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**PRIMARY SIDE POWER SWITCHER FOR OFF-LINE SMPS**
**Description**

The AP3988 is a performance enhanced power switcher for power supplies with better conversion efficiency, better voltage & current accuracy, and improved protection functions. Typical applications include charger, adapter for ADSL, home appliance power supply, LED lighting power supply and PC auxiliary power supplies. The controller regulates the output voltage and current in the primary side by piece-wise Pulse Frequency Modulation (p-PFM) in discontinuous conduction mode (DCM). The system operating frequency reduces linearly from heavy load to light load in each interval of the p-PFM, and enters constant current mode when the load current equals to the maximum system output current.

The AP3988 provides operating frequency dithering function to improve EMC performance of power supply. It also has built-in fixed cable voltage drop compensation (5% of nominal system output voltage) and adjustable line voltage compensation.

The AP3988 solution has fewer component number, smaller size, and lower total cost.

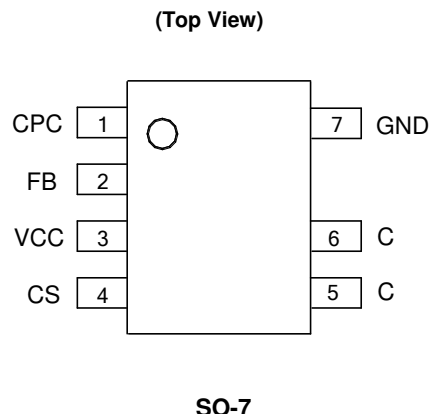
The AP3988 is packaged in SO-7.

**Features**

- Primary Side Control for Eliminating Opto-coupler and Secondary CV/CC Control Circuitry
- Built-in NPN Transistor with 700V<sub>CBO</sub>
- Low Start-up Current: 0.2μA (Typ.)
- Internal Output Cable Voltage Drop Compensation
- Hiccup Function to Improve Short Circuit Protection
- Better Over Voltage Protection
- Better Over Temperature Protection
- Low Total Cost Solution
- Output Power Range (Note 1): for 5.5W Adapter
- **Totally Lead-free & Fully RoHS Compliant (Note 2 & 3)**
- **Halogen and Antimony Free. "Green" Device (Note 4)**

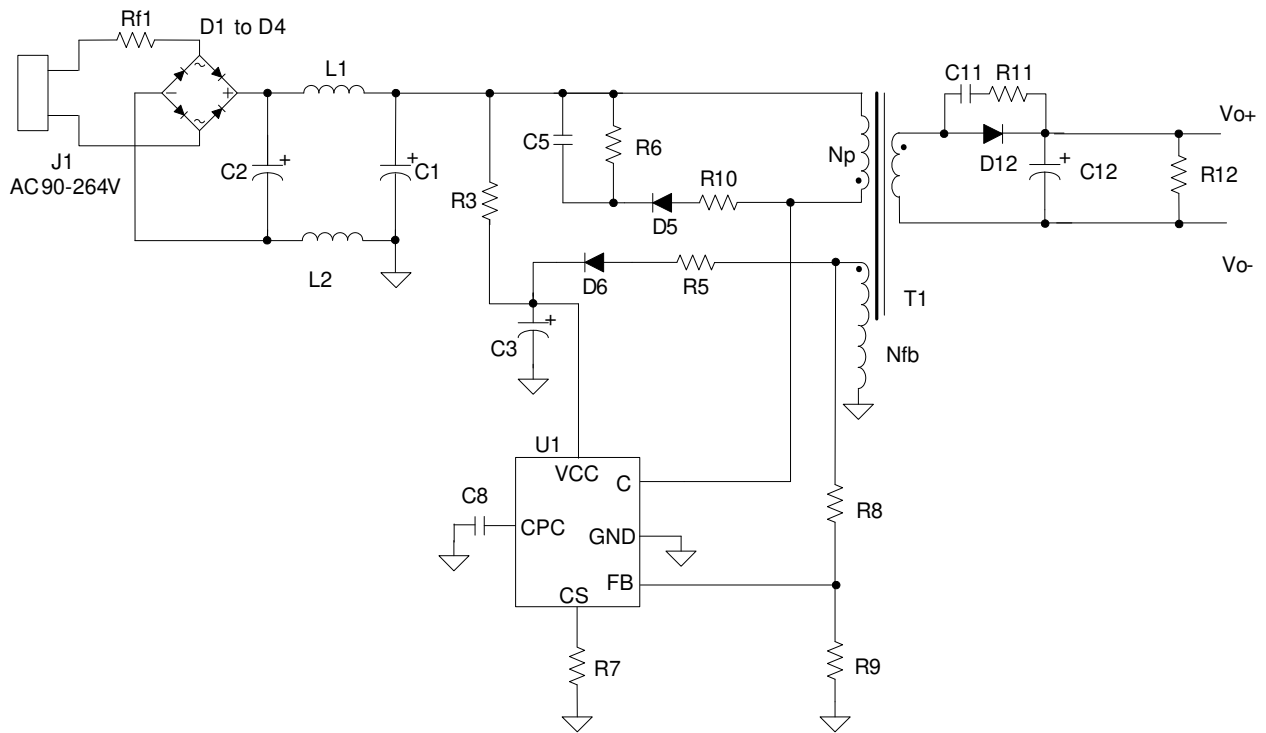
Notes:

