COMBINATION HALL SWITCH AND LED DRIVER IC SIMPLIFIES ENCLOSURE LIGHTING AND PROXIMITY SENSING

By Shashank Wekhande and Ranjit Farakate, AvantGarde Solutions Pvt Ltd.,
Consultants to Allegro Microsystems

ABSTRACT

Most of today's white goods use LED lighting for internal illumination. For example, refrigerators, microwave ovens, and kitchen cabinets all use LEDs for interior illumination when the door opens. LEDs are also used for illumination in ice cream freezers, vending machines, and other enclosures. Personal mobility trunks and glove boxes such as on scooters and small vehicles are other areas where LED actuation occurs. LEDs are controlled with a switch operated by the door opening/closing. When the door is opened, the switch closes and powers on the LED.

Applications that combine proximity sensing with lighting actuation can achieve reduced system footprints and design simplification by the use of a single highly integrated circuit (IC). Example use cases and technical considerations are presented in this application note using the Allegro APS13568 combination switch and LED driver.

INTRODUCTION

Allegro MicroSystems has developed the APS13568, an integrated LED driver with non-contact Hall-effect switch in a single-chip solution. This IC provides reliability and ease of design for contactless door opening illumination in white goods, battery-operated cabinet lighting, two-wheeler boot lamp, and similar applications. The end results are a shorter design phase and a faster time to market.

APS13568 INTEGRATED LED DRIVER WITH HALL-EFFECT SWITCH

The APS13568 is an integrated circuit that combines an ultra-sensitive, omnipolar, micropower Hall-effect switch with a linear programmable current regulator which can provide up to 150 mA current to drive high brightness LEDs. This highly integrated solution offers high reliability and ease of design compared to a discrete solution.

FEATURES AND BENEFITS

- Integrated LED driver and Hall-effect switch
- Low quiescent current (25 µA, typical) when LED is off
- Hall-effect switch output with selectable output polarity
- Active-low LED drive enable pin
- Linear, low-dropout LED drive up to 150 mA
  - □ Set by external reference resistor
  - □ Reverse battery and load dump protection
  - □ Short-to-ground and thermal protection
  - □ Programmable fade-in and fade-out duration with external capacitor

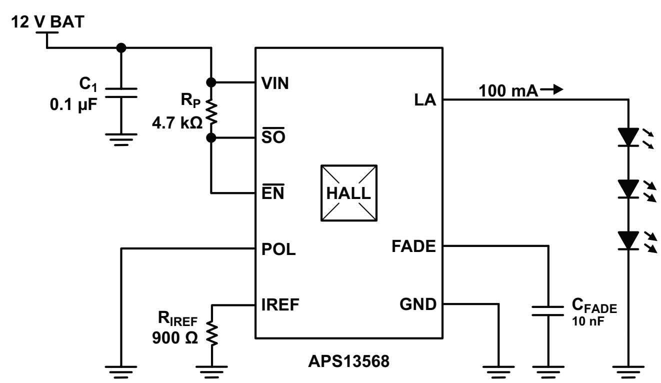


Figure 1: Typical Application Circuit of APS13568

CIRCUIT DESCRIPTION

The APS13568 operates from 7 to 24 V—typically, a 12 V supply is used for the input supply. Capacitor C1 is a bypass capacitor placed close to the IC and is recommended for maximum EMI/EMC compliance.

The current through the LEDs is set by a resistor connected to the IREF pin. LED current is set using Equation 1 :

Equation 1:

$$I_{\mathrm{LA}} = 90 \; / \; R_{\mathrm{IREF}}$$

where I_{LA} is in amps, R_{IREF} is in ohms. A 900 Ω resistor connected between the IREF and GND pins sets the 100 mA current of the LED.

FADE-IN AND FADE-OUT FEATURE

The FADE pin is connected to a ground through a C_{FADE} capacitor to illuminate the LED slowly in order to avoid flash blindness at night when the door opens. Fade timing is controlled by an external capacitor C_{FADE} on the FADE pin.

Fade-in is trigged when the LED driver is enabled, and fade-out triggered when the LED driver is disabled as shown in below Figure 2. A 10 nF capacitor on the fade pin to ground pin will set 10 ms of the fade in; fade out time is achieved as shown in the Figure 2. The fade time is approximated by using the Equation 2.

