July 1997

**N**ational *Semiconductor*

# LM2688
# Non-synchronous Step-down Controller for Pentium Microprocessors

## General Description

The LM2688 is a low-cost non-synchronous voltage-mode PWM controller which maintains an accurate and adjustable output voltage for high current, low voltage DC/DC applications such as the Pentium microprocessor family. By using different combinations of feedback resistors, the regulator output voltage can be precisely adjusted to match different requirements. Coming in an 8-lead surface mount package, the LM2688 can be used to control a buck regulator with an load current up to 10A. An on-chip precision trimmed reference allows tight voltage regulation and an internal 150 kHz fixed-frequency oscillator eliminates extra components to set the switching frequency. The LM2688 also provides an ON/OFF pin which enables the CPU to shutdown the regulator when necessary. Self protection features include a two stage current limit for the output switch and an over temperature shutdown for complete protection under fault conditions. The controller also provides internal loop gain compensation, minimizing the number of external components.
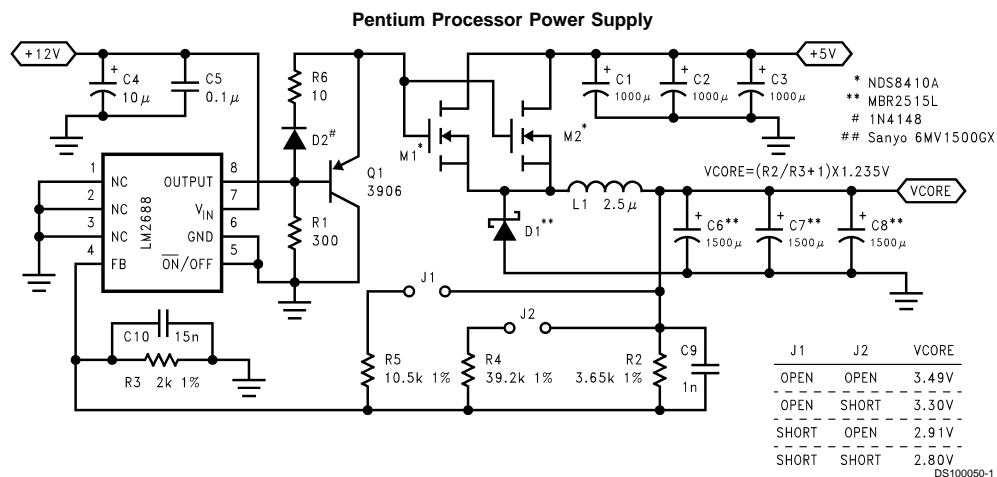
## Features

- Adjustable output voltage
- Available in 8-pin surface mount
- Guaranteed 0.5A gate drive current
- Supply voltage up to 40V
- 150 kHz fixed frequency internal oscillator
- TTL shutdown capability
- Low power standby mode, $I_Q$ typically <85 µA
- Thermal shutdown and current limit protection

## Applications

- Controller for voltage regulators for Pentium, Pentium MMX, K5, K6 MMX, Alpha and PowerPC processors
- Efficient pre-regulator for linear regulators

## Typical Application

**Pentium Processor Power Supply**



$VCORE = (R2/R3+1) \times 1.235V$

* NDS8410A
** MBR2515L
# 1N4148
## Sanyo 6MV1500GX

| J1 | J2 | VCORE |
|-------|-------|-------|
| OPEN | OPEN | 3.49V |
| OPEN | SHORT | 3.30V |
| SHORT | OPEN | 2.91V |
| SHORT | SHORT | 2.80V |

DS100050-1

For more information about the above application, please refer to the Application Hints section.

## Absolute Maximum Ratings (Note 1)

**If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.**

| | |
|---|---|
| Maximum Supply Volatge | 45V |
| $\overline{ON}$/OFF Pin Input Voltage | $-0.3V \leq V \leq +25V$ |
| Feedback Pin Voltage | $-0.3V \leq V \leq +25V$ |
| Output Voltage to Ground | |
| (Steady State) | $-1V$ |
| Power Dissipation | Internally Limited |
| Storage Temperature Range | $-65°C$ to $+150°C$ |
| ESD Susceptibility | |
| Human Body Model (Note 2) | 2 kV |

| | |
|---|---|
| Lead Temperature | |
| M8 Package | |
| Vapor Phase (60 seconds) | $+215°C$ |
| Infrared (15 seconds) | $+220°C$ |
| Maximum Junction Temperature | $+150°C$ |

## Operating Ratings

| | |
|---|---|
| Temperature Range | $-40°C \leq T_J \leq +125°C$ |
| Supply Voltage | 4.5V to 40V |