1. Typical continuous power in a non-ventilated enclosed adapter measured at +50°C ambient.
2. No purposely added lead. Fully EU Directive 2002/95/EC (RoHS) & 2011/65/EU (RoHS 2) compliant.
3. See [http://www.diodes.com/quality/lead\\_free.html](http://www.diodes.com/quality/lead_free.html) for more information about Diodes Incorporated's definitions of Halogen- and Antimony-free, "Green" and Lead-free.
4. Halogen- and Antimony-free "Green" products are defined as those which contain <900ppm bromine, <900ppm chlorine (<1500ppm total Br + Cl) and <1000ppm antimony compounds.

**Pin Assignments**

**Applications**

- Adapters
- Set Top Boxes
- Appliances

## Typical Applications Circuit



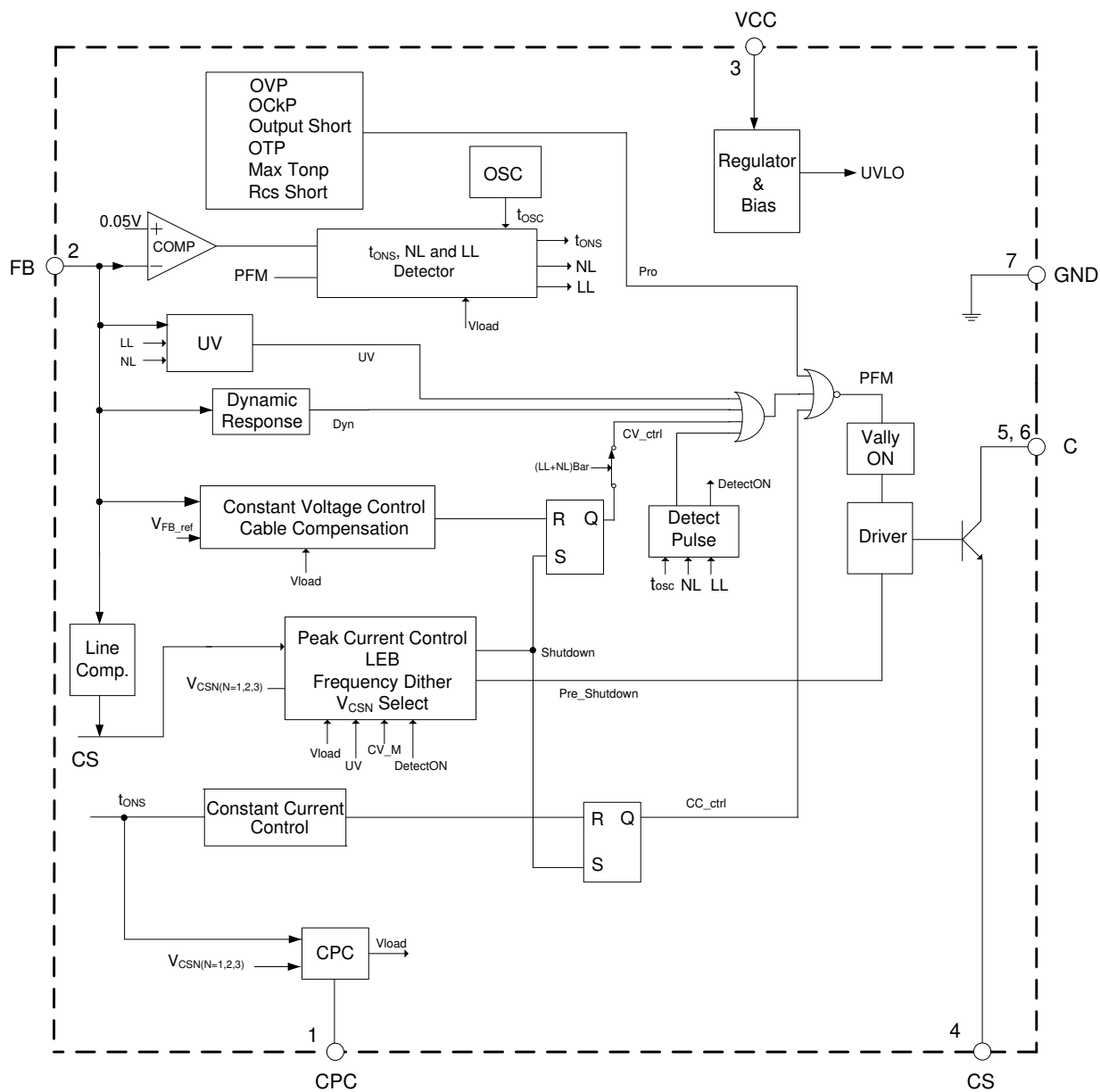
For AP3988 (5V/1A)

