PFM/PWM Step-up DC/DC Converter

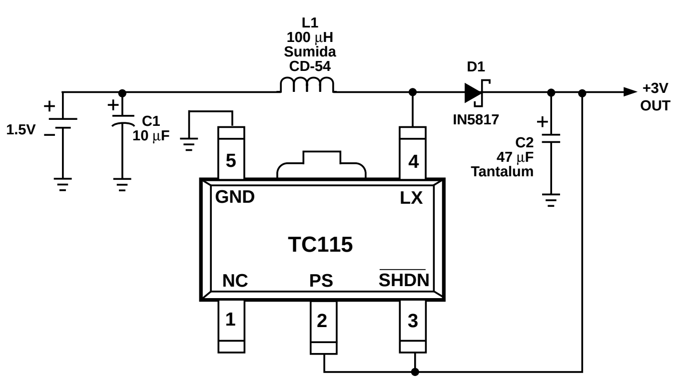
FEATURES

- High Efficiency at Low Output Load Currents via PFM Mode
- Space-Saving SOT-89 Package
- Start-Up at 0.9V
- 80 µA (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



1.5V to +3V, 50 mA Supply

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 µA. 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 µA, max when $\overline{SHDN}$ 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.

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.

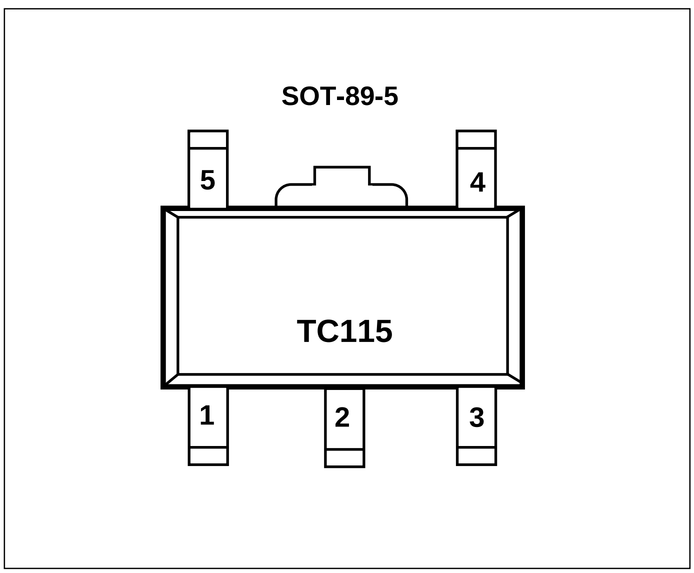
Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
V_{IN}	Operating Supply Voltage	Note 5	0.9	—	10.0	V
V_{START}	Start-Up Voltage	I_{OUT} = 1 mA	—	—	0.9	V
$I_{LX(MAX)}$	LX Maximum Sink Current		—	—	350	mA
f_{LIM}	LX Limit Frequency	V_{LX} = VLX_{LIM}	—	200	—	KHz
VLX_{LIM}	LX Limit Voltage	Note 2	0.7	—	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	$\overline{SHDN}$ = 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}	$\overline{SHDN}$ Input Low		—	—	0.2	V
V_{IL}	$\overline{SHDN}$ 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 *Applications* section).
3	$\overline{SHDN}$	Shutdown Input. A logic low on this input suspends device operation and reduces supply current to less than 0.5 µA. Device operation resumes when $\overline{SHDN}$ 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



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 $\overline{SHDN}$ is brought low. While in shutdown, the oscillator is disabled and the internal switch is shut off. Normal regulator operation resumes when $\overline{SHDN}$ is brought high. $\overline{SHDN}$ 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_{IN} > 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_{IN}/V_{OUT} leakage path is problematic.

