TC120

PWM/PFM Step-Down Combination Regulator/Controller

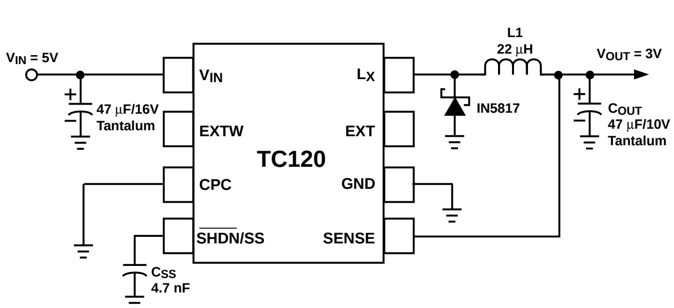
FEATURES

- **Internal Switching Transistor Supports 600mA Output Current**
- **External Switching Transistor Control for Output Currents of 2A+**
- **300 KHz Oscillator Frequency Supports Small Inductor Size**
- **Short Circuit Protection**
- **Built-In Undervoltage Lockout**
- **High (95%, Typ) Efficiency**
- **Automatic Switchover to Current-Saving PFM Mode at Low Output Loads**
- **Automatic Output Capacitor Discharge While in Shutdown**
- **Programmable Soft-Start Time**
- **Power-Saving Shutdown Mode**
- **Small 8-Pin SOP Package**

TYPICAL APPLICATIONS

- **Portable Test Equipment**
- **Local Logic Supplies**
- **Portable Audio Systems**
- **Portable Scanners**
- **Palmtops**
- **Electronic Organizers**

TYPICAL APPLICATION



5V to 3.0V, 500 mA Step-Down Converter

GENERAL DESCRIPTION

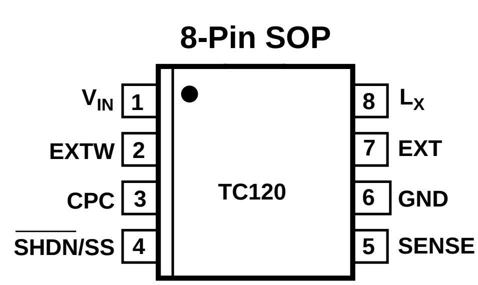
TC120 is a 300 KHz PFM/PWM step-down (Buck) DC/DC regulator/controller combination for use in systems operating from two or more cells, or in line-powered applications. It uses PWM as the primary modulation scheme, but automatically converts to PFM at low output loads for greater efficiency. It requires only an external inductor, Schottky diode, and two capacitors to implement a step-down converter having a maximum output current of 600 mA (V_{IN} =5V, V_{OUT} = 3.3V). An external switching transistor (P-channel MOSFET) can be added to increase output current capability to support output loads of 2A or more.

The TC120 consumes only 55µA (max) of supply current (V_{OUT} = 3.3V) and can be placed in shutdown mode by bringing the shutdown input ($\overline{SHDN}$) low. During shutdown, the regulator is disabled, supply current is reduced to 2.5 µA(max), and V_{OUT} is internally pulled to ground, discharging the output capacitor. Normal operation resumes when $\overline{SHDN}$ is brought high. Other features include a built-in undervoltage lockout (UVLO), an externally programmable soft start time, and output short circuit protection. The TC120 operates from a maximum input voltage of 10V and is available in a low-profile 8-Pin SOP package.

ORDERING INFORMATION

Part No.	Output Voltage (V)	Package	Temperature Range
TC120303EHA	3.0	8-Pin SOP	– 40°C to +85°C
TC120333EHA	3.3	8-Pin SOP	– 40°C to +85°C
TC120503EHA	5.0	8-Pin SOP	– 40°C to +85°C

PIN CONFIGURATION



ABSOLUTE MAXIMUM RATINGS*

Power Supply Voltage (V_{IN}) .... –0.3V to +12V
Voltage on V_{OUT} Pin .... –0.3V to +12V
Voltage on LX, Boost Pins ...... (V_{IN} – 12V) to (V_{IN} + 0.3V)
Voltage on EXT1, EXT2, SHDN Pins
.... (–0.3V) to (V_{IN} + 0.3V)
L_X Pin Current 700mA
EXT1, EXT2 Pin Current .... ±50mA
Continuous Power Dissipation 300mW
Operating Temperature (T_C) .... –40°C to 85°C
Storage Temperature (T_{STG}) .... –40°C to 150°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: (Test Circuit of Figure 1, T_A = 25°C, V_{IN} =V_R x 1.2, Note 1, unless other-wise noted)