Item	Function	QTY	Item	Function	QTY
C1,C2	4.7μF/400V, electrolytic	2	Rf1	10Ω/1W, fuse resistor	1
C3	4.7μF/50V, electrolytic	1	R3	3.3MΩ/0.25W	1
C5	1nF/250V, ceramic	1	R5	3.9Ω, 0805	1
C8	0.01μF, 0805	1	R6	150kΩ, 1206	1
C11	1nF, 0805	1	R7	2.7Ω, 1206	1
C12	680μF/10V	1	R8	75kΩ, 0805	1
D1 to D6	1N4007, rectifier diode	6	R9	43kΩ, 0805	1
D12	APD340, Schottky diode	1	R10	200Ω, 0805	1
L1	1mH, inductor	1	R11	27Ω, 0805	1
L2	Bead, 0805	1	R12	1.5kΩ, 0805	1
U1	AP3988, SO-7	1	T1	EE13 core, PC40, transformer	1

## Pin Descriptions

Pin Number	Pin Name	Function
1	CPC	This pin connects a capacitor to GND for output cable compensation
2	FB	The voltage feedback from auxiliary winding
3	VCC	This pin receives rectified voltage from the auxiliary winding of the transformer
4	CS	Current sense for primary side of transformer
5, 6	C	This pin is connected with an internal power BJT's collector
7	GND	This pin is the signal reference ground

## Functional Block Diagram





## Absolute Maximum Ratings (Note 5)

Symbol	Parameter	Rating	Unit
$V_{CC}$	Supply Voltage	-0.3 to 30	V
$V_{CS}, V_{CPC}$	Voltage on CS, CPC Pin	-0.3 to 7	V
$V_{FB}$	FB Input Voltage	-0.3 to 8	V
$V_{CBO}$	Collector-emitter Voltage	700	V
$I_{CDC}$	Collector DC Current	1.5	A
$T_J$	Operating Junction Temperature	+150	°C
$T_{STG}$	Storage Temperature	-65 to +150	°C
$T_{LEAD}$	Lead Temperature (Soldering, 10 sec)	+300	°C
–	ESD (Machine Model)	200	V
–	ESD (Human Body Model)	2000	V
$P_D$	Total Power Dissipation	0.7	W

Note 5: Stresses greater than those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “Recommended Operating Conditions” is not implied. Exposure to “Absolute Maximum Ratings” for extended periods may affect device reliability.

