

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. $T_A=25^{\circ}\text{C}$ 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/ns
T_A	Operating temperature range		-25		125	$^{\circ}\text{C}$
T_{STG}	Storage temperature range		-65		150	$^{\circ}\text{C}$
P_D	Power dissipation	8-SOP		0.625		W
		8-DIP		1.2		
θ_{JA}	Thermal resistance (junction-to-air)	8-SOP		200		$^{\circ}\text{C/W}$
		8-DIP		100		

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_{BS}) = 14.0V, T_A = 25°C, unless otherwise specified.

Symbol	Characteristics	Conditions	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	$I_{DD} = 10mA$	14.8	15.2		
I_{ST}	Start-up supply current	$V_{DD} = 10V$		120		μA
I_{DD}	Dynamic operating supply current	50kHz, $C_L = 1nF$		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	$V_{BS} = 14V$		50		μA
I_{HD}	High-side dynamic operating supply current	50kHz, $C_L = 1nF$		1		mA
I_{LK}	Offset supply leakage current	$V_B = V_S = 600V$			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	$V_{CPH} = 1V$	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	$R_T = 80k\Omega$, $V_{CPH} = 2V$	72	85	98	kHz
f_{OSC}	Running frequency	$R_T = 80k\Omega$	48.7	53.0	57.3	kHz
DT_{MAX}	Maximum dead time	$V_{CPH} = 1V$, $V_S = GND$ during preheat mode		3.1		μs
DT_{MIN}	Minimum dead time	$V_{CPH} = 6V$, $V_S = GND$ during run mode		1.0		μs
Output Section						
I_{OH+}	High-side driver sourcing current	$PW = 10\mu s$	250	350		mA
I_{OH-}	High-side driver sinking current	$PW = 10\mu s$	500	650		
I_{OL+}	Low-side driver sourcing current	$PW = 10\mu s$	250	350		
I_{OL-}	Low-side driver sink current	$PW = 10\mu s$	500	650		
t_{HOR}	High-side driver turn-on rising time	$C_L = 1nF$, $V_{BS} = 15V$		45		ns
t_{HOL}	High-side driver turn-off rising time	$C_L = 1nF$, $V_{BS} = 15V$		25		
t_{LOR}	Low-side driver turn-on rising time	$C_L = 1nF$, $V_{BS} = 15V$		45		
t_{LOL}	Low-side driver turn-off rising time	$C_L = 1nF$, $V_{BS} = 15V$		25		
$V_S^{(2)}$	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	450	μA
TSD	Thermal shutdown ⁽²⁾			165		°C

Note:

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

Typical Characteristics

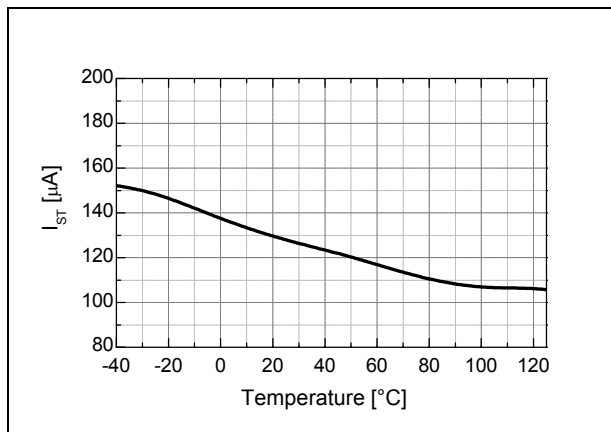


Figure 4. Start-Up Current vs. Temp.

