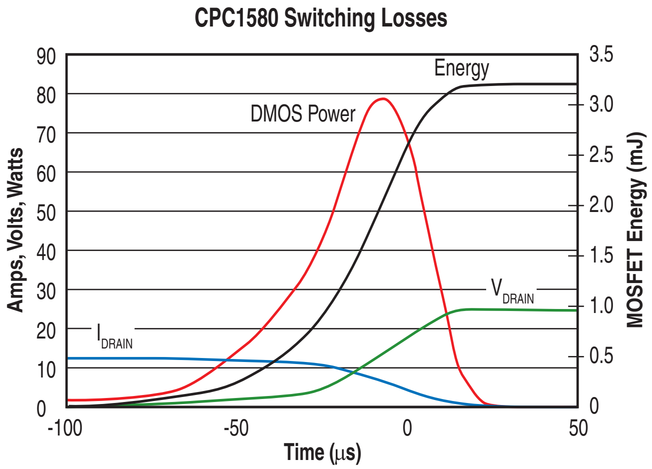


Figure 10 Moderate Inductive Current and t_{RISE}

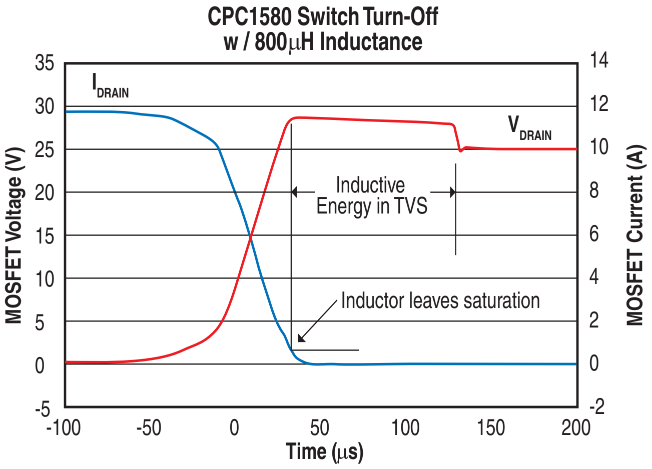


Figure 11 Inductive Turn-On

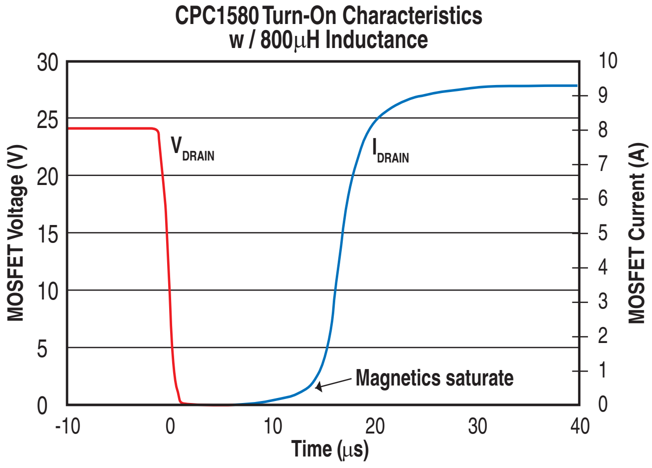


Figure 12 Turn-On with Modified Load

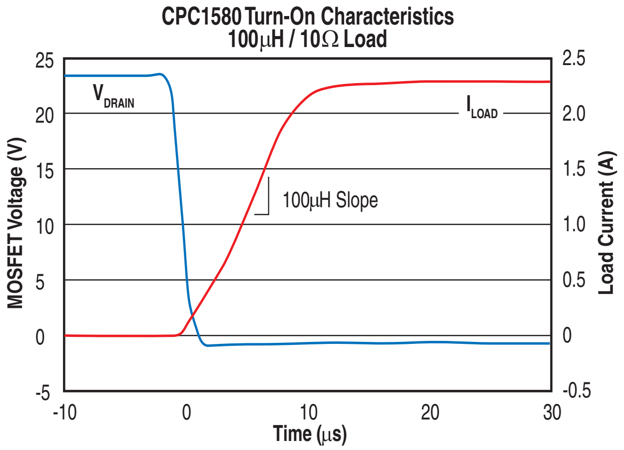
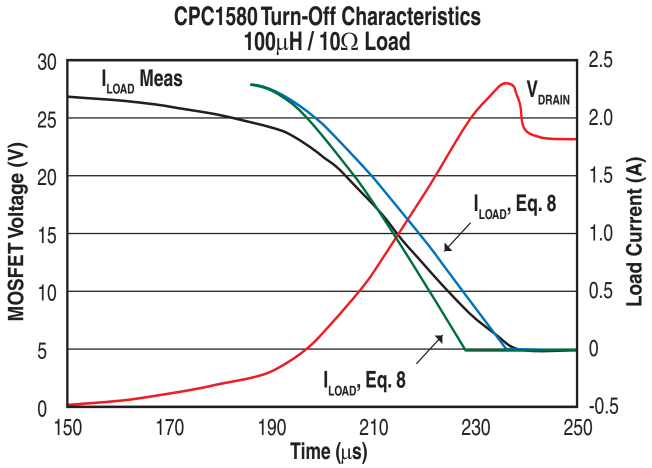


Figure 13 Turn-Off with Modified Load



The load was modified to avoid saturating the magnetics allowing comparison of the expected load current (from Equation 8) versus the measured load current. The circuit changes were to increase the resistance to 10.2 Ohms and change the magnetic inductance to 113µH.

As seen in the turn-on characteristic is almost perfectly inductive where the di/dt forms a non-saturating V/L curve. The voltage applied remains at 24V.

Figure 13 shows the inductive nature of the turn-off as seen in the overshoot. In this case **Equation 8** was fit to the time-base and the resistance, inductance, and capacitance were plugged in. The slope of the line is steeper than expected, which is what has been observed in the previous example. **Equation 8** was then modified to include the C_{ISS} factor $(C_{RSS} + C_{ISS}/(g_{FS} \bullet R_{LOAD}))$ and the resultant slope better approximates the actual slope as expected. It is worth restating that the slow change at the beginning of the transition is due to the large non-linearity in capacitance vs. voltage. While this interval is an important component of the total energy (~30%) the calculation is more complicated and not readily available from the component datasheets. Analysis described in the references listed will improve the characteristic to within 10%.