## Recommended Operating Conditions

Symbol	Parameter	Min	Max	Unit
$V_{CC}$	Supply Voltage	–	25	V
$T_{OP}$	Operating Temperature Range	-40	+85	°C
$f_{S(MAX)}$	Maximum Operating Frequency	–	60	kHz

## Thermal Impedance (Note 6)

Symbol	Parameter	Value	Unit
$\theta_{JA}$	Junction to Ambient	140	°C/W
$\theta_{JC}$	Junction to Case	70	

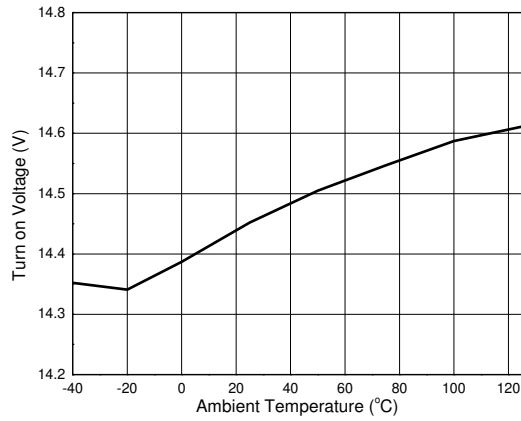
Note 6: When mounted a standard single-sided FR4 board with 300mm<sup>2</sup> Cu (at least 35µm thick) connected to CS pin and all collectors.

**Electrical Characteristics** (@V<sub>CC</sub>=15V, T<sub>J</sub>=+25°C, unless otherwise specified.)

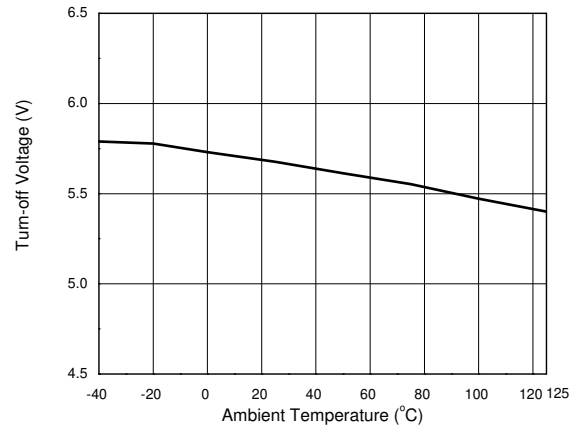
Symbol	Parameters	Conditions	Min	Typ	Max	Unit
STARTUP AND UVLO SECTION						
V <sub>TH_ST</sub>	Turn-on Voltage	–	13	15	17	V
V <sub>OPR(MIN)</sub>	Turn-off Voltage	–	5.2	5.8	6.4	V
STANDBY CURRENT SECTION						
I <sub>ST</sub>	Turn-on Current	V <sub>CC</sub> =V <sub>TH_ST</sub> -1V before startup	0	0.2	0.6	μA
I <sub>CC_OPR</sub>	Operating Current	Static current @ no load	550	650	750	
OPERATING FREQUENCY SECTION (5% LOAD TO FULL LOAD)						
f <sub>S(MAX)</sub>	Operating Frequency in Full Load Condition	–	–	–	60	kHz
Δf/f	Frequency Dithering	5% to 100% of full load range	4.5	5	5.5	%
OPERATING FREQUENCY SECTION (NO LOAD TO 5% OF I <sub>OUT(MAX)</sub> )						
f <sub>S(MIN)</sub>	Output Voltage Detection Frequency	–	1.8	2	2.2	kHz
CURRENT SENSE SECTION						
V <sub>CS_H</sub>	Peak Current Sense Voltage in Heavy Load	40% to 100% of full load	874	910	946	mV
V <sub>CS_M</sub>	Peak Current Sense Voltage in Middle Load	17% to 40% of full load	581	605	630	mV
V <sub>CS_L</sub>	Peak Current Sense Voltage in Light Load	5% to 17% of full load	390	405	425	mV
ΔV <sub>CS</sub> /V <sub>CS</sub>	V <sub>CS</sub> Modulation for Frequency Dithering	–	–	2.5	–	%
t <sub>MOD</sub>	V <sub>CS</sub> Modulation Period	–	225	250	275	μs
R <sub>LINE</sub>	Built-in Line Compensation Resistor	–	260	330	400	Ω
t <sub>LEB</sub>	Leading Edge Blanking	@ V <sub>CS_H</sub> and V <sub>CS_M</sub>	600	750	900	ns
CONSTANT VOLTAGE SECTION						
V <sub>FB</sub>	Equivalent Feedback Voltage @ 90% Load	Closed loop test of V <sub>OUT</sub>	4.13	4.20	4.27	V
I <sub>FB</sub>	FB Pin Input Current	V <sub>FB</sub> =4V	3.36	4.20	5.04	μA
V <sub>CABLE</sub>	Cable Compensation Drop	–	–	0.35	–	V
CONSTANT CURRENT SECTION						
t <sub>ONS</sub> /t <sub>SW</sub>	Secondary Winding Conduction Duty	V <sub>FB</sub> =3V	–	4/7	–	–
POWER TRANSISTOR SECTION						
V <sub>CE(SAT)</sub>	Collector-emitter Saturation Voltage	I <sub>C</sub> =0.5A	–	–	0.3	V
h <sub>FE</sub>	DC Current Gain	–	14	17	–	–
I <sub>CEO</sub>	Leakage Current	–	–	–	60	μA
PROTECTION FUNCTION SECTION						
V <sub>FB(OVP)</sub>	Over Voltage Protection	–	–	7.5	–	V
V <sub>FB(SCP)</sub>	Short Circuit Protection	V <sub>FB</sub> @ Hiccup	2.6	3.3	3.7	V
T <sub>OTP</sub>	Shutdown Temperature	–	+125	+160	–	°C
T <sub>HYS</sub>	Temperature Hysteresis	–	–	+40	–	°C

