SMC321

Product Preview
Ballast Control IC

Description

The SMC321, developed using ON Semiconductor's unique high−voltage process, is a ballast control integrated circuit (IC) for a fluorescent lamp. SMC321 incorporates a preheating / ignition function, controlled by an user−selected external capacitor, to increase lamp life. The SMC321 detects switch operation from after ignition mode through an internal active Zero−Voltage Switching (ZVS) control circuit. This control scheme enables the SMC321 to detect an open−lamp condition, without the expense of external circuitry, and prevents stress on MOSFETs. The high−side driver built into the SMC321 has a common−mode noise cancellation circuit that provides robust operation against high−dv/dt noise intrusion.

Features

- Floating Channel for Bootstrap Operation to +600 V
- Low Start−up and Operating Current: 120 μA, 3.2 mA
- Under−Voltage Lockout with 1.8 V of Hysteresis
- Adjustable Run Frequency and Preheat Time
- Internal Active ZVS Control
- Internal Protection Function (Latch Mode)
- Internal Clamping Zener Diode
- High Accuracy Oscillator
- Soft−Start Functionality
- This is a Pb−Free Device

Applications

- Electronic Ballast

This document contains information on a product under development. ON Semiconductor reserves the right to change or discontinue this product without notice.

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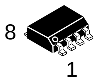
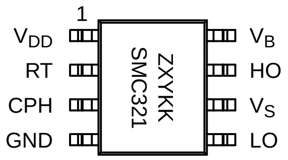


SOIC8
(SOP)
CASE 751EG

MARKING DIAGRAM AND PIN CONFIGURATION



(Top View)

ZXYKK = Plant and Week and Lot Code
SMC321 = Device Code

ORDERING INFORMATION

Device	Package	Shipping†
SMC321	SOIC8	Tape & Reel

†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specification Brochure, BRD8011/D.

August, 2017 − Rev. P0

Publication Order Number:
SMC321/D

Typical Application Diagrams

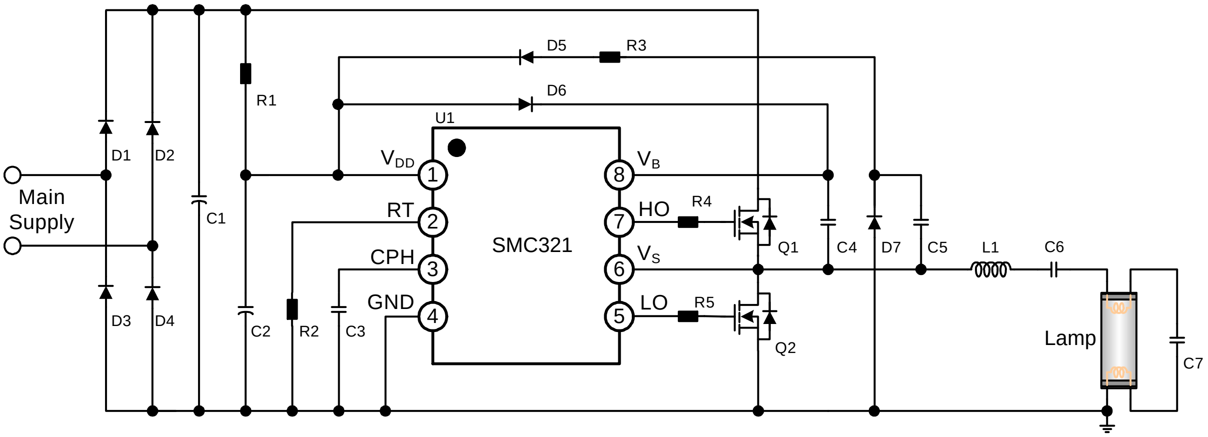


Figure 1. Typical Application Circuit for Compact Fluorescent Lamp

Internal Block Diagram

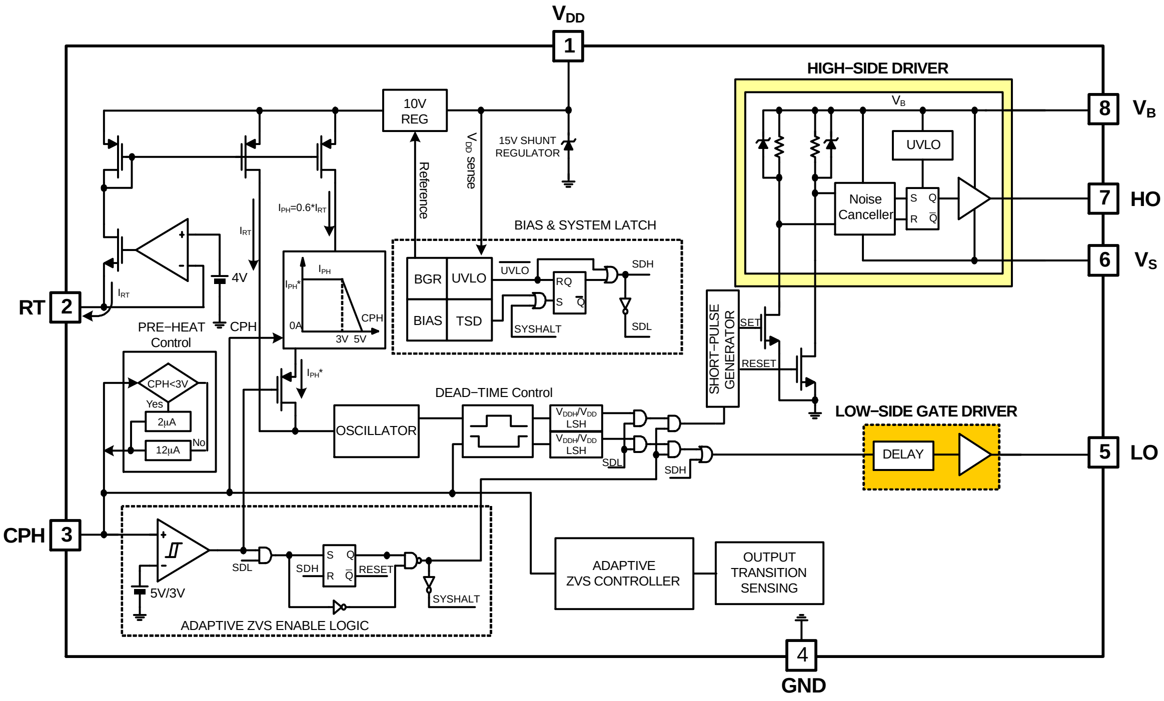


Figure 2. Functional Block Diagram

Table 1. PIN DEFINITIONS

Pin #	Name	Description
1	V_{DD}	Supply voltage
2	RT	Oscillator frequency set resistor
3	CPH	Preheating time set capacitor
4	GND	Ground
5	LO	Low−side output
6	V_S	High−side floating supply return
7	HO	High−side output
8	V_B	High−side floating supply

Table 2. ABSOLUTE MAXIMUM RATINGS T_A=25°C unless otherwise specified.

