LINEAR VOLTAGE REGULATORS

INTRODUCTION

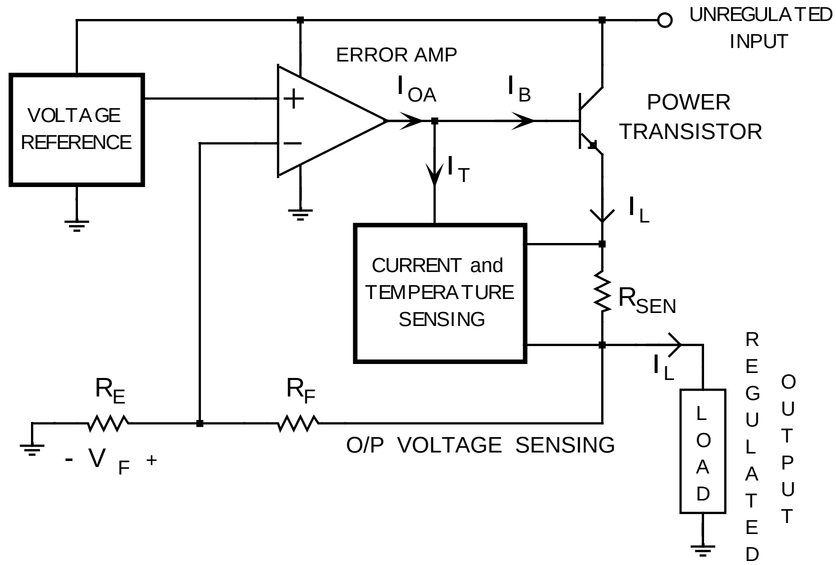
Block Diagram of Linear Voltage Regulator

$V_{OUT} = V_{REF}\,(1+R_F/R_E)$

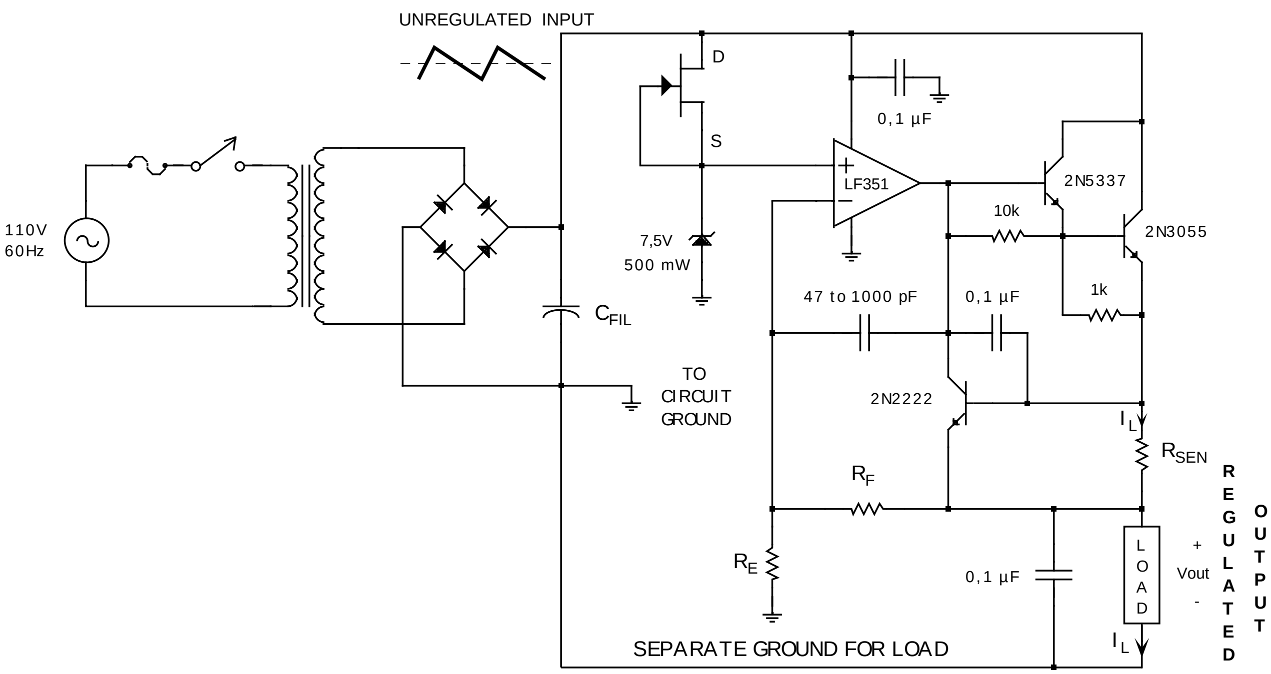
where V_{REF} is a temterature stabilised reference voltage.

$I_L\ max = V_{SEN\ max}/R_{SEN}$

where $V_{SEN\ max}$ is set by either T_{Jmax} or by the absolute maximum current, whichever is smaller.



Discrete Voltage Regulator

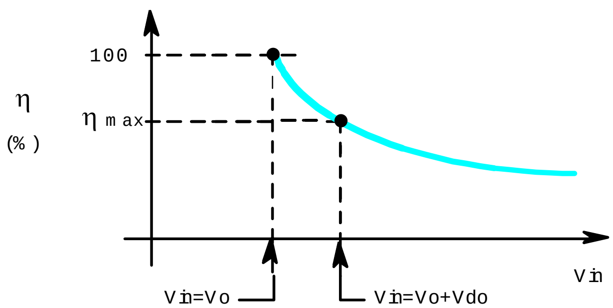


Discrete voltage regulators generally provide much better performance than IC regulators because the op amp used has more gain and because the power transistor does not heat up the rest of the circuit. For most applications, IC regulators perform very satisfactorily.

EFFICIENCY OF LINEAR REGULATORS

Linear regulators are easier to design and generally less expensive but waste more power because the power elements (transistors) operate in their active or linear mode. Switching regulators are more complex and more difficult to design but are more power efficient because their power elements (transistors) are switched ON and OFF alternately and consume very little power. Switching regulators also create a lot more Electro Magnetic Interference (EMI) and proper shielding should be used in order to minimize EMI.

Efficiency characteristics



$$P_{in} = V_{in} I_{in} \quad P_o = V_o I_o = V_o (I_{in} - I_Q) \approx V_o I_{in}$$

$$\eta = \frac{P_o}{P_{in}} = \frac{V_o I_{in}}{V_{in} I_{in}} = \frac{V_o}{V_{in}}$$

From the results shown left, efficiency will be maximum for the minimum value of V_{in}, V_o being fixed. The minimum value for $V_{in} = V_o + V_{DO}$ where V_{DO} is the drop-out voltage of the regulator which is defined as the minimum differential voltage between input and output. In practice, this minimum V_{in} is seldom used because one must use a good safety margin in order to guarantee output regulation.

Example

Using a 5V regulator, η = (5/10)*100=50% for V_{in}=10V, and η = (5/20)*100=25% for V_{in}=20V.

Using a 15V regulator with V_{in}=20V we have η = (15/20)*100=75% , and V_{in}=25V we have η = (15/25)*100=60%.

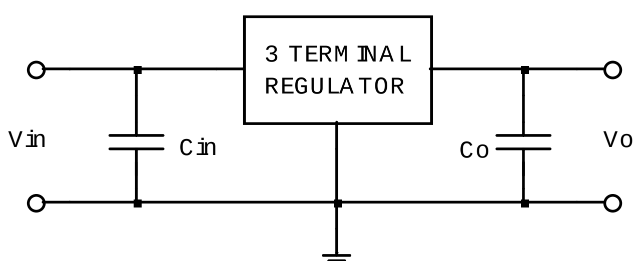
THREE-TERMINAL FIXED VOLTAGE REGULATORS

V_{in}: unregulated DC input

V_o: regulated DC output

C_{in}: required for stability of regulator - use manufaturer's recommended value.

C_o: required to improve transient response of regulator especially with switching load currents - use manufaturer's recommended value.



The steady state current limit is generally determined by thermal limitations. The transient (surge) current limit is generally limited to a higher value (sometimes lower) than the steady state current limit by the internal circuitry. Regulated V_o is available only for standard voltages.

NOTE: The input and output capacitors should be high frequency type and should be located as close as possible to the regulator pins to avoid high frequency self oscillations

National Semiconductors Fixed Voltage Regulator Selection

Fixed negative voltage regulators			
Amps	**Device**	**Output Voltage**	**Package**
3.0	LM145K LM345K	-5V, -5,2V	TO-3 TO-3
1.5	LM120K LM320K LM79XXCT,K	-5V, -12V, -15V	TO-3 TO-3, TO-220 TO-3, TO-220
0.5	LM320MP, LM79MXXCP,K	-5V, -12V, -15V	TO-220 TO-202, TO-3
0.2	LM120H LM320H	-5V, -12V, -15V	TO-39 TO-39
0.1	LM320LZ, LM79XXACZ,M	-5V, -12V, -15V	TO-92 TO-92, SO-8
Fixed Positive Voltage Regulators			
Amps	**Device**	**Output Voltage**	**Package**
3.0	LM123K LM2943CT LM323K	5V	TO-3 TO-220 TO-3
1	LM109K LM140AK LM140K LM2940CT LM309K LM340AK/ LM340K/T LM78XXCK/T	5V 5V, 12V, 15V 5V, 12V, 15V 5V, 12V, 15V 5V 5V, 12V, 15V 5V, 12V, 15V 5V, 12V, 15V	TO-3 TO-3 TO-3 TO-220 TO-3 TO-3, TO-220 TO-3, TO-220 TO-3, TO-220
0.5	LM2984CT LM341T/P LM78MXXCT	5V, 12V, 15V	TO-202, TO-220 TO-202, TO-220 TO-220
0.2	LM109H LM309H LM342P	5V 5V 5V, 12V, 15V	TO-39 TO-39 TO-202
0.15	LM2930T	5V, 8V	TO-220
0.1	LM140LAH LM2931Z/T LM340LZ/H LM78LXXACZ/H/M LP2950CZ	5V, 12V, 15V 5V 5V, 12V, 15V 5V, 12V, 15V 5V	TO-39 TO-92, TO-220 TO-92, TO-39 TO-92, TO-39, SO-8 TO-92

NOTE: The above list is not complete and not up to date.