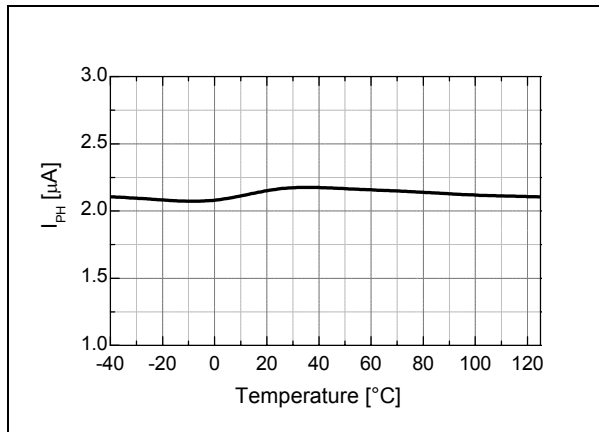


Figure 5. Preheating Current vs. Temp.

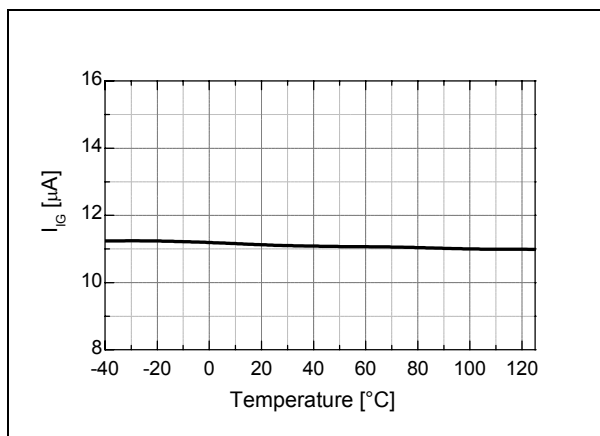


Figure 6. Ignition Current vs. Temp

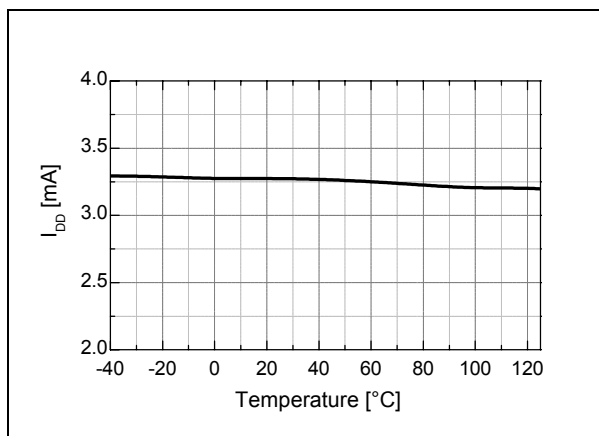


Figure 7. Operating Current vs. Temp.

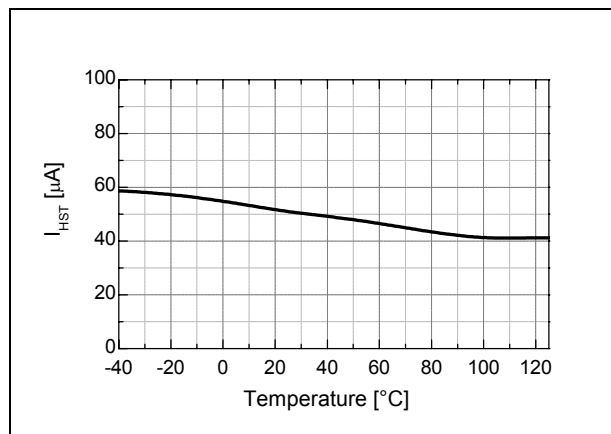


Figure 8. Start-Up Current vs. Temp.

