June 2007

FAN7710
Ballast Control IC for Compact Fluorescent Lamps

Features

- Integrated Half-Bridge MOSFET
- Floating Channel for Bootstrap Operation up to +550V
- Low Start-up and Operating Current: 120µA, 2.6mA
- Under-Voltage Lockout with 1.8V of Hysteresis
- Adjustable Run Frequency and Preheat Time
- Internal Active ZVS Control
- Internal Protection Function (No Lamp)
- Internal Clamping Zener Diode
- High Accuracy Oscillator
- Soft-Start Functionality

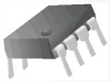
Applications

- Compact Fluorescent Lamp Ballast

Description

The FAN7710, developed using Fairchild's unique high-voltage process and system-in-package (SiP) concept, is a ballast control integrated circuit (IC) for a compact fluorescent lamp (CFL). The FAN7710 controls internal high-voltage stress and delivers 20W to the lamp at $310V_{DC}$ voltage. FAN7710 incorporates a preheating / ignition function, controlled by an user-selected external capacitor, to increase lamp life. The FAN7710 detects switch operation from after ignition-mode through an internal active Zero-Voltage Switching (ZVS) control circuit. This control scheme enables the FAN7710 to detect an open-lamp condition, without the expense of external circuitry, and prevents stress on MOSFETs. The high-side driver built into the FAN7710 has a common-mode noise cancellation circuit that provides robust operation against high-dv/dt noise intrusion.

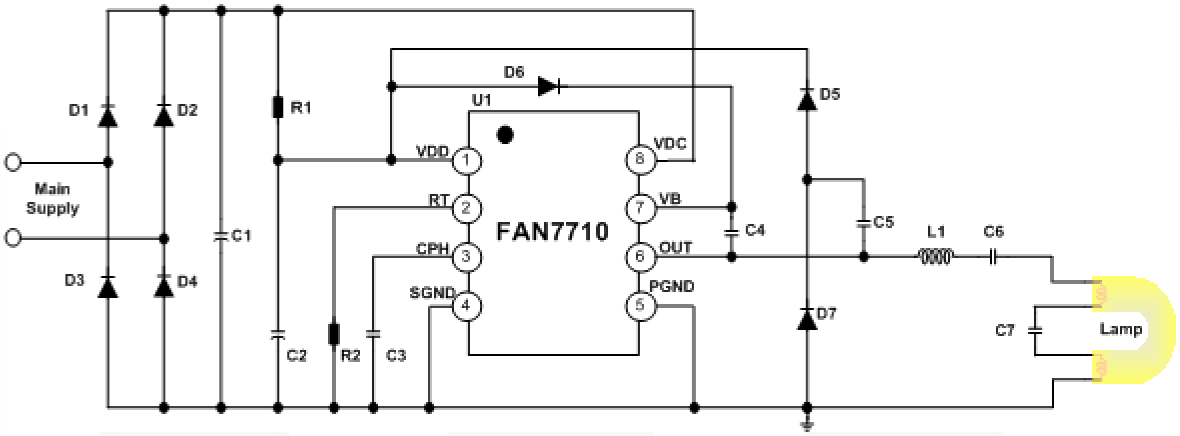
8-DIP



Ordering Information

Part Number	Package	Pb-Free	Operating Temperature Range	Packing Method
FAN7710N	8-DIP	Yes	-25°C ~ 125°C	Tube

Typical Application Diagrams



* Refer to the BOM and design guide provided on page16.

Figure 1. Typical Application Circuit for Compact Fluorescent Lamp

Internal Block Diagram

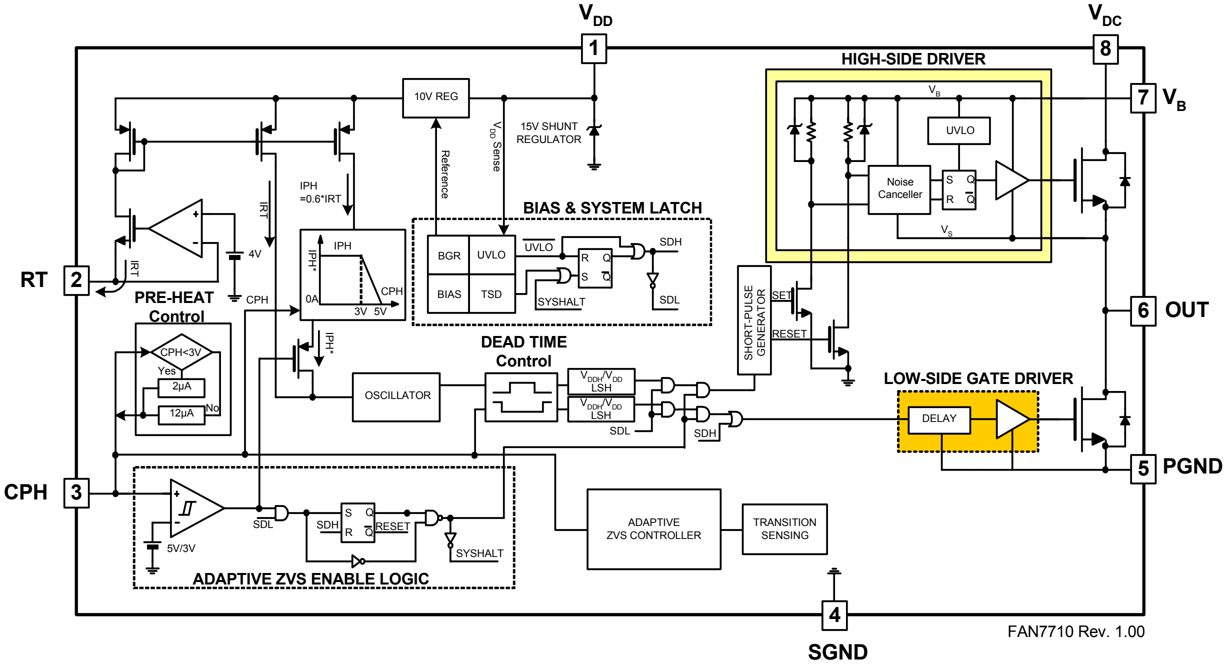


Figure 2. Functional Block Diagram

Pin Configuration

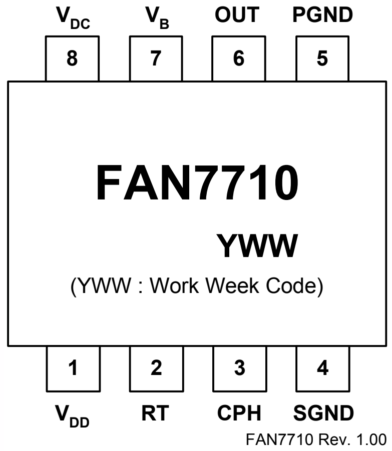


Figure 3. Pin Configuration (Top View)

