PFM/PWM Step-Up DC/DC Controller

FEATURES

- **Space-Saving 5-Pin SOT-23A Package**
- **Guaranteed Start-Up at 0.9V**
- **50 µA (Typ) Supply Current (f_{OSC} = 100 KHz)**
- **300 mA Output Current @ $V_{IN} \geq$ 2.7V**
- **0.5 µA Shutdown Mode**
- **100 KHz and 300 KHz Switching Frequency Options**
- **Programmable Soft-Start**
- **84% Efficiency**

TYPICAL APPLICATIONS

- **Palmtops**
- **Battery Powered Systems**
- **Positive LCD Bias Generators**
- **Portable Communicators**

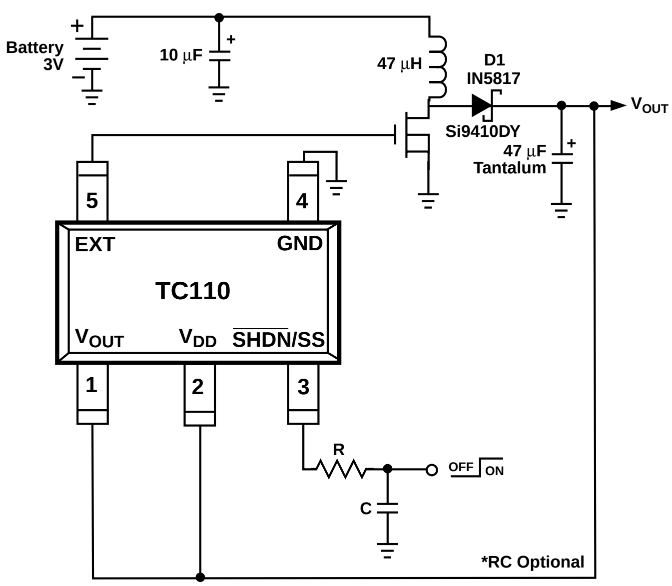
GENERAL DESCRIPTION

The TC110 is a step-up (Boost) switching controller that furnishes output currents as high as 300 mA while delivering a typical efficiency of 84%. The TC110 normally operates in pulse width modulation mode (PWM), but automatically switches to pulse frequency modulation (PFM) at low output loads for greater efficiency. Supply current draw for the 100 KHz version is typically only 50 µA, and is reduced to less than 0.5 µA when the $\overline{SHDN}$ input is brought low. Regulator operation is suspended during shutdown.

Housed in a tiny 5-pin SOT-23A package, the TC110 occupies minimum board space, and uses tiny external components (the 300 KHz version allows for less than 5 mm surface-mount magnetics).

The TC110 accepts input voltages from 2.0V to 10.0V, with a guaranteed start-up voltage of 0.9V.

TYPICAL OPERATING CIRCUIT



3V to 5V Supply

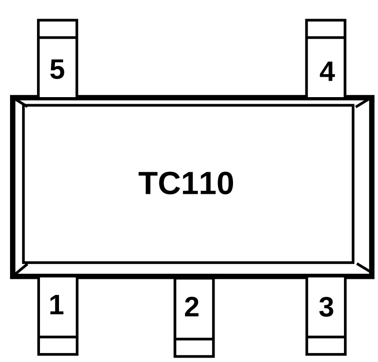
ORDERING INFORMATION

Part Number	Output Voltage* (V)	Package	Osc. Freq. (KHz)	Operating Temp. Range
TC110501ECT	5.0	5-Pin SOT-23A	100	–40 to +85°C
TC110331ECT	3.3	5-Pin SOT-23A	100	–40 to +85°C
TC110301ECT	3.0	5-Pin SOT-23A	100	–40 to +85°C
TC110503ECT	5.0	5-Pin SOT-23A	300	–40 to +85°C
TC110333ECT	3.3	5-Pin SOT-23A	300	–40 to +85°C
TC110303ECT	3.0	5-Pin SOT-23A	300	–40 to +85°C

