

PFM/PWM Step-up DC/DC Converter

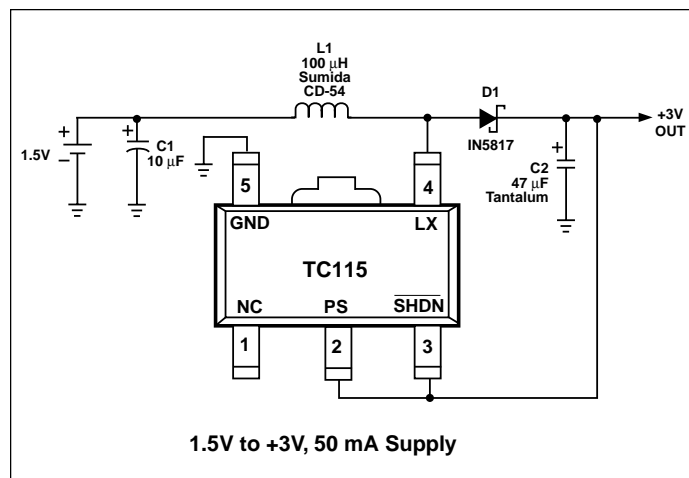
FEATURES

- High Efficiency at Low Output Load Currents via PFM Mode
- Space-Saving SOT-89 Package
- Guaranteed Start-Up at 0.9V
- 80 μ A (typ.) Supply Current
- 85% (typ.) Efficiency at 100 mA
- 140 mA Typical Output Current @ $V_{IN} = 2.0V$
- Low Power Shutdown Mode
- No External Switching Transistor Needed

TYPICAL APPLICATIONS

- Pagers
- Cellular Phones
- Palmtops
- 1-Cell to 3-Cell Battery Powered Systems
- Cameras, Video Recorders
- Local +3V to +5V Supplies

TYPICAL OPERATING CIRCUITS



GENERAL DESCRIPTION

The TC115 is a high-efficiency step-up DC/DC converter for small, low input voltage or battery powered systems. This device has a guaranteed start-up voltage of 0.9V and a typical supply current of 80 μ A. Phase compensation and soft-start circuitry are included on-chip. Unlike conventional PWM step-up converters, the TC115 automatically shifts to pulse frequency modulation (PFM) at low loads, resulting in reduced supply current and improved efficiency.

The TC115 requires only an external diode, an inductor, and a capacitor, and supports typical output currents of 140 mA. Supply current is reduced to less than 0.5 μ A, max when SHDN input is brought low.

Small size, low installed cost, and low supply current make the TC115 step-up converter ideal for use in a wide range of battery powered systems.

ORDERING INFORMATION

| Part Number | Output Voltage* (V) | Package | Osc. Freq. (KHz) | Operating Temp. Range |
|-------------|---------------------|----------|------------------|-----------------------|
| TC115501EMT | 5.0 | SOT-89-5 | 100 | -40 to +85°C |
| TC115331EMT | 3.3 | SOT89-5 | 100 | -40 to +85°C |
| TC115301EMT | 3.0 | SOT-89-5 | 100 | -40 to +85°C |

NOTE: *Other output voltages available. Please contact Microchip Technology Inc. for details.

TC115

ABSOLUTE MAXIMUM RATINGS*

| | |
|---|-----------------|
| Power Supply Voltage (PS) | 12V |
| Power Dissipation | 500 mW |
| LX Sink Current | 400 mA |
| SHDN Input Voltage | 12V |
| Operating Temperature | –40°C to +85°C |
| Storage Temperature (T _{STG}) | –40°C to +125°C |

*Static-sensitive device. Unused devices must be stored in conductive material. Protect devices from static discharge and static fields. Stresses above 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 above those indicated in the operational sections of the specifications is not implied. Exposure to Absolute Maximum Rating Conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS: V_{OUT} = 5V; T_A = 25°C, unless otherwise noted.

Circuit Configuration per Figure 1.