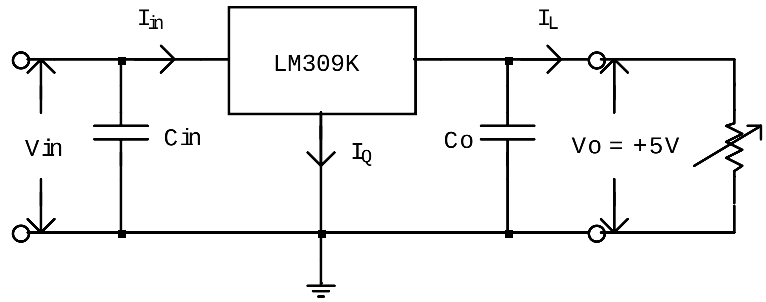
EXAMPLE-1 LM309 (+5V FIXED REGULATOR)

Operating junction temperature range:
0°C to 125°C

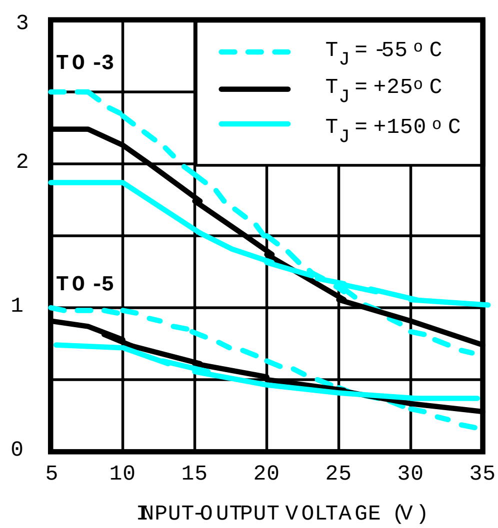
Thermal resistance
(TO-3 package, K suffix):
θ_{JC} = 2.5°C/W, θ_{JA} = 35°C/W

Quiescent current (I_Q):
5.2 mA typical.

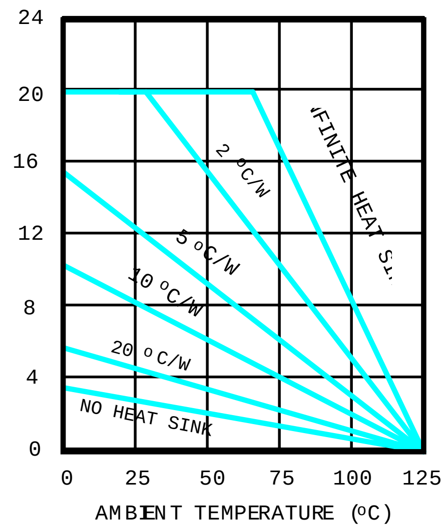
$P_{max(ABS)}$ = 20W



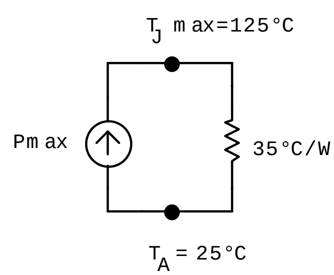
CURRENT LIMIT CHARACTERISTICS



MAXIMUM AVERAGE POWER DISSIPATION (LM309K)



A) Current limit without a heat sink



Without a heat sink, we have:

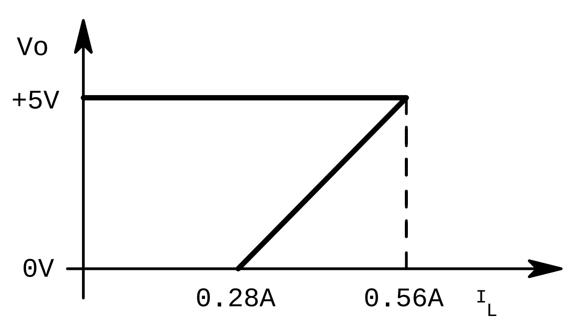
$P_{max} = (T_{Jmax} - T_A)/\theta_{JA} = (125\text{-}25)/35$

P_{max} = 2.857W

$P_{REG} = (V_{in}\text{-}V_o)\, I_L + V_{in}\, I_Q$

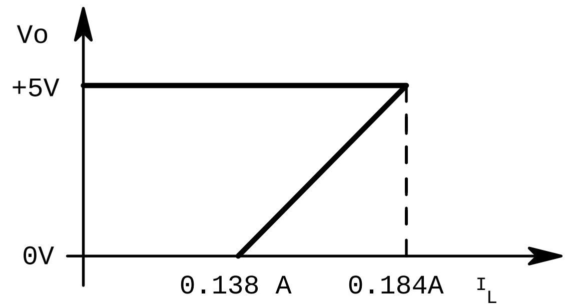
If V_{in} = +10V and V_o = +5V, regulated O/P
I_L max = (P_{max} -V_{in} I_Q)/(V_{in}-V_o)
I_L max = (2.857-10*5.2m)/(10-5)=0.561A

If V_{in} = +10V and V_o = 0V, short-circuited O/P
I_{SC} = (P_{max} -V_{in} I_Q)/(V_{in}-V_o)
I_{SC} = (2.857-10*5.2m)/(10-0)=0.28A



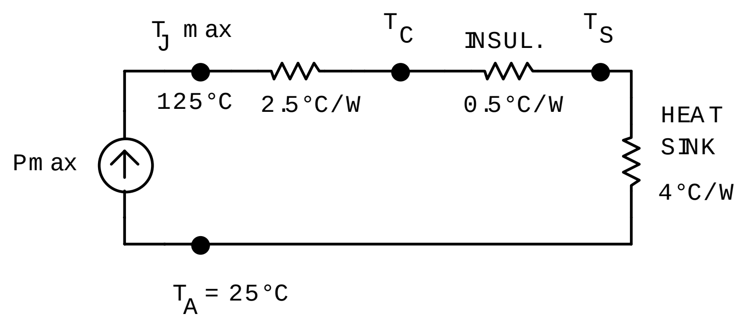
If V_{in} = +20V and V_o = +5V, regulated O/P
I_L max = $(P_{max} - V_{in} I_Q)/(V_{in}-V_o)$
I_L max = (2.857-20*5.2m)/(20-5)=0.184A

If V_{in} = +20V and V_o = 0V, short-circuited O/P
$I_{SC} = (P_{max} - V_{in} I_Q)/(V_{in}-V_o)$
I_{SC} = (2.857-20*5.2m)/(20-0)=0.138A



B) Current limit with a heat sink

Using a heat sink for TO-3 package with θ_{CA} = 4°C/W and assuming θ_{CS} = 0.5 °C/W for the insulator, we have:

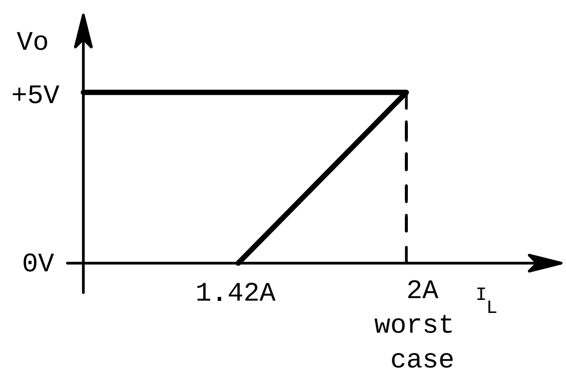


P_{max} = $(T_{Jmax} - T_A)/\theta_{JA}$
= (125-25)/(2.5+0.5+4)
= 14.28W
P_{max} must be less than $P_{max(ABS)}$=20W
If calculated P_{max} exceeds 20W, then 20W is the actual P_{max}.
$P_{REG} = (V_{in}-V_o) I_L + V_{in} I_Q$

If V_{in} = +10V and V_o = +5V, regulated O/P
I_L max = $(P_{max} - V_{in} I_Q)/(V_{in}-V_o)$
= (14.28-10*5.2m)/(10-5)= 2.84A

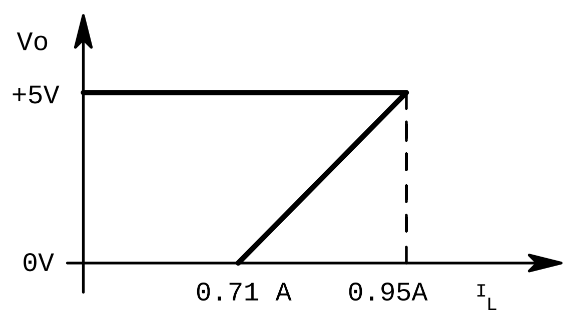
2.84A is the thermal limit but this value is wrong because the transient current limit is about 2.3A at T_J = 25°C and about 2A at T_J = 125°C.

