RC4191/4192/4193 Micropower Switching Regulators

Features

- High efficiency — 80% typical
- Low quiescent current — 215 μA
- Adjustable output — 2.2V to 30V
- High switch current — 150 mA
- Bandgap reference — 1.31V
- Remote shutdown capability
- Low battery detection circuitry
- Low component count
- Small 8-lead package

Description

Not recommended for new designs. Refer to RC4190 Data Sheet. The RC4193 series of monolithic ICs are low power switch mode regulators intended for miniature power supply applications. These dc-to-dc converter ICs provide all of the active functions needed to create supplies for micropower circuits (load power up to 400 mW, or up to 10W with external power transistor). Contained internally are an oscillator, switch, reference, comparator, and logic, plus a discharged battery detection circuit.

Application areas include on-card circuits where a non-standard voltage supply is needed, or in battery operated instruments where a 4193 can be used to extend battery lifetime.

These regulators can achieve up to 80% efficiency in most applications while operating over a wide supply voltage range, 2.2V to 30V, at a very low quiescent current drain of 215 μA.

The standard application circuit requires just seven external components for step-up operation: an inductor, a steering diode, three resistors, a low value timing capacitor, and an electrolytic filter capacitor. The combination of simple application circuit, low supply current, and small package make the 4193 adaptable to a wide range of miniature power supply applications.

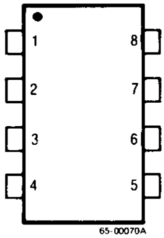
The 4193 is most suited for single ended step-up circuits because the internal switch transistor is referenced to ground. It is complemented by Raytheon's other micropower switching regulator, the 4391, which is dedicated to step-down and negative output (inverting) applications. Between the two devices the ability to create all three basic switching regulator configurations is assured. Refer to the 4391 data sheet for step-down and inverting applications.

The 4191/92/93 series of micropower switching regulators consists of three devices, each with slightly different specifications. The 4191 has a 1.5% maximum output voltage tolerance, 0.2% maximum line regulation, and operation to 30V. The 4192 has a 3.0% maximum output voltage tolerance, 0.5% maximum line regulation, and operation to 30V. The 4193 has a 5.0% maximum output voltage tolerance, 0.5% maximum line regulation, and operation to 24V. Other specifications are identical for the 4191, 4192 and 4193. Each type is available in commercial, industrial, and military temperature ranges, and in plastic and ceramic DIPs.

With some optional external components the application can be designed to signal a display when the battery has decayed below a predetermined level, or designed to signal a display at one level and then shut itself off after the battery decays to a second level. See the applications section for these and other unique circuits.

Connection Information

8-Lead
Dual In-Line Package
(Top View)



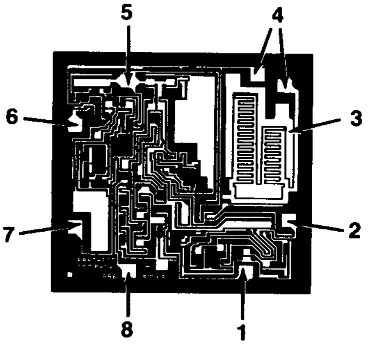
Pin	Function
1	Low Battery (Set) Resistor (LBR)
2	Timing Capacitor (C_X)
3	External Inductor (L_X)
4	Ground
5	+Supply Voltage ($+V_S$)
6	Reference Set Current (I_C)
7	Feedback Voltage (V_{FB})
8	Low Battery Detector Output (LBD)

Ordering Information

Part Number	Package	Operating Temperature Range
RC4191N	N	0°C to +70°C
RC4192N	N	0°C to +70°C
RC4193N	N	0°C to +70°C
RV4191N	N	-25°C to +85°C
RV4192N	N	-25°C to +85°C
RV4193N	N	-25°C to +85°C
RM4191D	D	-55°C to +125°C
RM4192D	D	-55°C to +125°C
RM4193D	D	-55°C to +125°C
RM4191D/883B	D	-55°C to +125°C
RM4192D/883B	D	-55°C to +125°C
RM4193D/883B	D	-55°C to +125°C

