Inductorless –2x Boost/Buck Regulator

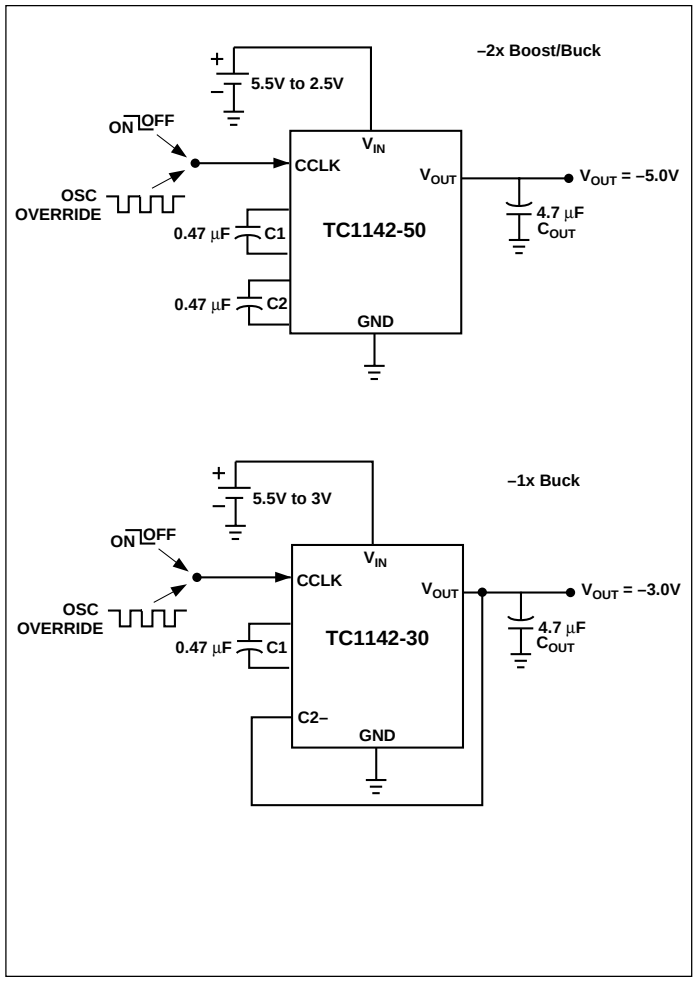
FEATURES

- **Input Range 2.5V to 5.5V**
- **Regulated Output Options from –3.0 to –5.0V**
- **Output Current 20 mA (max)**
- **200 KHz Internal Oscillator Frequency**
- **External Synchronizing Clock Input**
- **Logic Level Shutdown ..... 1μA (max) Supply Current**
- **8-Pin MSOP Package**

TYPICAL APPLICATIONS

- **Cellular Phones**
- **Battery Powered/Portable Equipment**

TYPICAL APPLICATION



GENERAL DESCRIPTION

The TC1142 generates a regulated negative voltage from –3V to –5V at 20 mA from an input of 2.5V to 5.5V, using only three external capacitors. Other boost/buck switching regulators must use an inductor, which is larger and radiates EMI. An internal voltage comparator inhibits the charge pump when V_{OUT} is more negative than the regulated value (per the ordering option). The values of flying capacitors C1 and C2 are chosen to be less than C_{OUT} in order to reduce the ripple generated from regulating V_{OUT} in this manner. The TC1142 also can be used as a –1x buck regulator by omitting C2, and connecting the C2-pin to V_{OUT}.

The part goes into shutdown when the CCLK input is driven low. When in shutdown mode, the part draws a maximum of 1 μA. When CCLK is pulled high, the part runs from the internal 200 KHz oscillator. The device may be run with an external clock, provided the frequency is greater than 3 KHz and less than 500 KHz.

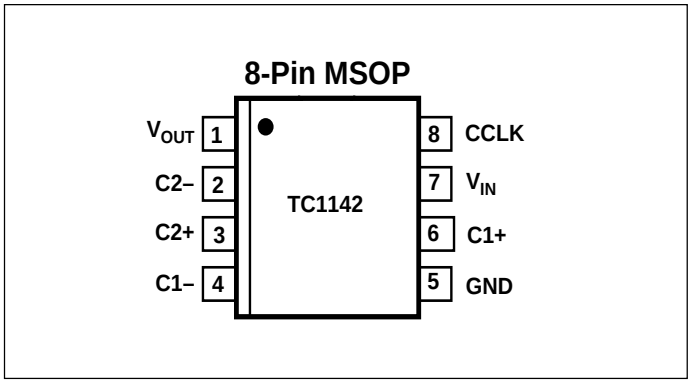
The TC1142 comes in a space-saving MSOP package.