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

PIN CONFIGURATION

5-Pin SOT-23A



ABSOLUTE MAXIMUM RATINGS*

Voltage on V_{DD}, V_{OUT}, $\overline{SHDN}$ Pins .... –0.3V to +12V
EXT Output Current ....±100 mA
Voltage on EXT Pin .... –0.3V to V_{DD} +0.3V
Power Dissipation .... 150 mW
Operating Temperature .... –40°C to +85°C
Storage Temperature .... –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: Note 1, T_A = 25°C, V_{IN} = 0.6V X V_R, V_{DD} = V_{OUT}, unless otherwise noted.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
V_{DD}	Supply Voltage	Note 2	2.0	—	10.0	V
V_{START}	Start-Up Supply Voltage	I_{OUT} = 1mA	—	—	0.9	V
$V_{HOLD-UP}$	Oscillator Hold-Up Voltage	I_{OUT} = 1mA	—	—	0.7	V
I_{DD}	Boost Mode Supply Current	V_{OUT} = $\overline{SHDN}$ = (0.95 x V_R); f_{OSC} = 300 KHz; V_R = 3.0V	—	120	190	µA
		V_R = 3.3V	—	130	200	µA
		V_R = 5.0V	—	180	280	µA
		f_{OSC} = 100 KHz; V_R = 3.0V	—	50	90	µA
		V_R = 3.3V	—	50	100	µA
		V_R = 5.0V	—	70	120	µA
I_{STBY}	Standby Supply Current	V_{OUT} = $\overline{SHDN}$ = (V_R + 0.5V); f_{OSC} = 300 KHz; V_R = 3.0V	—	20	34	µA
		V_R = 3.3V	—	20	35	µA
		V_R = 5.0V	—	22	38	µA
		f_{OSC} = 100 KHz; V_R = 3.0V	—	11	20	µA
		V_R = 3.3V	—	11	20	µA
		V_R = 5.0V	—	11	22	µA
I_{SHDN}	Shutdown Supply Current	$\overline{SHDN}$ = GND, V_O = (V_R x 0.95)	—	0.05	0.5	µA
f_{OSC}	Oscillator Frequency	V_{OUT} = $\overline{SHDN}$ = (0.95 x V_R); f_{OSC} = 300 KHz	255	300	345	KHz
		f_{OSC} = 100 KHz	85	100	115	KHz
V_{OUT}	Output Voltage	Note 3	V_R x 0.975	V_R	V_R x 1.025	V
DTYMAX	Maximum Duty Cycle (PWM Mode)	V_{OUT} = $\overline{SHDN}$ = 0.95 x VR	—	—	92	%
DTYPFM	Duty Cycle (PFM Mode)	I_{OUT} = 0 mA	15	25	35	%
V_{IH}	$\overline{SHDN}$ Input Logic High	V_{OUT} = (V_R x 0.95)	0.65	—	—	V
V_{IL}	$\overline{SHDN}$ Input Logic Low	V_{OUT} = (V_R x 0.95)	—	—	0.20	V
REXTH	EXT ON Resistance to V_{DD}	V_{OUT} = $\overline{SHDN}$ = (V_R x 0.95); V_R = 3.0V	—	32	47	Ω
		V_R = 3.3V	—	29	43	Ω
		V_{EXT} = (V_{OUT} – 0.4V) V_R = 5.0V	—	20	29	Ω
REXTL	EXT ON Resistance to GND	V_{OUT} = $\overline{SHDN}$ = (V_R x 0.95); V_R = 3.0V	—	20	30	Ω
		V_R = 3.3V	—	19	27	Ω
		V_{EXT} = 0.4V V_R = 5.0V	—	13	19	Ω
η	Efficiency		—	84	—	%

Notes: 1. For V_R = 3.0V, I_{OUT} = 120mA; For V_R = 3.3V, I_{OUT} = 130mA; For V_R = 5.0V I_{OUT} = 200 mA.
2. See Application Notes “Operating Mode” description for clarification.
3. V_R is the factory output voltage setting.

PIN DESCRIPTION

Pin Number	Name	Description
1	V_{OUT}	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).
2	V_{DD}	Power Supply Voltage Input.
3	$\overline{SHDN}$/SS	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. An RC circuit connected to this input also determines the soft-start time.
4	GND	Ground Terminal.
5	EXT	External Switch Transistor Drive Complimentary Output. This pin drives the external switching transistor. It may be connected to the base of the external bipolar transistor or gate of the external N-channel MOSFET. (See *Applications* section).