## LM2688-ADJ
## Electrical Characteristics

Specifications with standard typeface are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 12V$, $I_{OUT} = 100$ mA.

| Symbol | Parameter | Conditions | LM2688-ADJ | | Units (Limits) |
|---|---|---|---|---|---|
| | | | Typ (Note 3) | Limit (Note 4) | |
| **SYSTEM PARAMETERS (Note 5)** | | | | | |
| $V_{FB}$ | Feedback Voltage | Converter Input = 5V<br>$V_{CORE}$ Programmed for 3V | 1.230 | | V |
| $\eta$ | Efficiency | Converter Input = 5V, $V_{CORE}$ = 2.8V, $I_{CORE}$ = 10A | 86 | | % |
| **DEVICE PARAMETERS** | | | | | |
| $I_b$ | Feedback Bias Current | $V_{FB}$ = 1.3V | 10 | 50/**100** | nA |
| $f_O$ | Oscillator Frequency | (Note 6) | 150 | | kHz |
| | | | | 127/**110** | kHz(min) |
| | | | | 173/**173** | kHz(max) |
| $V_{SAT}$ | Saturation Voltage | $I_{OUT}$ = 0.5A (Notes 7, 8) | 0.9 | | V |
| | | | | 1.1/**1.2** | V(max) |
| DC | Max Duty Cycle (ON) | (Note 8) | 100 | | % |
| | Min Duty Cycle (OFF) | (Note 9) | 0 | | % |
| $I_{CL}$ | Current Limit | Peak Current, (Notes 7, 8) | 0.8 | | A |
| | | | | 0.65/**0.58** | A(min) |
| | | | | 1.3/**1.4** | A(max) |
| $I_L$ | Output Leakage Current | (Notes 7, 9, 10) Output = 0V | | 50 | µA(max) |
| | | Output = $-1V$ | 2 | | mA |
| | | | | 15 | mA(max) |
| $I_Q$ | Quiescent Current | (Note 9) | 5 | | mA |
| | | | | 10 | mA(max) |
| $I_{STBY}$ | Standby Quiescent Current | $\overline{ON}$/OFF Pin = 5V (OFF) (Note 10) | 85 | | µA |
| | | | | 200/**250** | µA(max) |
| $\theta_{JA}$ | Thermal Resistance | Junction to Ambient (Note 11) | 150 | | °C/W |
| **ON/OFF CONTROL** | | | | | |
| | $\overline{ON}$/OFF Pin Logic Input | | 1.3 | | V |
| $V_{IH}$ | Threshold Voltage | Low (Regulator ON) | | **0.6** | V(min) |
| $V_{IL}$ | | High (Regulator OFF) | | **2.0** | V(max) |
| $I_H$ | $\overline{ON}$/OFF Pin Input Current | $V_{LOGIC}$ = 2.5V (Regulator OFF) | 5 | | µA |
| | | | | 15 | µA(max) |

## LM2688-ADJ
## Electrical Characteristics (Continued)

Specifications with standard typeface are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 12V$, $I_{OUT} = 100$ mA.

| Symbol | Parameter | Conditions | LM2688-ADJ | | Units (Limits) |
|--------|-----------|------------|-----------|-----------|----------------|
| | | | Typ (Note 3) | Limit (Note 4) | |
| **ON/OFF CONTROL** | | | | | |
| $I_L$ | | $V_{LOGIC} = 0.5V$ (Regulator ON) | 0.02 | | µA |
| | | | | 5 | µA(max) |

**Note 1:** Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

**Note 2:** The human body model is a 100 pF capacitor discharged through a 1.5k resistor into each pin.

**Note 3:** Typical numbers are at 25°C and represent the most likely norm.

**Note 4:** All limits guaranteed at room temperature (standard typeface) and at **temperature extremes (bold typeface)**. All room temperature limits are 100% production tested. All limits at **temperature extremes** are guaranteed via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).

**Note 5:** External components such as the catch diode, inductor, input and output capacitors, and voltage programming resistors can affect switching regulator system performance. When the LM2688 is used as shown in the typical application, system performance will be shown in system parameters section Electrical Characteristics.

**Note 6:** The switching frequency is reduced when the second stage current limit is activated. The amount of reduction is determined by the severity of current overload.