ORDERING INFORMATION

Part No.	Package	Temp. Range
TC1142-3.0EUA	8-Pin MSOP	–40°C to 85°C
TC1142-4.0EUA	8-Pin MSOP	–40°C to 85°C
TC1142-5.0EUA	8-Pin MSOP	–40°C to 85°C

Note: Contact factory for availability of –3.5 and –4.5V options.

PIN CONFIGURATION



TC1142

ABSOLUTE MAXIMUM RATINGS*

Supply Voltage (V_{IN}) with C_{OUT} Connected 6.5V
CCLK Voltage ..... – 0.3V to (V^+ + 0.3V)
Operating Temperature Range
TC1142EUA ..... – 40°C to +85°C
Storage Temperature Range ..... – 65°C to +160°C
Lead Temperature (Soldering, 10 sec) ..... +300°C
Power Dissipation ..... 320 mW

*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:

(R_L = ∞, V_{IN} = 3.2V, Mode = –2X, C_1 = C_2 = 0.47 µF (Note 1), CCLK = V_{IH}, C_{OUT} = 4.7 µF, For V_R = 3V, V_{IN} = 3.5V, T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{IN}	Supply Voltage		2.5	—	5.5	V
V_{OUT}	Output Voltage	I_L = 0 mA (Note 2)	–(V_R + 0.2)	–V_R	–(V_R – 0.2)	V
V_{p-p}	Output Ripple	I_L = 10 mA	—	100	—	mV
I_{SUPPLY}	Supply Current		—	200	400	µA
$I_{SUPPLY1}$		CCLK = 0V	—	0.1	1	µA
R_{OUTCL}	Closed-Loop Output Resistance		—	2	6	Ω
R_{OUT}	Open-Loop Output Resistance	(Note 3)	—	30	—	Ω
f_{OSC}	Internal Oscillator Frequency		150	200	275	KHz
f_{CCLK}	External Clock Frequency, Typical	(Note 4)	3	—	500	KHz
P_{EFF}	Power Efficiency	I_L = 10 mA, V_R = 5V; (See Equation 5)	70	76	—	%
V_{IH}	CCLK Input High Threshold		2.2	—	—	V
V_{IL}	CCLK Input Low Threshold		—	—	1.0	V

Note: 1. Assume C1 and C2 have an ESR of 1Ω.
2. V_R is the voltage output specified in the ordering option
3. Measured in –1X Mode. For V_R = 3V, V_{IN} = 2.5V
4. CCLK is driven with an external clock. Minimum frequency = $1/2t_0$ at 50% duty cycle, where t_0 is the counter timeout period.

PIN DESCRIPTION

Pin No. (SOT-23A-5)	Symbol	Description
1	V_{OUT}	Regulated negative output voltage.
2	C2–	Negative terminal of flying capacitor C2.
3	C2+	Positive terminal of flying capacitor C2.
4	C1–	Negative terminal of flying capacitor C1.
5	GND	Power supply ground.
6	C1+	Positive terminal of flying capacitor C1.
7	V_{IN}	Power supply positive voltage input (2.5V to 5.5V).
8	CCLK	Clock control input: If low, the TC1142 is in Shutdown mode (1 µA, max). If high, the TC1142 runs off the internal oscillator (200 KHz, typ.). CCLK can be overridden by an external oscillator from 3 KHz to 500 KHz.

DETAILED DESCRIPTION

The TC1142 inductorless –2x boost/buck regulator is an inverting charge pump that uses a pulse-frequency modulation (PFM) control scheme to produce a regulated negative output voltage, $–V_R$, between –3V and –5V (depending on the output voltage option) at 20 mA maximum load. Output voltage regulation is achieved by gating ON the clock to the charge pump for a single half-clock period whenever the output is more positive than V_R, and gating it OFF when the output is more negative than $–V_R$. The resulting PFM of the clock applied to the charge pump has a high frequency spectral content consisting only of clock harmonics. When using an external clock, the transient noise is then synchronized to the clock and is easier to filter in sensitive applications.

The TC1142 also can be used as a –1x boost/buck regulator by omitting the C2 capacitor and connecting the C2– pin to V_{OUT}.