DETAILED DESCRIPTION

TC110 is a PFM/PWM step-up DC/DC controller for use in systems operating from two or more cells, or in low voltage, line-powered applications. It uses PWM as the primary modulation scheme, but automatically converts to PFM at output duty cycles less than approximately 10%. The conversion to PFM provides reduced supply current, and therefore higher operating efficiency at low loads. The TC110 uses an external switching transistor, allowing construction of switching regulators with maximum output currents of 300 mA.

The TC110 consumes only 70 µA, typical, of supply current and can be placed in a 0.5 µA shutdown mode by bringing $\overline{SHDN}$ low. The regulator is disabled during shutdown, and resumes normal operation when $\overline{SHDN}$ is brought high. Other features include start-up at V_{IN} = 0.9V, an externally-programmable soft start time and tiny 5-pin SOT-23A packaging.

Operating Mode

The TC110 is powered by the voltage present on the V_{DD} input. The applications circuits of Figures 1a and 1b show operation in the bootstrapped and non-bootstrapped modes. In bootstrapped mode, the TC110 is powered from the output (start-up voltage is supplied by V_{IN} through the inductor and Schottky diode while Q1 is off). In bootstrapped mode, the switching transistor is turned on harder because its gate voltage is higher (due to the boost action of the regulator), resulting in higher output current capacity.

The TC110 is powered from the input supply in the non-bootstrapped mode. In this mode, the supply current to the TC110 is minimized. However, the drive applied to the gate of the switching transistor swings from the input supply level to ground, so the transistor's ON resistance increases at low input voltages. Overall efficiency is increased since supply current is reduced, and less energy is consumed charging and discharging the gate of the MOSFET. While the TC110 is guaranteed to start up at 0.9V the device performs to specifications at 2.0V and higher.

Low Power Shutdown Mode

The TC110 enters a low power shutdown mode when $\overline{SHDN}$ is brought low. While in shutdown, the oscillator is disabled and the output switch (internal or external) 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 TC110 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.

Soft Start

Soft start allows the output voltage to gradually ramp from 0V to rated output value during start-up. This action minimizes (or eliminates) overshoot, and in general, reduces stress on circuit components. Figure 2 shows the circuit required to implement soft start. Values of 470K and 0.1 µF for R_{SS} and C_{SS} are adequate for most applications.

Input Bypass Capacitors

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. 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.

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.

A 22 µH inductor, therefore, is recommended for the 300 KHz versions and a 47µH inductor is recommended for the 100KHz versions. Inductors with a ferrite core (or equivalent) also are recommended. For highest efficiency, use an inductor with a series resistance less than 20mΩ.

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 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:

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

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.

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

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 substitute V_{CESAT} for 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.

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 959D series of tantalum capacitors are amongst the smallest of all low ESR surface mount capacitors available. Table 1 lists suggested component numbers and manufacturers.