Equation 2:

$$t_{\mathrm{FADE}} = C_{\mathrm{FADE}} \times 0.8 \times 10^{6}$$

where t_{FADE} is in seconds and C_{FADE} is in farads.

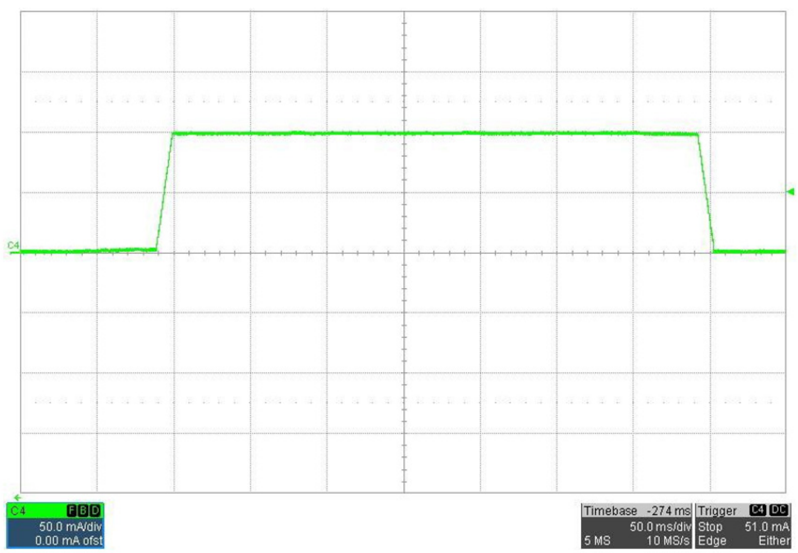


Figure 2: Fade-in and fade-out (C4 = Output Current)

MAGNET AND APS13568 IC PLACEMENT

The IC is mounted on a stationary frame and the magnet is fitted on the door as shown in Figure 3. The magnet and IC are aligned such that the IC can detect magnetic field variation by movement of the magnet.

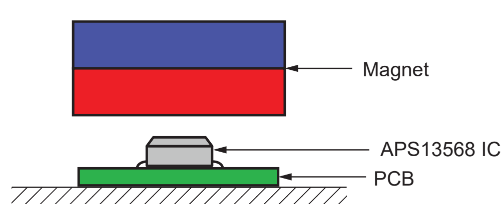


Figure 3: Magnet and APS13568 IC Placement

THERMAL MONITOR FEATURE

The APS13568 is a linear type of LED driver. These types of driver use power based on input and output voltage differential and current as shown in Equation 3.

Equation 3:

$$P = (V_{\mathrm{IN}} - V_{\mathrm{OUT}}) \times I_{\mathrm{LED}} + (V_{\mathrm{IN}} \times I_{\mathrm{IN}})$$

For example, at 12 Vin, having a single LED with 3 V forward voltage driving at 100 mA can use about 0.9 W. This power loss will increase driver IC temperature. A temperature monitor function is available in the APS13568 which reduces the LED current as the junction temperature increases above 130°C. This extends the operation over a wide range of ambient temperature and operating conditions.

As the junction temperature of the APS13568 increases beyond 130°C, the output current level is proportionally decreased, reducing power dissipation in the APS13568 and in the LEDs.

Above 130°C temperature, the current will continue to decrease at a lower rate until the temperature reaches the overtemperature shutdown threshold temperature (165°C). If the junction temperature exceeds the overtemperature limit, the driver will be disabled. The temperature will continue to be monitored and the regulator will be reactivated when junction temperature drops below the threshold.

APS13568 PROTOTYPE BOARD

The schematic of the APS13568 prototype board is as shown in the Figure 4. The CoB (chip-on-board) LEDs (3 LEDs in series inside the LED, chip-on-board), comes standard on this proto board.

HALL-EFFECT SWITCH OPERATION

The omnipolar Hall-effect switch provides contactless control of the LED. The Hall-effect omnipolar switch operates with either a north or a south magnetic pole. This offers ease of production due to polarity-independent operation. The switch output polarity can be set with an external pulldown on the POL input pin. This allows the user to select whether the APS13568 output turns on and off when a magnet is present or when the magnetic field is removed. The magnetic characteristics of the APS13568 is shown in Table 1.