Symbol	Parameter		Min	Typ	Max	Unit
V_B	High−side floating supply		−0.3		625	V
V_S	High−side floating supply return		−0.3		600	V
V_{IN}	RT, CPH pins input voltage		−0.3		8	V
I_{CL}	Clamping current level				25	mA
dV_S/dt	Allowable offset voltage slew rate			50		V/s
T_A	Operating temperature range		−25		125	°C
T_{STG}	Storage temperature range		−65		150	°C
P_D	Power dissipation	8−SOP		0.625		W
		8−DIP		1.2		
θ_{JA}	Thermal resistance (junction−to−air)	8−SOP		200		°C/W
		8−DIP		100		

Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.

1. Do not supply a low−impedance voltage source to the internal clamping Zener diode between the GND and the V_{DD} pin of this device.

Table 3. ELECTRICAL CHARACTERISTICS V_{BIAS} (V_{DD}, V_{BS}) = 15.0V, T_A = 25°C, unless otherwise specified.

Symbol	Characteristics	Condition	Min	Typ	Max	Unit
SUPPLY VOLTAGE SECTION						
$V_{DDTH(ST+)}$	V_{DD} UVLO positive going threshold	V_{DD} increasing	12.4	13.4	14.4	V
$V_{DDTH(ST-)}$	V_{DD} UVLO negative going threshold	V_{DD} decreasing	10.8	11.6	12.4	
$V_{DDHY(ST)}$	V_{DD}−side UVLO hysteresis			1.8		
V_{CL}	Supply clamping voltage	I_{DD} = 10 mA	14.8	15.2		
I_{ST}	Start−up supply current	V_{DD} = 10 V		120	200	μA
I_{DD}	Dynamic operating supply current	50 kHz, C_L = 1 nF		3.2		mA
HIGH−SIDE SUPPLY SECTION (V_B−V_S)						
$V_{HSTH(ST+)}$	High−side UVLO positive going threshold	V_{BS} increasing	8.5	9.2	10.0	V
$V_{HSTH(ST-)}$	High−side UVLO negative going threshold	V_{BS} decreasing	7.9	8.6	9.5	
$V_{HSHY(ST)}$	High−side UVLO hysteresis			0.6		
I_{HST}	High−side quiescent supply current	V_{BS} = 14 V		50		μA
I_{HD}	High−side dynamic operating supply current	50 kHz, C_L = 1 nF		1		mA
I_{LK}	Offset supply leakage current	V_B = V_S = 600 V			45	μA
OSCILLATOR SECTION						
V_{MPH}	CPH pin preheating voltage range		2.5	3.0	3.5	V
I_{PH}	CPH pin charging current during preheating	V_{CPH} = 1 V	1.25	2.00	2.85	μA
I_{IG}	CPH pin charging current during ignition	V_{CPH} = 4 V	8	12	16	
V_{MO}	CPH pin voltage level at running mode			7.0		V
f_{PRE}	Preheating frequency	RT = 80 kΩ, V_{CPH} = 2 V	72	85	98	kHz
f_{OSC}	Running frequency	RT = 80 kΩ	48.7	53.0	57.3	kHz
DT_{MAX}	Maximum dead time	V_{CPH} = 1 V, V_S = GND during preheat mode		3.1		μs
DT_{MIN}	Minimum dead time	V_{CPH} = 6 V, V_S = GND during run mode		1.0		μs
OUTPUT SECTION						
I_{OH+}	High−side driver sourcing current	PW = 10 μs	250	350		mA
I_{OH-}	High−side driver sinking current	PW = 10 μs	500	650		
I_{OL+}	Low−side driver sourcing current	PW = 10 μs	250	350		
I_{OL-}	Low−side driver sink current	PW = 10 μs	500	650		
t_{HOR}	High−side driver turn−on rising time	C_L = 1 nF, V_{BS} = 15 V		45		ns
t_{HOL}	High−side driver turn−off rising time	C_L = 1 nF, V_{BS} = 15 V		25		
t_{LOR}	Low−side driver turn−on rising time	C_L = 1 nF, V_{BS} = 15 V		45		
t_{LOL}	Low−side driver turn−off rising time	C_L = 1 nF, V_{BS} = 15 V		25		
V_S (Note 2)	Maximum allowable negative V_S swing range for signal propagation to high−side output			−9.8		V
PROTECTION SECTION						
V_{CPHSD}	Shutdown voltage	V_{RT} = 0 after run mode	2.6			V
I_{SD}	Shutdown current			250		μA
TSD	Thermal shutdown (Note 2)			165		°C

2. This parameter, although guaranteed, is not 100% tested in production.

Typical Characteristics

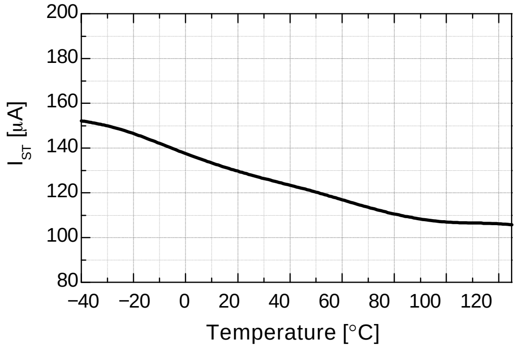


Figure 3. Start−Up Current vs. Temp.

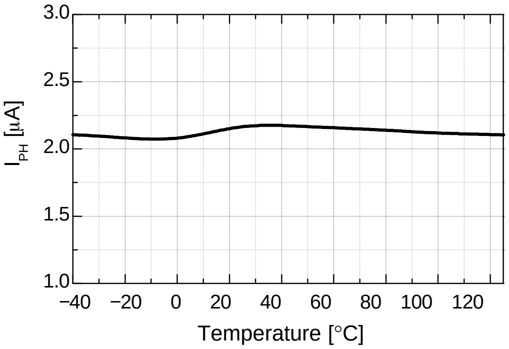


Figure 4. Preheating Current vs. Temp.

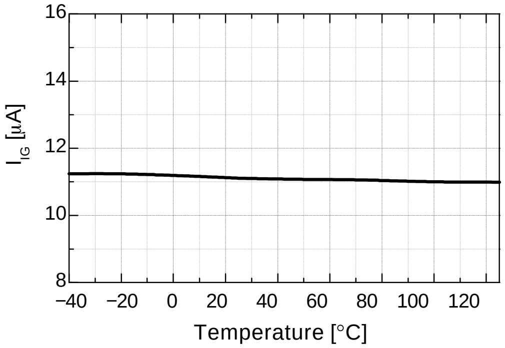


Figure 5. Ignition Current vs. Temp.

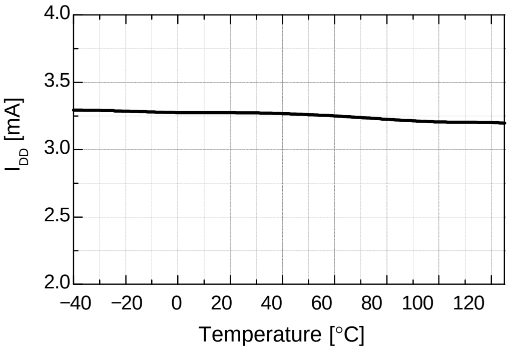


Figure 6. Operating Current vs. Temp.