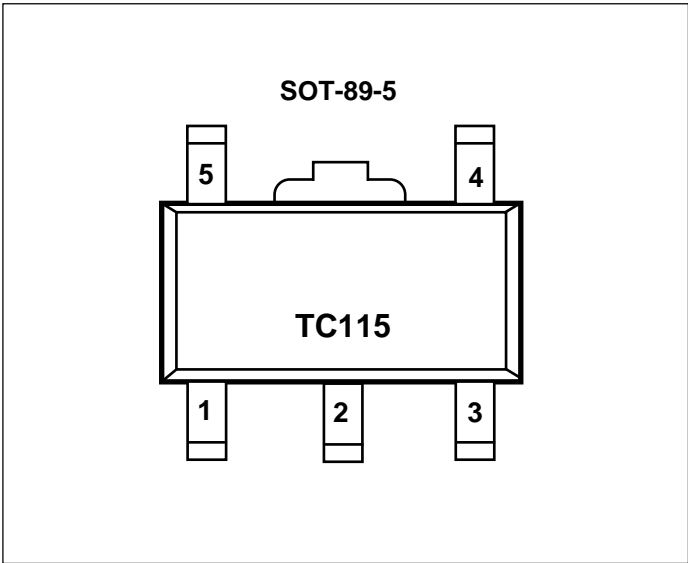
| Symbol | Parameter | Test Conditions | Min | Typ | Max | Unit |
|----------------------|---------------------------------------|--|---------------|-----|---------------|------|
| V _{IN} | Operating Supply Voltage | Note 5 | 0.9 | — | 10.0 | V |
| V _{START} | Start-Up Voltage | I _{OUT} = 1 mA | — | — | 0.9 | V |
| I _{LX(MAX)} | LX Maximum Sink Current | | — | — | 350 | mA |
| f _{LIM} | LX Limit Frequency | V _{LX} = VLX _{LIM} | — | 200 | — | KHz |
| VLX _{LIM} | LX Limit Voltage | Note 2 | 0.7 | — | 1.3 | V |
| I _{DD} | No Load Supply Current | I _{OUT} = 0; V _{IN} = V _{OUT} x 0.8 (Note 3) | — | 13 | 26 | μA |
| I _{CC} | Operating Supply Current (Boost Mode) | No external components. V _{IN} = (0.95 x V _{OUT}) applied to PS (or V _{DD}) input | — | 80 | 135 | μA |
| I _{STBY} | Operating Supply Current (Standby) | No external components. V _{IN} = (1.1 x V _{OUT}) applied to PS (or V _{DD}) input | — | 9 | 17 | μA |
| I _{SD} | Shutdown Supply Current | SHDN = 0V | — | — | 0.5 | μA |
| f _{OSC} | Oscillator Frequency | Note 2, Note 4 | 85 | 100 | 115 | KHz |
| V _{OUT} | Output Voltage | V _{IN} = 2.2V minimum, Note 1 | VR x 0.975 | VR | VR x 1.025 | V |
| R _{SWON} | LX Output ON Resistance | V _{LX} = 0.4V | — | 1.4 | 2.4 | Ω |
| PFMDUTY | Duty Cycle, PFM Operating Mode | No External Components | 10 | 17 | 25 | % |
| MAXDUTY | Maximum Duty Cycle | Note 4 | 80 | 87 | 92 | % |
| t _{SS} | Soft Start Time | | 4 | 10 | 20 | msec |
| η | Efficiency | | — | 85 | — | % |
| V _{IH} | SHDN Input Low | | — | — | 0.2 | V |
| V _{IL} | SHDN Input High | | 0.75 | — | — | V |

- Notes:
1. VR is the nominal factory-programmed output voltage setting.
 2. VLX_{LIM} is the voltage on the LX pin (with internal switch ON) that will cause the oscillator to run at twice nominal frequency in to limit the switch current through the internal N-channel switching transistor.
 3. Measured with D1 = MA735 (reverse current < 1 μA at a reverse voltage of 10V).
 4. With TC115 operating in PWM mode.
 5. See "Behavior when V_{IN} is greater than the Factory-Programmed V_{OUT} Setting" paragraph under "Detailed Description".

PIN DESCRIPTION

| Pin Number | Name | Description |
|------------|------|--|
| 1 | NC | Not Connected. |
| 2 | PS | Power and Voltage Sense Input. This dual function input provides both feedback voltage sensing and internal chip power. It should be connected to the regulator output. (See <i>Applications</i> section). |
| 3 | SHDN | Shutdown Input. A logic low on this input suspends device operation and reduces supply current to less than 0.5 μ A. Device operation resumes when $\overline{\text{SHDN}}$ is brought high. |
| 4 | LX | Inductor Switch Output. LX is the drain of an internal N-channel switching transistor. This terminal drives the external inductor, which ultimately provides current to the load. |
| 5 | GND | Ground Terminal. |

PIN CONFIGURATION



TC115

DETAILED DESCRIPTION

The TC115 is a combination PFM/PWM step-up (boost) regulator. It is particularly useful in 1, 2, and 3 cell applications where the required output current is 140 mA or less, and size/cost issues are a concern. The device operates in PWM mode when the output load is sufficient to demand a 10% (or greater) duty cycle. While in PWM mode, the TC115 behaves as any other PWM switching regulator, to a guaranteed maximum duty cycle of 92%. At low output loads (i.e. output loads requiring < 10% duty cycle to support); the TC115 automatically switches to pulse frequency modulation (PFM) operating mode with a fixed duty cycle of 25%, max, (17%, typical). While in PFM mode, the inductor is modulated with individual fixed width pulses only as needed to maintain output voltage. This action reduces supply current, thereby improving power efficiency at low output loads.

Input Power and Sensing

The TC115 is powered from the PS input, which *must* be connected to the regulated output as shown in Figure 1. PS also senses output voltage for closed-loop regulation. Start-up current is furnished through the inductor when input voltage is initially applied. This action starts the oscillator, causing the voltage at the PS input to rise, bootstrapping the regulator into full operation.

Output Diode

For best results, use a Schottky diode such as the MA735, 1N5817, EC10 or equivalent. Connect the diode between the PS and LX pins as close to the IC as possible. Do not use ordinary rectifier diodes since the higher threshold voltages reduce efficiency.

Low Power Shutdown Mode

The TC115 enters a low power shutdown mode when $\overline{\text{SHDN}}$ is brought low. While in shutdown, the oscillator is disabled and the internal switch is shut off. Normal regulator operation resumes when $\overline{\text{SHDN}}$ is brought high. $\overline{\text{SHDN}}$ may be tied to the input supply if not used. *Note:* Because the TC115 uses an external diode, a leakage path between the input voltage and the output node (through the inductor and diode) exists while the regulator is in shutdown. Care must be taken in system design to assure the input supply is isolated from the load during shutdown.

Behavior When V_{IN} is Greater Than the Factory-Programmed V_{OUT} Setting

The TC115 is designed to operate as a step-up regulator only. As such, V_{IN} is assumed to always be less than the

factory-programmed V_{OUT} setting (VR). Operating the TC115 with $V_{\text{IN}} > \text{VR}$ causes regulating action to be suspended (and corresponding supply current reduction to 9 μA , typical) until V_{IN} is again less than VR. While regulating action is suspended, V_{IN} is connected to V_{OUT} through the series combination of the inductor and Schottky diode. Care must be taken to add the appropriate isolation (MOSFET output switch or post LDO with shutdown) during system design if this $V_{\text{IN}}/V_{\text{OUT}}$ leakage path is problematic.