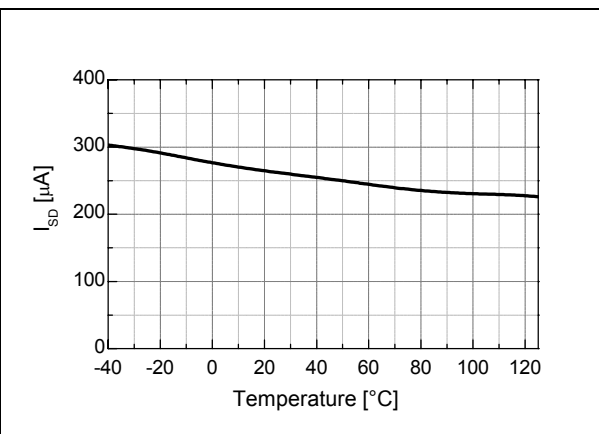


Figure 9. Shutdown Current vs. Temp.

Typical Characteristics (Continued)

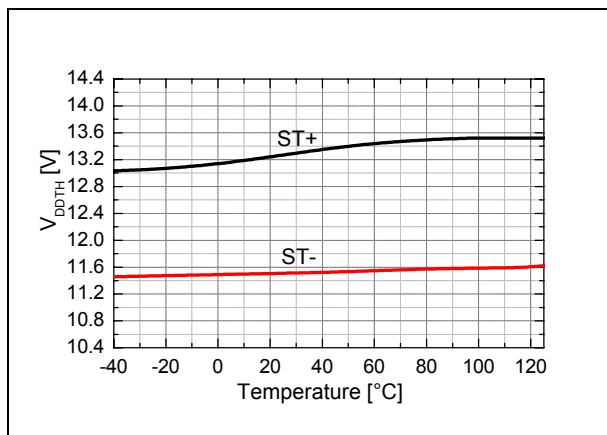
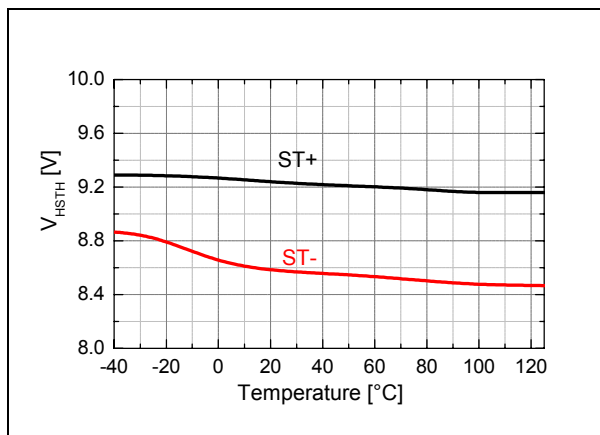
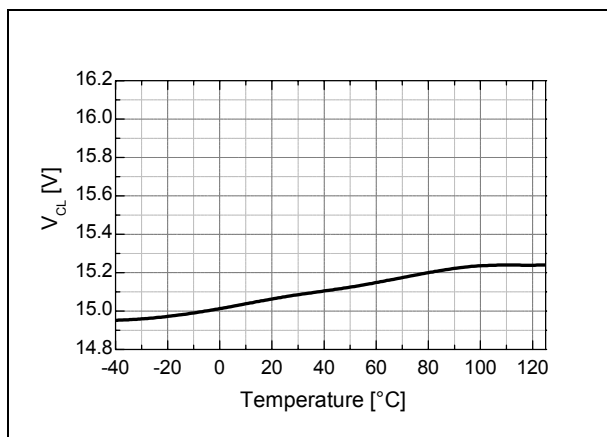
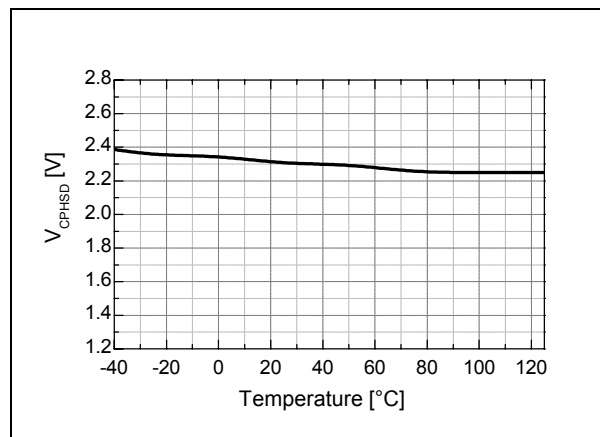
Figure 10. V_{DD} UVLO vs. Temp.Figure 11. V_{BS} UVLO vs. Temp.Figure 12. V_{DD} Clamp Voltage vs. Temp.