Pin Definitions

Pin #	Name	Description
1	V_{DD}	Supply voltage
2	RT	Oscillator frequency set resistor
3	CPH	Preheating time set capacitor
4	SGND	Signal ground
5	PGND	Power ground
6	OUT	High-side floating supply return
7	V_B	High-side floating supply
8	V_{DC}	High-voltage supply

Absolute Maximum Ratings

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only. T_A=25°C unless otherwise specified.

Symbol	Parameter	Min.	Typ.	Max.	Unit
V_B	High-side floating supply	-0.3		575	V
V_{OUT}	High-side floating supply return	-0.3		550	V
V_{IN}	RT, CPH pins input voltage	-0.3		8	V
I_{CL}	Clamping current level			25	mA
dV_{OUT}/dt	Allowable offset voltage slew rate		50		V/ns
T_A	Operating temperature range	-25		125	°C
T_{STG}	Storage temperature range	-65		150	°C
P_D	Power dissipation		2.1		W
θ_{JA}	Thermal resistance (junction-to-air)		70		°C/W

Note:

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.

Electrical Characteristics

V_{BIAS} (V_{DD}, V_B -V_{out}) = 14.0V, T_A = 25°C, unless otherwise specified.

Symbol	Parameter	Condition	Min.	Typ.	Max.	Unit
High-Voltage Supply Section						
V_{DC}	High-voltage supply voltage		550			V
Low-Side Supply Section (V_{DD})						
$V_{DDTH(ST+)}$	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} =20mA	14.8	15.2		
I_{ST}	Start-up supply current	V_{DD} = 10V		120		µA
I_{DD}	Dynamic operating supply current	Running freq,C_L = 1nF		2.6		mA
High-Side Supply Section (V_B-V_{OUT})						
$V_{HSTH(ST+)}$	High-side UVLO positive going threshold	V_B -V_{OUT} increasing	8.5	9.2	10.0	V
$V_{HSTH(ST-)}$	High-side UVLO negative going threshold	V_B -V_{OUT} decreasing	7.9	8.6	9.5	
$V_{HSHY(ST)}$	High-side UVLO hysteresis			0.6		
I_{HST}	High-side quiescent supply current	V_B -V_{OUT} = 14V		50		µA
I_{HD}	High-side dynamic operating supply current	Running freq,C_L = 1nF		250		
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} = 1V	1.25	2.00	2.85	µA
I_{IG}	CPH pin charging current during ignition	V_{CPH} = 4V	8	12	16	
V_{MO}	CPH pin voltage level at running mode			7.0		V
f_{PRE}	Preheating frequency	RT = 80kΩ, V_{CPH} = 2V	72	85	98	kHz
f_{OSC}	Running frequency	RT = 80kΩ	48.7	53.0	57.3	kHz
DT_{MAX}	Maximum dead time	V_{CPH} = 1V, V_{OUT} = GND during preheat mode		3.1		µs
DT_{MIN}	Minimum dead time	V_{CPH} = 6V, V_{OUT}= GND during run mode		1.0		µs
Protection Section						
V_{CPHSD}	Shutdown voltage	V_{RT} = 0 after run mode	2.6			V
I_{SD}	Shutdown current			250	450	µA
TSD	Thermal shutdown$^{(2)}$			165		°C
MOSFET Section						
I_{LKMOS}	MOSFET leakage current	V_{DS} = 500V			10	µA
R_{ON}	On resistance (dynamic)	V_{GS} = 12V, I_D = 100mA		6.2		Ω
		V_{GS} = 12V, I_D = 500mA		6.5		
I_{SAT}	Saturation current$^{(2)}$	V_{GS} = 12V, V_{DS} = 30V	800			mA

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

Typical Characteristics

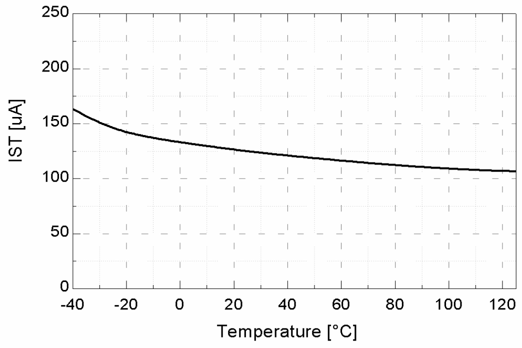


Figure 4. Start-up Current vs. Temp.

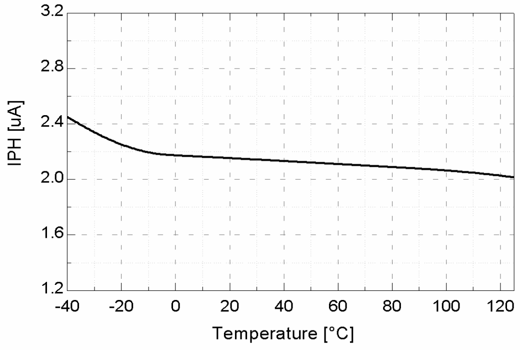


Figure 5. Preheating Current vs. Temp.