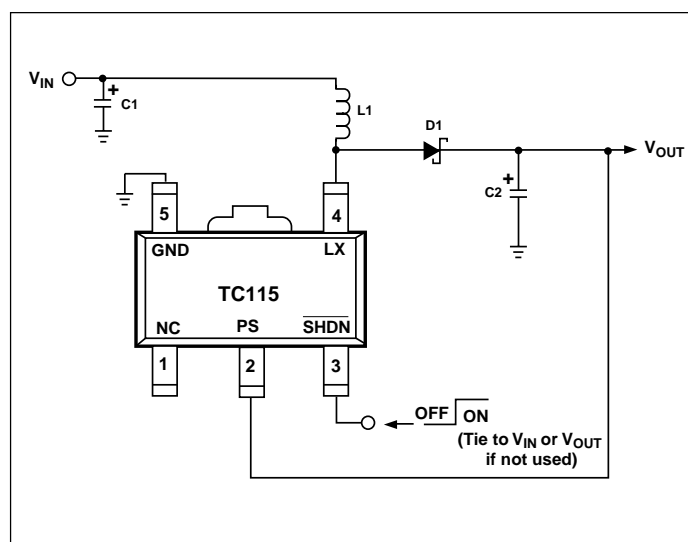


Figure 1. TC115 Typical Application

APPLICATIONS

Input Bypass Capacitors

Adding an input bypass capacitor reduces peak current transients drawn from the input supply, and reduces the switching noise generated by the regulator. The source impedance of the input supply determines the size of the capacitor that should be used.

Inductor Selection

Selecting the proper inductor value is a trade-off between physical size and power conversion requirements. Lower value inductors cost less, but result in higher ripple current and core losses. They are also more prone to saturate since the coil current ramps to a higher value. Larger inductor values reduce both ripple current and core losses, but are larger in physical size and tend to increase the start-up time slightly.

Practical inductor values, therefore, range from 50 μH to 300 μH . Inductors with a ferrite core (or equivalent) are recommended. For highest efficiency, use an inductor with a series resistance less than 20 m Ω .

The inductor value directly affects the output ripple voltage. Equation 3 is derived as shown below, and can be used to calculate an inductor value, given the required output ripple voltage (V_{RIPPLE}) and output capacitor series resistance:

$$V_{RIPPLE} \approx ESR(di)$$

Equation 1.

where ESR is the equivalent series resistance of the output filter capacitor, and V_{RIPPLE} is in volts.

Expressing di in terms of switch ON resistance and time:

$$V_{RIPPLE} \approx \frac{ESR [(V_{IN} - V_{SW})t_{ON}]}{L}$$

Equation 2.

Solving for L:

$$L \approx \frac{ESR [(V_{IN} - V_{SW})t_{ON}]}{V_{RIPPLE}}$$

Equation 3.

Care must be taken to ensure the inductor can handle peak switching currents, which can be several times load currents. Exceeding rated peak current will result in core saturation and loss of inductance. The inductor should be selected to withstand currents greater than I_{PK} (Equation 10) without saturating.

Calculating the peak inductor current is straightforward. Inductor current consists of an AC (sawtooth) current centered on an average DC current (i.e. input current). Equation 6 calculates the average DC current. Note that minimum input voltage and maximum load current values should be used:

$$\text{Input Power} = \frac{\text{Output Power}}{\text{Efficiency}}$$

Equation 4.

Re-writing in terms of input and output currents and voltages:

$$(V_{IN(MIN)}) (I_{N(MAX)}) = \frac{(V_{OUT(MAX)})(I_{OUT(MAX)})}{\text{Efficiency}}$$

Equation 5.

Solving for input current:

$$I_{IN(MAX)} = \frac{(V_{OUT(MAX)})(I_{OUT(MAX)})}{(\text{Efficiency})(V_{IN(MIN)})}$$

Equation 6.

The sawtooth current is centered on the DC current level; swinging equally above and below the DC current calculated in Equation 6. The peak inductor current is the sum of the DC current plus half the AC current. Note that minimum input voltage should be used when calculating the AC inductor current (Equation 9).

$$V = \frac{L(di)}{dt}$$

Equation 7.

$$di = \frac{V(dt)}{L}$$

Equation 8.

$$di = \frac{[(V_{IN(MIN)} - V_{SW})t_{ON}]}{L}$$

Equation 9.

where: $V_{SW} = V_{CESAT}$ of the switch (note if a CMOS switch is used to substitute V_{CESAT} with $R_{DS(ON)} \times I_{IN}$)

Combining the DC current calculated in Equation 6, with half the peak AC current calculated in Equation 9, the peak inductor current is given by:

$$I_{PK} = I_{IN(MAX)} + 0.5(di)$$

Equation 10.

Internal Transistor Switch

The LX pin has a typical ON resistance of 1.4Ω , therefore peak switch current is given by $(V_{IN}/1.4)$. The internal transistor switch has a maximum design rating of 350 mA. An oscillator frequency doubling circuit is included guard against high switching currents. Should the voltage on the LX pin rise above 1.3V, max, while the internal N-channel switch is ON, the oscillator frequency automatically doubles to minimize ON time. Although reduced, switch current still flows because the PWM remains in operation. *Therefore, the LX input is not internally current limited and care must be taken never to exceed the 350 mA maximum limit.* Failure to observe this will result in damage to the regulator.

