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IOR Rectifier

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IR2159

Dimming Ballast Controller IC

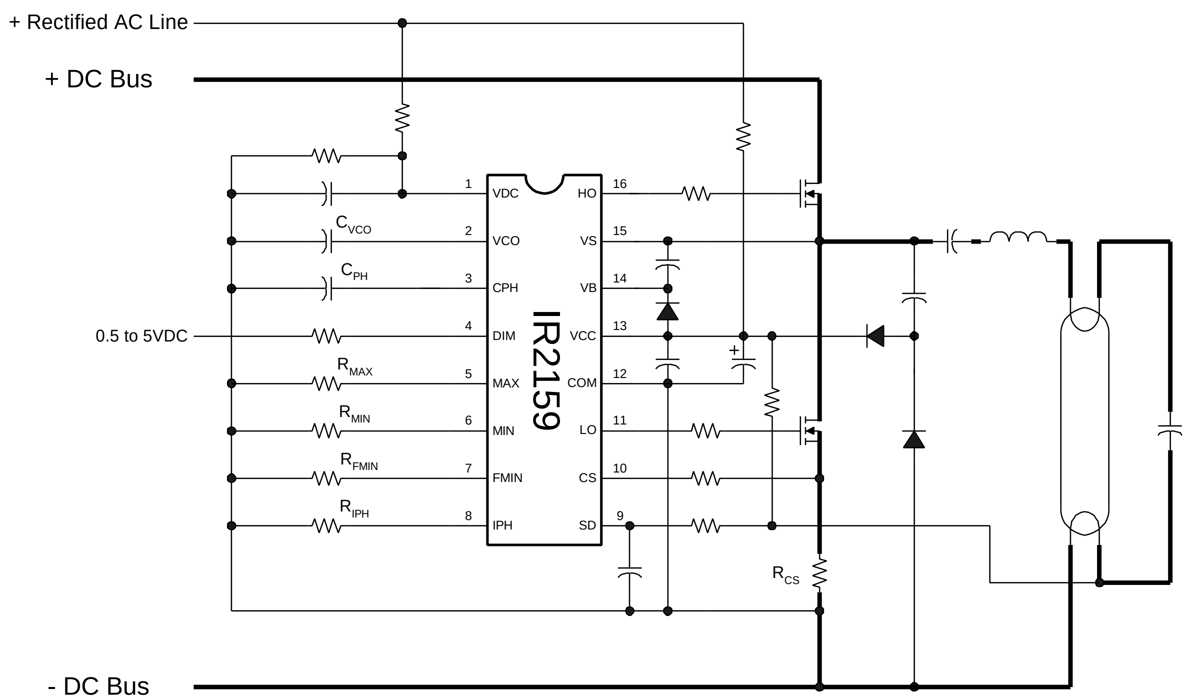
Description

The IR2159 is a complete dimming ballast controller and 600V half-bridge driver all in one IC. The architecture includes phase control for transformer-less lamp power sensing and regulation which minimizes changes needed to adapt non-dimming ballasts for dimming. Externally programmable features such as preheat time and current, ignition-to-dim time, and a complete dimming interface with minimum and maximum settings provide a high degree of flexibility for the ballast design engineer. Protection from failure of a lamp to strike, filament failures, thermal overload, or lamp failure during normal operation, as well as an automatic restart function, have been included in the design. The heart of this control IC is a voltage-controlled oscillator with externally programmable minimum frequency. The IR2159 is available in both 16 pin DIP and 16 pin narrow body SOIC packages.

Features

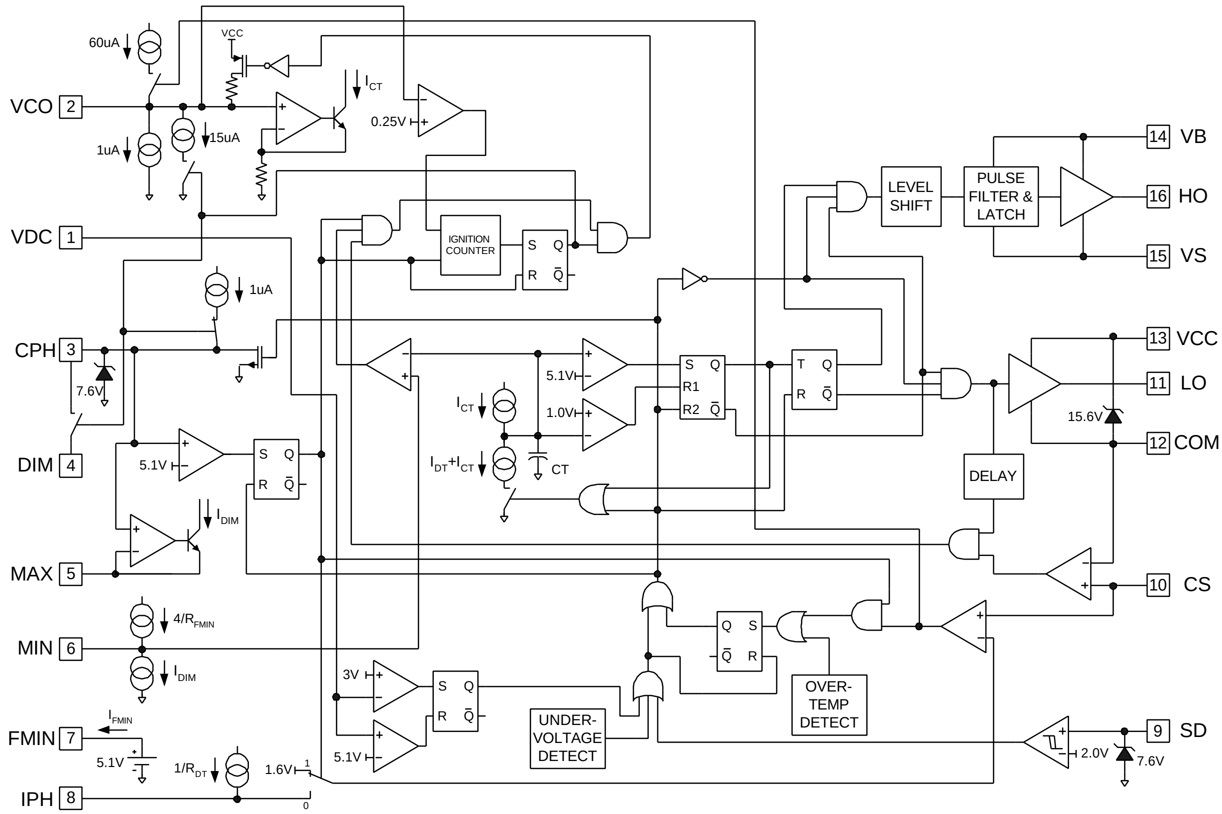
- Ballast control and half-bridge driver in one IC
- Transformer-less lamp power sensing
- Closed-loop lamp power control
- Closed-loop preheat current control
- Programmable preheat time
- Programmable preheat current
- Programmable ignition-to-dim time
- 0.5 to 5VDC Dimming control input
- Min and max lamp power adjustments
- Programmable minimum frequency
- Internal current sense blanking
- Full lamp fault protection
- Brown-out protection
- Automatic restart
- Micro-power startup
- Zener clamped Vcc
- Over-temperature protection
- 16-pin DIP and SOIC package types

Typical Connection Diagram

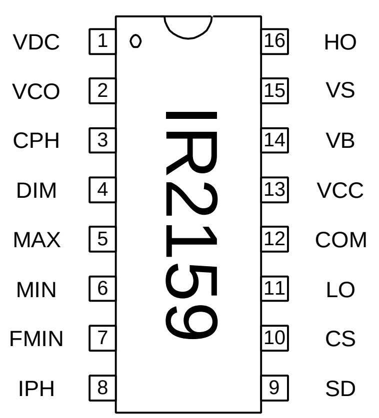


Single Lamp Dimmable

Block Diagram



Pin Assignments



Pin #	Symbol	Description
1	VDC	Line Input Voltage Detection
2	VCO	Voltage Controlled Oscillator Input
3	CPH	Preheat Timing Input
4	DIM	0.5 to 5VDC Dimming Control Input
5	MAX	Maximum Lamp Power Setting
6	MIN	Minimum Lamp Power Setting
7	FMIN	Minimum Frequency Setting
8	IPH	Peak Preheat Current Reference
9	SD	Shutdown Input
10	CS	Current Sensing Input
11	LO	Low-Side Gate Driver Output
12	COM	IC Power & Signal Ground
13	VCC	Logic & Low-Side Gate Driver Supply
14	VB	High-Side Gate Driver Floating Supply
15	VS	High Voltage Floating Return
16	HO	High-Side Gate Driver Output

Absolute Maximum Ratings

Absolute Maximum Ratings indicate sustained limits beyond which damage to the device may occur. All voltage parameters are absolute voltages referenced to COM, all currents are defined positive into any lead. The Thermal Resistance and Power Dissipation ratings are measured under board mounted and still air conditions.