Symbol	Parameter	Test Conditions		Min	Typ	Max	Unit
V_{OUT}	Output Voltage	V_R = 3.0, I_{OUT}=120mA (Note 1) V_R = 3.3, I_{OUT} =132mA V_R = 5.0, I_{OUT} =200mA		V_R x 0.975	V_R ± 0.5%	V_R x 1.025	V
V_{IN}	Input Voltage			1.8	—	10	V
$I_{OUT(MAX)}$	Maximum Output Current		V_{OUT} = 3.0V	500	—	—	mA
			V_{OUT} = 3.3V	600	—	—	
			V_{OUT} = 5.0V	600	—	—	
I_{IN}	Supply Current	V_{IN} = V_R x 1.05, No Load	V_{OUT} = 3.0V	—	52	82	µA
			V_{OUT} = 3.3V	—	55	86	
			V_{OUT} = 5.0V	—	71	110	
I_{SHDN}	Shutdown Supply Current	(Note 2), No Load, $\overline{SHDN}$ = 0V		—	1.5	2.5	µA
I_{LX}	LX Pin Leakage Current	Measured at EXT 1 Pin (Note 2) No Load, $\overline{SHDN}$ = 0V		— —	— 1.5	2 2.5	µA
$R_{DSON(LX)}$	LX Pin ON Resistance	V_{OUT} = V_R x 0.9 (Note 2) V_{LX} = V_{IN} – 0.2V, 10Ω Resistor from L_X to V_{IN}, SHDN = V_{IN}	V_{OUT} = 3.0V	—	0.69	0.94	Ω
			V_{OUT} = 3.3V	—	0.64	0.85	
			V_{OUT} = 5.0V	—	0.44	0.58	
R_{EXTH}	EXT1, EXT2 On Resistance to V_{IN}	(Note 2); $\overline{SHDN}$ = V_{IH}; EXT1 and EXT 2 connected to 200Ω load, V_{EXT1} = V_{EXT2} = (V_{IN} – 0.4V); V_{OUT} = V_{IN}	V_{OUT} = 3.0V	—	38	52	Ω
			V_{OUT} = 3.3V	—	35	47	
			V_{OUT} = 5.0V	—	24	32	
R_{EXTL}	EXT1, EXT2 On Resistance to GND	(Note 2); $\overline{SHDN}$ = V_{IH}; EXT1 and EXT2 pulled up through a series resistance of 200Ω to a voltage such that VEXT1, 2 = 0.4V	V_{OUT} = 3.0V	—	31	41	Ω
			V_{OUT} = 3.3V	—	29	37	
			V_{OUT} = 5.0V	—	20	26	
f_{OSC}	Oscillator Frequency	Measured at EXT1 Pin, V_{IN} = V_{OUT} +0.3V, I_{OUT} = 20mA, (Note 3)		255	300	345	KHz
D_{PWM}	Maximum PWM Duty Cycle			—	—	100	%
D_{PFM}	PFM Duty Cycle	No Load		15	25	35	%
η	Efficiency	V_{IN} > V_R x 1.2		—	95	—	%

ELECTRICAL CHARACTERISTICS: (Test Circuit of Figure 1, T_A = 25°C, V_{IN} =V_R x 1.2, Note 1, unless other-wise noted)

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
V_{UVLO}	Minimum Operating Voltage	V_{OUT} = V_R x 0.9 (Note 2), $\overline{SHDN}$ = V_{IN} Measured with internal transistor in OFF state and V_{IN} falling.	0.9	—	1.8	V
V_{IH}	$\overline{SHDN}$ Input Logic High Threshold Voltage	(Note 2), V_{OUT} = 0V	0.65	—	—	V
V_{IL}	$\overline{SHDN}$ Input Logic Low Threshold Voltage	(Note 2), V_{OUT} = 0V	—	—	0.2	V
t_{PRO}	Short Circuit Protection Response Time	(Note 2) Time from V_{OUT} = 0V to $\overline{SHDN}$ = V_{IL}	3	5	8	msec
t_{SS}	Soft Start Time		6	10	16	msec

Notes: 1. V_R is the factory-programmed output voltage setting.
2. No external components connected, except C_{SS}.
3. While operating in PWM Mode.

PIN DESCRIPTION

Pin Number	Name	Description
1	V_{IN}	Unregulated Supply Input.
2	EXTW	Extended External Switching Transistor Drive Output. This output follows the timing on the EXT output with an additional 100nsec blanking time on both the leading and trailing edges. That is, this output transitions from high-to-low 100nsec prior to the same transition on EXT; and transitions low-to-high 100nsec after the same transition on EXT; resulting in a longer external switch ON time. (**See Operation as a Regulator Controller** for more information).
3	CPC	Charge Pump Capacitor Input. An inverting charge pump is formed by attaching a capacitor and diode to this input (please see **Improving High Load Efficiency In Regulator Operating Mode** section).
4	$\overline{SHDN}$/SS	Shutdown and Soft-Start Control Input. A soft start capacitor of 100pF (min) must be connected to this input. The soft start capacitor is charged by an internal 1µA current source that gently ramps the TC120 into service. Shutdown control is best implemented with an external open collector (or open drain) switch. The TC120 enters shutdown when this input is low. During shutdown, the regulator is disabled, and supply current is reduced to less than 2.5 µA. Normal operation is restored when this input is open-circuited, and allowed to float high. Please see $\overline{SHDN}$/SS section for details.
5	SENSE	Voltage Sense Input. This input must be connected to the output voltage node at the physical location that requires the tightest voltage regulation.
6	GND	Ground Terminal.
7	EXT	External Switching Transistor Drive Output. This output connects directly to the gate of an external P-channel MOSFET for applications requiring output currents greater than 600mA. The timing of this output exactly matches that of the gate drive for the internal P-channel transistor. This output can drive a maximum capacitance of 1000 pF. (See *Operation as a* **Regulator Controller** for more information).
8	L_X	Inductor Terminal. This pin is connected to the drain of the internal P-channel switching transistor. If the TC120 is operated as a regulator (i.e. using the internal switch); the inductor must be connected between this pin and the SENSE pin.