TC115

Output Capacitor

The effective series resistance of the output capacitor directly affects the amplitude of the output voltage ripple. (The product of the peak inductor current and the ESR determines output ripple amplitude.) Therefore, a capacitor with the lowest possible ESR should be selected. Smaller capacitors are acceptable for light loads or in applications where ripple is not a concern. The Sprague 595D series of tantalum capacitors are amongst the smallest of all low ESR surface mount capacitors available. Table 1 lists suggested component numbers and manufacturers.

Board Layout Guidelines

As with all inductive switching regulators, the TC115 generates fast switching waveforms which radiate noise. Interconnecting lead lengths should be minimized to keep stray capacitance, trace resistance and radiated noise as low as possible. In addition, the GND pin, input bypass capacitor and output filter capacitor ground leads should be connected to a single point. The input capacitor should be placed as close to power and ground pins of the TC115 as possible.

Table 1. Suggested Components and Manufacturers

| Type | Inductors | Capacitors | Diodes |
|---------------|---|--|---|
| Surface Mount | Sumida CD54 Series CDR125 Series Coiltronics CTX Series | Matsuo 267 Series Sprague 595D Sreies Nichicon F93 Series | Nihon EC10 Series Matshushita MA735 Series |
| Through Hole | Sumida RCH855 Series RCH110 Series Renco RL1284-12 | Sanyo OS-CON Series Nichicon PL Series | Motorola 1N5817 – 1N5822 |

TC115 DEMO CARD

The TC115 DEMO Card is a 1.5" x 0.9" card containing a TC115 with sites for the through-hole inductor, Schottky diode, and input and output capacitors. It supports both bootstrapped and non-bootstrapped converter operating modes. These cards are available from your local TelCom Semiconductor sales office.

The TC115DEMO is shipped with the TC115 installed, and separate Schottky diode, Coiltronics 100 μ H inductor, and 47 μ F tantalum capacitor. Two sets of mounting holes are supplied for the inductor to accommodate values from 20 μ H to 100 μ H.

The regulator is shut down when J1 terminal X is shorted to OFF, and operates normally when J1 terminal X is shorted to ON. Terminal Y (J2) *must* be connected to BS.