Parameter				
Symbol	Definition	Min.	Max.	Units
V_B	High Side Floating Supply Voltage	-0.3	625	V
V_S	High Side Floating Supply Offset Voltage	V_B - 25	V_B + 25	
V_{HO}	High-Side Floating Output Voltage	V_S - 0.3	V_B + 0.3	
V_{LO}	Low-Side Output Voltage	-0.3	V_{CC} + 0.3	
I_{OMAX}	Maximum Allowable Output Current (Either Output) Due to External Power Transistor Miller Effect	-500	500	mA
V_{VCO}	Voltage Controlled Oscillator Input Voltage	-0.3	5.0	V
I_{CPH}	CPH Current	-5	5	mA
V_{IPH}	IPH Voltage	-0.3	5.5	V
V_{DIM}	Dimming Control Pin Input Voltage	-0.3	5.5	
V_{MAX}	Maximum Lamp Power Setting Pin Input Voltage	-0.3	5.5	
V_{MIN}	Minimum Lamp Power Setting Pin Input Voltage	-0.3	5.5	
V_{CS}	Current Sense Input Voltage	-0.3	5.5	
I_{SD}	Shutdown Pin Current	-5	5	mA
I_{CC}	Supply Current (Note 1)	---	25	mA
dV/dt	Allowable Offset Voltage Slew Rate	-50	50	V/ns
P_D	Package Power Dissipation @ $T_A \leq +25$ºC	---	TBD	W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	---	TBD	ºC/W
T_J	Junction Temperature	-55	150	ºC
T_S	Storage Temperature	-55	150	
T_L	Lead Temperature (Soldering, 10 seconds)	---	300	

Recommended Operating Conditions

For proper operation the device should be used within the recommended conditions.

Parameter				
Symbol	Definition	Min.	Max.	Units
V_{BS}	High Side Floating Supply Voltage	**V_{CC} - 0.7**	V_{CLAMP}	
V_S	Steady State High Side Floating Supply Offset Voltage	-1	600	V
V_{CC}	Supply Voltage	**V_{CCUV+}**	V_{CLAMP}	
I_{CC}	Supply Current	see Note 2	10	mA
V_{VCO}	VCO Pin Voltage	1	5	V
V_{DIM}	DIM Pin Voltage	0	5	V
I_{MAX}	MAX Pin Current (Note 3)	-750	0	µA
V_{MIN}	MIN Pin Voltage	1	3	V
R_{DT}	Deadtime Resistance	20.0	40.0	kΩ
I_{SD}	Shutdown Pin Current	-1	1	mA
I_{CS}	Current Sense Pin Current	-1	1	mA
T_J	Junction Temperature	-40	125	ºC

Note 1: This IC contains a zener clamp structure between the chip V_{CC} and COM which has a nominal breakdown voltage of 15.6V. Please note that this supply pin should not be driven by a DC, low impedance power source greater than the diode clamp voltage (V_{CLAMP}) as specified in the Electrical Characteristics section.

Note 2: Enough current should be supplied into the VCC pin to keep the internal 15.6V zener clamp diode on this pin regulating its voltage.

Note 3: The MAX pin is a voltage-controlled current source. For optimum dim interface current mirror performance, this current should be kept between 0 and 750uA.

Electrical Characteristics

V_{CC} = V_{BS} = V_{BIAS} = 15V +/- 0.25V, V_{CS} = 0.5V, V_{SD} = 0.0V, R_{DT} = 40k, C_{VCO} = 10nF, V_{DIM} = 0.0V, R_{MAX} = 33k, R_{MIN} = 56k, V_{TPH} = 0.0V, C_L = 1000pF unless otherwise specified.

Parameter		T_A = 25ºC				
Symbol	**Definition**	**Min**	**Typ**	**Max**	**Units**	**Test Conditions**
Supply Characteristics						
V_{CCUV+}	V_{CC} Supply Undervoltage Positive Going Threshold	---	12.5	---	V	
V_{CCHYS}	V_{CC} Supply Undervoltage Lockout Hysteresis	---	1.6	---		
I_{QCCUV}	UVLO Mode Quiescent Current	---	150	---	µA	V_{CC} < V_{CCUV-}
I_{QCCFLT}	Fault-Mode Quiescent Current	---	200	---	µA	**SD = 5V, CS = 2V, or Tj > T_{SD}**
I_{QCC}	Quiescent VCC Supply Current	---	TBD	---	mA	
$I_{QCC50kHz}$	VCC Supply Current, f = 50kHz	---	TBD	---	mA	
V_{CLAMP}	V_{CC} Zener Shunt Clamp Voltage	---	15.6	---	V	I_{CC} = 10mA
Floating Supply Characteristics						
I_{QBS0}	Quiescent V_{BS} Supply Current	---	0	---	µA	V_{HO} = V_S
I_{QBS1}	Quiescent V_{BS} Supply Current	---	30	---		V_{HO} = V_B
V_{BSMIN}	Minimum required V_{BS} Voltage for proper HO functionality	---	4	5	V	
I_{LK}	Offset Supply Leakage Current	---	---	50	µA	V_B = V_S = 600V
Oscillator I/O Characteristics						
f_{VCO}	Voltage Controlled Oscillator Frequency	---	30	---	kHz	R_{FMIN} = 40K
		---	100	---		V_{VCO} = 5V
df/dV_{CC}	Oscillator Frequency Voltage Stability	---	TBD	---	%	V_{VCO} = TBD, V_{CCUV+}<VCC<15V
df/dT	Oscillator Frequency Temperature Stability	---	TBD	---	%	V_{VCO} = TBD, -40°C < Tj < 125°C
d	Gate Drive Outputs Duty Cycle		50		%	V_{VCO} = TBD
V_{VCOFLT}	Fault-Mode VCO Pin Voltage (UVLO, Shutdown, Over-Current/Temp.)		5		V	
I_{VCOPH}	Preheat Mode VCO Pin Discharge Current		1.0		µA	V_{CPH} < 5V
I_{VCODIM}	Dim Mode VCO Pin Discharge Current		16.0		µA	

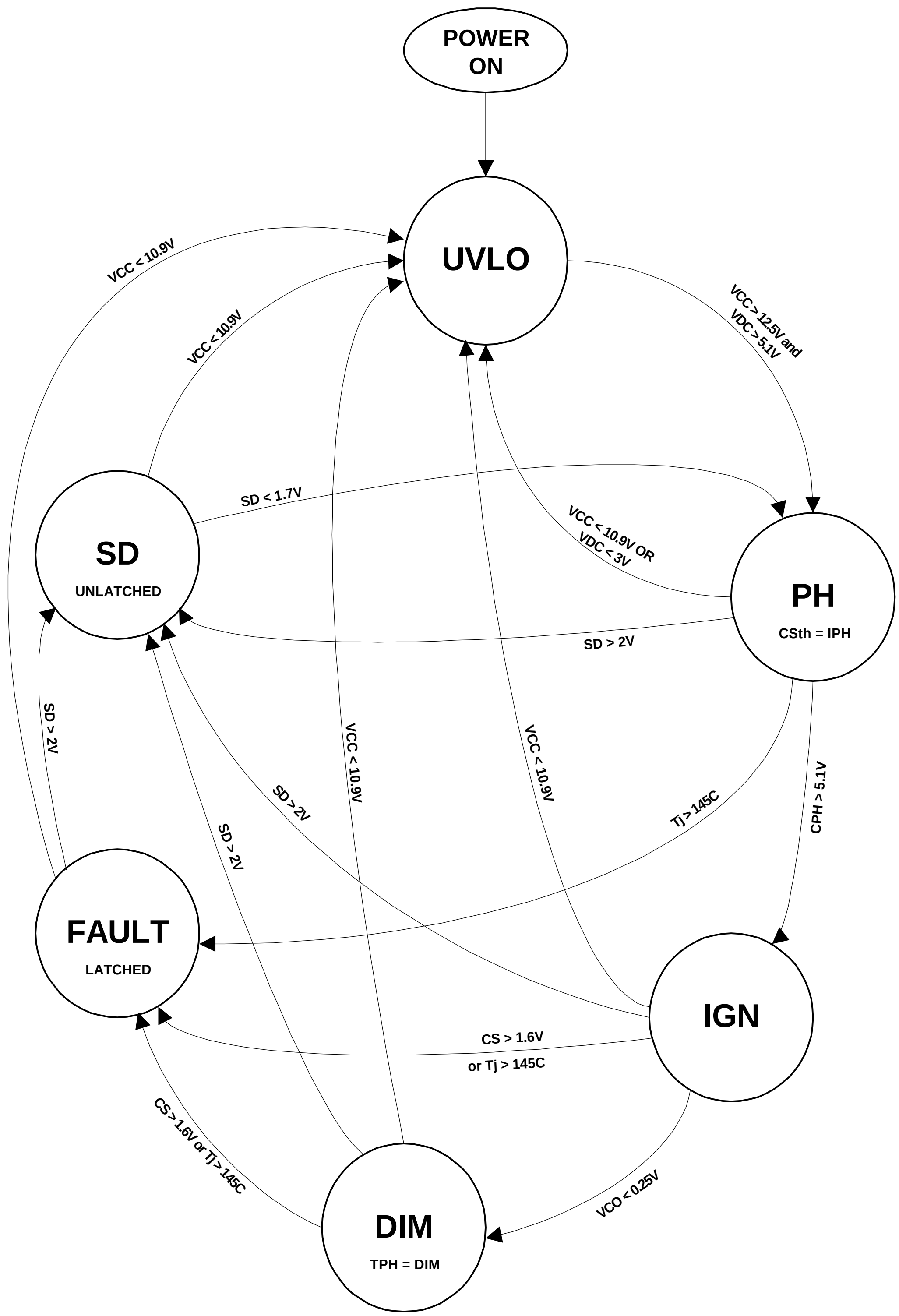
Electrical Characteristics (Cont.)