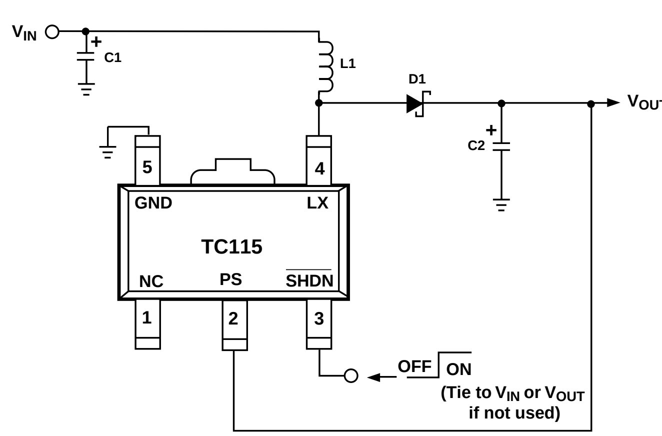


Figure 1. TC115 Typical Application

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 increse 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 mΩ.

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:

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

Equation 5.

Solving for input curent:

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

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_{DSON} x 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 an 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.

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

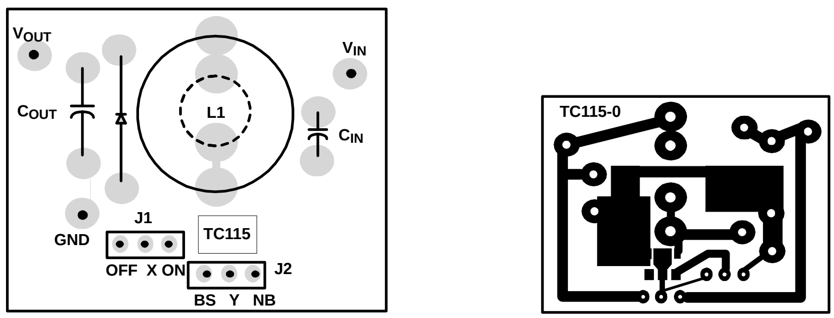
Type	Inductors	Capacitors	Diodes
Surface Mount	Sumida CD54 Series CDR125 Series Coiltronics CTX Series	Matsuo 267 Series Sprague 595D Sreies Nichicon F93 Series	Nihon EC10 Series Matshushita MA735 Series
Through Hole	Sumida RCH855 Series RCH110 Series Renco RL1284-12	Sanyo OS-CON Series Nichicon PL Series	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 Microchip Technology sales office.

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

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.



Component Side of Board **Full Size**

Figure 2. TC115 Demo Board Layout

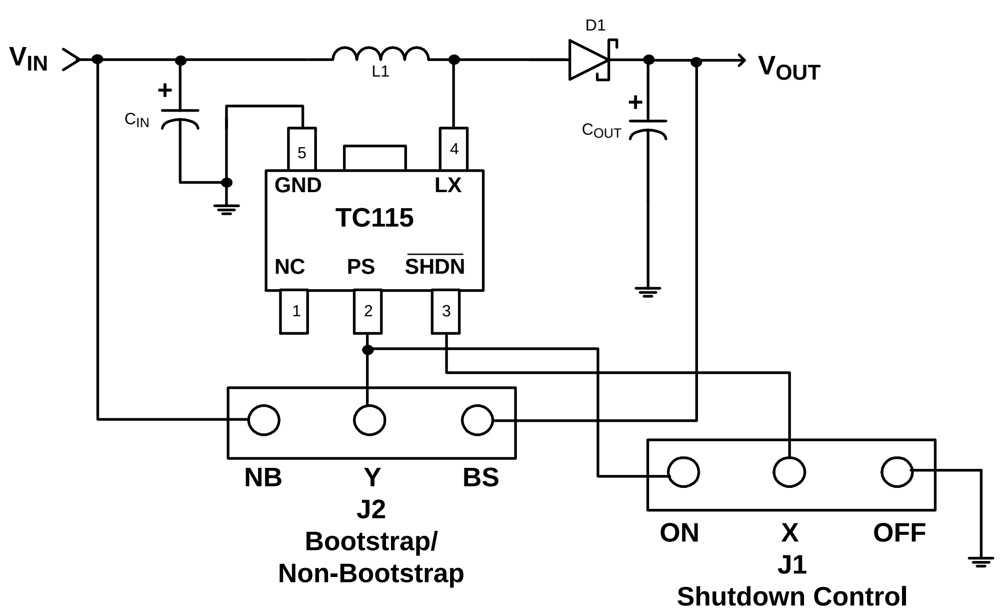
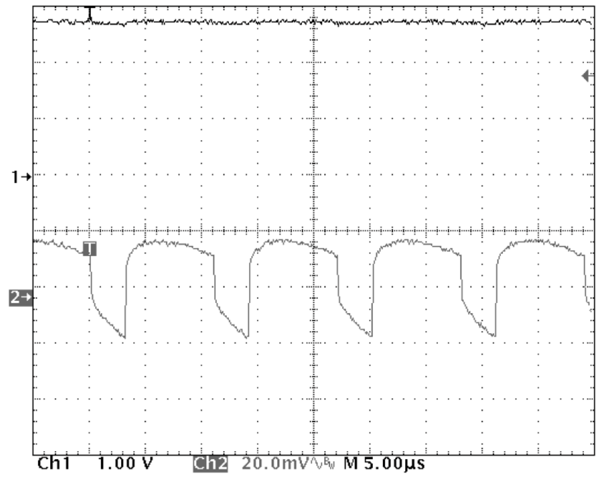