If V_{in} = +10V and V_o = 0V, short-circuited O/P
I_{SC} = $(P_{max} - V_{in} I_Q)/(V_{in}-V_o)$
= (14.28-10*5.2m)/(10-0)= 1.42A



If V_{in} = +20V and V_o = +5V, regulated O/P
I_L max = $(P_{max} - V_{in} I_Q)/(V_{in}-V_o)$
= (14.28-20*5.2m)/(20-5)= 0.945A

If V_{in} = +20V and V_o = 0V, short-circuited O/P
I_{SC} = $(P_{max} - V_{in} I_Q)/(V_{in}-V_o)$
= (14.28-20*5.2m)/(20-0)= 0.71A



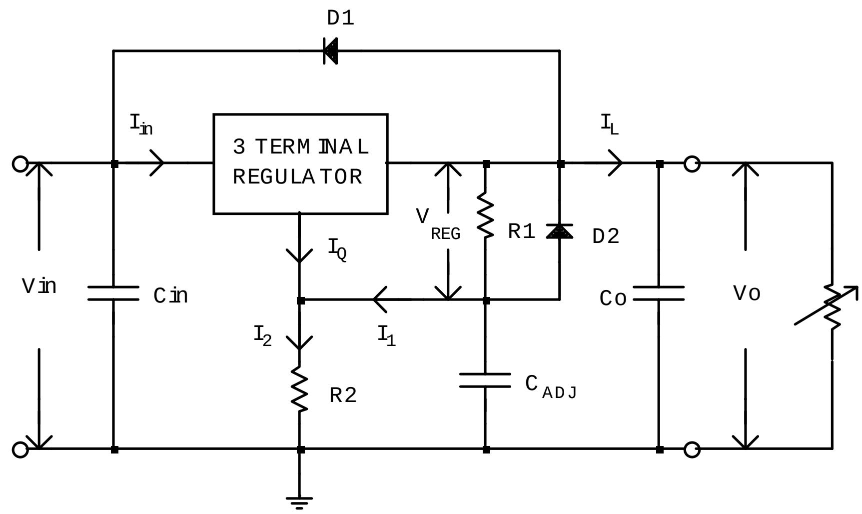
THREE-TERMINAL ADJUSTABLE VOLTAGE REGULATORS

$$V_0 = V_{REG} + (I_1 + I_Q)R_2$$

$$V_0 = V_{REG} + \left(\frac{V_{REG}}{R_1} + I_Q\right)R_2$$

$$V_0 = V_{REG}\left(1 + \frac{R_2}{R_1}\right) + I_Q R_2$$

Make $I_1 >> \Delta I_Q$ max in order to have a stable V_o as I_Q changes with temperature and is different from one device to another. Select R_1 and R_2 for desired V_o.



D1 provides a discharge path for Co when V_{in} is shut down and thereby prevents Co from discharging through the regulator O/P. D1-D2 provide a discharge path for C_{adj}. D1 and D2 also protect the regulator against reverse polarity at V_{in} and V_o. Regular 3-pin fixed output regulators can be adjustable as shown above, but it is preferrable to use the 3-pin adjustable regulators which have a much lower I_Q and ΔI_Q which makes them more stable with respect to I_Q variations.

EXAMPLE-2 DESIGN WITH LM317

Design a +18V regulator for a load of 0 to 1A using an LM317K. No potentiometers are to be used and the O/P voltage should not vary by more than ±1,3V about +18V from unit to unit if we mass produce the regulator. Assume 1% resistors, V_{in} = +24V to +28V, θ_{CS}=0,5'C/W max and T_A = 10'C to 40'C.

PARAMETER	MINIMUM	TYPICAL	MAXIMUM
Adjustment pin current 0 $^oC < T_J <$ 125 ^oC $V_{in}-V_o$ = 5V	-	50 µA	100 µA
Reference Voltage 3V $< V_{in}-V_o <$ 40V 10 mA $< I_o <$ 0.5A $P_D < P_{MAX}$	1.2V	1.25V	1.3V
Thermal resistance junction to case	-	2.3 ^{o}C/W	3 ^{o}C/W
Thermal resistance junction to ambient	-	35 ^{o}C/W	-
Operating Junction Temperature	0 ^{o}C		125 ^{o}C

$$V_o = V_{REF} + (I_1 + I_Q)R_2 = V_{REF} + (\frac{V_{REF}}{R_1} + I_Q)R_2 \Rightarrow V_o = V_{REF}\left(1 + \frac{R_2}{R_1}\right) + I_Q R_2$$

$$\Delta V_o = \Delta V_{REF}\left(1 + \frac{R_2}{R_1}\right) + \Delta I_Q R_2 + V_{REF}\frac{R_2}{R_1}\left(\frac{\Delta R_1}{R_1} + \frac{\Delta R_2}{R_2}\right)$$

$$\Delta V_o = \Delta V_{REF}\left(1 + \frac{R_2}{R_1}\right) + \Delta I_Q R_2 + (V_o - V_{REF})(TOL_1 + TOL_2)$$

NOTE:

Use typical values of V_o, V_{REF} and I_Q in formula for R_2 max.

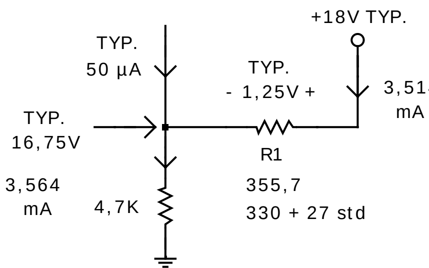
$$V_o \approx V_{REF}\left(1+\frac{R_2}{R_1}\right) \quad if \quad I_1 \rangle\rangle I_Q \quad and \quad \frac{R_2}{R_1} \approx \frac{V_0}{V_{REF}} - 1 \approx \frac{18}{1.25} - 1 = 13.4$$

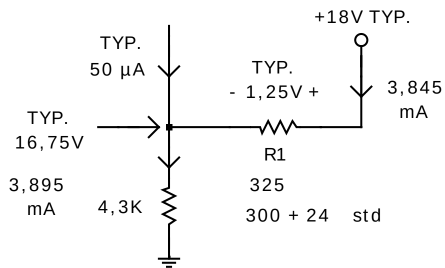
$$\Delta V_o = \Delta V_{REF}\left(1+\frac{R_2}{R_1}\right) + \Delta I_Q R_2 + \left(V_o - V_{REF}\right)\left(TOL_1 + TOL_2\right)$$

$$\Delta V_o = \pm 0.05\,(1+13.4) \pm 50\mu\, R_2 \pm 16.75\,(0.01+0.01) = \pm 0.72 \pm 50\mu\, R_2 \pm 0.335$$

$$50\mu\, R_2 \,\langle\, \Delta V_{o(\max)} - 0.72 - 0.335 \quad \Rightarrow \quad R_2 \,\langle\, \frac{1.3 - 0.72 - 0.335}{50\mu} = 4.9K$$

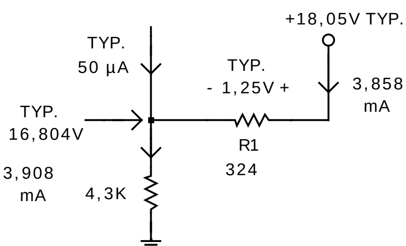
Select standard R_2 values and calculate R_1 from circuit diagram using typical values of V_{REF} and I_Q.

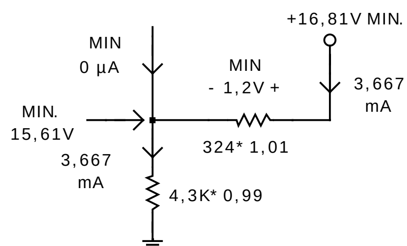


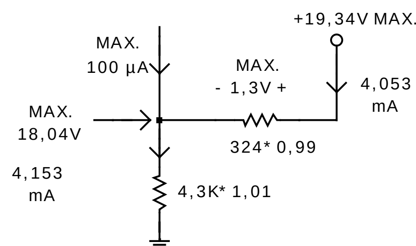


Let us select the last set of values, that is R_1=324Ω and R_2=4,3K
Power check:
P_1=$1{,}25^2$/324
=4.8 mW , 1/4W OK
P_2 = $16{,}75^2$/4,3k
= 65,2 mW , 1/4W OK

<u>Typical and worst case analyses</u>





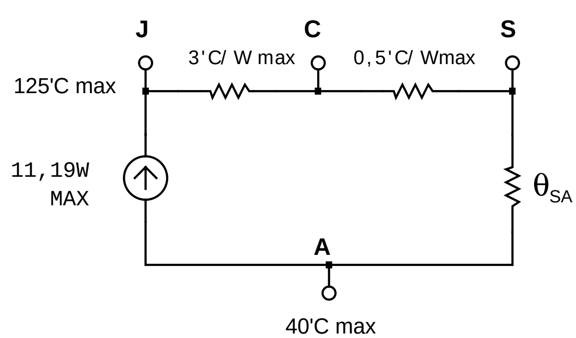


We can see that V_O ranges from 18,05-1,24 to 18,05V+1,29V which is very close to the maximum 1,3V variation specified. Actually, the variation with respect to the specified +18,0V is slightly higher than 1,3V, that is V_0 = 18,0-1,19 to 18,0V+1,34V.

NOTE: For substantially smaller variations of V_o, we would have to use a regulator with a more stable reference voltage and lower % tolerance of the resistors.

<u>Heat Sink Calculation</u>

$P_{REG} = (V_{in}-V_o)I_o+I_QV_{in}$
$P_{REG\,(MAX)}$ = (28-16,81)x1+100µ *28
$P_{REG\,(MAX)}$= 11,19W max



θ_{JA}max = (T_J max-$T_A$max)/P_{MAX}
θ_{JA}max = (125-40)/11,19 = 7,6'C/W
θ_{SA}max = 7,6 - 3 - 0,5 = 4,1'C/W
Select heat sink with less than 4,1'C/W.