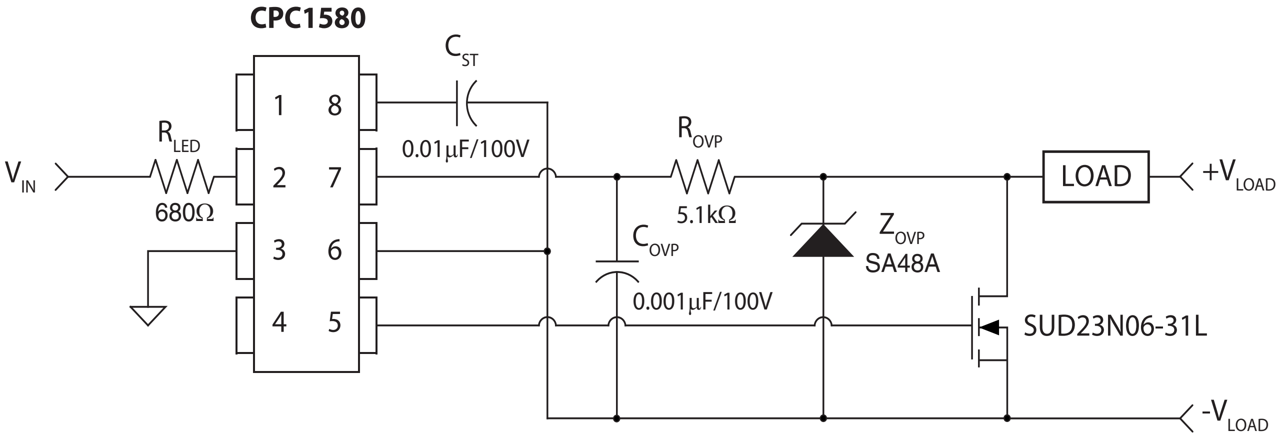
Equation 8 proves to be an accurate model for load current during the turn-off time, which can be subsequently used to consume inductive energy during the turn-off event. The equation can include second-order terms to more accurately model the transition region of switching.

6.2 Case 2: 48V Load Switching

Voltages closer to the peak operating voltage of the CPC1580 can also be accommodated, but the over-voltage protection becomes more important. **Table 1:** shows a sample over-voltage protection component selection for a 48V/5A design requirement.

The design criteria are more complicated because the peak voltage at 5A for the TVS component is 77V which exceeds the voltage rating for the CPC1580 and MOSFET of 60 volts maximum. Two conditions must be met for using such a protector: (1) protecting the CPC1580 from going above it's maximum voltage, and (2) ensuring the avalanche energy of the MOSFET is not exceeded. Since the MOSFET breakdown voltage will be nominally higher than the specification, (or if the user selects a higher voltage MOSFET), then C_{OVP} should be replaced with a zener diode/TVS to keep the voltage at pin 7 (V_D) to less than 60V but greater than 48V. (Until the parasitic inductance discharges to 1mA at which the TVS voltage is 59V.)

Figure 14 Case 2 Application Circuit



6.2.1 Measured Results

The design for Case 2 was implemented and the following characteristics observed. **Figure 15** shows the fall time for a resistive load. The calculated fall time is ~1µS. The rise time is shown in **Figure 16**. The calculated value is 34µS in the linear region shown on the graph. The peak energy during the transient is shown in **Figure 17**. The calculated Peak Energy, from Equation 6 is 1.36mJ. This value is consistent with the linear-region switching losses. The additional energy dissipation is due to the large non-linear capacitance at the beginning of the transition.

Figure 18 and **Figure 19** demonstrate the response with the inclusion of the inductive load. For the case shown, the MOSFET energy dissipation exceeds the stored inductive energy of 160µJ, so no energy is transferred to the TVS.

The charge time plays a significant role in the calculation of the maximum switching frequency for this case study. However, the charging voltage is very small so the resulting charge time can be reduced, knowing that the voltage dropped across R_{OVP} will increase proportionally. The maximum switching frequency of the example in **Table 1:** is $F_{MAX} = 0.333 \bullet (40\mu s + 600\mu s + (34\mu s \mid 181\mu s) + 2\mu s)^{-1} < \sim 400Hz$.