$V_{CC} = V_{BS} = V_{BIAS}$ = 15V +/- 0.25V, V_{CS} = 0.5V, V_{SD} = 0.0V, R_{DT} = 40k, R_{IPH} = 28k, C_{VCO} = 10nF, V_{DIM} = 0.0V, R_{MAX} = 33k, R_{MIN} = 56k, V_{TPH} = 0.0V, C_L = 1000pF unless otherwise specified.

Parameter		T_A = 25ºC				
Symbol	**Definition**	**Min**	**Typ**	**Max**	**Units**	**Test Conditions**
I_{VCOPK}	Peak Current Control VCO Pin Charging Current		60.0		µA	V_{CPH} < 5V, V_{CS} > V_{IPH}
td_{LO}	LO Output Deadtime		2.0		µs	
td_{HO}	HO Output Deadtime		2.0		µs	
dtd	Deadtime Matching		0.1		µs	
dtd/dV_{CC}	Deadtime Voltage Stability		TBD		%	V_{CCUV+}<VCC<15V
dtd/dT	Deadtime Temperature Stability		TBD		%	-40°C < Tj < 125°C
Gate Driver Output Characteristics						
V_{OL}	Low-Level Output Voltage			100	mV	
V_{OH}	High-Level Output Voltage			100	mV	$V_{BIAS} - V_O$
t_r	Turn-On Rise Time			150	ns	
t_f	Turn-Off Fall Time			100	ns	
Preheat Characteristics						
I_{CPH}	CPH Pin Charging Current	---	1.0	---	µA	
V_{CPHIGN}	CPH Pin Ignition Mode Threshold Voltage		5.0		V	
$V_{CPHCLMP}$	CPH Pin Clamp Voltage		7.6		V	
I_{IPH}	IPH Pin DC Source Current		25.0		µA	$I_{IPH} = 1/R_{FMIN}$
V_{CSTH}	Peak Preheat Current Regulation Threshold (Programmable)		0.7		V	$V_{CSTH} = (I_{IPH}) \times (R_{IPH})$
Ignition Characteristics						
V_{CSTH}	Peak Over Current Threshold		1.6		V	5V < V_{CPH}
Protection Characteristics						
V_{SDTH+}	Rising Shutdown Pin Threshold Voltage		2.0		V	
V_{SDHYS}	SD Pin Threshold Hysteresis		150		mV	
V_{SDCLMP}	SD Pin Clamp Voltage		7.6		V	I_{SD} = 100uA
V_{CSTH}	Peak Over-Current Latch Threshold Voltage	---	1.6	---	V	V_{CPH} > 5V
T_{SD} *	Thermal Shutdown Junction Temperature	---	150	---	ºC	
Phase Control						
V_{CSTHZX}	Zero-Crossing Threshold Voltage		0.0		V	
R_{FB}	FB Resistor to VCO Pin During Dimming		5.7		$k\Omega$	
Dim Interface						
V_{DIMOFF}	DIM Pin Offset Voltage		0.5		V	
V_{DIM}	Dim Input Voltage Range	0.0		5.0	V	
V_{MIN}	Dim Reference Voltage Range (MIN pin)	1.0		3.0	V	

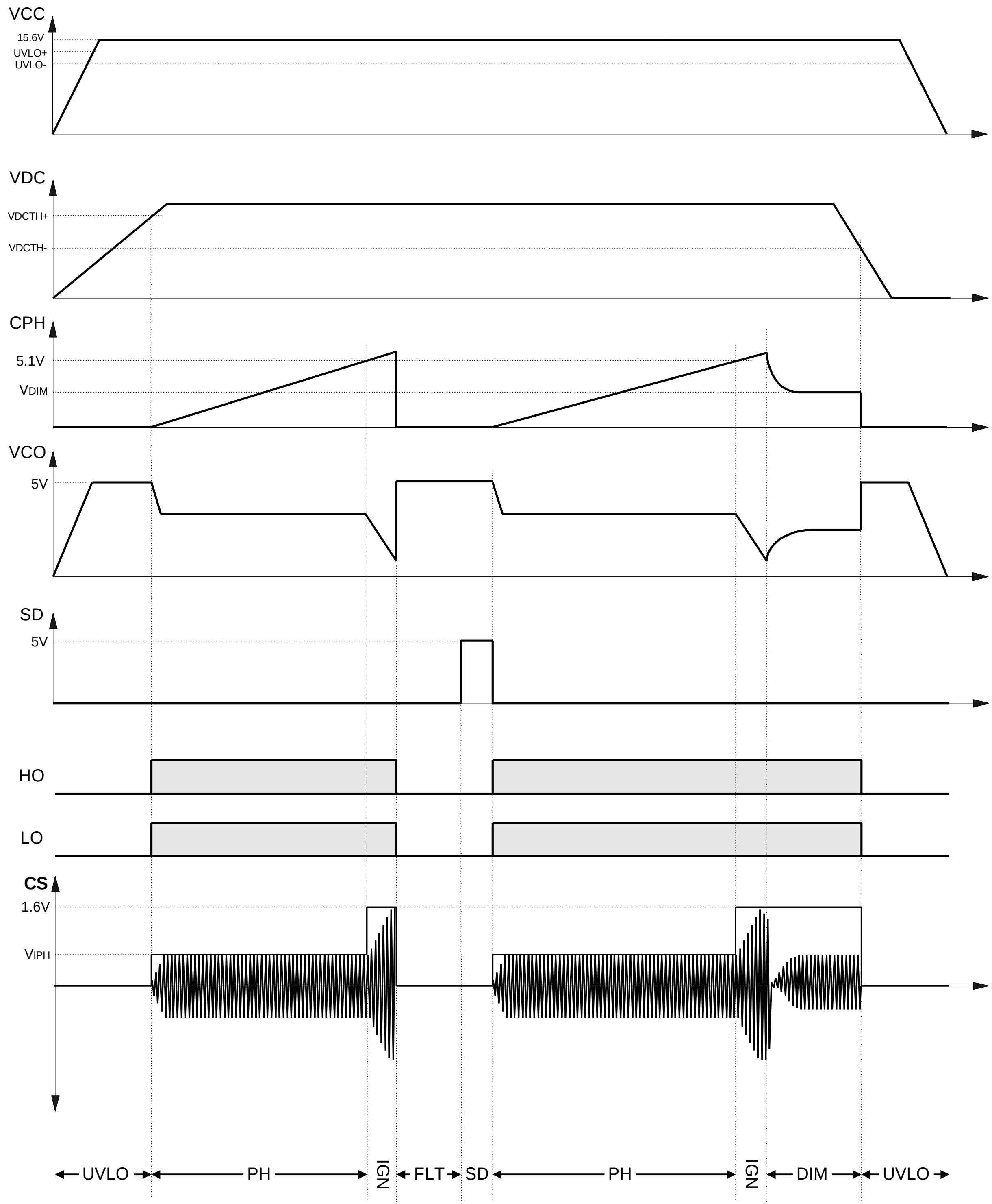
* When the IC senses an over-temperature condition (Tj > 125°C), the chip is latched off. In order to reset this latch, the supply to the IC must be cycled below the falling undervoltage lockout threshold, V_{CCUV-} , or the SD pin must be cycled.

State Diagram



Timing Diagrams

Non-strike fault condition with lamp exchange



Functional Description

Under-voltage Lock-Out (UVLO)

The IR2159 undervoltage lock-out is designed to maintain an ultra low quiescent current of less than 200uA, while guaranteeing the IC is fully functional before the high and low side output drivers are activated. Figure 1 shows an efficient supply voltage using the start-up current of the IR2159 together with a charge pump from the ballast output stage (C2, R2, D1 and D2).

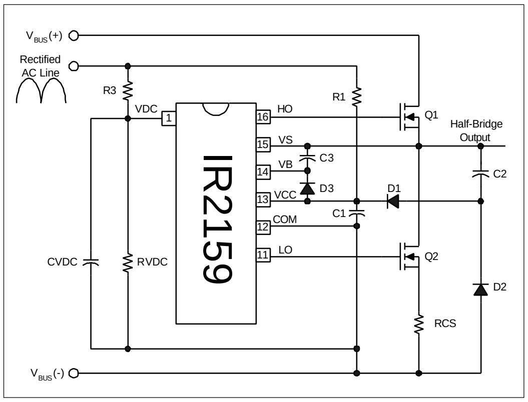


Figure 1, Typical application of start-up circuitry.

The start-up capacitor (C1) is charged by current through resistor (R1) minus the start-up current drawn by the IC. This resistor is typically chosen to provide 2X the maximum start-up current at low line to guarantee start-up under the worst case condition. Once the capacitor voltage reaches the start-up threshold, and, the voltage on pin VDC is above 5.1V (see Brown-out Protection), the IC turns on and HO and LO begin to oscillate. The capacitor begins to discharge due to the increase in IC operating current (Figure 2).

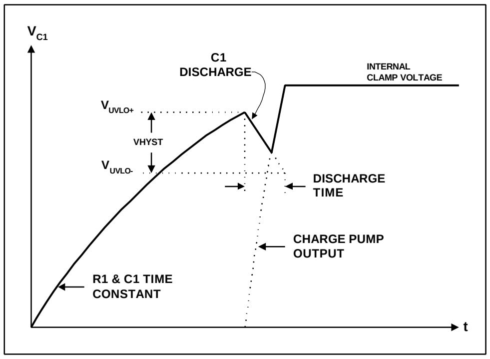


Figure 2, Start-up capacitor (C1) voltage.