Figure 13. Shutdown Voltage vs. Temp.

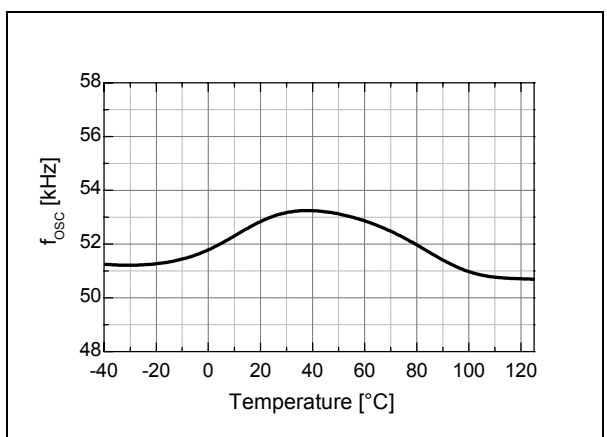


Figure 14. Running Frequency vs. Temp.

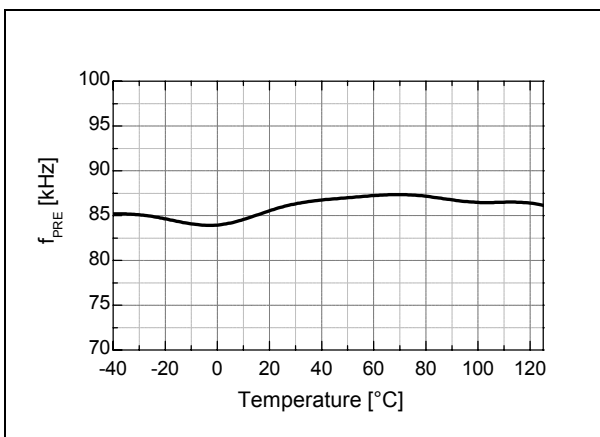
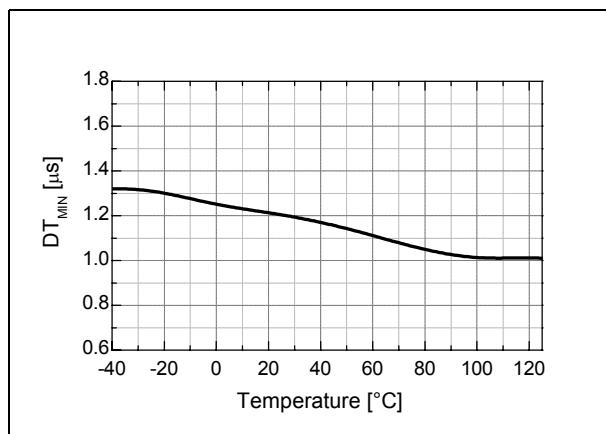
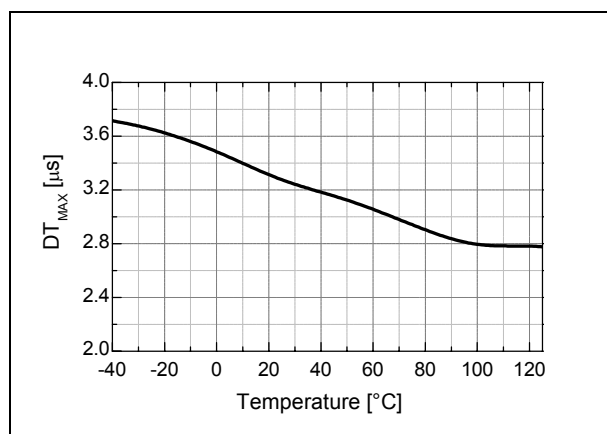


Figure 15. Preheating Frequency vs. Temp.