## Performance Characteristics

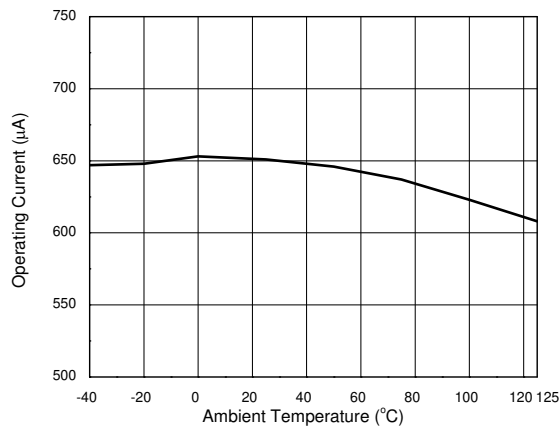
Turn-on Voltage vs. Ambient Temperature



Turn-off Voltage vs. Ambient Temperature



Operating Current vs. Ambient Temperature



## Operation Description

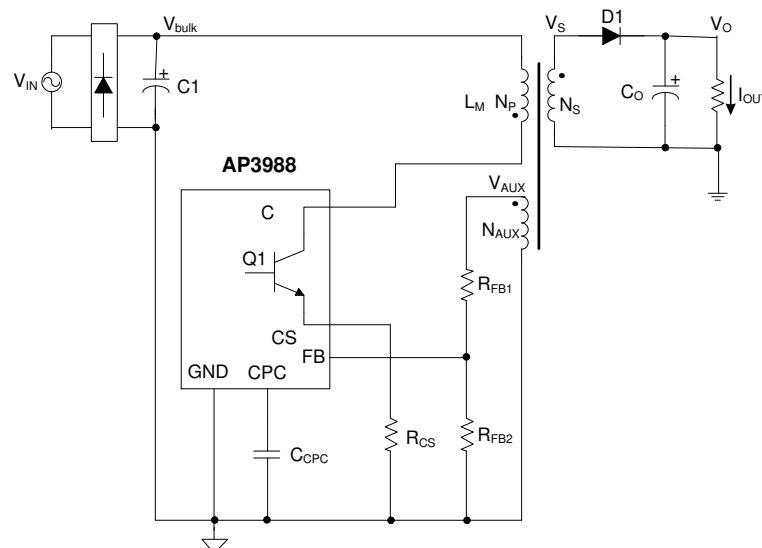


Figure 1. Simplified Flyback Converter Controlled by AP3988

## Operation Description (Cont.)

### Constant Primary Peak Current

The primary  $i_p(t)$  current is sensed by a current sense resistor  $R_{CS}$  as shown in Figure 1.