During the discharge cycle, the rectified current from the charge pump charges the capacitor above the minimum operating voltage of the device and the charge pump and internal 15.6V zener clamp of the IC take over as the supply voltage. The start-up capacitor and snubber capacitor must be selected such that worst case IC conditions are satisfied. A bootstrap diode (D3) and supply capacitor (C3) comprise the supply voltage for the high side driver circuitry. To guarantee that the high-side supply is charged up before the first pulse on pin HO, the first pulse from the output drivers comes from the LO pin. During UVLO, the high and low side driver outputs are low, pin VCO is pulled-up internally to 5V resetting the starting frequency to the maximum, and pin CPH is short-circuited internally to COM resetting the preheat time.

Brown-out Protection

In addition to the voltage on VCC being above the start-up threshold, pin VDC must also be above 5.1V for HO and LO to begin oscillating. A voltage divider (R3,RVDC) from the rectified AC line connected to pin VDC measures the rectified AC line input voltage to the ballast and programs the turn-on and turn-off line voltages. A filter capacitor (CVDC) is also connected to pin VDC that must be chosen such that the ripple is low enough and the lower turn-off threshold of 3V is not crossed during normal line conditions. This detection is necessary due to the possibility of the lamp extinguishing during low-line conditions before the IC is properly reset. Should a brown-out occur, the DC bus can drop to a level below the minimum required for the tank circuit to maintain the necessary lamp voltage. This detection will insure a clean turn-off before the DC bus drops too low and properly reset the IC to the preheat mode when the line returns.

Preheat (PH)

The IR2159 enters preheat mode when VCC exceeds the UVLO+ threshold and VDC exceeds 5.1V. HO and LO begin to oscillate at the maximum operating frequency with 50% duty cycle and at the internally set dead-time of 2us. Pin CPH is disconnected from COM and an internal 1uA current source (Figure 3) charges the external timing capacitor on CPH linearly.

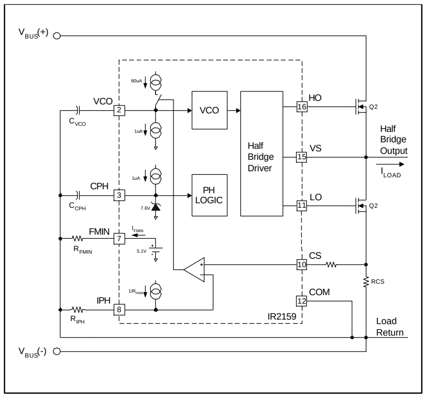


Figure 3, IR2159 preheat circuitry.

An internal 1uA current source slowly discharges the external capacitor on pin VCO and the voltage on pin VCO begins to decrease. This decreases the frequency, which, for operating frequencies above resonance, increases the load current. When the peak voltage measured on pin CS, produced by a portion of the load current flowing through an external sense resistor (RCS), exceeds the voltage level on pin IPH, a 60uA internal current source is connected to pin VCO and the capacitor charges (Figure 4). This forces the frequency to increase and the load current to decrease. When the voltage on pin CS decreases below IPH, the 60uA current source is disconnected and the frequency decreases again.

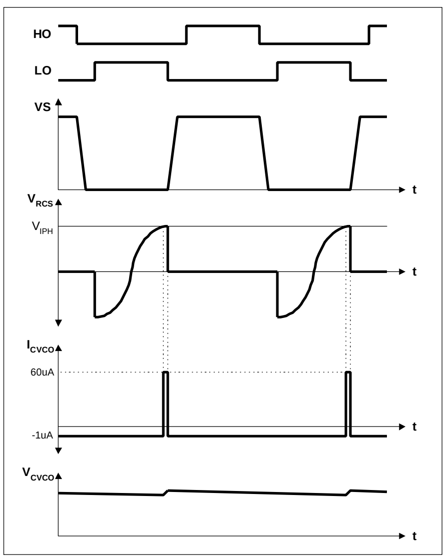


Figure 4, Peak load current regulation timing diagram.

This feedback keeps the peak preheat current regulated to the user-programmable setting on pin IPH for the duration of the preheat time. An internal current source connected to an external resistor on pin IPH sets a voltage reference for the peak pre-heat current. The pre-heat time continues until the voltage on pin CPH exceeds 5V.

Ignition (IGN)

The IR2159 enters ignition mode when the voltage on pin CPH exceeds 5V. The peak current regulation reference voltage is disconnected from the user-programmable setting on pin IPH and is connected to a higher internal threshold of 1.6V (Figure 5).

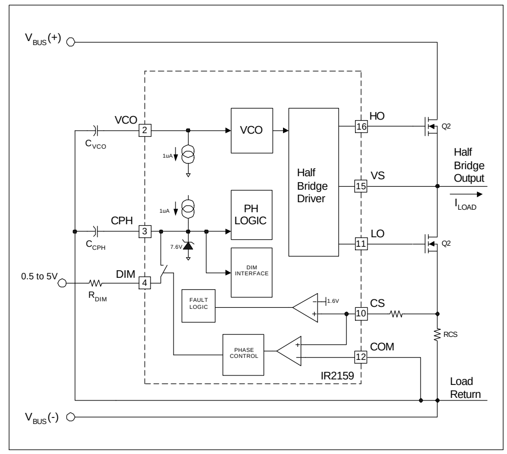


Figure 5, IR2159 ignition circuitry.

The ignition ramp is then initiated as the capacitor on pin VCO discharges linearly through an internal 1uA current source. The frequency decreases linearly towards the resonance frequency of the high-Q ballast output stage, causing the lamp voltage and load current to increase (Figure 6). The frequency continues to decrease until the lamp ignites or the current limit of the IR2159 is reached. If the current limit is reached, the IR2159 enters FAULT mode. The 1.6V threshold together with the external current sensing resistor on pin CS determine the maximum allowable peak ignition current (and therefore peak ignition voltage) of the ballast output stage. The peak ignition current must not exceed the maximum allowable current ratings of the output stage MOSFETs or IGBTs, and, **the resonant inductor must not saturate at any time**.

Should the lamp ignite, the frequency continues to decrease until the voltage on pin VCO reaches 0.25V, corresponding to the minimum operating frequency set by the external resistor on pin FMIN, and the IR2159 enters DIM mode and the phase control loop is closed .

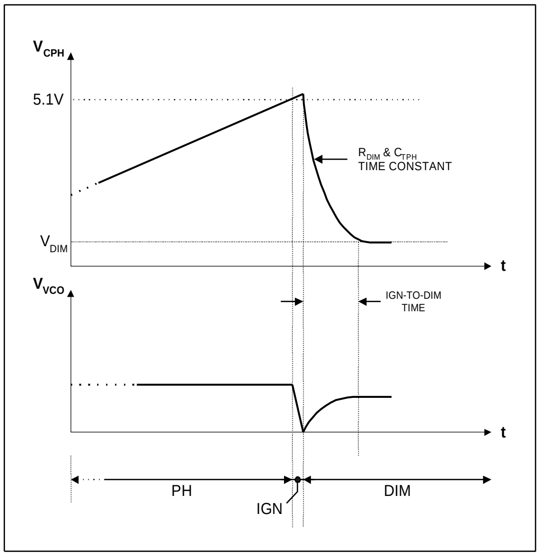


Figure 6, IR2159 ignition timing diagram.

For a reliable ignition with minimal start-up flash, the resistor on FMIN should be set to 5kHz lower than the ignition frequency or the 100% brightness dimming frequency, whichever is lower.

Ignition-to-Dim (IGN-to-DIM)

When the VCO decreases below 0.25V, the IR2159 enters dim mode. The phase control loop is closed and the phase of the load current is regulated against the user control input on pin DIM. To control the rate at which the dim setting changes from maximum brightness to the user setting (IGN-TO-DIM time, Figure 6), pin DIM is connected internally to pin CPH when the IR2159 enters DIM mode. The resistor on pin DIM (RDIM) discharges the capacitor on pin CPH down to the user dim setting. The resistor can be selected for a fast time constant to minimize the amount of flash visible over the lamp just after ignition, or, a long time constant such that the brightness ramps down smoothly to the user setting. Should the ignition-to-dim time be too fast, however, the loop can respond faster than the ionization constant of the lamp (milliseconds) causing the VCO to over-shoot. This can result in a frequency that is higher than the minimum brightness frequency and can extinguish the lamp. The capacitor on pin CPH serves multiple functions by setting the preheat time, the travel rate just after ignition (together with resistor RDIM), and, serving as a filter capacitor on pin DIM during dimming to increase high-frequency noise immunity and minimize component count.

Phase Control

To understand phase control, a simplified model for the ballast output stage is used (Figure 7). The lamp and filaments are replaced with resistors, with the lamp inserted between the filament resistors (R1, R2, R3 and R4).

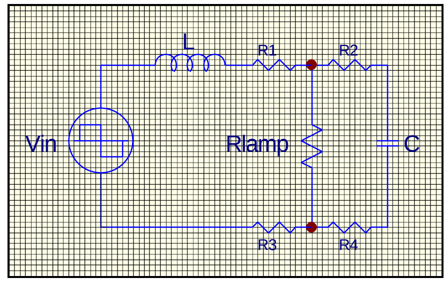


Figure 7, Dimming ballast output stage.