TC110

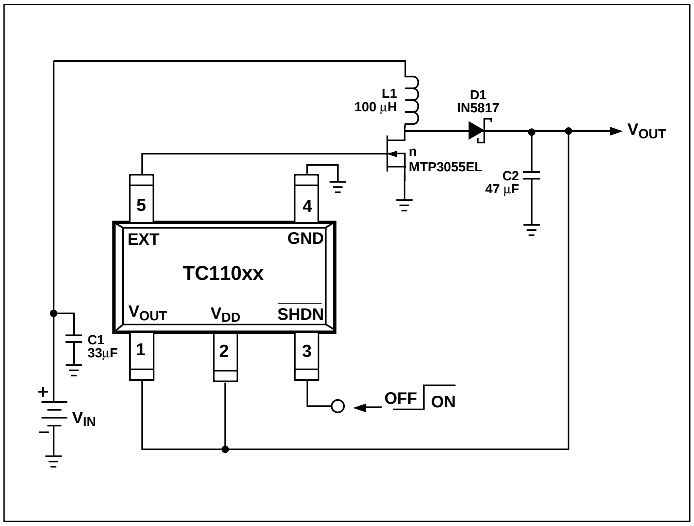


Figure 1a. Bootstrapped Operation

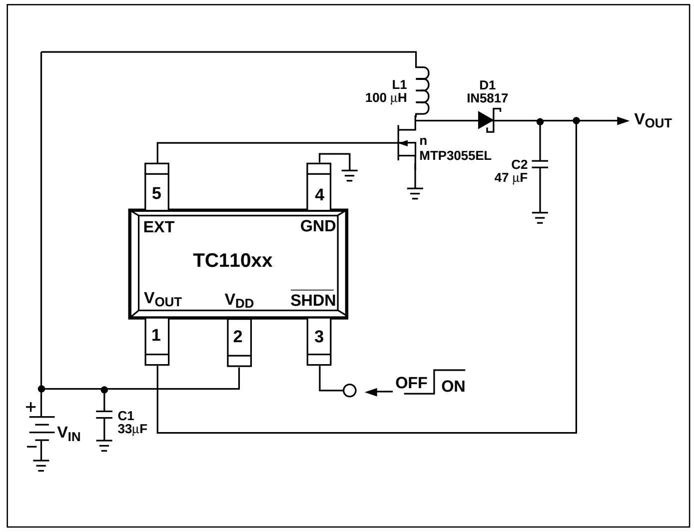


Figure 1b. Non-Bootstrapped Operation

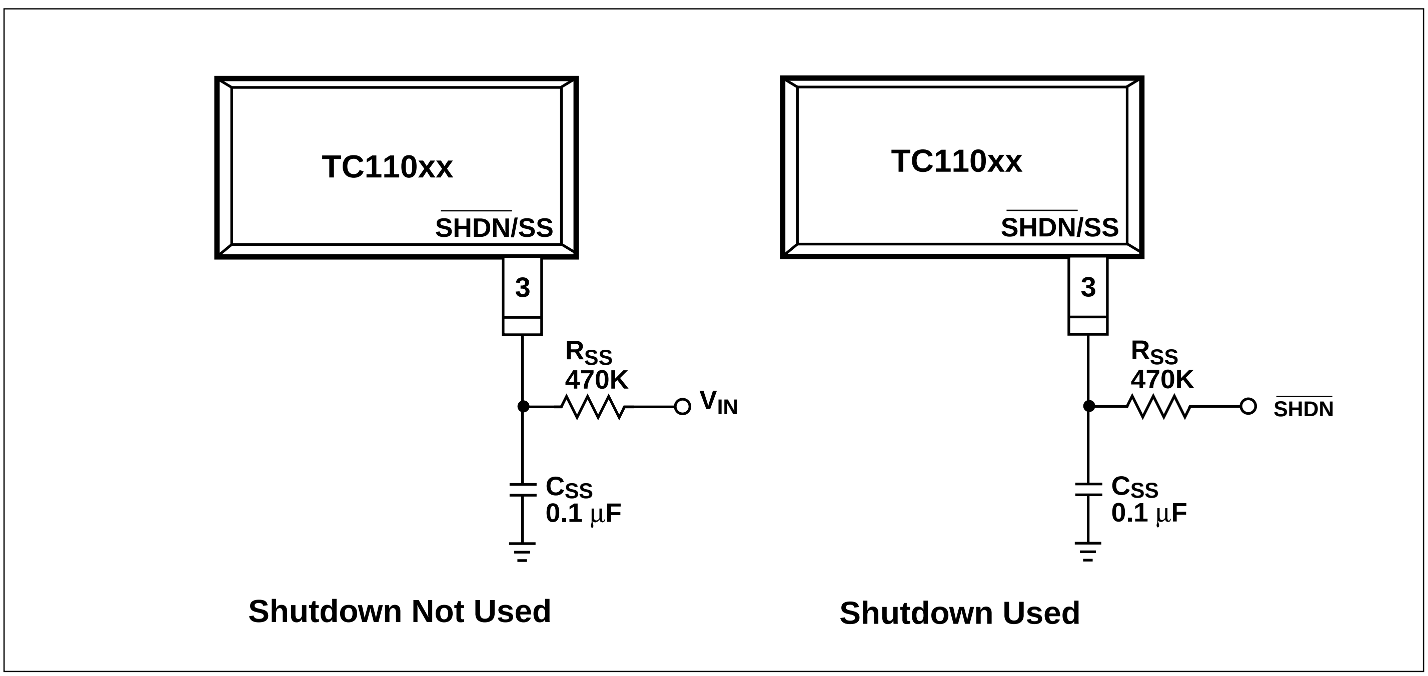


Figure 2. Soft Start/Shutdown Circuit

Board Layout Guidelines

As with all inductive switching regulators, the TC110 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 TC110 as possible.