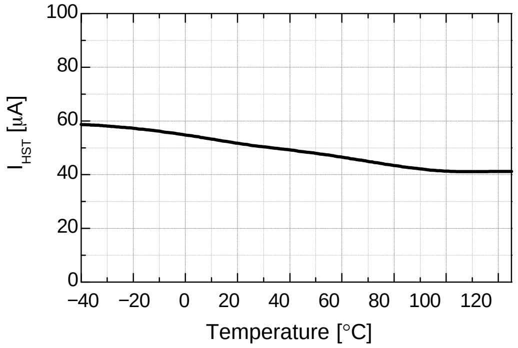


Figure 7. High−Side Quiescent Current vs. Temp.

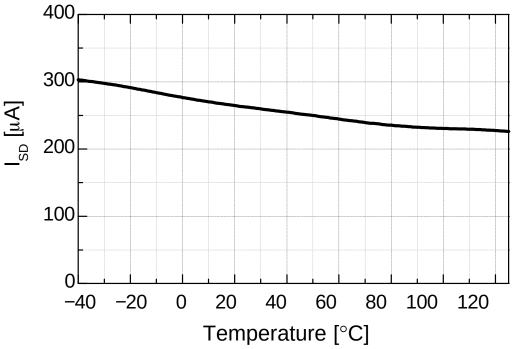


Figure 8. Shutdown Current vs. Temp.

Typical Characteristics

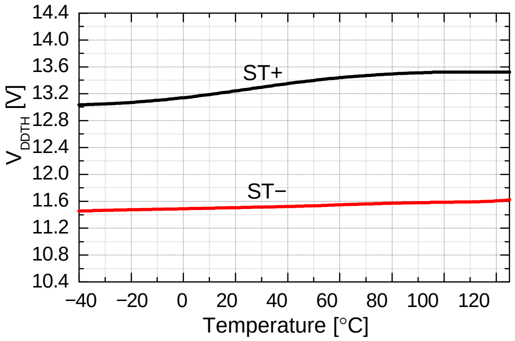


Figure 9. V_{DD} UVLO vs. Temp.

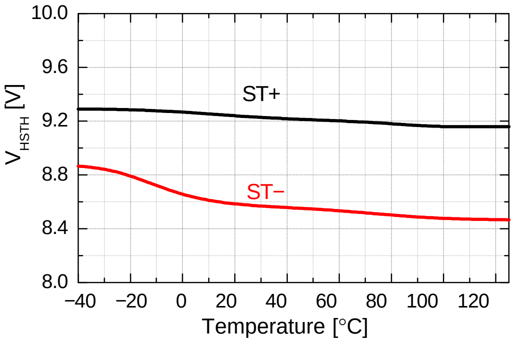


Figure 10. V_{BS} UVLO vs. Temp.

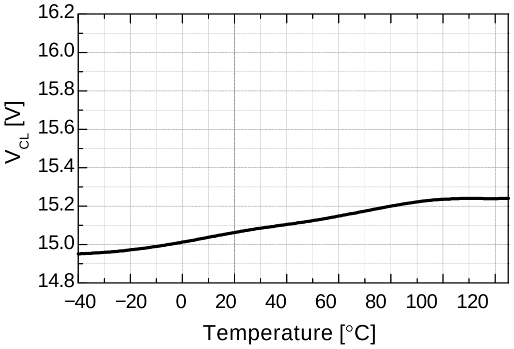


Figure 11. V_{DD} Clamp Voltage vs. Temp.

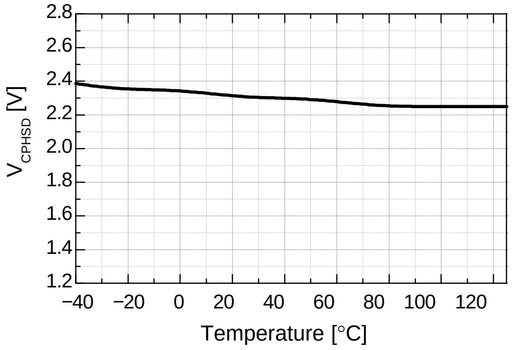


Figure 12. Shutdown Voltage vs. Temp.

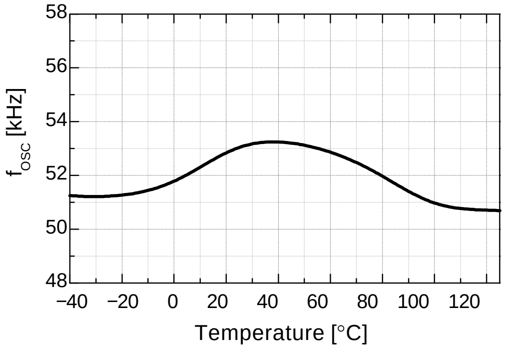


Figure 13. Running Frequency vs. Temp.

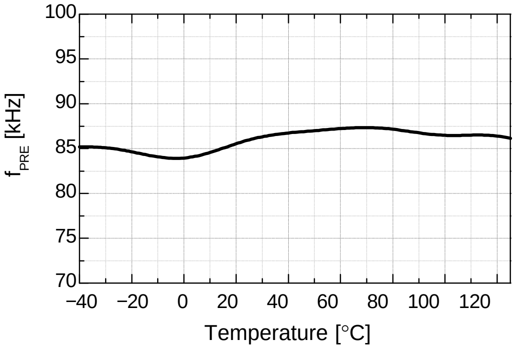


Figure 14. Preheating Frequency vs. Temp.

Typical Characteristics

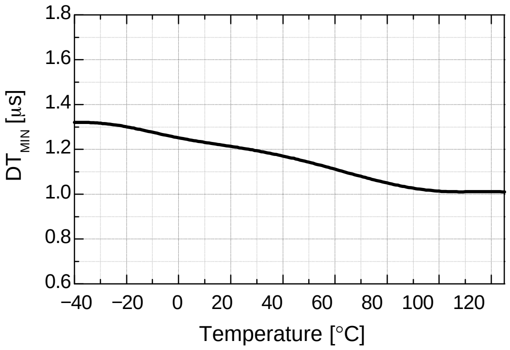


Figure 15. Minimum Dead Time vs. Temp.

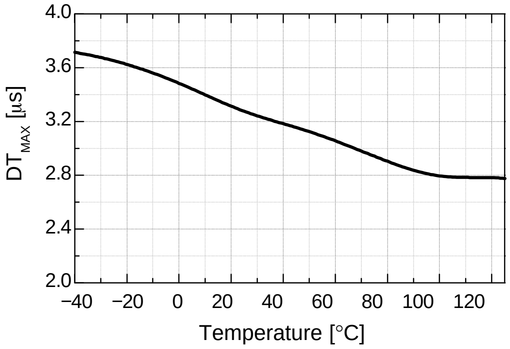


Figure 16. Maximum Dead Time vs. Temp.

Typical Application Information

Under−Voltage Lockout (UVLO) Function

The SMC321 has UVLO circuits for both high−side and low−side circuits. When V_{DD} reaches $V_{DDTH(ST+)}$, UVLO is released and the SMC321 operates normally. At UVLO condition, SMC321 consumes little current, noted I_{ST}. Once UVLO is released, SMC321 operates normally until V_{DD} goes below $V_{DDTH(ST-)}$, the UVLO hysteresis. At UVLO condition, all latches that determine the status of the IC are reset. When the IC is in the shutdown mode, the IC can restart by lowering V_{DD} voltage below $V_{DDTH(ST-)}$.