National Semiconductors Adjustable Voltage Regulator Selection

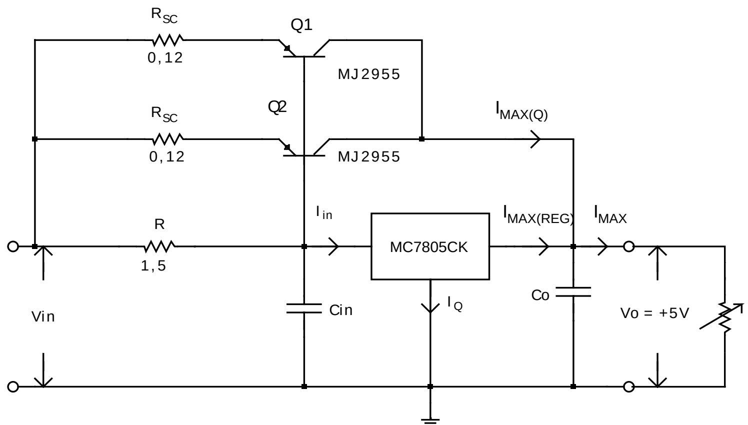
Adjustable NegativeVoltage Regulators			
Amps	**Device**	**Output Voltage**	**Package**
3.0	LM133K	-1.2V to -32V	TO-3
	LM333K/T	-1.2V to -32V	TO-3,TO-220
1.5	LM137K	-1.2V to -37V	TO-3
	LM137HVK	-1.2V to -47V	TO-3
	LM337K/T	-1.2V to -37V	TO-3, TO-220
	LM337HVK	-1.2V to -47V	TO-3
0.5	LM137H	-1.2V to -37V	TO-39
	LM137HVH	-1.2V to -47V	TO-39
	LM337H	-1.2V to -37V	TO-39
	LM337HVH	-1.2V to -47V	TO-39
	LM337MP	-1.2V to -37V	TO-202
0.1	LM337LZ/M	-1.2V to -37V	TO-92, SO-8
Adjustable Positive Voltage Regulators			
Amps	**Device**	**Output Voltage**	**Package**
10.0	LM196K	1.25V to 15V	TO-3
	LM396K	1.25V to 15V	TO-3
5.0	LM138K	1.2V to 32V	TO-3
	LM338K	1.2V to 32V	TO-3
3.0	LM150K	1.2V to 33V	TO-3
	LM350K/T	1.2V to 33V	TO-3, TO-220
1.5	LM117K	1.2V to 37V	TO-3
	LM117HVK	1.2V to 57V	TO-3
	LM2941CT	5V to 24V	TO-220
	LM317K/T	1.2V to 37V	TO-3,TO-220
	LM317HVK	1.2V to 57V	TO-3
0.5	LM117H	1.2V to 37V	TO-39
	LM117HVH	1.2V to 57V	TO-39
	LM317H	1.2V to 57V	TO-39
	LM317HVH	1.2V to 37V	TO-39
	LM317MP	1.2V to 37V	TO-202
0.1	LM317LZ/M	1.2V to 37V	TO-92,SO-8
	LM2931CT	3V to 24V	TO-220, 5-LEAD
	LM2951CN/J/H/M	1.24V to 29V	DIP,HEADER,SO-8

NOTE: The above list is not complete and not up to date.

CURRENT BOOSTING

Let us assume that the maximum current provided by the voltage regulator is 1A for a regulated output, in each of the following circuits - the value of $I_{MAX(REG)}$ depends on the size of the heat sink used. Q1 and Q2 are power transistors that provide additional current to the load without altering the output voltage. Assuming V_{BE} = 0,7V and h_{FE} > 25 throughout, let us determine the current capacity of each of the following circuits.

Circuit 1



Assuming $h_{FE} = \infty$, or I_B = 0A,

V_R max = $I_{MAX\ (REG)}$ R = 1 x 1,5 = 1,5V

$I_{E1} = I_{E2}$ = (1,5 - 0,7)/0,12 = 6,67A

I_{MAX} = 6,67 + 6,67 +1 = 14,33A max

Assuming h_{FE} = 25, we have

$$V_{R_E} + V_{BE} = \left(I_{in} - I_{B1} - I_{B2}\right)R$$

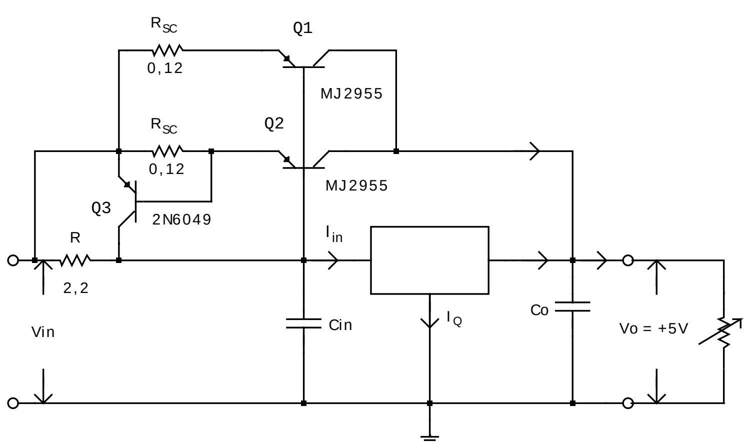
$$I_E R_{SC} + V_{BE} = \left(I_{in} - \frac{2I_E}{h_{FE}+1}\right)R$$

$$I_E = \frac{I_{in}R - V_{BE}}{R_{SC} + \frac{2R}{h_{FE}+1}} = \frac{1\times 1,5 - 0,7}{0,12 + \frac{2\times 1,5}{25+1}} = 3,4A$$

I_{MAX} = 3,4+ 3,4 +1 = 7,8A min

The maximum load current can be anywhere between 7,8A and 14,33A assuming that V_{BE} = 0,7V. If V_{BE} is different, then the range of I_{MAX} will also change. (I_L min + $I_Q$max) R should not turn ON the power transistors otherwise they may saturate. V_{BE} = (8 mA +5 mA) * 1,5 = 19,5 mV, this is OK as it is much too low to to make Q1 and Q2 conduct.

Circuit 2



Assuming h_{FE} = 25 to ∞, we have

V_R max = $V_{BE1} + V_{BE3}$= 1,4V

$I_{E1}= I_{E2}$ = (1,4 - 0,7)/0,12 = 5,83A

I_{MAX} = 5.83 + 5.83 + 1 = 12,67A

Here h_{FE} does not affect I_{MAX} of the load as long as

$(I_{B1}+I_{B2})_{max} < I_{in} - 2\ V_{BE}/R$

$(I_{B1}+I_{B2})_{max}$ = 2 x 5.83/26 = 0.448A

$I_{in} - 2\ V_{BE}/R$ = 1 - 1,4/2,2 = 0.364A

Condition is not met, therefore let us modify R to :

R > 2 $V_{BE}/(I_{in} - (I_{B1}+I_{B2})_{max})$= 2,54Ω

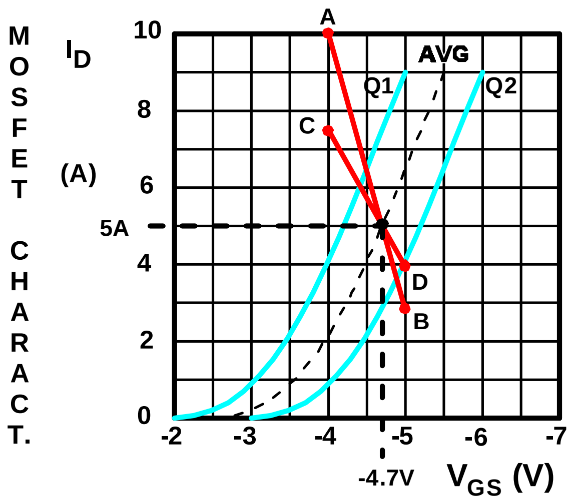
Let R = 3Ω

The maximum current of Q3 will be :

I_{C2max} (HI)= $I_{in\ max}-(I_{B1}+I_{B2})_{min}-2V_{BE/R}$ $\qquad$ I_{C2max}=1A-$(0+0)_{min}$-1,4/3=0,533A

I_{C2max} (LO)= $I_{in\ max}-(I_{B1}+I_{B2})_{max}-2V_{BE/R}$ $\qquad$ I_{C2max}=1A-$(0.448)_{max}$-1,4/3=85,3 mA

I_{C2max} (LO) may get too close to 0A if $V_{BE's}$ are different, this means that V_R may not reach a high enough voltage to turn ON Q3. Increasing R to 3,9Ω would be safer for higher V_{BE} values.



If the two FET's are not matched, the larger the source resistor is, the less difference there will be between I_{D1} and I_{D2} as can be observed on the graph shown beside. Line A-B is the bias line for circuit-3 and line C-D is the bias line for circuit-4.

Example: bias line A-B

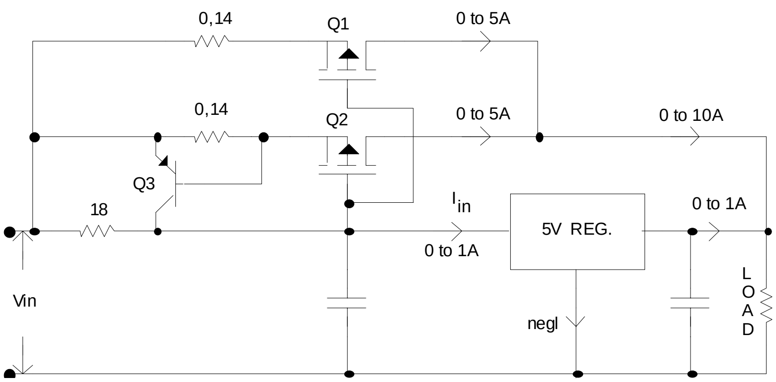
$V_R = 4.7 + 0.7 = 5.4$ V avg

<u>point A</u> $V_{GS} = -4V$, $I_D = (V_R - V_{SG})/R_{SC}$
$I_D = (5.4-4)/0.14 = 10A$

<u>point B</u> $V_{GS} = -5V$, $I_D = (V_R - V_{SG})/R_{SC}$
$I_D = (5.4-5)/0.14 = 2.86A$

For line C-D, $V_R = 4.7 + 1.4 = 6.1V$

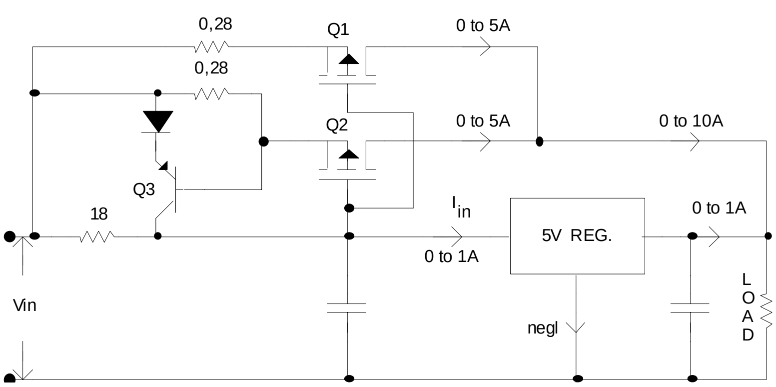
Circuit 3



The maximum load current will be:

$I_{MAX} = I_{MAX(REG)} + 2\ I_{MAX(Q)}$
$I_{MAX} = 1A + 2 \times 0{,}7/0.14 = 11A$
$I_{C3max} = I_{in} - (V_{GS} + V_{BE})/R =$
$I_{C3max} = 1 - (4.7+0.7)/18 = 0.7A$
Here there is no DC gate current therefore I_{MAX} will vary only due to variations of V_{BE3}.
R is made higher here in order to keep its maximum power rating down because the voltage is substantially higher then what it was for BJT's.
$V_{Rmax} = V_{BE3} + V_{GSmax} = 0{,}7 + 4.7 = 5{,}4V$
$I_{Rmax} = 5.4/18 = 0.3A < I_{REGmax}$ OK
$P_{Rmax} = 5{,}4^2/18 = 1{,}62W$ (use 5W rating)

Circuit 4



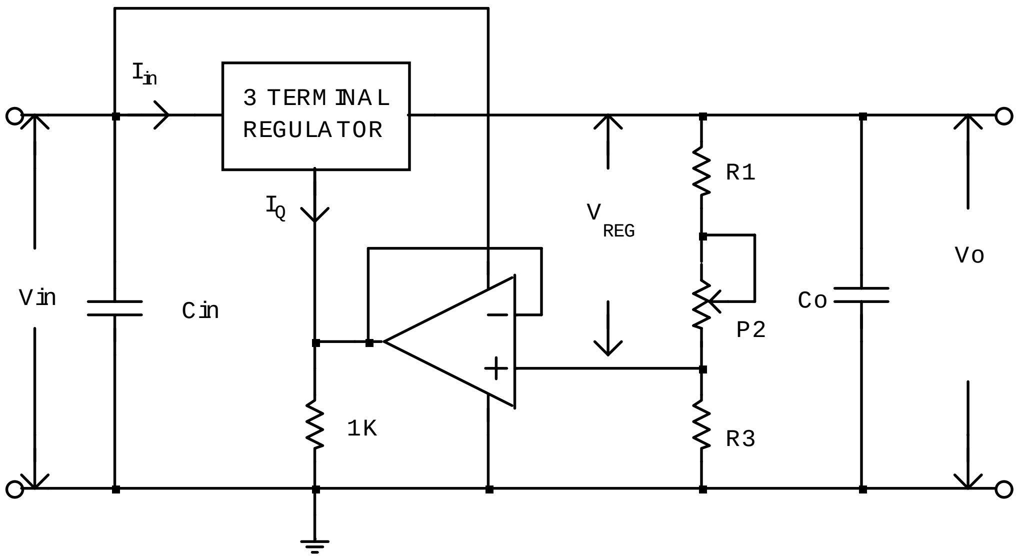
The maximum load current will be:

$I_{MAX} = I_{MAX(REG)} + 2\ I_{MAX(Q)}$
$I_{MAX} = 1A + 2 \times 1.4/0.28 = 11A$

$I_{C3max} = I_{in} - (V_{GS} + V_{BE})/R =$
$I_{C3max} = 1 - (4.7+1.4)/18 = 0.661A$

Here there is no DC gate current therefore I_{MAX} will vary only due to variations of V_{DF} and V_{BE3}.
R is made higher here in order to keep its maximum power rating down because the voltage is substantially higher then what it was for BJT's.
$V_{Rmax} = V_{BE3} + V_{GSmax} = 1.4 + 4.7 = 6.1V$
$I_{Rmax} = 6.1/18 = 0.339A < I_{REGmax}$ OK
$P_{Rmax} = 6.1^2/18 = 2.07W$ (use 5W rating)

IMPROVED ADJUSTABLE OUTPUT VOLTAGE



$$V_o = \frac{V_{REG}}{R_1 + P_2} \times (R_1 + P_2 + R_3) = V_{REG}\left(1 + \frac{R_3}{R_1 + P_2}\right)$$

Select R1, P2 and R3 for desired V_{out} and such that the current through them is in the mA range. One must also ensure that V^+ and V^- are within input voltage range of op amp and that op amp O/P voltage is also within specified range. A good choice here would be a "rail-to-rail" CMOS op amp that can operate anywhere between its two supply voltages.

The above circuit makes the output voltage independant of I_Q and thereby improves the regulation of V_o. It is therefore useful to make a three-terminal fixed regulator into a variable one because of the high value of I_Q for such regulators. Protection diodes not shown.

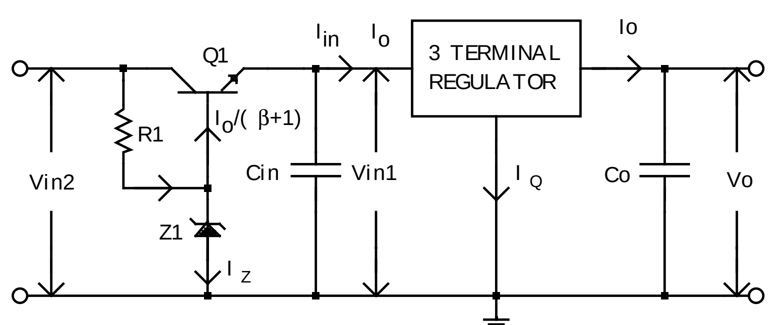
PRE-REGULATOR FOR V_{in} ABOVE V_{in} MAX OF REGULATOR

Z_1: $V_Z > V_o\text{max} + (V_{in1} - V_o)_{min} + 3$

$$I_{R1} = \frac{V_{in2} - V_Z}{R_1} = I_Z + \frac{I_{in}}{\beta + 1} \approx I_Z + \frac{I_o}{\beta}$$

$$\frac{V_{in2(\min)} - V_Z}{R_1} \rangle I_{Z(\min)} + \frac{I_{o(\max)}}{\beta_{\min}}$$

$$R_1 \langle \frac{V_{in2(\min)} - V_Z}{I_{Z(\min)} + \frac{I_{o(\max)}}{\beta_{\min}}}$$



Be careful of power dissipation of R_1 and Z_1. Q1 can be replaced by an N channel power MOSFET, then R_1 only provides bias current to the zener (Z_1).

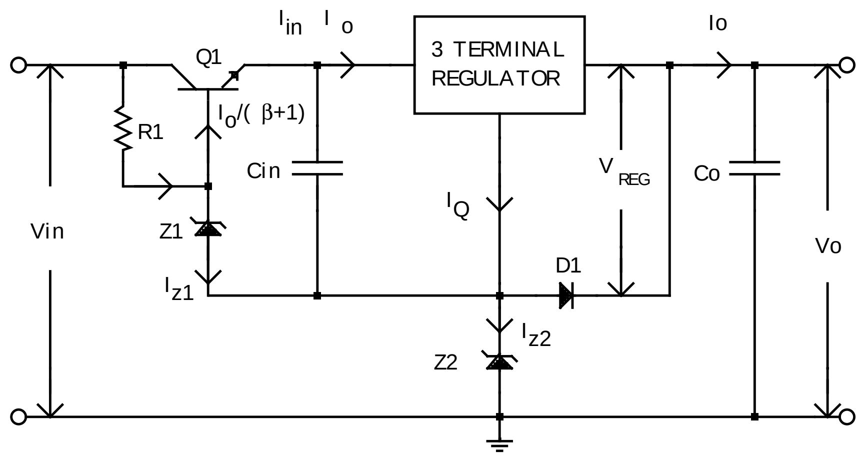
HIGH OUTPUT VOLTAGE FOR THREE-TERMINAL REGULATORS

$V_o = V_{Z2} + V_{REG}$

Be careful of power dissipation of R_1, Z_1 and Z_2. $I_{Z2} = I_{Z1} + I_Q$

Q1 can be replaced by an N channel power MOSFET, then R_1 only provides bias current to the zeners (Z_1 and Z_2).

$$R_1 < \frac{V_{in(\min)} - V_{Z1} - V_{Z2}}{I_{Z1(\min)} + \frac{I_{o(\max)}}{\beta_{\min}}}$$

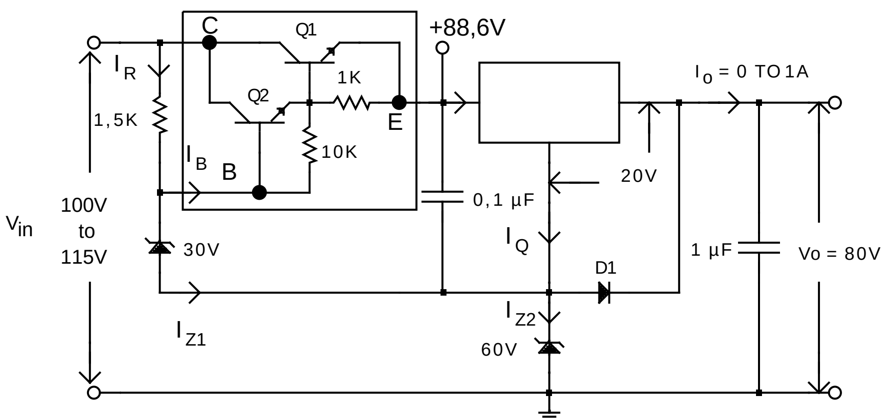


$$I_{R1} = \frac{V_{in} - V_{Z1} - V_{Z2}}{R_1} = I_{Z1} + \frac{I_{in}}{\beta + 1} \approx I_{Z1} + \frac{I_o}{\beta} \Rightarrow \frac{V_{in(\min)} - V_{Z1} - V_{Z2}}{R_1} > I_{Z1(\min)} + \frac{I_{o(\max)}}{\beta_{\min}}$$

Example

Let I_{Z1}=5 mA min and β≥24.
I_B = 1,7 mA max for the Darlington pair.
R_B≤(100-90)/6.7m=1,5k
Let us use 1,5K for minimum power in R_B.