In the closed-door condition, the magnet is on the surface of the LED driver, such that the magnetic field is above B_{OP} and the internal Hall-effect switch turns off (POL = 1). In this case, the $\overline{\mathrm{SO}}$ and $\overline{\mathrm{EN}}$ pins are connected to the battery voltage through the pull-up resistor R_p.

When $\overline{\mathrm{EN}}$ is HIGH (disabled), the LEDs turn off (POL = 1). Reverse operation will happen in a POL = 0 (float) condition.

Table 1: Magnetic Characteristics of APS13568

Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Unit
Operate Point	B_{OPS}	$\lvert B_{FIELD}\rvert > \lvert B_{OP}\rvert$	–	40	70	G
	B_{OPN}		–70	–40	–	G
Release Point	B_{RPS}	$\lvert B_{FIELD}\rvert < \lvert B_{RP}\rvert$	5	25	–	G
	B_{RPN}		–	–25	–5	G
Hysteresis	B_{HYS}	$\lvert B_{OPX} - B_{RPX}\rvert$	5	15	25	G

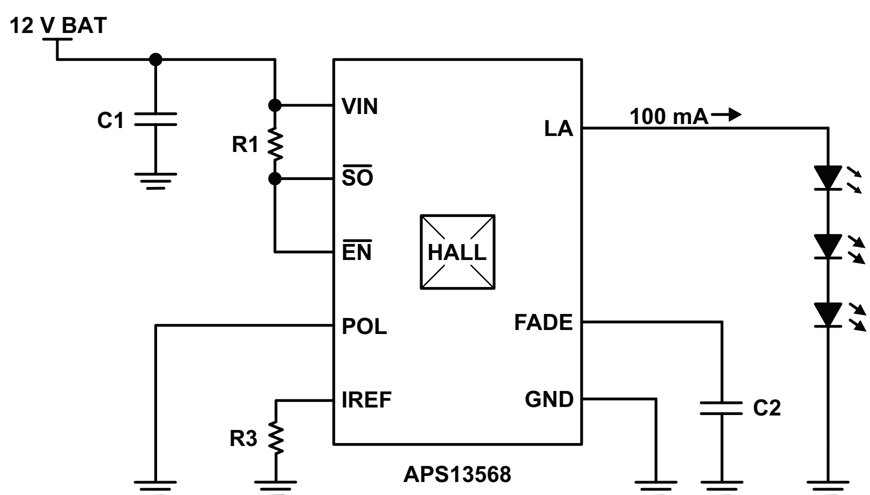


Figure 4: Schematic of APS13568 Prototype Board

The bill of materials of the APS13568 prototype board is shown in Table 2.

Table 2: Bill of Material of APS13568 Prototype Board

Number	Part Designator	Description	Package	Quantity
1	U1	APS13568 IC	SOIC-8	1
2	LED1	White CoB LEDs (CXA1304-0000-000C00B40E1)	CoB	1
3	C1	100 nF SMD capacitor, X7R	805	1
4	C2	10 nF SMD capacitor, X7R	805	1
5	R1	4.7 kΩ, SMD resistor	805	1
6	R2	0 Ω, SMD resistor	805	1
7	R3	900 Ω, SMD resistor	805	1

PRINTED CIRCUIT BOARD

A printed circuit board of the APS13568 IC is shown in Figure 5. +V = Battery Voltage Input, LEDs connected between LA and Ground pin.

Figure 6 shows the surface temperature of the APS13568 at 12 V supply voltage with white CoB LEDs (CXA1304-0000-000C00B40E1) in series for 100 mA continuous current.