Output Diode

For best results, use a Schottky diode such as the MA735, 1N5817, MBR0520L or equivalent. Connect the diode between the FB (or SENSE) input as close to the IC as possible. Do not use ordinary rectifier diodes since the higher threshold voltages reduce efficiency.

External Switching Transistor Selection

The EXT output is designed to directly drive an N-channel MOSFET or NPN bipolar transistor. N-channel MOSFETs afford the highest efficiency because they do not draw any gate drive current, but are typically more expensive than bipolar transistors. If using an N-Channel MOSFET, the gate should be connected directly to the EXT output as shown in Figure 1. EXT is a complimentary output with a maximum ON resistances of 43Ω to V_{DD} when high and 27Ω to ground when low. Peak currents should be kept below 10 mA.

When selecting an N-channel MOSFET, there are three important parameters to consider: total gate charge (Qg); ON resistance (rDS(on)) and reverse transfer capacitance (CRSS). Qg is a measure of the total gate capacitance that will ultimately load the EXT output. Too high a Qg can reduce the slew rate of the EXT output sufficiently to grossly lower operating efficiency. Transistors with typical Qg data sheet values of 50 nC or less can be used. For example, the Si9410DY has a Qg(typ) of 17nC @ V_{GS} = 5V. This equates to a gate current of:

$$IGATE(max) = f_{MAX} \times Qg = 115 \text{ KHZ} \times 17 \text{ nC} = 2 \text{ mA}$$

The two most significant losses in the N-Channel MOSFET are switching loss and I^2R loss. To minimize these, a transistor with low rDS(on) and low CRSS should be used.

Bipolar NPN transistors can be used, but care must be taken when determining base current drive. Too little current will not fully turn the transistor on, and result in unstable regulator operation and low efficiency. Too high a base drive causes excessive power dissipation in the transistor and increase switching time due to over-saturation. For peak efficiency, make RB as large as possible, but still guaranteeing the switching transistor is completely saturated when the minimum value of h_{FE} is used.

APPLICATIONS

Circuit Design

Figure 3 shows a TC110 operating as a 100 KHz bootstrapped regulator with soft start. This circuit uses an NPN switching transistor (Zetex FZT690B) that has an h_{FE} of 400 and V_{CESAT} of 100 mV at IC = 1A. Other high beta transistors can be used, but the values of RB and CB may need adjustment if h_{FE} is significantly different from that of the FZT690B.

Figure 4 and 5 both utilize an N-Channel switching transistor (Silconix Si9410DY). This transistor is a member of the Littlefoot™ family of small outline MOSFETs. The circuit of Figure 4 operates in bootstrapped mode, while the circuit of Figure 5 operates in non-bootstrapped mode.

TC110

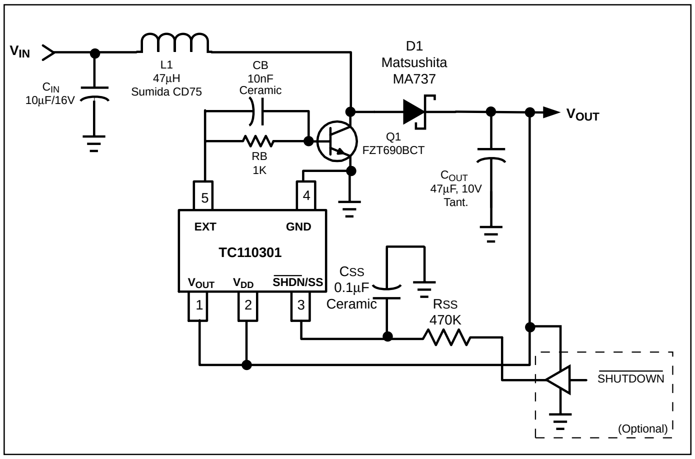


Figure 3. 100 KHz Bootstrapped Regulator with Soft Start Using a Bipolar Transistor