During preheat and ignition (Figure 8), the circuit is a high-Q series LC with a strong input current to input voltage phase inversion from +90 to -90 degrees at the resonance frequency. For operating frequencies slightly above resonance and higher, the phase is fixed at -90 degrees for the duration of preheat and ignition. During dimming, the circuit is an L in series with a parallel R and C, with a weak phase inversion at high lamp power and a strong phase inversion at low lamp power.

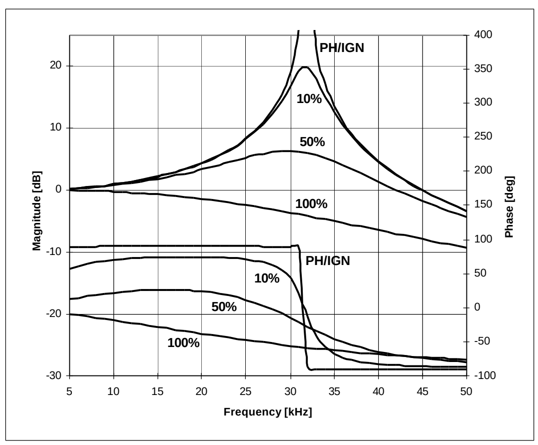


Figure 8, Typical output stage transfer function for different lamp power levels.

In the time domain (Figure 9), the input current is shifted -90 degrees from the input half-bridge voltage during preheat and ignition, and somewhere between 0 and -90 degrees after ignition during running. Zero phase-shift corresponds to maximum power.

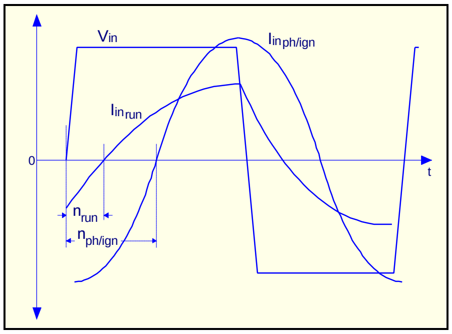


Figure 9, Typical ballast output stage waveforms.

When the phase is calculated and plotted versus lamp power (Figure 10), the result is a linear dimming curve, even down to ultra-low light levels where the resistance of the lamp can change by orders of magnitude.

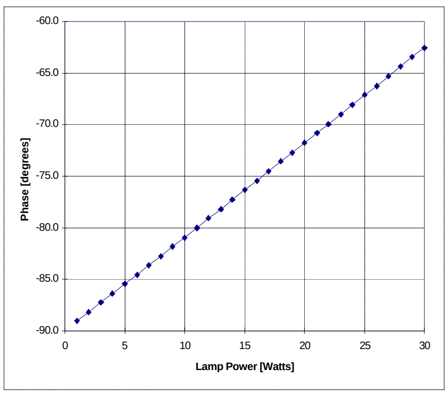


Figure 10, Lamp power vs. phase of output stage.

Dimming (DIM)

To regulate lamp power, the error between the reference phase and the phase of the output stage current forces the VCO to steer the frequency in the proper direction, as determined by the transfer function of the output stage, such that the error is forced to zero. An internal 15uA current source is connected to pin VCO during dimming mode (Figure 11) to discharge the VCO capacitor and decrease the frequency towards lock.

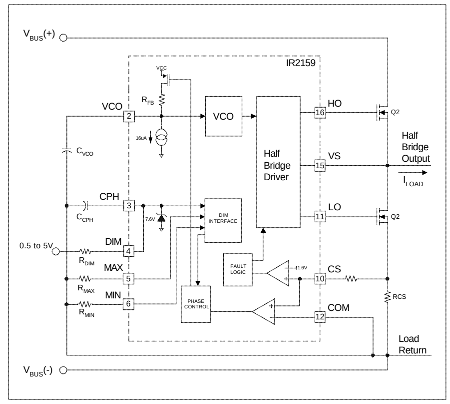


Figure 11, IR2159 dimming circuitry.

Once lock is achieved, the phase detector (PDET) outputs short pulses to an open-drain PMOS that charges the VCO capacitor through an internal resistor (RFB) each time an error pulse occurs (Figure 12). This action "nudges" the integrator at the input of the VCO to keep the phase of the output stage current exactly locked in phase with the reference.

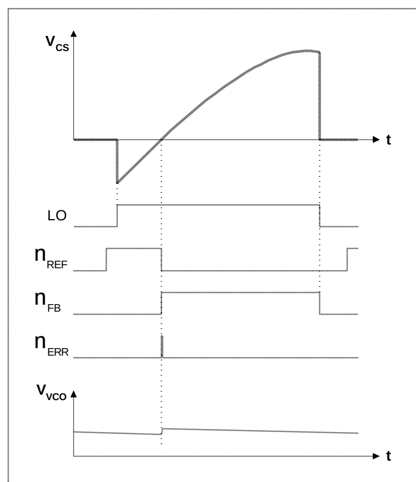


Figure 12, Phase control timing diagram.

The IR2159 includes a dimming interface for analog lamp power control. The DIM pin input requires a voltage in the range of 0.5 to 5VDC, with 5V corresponding to minimum phase shift (maximum lamp power). The output of the dim interface is the voltage on pin MIN, which is compared with the internal timing capacitor (CT) voltage to produce a frequency-independent digital reference phase (Figure 13).

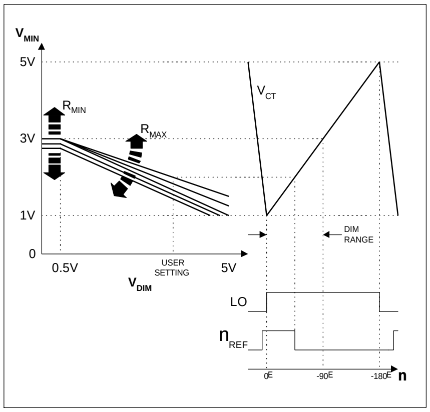


Figure 13, Dimming interface

The charging time of CT from 1V to 5.1V determines the on-time of output gate drivers HO and LO and corresponds to -180 degrees of possible phase shift in load current (minus deadtime). For the 0 to -90 degree dim range, the voltage on pin MIN is bounded between 1V and 3V using pins MIN and MAX. An external resistor on pin MAX programs the minimum phase shift reference (maximum lamp power) corresponding to 5V on pin DIM, and an external resistor on pin MIN sets the maximum phase shift (minimum lamp power) corresponding to 0.5V on pin DIM.

Current Sensing

During dimming, the current sensing circuitry (Figure 14) detects over-current which can occur during hard-switching (see Fault section), and zero-crossing to measure the phase of the total load current. To reject any switching noise which can occur at the turn-on of the low-side MOSFET or IGBT, a digital current sense blanking circuit blanks out the signal from the zero-crossing detection comparator for 400ns after LO goes 'high' (Figure 15).

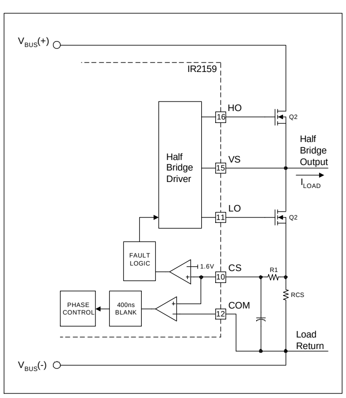


Figure 14, Current sensing circuitry.

The internal blank time reduces the dimming range slightly (Figure 15) when operating at minimum phase shift (maximum lamp power). The external programming resistor on pin MAX must be selected such that the minimum phase shift is set a safe margin away from the blank time. A series resistor (R1) is required to limit the amount of current flowing out of pin CS when the voltage across R_{CS} goes below -0.7V. A filter capacitor at pin CS may be required due to other asynchronous noise sources present in the ballast.

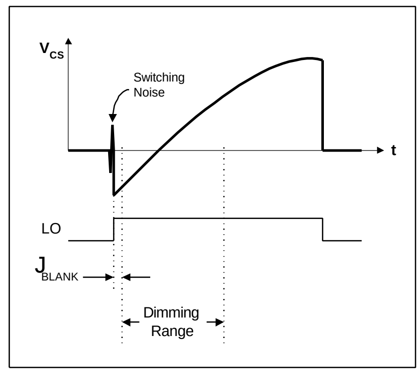


Figure 15, Current sense timing diagram.

Fault Mode (FAULT)

During dimming, the peak current regulation circuit active during preheat and ignition is disabled. Should non-zero voltage switching at the output of the half-bridge occur (Figure 18), high current spikes will result. A lamp filament failure, lamp end-of-life, lamp removal, or a deadtime shorter than what is required for commutation, can all cause hard-switching.

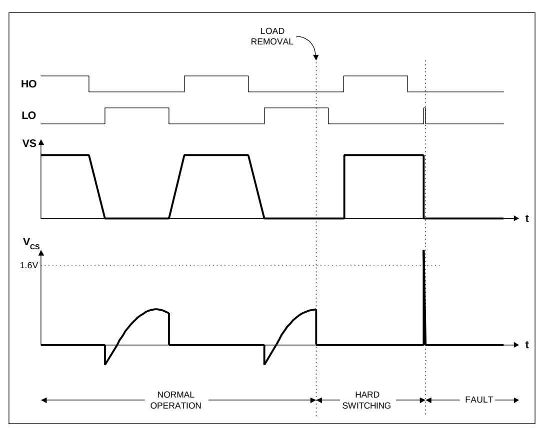


Figure 18, hard-switching with latch off

Should the peak voltage on pin CS exceed 1.6V at any time during dimming, the IR2159 enters FAULT mode and the high and low-side driver outputs, HO and LO, are both turned off . Cycling the supply voltage on VCC below or the voltage on pin SD will reset the IR2159 to preheat (PH) mode (see STATE DIAGRAM).