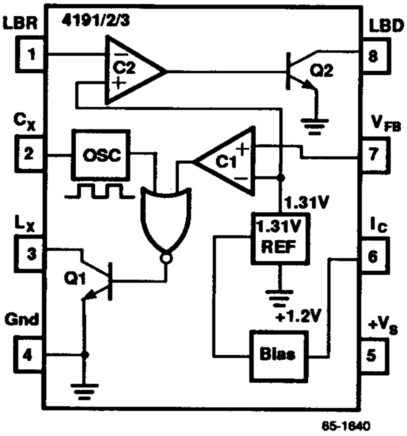
Notes:
/883B suffix denotes Mil-Std-883, Level B processing
N = 8-lead plastic DIP
D = 8 lead ceramic DIP
Contact a Raytheon sales office or representative for ordering information on special package/temperature range combinations.

Mask Pattern



Die Size: 66 x 67 mils
Min. Pad Dimensions: 4 x 4 mils 65-01482A

Functional Block Diagram



Absolute Maximum Ratings

Supply Voltage (Without External Series Pass Transistor	
4191, 4192	+30V
4193	+24V
Storage Temperature Range	-65°C to +150°C
Operating Temperature Range	
RM4191/2/3	-55°C to +125°C
RV4191/2/3	-25°C to +85°C
RC4191/2/3	0°C to +70°C
Switch Current	375 mA Peak

Thermal Characteristics

	8-Lead Plastic DIP	8-Lead Ceramic DIP
Max. Junction Temp.	125°C	175°C
Max. P_D $T_A < 50°C$	468mW	833mW
Therm. Res. θ_{JC}	—	45°C/W
Therm. Res. θ_{JA}	160°C/W	150°C/W
For $T_A > 50°C$ Derate at	6.25mW per °C	8.33mW per °C

Electrical Characteristics (V_S = +6.0V, I_C = 5.0 μA, and T_A = +25°C unless otherwise noted)

Parameters	Symbol	Conditions	4191			4192			4193			Units
			Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Supply Voltage	$+V_S$		2.2		30	2.2		30	2.2		24	V
Reference Voltage (Internal)	V_{REF}		1.29	1.31	1.33	1.27	1.31	1.35	1.24	1.31	1.38	V
Switch Current	I_{SW}	V_3 = 400mV	100	200		100	200		100	200		mA
Supply Current	I_S	Measure at Pin 5 $I_3 = 0$		215	300		215	300		215	300	μA
Efficiency	ef			85			85			85		%
Line Regulation		$0.5 V_O < V_S < V_O$		0.04	0.2		0.04	0.5		0.04	0.5	% V_O
Load Regulation	L_l	$V_S = +0.5 V_O$, P_L = 150mW		0.2	0.5		0.2	0.5		0.2	0.5	% V_O
Operating Frequency Range[1]	F_O		0.1	25	75	0.1	25	75	0.1	25	75	kHz
Reference Set Current	I_C		1.0	5.0	50	1.0	5.0	50	1.0	5.0	50	μA
Switch Leakage Current	I_{CO}	V_3 = 24V		0.01	5.0		0.01	5.0		0.01	5.0	μA
Supply Current (Disabled)	I_{SO}	$V_C \leq 200$ mV		0.1	5.0		0.1	5.0		0.1	5.0	μA
Low Battery Bias Current	I_1	V_1 = 1.2V		0.7			0.7			0.7		μA
Capacitor Charging Current	I_{CX}			8.6			8.6			8.6		μA
Oscillator Frequency Tolerance				±10						±10		%

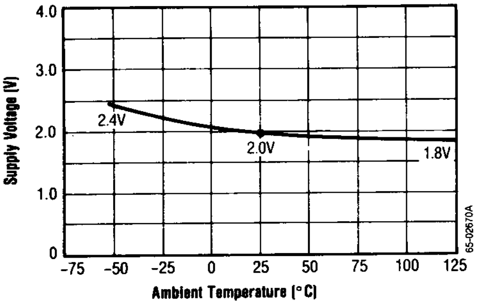
Note 1: Guaranteed by design.