SMC321 has a high−side gate driver circuit. The supply for the high−side driver is applied between V_B and V_S. To protect the malfunction of the driver at low supply voltage, between V_B and V_S, SMC321 provides an additional UVLO circuit between the supply rails. If V_B−V_S is under $V_{HSTH(ST+)}$, the driver holds low−state to turn off the high−side switch, as shown in Figure 17. As long as V_B−V_S is higher than $V_{HSTH(ST-)}$ after V_B−V_S exceeds $V_{HSTH(ST+)}$, operation of the driver continues.

Oscillator

The ballast circuit for a fluorescent lamp is based on the LCC resonant tank and a half−bridge inverter circuit, as shown in Figure 17. To accomplish Zero−Voltage Switching (ZVS) of the half−bridge inverter circuit, the LCC is driven at a higher frequency than its resonant frequency, which is determined by L, C_S, C_P, and R_L, where R_L is the equivalent lamp’s impedance.

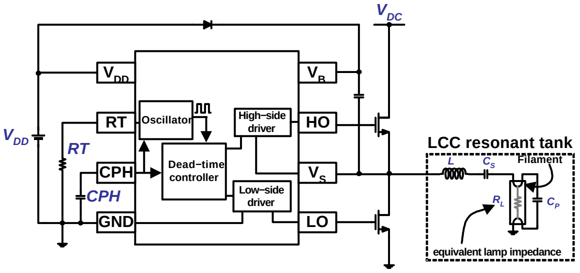


Figure 17. Resonant Inverter Circuit Based on LCC Resonant Tank

The transfer function of LCC resonant tank is heavily dependent on the lamp impedance, R_L, as illustrated in Figure 18. The oscillator in SMC321 generates effective driving frequencies to assist lamp ignition and improve lamp life longevity. Accordingly, the oscillation frequency is changed in the following sequence:

Preheating freq.−>Ignition freq.−> Normal running freq.

Before the lamp is ignited, the lamp impedance is very high. Once the lamp is turned on, the lamp impedance significantly decreases. Since the resonant peak is very high due to the high−resistance of the lamp at the instant of turning on the lamp, the lamp must be driven at higher frequency than the resonant frequency, shown as (A) in Figure 18. In this mode, the current supplied by the inverter mainly flows through C_P. C_P connects both filaments and makes the current path to ground. As a result, the current warms up the filament for easy ignition. The amount of the current can be adjusted by controlling the oscillation frequency or changing the capacitance of C_P. The driving frequency, f_{PRE}, is called preheating frequency and is derived by:

$$f_{PRE} = 1.6 \times f_{OSC} \qquad \text{(eq. 1)}$$

After the warm−up, the SMC321 decreases the frequency, shown as (B) of Figure 18. This action increases the voltage of the lamp and helps the fluorescent lamp ignite. The ignition frequency is described as a function of CPH voltage, as follows:

$$f_{IG} = \left[0.3 \times \left(5 - V_{CPH}\right) + 1\right] \times f_{OSC} \qquad \text{(eq. 2)}$$

where V_{CPH} is the voltage of CPH capacitor.

Equation 2 is valid only when V_{CPH} is between 3 V to 5 V before SMC321 enters running mode. Once V_{CPH} reaches 5 V, the internal latch records the exit from ignition mode. Unless V_{DD} is below $V_{DDTH(ST-)}$, the preheating and ignition modes appear only once during lamp start transition.

Finally, the lamp is driven at a fixed frequency by an external resistor, RT, shown as (C) of Figure 18. If V_{DD} is higher than $V_{DDTH(ST+)}$ and UVLO is released, the voltage of RT pin is regulated to 4 V. This voltage adjusts the oscillator’s control current according to the resistance of R_T. Because this current and an internal capacitor set the oscillation frequency, the SMC321 does not need any external capacitors.

The proposed oscillation characteristic is given by:

$$f_{OSC} = \frac{4 \times 10^9}{RT} \qquad \text{(eq. 3)}$$

Even in the active ZVS mode, shown as (D) in Figure 18, the oscillation frequency is not changed. The dead−time is varied according to the resonant tank characteristic.

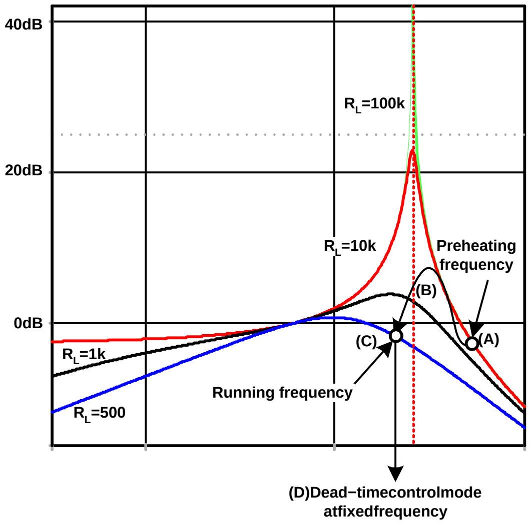


Figure 18. LCC Transfer Function in Terms of Lamp Impedance

Operation Modes

SMC321 has four operation modes: (A) preheating mode, (B) ignition mode, (C) active ZVS mode, and (D) shutdown mode, depicted in Figure 20. The modes are automatically selected by the voltage of CPH capacitor, shown in Figure 19. In modes (A) and (B), the CPH acts as a timer to determine the preheating and ignition times. After the preheating and ignition modes, the role of the CPH is changed to stabilize the active ZVS control circuit. In this mode, the dead time of the inverter is selected by the voltage of CPH. Only when SMC321 is in active ZVS mode is it possible to shut off the whole system using CPH pin. Pulling the CPH pin below 2 V in active ZVS mode, causes the SMC321 to enter shutdown mode. In shutdown mode, all active operation is stopped, except UVLO and some bias circuitry. The shutdown mode is triggered by the external CPH control or the active ZVS circuit. The active ZVS circuit automatically detects lamp removal (open−lamp condition) and decreases CPH voltage below 2 V to protect the inverter switches from damage.

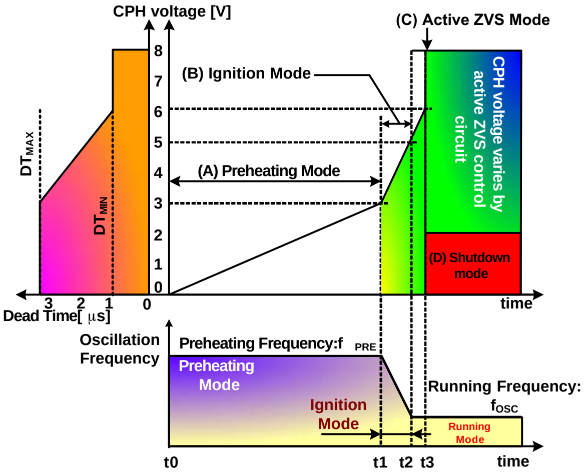


Figure 19. Operation Modes

Preheating Mode (t0~t1)

When V_{DD} exceeds $V_{DDTH(ST+)}$, the SMC321 starts operation. At this time, an internal current source (I_{PH}) charges CPH. CPH voltage increases from 0 V to 3 V in preheating mode. Accordingly, the oscillation frequency follows the Equation 4. In this mode, the lamp is not ignited, but warmed up for easy ignition. The preheating time depends on the size of CPH:

$$f_{preheat} = \frac{3 \times CPH}{I_{PH}} \qquad \text{(eq. 4)}$$

According to preheating process, the voltage across the lamp to ignite is reduced and the lifetime of the lamp is increased. In this mode, the dead time is fixed at its maximum value.

