Undervoltage/Overvoltage Lockout for VI-200/VI-J00 and Maxi, Mini, Micro Converters

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Introduction

For many applications it is necessary to disable a DC-DC converter when its input voltage goes outside a specified range. This note describes circuits that can be used to disable a Vicor converter based on programmable undervoltage or overvoltage set points. These circuits operate as comparators that monitor the input voltage and disable the converter via the Gate IN or PC pin when the comparator trips. Configurable hysteresis is included in each circuit so that lockout will occur cleanly in the presence of noise.

Design Considerations

To disable a Vicor DC-DC converter the Gate In / PC pin should be pulled low. The modules require a switch capable of sinking a minimum of 6mA for the VI-200 / VI-J00 converters and 3mA for Maxi, Mini, Micro converters. When Gate IN / PC is allowed to go high in the absence of a fault condition it will rise to about 6V.

VI-200 / VI-J00 modules are capable of turning on at very low input voltages, i.e., lower than the voltage at which they can operate correctly. This necessitates the use of a lockout circuit (Figure 1) for applications where the input voltage may drop below low line. Vicor's Maxi, Mini, Micro modules have built-in undervoltage and overvoltage protection. For these converters the following circuits should be implemented if lockout is required inside the preexisting range of the converter.

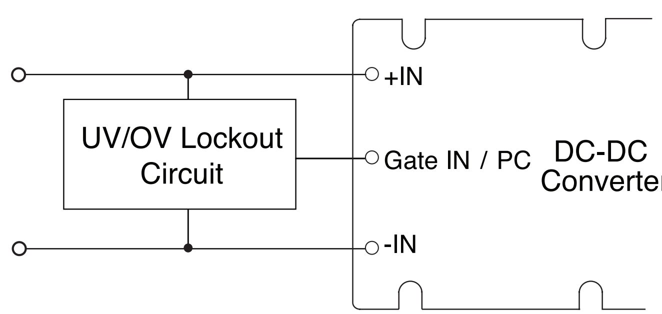
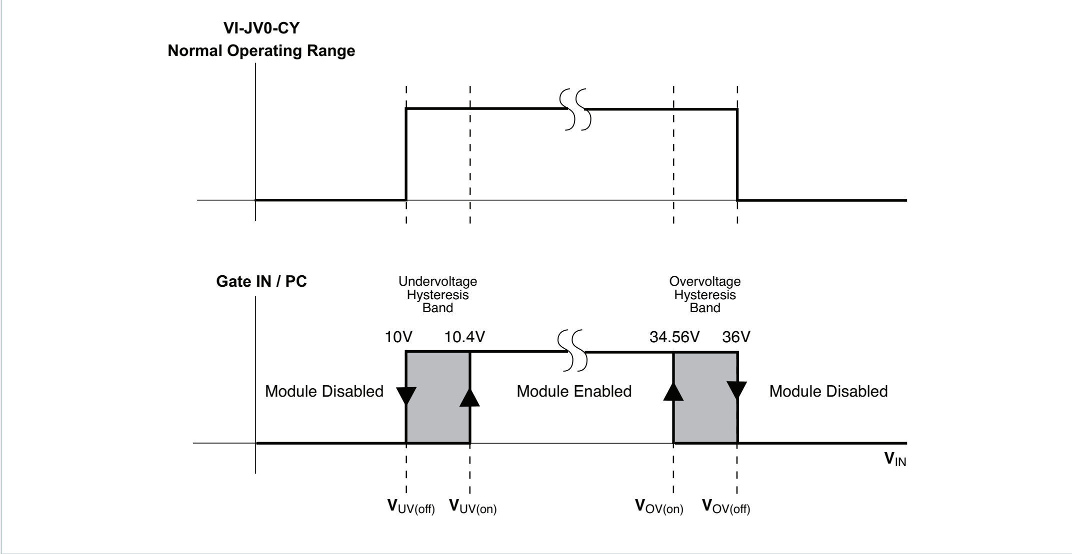


Figure 1
Undervoltage / Overvoltage Lockout Block Diagram

All input sources have some noise that could cause glitching at the transition point if it was fed directly into a comparator. Using positive feedback to add hysteresis to the circuit cleans up the transitions. For example, Figure 2 shows how this hysteresis will affect lockout of the VI-JV0-CY module. The diagram shows a circuit configured for 4% hysteresis such that the converter cannot be enabled outside its normal operating range. Inside the hysteresis bands the status of Gate IN / PC will depend on whether the input voltage is going into or out of range.