Electrical Characteristics (Continued)

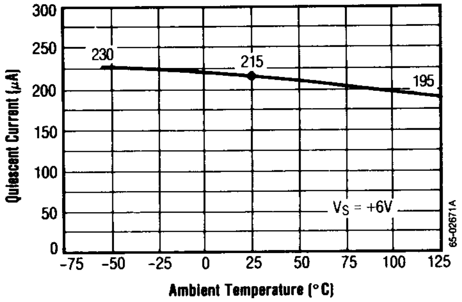
(V_S = +6.0V, I_C = 5.0 μA, and T_A = +25°C unless otherwise noted)

Parameters	Symbol	Conditions	4191			4192			4193			Units
			Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Capacitor Threshold Voltage +	$+V_{THX}$			1.4			1.4			1.4		V
Capacitor Threshold Voltage −	$-V_{THX}$			0.5			0.5			0.5		V
Feedback Input Current	I_{FB}	V_7 = 1.3V		0.1			0.1			0.1		μA
Low Battery Output Current	I_{LBD}	V_8 = 0.4V, V_1 = 1.1V	500	1500		500	1500		500	1500		μA
$+V_S$ = 6.0V, I_C = 5.0 μA, unless otherwise noted, over the full operating temperature range)												
Supply Voltage	$+V_S$		2.6		30	2.6		30	2.6		24	V
Reference Voltage (Internal)	V_{REF}		1.25	1.31	1.37	1.23	1.31	1.39	1.20	1.31	1.42	V
Supply Current	I_S	Measure at Pin 5 I_3 = 0		225	350		225	350		225	350	μA
Line Regulation		0.5 V_O < $+V_S$ < V_O		0.2	0.5		0.5	1.0		0.5	1.0	% V_O
Load Regulation	L_I	$+V_S$ = 0.5 V_O, P_L = 150 mW		0.5	1.0		0.5	1.0		0.5	1.0	% V_O
Reference Set Current	I_C		1.0	5.0	50	1.0	5.0	50	1.0	5.0	50	μA
Switch Leakage Current	I_{CO}	V_3 = 24V			30			30			30	μA
Supply Current (Disabled)	I_{SO}	V_C < 200 mV			30			30			30	μA
Low Battery Output Current	I_{LBD}	V_8 = 0.4V, V_1 = 1.1V	500	1200		500	1200		500	1200		μA
Oscillator Frequency Temperature Drift				±200			±200			±200		ppm/°C

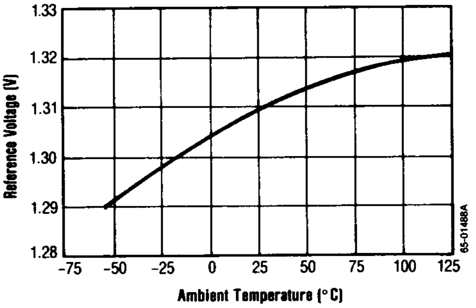
Typical Performance Characteristics



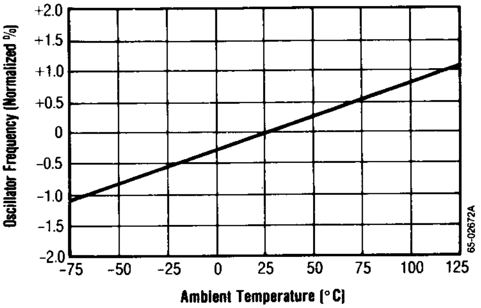
Minimum Supply Voltage vs. Temperature



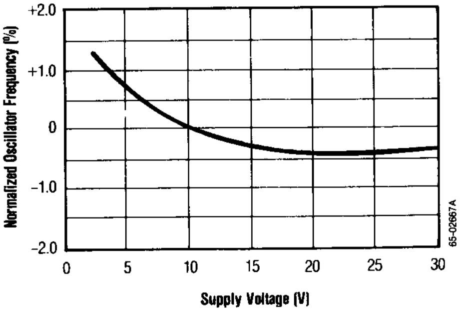
Quiescent Current vs. Temperature



Reference Voltage vs. Temperature



Oscillator Frequency vs. Temperature



Oscillator Frequency vs. Supply Voltage

Principles of Operation

Simple Step-Up Converter

The most common application, the step-up regulator, is derived from a simple step-up DC-to-DC converter (Figure 1).