Typical Characteristics (Continued)**Figure 16. Minimum Dead Time vs. Temp.****Figure 17. Maximum Dead Time vs. Temp.**

Typical Application Information

1. Under-Voltage Lockout (UVLO) Function

The FAN7711 has UVLO circuits for both high-side and low-side circuits. When V_{DD} reaches $V_{DDTH(ST+)}$, UVLO is released and the FAN7711 operates normally. At UVLO condition, FAN7711 consumes little current, noted I_{ST} . Once UVLO is released, FAN7711 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} below $V_{DDTH(ST-)}$.

FAN7711 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 , FAN7711 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 18. 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.

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 18. 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

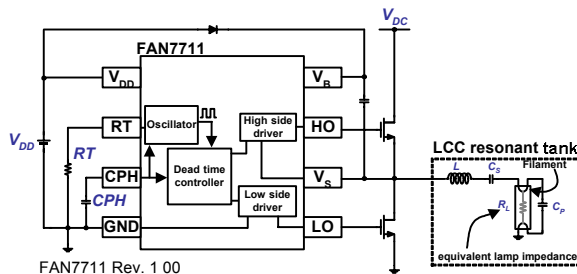


Figure 18. Resonant Inverter Circuit Based on LCC Resonant Tank

The transfer function of LCC resonant tank is heavily dependent on the lamp impedance, R_L , as illustrated in Figure 19. The oscillator in FAN7711 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 19. 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:

$$f_{PRE} = 1.6 \times f_{OSC} \quad (EQ 1)$$

After the warm-up, the FAN7711 decreases the frequency, shown as (B) of Figure 19. 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:

$$f_{IG} = [0.3 \times (5 - V_{CPH}) + 1] \times f_{OSC} \quad (EQ 2)$$

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

Equation 2 is valid only when V_{CPH} is between 3V to 5V before FAN7711 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) of Figure 19. If V_{DD} is higher than $V_{DDTH(ST+)}$ and UVLO is released, the voltage of R_T 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 FAN7711 does not need any external capacitors.

The proposed oscillation characteristic is given by:

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

Even in the active ZVS mode, shown as (D) in Figure 19, the oscillation frequency is not changed. The dead-time is varied according to the resonant tank characteristic.

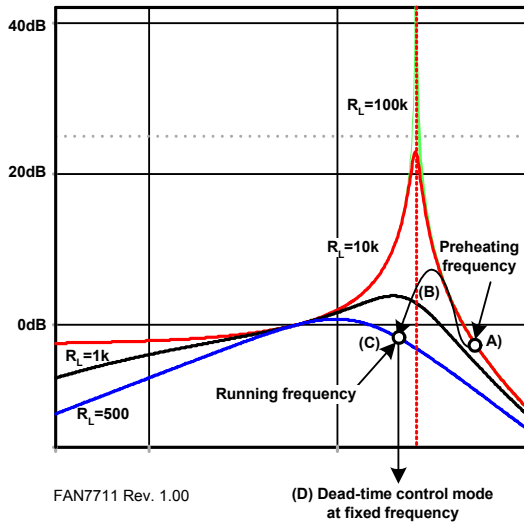


Figure 19. LCC Transfer Function in Terms of Lamp Impedance

3. Operation Modes

FAN7711 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 20. 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 FAN7711 is in active ZVS mode is it possible to shut off the whole system using CPH pin. Pulling the CPH pin below 2V in active ZVS mode, causes the FAN7711 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 2V to protect the inverter switches from damage.