The hysteresis voltage bands will ensure clean transitions if they are greater than the maximum possible peak-to-peak change in input voltage. Their widths should be chosen based on the maximum anticipated noise and ripple.

Figure 2
Hysteresis Diagram



Figures 3 and 4 show startup and shutdown waveforms for a converter configured for the lockout voltages in Figure 2. Gate IN / PC shows clean transitions in spite of the slowly changing input.

For high-input voltage modules, care should be taken not to exceed either maximum power or maximum voltage ratings of the resistors. One way to achieve this is to replace a single resistor with a series of smaller resistors that share power and voltage.

Figure 3
VI-JV0-CY with Input Rising from Undervoltage Lockout to Overvoltage Lockout

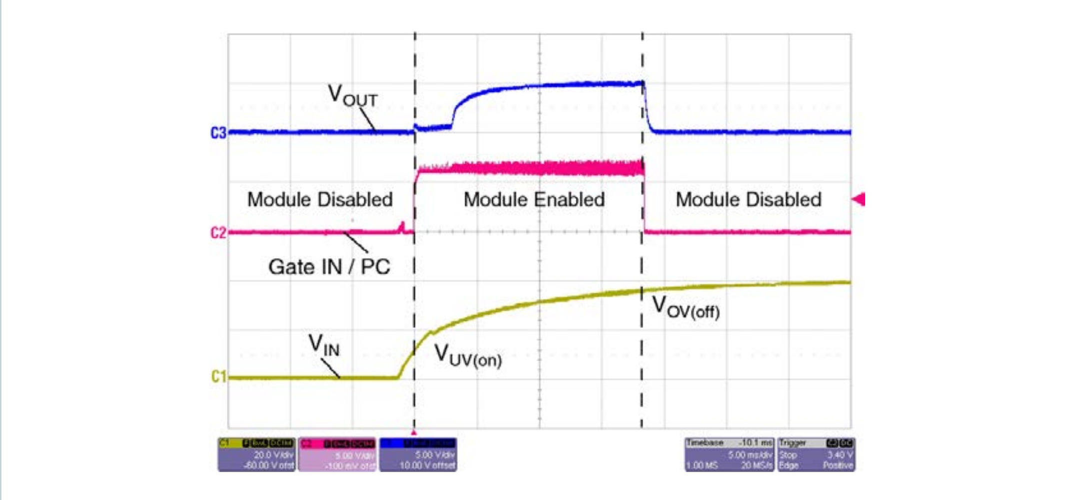
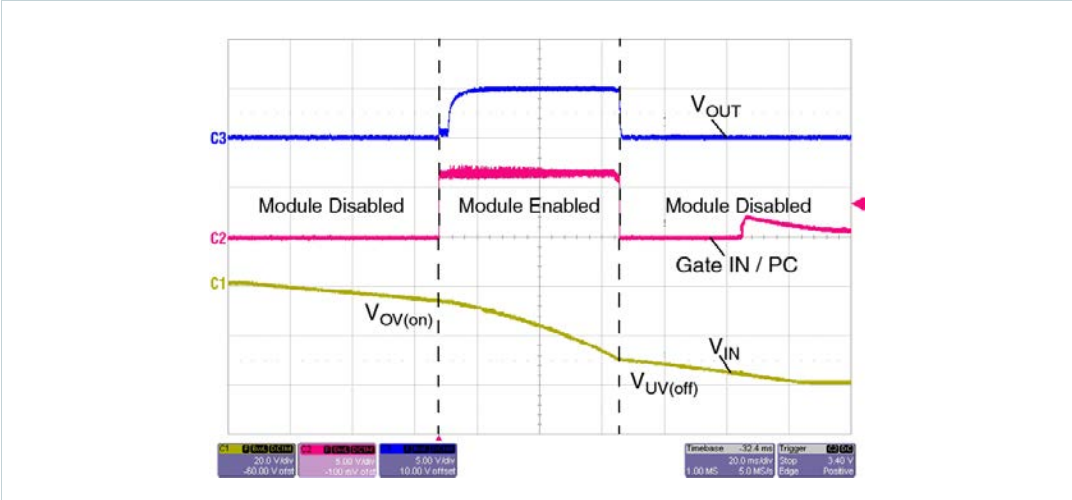