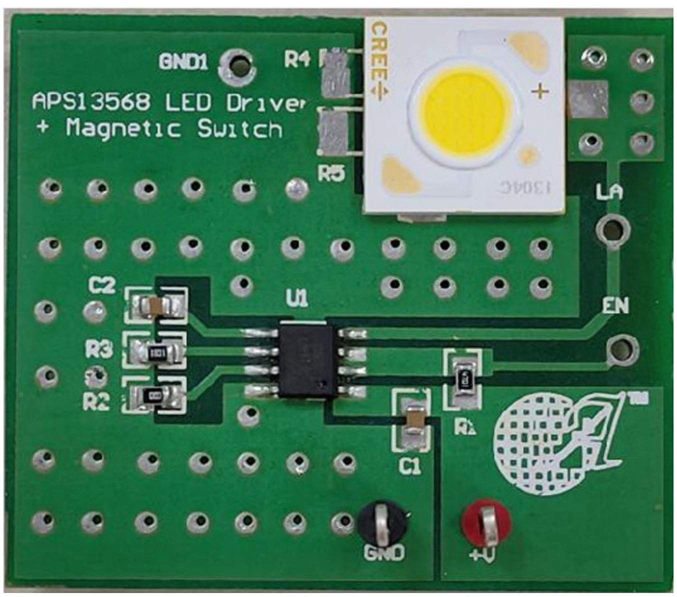


Figure 5: APS13568 PCB with CoB LEDs

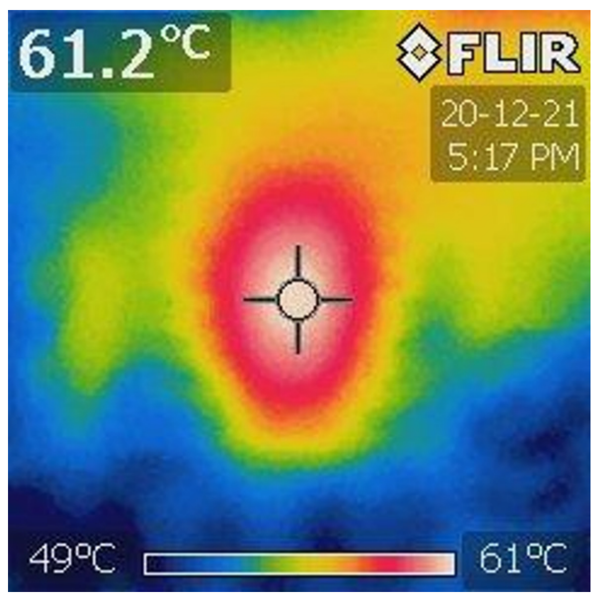


Figure 6: Surface temperatures of APS13568 IC

VARIOUS APPLICATIONS USING THE APS13568 IC

Door Opening Lights for Refrigerator or Microwave Oven

Typical white goods door opening illumination is shown in Figure 7. LEDs are preferred for lighting as the offer longer life and generate less heat than incandescent solutions. Also, mechanical switches tend to become stuck after some time and do not continue to work properly.

The APS13568, which provides an LED driver and Hall-effect switch in a single-chip solution, is an effective design for BOM reduction as its features provide the contactless sensing and LED lighting for applications like refrigerator or microwave door opening. The application circuit for a refrigerator or microwave is shown in Figure 1.

A magnet is attached to the door, and the IC is placed perpendicular to the magnet inside the refrigerator. When the door opens, the magnet moves away from the sensor, applying lower magnetic field, which pulls the $\overline{SO}$ pin (active-low open-drain output) low. This pulls the $\overline{EN}$ pin to low through resistor R_{PU} and enables the driver. Resistor R_{IREF} sets the current. When the door closes, the magnet moves close to the driver and the $\overline{SO}$ pin goes high. This pulls the $\overline{EN}$ pin high to disable the driver.

APS13568 features suitable for door opening light applications:

- Low quiescent current (25 µA, typical) when LED is off
- Hall-effect switch output with selectable output polarity
- Linear low-dropout LED driver, up to 150 mA
  - Set by external reference resistor
  - Programmable fade-in and fade-out duration with external capacitor
  - External input pin for LED control and dimming (PWM)

Figure 7: Refrigerator and microwave door opening lighting applications

Ice Cream Freezer and Beverage Dispenser Applications

Traditional incandescent bulbs generate significant heat which is an additional burden on a cooling compressor. This is especially important for devices with a glass opening such as a beverage dispenser or ice cream freezer as shown in Figure 8.

Working Principle

A magnet is attached to the side of the door and the IC is placed perpendicular to the magnet inside the ice cream freezer. When door is in a closed condition, the magnet is close to the driver, and the magnetic field is higher than the B_{OP} level such that the $\overline{SO}$ pin goes high. The driver is always enabled with the $\overline{EN}$ pin connected to ground and LEDs illuminated by the current set with the R1 resistor.

When the door opens, the magnet moves away from the driver and the magnetic field is lower than the B_{RP} level such that the $\overline{SO}$ pin goes low. When the $\overline{SO}$ pin goes low, it draws R1 and R2 in parallel and illuminates the light with double intensity with the $\overline{EN}$ pin connected to ground.