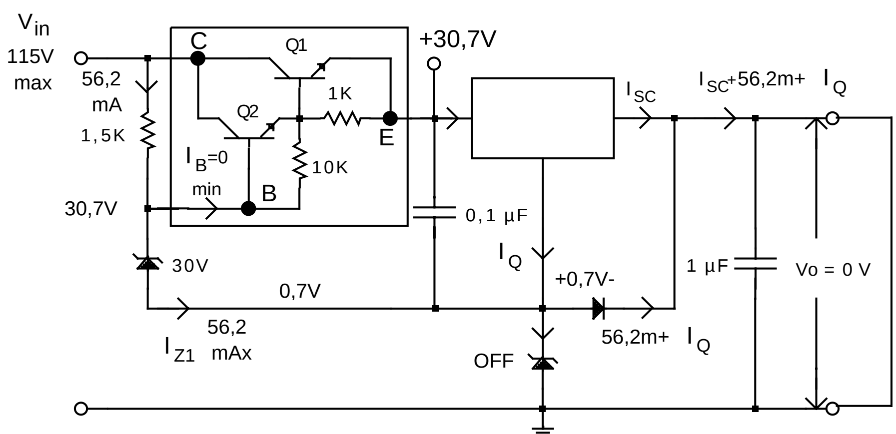
I_{Z2} > 5m + I_Q is OK
P_{Z2} > 2x60x(5m+I_{Qmax})



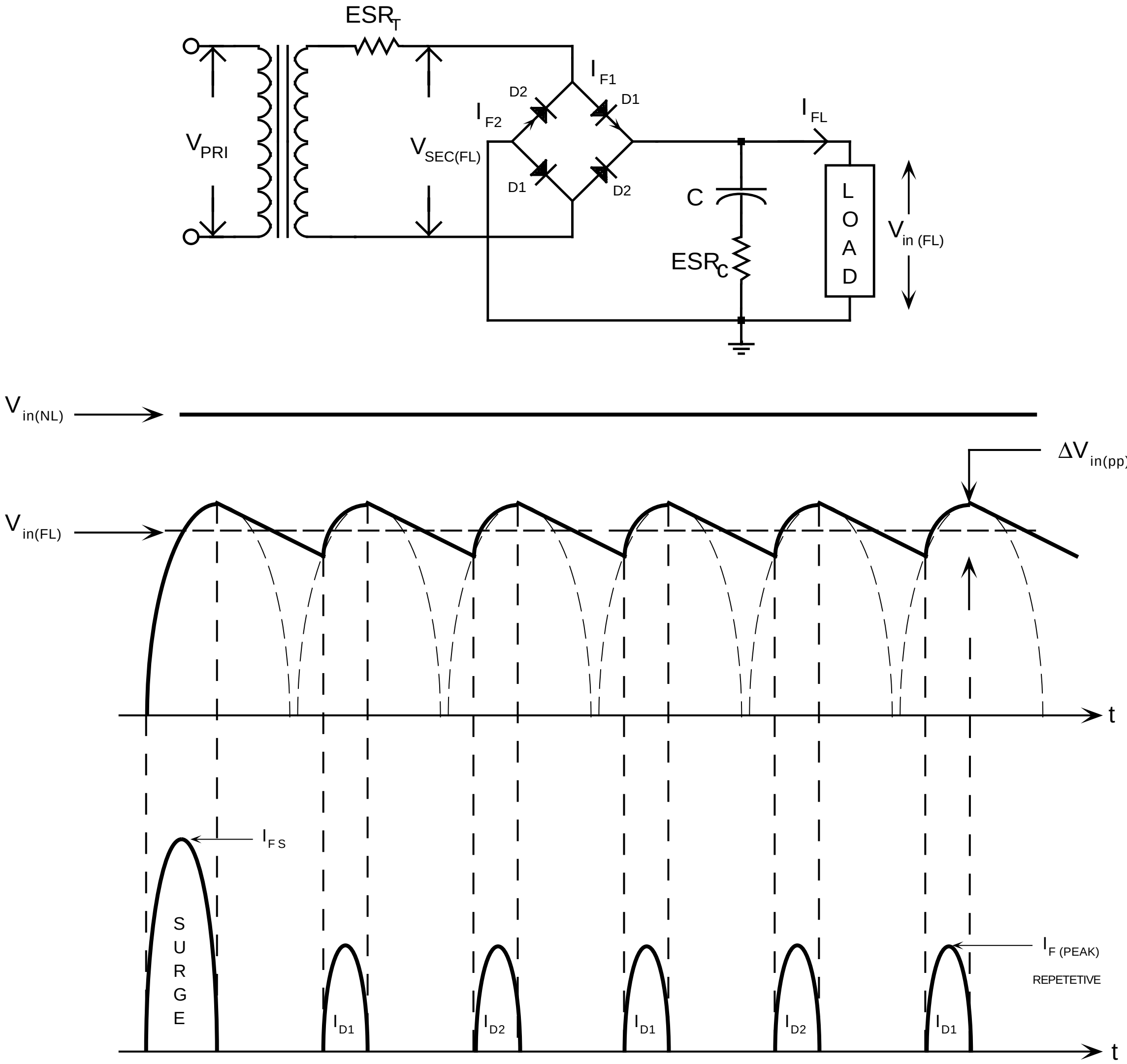
P_{RB} > 2x(56.21m)^{2}x1,5K
P_{RB} > 9,47W, use 10W rate

D_1 and Z_1 clamp input voltage of regulator to 30,7V whcih should be below max differential voltage of regulator.

NOTE: Accuracy of V_{out} can be impaired substantially if Z_2 has a high tolerance



UNREGULATED POWER SUPPLY DESIGN



In designing the unregulated power supply, one must be able to calculate the following:

Transformer: $V_{SEC(rms)}$, $I_{SEC(rms)}$ at full load and $V_{SEC(rms)}$ no load.

Diodes: surge current, peak repetitive current, average rectified current, rms current, PIV

Capacitor: capacitance, maximum operating voltage, maximum ripple voltage or current.

A mathematical analysis is very difficult, therefore we will use a graphical solution using Schade's curves that were originally derived for power supplies using vacuum tube diodes. The graphs can be used also for solid state diodes by taking into account their forward voltage drop (different for vacuum tube diodes). The amplitude of the initial current surge and the peak repetitive current is a function of the total equivalent series resistance in the the secondary of the transformer, that is

R_S total = $ESR_T + ESR_C + ESR_{DIODES}$

UNREGULATED DC POWER SUPPLY DESIGN PROCEDURE

(Valid only for $\omega C R_L > 10$ and $1\% < R_S/R_L < 15\%$)

A) TRANSFORMER SELECTION

1. **Calculation of $I_{SEC\ (FL)\ rms}$ of transformer secondary**

half wave rectifier	$I_{SEC\ (FL)\ rms} = 2*I_{FL}$ to $3*I_{FL}$
full wave center tap rectifier	$I_{SEC\ (FL)\ rms} = 1*I_{FL}$ to $1.5*I_{FL}$
full wave bridge rectifier	$I_{SEC\ (FL)\ rms} = 1.5*I_{FL}$ to $2*I_{FL}$

2. **Calculation of $V_{SEC\ (FL)\ rms}$ of transformer secondary**

half wave rectifier	$V_{SEC\ (FL)\ rms} = (V_{in(FL)} + \Delta V_{in(pk)} + V_{DF})/\sqrt{2}$	minimum
full wave center tap rectifier	$V_{SEC\ (FL)\ rms} = 2*(V_{in(FL)} + \Delta V_{in(pk)} + V_{DF})/\sqrt{2}$	minimum
full wave bridge rectifier	$V_{SEC\ (FL)\ rms} = (V_{in(FL)} + \Delta V_{in(pk)} + 2V_{DF})/\sqrt{2}$	minimum

3. **Transformer selection:** select a transformer according to the minimum values of $I_{SEC\ (FL)\ rms}$ and $V_{SEC\ (FL)\ rms}$ calculated above.

4. **R_S of transformer** $$R_S \approx \frac{V_{SEC(NL)} - V_{SEC(FL)}}{I_{SEC(FL)}}$$ R_S total includes bulk resistance of diodes and ESR of filter capacitor and will therefore be higher than R_S of transformer alone.

B) CAPACITOR SELECTION

Calculation of R_S/R_L Calculate $R_L = V_{in(FL)} / I_{FL}$ $\% R_S/R_L = 100*R_S / R_L$
n=1 for halfwave and full wave CT, n=2 for full wave bridge, $V_{in(NL)} = \sqrt{2} * V_{SEC(NL)} - n*1.0$

Minimum DC voltage ratio

$$\% \frac{V_{in(FL)}}{V_{in(NL)}} \min = \frac{V_{in(FL)} \min}{V_{in(NL)}} \times 100$$

Maximum Ripple Factor

$$r.f. \max = \frac{\Delta V_{in(pp)} \max}{2\sqrt{3} \times V_{in(FL)}} \times 100 = \frac{\Delta V_{in(rms)} \max}{V_{in(FL)}} \times 100$$

Determine ωCR_L min: Using the appropriate graphs, determine the minimum value of $\omega \mathbf{CR_L}$ required for r.f. max and $\%V_{in(FL)}/V_{in(NL)}$ min calculated above. Calculate minimum C value from ωCR_L value and pick standard value. Calculate maximum operating voltage of capacitor $V_{C(max)} = V_{in(NL)}$: double this value for maximum rating.

C) DIODE SELECTION

1. Average rectified current per diode: $I_{F(AVE)} = I_{FL}$ for halfwave and $I_{F(AVE)} = I_{FL} / 2$ for full wave
2. Rms and peak rectified currents per diode.
   Read rms and peak values on figure 8.4 for R_S/nR_L and $n\omega CR_L$ values already selected.
3. Peak inverse voltage — $PIV = 2*V_{in(NL)}$ for halfwave and fullwave CT; $PIV = V_{in(NL)}$ for fullwave bridge
4. Surge current — $I_{SURGE} = V_{in(NL)} / R_S$

NOTE: Maximum current and voltage ratings of diode should be at least twice the actual values.