Ignition Mode (t1~t2)

When the CPH voltage exceeds 3 V, the internal current source to charge CPH is increased about six times larger than I_{PH}, noted as I_{IG}, causing rapid increase in CPH voltage. The internal oscillator decreases the oscillation frequency from f_{PRE} to f_{OSC} as CPH voltage increases. As depicted in Figure 20, lowering the frequency increases the voltage across the lamp. Finally, the lamp ignites. Ignition mode is defined when CPH voltage lies between 3 V and 5 V. Once CPH voltage reaches 5 V, the SMC321 does not return to ignition mode, even if the CPH voltage is in that range, until the SMC321 restarts from below $V_{DDTH(ST-)}$. Since the ignition mode continues when CPH is from 3 V to 5 V, the ignition time is given by:

$$t_{ignition} = \frac{2 \times CPH}{I_{IG}} \text{ [Sec.]} \qquad \text{(eq. 5)}$$

In this mode, dead time varies according to the CPH voltage.

Running and Active Zero−Voltage Switching (AZVS) Modes (t2~)

When CPH voltage exceeds 5 V, the operating frequency is fixed to f_{OSC} by RT. However, active ZVS operation is not activated until CPH reaches ~6 V. The SMC321 prepares for active ZVS operation from the instant CPH exceeds 5 V during t2 to t3. When CPH becomes higher than ~6 V at t3, the active ZVS operation is activated. To determine the switching condition, SMC321 detects the transition time of the output (V_S pin) of the inverter. From the output−transition information, SMC321 controls the dead time to meet the ZVS condition. If ZVS is satisfied, the SMC321 slightly increases the CPH voltage to reduce the dead time and to find optimal dead time, which increases the efficiency and decreases the thermal dissipation and EMI of the inverter switches. If ZVS fails, the SMC321 decreases CPH voltage to increase the dead time. CPH voltage is adjusted to meet optimal ZVS operation. During the active ZVS mode, the amount of the charging/discharging current is the same as I_{PH}. Figure 20 depicts normal operation waveforms.

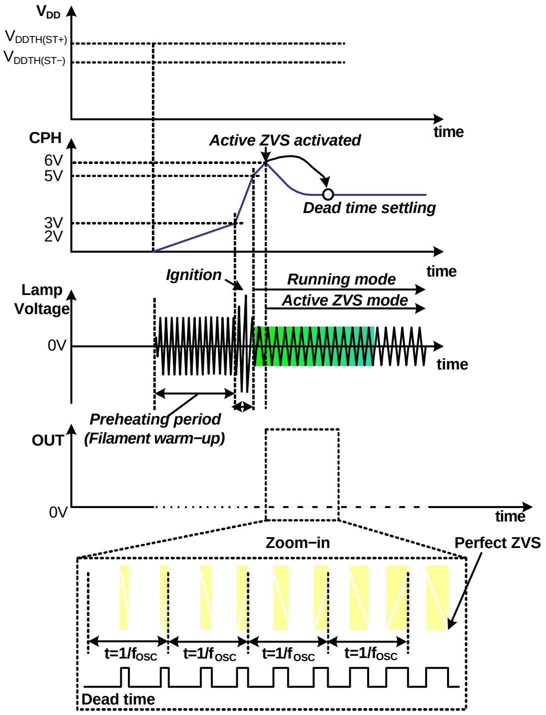


Figure 20. Typical Transient Waveform from Preheating to Active ZVS Mode

Shutdown Mode

If the voltage of capacitor CPH is decreased below ~2.6V by an external application circuit or internal protection circuit, the IC enters shutdown mode. Once the IC enters shutdown mode, this status continues until an internal latch is reset by decreasing V_{DD} below $V_{DDTH(ST-)}$. Figure 21 shows an example of external shutdown control circuit.

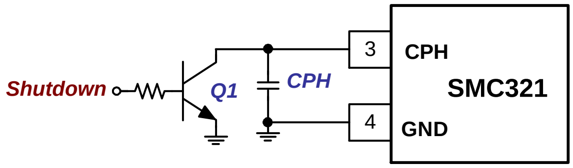


Figure 21. External Shutdown Circuit

The amount of the CPH charging current is the same as I_{PH}, making it possible to shut off the IC using small signal transistor. SMC321 provides active ZVS operation by controlling the dead time according to the voltage of CPH. If ZVS fails, even at the maximum dead time, SMC321 stops driving the inverter.

The SMC321 thermal shutdown circuit senses the junction temperature of the IC. If the temperature exceeds ~160°C, the thermal shutdown circuit stops operation of the SMC321.

The current usages of shutdown mode and under−voltage lockout status are different. In shutdown mode, some circuit blocks, such as bias circuits, are kept alive. Therefore, the current consumption is slightly higher than during under−voltage lockout.

Automatic Open−Lamp Detection

SMC321 can automatically detect the open−lamp condition. When the lamp is opened, the resonant tank fails to make a closed−loop to the ground, as shown in Figure 23. The supplied current from the V_S pin is used to charge and discharge the charge pump capacitor, C_P. Since the open−lamp condition means resonant tank absence, it is impossible to meet ZVS condition. In this condition, the power dissipation of the SMC321, due to capacitive load drive, is estimated as:

$$P_{Dissipation} = \frac{1}{2} \times C_P \times V_{DC}{}^2 \times f\,[W] \qquad \text{(eq. 6)}$$

where f is driving frequency and V_{DC} is DC−link voltage.

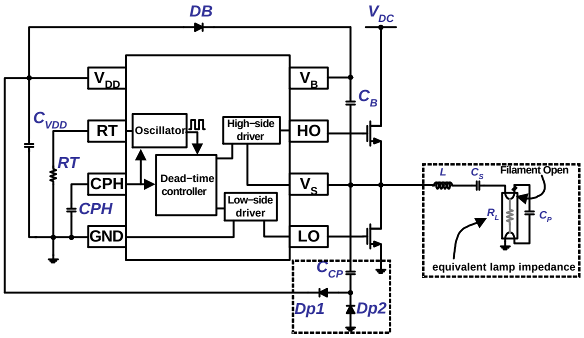


Figure 22. Current Flow When the Lamp is Open

Assuming that C_P, V_{DC}, and f are 1 nF, 311 V, and 50 kHz, respectively; the power dissipation reaches about 2.4 W and the temperature of SMC321 is increased rapidly. If no protection is provided, the IC can be damaged by the thermal attack. Note that hard−switching condition during the capacitive−load drive causes lots of EMI.

Figure 23 illustrates the waveforms during the open−lamp condition. In this condition, the charging and discharging current of C_P is directly determined by SMC321 and considered hard−switching condition. The SMC321 tries to meet ZVS condition by decreasing CPH voltage to increase dead time. If ZVS fails and CPH goes below 2 V, even though the dead time reaches its maximum value, SMC321 shuts off the IC to protect against damage. To restart SMC321, V_{DD} must be below $V_{DDTH(ST-)}$ to reset an internal latch circuit, which remembers the status of the IC.

