

# Off-line Power Supply Controller

## FEATURES

- Transformerless Off-line Power Supply
- Wide 100VDC to 400VDC Allowable Input Range
- Fixed 5VDC or Adjustable Low Voltage Output
- Output Sinks 200mA, Sources 150mA Into a MOSFET Gate
- Uses Low Cost SMD Inductors
- Short Circuit Protected
- Optional Isolation Capability

## DESCRIPTION

The UCC3888 controller is optimized for use as an off-line, low power, low voltage, regulated bias supply. The unique circuit topology utilized in this device can be visualized as two cascaded flyback converters, each operating in the discontinuous mode, both driven from a single external power switch. The significant benefit of this approach is the ability to achieve voltage conversion ratios as high as 400V to 2.7V with no transformer and low internal losses.

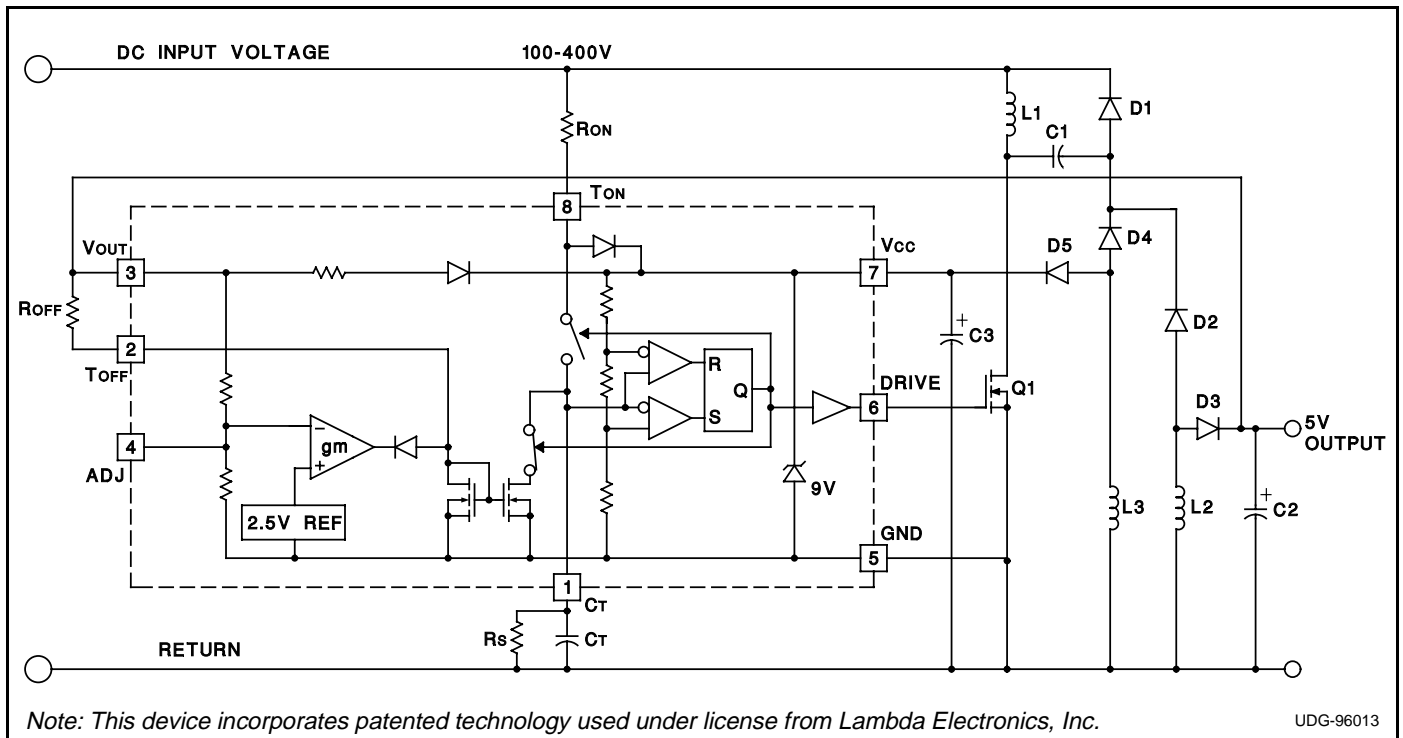
The control algorithm utilized by the UCC3888 sets the switch on time inversely proportional to the input line voltage and sets the switch off time inversely proportional to the output voltage. This action is automatically controlled by an internal feedback loop and reference. The cascaded configuration allows a voltage conversion from 400V to 2.7V to be achieved with a switch duty cycle of 7.6%. This topology also offers inherent short circuit protection since as the output voltage falls to zero, the switch off time approaches infinity.