Figure 15 48V Case Study t_{FALL}

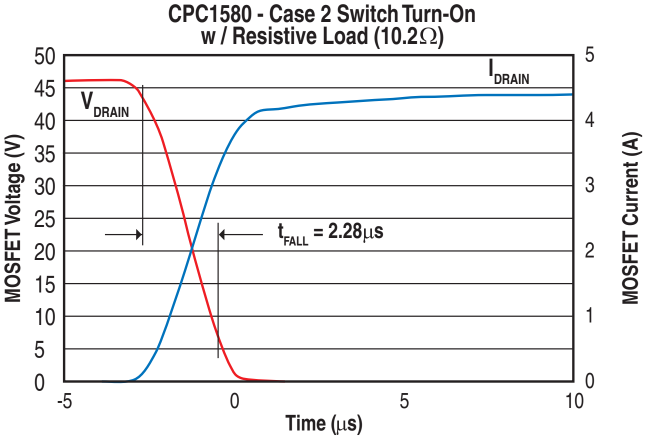


Figure 16 48V Case Study t_{RISE}

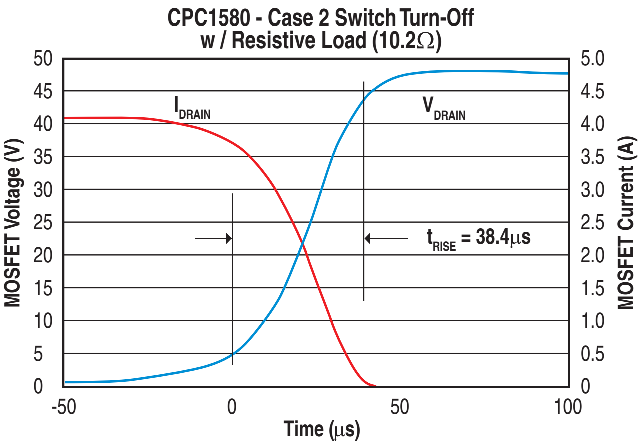


Figure 17 48V Case Study Peak Power and Energy

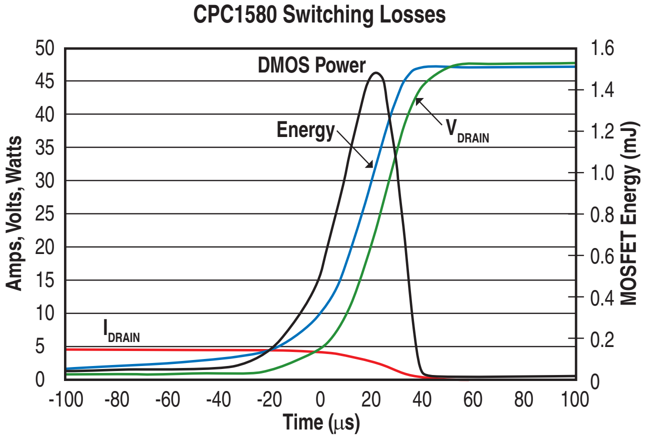


Figure 18 Inductive Turn-On Transition

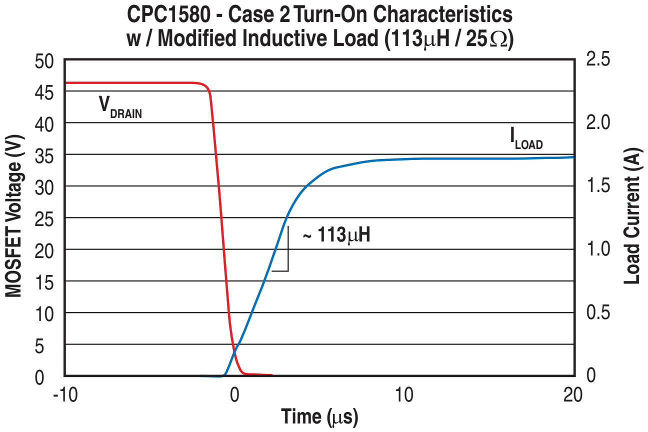
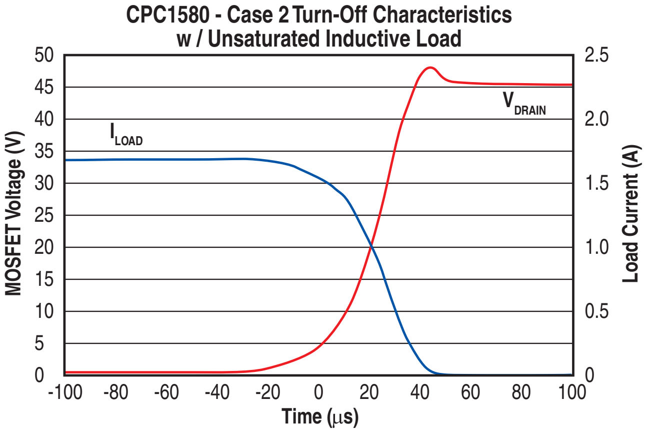


Figure 19 Inductive Turn-Off Transition



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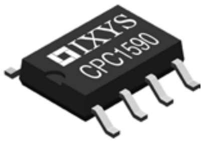


CPC1590

Optically Isolated Gate Driver

Driver Characteristics

Parameter	Rating	Units
Input Current	2.5	mA
Switching Speed (I_F=5mA, MOS Input Capacitance=4nF)		
$t_{d(on)}$	12	µs
$t_{d(off1)}$ (V_{GS}=2V)	125	
$t_{d(off2)}$ (V_{GS}=1V)	210	

Features

- 3750V_{rms} Input-to-Output Isolation
- Drives External Power MOSFET
- Low LED Current (2.5mA)
- Requires No External Power Supply
- Load Voltages up to 200V
- High Reliability
- Small 8-pin Surface Mount Flatpack Package
- Machine Insertable, Wave Solderable
- Tape and Reel Version Available
- Flammability Rating UL 94 V-0

Applications

- Industrial Controls
- Instrumentation
- Medical Equipment Isolation
- Electronic Switching
- I/O Subsystems
- Appliances

Description

The CPC1590 is a MOSFET Gate Driver that requires no external power supply: it regulates the input voltage drawn from the load (up to 200V), down to 12.2V for internal use. It is specifically designed for low duty cycle switching applications that drive up to 4nF of gate capacitance.

The CPC1590 accomplishes very fast MOSFET turn-on by supplying stored charge, from an external capacitor, to the MOSFET gate when input control current is applied to the device's LED. After the MOSFET is turned on, photocurrent from the input optocoupler keeps it on for as long as sufficient input control current flows, so there is no low-frequency operating limit. When the MOSFET is turned off, the storage capacitor charges from the device's regulated internal voltage in preparation for the next turn-on.

Because it is provided in a small, 8-pin Flatpack package and requires no separate power supply, the CPC1590 provides a flexible design solution that consumes the least amount of PCB land area.