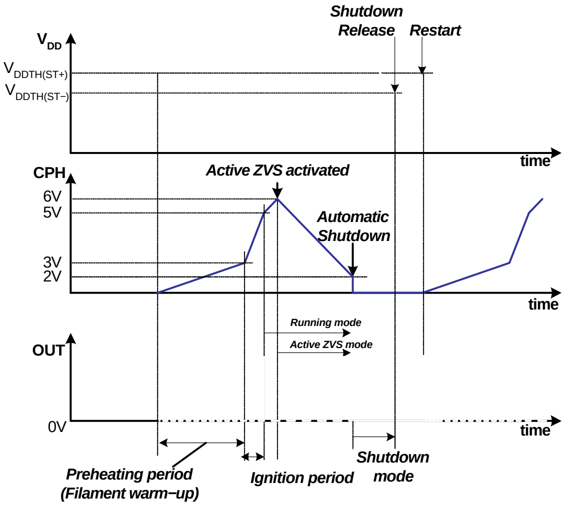


Figure 23. CPH Voltage Variation in Open−Lamp Condition

Power Supply

When V_{DD} is lower than $V_{DDTH(ST+)}$, it consumes very little current, I_{ST}, making it possible to supply current to the V_{DD} pin using a resistor with high resistance (R_{start} in Figure 24). Once UVLO is released, the current consumption is increased and whole circuits are operated, which requires additional power supply for stable operation. The supply must deliver at least several mA. A charge pump circuit is a cost−effective method to create an additional power supply and allows C_P to be used to reduce the EMI.

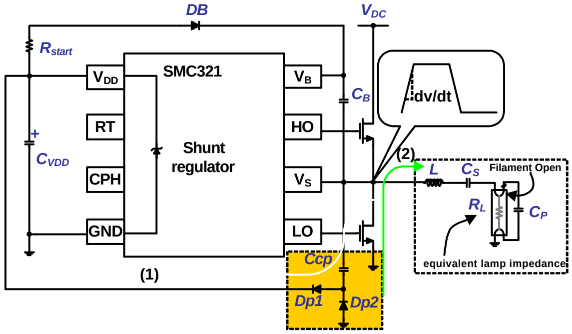


Figure 24. Local Power Supply for V_{DD} Using a Charge Pump Circuit

As presented in Figure 24, when V_S is high, the inductor current and C_{CP} create an output transition with the slope of dv/dt. The rising edge of V_S charges C_{CP}. At that time, the current that flows through C_{CP} is:

$$I \cong C_{CP} \times \frac{dv}{dt} \qquad \text{(eq. 7)}$$

This current flows along the path (1). It charges C_{VDD}, which is a bypass capacitor to reduce the noise on the supply rail. If C_{VDD} is charged over the threshold voltage of the internal shunt regulator, the shunt regulator is turned on and regulates V_{DD} with the trigger voltage.

When V_S is changing from high to low state, C_{CP} is discharged through Dp2, shown as path (2) in Figure 25. These charging/discharging operations are continued until SMC321 is halted by shutdown operation. The charging current, I, must be large enough to supply the operating current of SMC321.

The supply for the high−side gate driver is provided by the boot−strap technique, as illustrated in Figure 25. When the low−side MOSFET connected between V_S and GND pins is turned on, the charging current for V_B flows through D_B. Every low V_S gives the chance to charge the C_B. Therefore C_B voltage builds up only when SMC321 operates normally.

When V_S goes high, the diode D_B is reverse−biased and C_B supplies the current to the high−side driver. At this time, since C_B discharges, V_B−V_S voltage decreases. If V_B−V_S goes below $V_{HSTH(ST-)}$, the high−side driver cannot operate due to the high−side UVLO protection circuit. C_B must be chosen to be large enough not to fall into UVLO range due to the discharge during a half of the oscillation period, especially when the high−side MOSFET is turned on.

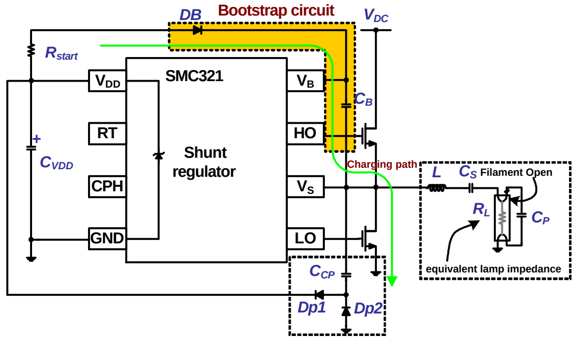


Figure 25. Implementation of Floating Power Supply Using the Bootstrap Method

Design Guide

Start−up Circuit

The start−up current (I_{ST}) is supplied to the IC through the start−up resistor, R_{start}. Once operation starts, the power is supplied by the charge pump circuit. To reduce the power dissipation in R_{start}, select R_{start} as high as possible, considering the current requirements at start−up. For 220 V_{AC} power, the rectified voltage by the full−wave rectifier makes DC voltage, as shown in Equation 8. The voltage contains lots of AC component due to poor regulation characteristic of the simple full−wave rectifier:

$$V_{DC} = \sqrt{2} \times 220[V] \cong 311[V] \qquad \text{(eq. 8)}$$

Considering the selected parameters, R_{start} must satisfy the following equation:

$$\frac{V_{DC} - V_{DDTH(ST+)}}{R_{start}} > I_{ST} \qquad \text{(eq. 9)}$$

From Equation 9, R_{start} is selected as:

$$\frac{V_{DC} - V_{DDTH(ST+)}}{I_{ST}} > R_{start} \qquad \text{(eq. 10)}$$

Note that if choosing the maximum R_{start}, it takes long time for V_{DD} to reach $V_{DDTH(st+)}$. Considering V_{DD} rising time, R_{start} must be selected as shown in Figure 29.

Another important concern for choosing R_{start} is the available power rating of R_{start}. To use a commercially available, low−cost 1/4 Ω resistor, R_{start} must obey the following rule:

$$\frac{\left(V_{DC} - V_{CL}\right)^2}{R_{start}} < \frac{1}{4}\,[W] \qquad \text{(eq. 11)}$$

Assuming V_{DC} = 311 V and V_{CL} = 15 V, the minimum resistance of R_{start} is about 350 kΩ.

When the IC operates in shutdown mode due to thermal protection, open−lamp protection, or hard−switching protection, the IC consumes shutdown current, I_{SD}, which is larger than I_{ST}. To prevent restart during this mode, R_{start} must be selected to cover I_{SD} current consumption. The following equation must be satisfied:

$$\frac{V_{DC} - V_{DDTH(ST+)}}{I_{SD}} > R_{start} \qquad \text{(eq. 12)}$$

From Equations 10 − 12; it is possible to select R_{start}:

1. For safe start−up without restart in shutdown mode:

$$4\left(V_{DC} - V_{CL}\right)^2 < R_{start} < \frac{V_{DC} - V_{DDTH(ST+)}}{I_{SD}} \qquad \text{(eq. 13)}$$

2. For safe start−up with restart from shutdown mode:

$$\frac{V_{DC} - V_{DDTH(ST+)}}{I_{SD}} < R_{start} < \frac{V_{DC} - V_{DDTH(ST+)}}{I_{ST}} \qquad \text{(eq. 14)}$$

If R_{start} meets Equation 14, restart operation is possible. However, it is not recommended to choose R_{start} at that range because V_{DD} rising time could be long and it increases the lamp’s turn−on delay time, as depicted in Figure 26.