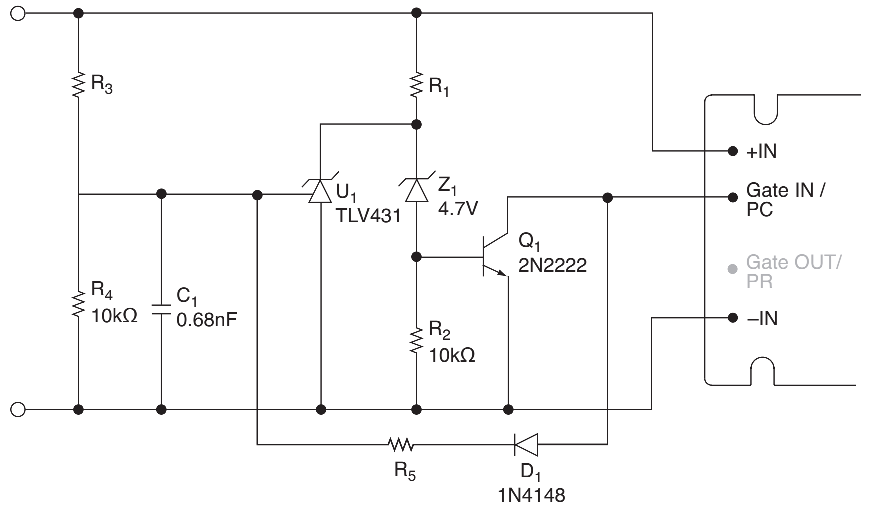
Figure 4
VI-JV0-CY with Input Falling from Overvoltage Lockout to Undervoltage Lockout



Undervoltage Lockout

Figure 5 shows the undervoltage lockout circuit schematic.

Figure 5
Undervoltage Lockout Circuit Schematic



Resistor Values for VI-200 / VI-J00 Converters

Table 1 lists standard lockout voltages for VI-200 / VI-J00 family modules and resistor values. Use the formulas that follow for applications not listed.

Table 1
Resistor Values for Common Undervoltage Thresholds

Input Des.	$V_{UV(off)}$ (V)	$V_{UV(on)}$ (V)	Max. V_{IN} (V)	R_1 (kΩ)	R_3 (kΩ)	R_5 (kΩ)	R_1 Rating (W)	R_3 Rating (W)
0, V	10	10.4	40	3.65	73.2	806	1.00	0.25
W, 1*, 2*	18	18.72	60	3.65	140.0	845	1.50	0.25
1, 2	21	21.84	60	6.98	165.0	866	1.00	0.25
N, 3*	36	37.44	84	23.70	294.0	887	0.50	0.25
3	42	43.68	72	30.10	340.0	887	0.25	0.25
4*	45	46.8	110	34.00	365.0	887	0.50	0.25
4	55	57.2	110	45.30	453.0	887	0.50	0.25
T	66	68.64	176	57.60	549.0	887	1.00	0.25
5*	85	88.4	215	78.70	698.0	909	1.00	0.25
5, 7	100	104	413	95.30	825.0	909	3.00	0.50
6*	170	176.8	425	174.00	1430.0	909	1.50	0.25
6	200	208	425	205.00	1650.0	909	1.50	0.25

Notes:
1. *Voltage ranges that allow the converter to support 75% load (brown out).
2. Hysteresis is set at 4%.
3. All resistors are 0.25 W unless otherwise specified.