The current rises up linearly at a rate of:

$$\frac{di_p(t)}{dt} = \frac{V_{bulk}(t)}{L_M} \dots\dots\dots (1)$$

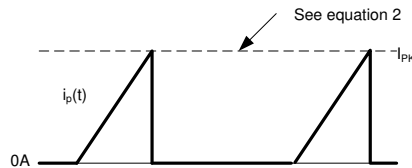


Figure 2. Primary Current Waveform

As illustrated in Figure 2, when the current  $i_p(t)$  rises up to  $I_{PK}$ , the switch Q1 turns off. The constant peak current is given by:

$$I_{PK} = \frac{V_{CS}}{R_{CS}} \dots\dots\dots (2)$$

The energy stored in the magnetizing inductance  $L_M$  each cycle is therefore:

$$E_g = \frac{1}{2} \cdot L_M \cdot I_{PK}^2 \dots\dots\dots (3)$$

So the power transferring from input to output is given by:

$$P = \frac{1}{2} \cdot L_M \cdot I_{PK}^2 \cdot f_{SW} \dots\dots\dots (4)$$

Where  $f_{SW}$  is the switching frequency. When the peak current  $I_{PK}$  is constant, the output power depends on the switching frequency  $f_{SW}$ .

### Constant Voltage Operation

The AP3988 captures the auxiliary winding feedback voltage at FB pin and operates in constant-voltage (CV) mode to regulate the output voltage. Assuming the secondary winding is master, the auxiliary winding is slave during the D1 on-time. The auxiliary voltage is given by:

$$V_{AUX} = \frac{N_{AUX}}{N_S} \cdot (V_O + V_d) \dots\dots\dots (5)$$

Where  $V_d$  is the diode forward drop voltage,  $N_{AUX}$  is the turns of auxiliary winding, and  $N_S$  is the turns of secondary winding.

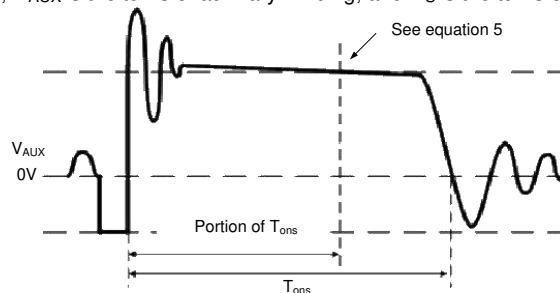


Figure 3. Auxiliary Voltage Waveform

The output voltage is different from the secondary voltage in a diode forward drop voltage  $V_d$  which depends on the current. If the secondary voltage is always detected at a constant secondary current, the difference between the output voltage and the secondary voltage will be a fixed  $V_d$ . The voltage detection point is portion of  $T_{ons}$  after D1 is turned on. The CV loop control function of AP3988 then generates a D1 off-time to regulate the output voltage.



## Operation Description (Cont.)

### Constant Current Operation

The AP3988 is designed to work in constant current (CC) mode. Figure 4 shows the secondary current waveforms.

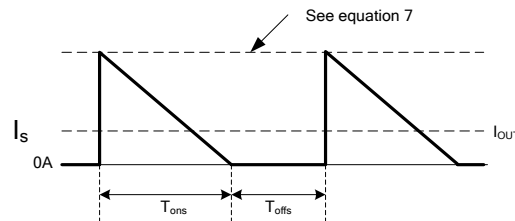


Figure 4. Secondary Current Waveform

In CC operation, the CC loop control function of AP3988 will keep a fixed proportion between D1 on-time  $T_{ons}$  and D1 off-time  $T_{offs}$  by discharging or charging the built-in capacitance connected. This fixed proportion is

$$\frac{T_{ons}}{T_{offs}} = \frac{4}{3} \dots \dots \dots (6)$$

The relation between the output constant-current and secondary peak current  $I_{PKS}$  is given by:

$$I_{OUT} = \frac{1}{2} \cdot I_{PKS} \cdot \frac{T_{ons}}{T_{ons} + T_{offs}} \dots \dots \dots (7)$$