APS13568 features suitable for ice cream freezer or beverage dispenser application:

- Hall-effect switch output with selectable output polarity
- Linear low-dropout LED driver with programmable output current up to 150 mA, set by external reference resistor

Figure 8: Ice cream freezer

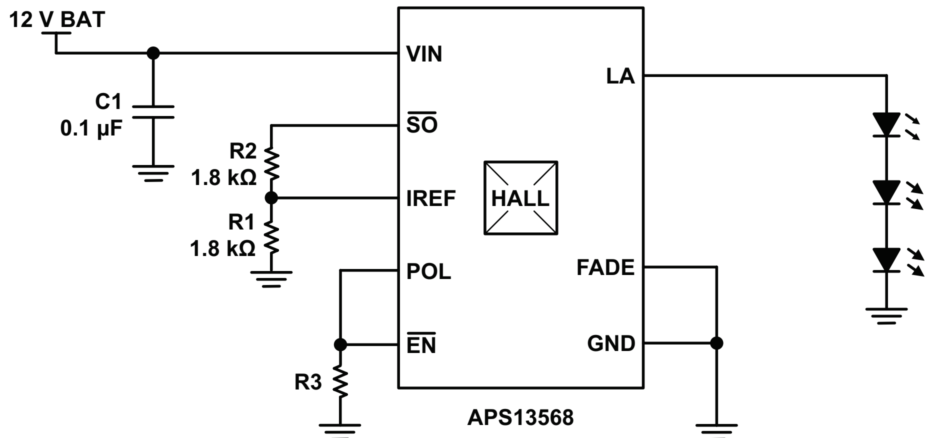


Figure 9: Application circuit of APS13568 for door opening lights for ice cream freezer or beverage dispenser

Battery-Operated Inner Cabinet Lighting

For existing inner cabinet lighting, customers are using an IR sensor switch to turn on and off the LED when the door opens and closes. The inner cabinet lighting picture is as shown in the Figure 10 and 11 when the LED lights turns on in the door open condition and turns off in the door close condition.

The APS13568 operates on a 12 V battery, and it is possible to use three white LEDs for higher brightness. When the LEDs is in the off condition, the APS13568 has lower leakage current, less than 25 µA, which increases battery life.

APS13568 features suitable for battery-operated inner cabinet lighting application

- Low quiescent current (25 µA, typical) when LED is off
- Hall-effect switch output with selectable output polarity
- Linear low-dropout LED driver, up to 150 mA
  - Set by external reference resistor
  - Programmable fade-in and fade-out duration with external capacitor.
  - External input pin for LED control and dimming (PWM)

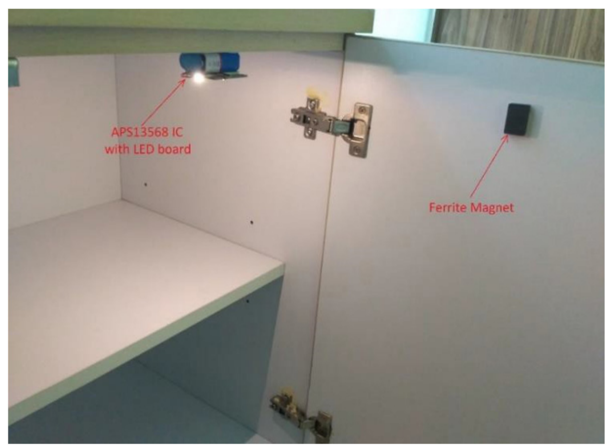


Figure 10: Inner cabinet lighting (LED turns on when door opens)

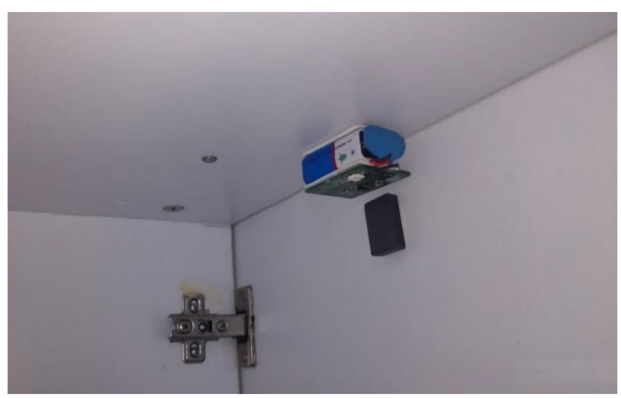


Figure 11: Inner cabinet lighting (LED turns off when door closes)

Boot Lamp Application

In two-wheeler scooters, boot space is provided to store accessories. This boot is normally illuminated by an incandescent lamp through a mechanical switch. This boot lamp is operated directly from the battery before the ignition switches on, so it is very important that the LED driver has a very low quiescent current when the LED is off to avoid battery drain.