Circuit Operation

As the input voltage ramps up R_1 feeds the base of Q_1 through zener Z_1. This turns Q_1 on, which pulls the Gate IN / PC pin low and disables the module.

Q1 remains on until the input voltage scaled by R_3 and R_4 reaches 1.24V, the reference voltage of U_1 (TLV431). When this occurs U_1 shunts current from the cathode of Z_1 and pulls this point down to about 1V. This in turn pulls the base of Q_1 low forcing it into cutoff and enabling the module. R_2 prevents Z_1 leakage from pulling Q_1 out of cutoff.

When the Gate IN / PC pin goes high the feedback resistor (R_5) pulls up the reference of U_1 thereby adding hysteresis to the circuit. D_1 disables the feedback when Gate IN / PC is low.

C_1 acts as a low-pass filter with a 20kHz bandwidth that decouples high-frequency noise from the reference of U_1.

Formulas for Customized UV Lockout Voltages and Maxi, Mini, Micro Converters

Solving For R_1

R_1 should be selected so that the base of Q_1 is fed enough current to saturate it but not more than U_1 is capable of sinking. Assuming R_2 is large enough to be neglected and the worst case Beta of Q_1 is 20, then R_1 should provide at least 0.3mA to sink 6mA from Gate IN / PC. This leads to the following formula for R_1:

$$R_1 = \frac{V_{IN(min)} - 4.9V}{0.3mA}$$

Where:

$V_{IN(min)}$ is the minimum voltage at which the converter should be disabled, typically 6V or one third the converter's minimum input voltage whichever is greater.

At high line the current though R_1 is then:

$$I_{R1(HL)} = \frac{V_{HL} - 1V}{R_1}$$

Where:

V_{HL} is the maximum operating voltage of the module.

$IR_{1(HL)}$ should not exceed the 15mA limit of U_1. Power dissipation is governed by the following formula:

$$P_{R_1} = \frac{\left(V_{IN(max)} - 1V\right)^2}{R_1}$$

Where:

$V_{IN(max)}$ is the maximum input voltage the circuit can withstand.

Solving For R_3

A good starting value for R_4 is 10kΩ. With the value of R_4 known, R_3 can be calculated as follows:

$$R_3 = R_4\left(\frac{V_{UV(on)}}{1.24V} - 1\right)$$

Where:

$V_{UV(on)}$ is the voltage at which the module is enabled as the input voltage transitions low to high (See Figure 2). The power dissipated in R_3 can be calculated using the formula below:

$$P_{R_3} = \left(\frac{V_{IN(max)}}{R_3 + R_4}\right)^2 R_3$$

Solving For R_5

R_5 should be set to add the proper amount of hysteresis to the circuit based on input noise. It can be calculated using this formula:

$$R_5 = \frac{(4.36V)\, R_3 R_4}{1.24V\,(R_3 + R_4) - V_{UV(off)}\, R_4}$$

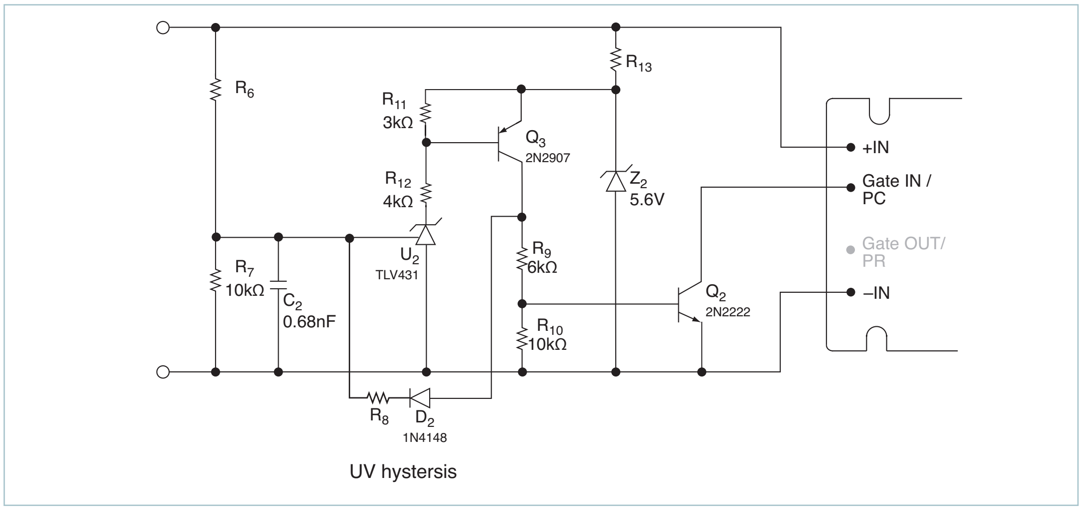
Where:
$V_{UV(off)}$ is the voltage at which the module is disabled as the input voltage transitions high to low (See Figure 2).

Overvoltage Lockout

Figure 6 shows the overvoltage lockout circuit schematic.

Reference designations are continued from the undervoltage lockout schematic of Figure 5 so that the circuits can be cascaded without confusion.

Figure 6
Overvoltage Lockout Circuit Schematic



Resistor Values for VI-200/VI-J00 Converters

Table 2 lists common lockout voltages for VI-200 / VI-J00 family modules and resistor values. Use the formulas that follow for applications not listed.

Table 2
Resistor Values for Common Overvoltage Thresholds.

Input Des.	$V_{OV(off)}$ (V)	$V_{OV(on)}$ (V)	Max. V_{IN} (V)	R_6 (kΩ)	R_8 (kΩ)	R_{13} (kΩ)	R_{13} Rating (W)
0	20	19.2	22	150	715	2.87	0.25
1	32	30.72	36	249	732	5.23	0.25
V, W	36	34.56	40	280	732	6.04	0.25
2	56	53.76	60	442	750	10.00	0.50
3	60	57.6	72	475	750	11.00	1.00
N	76	72.96	84	604	750	14.00	1.00
4	100	96	110	787	750	18.70	1.00
T	160	153.6	167	1270	750	30.90	1.50
5	200	192	215	1620	750	39.20	1.50
7	375	360	413	3010	750	73.20	3.00
6	400	384	425	3240	750	78.70	3.00

Notes:
1. Hysteresis is set at 4%.
2. All resistors are 0.25W unless otherwise specified.

Circuit Operation

When the input voltage transitions high, a 5.6V source is established by Z_2 at the emitter of Q_3. For voltages less than lockout, Q_3 is in cutoff since U_2 conducts minimal cathode current. Thus, Q_3 passes negligible current to the base of Q_2 cutting Q_2 off and allowing Gate IN / PC to go high.

When the input voltage as scaled by R_6 and R_7 increases above the reference of U_2, U_2 will pull the base of Q_3 low through R_{12}. As Q_3 turns on, current flows into the base of Q_2 through R_6 causing it to conduct and pull Gate IN / PC low, thereby disabling the module.

R_8 adds positive feedback by coupling Q_3's collector to the reference of U_2. D_2 disables the feedback when Gate IN / PC is high.

C_2 acts as a low-pass filter with a 20kHz bandwidth that decouples high-frequency noise from the reference of U_2.

Formulas for Customized OV Lockout Voltages and Maxi, Mini, Micro Converters

Solving For R_6

A good starting value for R_7 is 10kΩ. With the value of R_7 known R_6 can be calculated as follows:

$$R_6 = R_7\left(\frac{V_{OV(off)}}{1.24V} - 1\right)$$

Where:
$V_{OV(off)}$ is the voltage at which the module is disabled as the input voltage transitions low to high (See Figure 2).