The PFM control scheme minimizes supply current at small loads and permits the use of low value flying capacitors, which saves on printed circuit board space and cost. Due to the TC1142's doubling and inverting charge pump mechanism, the output voltage is limited to $–2V_{IN}$. To produce a –5V regulated output, for example, a minimum input voltage of 2.5V is required at V_{IN}.

The CCLK pin of the TC1142 has three functions: It can select the internal 200 KHz oscillator (when held HIGH), put the TC1142 into shutdown (when held LOW), or provide an external clock input. To achieve this functionality, an internal counter is reset by any positive transition at the CCLK pin, but will time out in typically 160 µsec (i.e. a frequency higher than about 3 KHz). If the counter times out following the last positive transition, then the internal clock will be gated through to the charge pump if CCLK is HIGH, or the device will enter shutdown mode if it is LOW. To enter shutdown, CCLK must be LOW and the counter must have timed out. These timing diagrams are shown in Figure 4.

A functional circuit diagram of the TC1142 is shown in Figure 1. The output voltage V_{OUT} is compared to an on-chip reference voltage, and the comparator output is used to gate the charge pump clock. The charge pump is a negative voltage doubler and has two phases of operation which are further illustrated in Figures 2 and 3. In phase 1, shown in Figure 2, the flying capacitor C1 charges the flying capacitor C2 while the device load is totally serviced by the charge stored on the reservoir capacitor C_{OUT}. In phase 2, shown in Figure 3, the capacitor C1 is recharged to V_{IN} while the capacitor C2 transfers its charge to the reservoir capacitor C_{OUT}.

In normal operation, the TC1142 charge pump stays in phase 2 and only switches to phase 1 as required to maintain output voltage regulation.

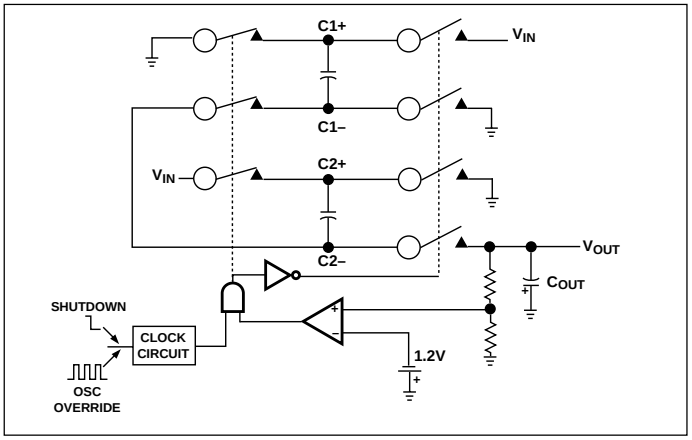
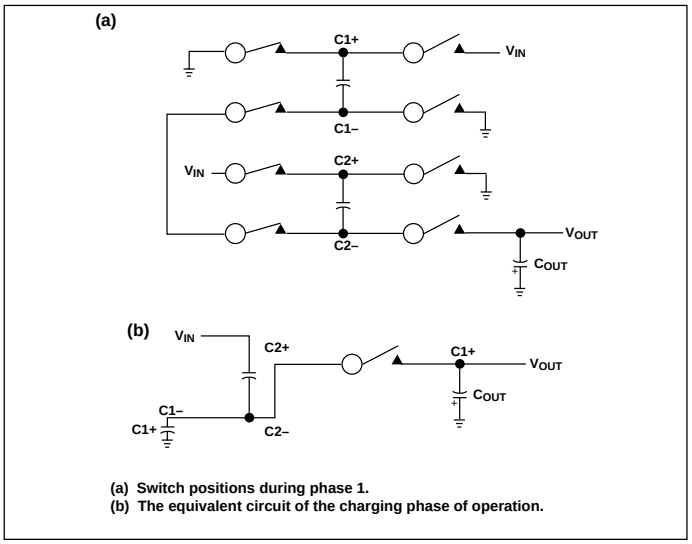
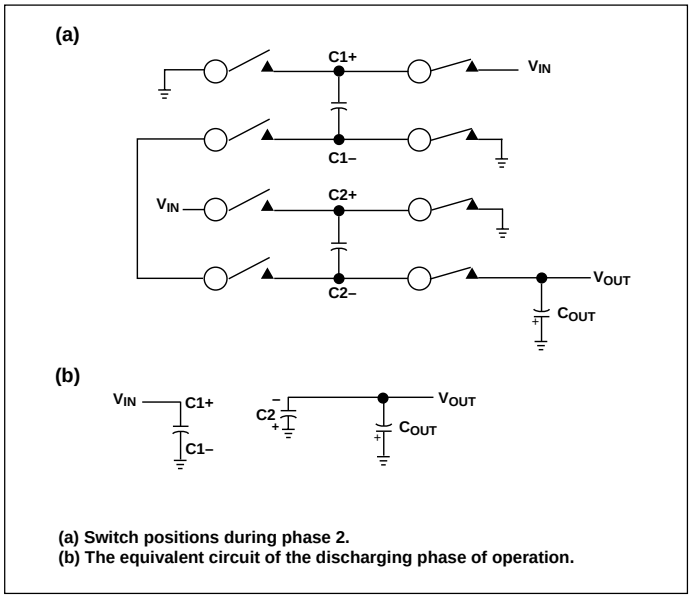