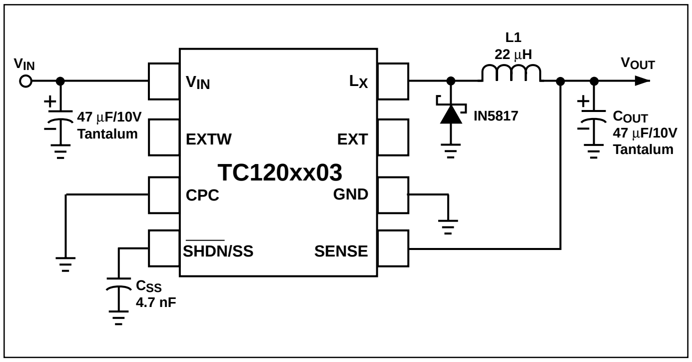


Figure 1. Test Circuit

DETAILED DESCRIPTION

The TC120 can be operated as an integrated step-down regulator (using the internal switching transistor); or as a step-down regulator controller (using an external switching transistor). When operating as an integrated regulator, the only required external components are a Shottky diode, inductor and an output capacitor. Operating in this configuration, the TC120 is capable of supporting output load currents to a maximum of 600 mA with operating efficiencies above 85%. (Efficiencies at high loads can be further improved by using the on-board charge pump circuit to pull the gate of the internal switching transistor below ground for the lowest possible ON resistance. For more information, see *Improving High Load Efficiency in Regulator Operating Mode* section).

Higher output currents are achieved by operating the TC120 with an external P-Channel switching transistor (*Controller* mode). In this operating configuration, the maximum output current is determined primarily by the ON resistance of the P-Channel switch and the series resistance of the inductor.

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 faster and could overshoot the desired peak value. This not only reduces efficiency, but could also cause the current rating of the external components to be exceeded. 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. A 22 µH inductor is the best overall compromise and is recommended for use with the TC120. For highest efficiency, use inductors with a low DC resistance (less than 20 mΩ). To minimize radiated noise, consider using a toroid, pot core or shielded-bobbin inductor.

Input Bypass Capacitor

Using 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.

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. A 47 µF Tantalum capacitor is recommended for most applications. 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.

Catch Diode

The high operating frequency of the TC120 requires a high-speed diode. Schottky diodes such as the MA737 or 1N5817 through 1N5823 (and the equivalent surface mount versions) are recommended. Select a diode whose average current rating is greater than the peak inductor current; and whose voltage rating is higher than $V_{IN(MAX)}$.

Improving High Load Efficiency in Regulator Operating Mode

If the TC120 is operated at high output loads most (or all) of the time, efficiency can be improved with the addition of two components. Ordinarily, the voltage swing on the gate of the internal P-Channel transistor is from ground to V_{IN}. By adding a capacitor and diode as shown in Figure 3, an inverting charge pump is formed, enabling the internal gate voltage to swing from a negative voltage to $+V_{IN}$. This increased drive lowers the $R_{DS(ON)}$ of the internal transistor, improving efficiency at high output currents. Care must be taken to ensure the voltage measured between V_{IN} and CPC does not exceed an absolute value of 10V. While this is not a problem at values of V_{IN} at (or below) 5V, higher V_{IN} values will require the addition of a clamping mechanism (such as a Zener diode) to limit the voltage as described. While this technique improves efficiency at high output loads, it is at the expense of low load efficiency because energy is expended charging and discharging the charge pump capacitor. This technique is therefore not recommended for applications that operate the TC120 at low output currents for extended time periods. If unused, CPC must be grounded.

Low Power Shutdown Mode/Soft Start Input

The $\overline{SHDN}$/SS input acts as both the shutdown control and the node for the external soft start capacitor, which is charged by an internal 1 μA current source. A value of 4700 pF (100 pF minimum) is recommended for the soft start capacitor. /Failure to do this may cause large overshoot voltages and/or large inrush currents resulting in possible instability. The TC120 enters a low power shutdown mode when $\overline{SHDN}$/SS is brought low. While in shutdown, the oscillator is disabled and the output discharge switch is turned on, discharging the output capacitor. Figure 4 shows the recommended interface circuits to the $\overline{SHDN}$/SS input. As shown, the $\overline{SHDN}$/SS input should be controlled using an open collector (or open drain) device, such that the $\overline{SHDN}$/SS input is grounded for shutdown mode, and open-circuited for normal operation (Figure 5a). If a CMOS device is used to control shutdown (Figure 5b), the value of R1 and C_{SS} should be chosen such that the voltage on $\overline{SHDN}$/SS rises from ground to 0.65V in 1.5 msec (Figure 6). If shutdown is not used, C_{SS} must still be connected as shown in Figures 5c and 5d. $\overline{SHDN}$/SS may be pulled up with a resistor (Figure 5c) as long as the values of R_{SS} and C_{SS} provide the approximate charging characteristic on power up shown in Figure 6. C_{SS} only may also be connected as shown in Figure 5d with C_{SS} chosen at 4700 pF (minimum 100 pF).

Undervoltage Lockout (UVLO)

The TC120 is disabled whenever V_{IN} is below the undervoltage lockout threshold. This threshold is equal to the guaranteed minimum operating voltage for the TC120 (i.e. 2.2V). When UVLO is active, the TC120 is completely disabled.

Short Circuit Protection

Upon detection of an output short circuit condition, the TC120 reduces the PWM duty cycle to a minimum value using its internal protection timer. The sequence of events is as follows: when an output voltage decrease to near zero is detected (as the result of an overload), the internal (5 msec) protection timer is started. If the output voltage has not recovered to nominal value prior to the expiration of the protection timer, the TC120 is momentarily shut down by dedicated, internal circuitry. Immediately following this action, the soft start sequence is engaged in an attempt to restart the TC120. If the output short circuit is removed, normal operation is automatically restored. If the short circuit is still present, the timed self-shutdown sequence described above is repeated.