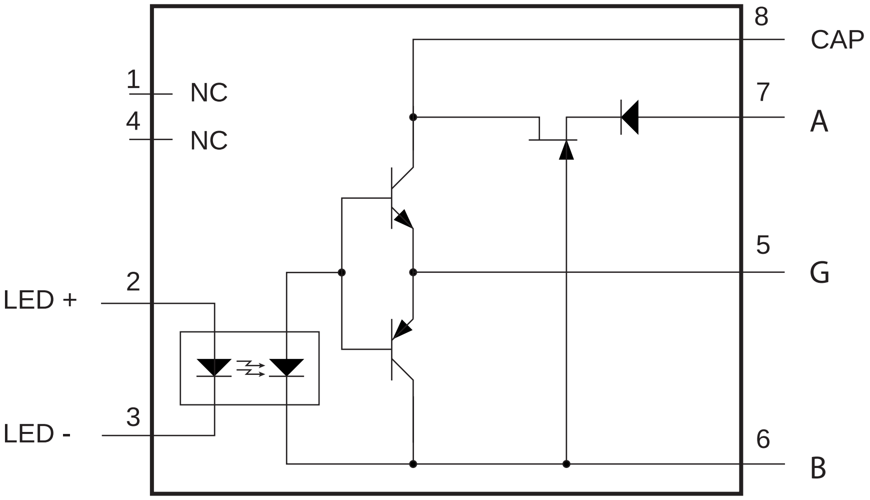
Approvals

- UL Recognized Component: File E76270

Ordering Information

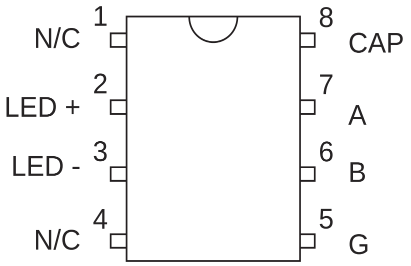
Part	Description
CPC1590P	8-Pin Flatpack (50/Tube)
CPC1590PTR	8-Pin Flatpack (1000/Reel)

Figure 1. CPC1590 Block Diagram



1. Specifications

1.1 Package Pinout



1.2 Pin Description

Pin#	Name	Description
1	-	Not connected
2	LED +	Positive input to LED
3	LED -	Negative input to LED
4	-	Not connected
5	V_G	Output, MOSFET Gate Control
6	V_{L2}	-Load Voltage DC, ±Load Voltage AC
7	V_{L1}	+Load Voltage DC, ±Load Voltage AC
8	V_{CAP}	Storage Capacitor Voltage

1.3 Absolute Maximum Ratings

Parameter	Rating	Units
Blocking Voltage (V_{DS})	200	V_P
Reverse Input Voltage	5	V
Input Control Current	50	mA
Peak (10ms)	1	A
Input Power Dissipation	20	mW
Total Package Dissipation	200	mW
Isolation Voltage (Input to Output)	3750	V_{rms}
Operational Temperature	-40 to +110	°C
Storage Temperature	-40 to +125	°C

Absolute maximum electrical ratings are at 25°C

Absolute maximum ratings are stress ratings. Stresses in excess of these ratings can cause permanent damage to the device. Functional operation of the device at conditions beyond those indicated in the operational sections of this data sheet is not implied.

1.4 ESD Rating

ESD Rating (Human Body Model)
1000 V

1.5 Recommended Operating Conditions

Parameter	Symbol	Min	Max	Units
Load Voltage	V_L	15	200	V
Input Control Current	I_F	2.5	10	mA
Forward Voltage Drop	V_F	1	1.5	V
Operating Temperature	T_A	-40	+110	°C

1.6 General Conditions

Unless otherwise specified, minimum and maximum values are guaranteed by production testing.

Typical values are characteristic of the device at 25°C and are the result of engineering evaluations. They are provided for informational purposes only and are not part of the manufacturing testing requirements.

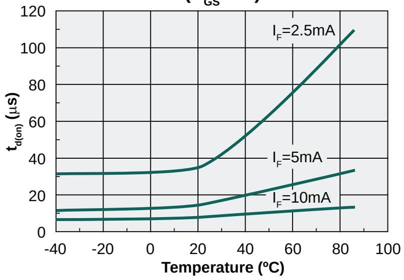
Unless otherwise noted, all electrical specifications are listed for T_A=25°C.

1.7 Electrical Specifications

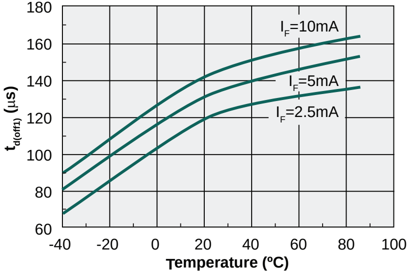
Parameter	Conditions	Symbol	Min	Typ	Max	Units
Load Side Characteristics						
Gate Voltage	I_F=2.5mA	V_{GS}	7.0	7.3	12	V
	I_F=5mA		7.5	8.0		
	I_F=10mA			8.4		
	I_F=2.5mA -40°C<T_A<110°C		4.2	-	14.4	
Capacitor Voltage	10V<V_{DS}<200V	V_{CAP}	10	12.2	16	V
Gate Drive Capability	I_F=2.5mA, V_{GS}=0V, V_{CAP}=15V	I_{G_source}	2	3.3	7	mA
	I_F=0mA, V_{GS}=8V, V_{CAP}=8V	I_{G_sink}	4.0	9.0	14	
	I_F=0mA, V_{GS}=4V, V_{CAP}=4V		1.5	3.3	6	
	I_F=0mA, V_{GS}=2V, V_{CAP}=2V		0.5	1.2	2	
Turn-On Delay	V_{DS}=48V, V_{GS}=4V, C_{VG}=4nF	t_{on}				µs
	I_F=2.5mA		1	40	140	
	I_F=5mA			12	40	
	I_F=10mA			5	20	
Turn-Off Delay	V_{DS}=48V, V_{GS}=2V, C_{VG}=4nF	t_{off1}				µs
	I_F=2.5mA		40	110	400	
	I_F=5mA			125		
	I_F=10mA			130		
	V_{DS}=48V, V_{GS}=1V, C_{VG}=4nF	t_{off2}				
	I_F=2.5mA		40	200	600	µs
	I_F=5mA			210		
	I_F=10mA			220		
Off-State Leakage Current	V_{DS}=200V	I_{DS}	-	-	1	µA
LED Characteristics						
Forward Voltage Drop	I_F=5mA	V_F	1	1.27	1.5	V
Input Dropout Current	V_{GS}=1V	I_F	0.2	0.75	1	mA
Reverse Bias Leakage Current	V_R=5V	I_R	-	-	10	µA
Common Characteristics						
Input to Output Capacitance	-	C_{IO}	-	3	-	pF