The APS13568 has 25 μA of quiescent current along with the Hall-effect switch—suitable for this application.

The APS13568, which provides an LED driver and Hall-effect switch in a single-chip solution, provides contactless LED lighting for the boot lamp application. The application circuit of the APS13568 for a boot lamp application for a two-wheeler scooter is as shown in Figure 1.

APS13568 features suitable for boot lamp application

- Low quiescent current (25 μA, typical) when LED is off
- Hall-effect switch output with selectable output polarity
- Linear low-dropout LED driver, up to 150 mA
  - Set by external reference resistor
  - Reverse battery and load dump protection
  - Short-to-ground and thermal protection
  - Programmable fade-in and fade-out duration with external capacitor

Figure 12: Boot lamp of scooter

Glove Box Lamp Application

In four-wheeler vehicles, glove box space is provided to store accessories. This glove box is normally illuminated by an incandescent lamp through a mechanical switch. This glove box lamp is operated directly from the battery before the ignition switches on, so it is very important that the LED driver has a very low quiescent current when the LED is off to avoid battery drain.

The APS13568 has 25 μA of quiescent current along with the Hall-effect switch—suitable for this application.

The APS13568, which provides an LED driver and Hall-effect switch in a single-chip solution, is an effective design for BOM reduction, as its features provide both contactless sensing and LED lighting for the boot lamp application. The application circuit of the APS13568 for the glove box lamp application for a four-wheeler car is shown in Figure 1.

APS13568 features suitable for glove box application

- Low quiescent current (25 μA, typical) when LED is off.
- Hall-effect switch output with selectable output polarity
- Linear low-dropout LED driver, up to 150 mA
  - Set by external reference resistor
  - Reverse battery and load dump protection
  - Short-to-ground and thermal protection
  - Programmable fade-in and fade-out duration with external capacitor

Figure 13: Glove box lamp application

CHOOSING LEDS FOR APS13568 IC

Choosing LEDs for the APS13568 LED driver with Hall-effect switch depends on current and supply voltage. The APS13568 IC's maximum current is 150 mA, so select LEDs up to 200 to 300 mA current range. The number of series LEDs is dependent on the supply voltage. If the battery supply is 12 V, then use three white LEDs in series, and if the battery voltage is 9 V, then use two white LEDs in series.

Power Dissipation Example for the Single and CoB LEDs for 12 V Supply Voltage

Power dissipation for single white LED:

Forward Voltage of White LED = 3 V

Output LED Current = 100 mA

Supply Voltage (V_{IN}) = 12 V

Supply Current (I_{IN}) = 4 mA

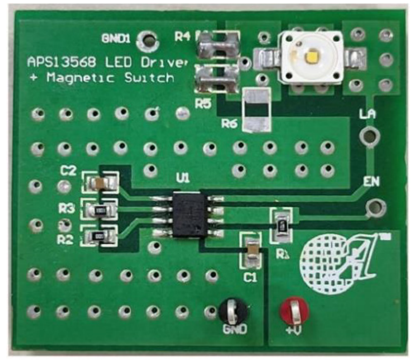
Printed Circuit Board Size: 44.8 mm length, 39 mm width

Power Dissipation (W) $= (V_{IN} - V_{LED}) \times I_{LED} + (V_{IN} \times I_{IN})$

$= (12 - 3) \times 100 + 12 \times 0.004$

$= 0.948$ W

The printed circuit board of the APS13568 IC with a single white LED and surface temperature for 12 V supply voltage at 100 mA continuous current is shown in Figure 14.