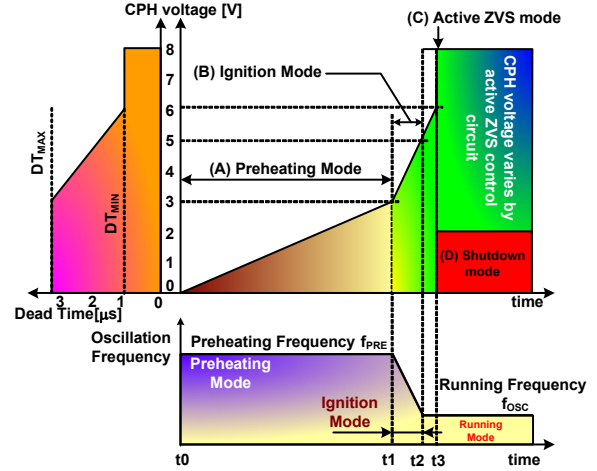


Figure 20. Operation Modes

3.1 Preheating Mode (t0~t1)

When V_{DD} exceeds $V_{DDTH(ST+)}$, the FAN7711 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 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:

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

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.

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. 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 3V and 5V. Once CPH voltage reaches 5V, the FAN7711 does not return to ignition mode, even if the CPH voltage is in that range, until the FAN7711 restarts from below $V_{DDTH(ST-)}$. Since the ignition mode continues when CPH is from 3V to 5V, the ignition time is given by:

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

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

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

When CPH voltage exceeds 5V, the operating frequency is fixed to f_{OSC} by R_T . However, active ZVS operation is not activated until CPH reaches ~6V. The FAN7711 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, FAN7711 detects the transition time of the output (V_S pin) of the inverter by using V_B pin. From the output-transition information, FAN7711 controls the dead time to meet the ZVS condition. If ZVS is satisfied, the FAN7711 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 FAN7711 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 21 depicts normal operation waveforms.

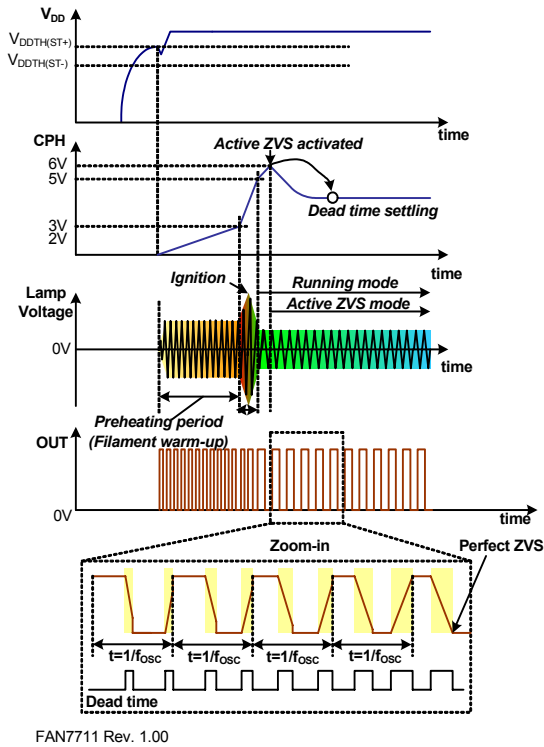


Figure 21. Typical Transient Waveform from Preheating to Active ZVS Mode

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 22 shows an example of external shutdown control circuit.

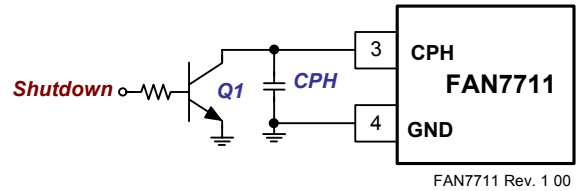


Figure 22. External Shutdown Circuit

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. FAN7711 provides active ZVS operation by controlling the dead time according to the voltage of CPH. If ZVS fails, even at the maximum dead time, FAN7711 stops driving the inverter.