1.8 Performance Data*

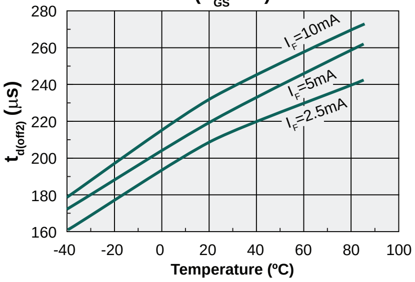
$t_{d(on)}$ vs. Temperature
(V_{GS}=4V)



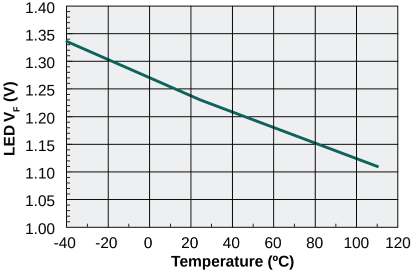
$t_{d(off1)}$ vs. Temperature
(V_{GS}=2V)



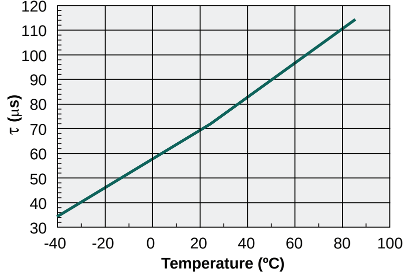
$t_{d(off2)}$ vs. Temperature
(V_{GS}=1V)



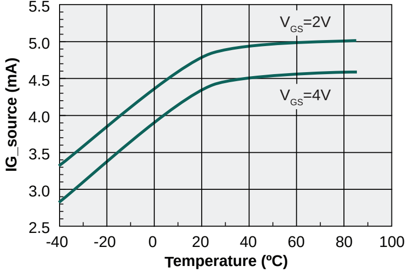
LED Forward Voltage Drop
vs. Temperature
(I_F=5mA)



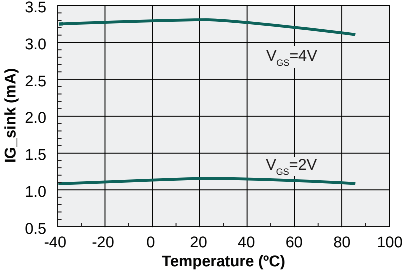
Time Constant (τ) vs. Temperature
(I_F=5mA)



Gate Source Current vs. Temperature
(I_F=5mA, V_{CAP}=15V)



Gate Sink Current vs. Temperature
(I_F=0mA, V_{GS}=V_{CAP})



* Unless otherwise noted, data presented in these graphs is typical of device operation at 25ºC. For guaranteed parameters not indicated in the written specifications, please contact our application department.

2. Introduction

The CPC1590 is a MOSFET Gate Driver that requires no external power supply. It can regulate an input voltage, up to 200V, down to 12.2V for internal use. It is specifically designed for low-duty-cycle switching frequencies that drive 4nF of gate capacitance.

3. Functional Description

The CPC1590 is used in conjunction with a single MOSFET transistor for remote switching of DC loads (**Figure 2**), and two MOSFETS and a diode for remote switching of low-frequency AC loads (**Figure 3**) where isolated power is unavailable.

The device uses external components, most notably a charge storage capacitor, to satisfy design switching and over-voltage protection requirements. Because of this design flexibility, the designer may choose a great number of MOSFETs for use in a wide variety of applications. The designer simply needs to know the MOSFET total gate charge (Q_G), and with this information a capacitor can be chosen. The capacitance of the storage capacitor should be greater than, or equal to, Q_G/0.5V.

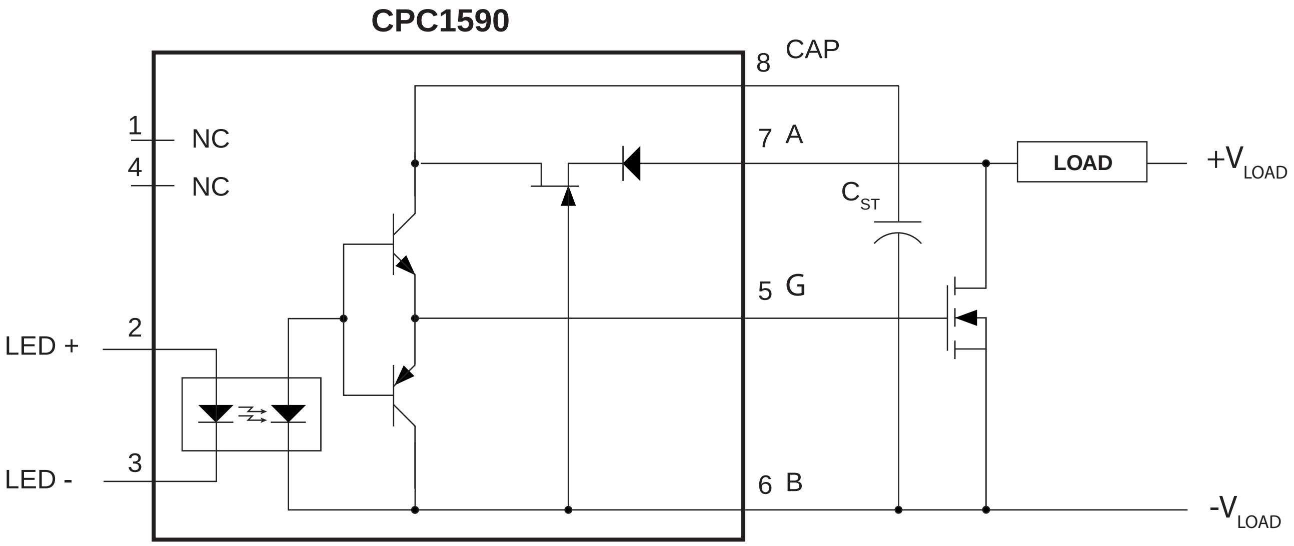
The CPC1590 has two states of operation:
(1) sufficient input control current is flowing, the LED is turned on, and the gate current is being applied. The light from the LED is being reflected onto the photovoltaic, which then produces a photocurrent that turns on the NPN bipolar transistor and provides the charge (I x t = Q), or the gate current that is being applied to turn on the MOSFET. (2) Sufficient input control current is not flowing, the LED is turned off, and gate current is not flowing. The LED is off because V_F << the minimum forward voltage required, and not enough current is being applied. This turns on the PNP bipolar transistor, providing a path for gate current to discharge to V_{L2}.