Figure 1. Functional Circuit Diagram



(a) Switch positions during phase 1.
(b) The equivalent circuit of the charging phase of operation.

Figure 2. TC1142 Phase 1



(a) Switch positions during phase 2.
(b) The equivalent circuit of the discharging phase of operation.

Figure 3. TC1142 Phase 2

OUTPUT VOLTAGE AND RIPPLE

For a –2x boost:

a.) For unregulated operation when $V_{IN} \leq \left| \frac{V_R}{2} \right|$.

In this case, the output voltage is given by:

$$V_{OUT} = -|2V_{IN}| + I_O R_{OUT}$$

Equation 1.

where $R_{OUT} = \frac{1}{f}\left(\frac{1}{C1} + \frac{1}{C2}\right) + \frac{R_S C2}{(C2 + C_{OUT})}$

Here, f is the clock frequency and R_S is the total ON resistance of the switches connecting C2 to GND and V_{OUT} in phase 2 of the charge pump operating cycle with the equivalent series resistance (ESR) of C2.

The output ripple voltage is given by:

$$V_{RIPPLE} = I_O R_{RIPPLE}$$

Equation 2.

where $R_{RIPPLE} = \frac{1}{2f(C2 + C_{OUT})} + \frac{1}{2fC_{OUT}} + \frac{ESR\ C2}{(C2 + C_{OUT})}$

Here, ESR is the equivalent series resistance of C_{OUT}.

b). For regulated operation when $V_{IN} > \left| \frac{V_R}{2} \right|$.

In this case, the TC1142 is held in phase 2 until the output voltage drops below V_R. When this occurs, the TC1142 reverts to phase 1 for a half period of the clock, during which C2 is charged from C1. At the end of this half-period, C2 is reconnected to C_{OUT} to boost the output voltage. During the phase 1 time period, the output voltage will drop below V_R before it is boosted back, so the minimum output voltage is approximated by:

$$V_{OUT(MIN)} = -|V_R| + I_O R_{OUT}$$

Equation 3.

where $R_{OUT} = \frac{1}{2fC_{OUT}} + \frac{ESR\ C2}{(C2 + C_{OUT})}$

The output ripple voltage is given approximately by:

$$V_{RIPPLE} = \frac{(2V_{IN} - |V_R| + ESR\ I_O C2\left(\frac{1}{C1} + \frac{1}{C2}\right))}{N}$$

Equation 4.

where $N = \left(\frac{1}{C1} + \frac{1}{C2}\right)(C2 + C_{OUT})$

For values of V_{IN} higher than $|V_R/2|$ by several hundred mV, the effect on ripple of the ESR of C_{OUT} can be neglected compared to the "overdrive" effect of V_{IN}.

Here, it can be seen that V_{RIPPLE} increases with increasing V_{IN}, but can be minimized by choosing small C1 and C2 values and a large C_{OUT} value.

CAPACITOR SELECTION

To maintain low output impedance and ripple, it is recommended that capacitors with low equivalent series resistance (ESR) be used. Additionally, larger values of the output capacitor and smaller values of the flying capacitors will reduce output ripple. For a capacitor value of 4.7 µF for C_{OUT}, and values of 0.47 µF for C1 and C2, the typical output impedance of the TC1142 in regulation is 0.5Ω. For the capacitor ESR not to have a noticeable effect on output impedance, it should not be larger than $1/2fC_{OUT}$. This also makes its effect on ripple voltage negligible. For V_{IN} = 3.2V and V_R = –5V, the output ripple voltage is less than 70 mV_{PP}. Table 1 summarizes output ripple versus capacitor size for an input voltage of 3.2V and a regulated output voltage of –5V.