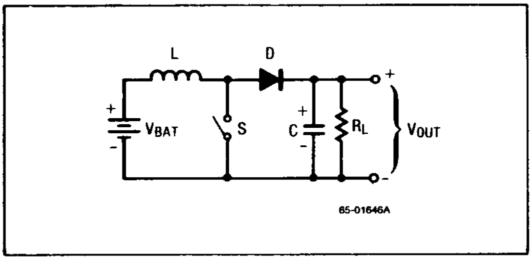


Figure 1. Simple Step-Up DC-to-DC Converter ($V_{OUT} > V_{BAT}$)

When switch S is closed the battery voltage is applied across the inductor L. Charging current flows through the inductor, building up a magnetic field, increasing as the switch is held closed. While the switch is closed, the diode D is reverse biased (open circuit) and current is supplied to the load by the capacitor C. Until the switch is opened the inductor current will increase linearly to a maximum value determined by the battery voltage, inductor value, and the amount of time the switch is held closed ($I_{PEAK} = V_{BAT}/L \times T_{ON}$). When the switch is opened, the magnetic field collapses, and the energy stored in the magnetic field is converted into a discharge current which flows through the inductor in the same direction as the charging current. Because there is no path for current to flow through the switch, the current must flow through the diode to supply the load and charge the output capacitor.

If the switch is opened and closed repeatedly, at a rate much greater than the time constant of the output RC, then a constant DC voltage will be produced at the output.

An output voltage higher than the input voltage is possible because of the high voltage produced by a rapid change of current in the inductor. When the switch is opened the inductor voltage will instantly rise high enough to forward bias the diode, to $V_{OUT} + V_D$.

In the complete 4193 regulator a feedback control system adjusts the on time of the switch, controlling the level of inductor current, so that the average inductor discharge current equals the load current, thus regulating the output voltage.

Complete Step-Up Regulator

A complete schematic of the minimum step-up application is shown in Figure 2. The ideal switch in the DC-to-DC converter diagram is replaced by an open collector NPN transistor Q1. C1 functions as the output filter capacitor, and D1 and L_X replace D and L.

When power is first applied, the current in R1 supplies bias current to pin 6 (I_C). This current is stabilized by a unity gain current source amplifier and then used as bias current for the 1.31V bandgap reference. A very stable bias current generated by the bandgap is mirrored and used to bias the remainder of the chip. At the same time the 4193 is starting up, current will flow through the inductor and the diode to charge the output capacitor to $V_{BAT} - V_D$.

At this point the feedback (pin 7) senses that the output voltage is too low, by comparing a division of the output voltage (set by the ratio of R2 to R3) to the +1.31V reference. If the output voltage is too low then the comparator output changes to a logical zero. The NOR gate then effectively ANDs the oscillator square wave with the comparator signal; if the comparator output is zero AND the oscillator output is low, then the NOR gate output is high and the switch transistor will be forced on. When the oscillator goes high again the NOR gate output goes low and the switch transistor will turn off. This turning on and off of the switch transistor performs the same function that opening and closing the switch in the simple DC-to-DC converter does; i.e., it stores energy in the inductor during the on time and releases it into the capacitor during the off time.

The comparator will continue to allow the oscillator to turn the switch on and off until enough charge has been delivered to the capacitor to raise the feedback voltage above 1.31V.

Thereafter this feedback system will vary the duration of the on time in response to changes in load current or battery voltage (see Figure 3). If the load current increases (waveform C), then the transistor will remain on (waveform D) for a longer portion of the oscillator cycle, thus allowing the inductor current (waveform E) to build up to a higher peak value. The duty cycle of the switch transistor varies in response to changes in load and line.