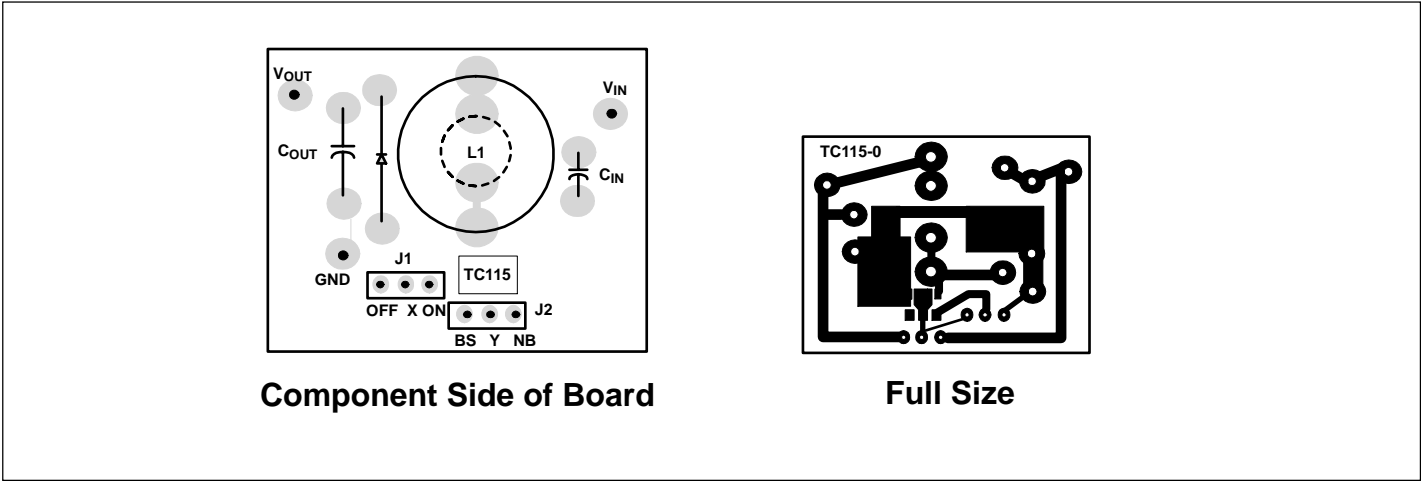


Figure 2. TC115 Demo Board Layout

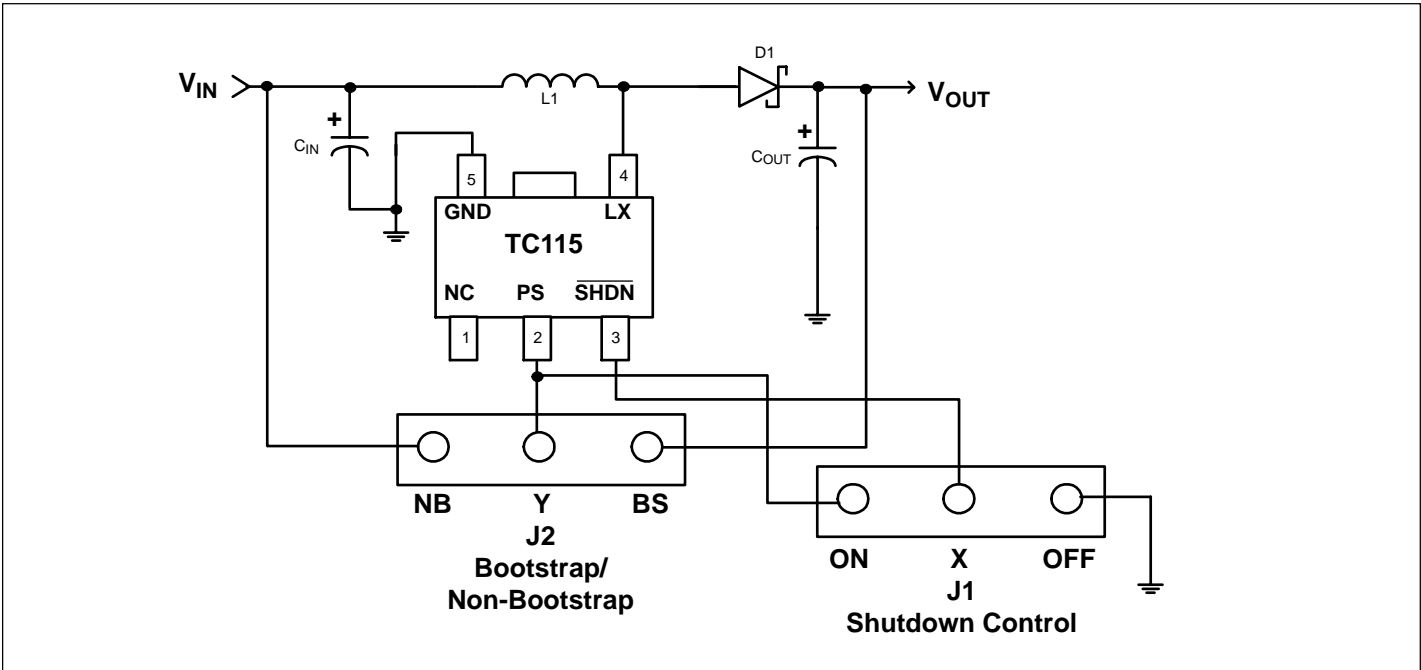


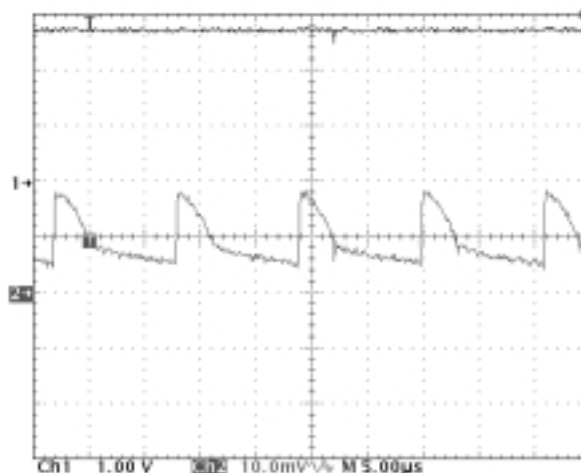
Figure 3. TC115 Demo Schematic

TC115

TYPICAL RIPPLE WAVEFORMS

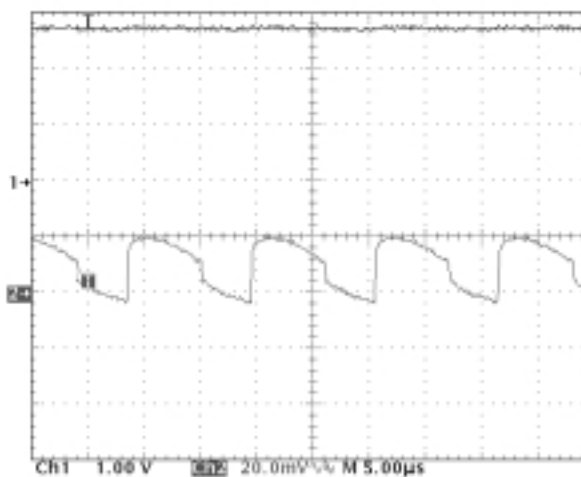
TC115301

$V_{IN} = 1.0V$
 $I_{LOAD} = 10\text{ mA}$
 CH1: V_{OUT} (DC)
 CH2: V_{OUT} (AC Ripple)
 $L = 100\mu H$
 $C = 47\mu F$
 $D1 = MA735$



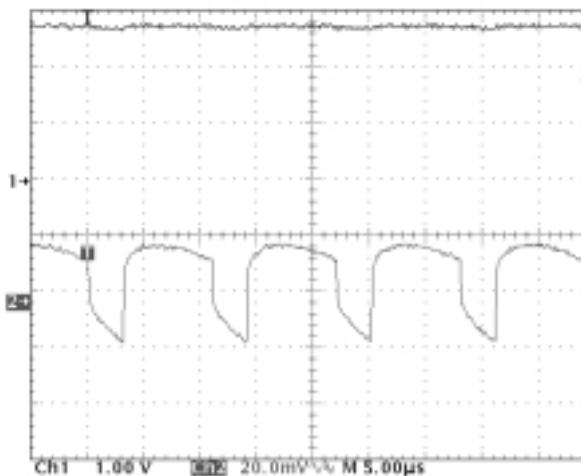
TC115301

$V_{IN} = 2.0V$
 $I_{LOAD} = 40mA$
 CH1: V_{OUT} (DC)
 CH2: V_{OUT} (AC Ripple)
 $L = 100\mu H$
 $C = 47\mu F$
 $D1 = MA735$