**Note 7:** No diode, inductor or capacitor connected to output pin.

**Note 8:** Feedback pin removed from output and connected to 0V to force the output transistor switch ON.

**Note 9:** Feedback pin removed from output and connected to 12V to force the output transistor switch OFF.
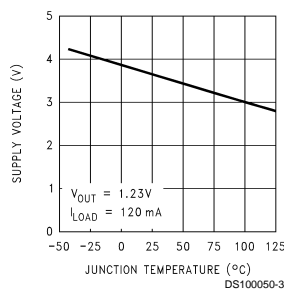
**Note 10:** $V_{IN} = 40V$.

**Note 11:** Junction to ambient thermal resistance with approximately 1 square inch of printed circuit board copper surrounding the leads. Additional copper area will lower thermal resistance further.
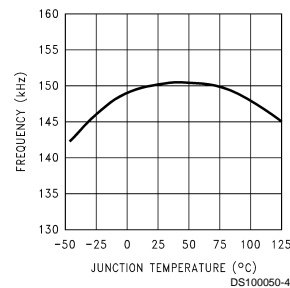
## Typical Performance Characteristics
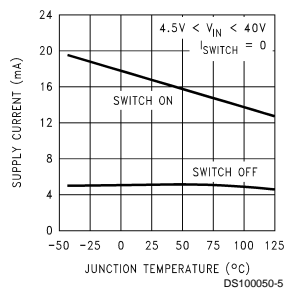
**Switch Current Limit**
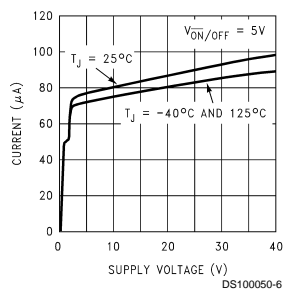


DS100050-2
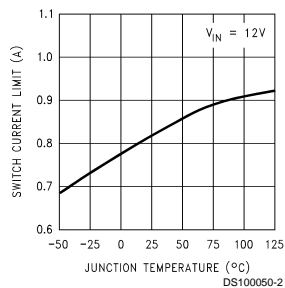
**Minimum Operating Supply Voltage**



DS100050-3

**Switching Frequency**



DS100050-4

**Quiescent Current**



DS100050-5

**Standby Quiescent Current**



DS100050-6

**Feedback Pin Bias Current**



DS100050-7
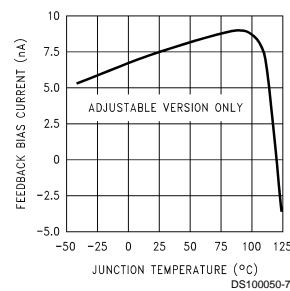
# Typical Performance Characteristics (Continued)

ON/OFF Threshold
Voltage



DS100050-8
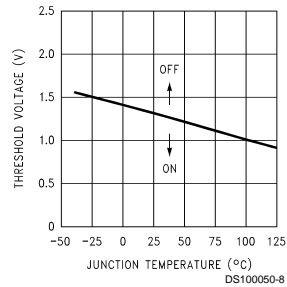
ON/OFF Pin Current
(Sinking)



DS100050-9
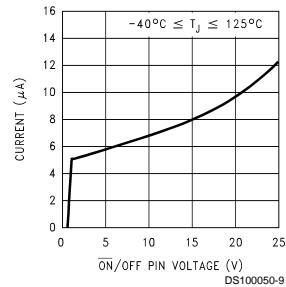
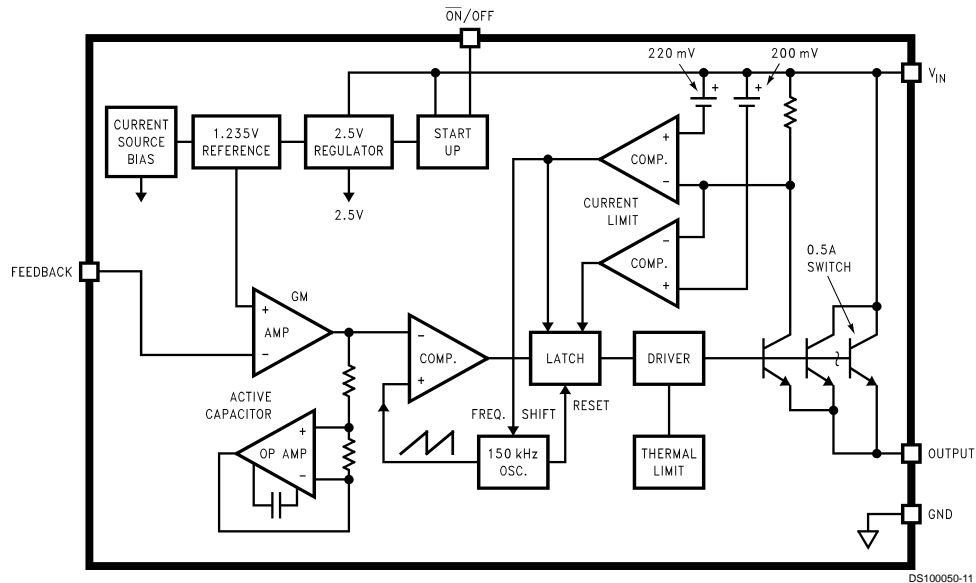# Connection Diagram and Ordering Information