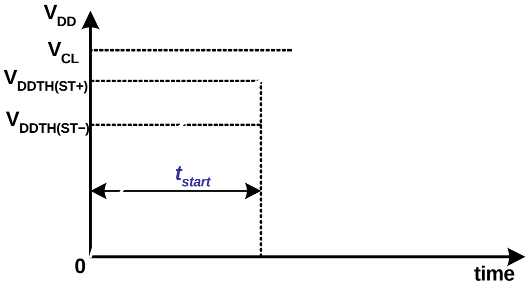


Figure 26. V_{DD} Build−up

Figure 27 shows the equivalent circuit for estimating t_{start}. From the circuit analysis, V_{DD} variation versus time is given by:

$$V_{DD}(t) = \left(V_{DC} - R_{start} \cdot I_{ST}\right)\left(1 - e^{-t/(R_{start} \cdot C_{VDD})}\right) \qquad \text{(eq. 15)}$$

where C_{VDD} is the total capacitance of the bypass capacitors connected between V_{DD} and GND.

From Equation 15, it is possible to calculate t_{start} by substituting $V_{DD(t)}$ with $V_{DDTH(ST+)}$:

$$t_{start} = -R_{start} \cdot C_{VDD} \cdot \ln \frac{V_{DC} - R_{start} \cdot I_{ST} - V_{DDTH(ST+)}}{V_{DD} - R_{start} \cdot I_{ST}} \qquad \text{(eq. 16)}$$

In general, Equation 16 can be simplified as:

$$t_{start} \approx \frac{R_{start} \cdot C_{VDD} \cdot V_{DDTH(ST+)}}{V_{DC} - R_{start} \cdot I_{ST} - V_{DDTH(ST+)}} \qquad \text{(eq. 17)}$$

Accordingly, t_{start} can be controlled by adjusting the value of R_{start} and C_{VDD}. For example, if V_{DC} = 311 V, R_{start} = 560 k, C_{VDD} = 10 mF, I_{st} = 120 mA, and $V_{DDTH(ST+)}$ = 13.5 V, t_{start} is about 0.33 s.

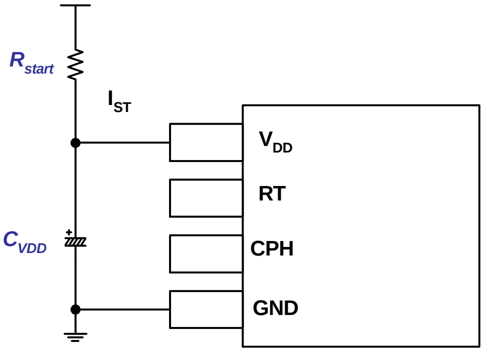


Figure 27. Equivalent Circuit During Start

Current Supplied by Charge Pump

For the IC supply, the charge pump method is used in Figure 28. Since C_{CP} is connected to the half−bridge output, the supplied current by C_{CP} to the IC is determined by the output voltage of the half−bridge.

When the half−bridge output shows rising slope, C_{CP} is charged and the charging current is supplied to the IC. The current can be estimated as:

$$I = C_{CP}\frac{dV}{dt} \approx C_{CP}\frac{V_{DC}}{DT} \qquad \text{(eq. 18)}$$

where DT is the dead time and dV/dt is the voltage variation of the half−bridge output.

When the half−bridge shows falling slope, C_{CP} is discharged through Dp2. Total supplied current, I_{total}, to the IC during switching period, t, is:

$$I_{total} = I \cdot DT = C_{CP} \cdot V_{DC} \qquad \text{(eq. 19)}$$

From Equation 19, the average current, I_{avg}, supplied to the IC is obtained by:

$$I_{avg} = \frac{I_{total}}{t} = \frac{C_{CP} \cdot V_{DC}}{t} = C_{CP} \cdot V_{DC} \cdot f \qquad \text{(eq. 20)}$$

For the stable operation, I_{avg} must be higher than the required current. If I_{avg} exceeds the required current, the residual current flows through the shunt regulator implemented on the chip, which can cause unwanted heat generation. Therefore, C_{CP} must be selected considering stable operation and thermal generation.

For example, if $C_{CP} = 0.5$ nF, $V_{DC} = 311$ V, and f = 50 kHz, I_{avg} is ~7.8 mA; it is enough current for stable operation.

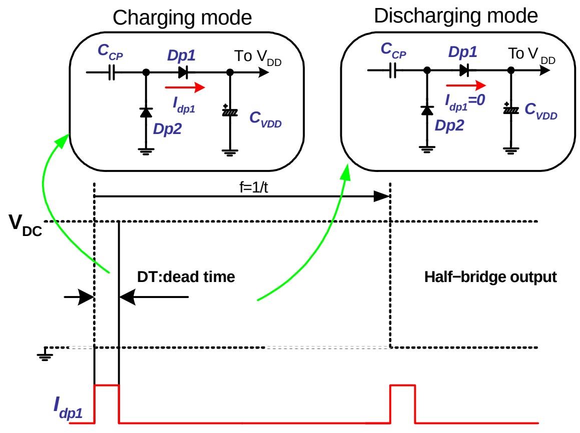


Figure 28. Charge Pump Operation

Lamp Turn−on Time

The turn−on time of the lamp is determined by supply build−up time t_{start}, preheating time, and ignition time; where t_{start} has been obtained by Equation 17. When the IC's supply voltage exceeds $V_{DDTH(ST+)}$ after turn−on or restart, the IC operates in preheating mode. This operation continues until CPH pin's voltage reaches ~3 V. In this mode, CPH capacitor is charged by I_{PH} current, as depicted in Figure 29. The preheating time is achieved by calculating:

$$t_{preheat} = 3\frac{CPH}{I_{PH}} \qquad \text{(eq. 21)}$$

The preheating time is related to lamp life (especially filament); therefore, the characteristics of a given lamp should be considered when choosing the time.

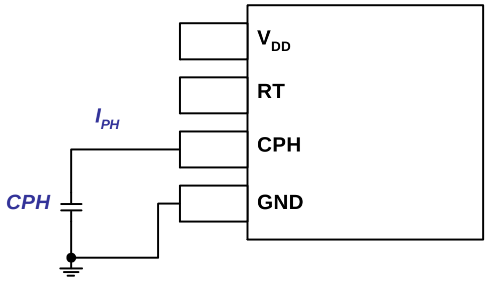


Figure 29. Preheating Timer

Compared to the preheating time, it is almost impossible to exactly predict the ignition time, whose definition is the time from the end of the preheating time to ignition. In general, the lamp ignites during the ignition mode. Therefore, assume that the maximum ignition time is the same as the duration of ignition mode, from 3 V until CPH reaches 5 V. Thus, ignition time can be defined as

$$t_{ignition} = (5 - 3)\frac{CPH}{I_{IG}} = 2\frac{CPH}{I_{IG}} \qquad \text{(eq. 22)}$$

Note that, at ignition mode, CPH is charged by I_{IG}, which is six times larger than I_{PH}. Consequently, total turn−on time is approximately:

VDD Build−Time + Preheating Time + Ignition Time =

$$t_{ignition} = (5 - 3)\frac{CPH}{I_{IG}} = 2\frac{CPH}{I_{IG}}[\text{Sec.}] \qquad \text{(eq. 23)}$$

PCB Guide line

Component selection and placement on the PCB is very important when using power control ICs. Bypass the V_{CC} to GND as close to the IC terminals as possible with a low−ESR/ESL capacitor, as shown in Figure 30. This bypassed capacitor (Cbp) can reduce the noise from the power supply parts, such as start−up resistor and charge pump.