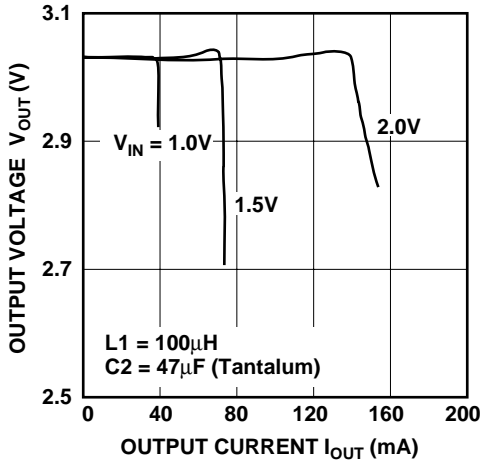
TC115301

$V_{IN} = 2.5V$
 $I_{LOAD} = 80mA$
 CH1: V_{OUT} (DC)
 CH2: V_{OUT} (AC Ripple)
 $L = 100\mu H$
 $C = 47\mu F$
 $D1 = MA735$

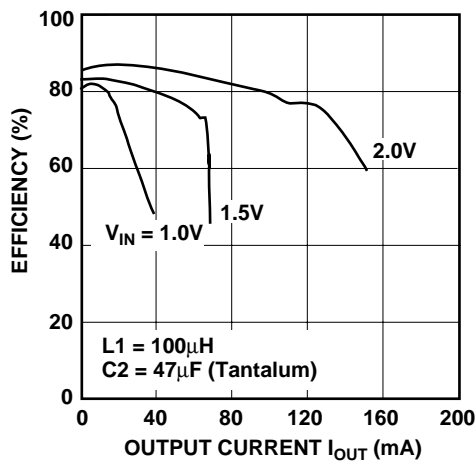


TYPICAL CHARACTERISTICS CURVES

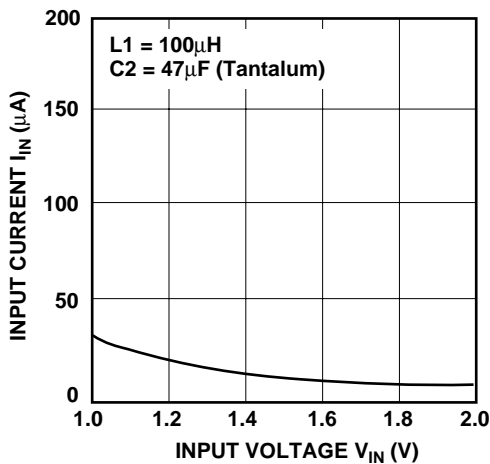
TC115301EMT
OUTPUT VOLTAGE vs. OUTPUT CURRENT



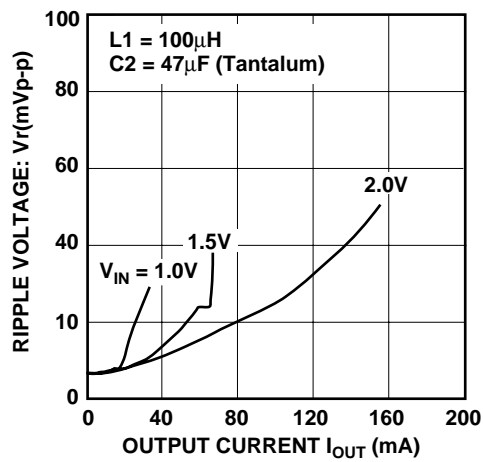
TC115301EMT
EFFICIENCY vs. OUTPUT CURRENT



TC115301EMT
NO LOAD INPUT CURRENT vs. INPUT VOLTAGE

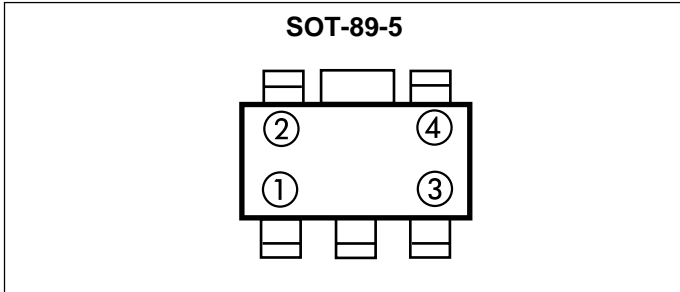


TC115301EMT
RIPPLE VOLTAGE vs. OUTPUT CURRENT



TC115

MARKINGS



① represents product classification; TC115 = 1

② represents 1st integer of voltage and frequency

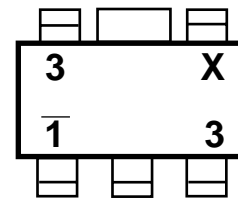
| Symbol | |
|--------|----------------|
| 100KHz | Output Voltage |
| 1 | 1. |
| 2 | 2. |
| 3 | 3. |
| 4 | 4. |
| 5 | 5. |
| 6 | 6. |