**8-Lead Surface Mount (M)**



DS100050-10
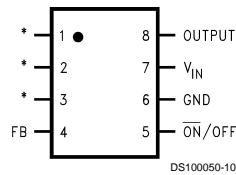
*No internal connection, but should be soldered to PC board for best heat transfer.

**Top View**
**Order Number LM2688M-ADJ**
**See NS Package Number M08A**

# LM2688 Block Diagram



DS100050-11

# Application Hints

## GENERAL

This is a cost effective non-synchronous buck solution for powering Pentium and similar microprocessors (AMD's K5, Motorola's PowerPC, etc.) that draws large current at a low voltage. Fairly high efficiency of 86% or better at 10A load can be achieved by properly selecting the components.

## PIN FUNCTIONS

**+V$_{IN}$**—This is the positive input supply for the controller to work. A suitable input bypass capacitor must be present at this pin to minimize voltage transients and to supply the current needed to drive the external MOSFET.

**Ground**—Circuit ground.

**Output**—Sources pulsed current up to 1.4A maximum to drive external MOSFET. To minimize turn-on delay of the external MOSFET, copper trace between this pin and the gate of the MOSFET should be kept as short as possible.

**Feedback**—Senses the regulator output voltage so that a feedback control loop is achieved. A resistor divider can be used to choose the desired output voltage.

**ON/OFF**—Allows the controller to be shut down by a logic level signal. If the shutdown feature is not needed, the pin can be either grounded or left open, both of which enable the controller.

## COMPONENTS SELECTION

### Input Filter

Depending on the system requirement, an inductor may or may not be necessary. When there is no explicit input di/dt limitation, the filter can be composed of capacitors only. The inductor plays an important role in limiting the input di/dt so that the input power rail appears a quiet supply for other loads. It also limits the inrush current during power on. The best inductance value is too complicated to calculate but can be easily determined by experiment. For a typical Pentium motherboard application, 2µH is recommended. The bulk capacitors in the input filter should be of low ESR type or otherwise the input di/dt requirement may not be met. A low cost low ESR electrolytic capacitor manufactured by United Chemicon, LXV16VB102M, is recommended here.

### Output Filter

The output filter plays an extremely important role in meeting the load transient requirement. From the viewpoint of load transient response, it is desirable to have a low inductance and a high output capacitance. However, too low an inductance causes huge ripple current through the MOSFETs which translates into lower efficiency. Also too big a bank of output capacitors may not be economical in terms of both cost of the regulator and motherboard real estate. It may also require a larger input capacitor bank to stay within input di/dt specification. The output voltage ripple is determined by the amount of ripple current in the inductor and the ESR of the output capacitor bank. For the typical situation where Pentium processor is the load, a 2.5µH inductor and a bank of three 1500µF electrolytic capacitors are recommended. Sanyo's ultra low-ESR electrolytic capacitor, the 6MV1500GX, is recommended.

### MOSFET Selection

It is desirable to have the on-resistance of the MOSFET as low as possible so that its conduction loss is minimized and high efficiency can be maintained. A good idea is to use two low-R$_{dson}$ MOSFETs in parallel so that the total conduction loss is halved compared with using one MOSFET. In the typical application circuit, two Fairchild low R$_{dson}$ (10 mΩ) MOSFETs, the NDS8410A, are used in parallel.