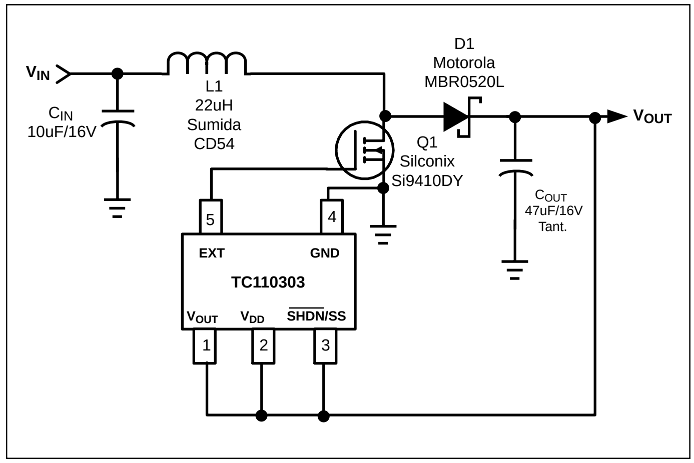


Figure 4. 300 KHz Bootstrapped, N-Channel Transistor

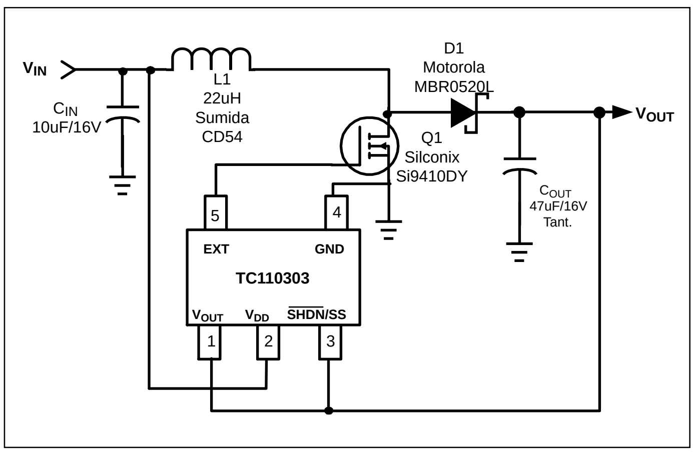
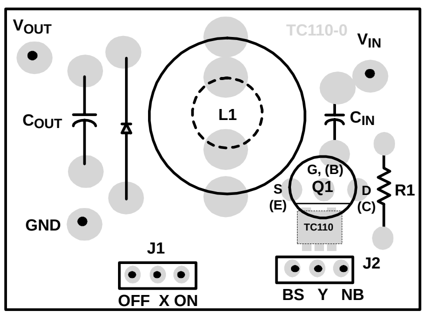


Figure 5. 300 KHz Non-Bootstrapped, N-Channel Transistor

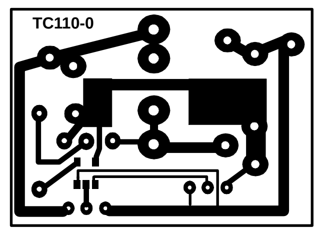
TC110 DEMO CARD

The TC110DEMO allows the user to quickly prototype TC110-based circuits. The TC110DEMO consists of a printed circuit board (with TC110 installed on the foil side of the board); with separate Schottky diode, output capacitor and 100 µH Coiltronics inductor. The circuit schematic appears in Figure 7.

The board is designed to accept either a 100 µH or 20 µH torroidal inductor. The remaining components install in accordance with the component side layout diagram of Figure 6. Jumper blocks J1 and J2 control shutdown and operating mode selection respectively. Shorting J1, terminal X to OFF, places the TC110 in shutdown; normal operation is enabled when J1 terminal X is shorted to ON. Shorting J2, terminal Y to BS, selects bootstrapped operating mode; shorting J2 terminal Y to NB, selects non-bootstrapped operation.