Operation as a Regulator Controller

External Switching Transistor Selection

EXT is a complimentary output with a maximum ON resistances of 32Ω to V_{DD} when high and 26Ω to ground when low, at V_{OUT} = 5V. It is designed to directly drive a P-channel MOSFET (Figure 7). The P-channel MOSFET selection is determined mainly by the on-resistance, gate-source threshold and gate charge requirements. Also, the drain-to-source and gate-to-source breakdown voltage ratings must be greater than $V_{IN(MAX)}$. The total gate charge specification should be less than 100 nC for best efficiency. The MOSFET must be capable of handling the required peak inductor current, and should have a very low on-resistance at that current. For example, a Si9430 MOSFET has a drain-to-source rating of –20V, and a typical on-resistance $r_{DS(ON)}$ of 0.07Ω at 2A, with V_{GS} = –4.5V. (EXTW (Figure 8) may be gated with external circuitry to add blanking, or as an auxiliary timing signal.) Table A lists suppliers of external components recommended for use with the TC120.

Board Layout Guidelines

As with all inductive switching regulators, the TC120 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 TC120 as possible. The length of the EXT trace must also be kept as short as possible.

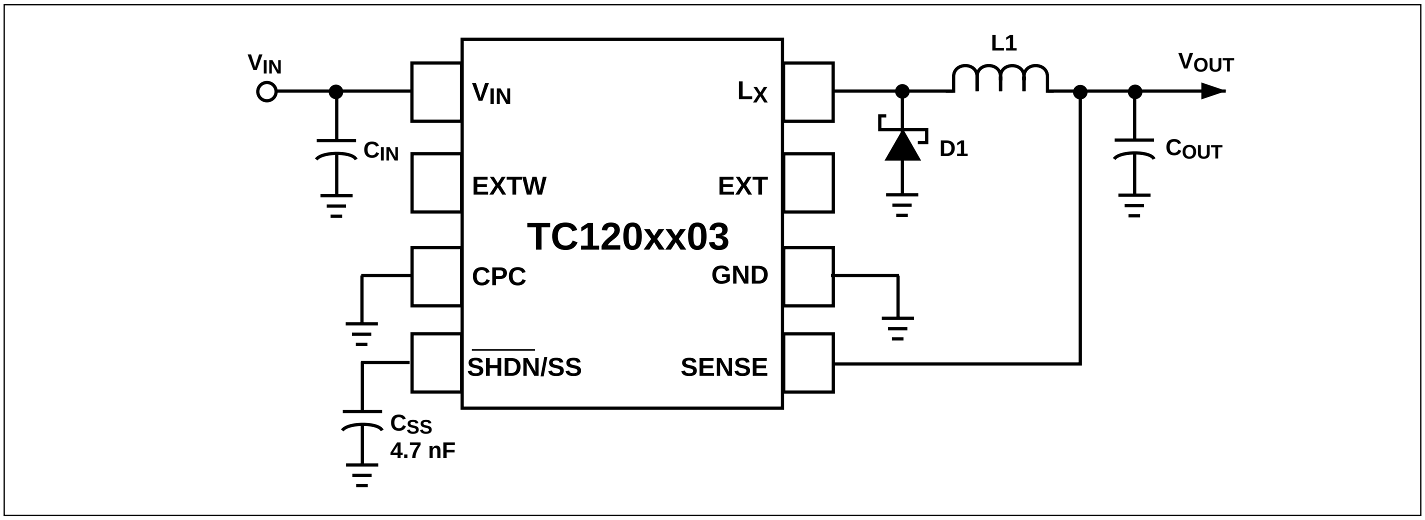


Figure 2. TC120 Typical Application

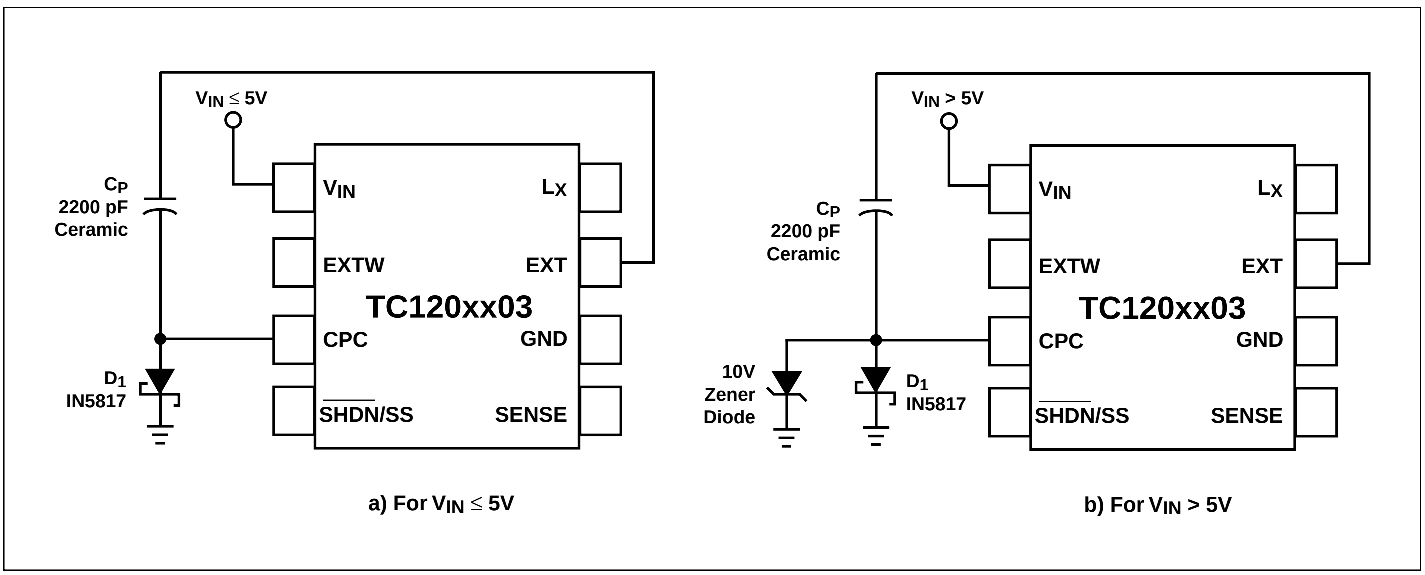


Figure 3. TC120 with Added Components for Improved Efficiency at High Output Currents