The output voltage is set internally to 5V. It can be programmed for other output voltages with two external resistors. An isolated version can be achieved with this topology as described further in Unitrode Application Note U-149.

## OPERATION

With reference to the application diagram below, when input voltage is first applied, the current through  $R_{ON}$  into  $T_{ON}$  is directed to  $V_{CC}$  where it charges the external capacitor,  $C_3$ , connected to  $V_{CC}$ . As voltage builds on  $V_{CC}$ , an internal undervoltage lockout holds the circuit off and the output at  $DRIVE$  low until  $V_{CC}$  reaches 8.4V. At this time,  $DRIVE$  goes high turning on the power switch,  $Q_1$ , and redirecting the current into  $T_{ON}$  to the timing capacitor,  $C_T$ .  $C_T$  charges to a fixed threshold with a current  $I_{CHG} = 0.8 \cdot (V_{IN} - 4.5V) / R_{ON}$ . Since  $DRIVE$  will only be high for as long as  $C_T$  charges, the power switch on time will be inversely proportional to line voltage. This provides a constant (line voltage)  $\cdot$  (switch on time) product.

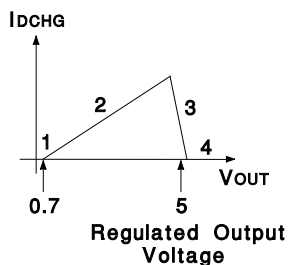
## TYPICAL APPLICATION



## OPERATION (cont.)

At the end of the on time, Q1 is turned off and the current through RON is again diverted to VCC. Thus the current through RON, which charges CT during the on time, contributes to supplying power to the chip during the off time.

The power switch off time is controlled by the discharge of CT which, in turn, is programmed by the regulated output voltage. The relationship between CT discharge current, IDCHG, and output voltage is illustrated as follows:



Region 1. When  $V_{OUT} = 0$ , the off time is infinite. This feature provides inherent short circuit protection. However, to ensure output voltage startup when the output is not a short, a high value resistor,  $R_S$ , is placed in parallel with  $C_T$  to establish a minimum switching frequency.

Region 2. As  $V_{OUT}$  rises above approximately 0.7V to its regulated value,  $IDCHG$  is defined by  $R_{OFF}$ , and is equal to:

$$IDCHG = (V_{OUT} - 0.7V) / R_{OFF}$$

As  $V_{OUT}$  increases,  $IDCHG$  increases reducing off time. The operating frequency increases and  $V_{OUT}$  rises quickly to its regulated value.

Region 3. In this region, a transconductance amplifier reduces  $IDCHG$  in order to maintain a regulated  $V_{OUT}$ .

Region 4. If  $V_{OUT}$  should rise above its regulation range,  $IDCHG$  falls to zero and the circuit returns to the minimum frequency established by  $R_S$  and  $C_T$ .

The range of switching frequencies is established by  $R_{ON}$ ,  $R_{OFF}$ ,  $R_S$ , and  $C_T$  as follows:

$$\text{Frequency} = 1 / (T_{ON} + T_{OFF})$$

$$T_{ON} = R_{ON} \cdot C_T \cdot 4.6 V / (V_{IN} - 4.5V)$$

$$T_{OFF} (\text{max}) = 1.4 \cdot R_S \cdot C_T$$

Regions 1 and 4

$$T_{OFF} = R_{OFF} \cdot C_T \cdot 3.7V / (V_{OUT} - 0.7V)$$

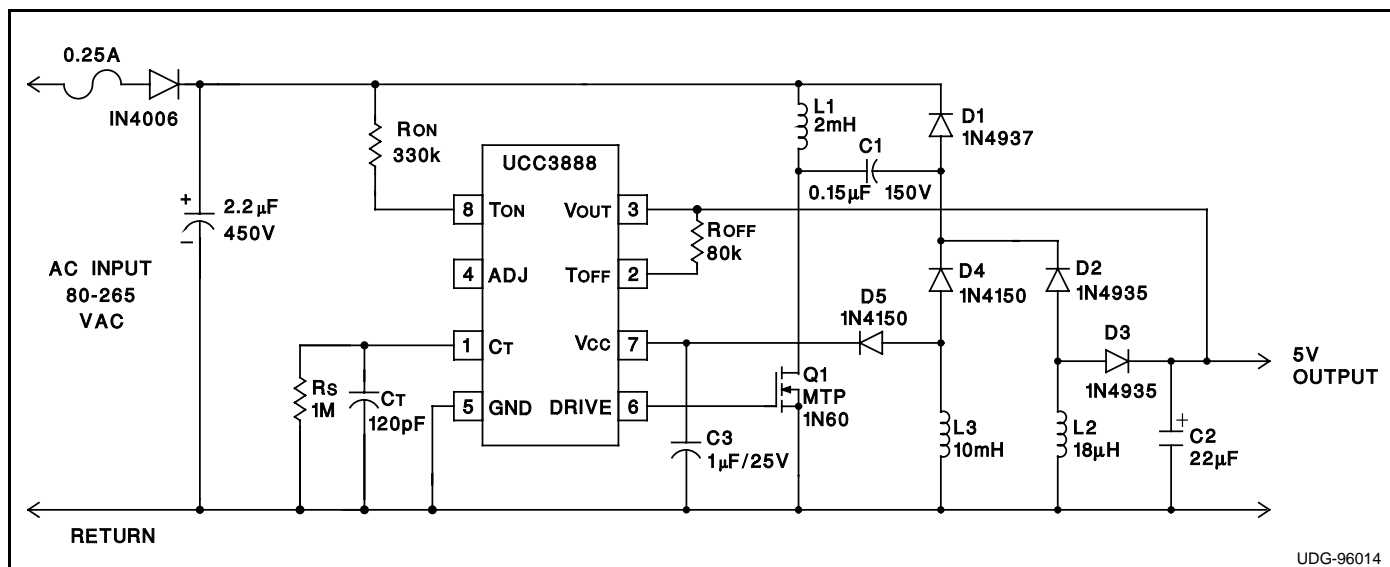
Region 2, excluding the effects of  $R_S$

which have a minimal impact on  $T_{OFF}$ .

The above equations assume that  $V_{CC}$  equals 9V. The voltage at  $T_{ON}$  increases from approximately 2.5V to 6.5V while  $C_T$  is charging. To take this into account,  $V_{IN}$  is adjusted by 4.5V in the calculation of  $T_{ON}$ . The voltage at  $T_{OFF}$  is approximately 0.7V.

## DESIGN EXAMPLE

The UCC3888 regulates a 5 volt, 1 Watt nonisolated DC output from AC inputs between 80 and 265 volts. In this example, the IC is programmed to deliver a maximum on time gate drive pulse width of 2.2 microseconds which occurs at 80 VAC. The corresponding switching frequency is approximately 100kHz at low line, and overall efficiency is approximately 50%. Additional design information is available in Unitorde Application Note U-149.



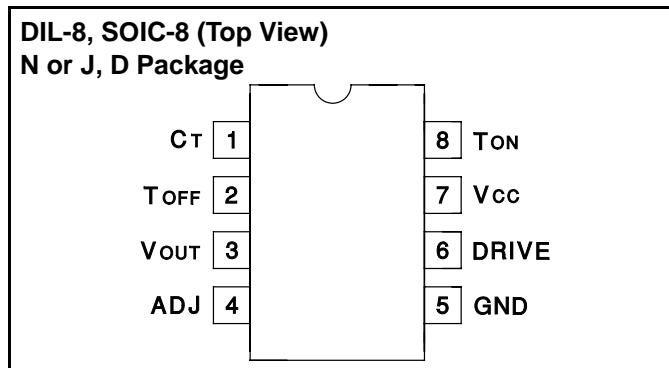
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## ABSOLUTE MAXIMUM RATINGS

I <sub>CC</sub> .....	8mA
Current into TON Pin .....	1.5mA
Voltage on VOUT Pin .....	20V
Current into TOFF Pin .....	250µA
Storage Temperature .....	-65°C to +150°C

Note: Unless otherwise indicated, voltages are referenced to ground and currents are positive into, negative out of, the specified terminals.

## CONNECTION DIAGRAM



**ELECTRICAL CHARACTERISTICS** Unless otherwise stated, these specifications hold for T<sub>A</sub> = 0°C to 70°C for the UCC3888, -40°C to +85°C for the UCC2888, and -55°C to +125°C for the UCC1888. No load at DRIVE pin (C<sub>LOAD</sub>=0).