Component Side of Board



Full Size

Figure 6. TC110 Demo Board Layout

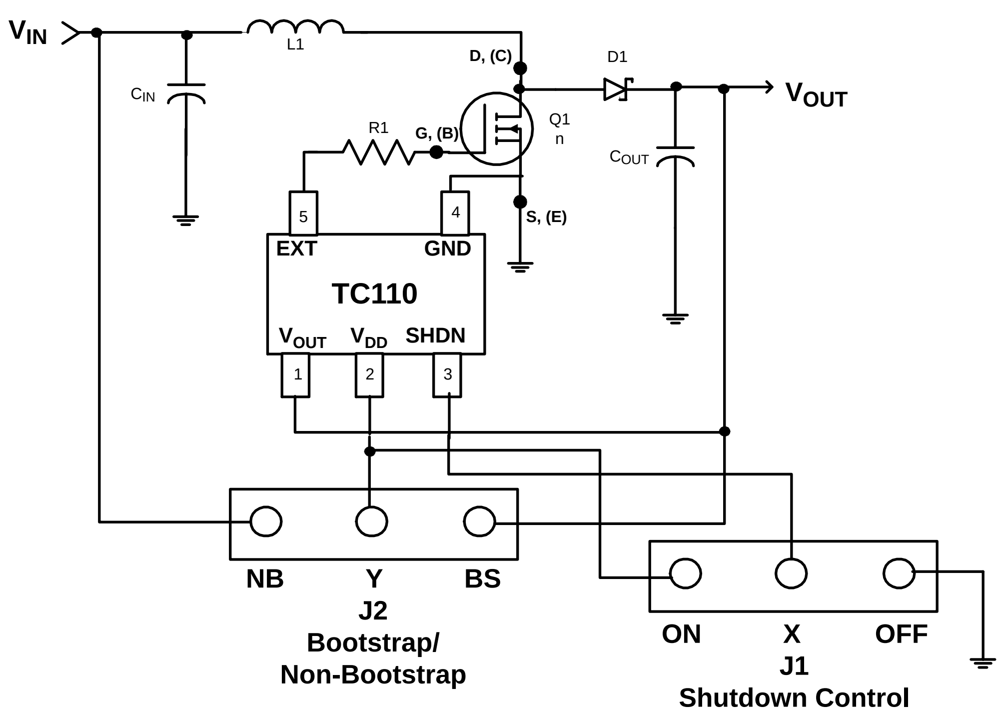


Figure 7. TC110 Demo Schematic

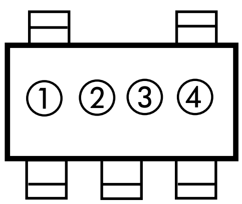
TC110

Table 1. Suggested Components and Manufacturers

Type	Inductors	Capacitors	Transistors	Diodes
Surface Mount	Sumida CD54 Series (300 KHz) CD75 (100 KHz) Coiltronics CTX Series	Matsuo 267 Series Sprague 595D Series Nichicon F93 Series	N-channel Silconix Si9410DY Motorola MTP3055EL MTD20N03	Nihon EC10 Series Matshushita MA735 Series
Through Hole	Sumida RCH855 Series RCH110 Series Renco RL1284-12	Sanyo OS-CON Series Nichicon PL Series	NPN Zetex ZTX694B	Motorola 1N5817 – 1N5822

MARKINGS

5-Pin SOT-23A



① represents product classification; TC110 = M

② represents 1st integer of voltage and frequency

Symbol		
100KHz	**300KHz**	**Output Voltage**
B	1	1.
C	2	2.
D	3	3.
E	4	4.
F	5	5.
H	6	6.

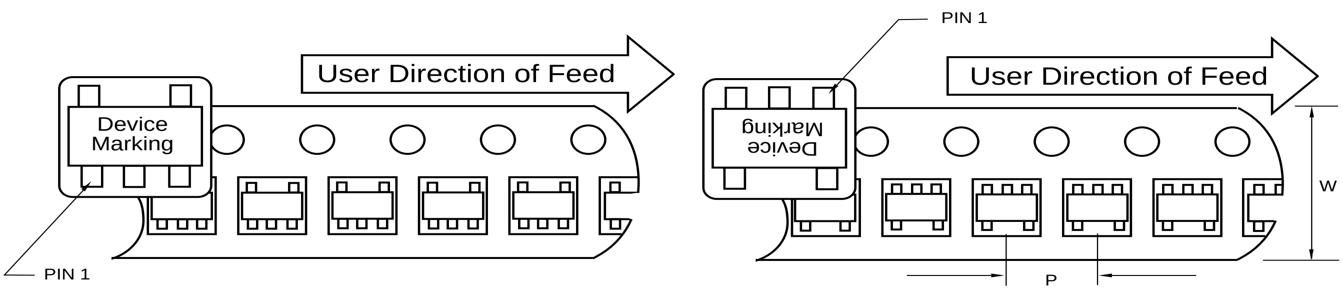
③ represents 1st decimal of voltage and frequency

Symbol		
100KHz	**300KHz**	**Output Voltage**
0	A	.0
1	B	.1
2	C	.2
3	D	.3
4	E	.4
5	F	.5
6	H	.6
7	K	.7
8	L	.8
9	M	.9