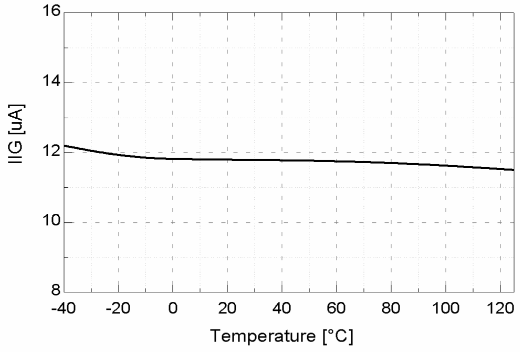


Figure 6. Ignition Current vs. Temp.

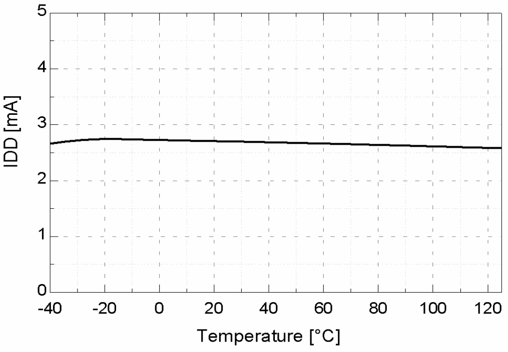


Figure 7. Operating Current vs. Temp.

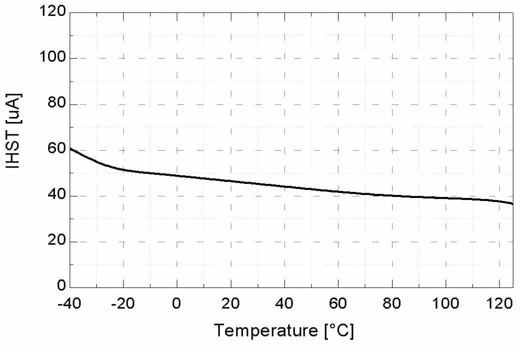


Figure 8. High-Side Quiescent Current vs. Temp.

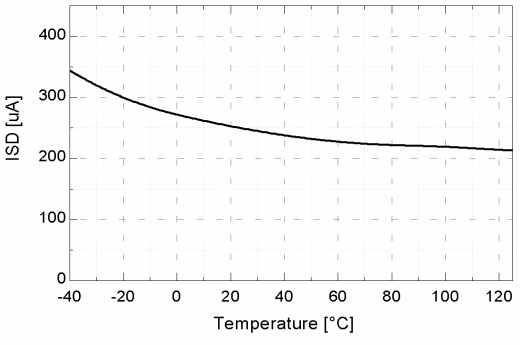


Figure 9. Shutdown Current vs. Temp.

Typical Characteristics (Continued)

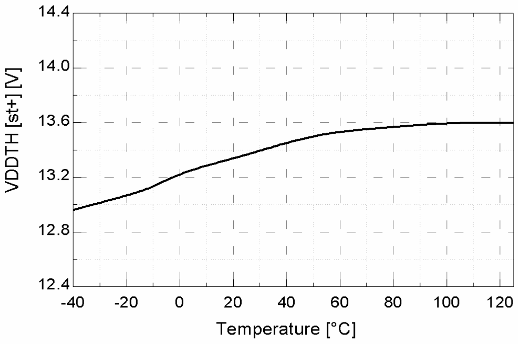


Figure 10. V_{DD} UVLO+ vs. Temp.

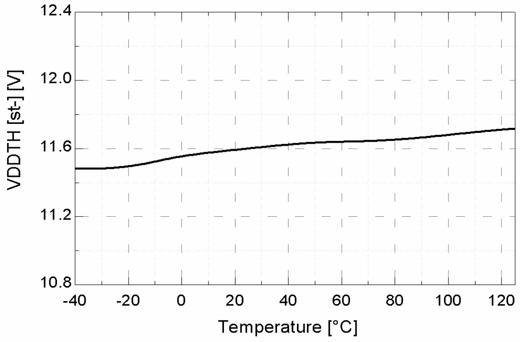


Figure 11. V_{DD} UVLO- vs. Temp.

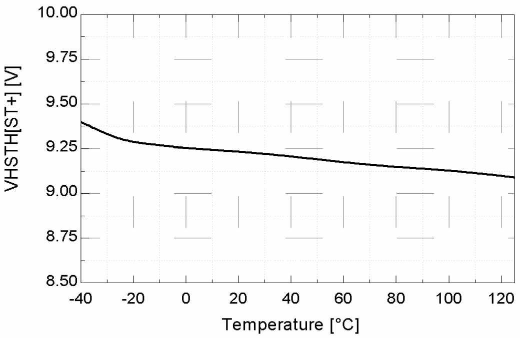


Figure 12. V_{HS} UVLO+ vs. Temp.

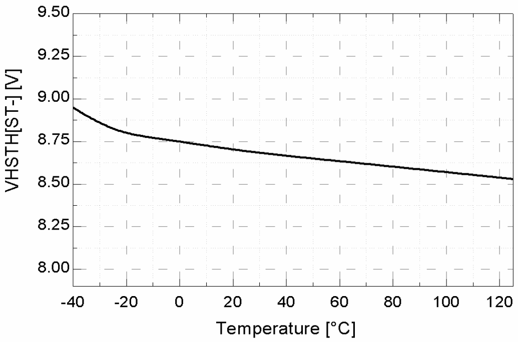


Figure 13. V_{HS} UVLO- vs. Temp.

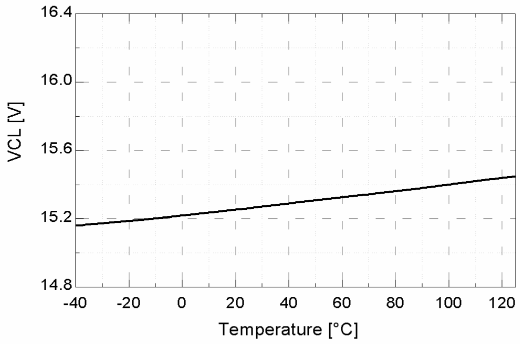


Figure 14. V_{DD} Clamp Voltage vs. Temp.