Surface mount ceramic capacitors are preferred for their small size, low cost, and low ESR. Low ESR tantalum capacitors also are acceptable. See Table 2 for a list of suggested capacitor suppliers.

Table 1. Voltage Ripple vs. C1/C2 Flying Capacitors and Output Capacitor C_{OUT} ESR = 0.1Ω, I_{OUT} = 20 mA

C1, C2 (µF)	C_{OUT} (µF)	V_{IN} (V)	V_{OUT} (V)	V_{RIPPLE} (mV)
0.1	4.7	3.2	–5	14.6
0.22	4.7	3.2	–5	31.4
0.33	4.7	3.2	–5	46.1
0.47	4.7	3.2	–5	63.9
0.68	4.7	3.2	–5	88.7
1.0	4.7	3.2	–5	123.2
0.1	10	3.2	–5	7.0
0.22	10	3.2	–5	15.1
0.33	10	3.2	–5	22.4
0.47	10	3.2	–5	31.5
0.68	10	3.2	–5	44.7
1.0	10	3.2	–5	63.8

Table 2. Low ESR Surface-Mount Capacitor Manufacturers

Manufacturer	Type	Phone
AVX Corp.	TPS series surface-mount tantalum	(803) 448-9411
Matsuo	267 series surface-mount tantalum	(714) 969-2491
Sprague	593D, 594D, 595D, series surface-mount tantalum	(207) 324-4140
AVX Corp.	X7R type surface-mount ceramic	(803) 448-9411
Matsuo	X7R type surface-mount ceramic	(714) 969-2491
Murata	Ceramic chip capacitors	(800) 831-9172
Taiyo Yuden	Ceramic chip capacitors	(800) 348-2496
Tokin	Ceramic chip capacitors	(408) 432-8020

POWER EFFICIENCY

Assuming the output is loaded with at least 20% of the maximum available output current, the power efficiency of the TC1142 can be estimated using the following equation:

$$\eta = \frac{|V_R|}{2(V_{IN})}$$

Equation 5.

For example, a 3.2 Volt V_{IN}, and a –5 Volt V_R will have an efficiency of approximately 78%. For loads less than 20% of the maximum available output current, the power efficiency will be substantially reduced. Other factors that affect the actual efficiency include:

1) Losses from power consumed by the internal oscillator (if used).
2) I^2R losses due to the on-resistance of the MOSFET charge pump switches.
3) Charge pump capacitor losses due to ESR.
4) Losses that occur during charge transfer (from the flying capacitors to the output capacitor) when a voltage difference exists between these capacitors.

CHOICE OF –2X OR –1X CONNECTIONS

If required output voltage can be achieved using a -1x configuration then this is preferred for the following reasons:

1) Power efficiency is improved from $V_R/2V_{IN}$ to V_R/V_{IN}
2) Only one flying capacitor needed
3) The output ripple becomes proportional to $V_{IN} – V_R$ rather than 2 $V_{IN} – V_R$.

LAYOUT CONSIDERATIONS

Proper layout is important to obtain optimal performance. Mount capacitors as close to their connecting device pins as possible to minimize stray inductance and capacitance. It is recommended that a large ground plane be used to reduce noise leakage into other circuitry.