③ represents 1st decimal of voltage and frequency

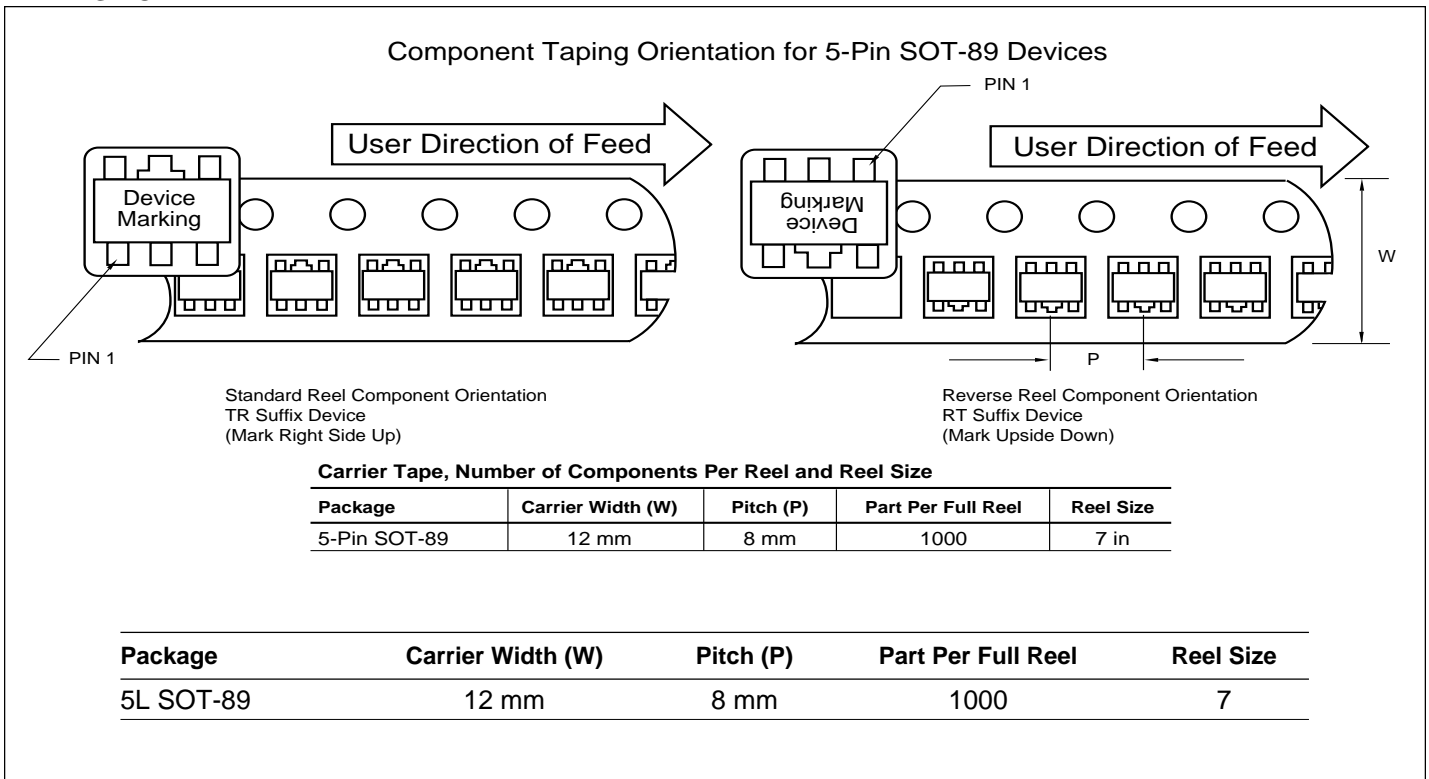
| Symbol | |
|--------|----------------|
| 100KHz | Output Voltage |
| 0 | .0 |
| 1 | .1 |
| 2 | .2 |
| 3 | .3 |
| 4 | .4 |
| 5 | .5 |
| 6 | .6 |
| 7 | .7 |
| 8 | .8 |
| 9 | .9 |

④ represents lot ID number

Example: For TC115331, the marking code is



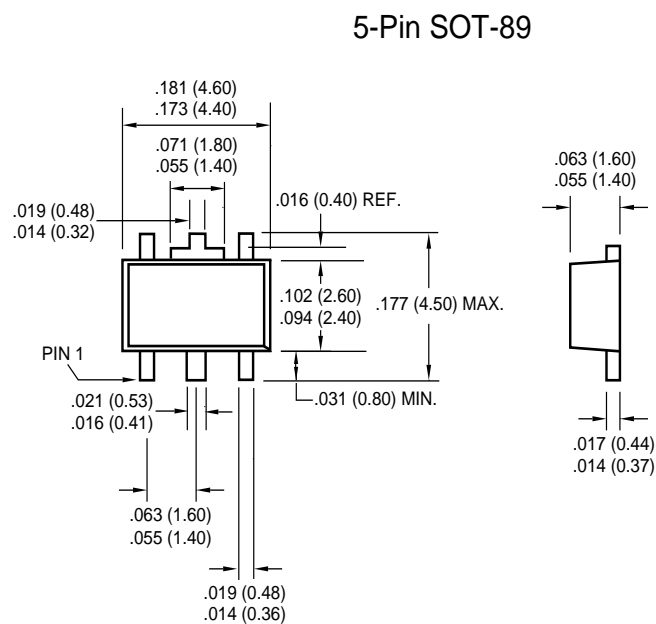
TAPING FORM



PFM/PWM Step-up DC/DC Converter

TC115

PACKAGE DIMENSIONS



Dimensions: inches (mm)



WORLDWIDE SALES AND SERVICE

AMERICAS

Corporate Office

2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200 Fax: 480-792-7277
Technical Support: 480-792-7627
Web Address: <http://www.microchip.com>

Rocky Mountain

2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7966 Fax: 480-792-7456

Atlanta

500 Sugar Mill Road, Suite 200B
Atlanta, GA 30350
Tel: 770-640-0034 Fax: 770-640-0307

Austin

Analog Product Sales
8303 MoPac Expressway North
Suite A-201
Austin, TX 78759
Tel: 512-345-2030 Fax: 512-345-6085

Boston

2 Lan Drive, Suite 120
Westford, MA 01886
Tel: 978-692-3848 Fax: 978-692-3821

Boston

Analog Product Sales
Unit A-8-1 Millbrook Tarry Condominium
97 Lowell Road
Concord, MA 01742
Tel: 978-371-6400 Fax: 978-371-0050