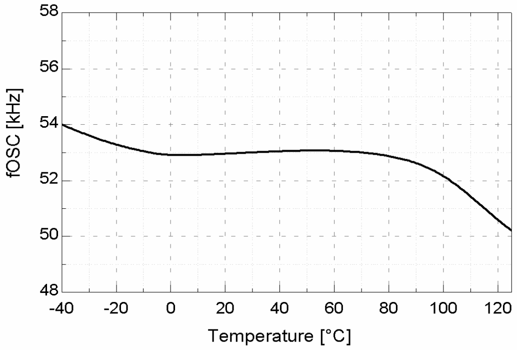


Figure 15. Running Frequency vs. Temp.

Typical Characteristics (Continued)

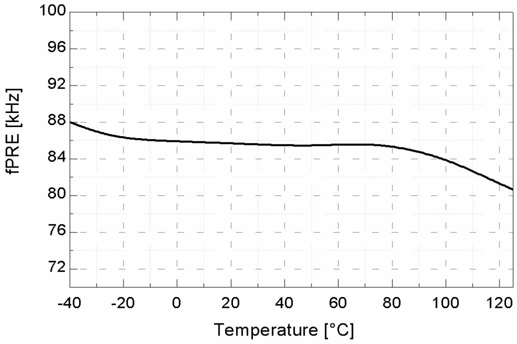


Figure 16. Preheating Frequency vs. Temp.

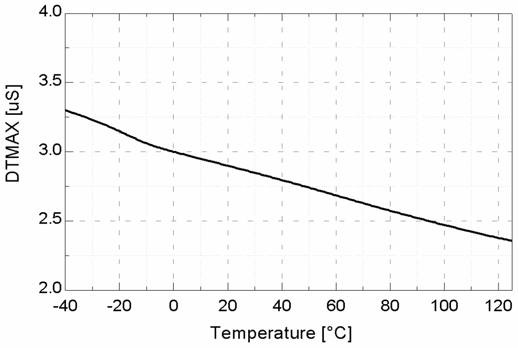


Figure 17. Maximum Dead Time vs. Temp.

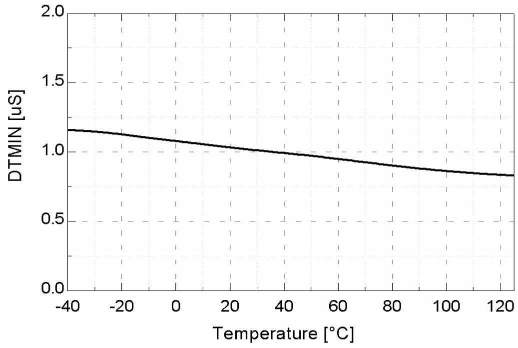


Figure 18. Minimum Dead Time vs. Temp.

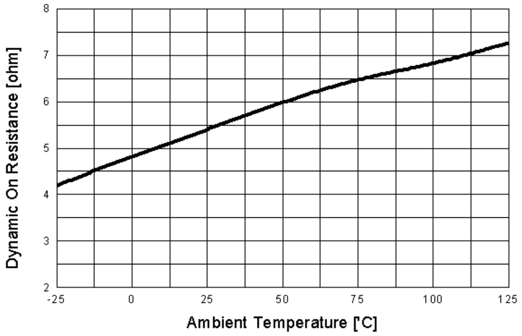


Figure 19. Internal MOSFET Turn-on Resistance vs. Temp.

Typical Application Information

1. Under-Voltage Lockout (UVLO) Function

The FAN7710 has UVLO circuits for both high-side and low-side circuits. When V_{DD} reaches $V_{DDTH(ST+)}$, UVLO is released and the FAN7710 operates normally. At UVLO condition, FAN7710 consumes little current, noted as I_{ST}. Once UVLO is released, FAN7710 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 $V_{DDTH(ST-)}$.

FAN7710 has a high-side gate driver circuit. The supply for the high-side driver is applied between V_B and V_{OUT}. To protect from malfunction of the driver at low supply voltage between V_B and V_{OUT}, FAN7710 provides an additional UVLO circuit between the supply rails. If V_B-V_{OUT} is under $V_{HSTH(ST+)}$, the driver holds low state to turn off the high-side switch, as shown in Figure 20. As long as V_B-V_{OUT} is higher than $V_{HSTH(ST-)}$ after V_B-V_{OUT} exceeds $V_{HSTH(ST+)}$, operation of the driver continues.

2. 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 20. 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.

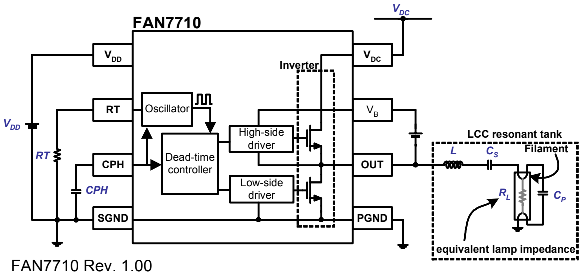


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Figure 20. Resonant Inverter Circuit Based on LCC Resonant Tank

The transfer function of LCC resonant tank is heavily dependent on the lamp impedance, R_L, as illustrated in Figure 20. The oscillator in FAN7710 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 21. 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 FAN7710 decreases the frequency, shown as (B) of Figure 21. 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 3V and 5V before FAN7710 enters running mode. Once V_{CPH} reaches 5V, 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, R_T, shown as (C) in Figure 21. If V_{DD} is higher than $V_{DDTH(ST+)}$ and UVLO is released, the voltage of the RT pin is regulated to 4V. 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 FAN7710 does not need any external capacitors.

The proposed oscillation characteristic is given by:

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

The oscillation frequency is not changed even in the active ZVS mode, shown as (D) in Figure 21. The dead time is varied according to resonant tank characteristics.