The signal GND must be separated from the power GND. So, the signal GND should be directly connected to the rectify capacitor using an individual PCB trace. In addition, the ground return path of the timing components (CPH, RT) and V_{DD} decoupling capacitor should be connected directly to the IC GND lead and not via separate traces or jumpers to other ground traces on the board. These connection techniques prevent high−current ground loops from interfering with sensitive timing component operations and allow the entire control circuit to reduce common−mode noise due to output switching.

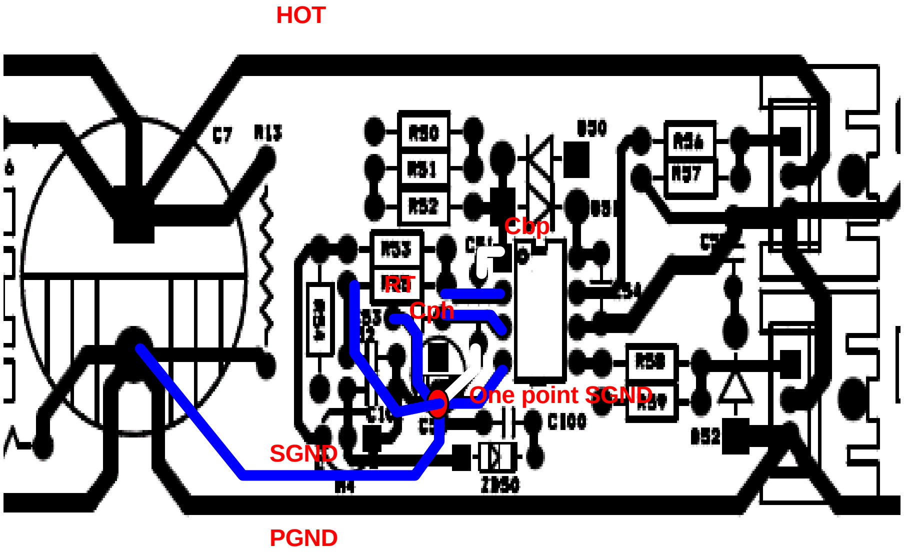


Figure 30. Preheating Timer

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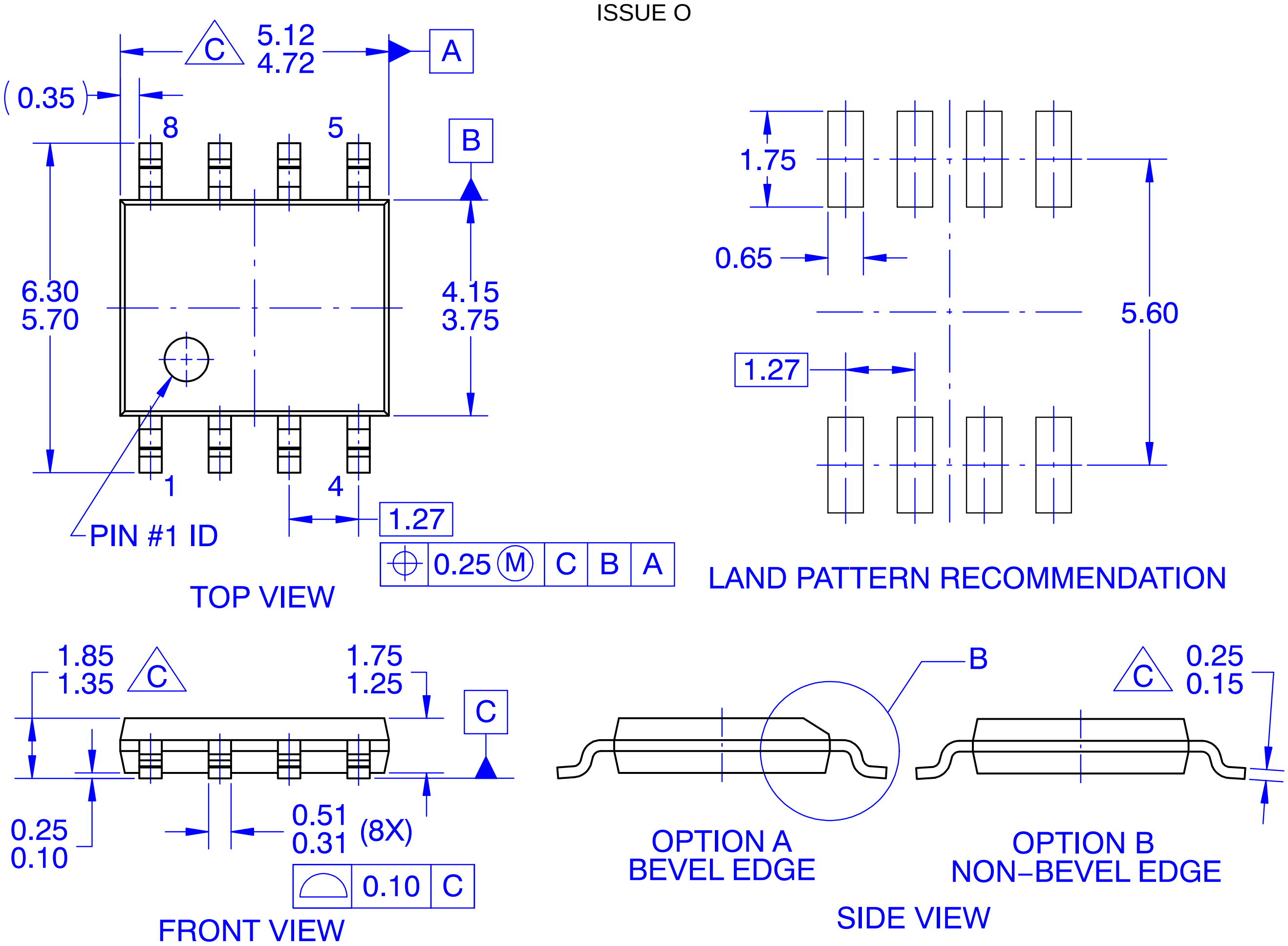

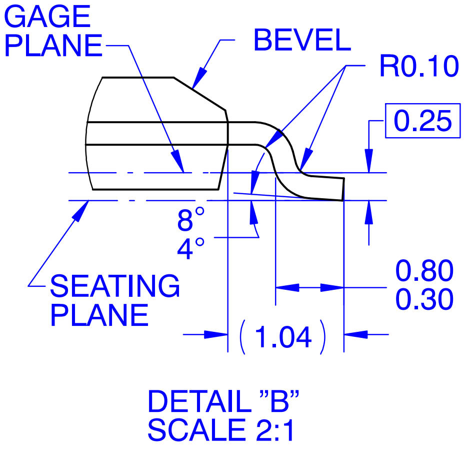

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