### Diode Selection

Since current flows through the freewheeling diode when the MOSFETs are off, efficiency is affected greatly by the forward voltage drop of the diode. Generally a Schottky diode is used here. Motorola MBR2515L Schottky diode has a forward voltage drop of less than 0.4V at 20A which fits very well in this application.
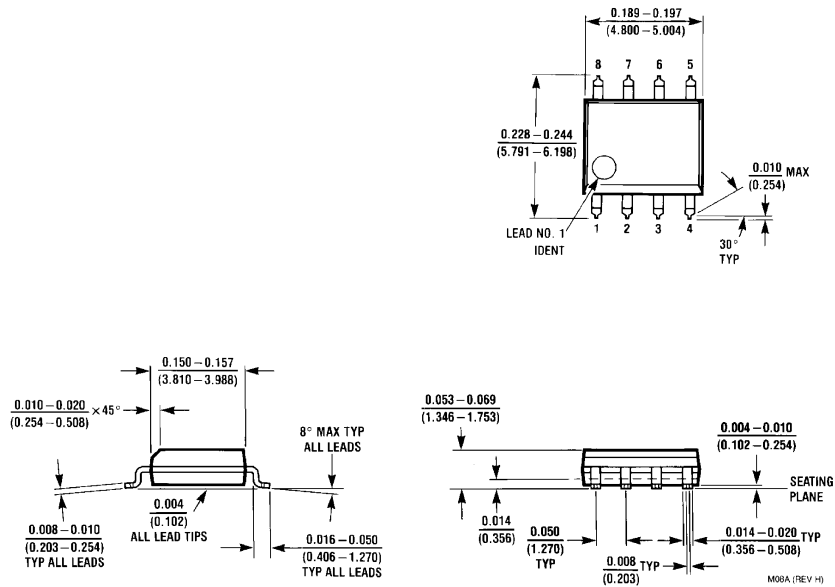
### Output Voltage Adjustment

Different output voltages can be obtained by using different combinations of feedback resistors. The formula to calculate output voltage is VCORE=(R2/R3+1)X1.235V. In the "typical application" circuit, two jumpers are used to adjust the value of R2 so that four output voltages can be obtained. When necessary, C9 and C10 can be used to further compensate the converter to result in a more stable circuit, the penalty is a slower transient recovery speed.

# Bill of Material

| Label | Value | Type | Part Number | Manufacturer |
|-------|-------|------|-------------|--------------|
| C1 | 1000µ | Capacitor | LXV16VB102M | United Chemi-Con |
| C2 | 1000µ | Capacitor | LXV16VB102M | United Chemi-Con |
| C3 | 1000µ | Capacitor | LXV16VB102M | United Chemi-Con |
| C4 | 10µ | Capacitor, Tantalum | | |
| C5 | 0.1µ | Capacitor, Ceramic | | |
| C6 | 1500µ | Capacitor | 6MV1500GX | Sanyo |
| C7 | 1500µ | Capacitor | 6MV1500GX | Sanyo |
| C8 | 1500µ | Capacitor | 6MV1500GX | Sanyo |
| C9 | 1n | Capacitor, Ceramic | | |
| C10 | 15n | Capacitor, Ceramic | | |
| L1 | 2.5µ | Inductor | | |
| R1 | 300, 0.5W | Resistor | | |
| R2 | 3.65k 1% | Resistor | | |
| R3 | 2k 1% | Resistor | | |

## Bill of Material (Continued)

| Label | Value | Type | Part Number | Manufacturer |
|---|---|---|---|---|
| R6 | 10 | Resistor | | |
| Q1 | | BJT, PNP | 3906 | National |
| U1 | | IC, PWM | LM2688M-ADJ | National |
| D1 | | Diode, Schottky | MBR2515L | Motorola |
| D2 | | Diode | 1N4148 | National |
| M1 | | MOSFET, 10 m$\Omega$ $R_{dson}$ | NDS8410A | Fairchild |
| M2 | | MOSFET, 10 m$\Omega$ $R_{dson}$ | NDS8410A | Fairchild |

## Physical Dimensions inches (millimeters) unless otherwise noted



0.189 − 0.197
(4.800 − 5.004)

0.228 − 0.244
(5.791 − 6.198)

0.010 MAX
(0.254)

LEAD NO. 1
IDENT

30°
TYP

0.150 − 0.157
(3.810 − 3.988)

0.010 − 0.020 × 45°
(0.254 − 0.508)

8° MAX TYP
ALL LEADS

0.004
(0.102)
ALL LEAD TIPS

0.008 − 0.010
(0.203 − 0.254)
TYP ALL LEADS

0.016 − 0.050
(0.406 − 1.270)
TYP ALL LEADS

0.053 − 0.069
(1.346 − 1.753)

0.004 − 0.010
(0.102 − 0.254)

SEATING
PLANE

0.014
(0.356)

0.050
(1.270)
TYP

0.008 TYP
(0.203)

0.014 − 0.020 TYP
(0.356 − 0.508)

M08A (REV H)

**Order Number LM2688M-ADJ**
**See NS Package Number M08A**

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ure to perform when properly used in accordance
with instructions for use provided in the labeling, can
be reasonably expected to result in a significant injury
to the user.

2. A critical component in any component of a life support
device or system whose failure to perform can be rea-
sonably expected to cause the failure of the life support
device or system, or to affect its safety or effectiveness.