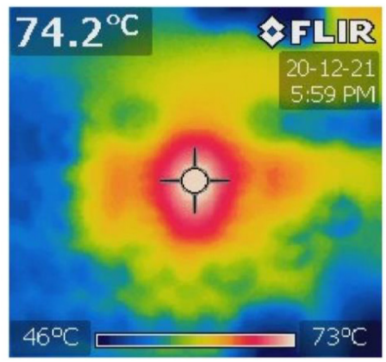


Figure 14: APS13568 with Single White LED (top) and Surface Temperature of IC (bottom)

Power dissipation for single white LED with sense resistor:

Forward Voltage of White LED = 3 V

Output LED Current = 100 mA

Supply Voltage (V_{IN}) = 12 V

Supply Current (I_{IN}) = 4 mA

Rsense Resistor = 75 Ω

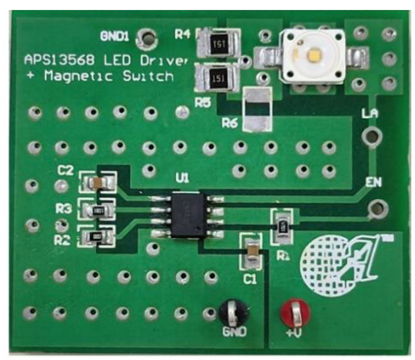
Printed Circuit Board Size: 44.8 mm length, 39 mm width

Power Dissipation (W) $= (V_{IN} - (V_{LED} + (\text{Rsense} \times I_{LED})) \times I_{LED}) + (V_{IN} \times I_{IN})$

$= (12 - (3 + (75 \times 0.100)) \times 0.100) + (12 \times 0.004)$

$= 0.198$W

The printed circuit board of the APS13568 IC with a single white LED with sense resistor and surface temperature for 12 V supply voltage at 100 mA continuous current is shown in Figure 15.



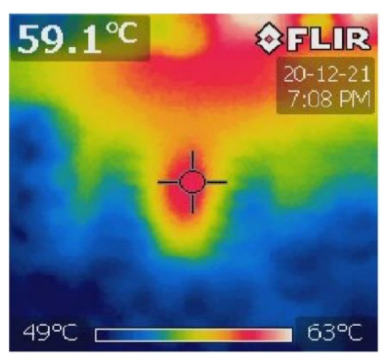


Figure 15: APS13568 with Single White LED and Sense Resistor (top) and Surface Temperature of IC (bottom)

Power dissipation in linear type LED driver limits output current. For higher brightness, use CoB LEDs.

Power dissipation for CoB LED:

Forward Voltage of White LED = 9 V

Output LED Current = 100 mA

Supply Voltage (V_{IN}) = 12 V

Supply Current (I_{IN}) = 4 mA

Printed Circuit Board Size: 44.8 mm length, 39 mm width

Power Dissipation (W) = $(V_{IN} – V_{LED}) \times I_{LED} + (V_{IN} \times I_{IN})$

Power Dissipation (W) = $(12 – 9) \times 100 + (12 \times 0.004)$

Power Dissipation (W) = 0.348 W

The printed circuit board of the APS13568 IC with white CoB LEDs is shown in Figure 5, and the surface temperature for 12 V supply voltage at 100 mA continuous current is as shown in Figure 6.

Below are two LEDs part numbers suitable for the APS13568 IC with 12 V and 9 V battery supply voltage.

High Power LEDs – White (for 12 V battery supply)

Manufacture Part Number: CXA1304-0000-000C00B40E1

Product: White CoB LEDs

Forward Current: 400 mA

Forward Voltage: 9 V

High Power LEDs – White 3030 Mid Power LED White (for 9 V battery supply)

Manufacture Part Number: MP-3030-2100-50-80

Product: White CoB LEDs

Forward Current: 150 mA

Forward Voltage: 6.1 V

CHOOSING A MAGNET FOR APS13568 IC

Magnets are available in different materials, shapes, and sizes; customers can select the magnet as per the application requirements. The magnet must have sufficient flux density to generate the desired switching output at the working air gap required by the application.

Magnetic material properties are shown in Table 3. The flux density of the magnet is required to be greater than 70 gauss (south pole) or –70 gauss (north pole) on the surface of the sensor for switching the output at the desired air gap. Select the magnet size such that magnet should cover the sensor face properly.

For the door/boot opening application, a ferrite magnet is suitable. Ferrite magnets are cheap and readily available on the market. Where size constraint is a problem, a NdFeB magnet is suitable. The NdFeB magnet provides a stronger magnetic field than the ferrite magnet for a smaller size of magnet.

By using simple formulas, it is also possible to calculate the flux density of the magnet. Calculations of the flux density of cylindrical and rectangular magnets is shown in the formulas below.