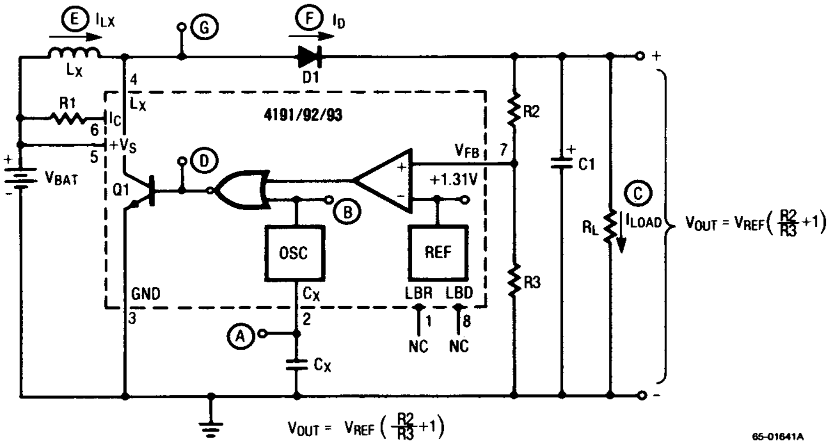


Figure 2. Minimum Step-Up Application

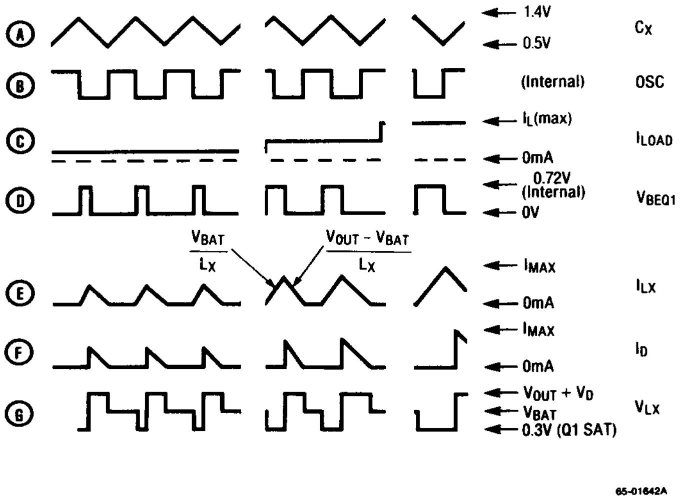


Figure 3. Step-Up Regulator Waveforms

Design Equations

The inductor value and timing capacitor (C_X) value must be carefully tailored to the input voltage, input voltage range, output voltage, and load current requirements of the application. The key to the problem is to select the correct inductor value for a given oscillator frequency, such that the inductor current rises to a high enough peak value (I_{MAX}) to meet the average load current drain. The selection of this inductor value must take into account the variation of oscillator frequency from unit to unit and the drift of frequency over temperature. Use ±20% as a maximum change from the nominal oscillator frequency.

The value of the timing capacitor is set according to the following equation:

$$f_O\,(H_Z) = \frac{2.4 \times 10^{-6}}{C_X}$$

The squarewave output of the oscillator is internal and cannot be directly measured, but is equal in frequency to the triangle waveform measurable at pin 3. The switch transistor is normally on when the triangle waveform is ramping up and off when ramping down. Capacitor selection depends on the application; higher operating frequencies will reduce the output voltage ripple and will allow the use of an inductor with a physically smaller inductor core, but excessively high frequencies will reduce load driving capability and efficiency.

Find a value for the start-up resistor R1:

$$R1 = \frac{V_S - 1.2V}{5\mu A}$$

Find a value for the feedback resistors R2 and R3:

$$R2 = \frac{V_{OUT} - 1.31V}{I_A}$$

$$R3 = \frac{1.31V}{I_A}$$

Where I_A is the feedback divider current (recommended value is between 50μA and 100μA).

Step-Up Design Procedure

1. Select an operating frequency and timing capacitor as shown above (10kHz to 40kHz is typical).
2. Find the maximum on time (add 5μS for the turn-off base recombination delay of Q1):

$$T_{ON} = \frac{1}{2f_O} + 5\mu S$$

3. Calculate the peak inductor current I_{MAX} (if this value is greater than 375mA, then an external power transistor must be used in place of Q1):

$$I_{MAX} = \left(\frac{V_{OUT} + V_D - V_S}{(f_O)\,T_{ON}\,[V_S - V_{SW}]}\right) 2I_L$$

Where:

V_S = Supply Voltage

V_D = Diode Forward Voltage

I_L = DC Load Current

V_{SW} = Saturation Voltage of Q1 (typically 0.5V)

4. Find an inductance value for L_X:

$$L_X\,(\text{Henries}) = \left(\frac{V_S - V_{SW}}{I_{MAX}}\right) T_{ON}$$

The inductor chosen must exhibit approximately this value at a current level equal to I_{MAX}.