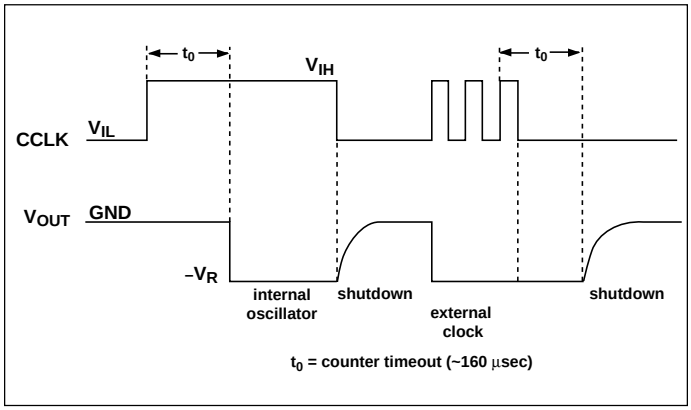
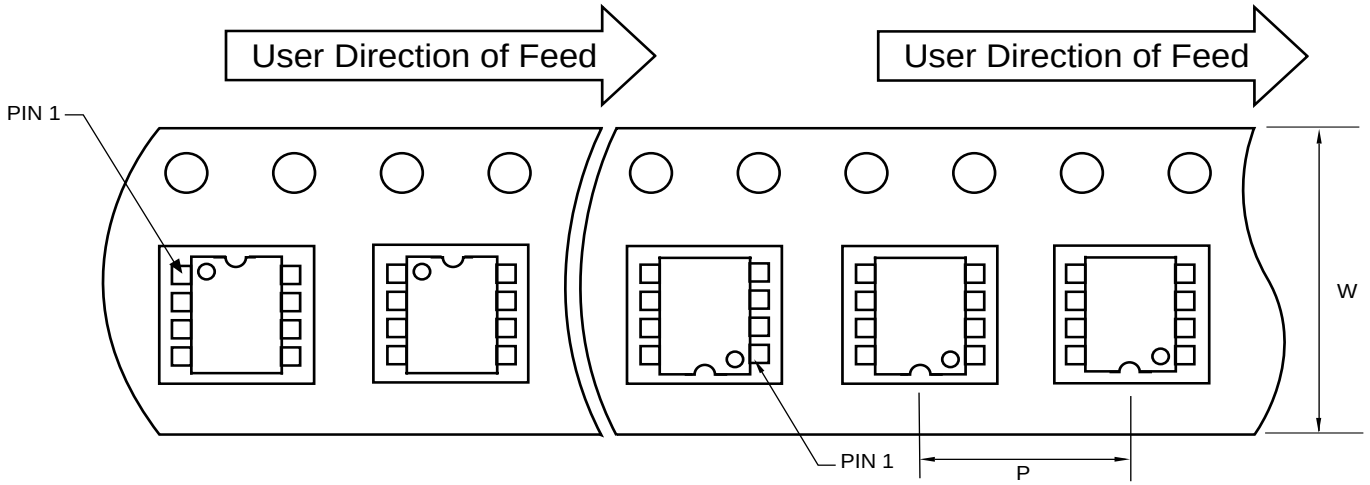


Figure 4. Timing Diagram

TC1142

TAPING FORM

Component Taping Orientation for 8-Pin MSOP Devices



Standard Reel Component Orientation
for TR Suffix Device

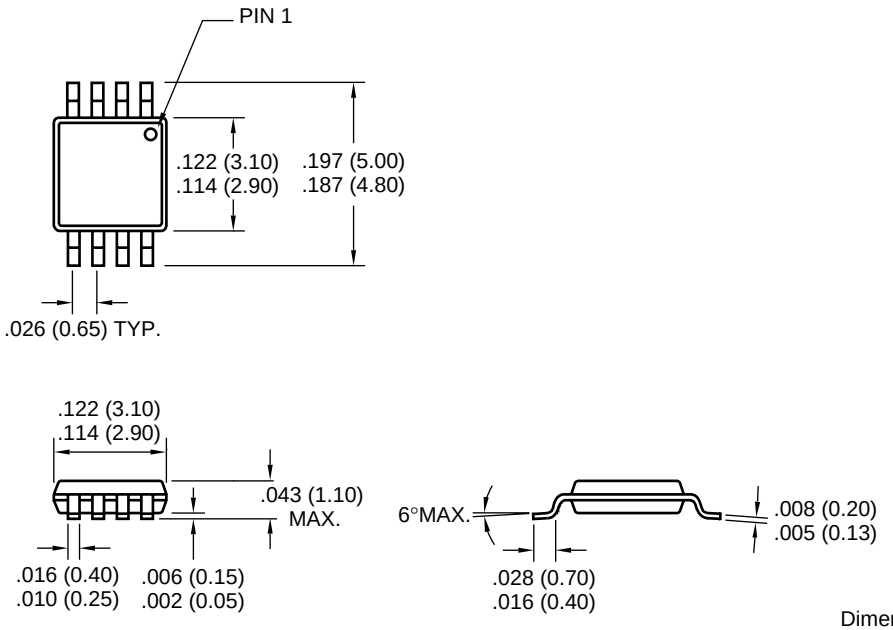
Reverse Reel Component Orientation
for RT Suffix Device

Carrier Tape, Number of Components Per Reel and Reel Size

Package	Carrier Width (W)	Pitch (P)	Part Per Full Reel	Reel Size
8-Pin MSOP	12 mm	8 mm	2500	13 in

PACKAGE DIMENSIONS

8-Pin MSOP



Dimensions: inches (mm)

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