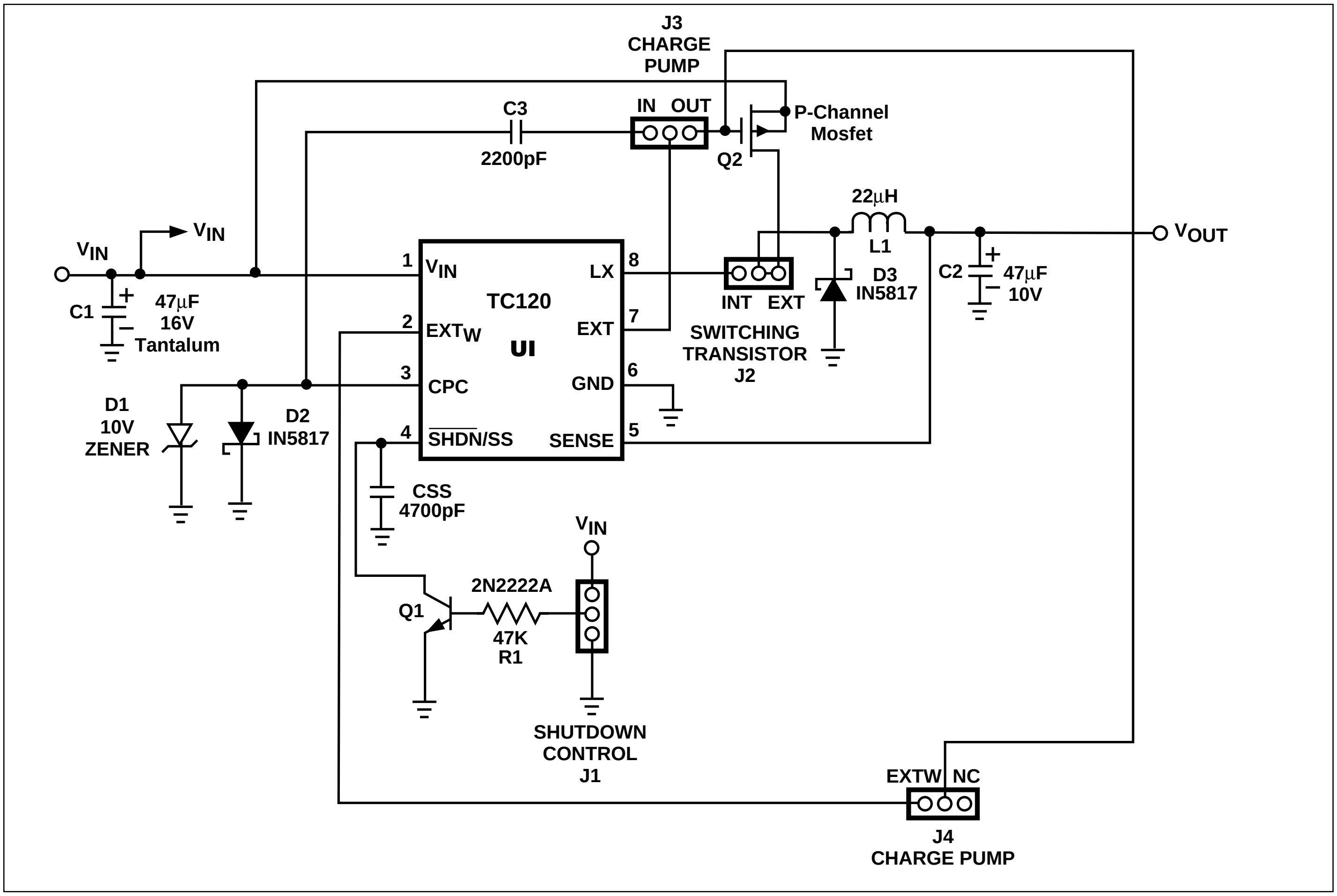


Figure 4. DEMO Board Schematic

TC120 Demo Board

The TC120 DEMO allows the user to quickly prototype TC120-based circuits. The TC120 DEMO consists of a printed circuit board and TC120. The Schottky diodes, zener diode, input capacitor, output capacitor, charge pump capacitor, external P-channel FET switch, NPN transistor (for shutdown), soft-start capacitor (C_{SS}), and 22µH inductor may be selected by the design engineer utilizing the component selection criteria previously discussed as well as the suggested components in Table 1. The circuit schematic appears in Figure 4.

Jumper block J1 controls shutdown by: 1) connecting to V_{IN} to shut down the TC120 (NOTE: the TC120's soft-start feature is disabled in this mode), or 2) connecting to Ground to enable the TC120. Capacitor C_{SS} allows the TC120 to power on in a soft-start mode. Connecting jumper block J2 to INT disables the gate drive to the external P-channel MOSFET and the TC120's internal switching transistor is used to control the output. The internal transistor of the TC120 can be used for output loads up to 600 mA. Connecting J2 to EXT and J3 to OUT (**NOTE: Both of these connections are required to drive the external P-channel FET**) allows the user to enable the gate drive to the external P-channel MOSFET to drive higher current output loads (up to 2 amps).

Connecting jumper block J3 to IN enables an inverting charge pump (via external components D2 and C3) in the TC120 that improves the efficiency of the device at higher loads when the internal switch of the TC120 is used (for loads up to 600 mA). An inverting charge pump is formed in this configuration which increases the internal transistor's gate voltage (from a negative voltage to VIN) to lower the ON resistance of the internal switching transistor. Connecting jumper block J4 to EXTW allows for an extended external gate drive to the P-channel FET (see Figure 8). In this mode, the FET will turn on about 100 nsec earlier and remain on about 100 nsec later than int he normal external switching mode.