Dissipation in R_6 can be calculated using the formula below:

$$P_{R_6} = \left(\frac{V_{IN(max)}}{R_6 + R_7}\right)^2 R_6$$

Where:
$V_{IN(max)}$ is the maximum input voltage the circuit can withstand.

Solving For R_8

The feedback resistor R_8 can be calculated using the formula below:

$$R_8 = \frac{(3.76V)\, R_6 R_7}{1.24V\,(R_6 + R_7) - V_{OV(on)}\, R_7}$$

Where:
$V_{OV(on)}$ is the voltage at which the module is enabled as the input voltage transitions high to low (See Figure 2).

Solving For R_{13}

The value of R_{13} should be chosen so that the current through Z_2 is about 5mA at the overvoltage lockout point. It can be set using this formula:

$$R_{13} = \frac{V_{OV(off)} - 5.6V}{5mA}$$

Power dissipation can be calculated as given below:

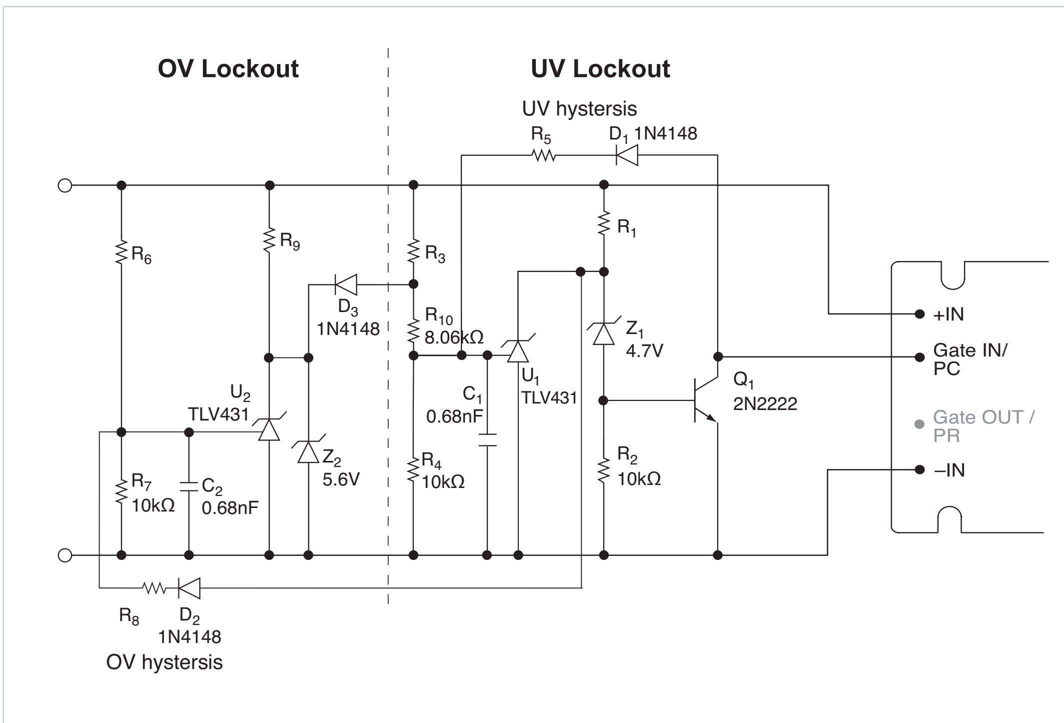
$$P_{R13} = \frac{\left(V_{IN(max)} - 5.6V\right)^2}{R_{13}}$$

Undervoltage / Overvoltage Lockout

Circuit Description / Operation

The circuit in Figure 7 combines the undervoltage and overvoltage circuits. When an overvoltage event occurs the second regulator (U_2) shunts the reference of U_1 forcing it to disable the module. R_9 is added to provide current to the cathode of U_2 when it is off so that D_3 can isolate it from the undervoltage circuit's divider. Z_2 acts as a clamp to prevent damage to U_2. For detailed circuit operation please refer to the individual circuit descriptions.