Ballast Design

Lamp Requirements

Before selecting component values for the ballast output stage and the programmable inputs of the IR2159, the following lamp requirements must first be defined:

Variable	Description	Units
I_{ph}	Filament pre-heat current	Arms
t_{ph}	Filament pre-heat time	s
$V_{ph\max}$	Maximum lamp pre-heat voltage	Vpp
V_{ign}	Lamp ignition voltage	Vpp
$P_{100\%}$	Lamp power at 100% brightness	W
$V_{100\%}$	Lamp voltage at 100% brightness	Vpp
$P_{1\%}$	Lamp power at 1% brightness	W
$V_{1\%}$	Lamp voltage at 1% brightness	Vpp
$I_{Cath\min}$	Minimum cathode heating current	Arms

Table I, Typical lamp requirements

Ballast Output Stage

The components comprising the output stage are selected using a set of equations. Different ballast operating frequencies and their respective voltages and currents are calculated.

The inductor and capacitor values are obtained using equations (2) through (7). The results of these equations reveal the location of each operating frequency and the corresponding voltages and currents. For a given L, C, DC bus voltage, and pre-heat current, the resulting voltage over the lamp during pre-heat is given as:

$$V_{ph} = \sqrt{\left(\frac{V_{DC}}{p}\right)^2 + \frac{8L}{C} I_{ph}^2} - \frac{V_{DC}}{p} \quad \text{[Vpp]} \qquad \textbf{(2)}$$

The resulting operating frequency during pre-heat is given as:

$$f_{ph} = \frac{\sqrt{2} I_{ph}}{pCV_{ph}} \quad \text{[Hz]} \qquad \textbf{(3)}$$

The resulting operating frequency during ignition is given as:

$$f_{ign} = \frac{1}{2p}\sqrt{\frac{1+\frac{\frac{4}{p}V_{DC}}{V_{ign}}}{LC}} \quad \text{[Hz]} \qquad \textbf{(4)}$$

The total load current during ignition is given as:

$$I_{ign} = f_{ign} C V_{ign} 2p \quad \text{[App]} \qquad \textbf{(5)}$$

The operating frequency [Hz] at maximum lamp power is given as:

$$f_{100\%} = \frac{1}{2p}\sqrt{\frac{1}{LC} - \frac{32P_{100\%}^2}{C^2V_{100\%}^4} + \sqrt{\left[\frac{1}{LC} - \frac{32P_{100\%}^2}{C^2V_{100\%}^4}\right]^2 - 4\frac{1-\left(\frac{4V_{DC}}{V_{100\%}p}\right)^2}{L^2C^2}}} \qquad \textbf{(6)}$$

The cathode heating current at minimum lamp power is given as:

$$I_{Cath1\%} = \frac{V_{1\%} f_{1\%} pC}{\sqrt{2}} \qquad \textbf{(7)}$$

Design Constraints

The inductor and capacitor values should be iterated until the following design constraints have been fulfilled (Table II).

Design Constraint	Reason
$V_{ph} < V_{ph\max}$	Ignition during pre-heat
$f_{ph} - f_{ign} > 5kHz$	Production tolerances
$I_{ign} < I_{ign\max}$	Inductor saturation
$I_{Cath1\%} \geq I_{Cath\min}$	Lamp extinguishing during dimming

Table II, Ballast design constraints

IR2159 Programmable Inputs

In order to program the MIN and MAX settings of the dimming interface, the phase of the output stage current at minimum and maximum lamp power must be calculated. This is obtained using the following equations:

$$f_{\%} = \frac{1}{2p}\sqrt{\frac{1}{LC} - \frac{32P_{\%}^2}{C^2V_{\%}^4} + \sqrt{\left[\frac{1}{LC} - \frac{32P_{\%}^2}{C^2V_{\%}^4}\right]^2 - 4\frac{1-\left(\frac{4V_{DC}}{V_{\%}p}\right)^2}{L^2C^2}}} \quad \textbf{(8)}$$

$$j_{\%} = \frac{180}{p}\tan^{-1}\left[\left(\frac{V_{\%}^2}{2P_{\%}}C - \frac{2P_{\%}}{V_{\%}^2}L\right)2pf_{\%} - 4\frac{V_{\%}^2}{P_{\%}}LC^2p^3f_{\%}^3\right] \quad \textbf{(9)}$$

With the lamp requirements defined, the L and C of the ballast output stage selected, and the minimum and maximum phase calculated, the component values for setting the programmable inputs of the IR2159 are obtained with the following equations:

$$R_{FMIN} = \frac{(25e-6) - (f_{MIN} - 10000)\cdot(1e-10)}{(f_{MIN} - 10000)\cdot(2e-14)} \quad \text{[Ohms]} \ \textbf{(10)}$$

$$R_{CS} = \frac{2\cdot(1.6)}{I_{ign}} \quad \text{[Ohms]} \ \textbf{(11)}$$

$$R_{IPH} = R_{FMIN}R_{CS}I_{ph}\sqrt{2} \quad \text{[Ohms]} \ \textbf{(12)}$$

$$C_{CPH} = (2E-7)(t_{PH}) \quad \text{[Farads]} \ \textbf{(13)}$$

$$R_{MIN} = \frac{R_{FMIN}}{4}\left(1 - \frac{j_{1\%}}{45}\right) \quad \text{[Ohms]} \ \textbf{(14)}$$

$$R_{MAX} = \frac{R_{FMIN}\cdot R_{MIN}}{4\cdot R_{MIN} - R_{FMIN}\cdot\left(1 - \frac{j_{100\%}}{45}\right)} \quad \text{[Ohms]} \textbf{(15)}$$

This ballast design procedure has been summarized into the following 4 steps:

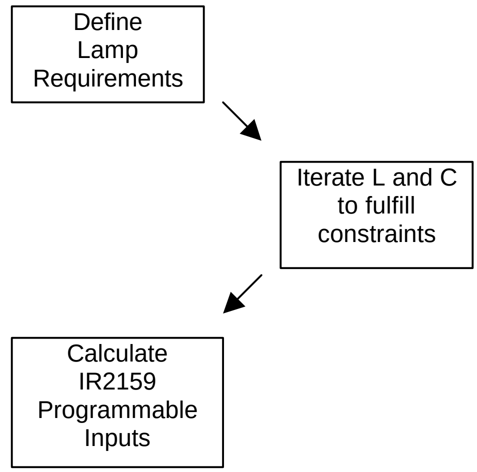


Figure 19, Simplified Ballast Design Procedure

IR2159 Demo Board Europe Version IRPLDIM1

Line Input Voltage: 185 to 265VAC
DC Bus Voltage: 400VDC
Lamp Power/Type: 36W/T8

1) Lamp Requirements

Typical high-frequency (25kHz) lamp requirements for the 36W/T8 lamp type are given as:

Variable	Value	Units
I_{ph}	0.6	Arms
t_{ph}	1.0	s
$V_{ph\max}$	600	Vpp
V_{ign}	1500	Vpp
$P_{\max}$	32	W
$V_{P\max}$	282	Vpp
$P_{\min}$	1	W
$V_{P\min}$	330	Vpp
$I_{Cath\min}$	0.35	Arms

Table III, 36W/T8 lamp requirements

2) Iterate L and C to Fulfill Constraints

To select the ballast output stage inductor and capacitor, a range of values were input into equations (2) through (7), which have been summarized in the following table:

L	[mH]	2.0	2.0	2.0
C	[nF]	6.8	8.2	10
V_{ph}	[Vpp]	700	622	546
f_{ph}	[kHz]	57	53	49
f_{ign}	[kHz]	51	46	42
I_{ign}	[App]	1.4	1.6	1.8
$f_{P\max}$	[kHz]	42	42	41
$I_{Cath\,P\min}$	[Arms]	0.32	0.35	0.38

Table IV, Ballast parameters for different C values.

When compared against the lamp requirements, a capacitor value of 6.8nF gives a lamp voltage during pre-heat that exceeds the maximum allowable specified for this lamp type. This can ignite the lamp before the cathodes have reached their emission temperature, drastically reducing lamp life. The pre-heat current can be reduced to give a lower pre-heat voltage, but the pre-heat time must then be increased for proper heating. Also, $I_{Cath\min}$ is too low, which will cause the lamp to extinguish at low light levels where the arc current alone is too low to heat the cathodes. Increasing the capacitor value to 10nF fulfills the lamp requirements quite well, even allowing some room in the pre-heat voltage for the pre-heat current to be increased and the pre-heat time shortened. During dimming, however, the lamp voltage increases with decreasing lamp power due to lamp negative incremental impedance effects. A maximum is reached around 10% brightness, after which the lamp voltage decreases as the lamp is further dimmed. The maximum filament current occurs at the maximum lamp voltage, which for a capacitor value of 10nF, is too high and will over-heat the filaments. A capacitor value of 8.2nF was chosen which fulfills the lamp requirements without over-heating the cathodes.