At the instant of D1 turn-on, the primary current transfers to the secondary at an amplitude of:

$$I_{PKS} = \frac{N_p}{N_s} \cdot I_{PK} \dots \dots \dots (8)$$

Thus the output constant current is given by:

$$I_{OUT} = \frac{2}{7} \cdot \frac{N_p}{N_s} \cdot I_{PK} \dots \dots \dots (9)$$

### Leading Edge Blanking (LEB)

When the power switch is turned on, a turn-on spike on the output pulse rising edge will occur on the sense-resistor. To avoid false termination of the switching pulse, a typical 750ns leading edge blanking is built in. During this blanking period, the current sense comparator is disabled and the gate driver cannot be switched off.

The built-in LEB in AP3988 has shorter delay time from current sense terminal to output pulse than those IC solutions adopting external RC filter as LEB.

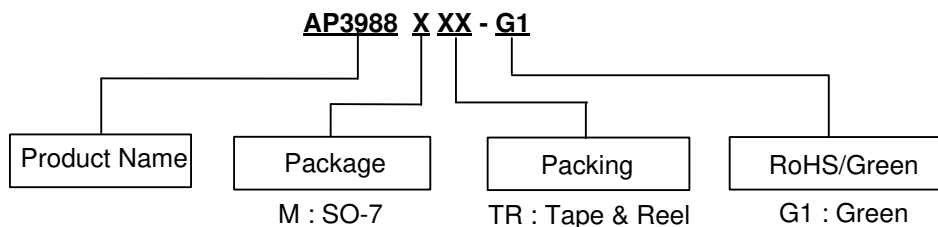
### Built-in Cable Compensation

The AP3988 has built-in fixed voltage of 0.35V typical to compensate the drop of output cable when the load is changed from zero to full load. A typical 10nF external capacitor connected to the CPC pin is used to smooth voltage signal for cable compensation.

### Over Temperature Protection

The AP3988 has internal thermal sensing circuit to shut down the PFM driver output when the die temperature reaches +160°C typical. When the die temperature drops about +40°C, the IC will recover automatically to normal operation.

## Ordering Information



Diodes IC's Pb-free products with "G1" suffix in the part number, are RoHS compliant and green.

Package	Temperature Range	Part Number	Marking ID	Packing
SO-7	-40°C to +85°C	AP3988MTR-G1	3988M-G1	4000/Tape & Reel