Chicago

333 Pierce Road, Suite 180
Itasca, IL 60143
Tel: 630-285-0071 Fax: 630-285-0075

Dallas

4570 Westgrove Drive, Suite 160
Addison, TX 75001
Tel: 972-818-7423 Fax: 972-818-2924

Dayton

Two Prestige Place, Suite 130
Miamisburg, OH 45342
Tel: 937-291-1654 Fax: 937-291-9175

Detroit

Tri-Atria Office Building
32255 Northwestern Highway, Suite 190
Farmington Hills, MI 48334
Tel: 248-538-2250 Fax: 248-538-2260

Los Angeles

18201 Von Karman, Suite 1090
Irvine, CA 92612
Tel: 949-263-1888 Fax: 949-263-1338

Mountain View

Analog Product Sales
1300 Terra Bella Avenue
Mountain View, CA 94043-1836
Tel: 650-968-9241 Fax: 650-967-1590

New York

150 Motor Parkway, Suite 202
Hauppauge, NY 11788
Tel: 631-273-5305 Fax: 631-273-5335

San Jose

Microchip Technology Inc.
2107 North First Street, Suite 590
San Jose, CA 95131
Tel: 408-436-7950 Fax: 408-436-7955

Toronto

6285 Northam Drive, Suite 108
Mississauga, Ontario L4V 1X5, Canada
Tel: 905-673-0699 Fax: 905-673-6509

ASIA/PACIFIC

China - Beijing

Microchip Technology Beijing Office
Unit 915
New China Hong Kong Manhattan Bldg.
No. 6 Chaoyangmen Beidajie
Beijing, 100027, No. China
Tel: 86-10-85282100 Fax: 86-10-85282104

China - Shanghai

Microchip Technology Shanghai Office
Room 701, Bldg. B
Far East International Plaza
No. 317 Xian Xia Road
Shanghai, 200051
Tel: 86-21-6275-5700 Fax: 86-21-6275-5060

Hong Kong

Microchip Asia Pacific
RM 2101, Tower 2, Metroplaza
223 Hing Fong Road
Kwai Fong, N.T., Hong Kong
Tel: 852-2401-1200 Fax: 852-2401-3431

India

Microchip Technology Inc.
India Liaison Office
Divyasree Chambers
1 Floor, Wing A (A3/A4)
No. 11, O'Shaughnessy Road
Bangalore, 560 025, India
Tel: 91-80-2290061 Fax: 91-80-2290062

Japan

Microchip Technology Intl. Inc.
Benex S-1 6F
3-18-20, Shinyokohama
Kohoku-Ku, Yokohama-shi
Kanagawa, 222-0033, Japan
Tel: 81-45-471- 6166 Fax: 81-45-471-6122

Korea

Microchip Technology Korea
168-1, Youngbo Bldg. 3 Floor
Samsung-Dong, Kangnam-Ku
Seoul, Korea
Tel: 82-2-554-7200 Fax: 82-2-558-5934

ASIA/PACIFIC (continued)

Singapore

Microchip Technology Singapore Pte Ltd.
200 Middle Road
#07-02 Prime Centre
Singapore, 188980
Tel: 65-334-8870 Fax: 65-334-8850

Taiwan

Microchip Technology Taiwan
11F-3, No. 207
Tung Hua North Road
Taipei, 105, Taiwan
Tel: 886-2-2717-7175 Fax: 886-2-2545-0139

EUROPE

Australia

Microchip Technology Australia Pty Ltd
Suite 22, 41 Rawson Street
Epping 2121, NSW
Australia
Tel: 61-2-9868-6733 Fax: 61-2-9868-6755

Denmark

Microchip Technology Denmark ApS
Regus Business Centre
Lautrup høj 1-3
Ballerup DK-2750 Denmark
Tel: 45 4420 9895 Fax: 45 4420 9910

France

Arizona Microchip Technology SARL
Parc d'Activite du Moulin de Massy
43 Rue du Saule Trapu
Batiment A - 1er Etage
91300 Massy, France
Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79

Germany

Arizona Microchip Technology GmbH
Gustav-Heinemann Ring 125
D-81739 Munich, Germany
Tel: 49-89-627-144 0 Fax: 49-89-627-144-44

Germany

Analog Product Sales
Lochhamer Strasse 13
D-82152 Martinsried, Germany
Tel: 49-89-895650-0 Fax: 49-89-895650-22

Italy

Arizona Microchip Technology SRL
Centro Direzionale Colleoni
Palazzo Taurus 1 V. Le Colleoni 1
20041 Agrate Brianza
Milan, Italy
Tel: 39-039-65791-1 Fax: 39-039-6899883

United Kingdom

Arizona Microchip Technology Ltd.
505 Eskdale Road
Winnersh Triangle
Wokingham
Berkshire, England RG41 5TU
Tel: 44 118 921 5869 Fax: 44-118 921-5820

All rights reserved. © 2001 Microchip Technology Incorporated. Printed in the USA. 1/01 Printed on recycled paper.

01/09/01

Information contained in this publication regarding device applications and the like is intended through suggestion only and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications. No representation or warranty is given and no liability is assumed by Microchip Technology Incorporated with respect to the accuracy or use of such information, or infringement of patents or other intellectual property rights arising from such use or otherwise. Use of Microchip's products as critical components in life support systems is not authorized except with express written approval by Microchip. No licenses are conveyed, implicitly or otherwise, except as maybe explicitly expressed herein, under any intellectual property rights. The Microchip logo and name are registered trademarks of Microchip Technology Inc. in the U.S.A. and other countries. All rights reserved. All other trademarks mentioned herein are the property of their respective companies.