3) IR2159 Programmable Inputs

With all of the lamp requirements fulfilled, the component values for setting the programmable inputs of the IR2159 are calculated as:

Equation No.	Variable	Value
(8)	$f_{100\%}$	46kHz
(8)	$f_{1\%}$	58kHz
(9)	$j_{100\%}$	-56.12deg
(9)	$j_{1\%}$	-89.27deg
(10)	R_{FMIN}	33kOhm
(11)	R_{CS}	0.8 Ohm
(12)	R_{IPH}	24kOhm
(13)	C_{TPH}	330nF
(14)	R_{MIN}	27kOhm
(15)	R_{MAX}	24kOhm

Table V, IR2159 Programmable Inputs for T8/32W lamp.

Power Factor Correction (PFC) Stage

The 34262 PFC IC was selected for controlling the PFC stage. The 34262 includes a soft-start function that reduces excessive transients on the DC bus during start-up and ignition. For a 90 to 140VAC line input voltage range, a DC bus of 300VDC, and an output power of 32W, the PFC inductor and peak inductor current are calculated as follows:

$$L_{PFC} = \frac{V_{AC}^2 (V_{DC} - \sqrt{2} V_{DC}) h}{2 P_{out} V_{DC} f_s p} \quad [H] \quad \mathbf{(1)}$$

$$I_{L_p} = \frac{P_{out} 2\sqrt{2}}{V_{AC\,\min} h} \quad [Apk] \quad \mathbf{(2)}$$

Where,

h = PFC stage efficiency

V_{AC} = Nominal AC input voltage [VAC]

V_{DC} = DC bus voltage [VDC]

P_{out} = Output power [W]

f_s = Switching frequency [Hz]

Waveforms

Important Note: This demo board is intended as a demonstration of the functionality and performance of the IR2159 Dimming Ballast Control IC only. Adequate EMI filtering, line transient protection, galvanic dim control input isolation, and ballast and lamp life testing are not considered in this design.

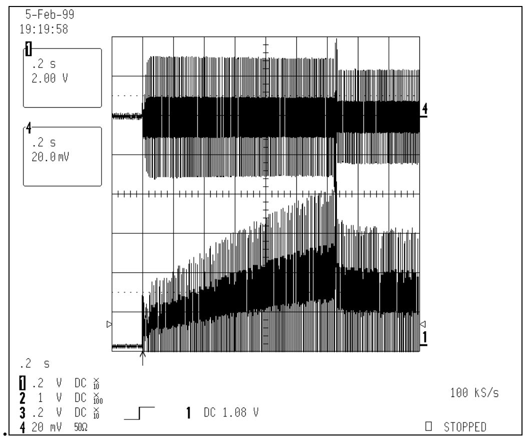


Figure 20, Pre-heat current and cathode voltage.

IR2159 Demo Board U.S. Version IRPLDIM1U

Line Input Voltage: 90 to 140VAC
DC Bus Voltage: 300VDC
Lamp Power/Type: 32W/T8

1) Lamp Requirements

Typical high-frequency (25kHz) lamp requirements for the 32W/T8 lamp type are given as:

Variable	Value	Units
I_{ph}	0.6	Arms
t_{ph}	1.0	s
$V_{ph\max}$	600	Vpp
V_{ign}	1300	Vpp
$P_{\max}$	30	W
$V_{P\max}$	400	Vpp
$P_{\min}$	1	W
$V_{P\min}$	330	Vpp
$I_{Cath\min}$	0.35	Arms

Table III, 32W/T8 lamp requirements

2) Iterate L and C to Fulfill Constraints

To select the ballast output stage inductor and capacitor, a range of values were input into equations (2) through (7), which have been summarized in the following table:

L	[mH]	2.0	2.0	2.0
C	[nF]	6.8	8.2	10
V_{ph}	[Vpp]	748	668	592
f_{ph}	[kHz]	53	49	46
f_{ign}	[kHz]	49	45	40
I_{ign}	[App]	1.4	1.5	1.7
$f_{P\max}$	[kHz]	49	46	43
$I_{Cath\,P\min}$	[Arms]	0.32	0.35	0.38

Table IV, Ballast parameters for different C values.

When compared against the lamp requirements, a capacitor value of 6.8nF gives a lamp voltage during pre-heat that exceeds the maximum allowable specified for this lamp type. This can ignite the lamp before the cathodes have reached their emission temperature, drastically reducing lamp life. The pre-heat current can be reduced to give a lower pre-heat voltage, but the pre-heat time must then be increased for proper heating. Also, $I_{Cath\min}$ is too low, which will cause the lamp to extinguish at low light levels where the arc current alone is too low to heat the cathodes. Increasing the capacitor value to 10nF fulfills the lamp requirements quite well, even allowing some room in the pre-heat voltage for the pre-heat current to be increased and the pre-heat time shortened. During dimming, however, the lamp voltage increases with decreasing lamp power due to lamp negative incremental impedance effects. A maximum is reached around 10% brightness, after which the lamp voltage decreases as the lamp is further dimmed. The maximum filament current occurs at the maximum lamp voltage, which for a capacitor value of 10nF, is too high and will over-heat the filaments. A capacitor value of 8.2nF was chosen which fulfills the lamp requirements without over-heating the cathodes.

3) IR2159 Programmable Inputs

With all of the lamp requirements fulfilled, the component values for setting the programmable inputs of the IR2159 are calculated as:

Equation No.	Variable	Value
(8)	$f_{100\%}$	46kHz
(8)	$f_{1\%}$	58kHz
(9)	$j_{100\%}$	-56.12deg
(9)	$j_{1\%}$	-89.27deg
(10)	R_{FMIN}	36kOhm
(11)	R_{CS}	1.0 Ohm
(12)	R_{IPH}	22kOhm
(13)	C_{TPH}	330nF
(14)	R_{MIN}	27kOhm
(15)	R_{MAX}	24kOhm

Table V, IR2159 Programmable Inputs for T8/32W lamp.

Power Factor Correction (PFC) Stage

The 34262 PFC IC was selected for controlling the PFC stage. The 34262 includes a soft-start function that reduces excessive transients on the DC bus during start-up and ignition. For a 90 to 140VAC line input voltage range, a DC bus of 300VDC, and an output power of 32W, the PFC inductor and peak inductor current are calculated as follows:

$$L_{PFC} = \frac{V_{AC}^2 (V_{DC} - \sqrt{2} V_{DC}) h}{2 P_{out} V_{DC} f_s p} \quad \text{[H]} \quad \textbf{(1)}$$

$$I_{L_p} = \frac{P_{out} 2\sqrt{2}}{V_{AC\,\min} h} \quad \text{[Apk]} \quad \textbf{(2)}$$

Where,

h = PFC stage efficiency

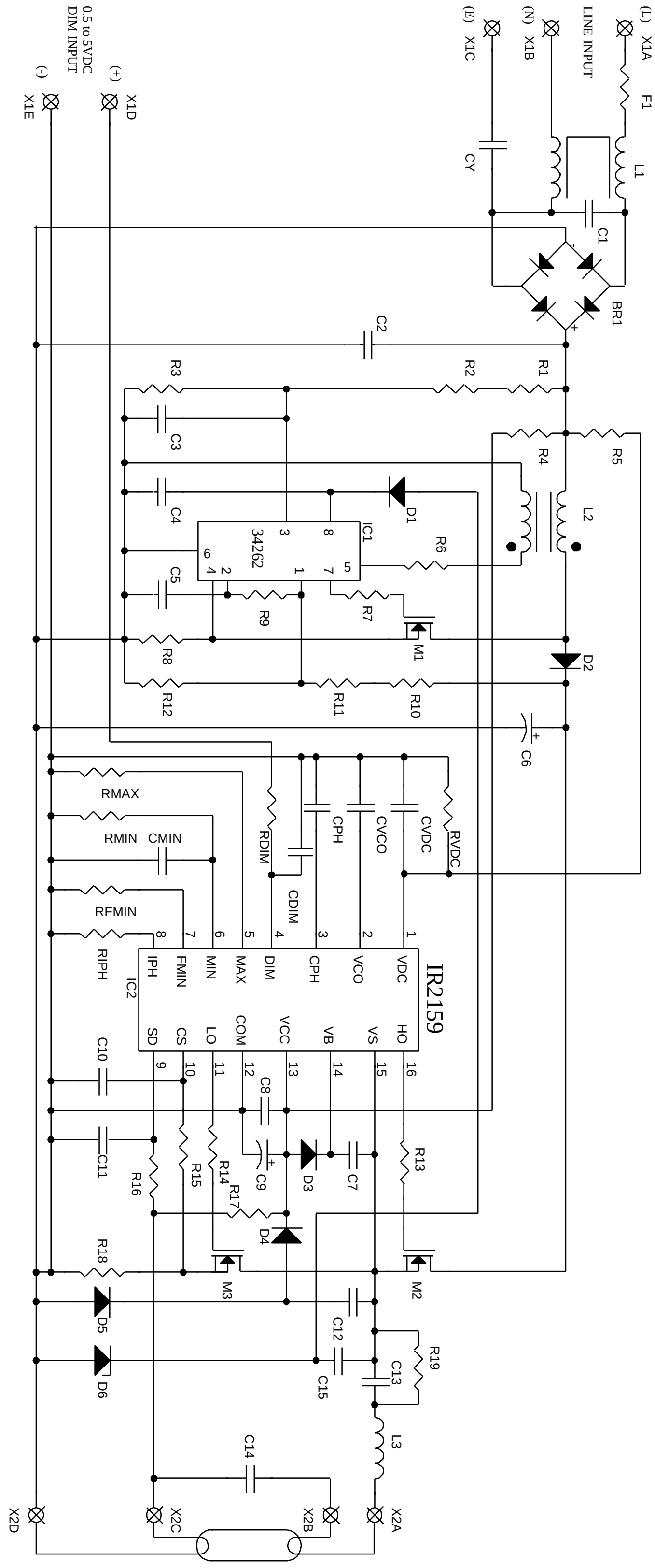
V_{AC} = Nominal AC input voltage [VAC]