When V_{LOAD} is first applied, the external storage capacitor begins to charge. The charge is sent through a bootstrap diode to prevent the charge from escaping and discharging through a turned-on MOSFET. The J-FET then regulates the voltage between 10V and 16V. The input control current is applied, then the charge is transferred from the storage capacitor through the NPN bipolar transistor, along with the charge from the photovoltaic, to the MOSFET gate to accomplish a rapid turn-on. After the capacitor has discharged and the MOSFET has turned on, the photocurrent from the input optocoupler continues to flow into the gate to keep the MOSFET turned on.

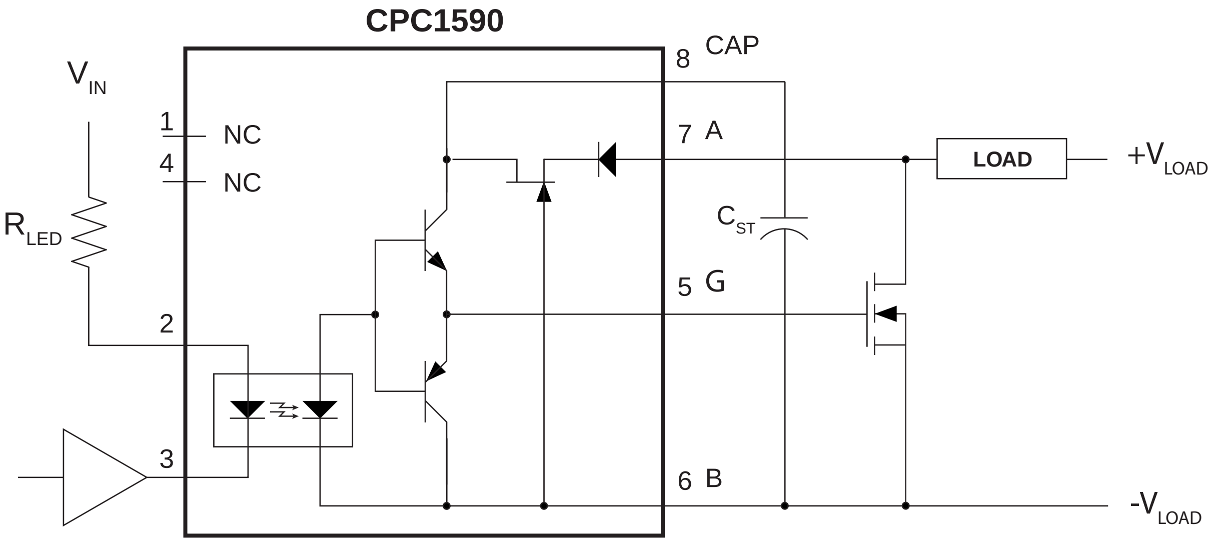
When the input control current is removed, the gate current stops flowing and the PNP bipolar transistor is on and is discharging the MOSFET gate. The MOSFET is now off. At this point the capacitor begins to recharge for the next turn on cycle.

The circuit below does not include over-voltage protection.

Figure 2. CPC1590 DC Application Circuit



4. Device Configuration



4.1 LED resistor

The input resistor is required to limit LED current to a value set by Recommended Operating Conditions in **"Recommended Operating Conditions" on page 3**. In some cases, higher LED operating current would improve driver speed; however, this higher current could also reduce LED lifespan, which would cause reliability issues.

The general equation used to calculate the resistor value is:

$$R_{LED} = \frac{V_{IN} - (V_F + V_{OL})}{I_F}$$

- I_F = Input Control Current
- V_{OL} = Low-level output of the driving logic gate or the collector-emitter voltage of the driving logic transistor. (This parameter is provided in the manufacturer's data sheet.)
- V_{IN} = Input Power Source
- V_F = Forward Voltage Drop of LED
- R_{LED} = Input Resistor

When calculating the resistor value, the designer should take into consideration power-supply variations, which can range about ±10%, temperature variations from -40°C to +85°C, LED forward voltage drop over the temperature range, and the resistor's tolerance and temperature stability rating.

When the LED resistor value is selected by the above formula, the R_{LED} power dissipation, P_D, can be obtained from the following equation:

$$P_D = I_F^2 \bullet R_{LED}$$

With power dissipation calculated, it is now possible to select an appropriate resistor size that can be used in the particular application circuit. It is recommended that a resistor with at least twice the calculated power rating should be selected.

4.2 Storage Capacitor

The storage capacitor (C_{ST}) enables the gate driver to turn on a power MOSFET faster by delivering a reservoir of charge to the gate. Selection of the storage capacitor is given by the following equation:

$$C_{ST} \geq Q_G / 0.5V$$

This equation shows that the storage capacitor needs to deliver enough charge to the gate while only dropping 0.5V. The CPC1590 can deliver 32nC of charge at rated operating speed, and will operate with much larger loads, >4nF, with slower turn-on and turn-off times.

The CPC1590 has an internal J-FET, which is used to regulate the voltage applied to the storage capacitor. The voltage applied to the storage capacitor will be between 10V and 16V. The capacitor's voltage rating should be two to three times this range.

The designer should select the storage capacitor based on the particular application requirements. If the final product requires operating at a higher ambient temperature range of -40°C to +110°C, then it is better to select COG/NPO capacitors in order to meet minimum capacitance requirements.

4.3 Transistor Selection

The CPC1590 charges and discharges an external MOSFET transistor. The selection of the MOSFET is determined by the user to meet the specific power requirements for the load. The CPC1590 output voltage is listed in the specification, but, as mentioned earlier, there must be little or no gate leakage.