Table 3: Properties of Magnetic Material

Material	Br (gauss)	Hc (oersted)	BHmax (MGOe)	Tcoef of Br (%/°C)	Cost
NdFeB	12,800	12,300	40	–0.12	High
Alnico	12500	640	5.5	–0.02	Medium
Ferrite	3,900	3,200	3.5	–0.2	Low

Cylindrical Magnet

Equation 4 gives an approximate formula for selecting the appropriate magnet based on required magnetic flux density [2], which is useful for calculating the magnetic flux density at d mm from the cylindrical magnet surface as shown in Figure 16.

Equation 4:

$$Bd = \frac{Br}{2}\left(\frac{(L+d)}{\sqrt{R^2+(L+d)^2}} - \frac{d}{\sqrt{R^2+d^2}}\right)$$

Bd = Magnetic flux density

Br = Residual flux density

L = Length

R = Radius of the magnet

d = Air gap (magnet surface to the sensor Hall element)

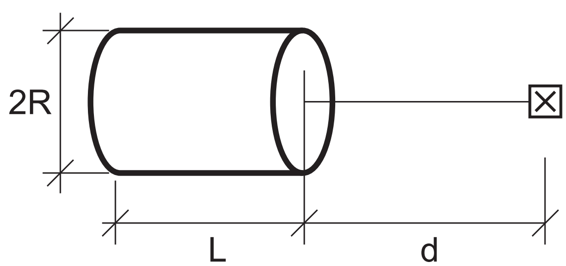


Figure 16: Cylindrical Magnet

Rectangular Magnet

Equation 5 gives an approximate formula for selecting the appropriate magnet dimensions based on required magnetic flux density [2], which is useful for calculation the magnetic flux density at d mm from the rectangular magnet surface as shown in Figure 17.

Equation 5:

$$Bd = \frac{Br}{\Pi}\left(\tan^{-1}\frac{AB}{2d\sqrt{4d^2+A^2+B^2}} - \tan^{-1}\frac{AB}{2(L+d)\sqrt{4(L+d)^2+A^2+B^2}}\right)$$

Bd = Magnetic flux density

Br = Residual flux density

L = Length

B = Width

A = Height

d = Air gap (magnet surface to the sensor Hall element)

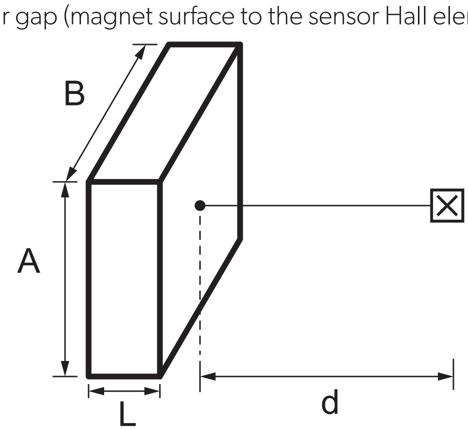


Figure 17: Rectangular Magnet

SUMMARY

Different applications are presented in this article along with a reduced size actuated lighting solution suitable for door opening lights of white goods, inner cabinet/drawers, two-wheeler boot lamps, study/desk light applications, etc.

The APS13568 LED driver combines an ultrasensitive, omnipolar micropower Hall-effect switch with a linear programmable LED driver and offers high reliability and ease of design with minimal external components. This IC has an integrated 150 mA LED driver and proximity switch for contactless operation of the door opening.

REFERENCES

[1] https://www.allegromicro.com/en/products/regulate/led-drivers/led-drivers-for-lighting

[2] https://www.intemag.com/magnet-design-guide

[3] https://www.allegromicro.com/en/search?q=AN296207

[4] https://marketbusinessnews.com/financial-glossary/white-goods-definition-meaning

[5] https://en.wikipedia.org/wiki/Scooter_(motorcycle)

[6] https://en.wikipedia.org/wiki/Building_automation#:~:text=Building%20automation%20is%20the%20automatic,Building%20Automation%20System%20(BAS).

Revision History

Number	Date	Description	Responsibility
–	May 27, 2021	Initial release	S. Wekhande, R. Farakate
1	May 16, 2022	Changes to title and abstract only.	S. Wekhande, R. Farakate

955 PERIMETER ROAD • MANCHESTER, NH 03103 • USA
+1-603-626-2300 • FAX: +1-603-641-5336 • ALLEGROMICRO.COM