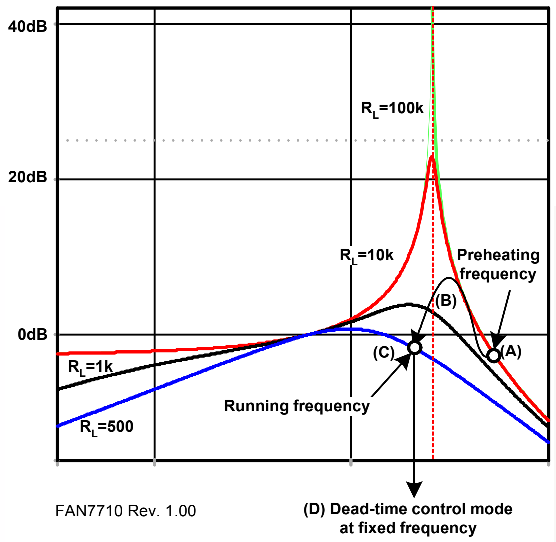

Figure 21. LCC Transfer Function in Terms of Lamp Impedance

3. Operation Modes

FAN7710 has four operation modes: (A) preheating mode, (B) ignition mode, (C) active ZVS mode, and (D) shutdown mode, depicted in Figure 22. The modes are automatically selected by the voltage of CPH capacitor shown in Figure 20. In modes (A) and (B), the CPH acts as a timer to determine the preheating and ignition times. After 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 FAN7710 is in active ZVS mode, is it possible to shut off the whole system using the CPH pin. Pulling the CPH pin below 2.6V in active ZVS mode causes the FAN7710 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 2.6V to protect the inverter switches from damage.

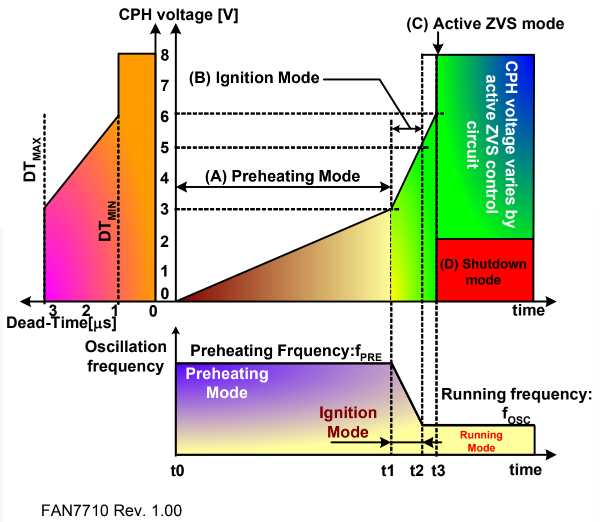

Figure 22. Operation Modes

3.1 Preheating Mode (t0~t1)

When V_{DD} exceeds $V_{DDTH(ST+)}$, the FAN7710 starts operation. At this time, an internal current source (I_{PH}) charges CPH. CPH voltage increases from 0V to 3V in preheating mode. Accordingly, the oscillation frequency follows 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:

$$f_{preheat} = \frac{3 \times CPH}{I_{PH}} \quad [Sec.] \qquad \text{(EQ 4)}$$

According to the 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.

3.2 Ignition Mode (t1~t2)

When the CPH voltage exceeds 3V, 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. Lowering the frequency increases the voltage across the lamp, as depicted in Figure 22. Finally, the lamp ignites. Ignition mode is defined when CPH voltage lies between 3V and 5V. Once CPH voltage reaches 5V, the FAN7710 does not return to ignition mode, even if the CPH voltage is in that range, until the FAN7710 restarts from below $V_{DDTH(ST-)}$. Since the ignition mode continues when CPH is from 3V to 5V, the ignition time is given by:

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

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

3.3 Running Mode and Active Zero-Voltage Switching (AZVS) Mode (t2~)

When CPH voltage exceeds 5V, the operating frequency is fixed to f_{OSC} by RT. However, active ZVS operation is not activated until CPH reaches ~6V. The FAN7710 prepares for active ZVS operation from the instant CPH exceeds 5V during t2 to t3. When CPH becomes higher than ~6V at t3, the active ZVS operation is activated. To determine the switching condition, FAN7710 detects the transition time of the output (V_{OUT} pin) of the inverter by using the VB pin. From the output-transition information, FAN7710 controls the dead time to meet the ZVS condition. If ZVS is satisfied, the FAN7710 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 FAN7710 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 23 depicts normal operation waveforms.

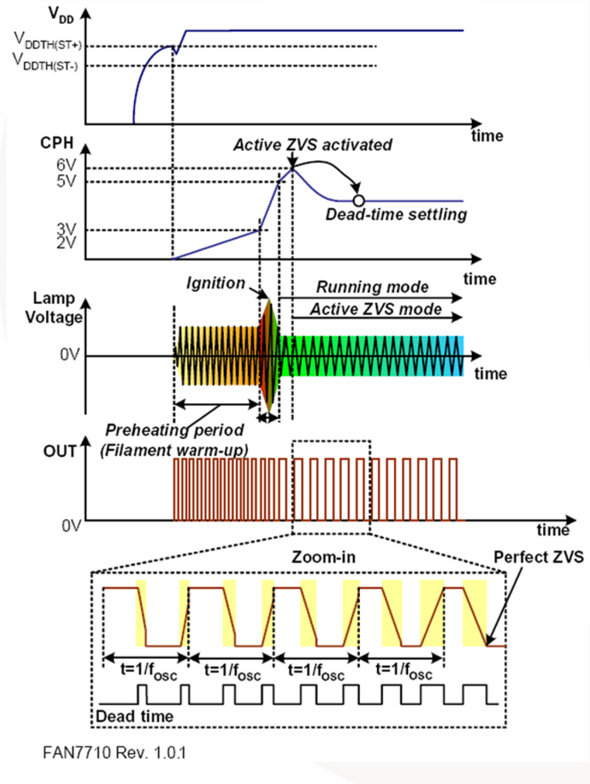

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Figure 23. Typical Transient Waveform from Preheating to Active ZVS Mode

3.4 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 24 shows an example of external shutdown control circuit.