## Marking Information

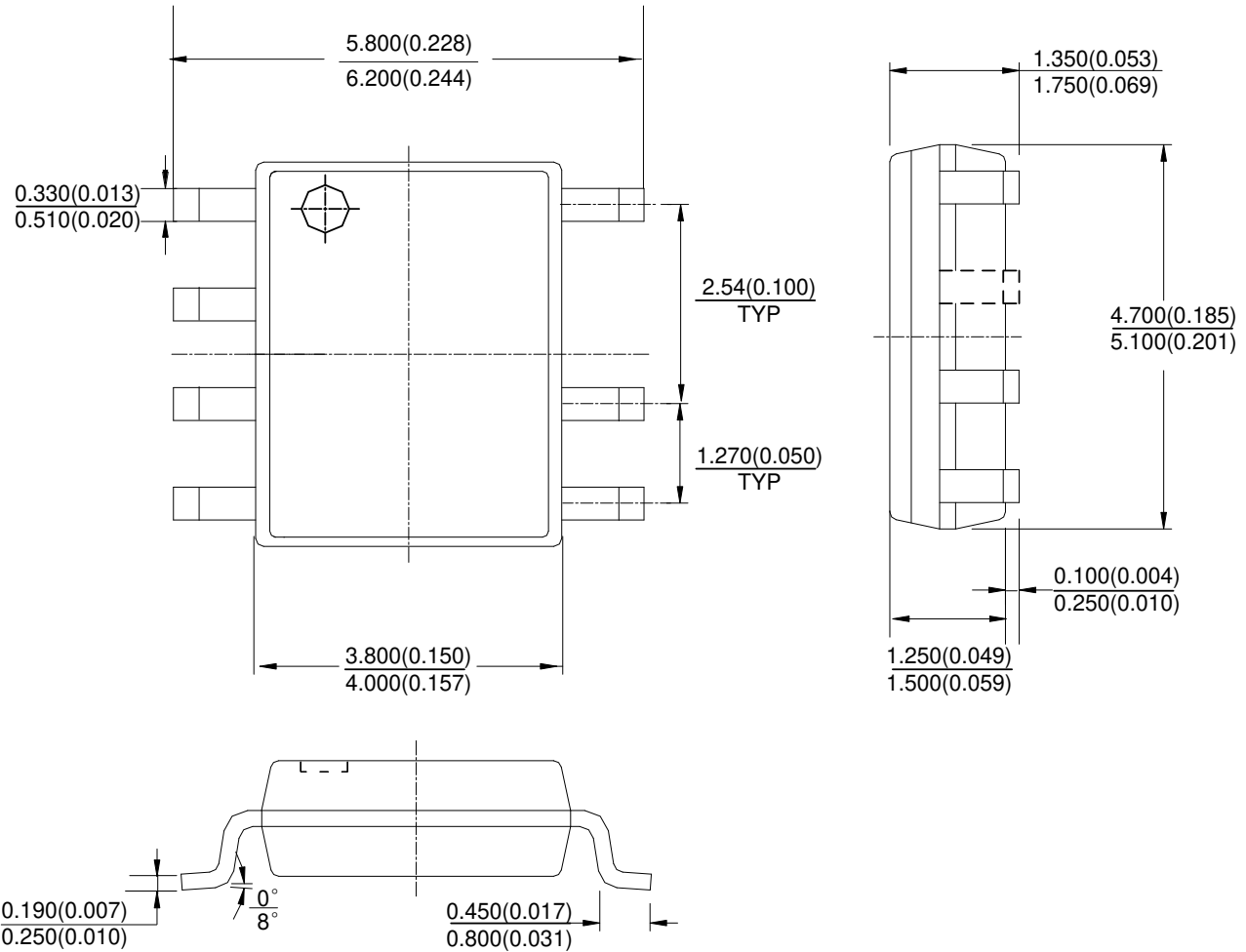
(Top View)



First and Second Lines: Logo and Marking ID  
Third Line: Date Code  
Y: Year  
WW: Work Week of Molding  
A: Assembly House Code  
XX: 7<sup>th</sup> and 8<sup>th</sup> Digits of Batch No.

**Package Outline Dimensions** (All dimensions in mm(inch).)

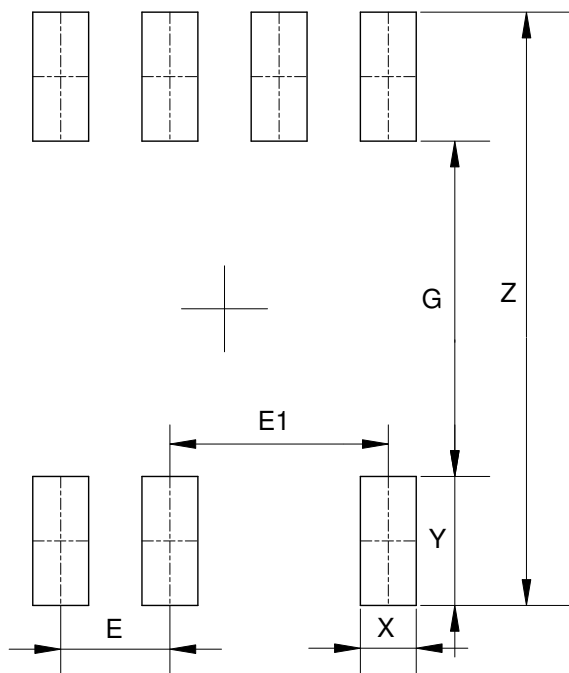
(1) Package Type: SO-7



Note: Eject hole, oriented hole and mold mark is optional.

## Suggested Pad Layout

(1) Package Type: SO-7



Dimensions	Z (mm)/(inch)	G (mm)/(inch)	X (mm)/(inch)	Y (mm)/(inch)	E (mm)/(inch)	E1 (mm)/(inch)
Value	6.900/0.272	3.900/0.154	0.650/0.026	1.500/0.059	1.270/0.050	2.540/0.100

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