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
<b>General</b>					
V <sub>CC</sub> Zener Voltage	I <sub>CC</sub> < 1.5mA	8.6	9.0	9.3	V
Startup Current	V <sub>OUT</sub> = 0		150	250	µA
Operating Current I(V <sub>CC</sub> )	V <sub>CC</sub> = V <sub>CC(zener)</sub> – 100mV, F = 150kHz		1.2	2.5	mA
<b>Under-Voltage-Lockout</b>					
Start Threshold	V <sub>OUT</sub> = 0	8.0	8.4	8.8	V
Minimum Operating Voltage after Start	V <sub>OUT</sub> = 0	6.0	6.3	6.6	V
Hysteresis	V <sub>OUT</sub> = 0	1.8			V
<b>Oscillator</b>					
Amplitude	V <sub>CC</sub> = 9V	3.5	3.7	3.9	V
C <sub>T</sub> to DRIVE high Propagation Delay	Overdrive = 0.2V		100	200	ns
C <sub>T</sub> to DRIVE low Propagation Delay	Overdrive = 0.2V		50	100	ns
<b>Driver</b>					
VOL	I = 20mA, V <sub>CC</sub> = 9V		0.15	0.4	V
	I = 100mA, V <sub>CC</sub> = 9V		0.7	1.8	V
VOH	I = –20mA, V <sub>CC</sub> = 9V	8.5	8.8		V
	I = –100mA, V <sub>CC</sub> = 9V	6.1	7.8		V
Rise Time	C <sub>LOAD</sub> = 1nF		35	70	ns
Fall Time	C <sub>LOAD</sub> = 1nF		30	60	ns
<b>Line Voltage Detection</b>					
Charge Coefficient: I <sub>CHG</sub> / I(TON)	V <sub>CT</sub> = 3V, DRIVE = High, I(TON) = 1mA	0.73	0.79	0.85	
Minimum Line Voltage for Fault	R <sub>ON</sub> = 330k	60	80	100	V
Minimum Current I(TON) for Fault	R <sub>ON</sub> = 330k		220		µA
On Time During Fault	C <sub>T</sub> = 150pF, V <sub>LINE</sub> = Min – 1V		2		µs
Oscillator Restart Delay after Fault			0.5		ms
<b>Vout Error Amp</b>					
V <sub>OUT</sub> Regulated 5V (ADJ Open)	V <sub>CC</sub> = 9V, I <sub>DCHG</sub> = I(TOFF)/2	4.5	5.0	5.5	V
Discharge Ratio: I <sub>DCHG</sub> / I(TOFF)	I(TOFF) = 50µA	0.95	1.01	1.07	
Voltage at TOFF	I(TOFF) = 50µA	0.6	0.95	1.3	V
Regulation gm (Note 1)	Max I <sub>DCHG</sub> = 50µA		2.4		mA/V
	Max I <sub>DCHG</sub> = 125µA	1.9	4.1	7.0	mA/V

Note 1: gm is defined as  $\frac{\Delta I_{DCHG}}{\Delta V_{OUT}}$  for the values of V<sub>OUT</sub> when V<sub>OUT</sub> is in regulation. The two points used to calculate gm are for I<sub>DCHG</sub> at 65% and 35% of its maximum value.

## PIN DESCRIPTIONS

**ADJ:** The ADJ pin is used to provide a 5V regulated supply without additional external components. Other output voltages can be obtained by connecting a resistor divider between VOUT, ADJ and GND. Use the formula

$$V_{OUT} = 2.5V \cdot \frac{R1 + R2}{R2}$$

where R1 is connected between VOUT and ADJ, and R2 is connected between ADJ and GND.  $R1 \parallel R2$  should be less than  $1k\Omega$  to minimize the effect of the temperature coefficient of the internal 30k resistors which also connect to VOUT, ADJ, and GND. See Block Diagram.

**CT (timing capacitor):** The signal voltage at CT has a peak-to-peak swing of 3.7V for 9V VCC. As the voltage at CT crosses the oscillator upper threshold, DRIVE goes low. As the voltage on CT crosses the oscillator lower threshold, DRIVE goes high.

**DRIVE:** This output is a CMOS stage capable of sinking 200mA peak and sourcing 150mA peak. The output voltage swing is 0 to VCC.

**GND (chip ground):** All voltages are measured with respect to GND.

**TOFF (regulated output control):** TOFF sets the discharge current of the timing capacitor through an external resistor connected between VOUT and TOFF.