Figure 3. TC115 Demo Schematic

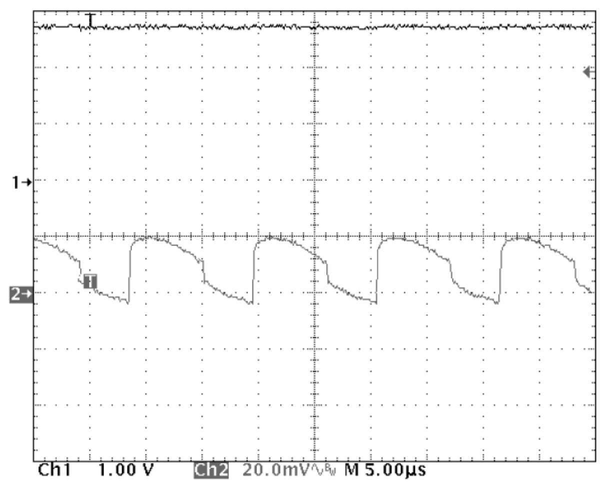
TC115

TYPICAL RIPPLE WAVEFORMS

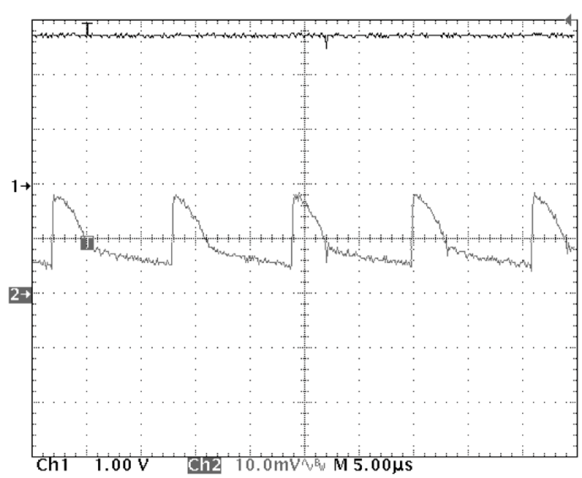
TC115301
V_{IN} = 1.0V
I_{LOAD} = 10 mA
CH1: V_{OUT} (DC)
CH2: V_{OUT} (AC Ripple)
L = 100µH
C = 47µF
D1 = MA735