5. Calculate a value for the output filter capacitor:

$$C_F(\mu F) = \frac{T_{ON}\left(\frac{V_S\,I_{MAX}}{V_{OUT}}\right) + I_L}{V_R}$$

Where V_R = Ripple Voltage (peak)

Step-Down Design Procedure

1. Select an operating frequency.
2. Determine the maximum on time (T_{ON}) as in the step-up design procedure.
3. Calculate I_{MAX}:

$$I_{MAX} = \frac{2I_L}{(f_O)\,(T_{ON})\left(\frac{V_S - V_{OUT}}{V_{OUT} - V_D} + 1\right)}$$

4. Calculate L_X:

$$L_X = \left(\frac{V_S - V_{OUT}}{I_{MAX}}\right) T_{ON}$$

5. Calculate a value for the output filter capacitor:

$$C_F(\mu F) = \frac{T_{ON}\left(\frac{[V_S - V_{OUT}]\, I_{MAX}}{V_{OUT}} + I_L\right)}{V_R}$$

Alternate Design Procedure

The design equations above will not work for certain input/output voltage ratios, and for these circuits another method of defining component values must be used. If the slope of the current discharge waveform is much less than the slope of the current charging waveform, then the inductor current will become continuous (never discharging completely), and the equations will become extremely complex. So, if the voltage applied across the inductor during the charge time is greater than during the discharge time, use the design procedure below. For example, a step-down circuit with 20V input and 5V output will have approximately 15V across the inductor when charging, and approximately 5V when discharging. So in this example the inductor current will be continuous and the alternate procedure will be necessary.

1. Select an operating frequency (a value between 10kHz and 40kHz is typical).
2. Build the circuit and apply the worst case conditions to it, i.e., the lowest battery voltage and the highest load current at the desired output voltage.
3. Adjust the inductor value down until the desired output voltage is achieved, then go a little lower (approximately 20%) to cover manufacturing tolerances.
4. Check the output voltage with an oscilloscope for ripple, at high supply voltages, at voltages as high as are expected. Also check for efficiency by monitoring supply and output voltages and currents (eff = $(V_{OUT})(I_{OUT})/(+V_S)(I_{SY}) \times 100\%$).
5. If the efficiency is poor, go back to (1) and start over. If the ripple is excessive, then increase the output filter capacitor value or start over.

Inductors

Efficiency and load regulation will improve if a quality high Q inductor is used. A ferrite pot core is recommended; the wind-yourself type with an air gap adjustable by washers or spacers is very useful for bread boarding prototypes. Care must be taken to choose a permeable enough core to handle the magnetic flux produced at I_{MAX}; if the core saturates then efficiency and output current capability are severely degraded and excessive current will flow through the switch transistor. An isolated AC current probe for an oscilloscope (example: Tektronix P6042) is an excellent tool for saturation problems; with it the inductor current can be monitored for nonlinearity at the peaks (a sign of saturation).

Low Battery Detector

An open collector signal transistor Q2 with comparator C2 provides the designer with a method of signaling a display or computer whenever the battery voltage falls below a programmed level (see Figure 8). This level is determined by the +1.31V reference level and by the selection of two external resistors according to the equation:

$$V_{TH} = V_{REF}\left(\frac{R4}{R5} + 1\right)$$

Where V_{TH} = Threshold Voltage for Detection

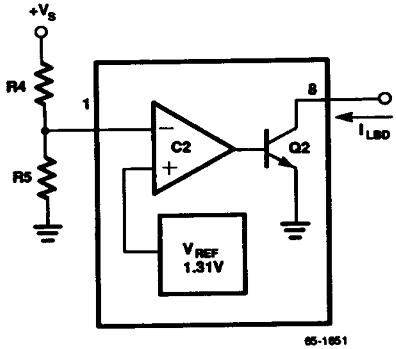


Figure 8. Low Battery Detector

Schematic Diagram