The FAN7711 thermal shutdown circuit senses the junction temperature of the IC. If the temperature exceeds ~160°C, the thermal shutdown circuit stops operation of the FAN7711.

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

FAN7711 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 FAN7711, due to capacitive load drive, is estimated as:

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

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

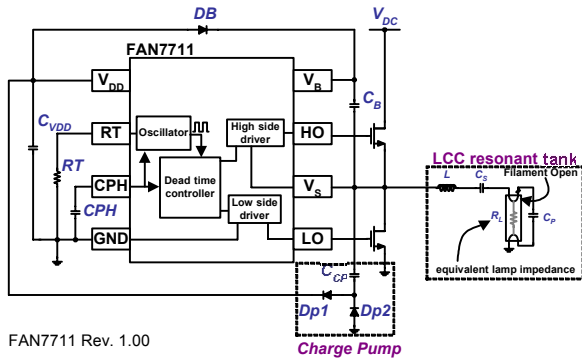


Figure 23. Current Flow When the Lamp is Open

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 FAN7711 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 24 illustrates the waveforms during the open-lamp condition. In this condition, the charging and discharging current of C_P is directly determined by FAN7711 and considered hard-switching condition. The FAN7711 tries to meet ZVS condition by decreasing CPH voltage to increase dead time. If ZVS fails and CPH goes below 2V, even though the dead time reaches its maximum value, FAN7711 shuts off the IC to protect against damage. To restart FAN7711, V_{DD} must be below $V_{DDTH(ST-)}$ to reset an internal latch circuit, which remembers the status of the IC.

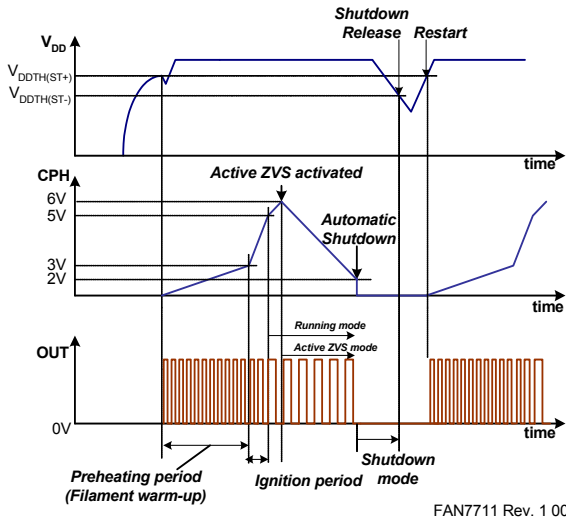


Figure 24. CPH Voltage Variation in Open-Lamp Condition

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 25). 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.

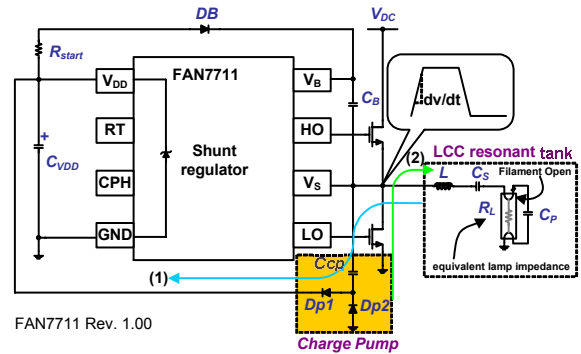


Figure 25. Local Power Supply for V_{DD} Using a Charge Pump Circuit

As presented in Figure 25, 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:

$$I \cong C_{CP} \times \frac{dv}{dt} \quad (\text{EQ 7})$$

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 26. These charging/discharging operations are continued until FAN7711 is halted by shutdown operation. The charging current, I , must be large enough to supply the operating current of FAN7711.

The supply for the high-side gate driver is provided by the boot-strap technique, as illustrated in Figure 26. 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 FAN7711 operates normally.

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