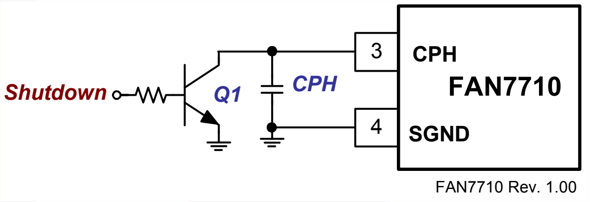

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Figure 24. External Shutdown Circuit

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. FAN7710 provides active ZVS operation by controlling the dead time according to the voltage of CPH. If ZVS fails even at the maximum dead time, FAN7710 stops driving the inverter.

The FAN7710 thermal shutdown circuit senses the junction temperature of the IC. If the temperature exceeds ~160°C, the thermal shutdown circuit stops operation of the FAN7710.

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.

4. Automatic Open-Lamp Detection

The FAN7710 can automatically detect an open-lamp condition. When the lamp is opened, the resonant tank fails to make a closed-loop to the ground, as shown in Figure 25. The supplied current from the OUT 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 FAN7710, due to capacitive load drive, is estimated as:

$$P_{dissipation} = \frac{1}{2} \times C_P \times V_{DC}^2 \times f \quad [W] \qquad \text{(EQ 6)}$$

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

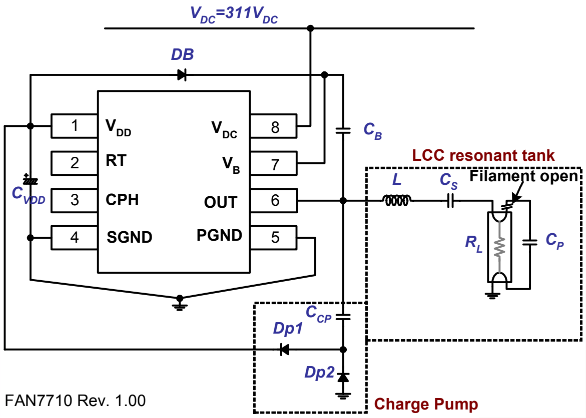

Figure 25. Current Flow When the Lamp is Open

Assuming that C_P, V_{DC}, and f are 1nF, 311V, and 50kHz, respectively; the power dissipation reaches about 2.4W and the temperature of FAN7710 is increased rapidly. If no protection is provided, the IC can be damaged by the thermal attack. Note that the hard switching condition during the capacitive-load drive causes EMI.

Figure 26 illustrates the waveforms during the open-lamp condition. In this condition, the charging and discharging current of C_P is directly determined by FAN7710 and considered hard switching condition. The FAN7710 tries to meet ZVS condition by decreasing CPH voltage to increase dead time. If ZVS fails and CPH goes below 2.6V, even though the dead time reaches its maximum value, FAN7710 shuts off the IC to protect against damage. To restart FAN7710, V_{DD} must be below $V_{DDTH(ST-)}$ to reset an internal latch circuit, which remembers the status of the IC.

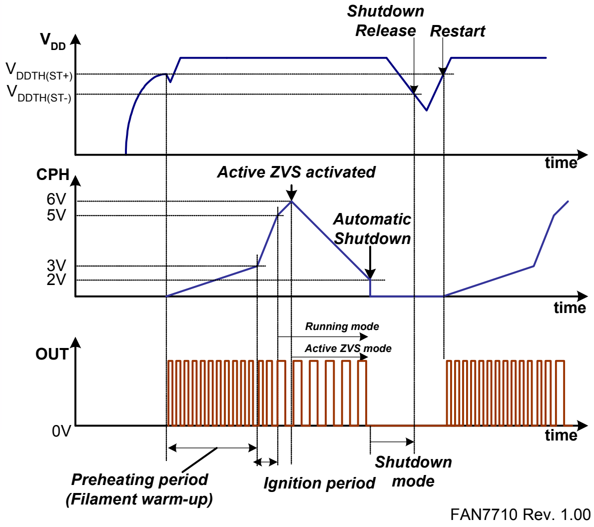

Figure 26. CPH Voltage Variation in Open-Lamp Condition

5. 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 27). Once UVLO is released, the current consumption is increased and the whole circuit is 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.

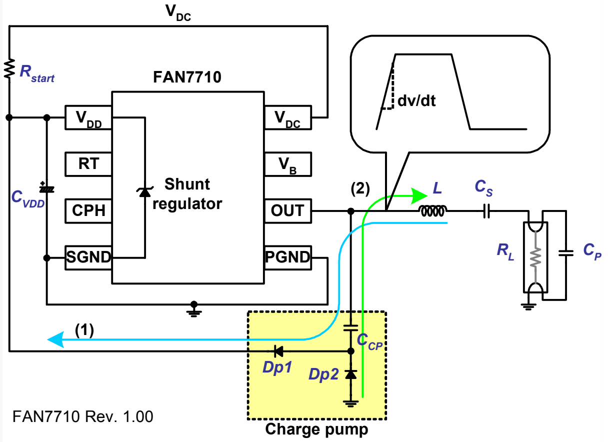

Figure 27. A Local Power Supply for V_{DD} Using a Charge Pump Circuit

As presented in Figure 27; when OUT is high, the inductor current and C_{CP} create an output transition with the slope of dv/dt. The rising edge of OUT 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 OUT is changing from HIGH to LOW state, C_{CP} is discharged through Dp2, shown as path (2) in Figure 27. These charging/discharging operations are continued until FAN7710 is halted by shutdown operation. The charging current, I, must be large enough to supply the operating current of FAN7710.

The supply for the high-side gate driver is provided by the boot-strap technique, as illustrated in Figure 28. When the low-side MOSFET connected between OUT and PGND pins is turned on, the charging current for V_B flows through D_B. Every low OUT gives the chance to charge the C_B. Therefore, C_B voltage builds up only when FAN7710 operates normally.

When OUT 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_{OUT} voltage decreases. If V_B-V_{OUT} 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.