D) TRANSFORMER CHECK

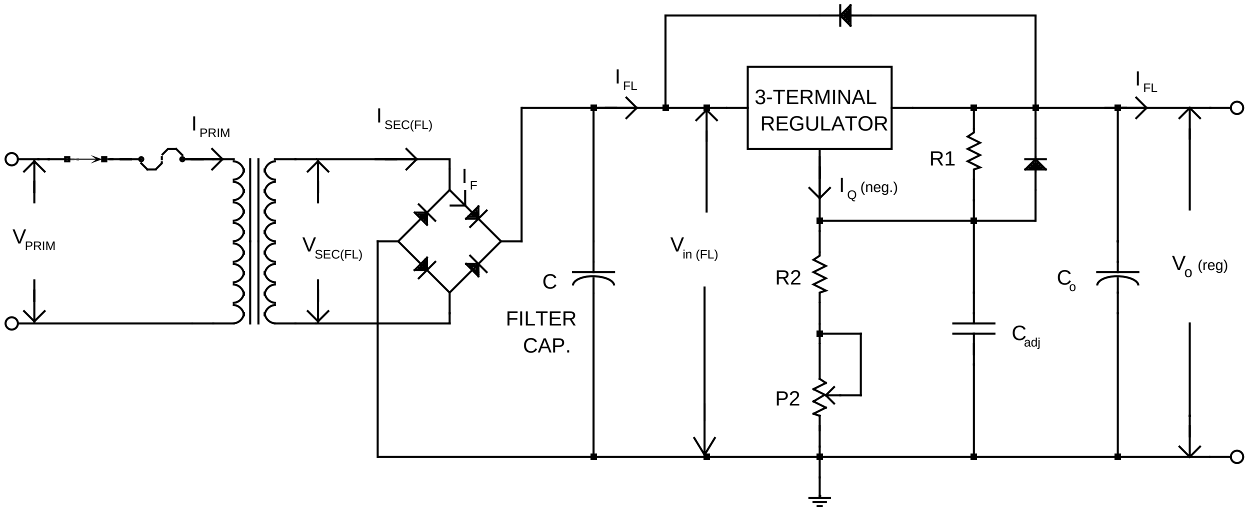
$I_{SEC\ (rms)} = I_{F\ (rms)}$ for halfwave and fullwave CT
$I_{SEC\ (rms)} = \sqrt{2}\, I_{F\ (rms)}$ for fullwave bridge

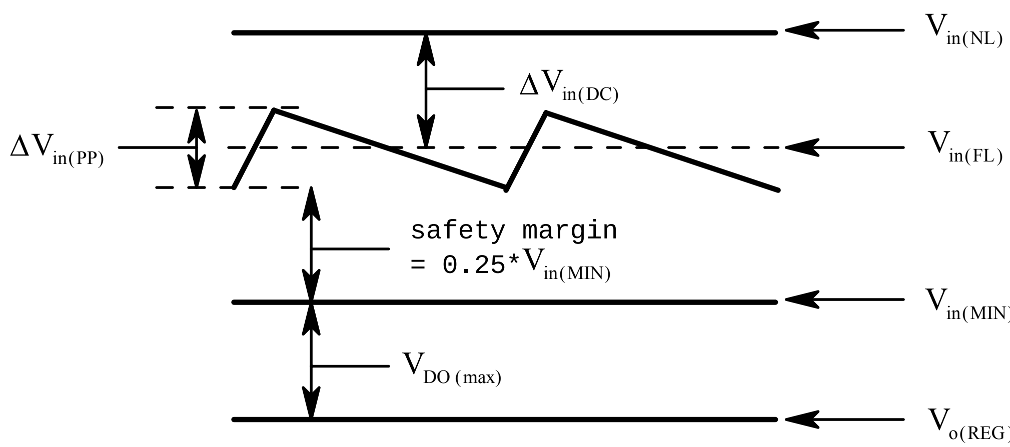
E) SWITCH AND FUSE SELECTION

$I_{PRIM\ (rms)} = I_{SEC\ (FL)\ rms} * (V_{SEC(NL)} / V_{PRIM})$

Fuse rating: max current $1.5*I_{PRIM\ (rms)}$, max voltage 2* 110V (rms) or more
Switch rating: max current > $2*I_{PRIM\ (rms)}$, max voltage 2*110V (rms) or more.

DESIGN OF REGULATED POWER SUPPLY





The above illustration shows the design parameters needed to design a regulated power supply. $V_{DO(max)}$ is the worst case dropout voltage of the voltage regulator. $V_{in(FL)}$ is the full load unregulated input voltage at I_{FL} where I_{FL} is the full load current in the regulated load plus the quiescent current of the voltage regulator which can be ignored in general. $V_{in(NL)}$ is not known until the transformer has been selected because it depends on $V_{SEC(NL)}$ of the transformer.

EXAMPLE-3 <u>DESIGN OF REGULATED POWER SUPPLY</u>

Design a +8.5V regulated power supply that can deliver 0 to 1A to the load using an LM317K voltage regulator mounted on a proper heat sink.

A) Voltage regulator design

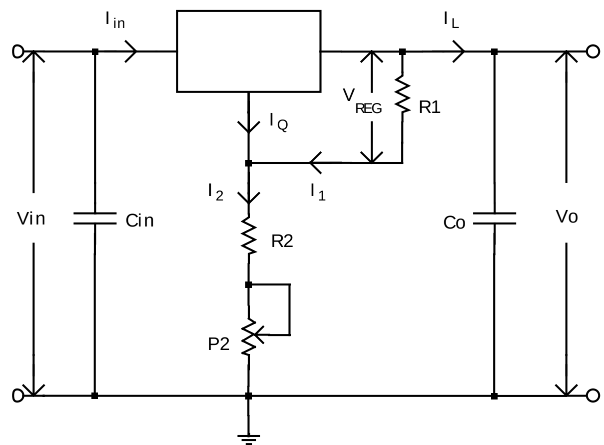
For the LM317, we have the following equations:

$$V_o = V_{REF} + (I_1 + I_Q) \times (R_2 + P_2)$$

$$V_o = V_{REF} + (\frac{V_{REF}}{R_1} + I_Q) \times (R_2 + P_2)$$

$$V_o = V_{REF}\left(1 + \frac{(R_2 + P_2)}{R_1}\right) + I_Q (R_2 + P_2)$$

$$V_o \approx V_{REF}\left(1 + \frac{(R_2 + P_2)}{R_1}\right) \quad if \quad I_1 \rangle\rangle I_Q$$



Let ΔV_o caused by ΔI_Q be less than 0,3V, that is:

$\Delta V_{o\ partial} = \Delta I_Q (R_2+P_2) < 0{,}3V$ or $(R_2+P_2) < 0{,}3/50\mu = 6k$

Let P_2 =1K and aim for a mid-range setting of 500, therefore select $R_2 < 6k - 500 = 5.5k$

$$\frac{R_2 + P_2}{R_1} \approx \frac{V_2}{V_1} \approx \frac{8{,}5 - 1{,}25}{1{,}25} = 5.8$$

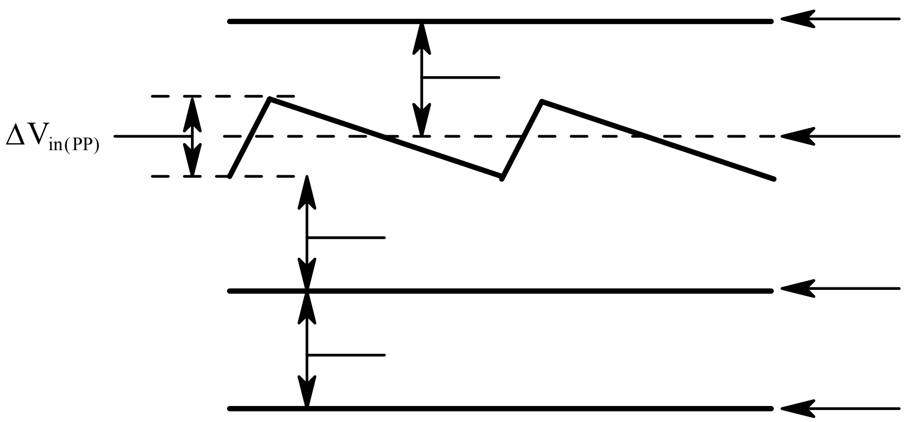
R_2 std	5.1K	4,7K	**4,3K**	3,9K
R_1 theo=$(R_2$+0.5K)/5.8	965.5	896.6	**827.6**	758.6
R_1 std	1K	910	**820**	750

The potentiometer should provide enough adjustment range to cover for the variations of V_{REF}, I_Q and resistor tolerance. This should be verified with appropriate calculations.

NOTE: Add a dummy load to provide minimum of 10 mA to insure regulation if the actual load current is expected to fall below 10 mA.

B) Unregulated power supply design

The typical dropout voltage of the LM317K is about 2V at I_{FL} = in order to use a reasonable filter capacitor - the larger the ripple voltage, the smaller the capacitance.



a) Transformer selection

1. $I_{SEC\ (FL)\ rms}$ = 1.5 I_{FL} to 2.0 I_{FL} = 1.5A to 2,0A
2. $V_{SEC\ (FL)\ rms}$=($V_{in(FL)}$+$\Delta V_{in(pk)}$+2V_{DF})/$\sqrt{2}$ min = (16+1,5+2)/$\sqrt{2}$ = 13,8V min

3. Transformer selection: a **Hammond 166L14 transformer** will be fine for the job, its specifications are as follows:

$V_{SEC\ (NL)\ (rms)}$ = 15.3V $\quad$ $V_{SEC\ (FL)\ rms}$ = 14V $\quad$ $I_{SEC\ (FL)\ rms}$ = 2A full load

4. $$R_S \approx \frac{V_{SEC(NL)} - V_{SEC(FL)}}{I_{SEC(FL)}} = \frac{15.3-14}{2} = \underline{0.65\Omega}$$

b) Capacitor selection

1. $R_L = V_{in(FL)} / I_{FL}$ = 16 / 1 = $\underline{16\Omega}$ $\quad$ % R_S/R_L = (0.65 / 16) * 100 = $\underline{4.06\%}$

2. Choice of ωCR_L and C

ripple factor
$$\text{r.f. max} = \frac{\Delta V_{in(pp)}\ \text{max}}{2\sqrt{3} \times V_{(in)FL}} \times 100 = \frac{3}{2\sqrt{3}\times 16} \times 100 = \underline{5.41\%}$$

Caculate $V_{in(NL)} = V_{SEC\ (NL)\ (peak)}$ - n*1.0 = 15.3 $\sqrt{2}$ - 2 = 19.64 V (DC)