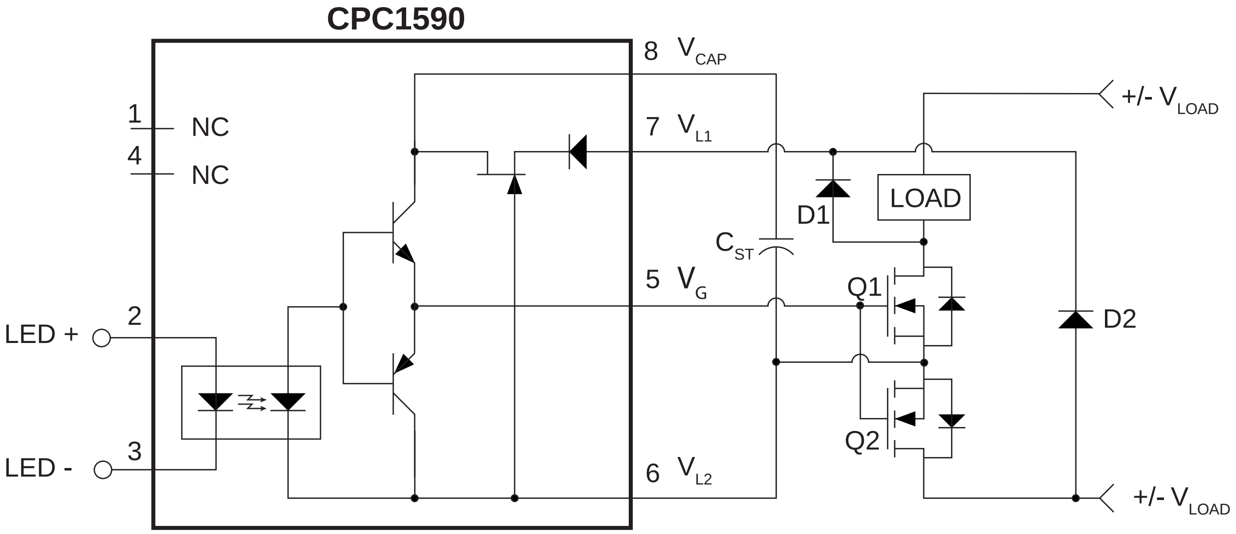
Another parameter that plays a significant role in the selection of the transistor is the gate drive voltage available from the part. The CPC1590 uses photovoltaic cells to collect the optical energy generated by the internal LED; to generate more voltage, the photovoltaic diodes are stacked. As such, the voltage of the photovoltaic stack reduces with increased temperature. The user must select a transistor that will maintain the load current at the maximum temperature, given the V_{GS} in the CPC1590 specifications.

5. CPC1590 Used as an AC Switch

The CPC1590 can be used in other configurations. One typical configuration is shown in **Figure 3**, which is called an AC Switch. This simply means that either terminal can be positive or negative. This configuration requires a second MOSFET (Q2) and two rectifying diodes (D1 and D2).

The design considerations are identical for this application. Diodes D1 and D2 must have voltage ratings greater than the breakdown voltage of the MOSFETs.

Figure 3. Application Circuit for Using the CPC1590 as an AC Switch



6. Conclusion

See IXYS Integrated Circuits' Application Note, AN-202, for a thorough discussion, and for examples of device usage, component selection, and over-voltage protection circuitry.

7. Manufacturing Information

7.1 Moisture Sensitivity

All plastic encapsulated semiconductor packages are susceptible to moisture ingression. IXYS Integrated Circuits classifies its plastic encapsulated devices for moisture sensitivity according to the latest version of the joint industry standard, **IPC/JEDEC J-STD-020**, in force at the time of product evaluation. We test all of our products to the maximum conditions set forth in the standard, and guarantee proper operation of our devices when handled according to the limitations and information in that standard as well as to any limitations set forth in the information or standards referenced below.

Failure to adhere to the warnings or limitations as established by the listed specifications could result in reduced product performance, reduction of operable life, and/or reduction of overall reliability.

This product carries a **Moisture Sensitivity Level (MSL)** classification as shown below, and should be handled according to the requirements of the latest version of the joint industry standard **IPC/JEDEC J-STD-033**.

Device	Moisture Sensitivity Level (MSL) Classification
CPC1590P	MSL 1

7.2 ESD Sensitivity

This product is **ESD Sensitive**, and should be handled according to the industry standard **JESD-625**.

7.3 Reflow Profile

Provided in the table below is the Classification Temperature (T_C) of this product and the maximum dwell time the body temperature of this device may be (T_C - 5)ºC or greater. The classification temperature sets the Maximum Body Temperature allowed for this device during lead-free reflow processes. For through-hole devices, and any other processes, the guidelines of **J-STD-020** must be observed.

Device	Classification Temperature (T_C)	Dwell Time (t_p)	Max Reflow Cycles
CPC1590P	260°C	30 seconds	3

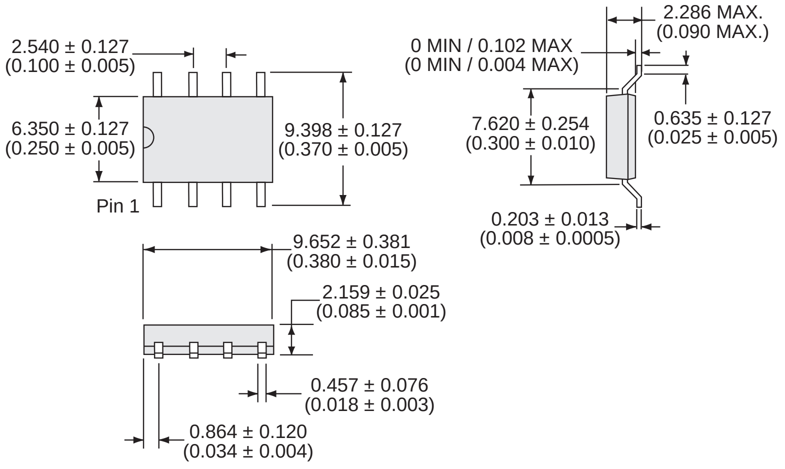
7.4 Board Wash

IXYS Integrated Circuits recommends the use of no-clean flux formulations. Board washing to reduce or remove flux residue following the solder reflow process is acceptable provided proper precautions are taken to prevent damage to the device. These precautions include but are not limited to: using a low pressure wash and providing a follow up bake cycle sufficient to remove any moisture trapped within the device due to the washing process. Due to the variability of the wash parameters used to clean the board, determination of the bake temperature and duration necessary to remove the moisture trapped within the package is the responsibility of the user (assembler). Cleaning or drying methods that employ ultrasonic energy may damage the device and should not be used. Additionally, the device must not be exposed to flux or solvents that are Chlorine- or Fluorine-based.