TC115301
V_{IN} = 2.0V
I_{LOAD} = 40mA
CH1: V_{OUT} (DC)
CH2: V_{OUT} (AC Ripple)
L = 100µH
C = 47µF
D1 = MA735



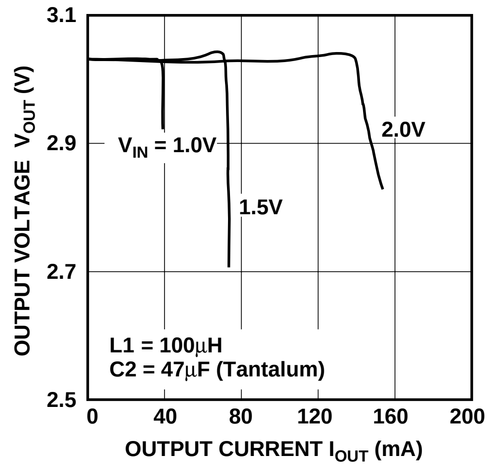
TC115301
V_{IN} = 2.5V
I_{LOAD} = 80mA
CH1: V_{OUT} (DC)
CH2: V_{OUT} (AC Ripple)
L = 100µH
C = 47µF
D1 = MA735



TYPICAL CHARACTERISTICS CURVES

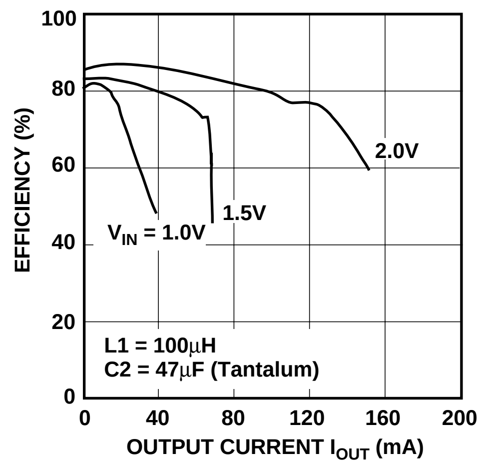
TC115301EMT

OUTPUT VOLTAGE vs. OUTPUT CURRENT



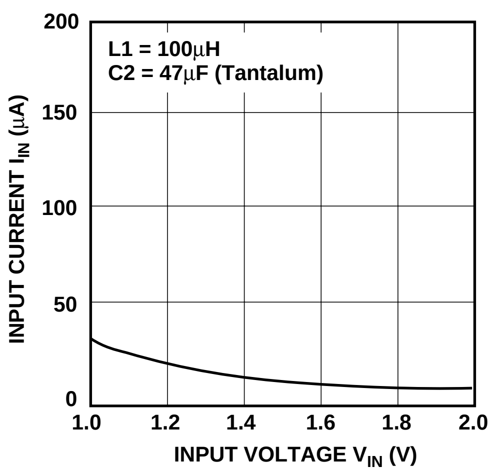
TC115301EMT

EFFICIENCY vs. OUTPUT CURRENT



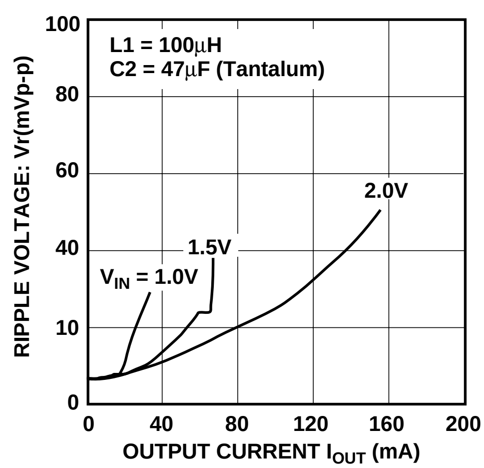
TC115301EMT

NO LOAD INPUT CURRENT vs. INPUT VOLTAGE



TC115301EMT

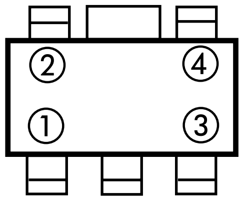
RIPPLE VOLTAGE vs. OUTPUT CURRENT



TC115

MARKINGS

SOT-89-5



① represents product classification; TC115 = $\overline{1}$

② represents 1st integer of voltage and frequency

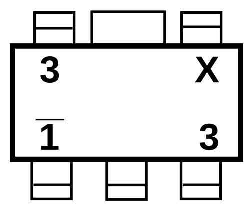
Symbol	
100KHz	**Output Voltage**
1	1.
2	2.
3	3.
4	4.
5	5.
6	6.