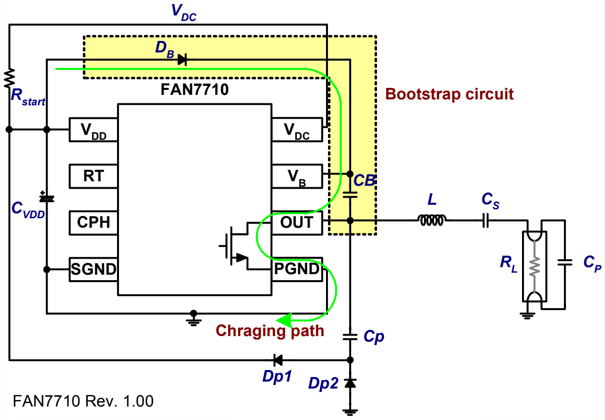

Figure 28. Implementation of Floating Power Supply Using the Bootstrap Method

Design Guide

1. Start-up Circuit

The start-up current (I_{ST}) has to be 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 220V_{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 a 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 1/4Ω resistor, R_{start} must obey the following rule:

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

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

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:

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

(2) For safe start-up with restart from shutdown mode:

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

As shown in Equation 14, if R_{start} meets Equation 14, restart operation is possible. However, it is not recommended to choose R_{start} at that range since V_{DD} rising time could be long and increase the lamp's turn-on delay time, as depicted in Figure 29.

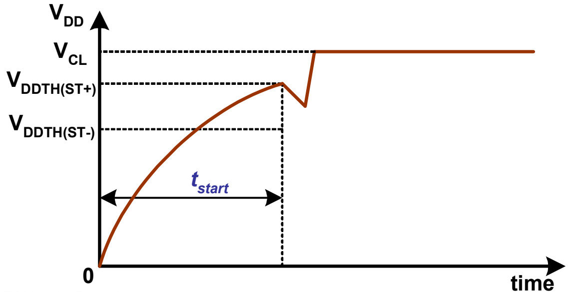

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Figure 29. V_{DD} Build-up

Figure 30 shows the equivalent circuit for estimating t_{start}. From the circuit analysis, V_{DD} variation versus time is given by:

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

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}=311V, R_{start}=560k, C_{VDD}=10μF, I_{st}=120μA, and $V_{DDTH(ST+)}$= 13.5V, t_{start} is about 0.33s.

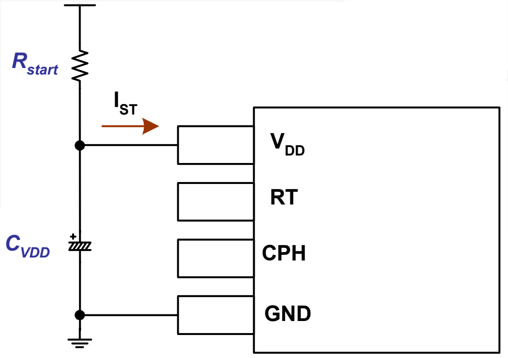

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Figure 30. Equivalent Circuit During Start

2. Current Supplied by Charge Pump

For the IC supply, the charge pump method is used in Figure 31. 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}=0.5nF, V_{DC}=311V, and f=50kHz, I_{avg} is ~7.8mA; it is enough current for stable operation.

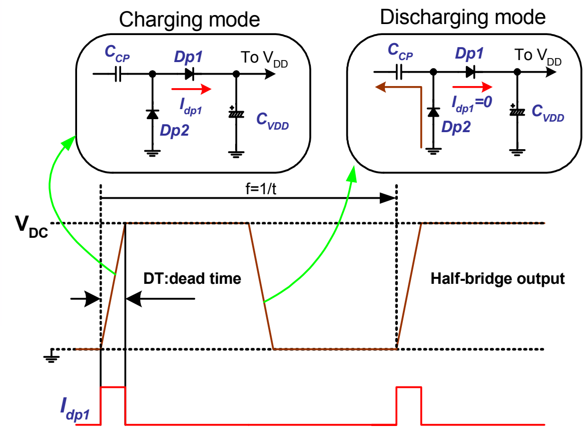

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Figure 31. Charge Pump Operation

3. 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 ~3V. In this mode, CPH capacitor is charged by I_{PH} current, as depicted in Figure 32. 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.

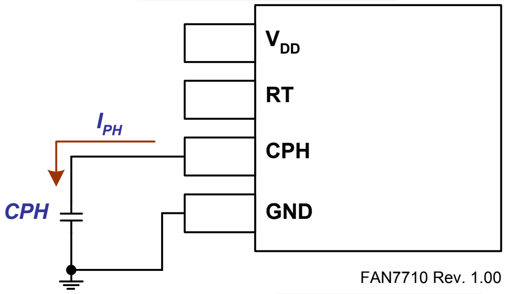

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Figure 32. Preheating Timer

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 3V until CPH reaches 5V. 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:

V_{DD} Build-Time + Preheating Time + Ignition Time =

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

Component List for 20W CFL Application

Part	Value	Note	Part	Value	Note
Resistor			**Diode**		
R1(3)	470kΩ	1/4W	D1	1N4007	1kV/1A
R2	82kΩ	1/4W,1%	D2	1N4007	1kV/1A
Capacitor			D3	1N4007	1kV/1A
C1	10µF/400V	Electrolytic Capacitor, 105°C	D4	1N4007	1kV/1A
C2	10µF/50V	Electrolytic Capacitor, 105°C	D6	UF4007	1kV/1A, Ultra Fast
C3(5)	0.68µF/25V	Miller Capacitor, 5%	D7	UF4007	1kV/1A, Ultra Fast
C4	100nF/25V	Miller Capacitor	**IC**		
C5	470pF/1kV	Ceramic Capacitor	U1	FAN7710	Ballast IC
C6(6)	33nF/630V	Miller Capacitor			
C7(6)	2.7nF/1kV	Miller Capacitor, 5%			
Inductor					
L1(6)	2.5mH (280T)	EE1916S			