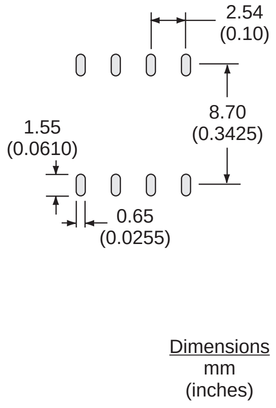
Pb RoHS e3

7.5 Mechanical Dimensions

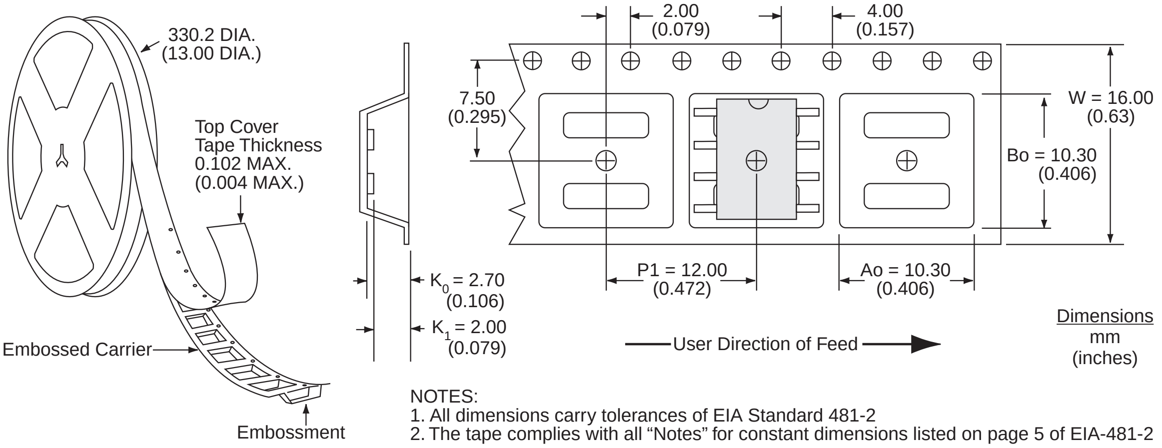
7.5.1 CPC1590P 8-Pin Flatpack Package



PCB Land Pattern



7.5.2 CPC1590PTR Tape & Reel



NOTES:
1. All dimensions carry tolerances of EIA Standard 481-2
2. The tape complies with all “Notes” for constant dimensions listed on page 5 of EIA-481-2

For additional information please visit www.ixysic.com

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Specification: DS-CPC1590-R02
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6/18/2018

The information below supercedes any previously presented material.

For additional information please visit our website at: **https://www.littelfuse.com**

IXYS
A **Littelfuse** Technology

Application Note: AN-131

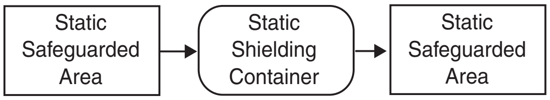
Handling MOS Devices

Static Discharge

Metal Oxide Semiconductor (MOS) devices have gained broad acceptance in telecommunications. This includes use of n-channel (NMOS) transistors, p-channel (PMOS) transistors, or both (complementary or CMOS) transistors. Most IXYS IC Division devices are fabricated using CMOS techniques, but some use PMOS. In any case, MOS circuits require special attention in design and handling because of their susceptibility to damage through buildup of static charges and the currents that occur during discharge.

Whether alone or mounted in circuit boards, MOS ICs are subject to buildup of static charges and damaging discharges. Voltage of several hundred volts can affect these devices, while one or two thousand volts will certainly cause harm. Five hundred volts can easily be generated by a person walking around or moving in a chair, and thousands of volts can be generated by the simple act of pulling out and tearing off a piece of transparent tape. Under these circumstances, precautions must be taken to limit the potential for damage to costly IC devices. MOS ICs should be handled in static-protected or "safeguarded" areas. Such areas include ionized air flow over nonconducting surfaces. When not in these areas, ICs should be kept in static shielded containers. ICs must be handled in safeguarded areas (receiving inspection, stores, assembly, and test) and, when moved from area to area, should be protected by shielded containers. Failure to implement procedures of this sort or relaxation of procedures can result in loss of valuable parts, increased production fallout, and higher repair costs.

Static Transmission



CMOS Latchup

Though all ICs are subject to static discharge damage, CMOS ICs can experience another kind of damaging event known as "latchup" or "SCR." In this case, large currents can follow-through the part from the power supply, damaging transistors and interconnections. This occurs when currents are injected into the chip where they were not intended, usually through an I/O pin which has been driven to a voltage outside the supply range by some external device or event. This phenomenon is equivalent to four-layer conduction as used in SCRs, where a semiconductor device is "turned on" by injecting a current into a trigger layer. The device stays "on" until voltage is removed. This is useful in SCR control circuits, but in the case of CMOS ICs they may (1) recover completely after power has been cycled, (2) recover, but act very strangely, or (3) blow up completely. Causes can be inadequate power supply filtering, transient protection, or coincidences of PWB track layout. Static discharge may also trigger latchup.

For additional information please visit our website at: www.ixysic.com

Specification: AN-130-R04

4/10/2014