④ represents lot ID number

TAPING FORMS

Component Taping Orientation for 5-Pin SOT-23A (EIAJ SC-74A) 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

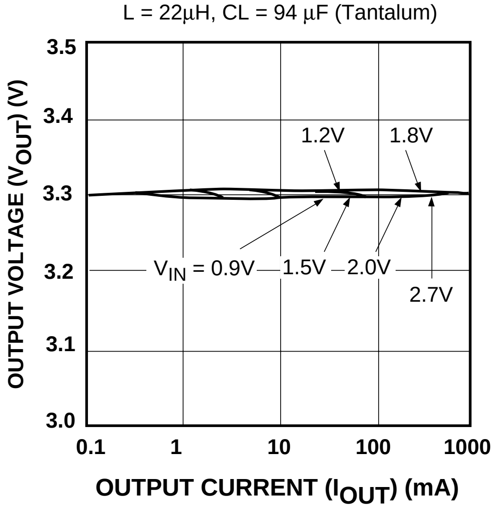
Package	Carrier Width (W)	Pitch (P)	Part Per Full Reel	Reel Size
5-Pin SOT-23A	8 mm	4 mm	3000	7 in

Package	Carrier Width (W)	Pitch (P)	Part Per Full Reel	Reel Size
5-Pin SOT-23A	8 mm	4 mm	3000	7

TYPICAL CHARACTERISTICS CURVES

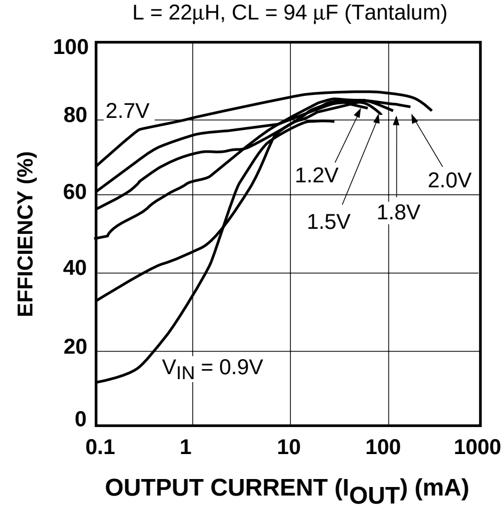
OUTPUT VOLTAGE vs. OUTPUT CURRENT

TC110 (300KHz, 3.3V)
L = 22µH, CL = 94 µF (Tantalum)



EFFICIENCY vs. OUTPUT CURRENT

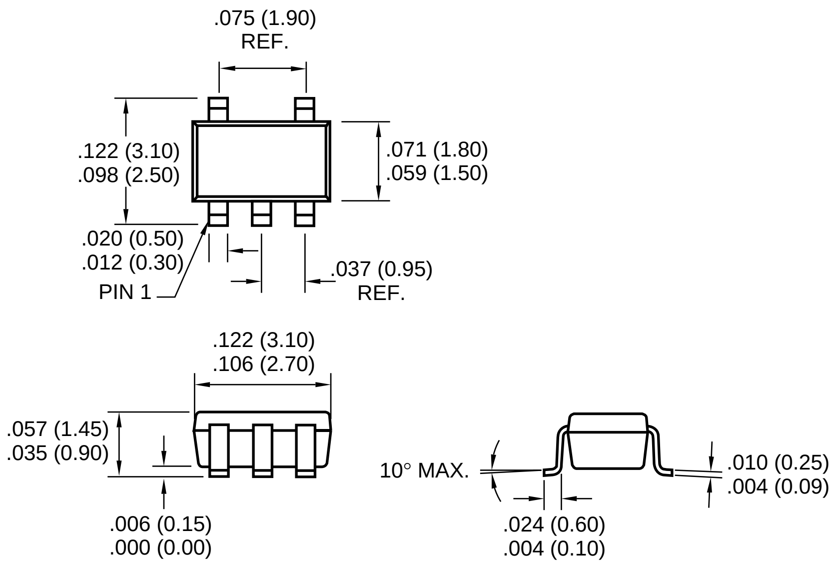
TC110 (300KHz, 3.3V)
L = 22µH, CL = 94 µF (Tantalum)



TC110

PACKAGE DIMENSIONS

5-Pin SOT-23A (EIAJ SC-74A)



Dimensions: inches (mm)

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