Figure 7
Undervoltage / Overvoltage Lockout Circuit Schematic



Resistor Values for VI-200/VI-J00 Converters

Table 3 lists common lockout voltages for VI-200/VI-J00 family modules and resistor values. Use the formulas that follow for applications not listed.

Table 3
Resistor Values for Common Undervoltage / Overvoltage Thresholds.

Input Des.	$V_{UV(off)}$ (V)	$V_{UV(on)}$ (V)	$V_{OV(on)}$ (V)	$V_{OV(off)}$ (V)	Max. V_{IN} (V)	R_1 (kΩ)	R_3 (kΩ)	R_5 (kΩ)	R_6 (kΩ)	R_8 (kΩ)	R_9 (kΩ)	R_1 Rating (W)	R_3 Rating (W)
0	10	10.4	19.2	20	22	3.65	66.5	806	150	715	44.2	0.25	0.25
V	10	10.4	34.56	36	40	3.65	66.5	806	280	732	44.2	0.50	0.25
1	21	21.84	30.72	32	36	6.98	158.0	866	249	732	154.0	0.25	0.25
1*	18	18.72	30.72	32	36	3.65	133.0	845	249	732	124.0	0.50	0.25
W	18	18.72	34.56	36	40	3.65	133.0	845	280	732	124.0	0.50	0.25
2	21	21.84	53.76	56	60	6.98	158.0	866	442	750	154.0	1.00	0.25
2*	18	18.72	53.76	56	60	3.65	133.0	845	442	750	124.0	1.50	0.25
3	42	43.68	57.6	60	72	30.10	332.0	887	475	750	365.0	0.25	0.25
3*	36	37.44	57.6	60	72	23.70	287.0	887	475	750	301.0	0.25	0.25
N	36	37.44	72.96	76	84	23.70	287.0	887	604	750	301.0	0.50	0.25
4	55	57.2	96	100	110	45.30	442.0	887	787	750	499.0	0.50	0.25
4*	45	46.8	96	100	110	34.00	357.0	887	787	750	392.0	0.50	0.25
T	66	68.64	153.6	160	176	57.60	536.0	887	1270	750	604.0	1.00	0.25
5	100	104	192	200	215	95.30	825.0	909	1620	750	953.0	1.00	0.25
5*	85	88.4	192	200	215	78.70	698.0	909	1620	750	787.0	1.00	0.25
6	200	208	384	400	425	205.00	1650.0	909	3240	750	1960.0	1.50	0.25
6*	170	176.8	384	400	425	174.00	1400.0	909	3240	750	1650.0	1.50	0.25
7	100	104	360	375	413	95.3	825.0	909	3010	750	953.0	3.00	0.50

Notes:
1. * Voltage ranges that allow the converter to support 75% load (brown out).
2. Hysteresis is set at 4% of the respective lockout voltages.
3. All resistors are 0.25W unless otherwise specified.

Formulas for Customized UV/OV Lockout Voltages and Maxi, Mini, Micro Converters

For this circuit, the zener voltages have been selected such that most of the resistor values need not be recalculated. With the exception of R_3, R_5 and R_9, resistor values can be found by using the equivalent resistors calculated for the stand-alone undervoltage and overvoltage circuits.

Solving For R_3

The formula below gives the value of R_3:

$$R_3 = R_4\left(\frac{V_{UV(on)}}{1.24V} - 1\right) - 8.06k\Omega$$

The power dissipated in R_3 can be calculated using the formula below:

$$P_{R_3} = \frac{\left(V_{IN(max)} - 1.7V\right)^2}{R_3}$$

Solving For R_5

R_5 adds the proper amount of hysteresis to the circuit based on input noise. R_5 can be calculated as follows:

$$R_5 = \frac{4.36V\,(R_3 + R_{10})\,R_4}{1.24V\,(R_3 + R_4 + R_{10})V_{UV(off)}\;R_4}$$

Solving For R_9

The value of R_9 can be calculated as follows:

$$R_9 = \frac{V_{UV(off)} - 5.6V}{100\mu A}$$

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