V_{DC} = DC bus voltage [VDC]

P_{out} = Output power [W]

f_s = Switching frequency [Hz]

IR2159 Demo Board IRPLDIM1 Schematic



Bill of Materials European Version IRPLDIM1

Line Input Voltage Range: 185 to 265VAC Lamp Type/Power: T8/36W

Item	Qty	Reference	Description	Manufacturer	Part Number
1	1	BR1	Bridge Rectifier, 1A, 1000V	International Rectifier	DF10S
2	1	RVDC	Resistor, 56K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ56KV
3	2	C4,C5	Capacitor, 0.47uF, SMT 1206	Panasonic	ECJ-3YB1E474K
4	3	CVCO,C3,CDIM	Capacitor, 0.01uF, SMT 1206	Panasonic	ECU-V1H103KBM
5	1	C1	Capacitor, 0.33uF, 275VAC	Roederstein	F1772433-2200
6	2	C2,C13	Capacitor, 0.1uF, 400VDC	Wima	MKP10
7	4	C7,C8,C11,CMIN	Capacitor, 0.1uF, SMT 1206	Panasonic	ECJ-3VB1E104K
8	2	CCPH,CVDC	Capacitor, 0.33uF, SMT 1206	Panasonic	ECJ-3VB1E334K
9	1	C6	Capacitor, 10uF, 450VDC,105C	Panasonic	EEU-EB2V100
10	1	C9	Capacitor, 4.7uF, 25VDC,105C	Panasonic	EEU-FC1H4R7
11	1	C10	Capacitor, 470pF, SMT 1206	Panasonic	ECU-V1H471KBM
12	2	C12,C15	Capacitor, 1nF,1KV, SMT 1812	Johanson	102S43W102KV4
13	1	C14	Capacitor, 10nF, 1600VDC	Panasonic	ECW-H16102JV
14	3	D1,D4,D5	Diode, 1N4148, SMT DL35	Diodes	LL4148
15	2	D2,D3	Diode, SMT SMB	International Rectifier	10DF60
16	1	D6	Zener Diode, 20V, SMT DL35	Motorola	MMSZ4702T1
17	1	IC1	IC, Power Factor Controller	Motorola	34262
18	1	IC2	IC, Dimming Ballast Controller	International Rectifier	IR2159
19	1	L1	EMI Inductor, 1x10mH, 0.7A	Panasonic	ELF-15N007A
20	1	L2	PFC Inductor, 2.0mH, 2.0Apk	RG Allen	RGA-EF25
21	1	L3	Inductor, 2.0mH, 2.0Apk	RG Allen	RGA-97408C
22	3	M1,M2,M3	Transistor, MOSFET	International Rectifier	IRF820
23	1	R15	Resistor, 1K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ1KV
24	1	RFMIN	Resistor, 33K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ33KV
25	1	RDIM	Resistor, 10K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ10KV
26	2	RIPH,RMAX	Resistor, 24K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ24KV
27	2	RVDC,RMIN	Resistor, 27K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ27KV
29	1	R12	Resistor, 10K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ10KV
30	2	R1,R2	Resistor, 680K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ680KV
31	1	R3	Resistor, 7.5K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ7.5KV
32	1	R4	Resistor, 470K Ohm	Yageo	470KQBK
33	1	R5	Resistor, 1M Ohm	Yageo	
34	1	R6	Resistor, 22K Ohm, SMT 1206	Panasonic	ERJ-8GEY22KV
35	3	R7,R13,R14	Resistor, 22 Ohm, SMT 1206	Panasonic	ERJ-8GEY22V
36	1	F1	Resistor, 0.5 Ohm, ½ Watt	Dale	CW-1/2
37	2	R9,R16	Resistor, 100K Ohm, SMT 1206	Panasonic	ERJ-8GEY100KV
38	2	R10,R11	Resistor, 820K Ohm, SMT 1206	Panasonic	ERJ-8GEY820KV
39	1	R17	Resistor, 1M Ohm, SMT 1206	Panasonic	ERJ-8GEY1MV
40	1	R8	Resistor, 1 Ohm, ¼ Watt	Yageo	1.0QBK

41	1	R18	Resistor, 0.8 Ohm, ¼ Watt	Yageo	1.0QBK
42	1	R19	Resistor, 100K Ohm, ¼ Watt	Yageo	
43	1	X1	Connector, 5 terminal	Wago	
44	1	X2	Connector, 4 terminal	Wago	236-404
45	1	J1	Jumper		
Total	**65**				

Bill of Materials U.S. Version IRPLDIM1U

Line Input Voltage Range: 90 to 140VAC   Lamp Type/Power: T8/32W

Item	Qty	Reference	Description	Manufacturer	Part Number
1	1	BR1	Bridge Rectifier, 1A, 1000V	International Rectifier	DF10S
2	2	C4,C5	Capacitor, 0.47uF, SMT 1206	Panasonic	ECJ-3YB1E474K
3	3	CVCO,C3,CDIM	Capacitor, 0.01uF, SMT 1206	Panasonic	ECU-V1H103KBM
4	1	C1	Capacitor, 0.33uF, 275VAC	Roederstein	F1772433-2200
5	2	C2,C13	Capacitor, 0.1uF, 400VDC	Wima	MKP10
6	4	C7,C8,C11,CMIN	Capacitor, 0.1uF, SMT 1206	Panasonic	ECJ-3VB1E104K
7	2	CCPH,CVDC	Capacitor, 0.33uF, SMT 1206	Panasonic	ECJ-3VB1E334K
8	1	C6	Capacitor, 10uF, 350VDC,105C	Panasonic	EEU-EB2V100
9	1	C9	Capacitor, 4.7uF, 25VDC,105C	Panasonic	EEU-FC1H4R7
10	1	C10	Capacitor, 470pF, SMT 1206	Panasonic	ECU-V1H471KBM
11	2	C12,C15	Capacitor, 1nF,1KV, SMT 1812	Johanson	102S43W102KV4
12	1	C14	Capacitor, 8.2nF, 1600VDC	Panasonic	ECW-H16822JV
13	3	D1,D4,D5	Diode, 1N4148, SMT DL35	Diodes	LL4148
14	2	D2,D3	Diode, SMT SMB	International Rectifier	10DF60
15	1	D6	Zener Diode, 20V, SMT DL35	Motorola	MMSZ4702T1
16	1	IC1	IC, Power Factor Controller	Motorola	34262
17	1	IC2	IC, Dimming Ballast Controller	International Rectifier	IR2159
18	1	L1	EMI Inductor, 1x10mH, 0.7A	Panasonic	ELF-15N007A
19	1	L2	PFC Inductor, 2.0mH, 2.0Apk	RG Allen	RGA-EF25
20	1	L3	Inductor, 2.0mH, 2.0Apk	RG Allen	RGA-97408C
21	2	M2,M3	Transistor, MOSFET	International Rectifier	IRF720
22	1	M1	Transistor, MOSFET	International Rectifier	IRF730
23	1	R15	Resistor, 1K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ1KV
24	1	RFMIN	Resistor, 36K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ36KV
25	1	RDIM	Resistor, 10K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ10KV
26	1	RMAX	Resistor, 24K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ24KV
27	1	RMIN	Resistor, 27K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ27KV
28	1	RVDC	Resistor, 47K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ47KV
29	1	RIPH	Resistor, 22K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ22KV
30	1	R12	Resistor, 13K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ13KV
31	2	R1,R2	Resistor, 680K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ680KV
32	1	R3	Resistor, 7.5K Ohm, SMT 1206	Panasonic	ERJ-8GEYJ7.5KV
33	1	R4	Resistor, 330K Ohm	Yageo	330KQBK
34	1	R5	Resistor, 1M Ohm	Yageo	
35	1	R6	Resistor, 22K Ohm, SMT 1206	Panasonic	ERJ-8GEY22KV
36	3	R7,R13,R14	Resistor, 22 Ohm, SMT 1206	Panasonic	ERJ-8GEY22V
37	1	F1	Resistor, 0.5 Ohm, ½ Watt	Dale	CW-1/2
38	2	R9,R16	Resistor, 100K Ohm, SMT 1206	Panasonic	ERJ-8GEY100KV

39	2	R10,R11	Resistor, 820K Ohm, SMT 1206	Panasonic	ERJ-8GEY820KV
40	1	R17	Resistor, 1M Ohm, SMT 1206	Panasonic	ERJ-8GEY1MV
41	1	R8	Resistor, 0.5 Ohm, ¼ Watt	Yageo	1.0QBK
42	1	R18	Resistor, 1.0 Ohm, ¼ Watt	Yageo	1.0QBK
43	1	R19	Resistor, 100K Ohm, ¼ Watt	Yageo	
44	1	X1	Connector, 5 terminal	Wago	
45	1	X2	Connector, 4 terminal	Wago	236-404
46	1	J1	Jumper		
Total	**65**				

International Rectifier

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IR CANADA: 7321 Victoria Park Ave., Suite 201, Markham, Ontario L3R 2Z8, Tel: (905) 475 1897
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