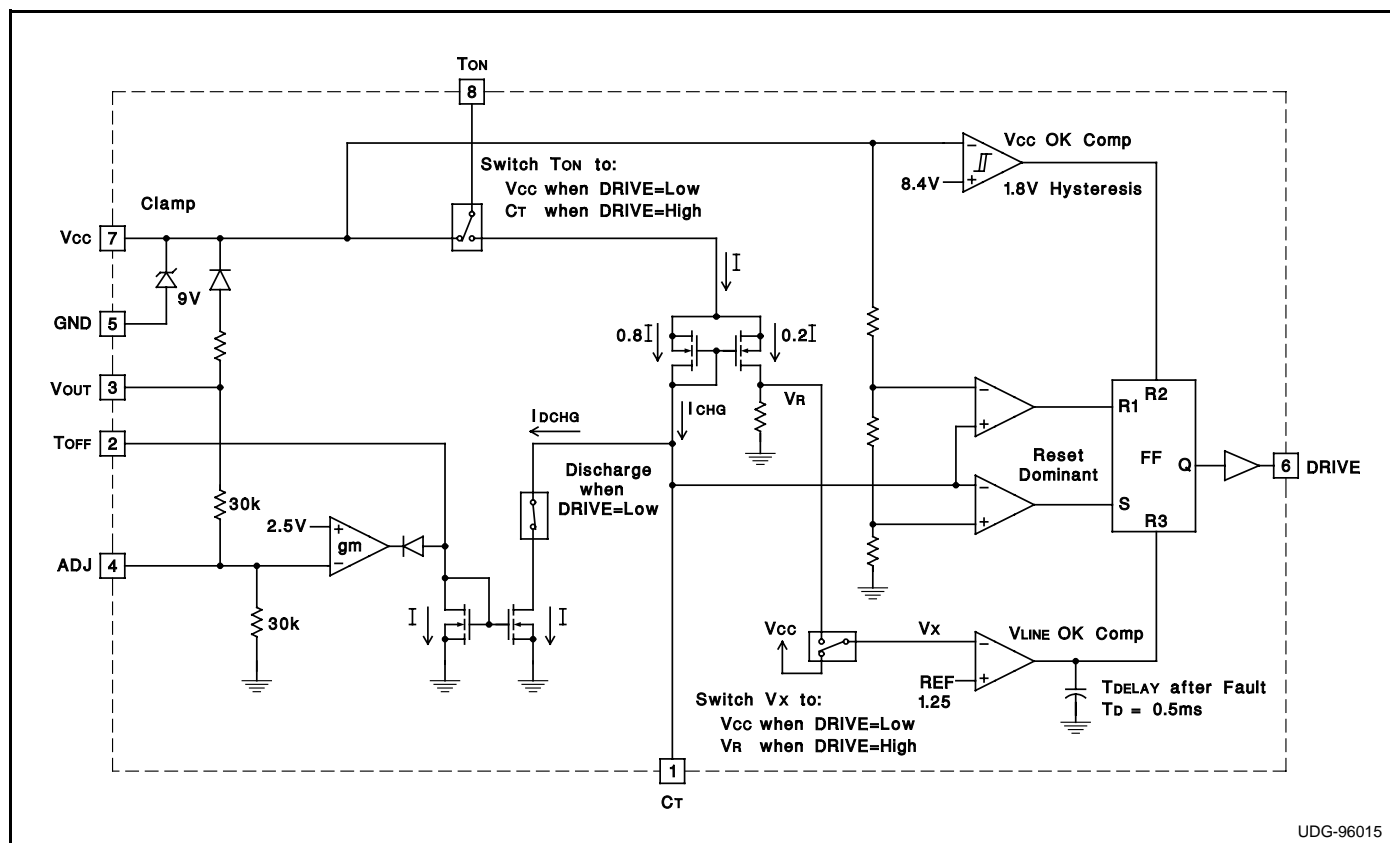
**TON (line voltage control):** TON serves three functions. When CT is discharging (off time), the current through TON is routed to VCC. When CT is charging (on time), the current through TON is split 80% to set the CT charge time and 20% to sense minimum line voltage which occurs for a TON current of  $220\mu A$ . For a minimum line voltage of 80V, RON is  $330k\Omega$ .

The CT voltage slightly affects the value of the charge current during the on time. During this time, the voltage at the TON pin increases from 2.5V to 6.5V.

**VCC (chip supply voltage):** The supply voltage of the device at pin VCC is internally clamped at 9V. The device needs an external supply, from a source such as the rectified AC line or derived from the switching circuit. Precautions must be taken to ensure that total ICC does not exceed 8mA.

**VOUT (regulated output):** The VOUT pin is directly connected to the power supply output voltage. When VOUT is greater than VCC, VOUT bootstraps VCC.

## BLOCK DIAGRAM



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TYPICAL CHARACTERISTICS CURVES