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

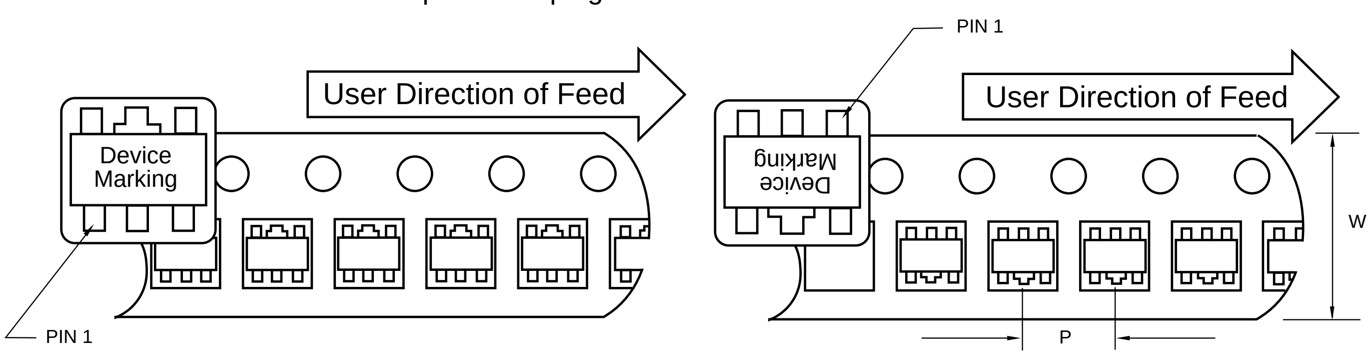
④ represents lot ID number

Example: For TC115331, the marking code is



TAPING FORM

Component Taping Orientation for 5-Pin SOT-89 Devices



Standard Reel Component Orientation
TR Suffix Device
(Mark Right Side Up)

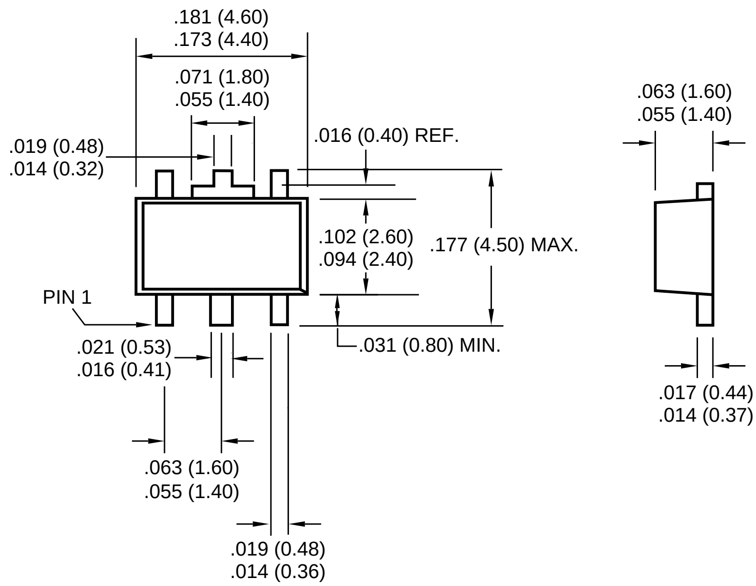
Reverse Reel Component Orientation
RT Suffix Device
(Mark Upside Down)

Carrier Tape, Number of Components Per Reel and Reel Size

Package	Carrier Width (W)	Pitch (P)	Part Per Full Reel	Reel Size
5-Pin SOT-89	12 mm	8 mm	1000	7 in

PACKAGE DIMENSIONS

5-Pin SOT-89



Dimensions: inches (mm)

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