The Table below summarizes the jumper connections for different modes of operation of the TC120.

MODE	J1	J2	J3	J4
Shutdown	V_{IN}	–	–	–
Internal Switching without Inverting Charge Pump	GROUND	INT	OPEN	OPEN
Internal Switching with Inverting Charge Pump	GROUND	INT	IN	OPEN
Normal External Switching (Via EXT)	GROUND	EXT	OUT	OPEN
Extended External Switching (Via EXT_W)	GROUND	EXT	OPEN	EXTW

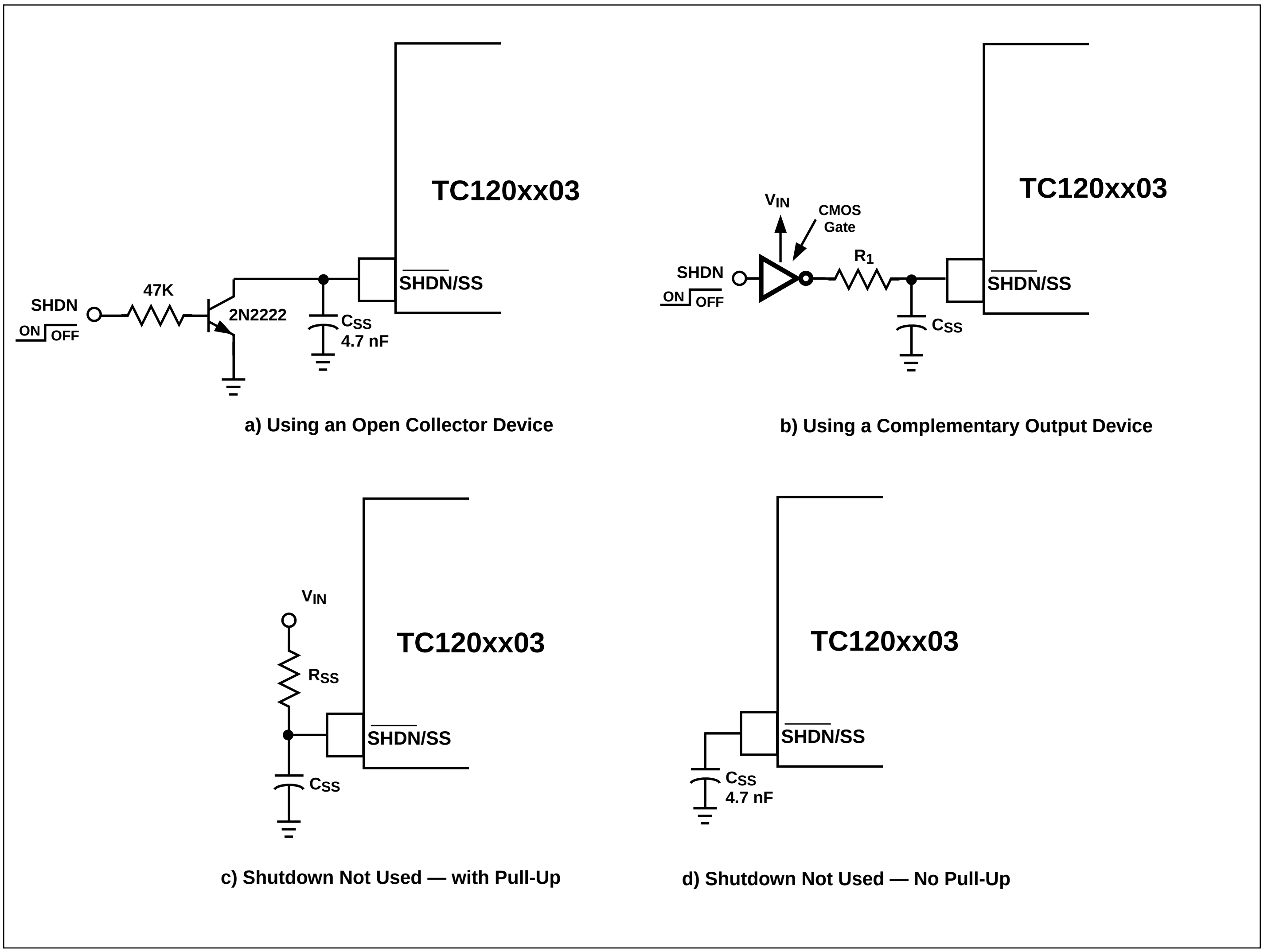


Figure 5. Shutdown Control Circuits

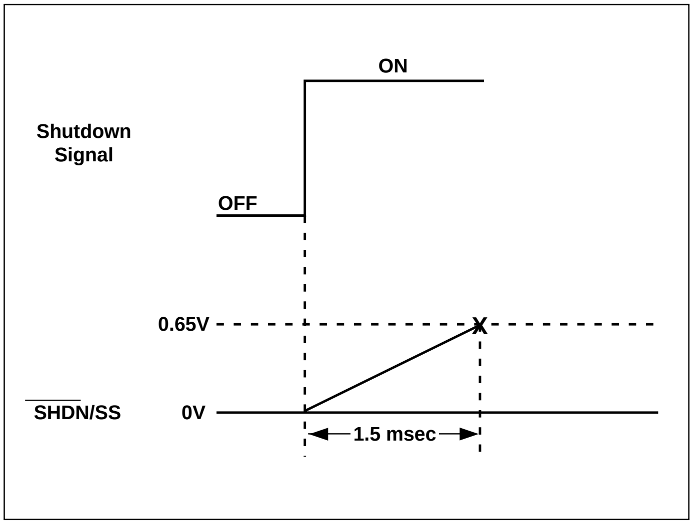


Figure 6. Soft Start Timing

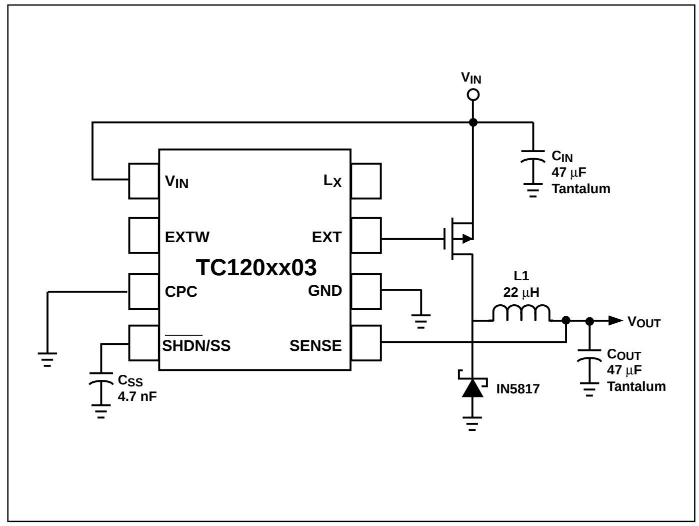


Figure 7. Using External Transistor Switch

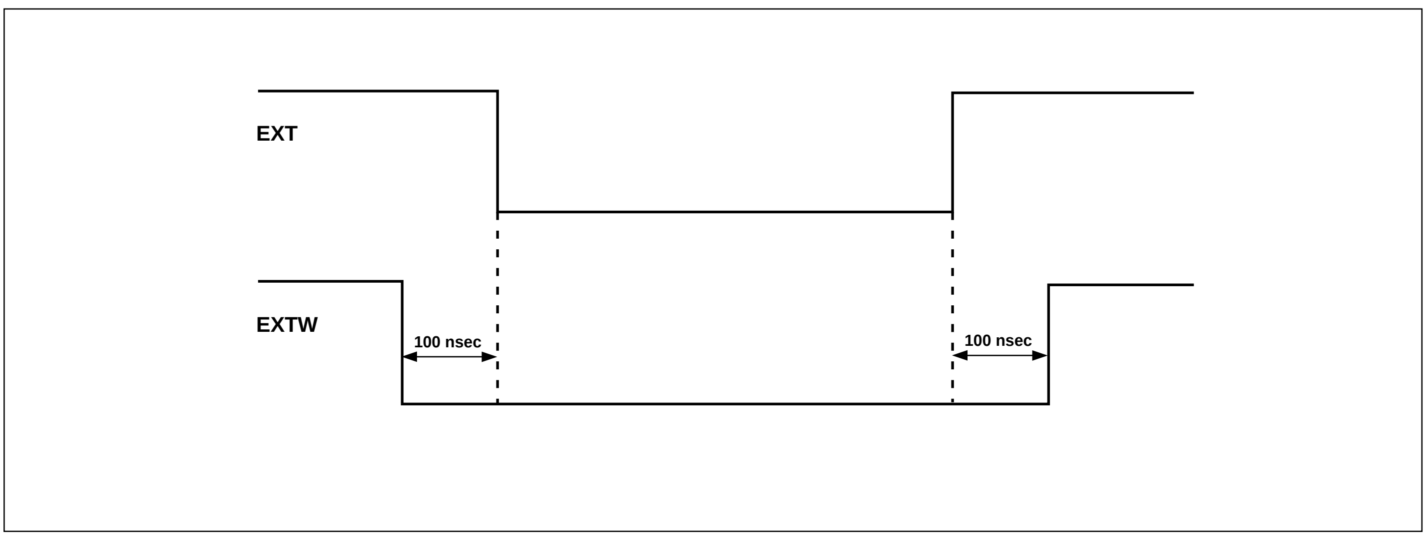


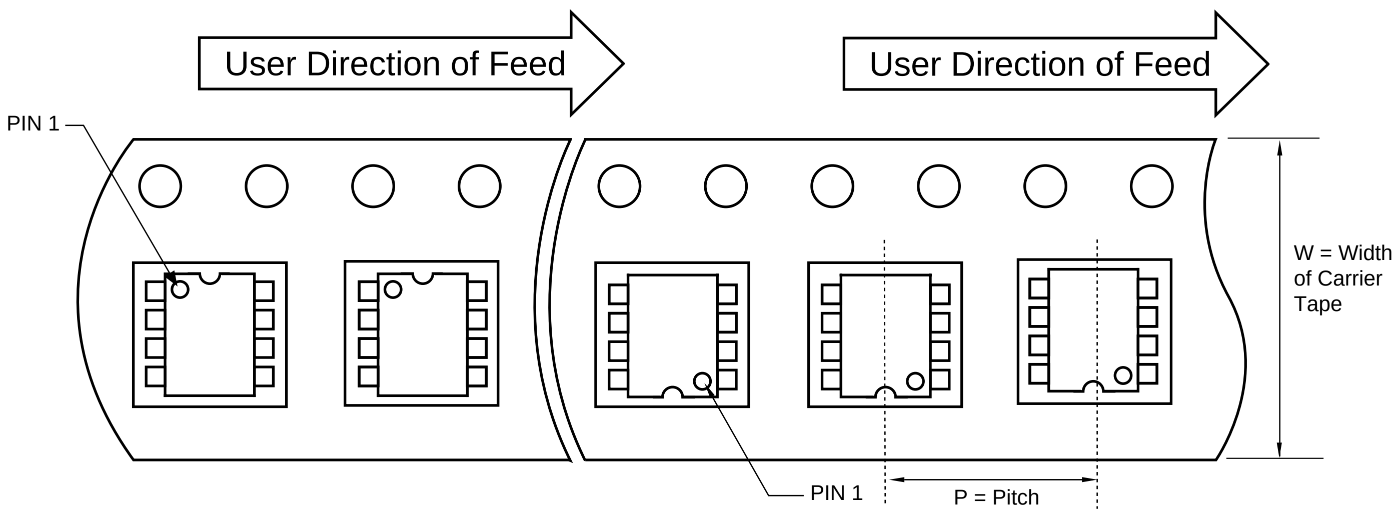
Figure 8. External (EXT) and Extended External (EXTW) Switching Transistor Drive Output