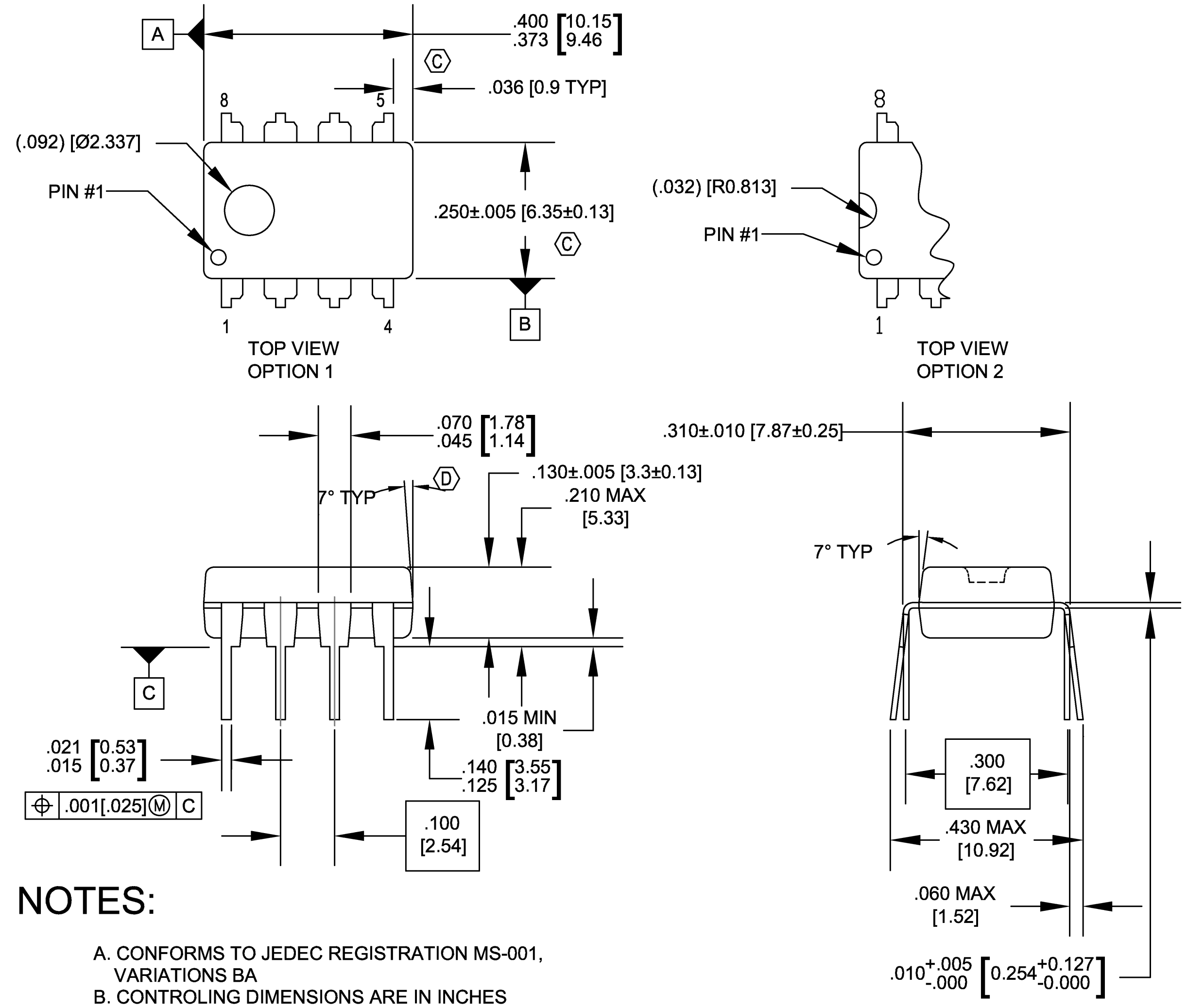
Note:

3. Refer to the Typical Application circuit provided in Figure 1.
4. Refer to the Design Guide start-up circuit, in Figure 30. Due to reducing power loss on the start-up resistor (R1) for high-efficiency systems, it is possible to use a higher resistor value than recommended. In this case, the IC doesn't reliably keep SD (shutdown) state for protection. Carefully select the start-up resistor (R1) or use the recommended value (470k) to sufficiently supply shutdown current (I_{SD}) and start-up current (I_{ST}).
5. Temperature dependency of the capacitance is important to prevent destruction of IC. Some capacitors show capacitance degradation at high temperatures and can not guarantee enough preheating time to safely ignite the lamp during the ignition period at high temperatures. If the lamp does not ignite during the ignition period, the IC cannot guarantee ZVS operation. Thus, the peak current of the switching devices can be increased above allowable peak current level of the switching devices. Especially in the high temperate, the switching device can be easily destroyed. Consequently, CPH capacitor (C3) must be large enough to warm the filaments of the lamp up over the target temperature range.
6. Consider the components (L1,C6,C7) of resonant tank variation over the target temperature range. Normally, these components would be changed toward increasing inductance and capacitance in high temperature. That means that the resonant frequency is decreased. In the lower resonant frequency condition, the preheating current is reduced, so the resonant tank cannot supply enough to preheat the filaments before lamps turn on. If the preheating current is insufficient, the ignition voltage/current is increased. With the ignition current at high temperature, the current capacity of internal MOSFETs on IC must be bigger than ignition current.

Package Dimensions

8-DIP

Dimensions are in millimeters unless otherwise noted.



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B. CONTROLING DIMENSIONS ARE IN INCHES REFERENCE DIMENSIONS ARE IN MILLIMETERS

C. DOES NOT INCLUDE MOLD FLASH OR PROTRUSIONS. MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED .010 INCHES OR 0.25MM.

D. DOES NOT INCLUDE DAMBAR PROTRUSIONS. DAMBAR PROTRUSIONS SHALL NOT EXCEED .010 INCHES OR 0.25MM.

E. DIMENSIONING AND TOLERANCING PER ASME Y14.5M-1994.

N08EREVG

Figure 33. 8-Lead Dual Inline Package (DIP)

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