Table 1. Suggested Components and Manufacturers

Type	Inductors	Capacitors	Diodes	Transistors
Surface Mount	Sumida CD54 Series CDRH Series Coilcraft DO Series	AVX TPS Series Sprague 595D Series	Motorola MBRS340T3 NiHon NSQ Series Matsushita MA737	Silconix Little Foot MOSFET Series Zetex FZT749 PNP Bipolar Transistor Toshiba 2SA1213 PNP Transistor
Miniature Through Hole	Sumida RCH Series	Sanyo OS-CON Series	IRC OAR Series	
Standard Through-Hole	Coilcraft PCH Series	Nichicon PL Series United Chemi-Con LXF Series		Motorola TMOS Power MOSFETs

TAPING DIAGRAM

Component Taping Orientation for 8-Pin SOP



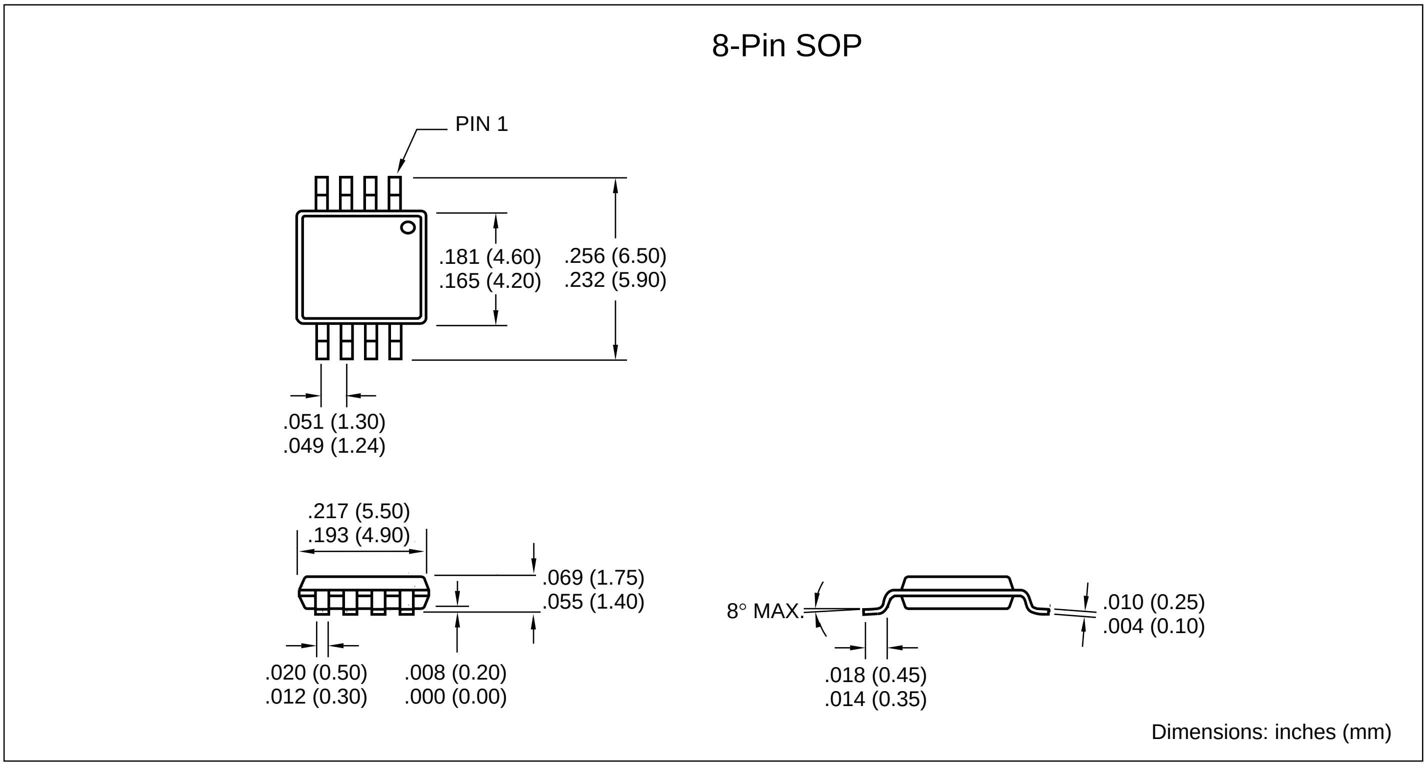
Standard Reel Component Orientation for 713 or TR Suffix Device

Reverse Reel Component Orientation for 723 or RT Suffix Device

Carrier Tape, Reel Size, and Number of Components Per Reel

Package	Carrier Width (W)	Pitch (P)	Part Per Full Reel	Reel Size
8-Pin SOP	12 mm	8.0 mm	1000	7 in

PACKAGE DIMENSIONS



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