Calculate
$$\% \frac{V_{in(FL)}}{V_{in(NL)}} \text{min} = \frac{16}{19.64} \times 100 = \underline{81.47\%}$$

Looking up the regulation graph (fig. 8.3) and the ripple graph (fig. 8.5) for % R_S/R_L = 4.06%, we find the following results:

$\omega CR_L > 7$ for $\% \frac{V_{in(FL)}}{V_{in(NL)}} \rangle \underline{81.47\%}$ and $\omega CR_L > 13$ for $r.f. \langle 5.41\%$

Calculate C value from $\omega CR_L > 13$, $C > 13 / (2\pi\ 60 * 16) = 2155\ \mu F$, therefore <u>C = 2200 μF standard.</u>

Maximum operating voltage of capacitor $V_{C(max)} = V_{in(NL)} = \underline{19.64V}$

Maximum ripple voltage 3 V_{pp}

Select 2200 μF, 40V, 6V_{pp} max ripple or better.

c) Diode selection (refer to fig. 8.4)

1. $I_{F(AVE)} = I_{FL} / 2 = 1/2 = \underline{0.5A}$

2. Read rms and peak rectified currents per diode for $n\omega CR_L = 2*2\pi*60*2200\mu*16=26.6$ and R_S/nR_L = 2.03%

   $I_{F(rms)} / I_{F(AVE)} = 2.7$ $\quad$ $I_{F(peak)} / I_{F(AVE)} = 8.0$

   $I_{F(rms)} = 2.7 * 0.5 = \underline{1.35A}$ $\quad$ $I_{F(peak)} = 8.0 * 0.5 = \underline{4.0A}$

3. PIV= $V_{in(NL)} = 19.64V$

4. $I_{SURGE} = V_{in(NL)} / R_S = 19.64 / 0.65 = \underline{30.2A}$

   We must now select diodes with ratings exceeding the above values with at least 100% safety margin.

Selected diodes: 1N4719

I_{SURGE} = 300A max $\quad$ $I_{F\ (AVE)}$ = 3.0A max $\quad$ PIV = 50V max

d) Transformer check

$I_{SEC(FL)rms} = \sqrt{2}\ I_{F(rms)} = \sqrt{2} * 1.35 = 1.9A$ which is below $I_{SEC\ (FL)\ rms} = 2.0A$ of 166L14 transformer.

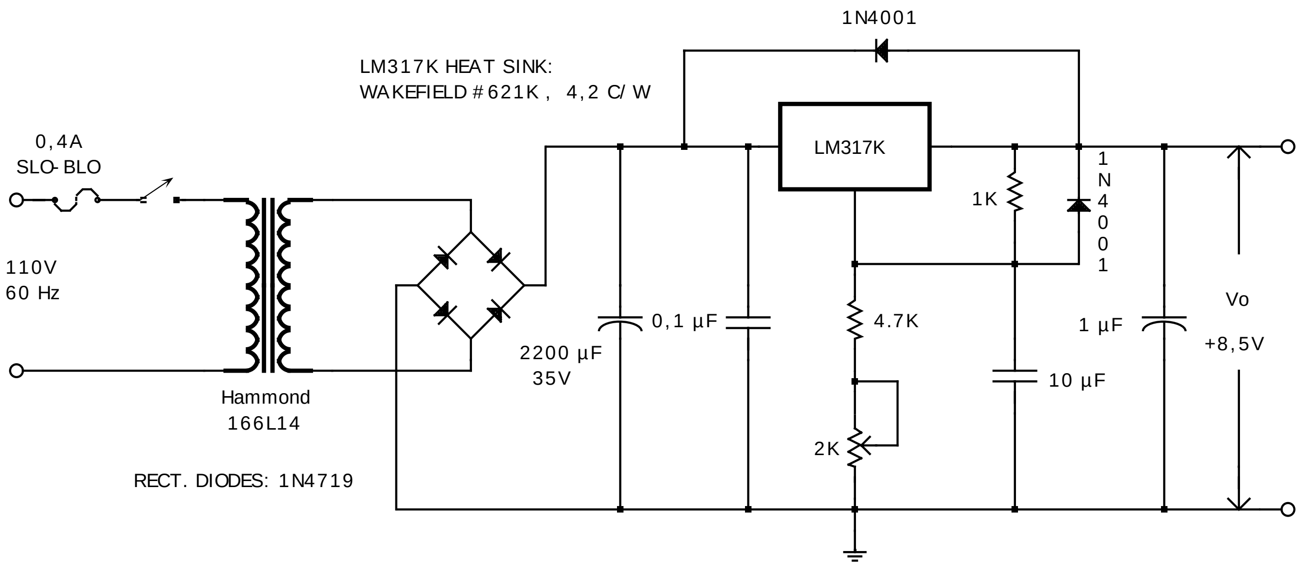
e) Switch and fuse selection

$I_{PRIM\ (rms)} = I_{SEC\ (FL)rms} * (V_{SEC(NL)}/V_{PRIM}) = 2.0 * (15.3 / 115) = 0{,}27A$

Fuse rating: max current 1.5*0.27 = 0.4A, max voltage 110V (rms) or more
Switch rating: max current 2*0.27 = 0.54A, max voltage 2*110V (rms) or more

Use a 0.4A,110V slo-blo fuse and a 1A, 200V switch

Final circuit



UNREGULATED POWER SUPPLY ANALYSIS

1. Calculation of $V_{in(NL)}$ and $V_{in(FL)}$

When starting the analysis, we do not know the value for $V_{in\ (FL)}$ we must therefore assume a value to find R_L and perform several iterations as shown below.

$V_{in\ (NL)} = \sqrt{2} * V_{SEC\ (NL)} - 2.0 = \sqrt{2} * 15.3 - 2 = 19.64V$

First iteration

Let $V_{in\ (FL)} = 15V$, then $R_L = V_{in\ (FL)} / I_{FL} = 15 / 1 = 15\Omega$
$R_S = (V_{SEC\ (NL)} - V_{SEC\ (FL)}) / I_{SEC\ (FL)} = (15.3-14)/2.0 = 0.65\Omega$
$\% R_S / R_L = (0.65 / 15) * 100 = 4.33 \%$
$\omega CR_L = 2\pi * 60 * 2200\mu * 15 = 12.44$
On figure 8.3 we read 84% therefore $V_{in(FL)} = 0.84 * 19.64 = 16.5V$

Second iteration

$V_{in\ (FL)} = 16.5V$, then $R_L = V_{in\ (FL)} / I_{FL} = 16.5 / 1 = 16.5\Omega$
$\% R_S / R_L = (0.65 / 16.5) * 100 = 3.94 \%$
$\omega CR_L = 2\pi * 60 * 2200\mu * 16.5 = 13.7$
On figure 8.3 we read 83% therefore $V_{in(FL)} = 0.83 * 19.64 =$ **16.3V**

Two iterations yield enough accuracy.

2. Calculation of $I_{F\ (rms)}$ and $I_{F\ (peak)}$ from figure 8.4

$n\omega CR_L = 2*2\pi*60*2200\mu * 16.3 = 27$
$\% R_S / nR_L = (0.65 / (2*16.3)) * 100 = 1.99 \%$

We read $I_{F\ (rms)} = 2.7 * I_{F\ (ave)} = 2.7 * 0.5 = 1.35A$
and $I_{F\ (peak)} = 8.0 * I_{F\ (ave)} = 8.0 * 0.5 = 4\ A_p$

3. Calculation of ripple voltage

On figure 8.5, for $\omega CR_L = 2\pi*60*2200\mu * 16.3 = 13.5$ and $\% R_S / R_L = (0.65 /16.3) * 100 = 3.98 \%$, we read r.f. = 5.5% which translates into:

$\Delta V_{in\ (pp)} = r.f. * 2 * \sqrt{3} * V_{in\ (FL)} = 0.055 * 2 * \sqrt{3} * 16.3 = 3.1\ V_{pp}$

THERMAL CALCULATIONS

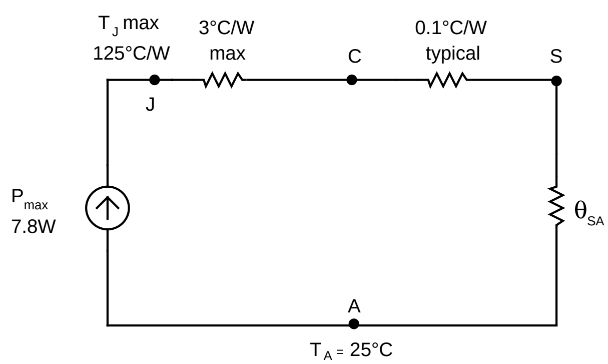
Assuming $V_{in(FL)}$ = 16.3V at I_{FL} = 1.0A, let's calculate the heat sink required for the LM317K to provide a regulated output of +8.5V for a load current of 0 to 1A.

From the LM317K datasheets we have the following: $T_{J\ max}$ = 125°C

$P_{max(ABS)}$ = 20Wθ_{JC} = 3°C/W max, 2.3°C/W typical θ_{JA} = 35°C/W typical

Thermal design

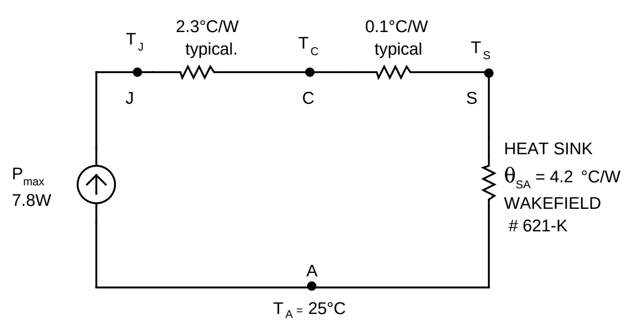
P_{REG} = (16.3 - 8.5) * 1A = 7.8W max when V_o is regulated - 16.3V is an approximate value of V_{in} obtained from Shade's curves.



$$\theta_{SA} = \frac{125-25}{7.8} - 3 - 0.1 = 9.72\ ^\circ C / W$$

To be safe, let's use 50% of 9.72 °C/W, that is 4.76 °C/W for the heat sink. Now we must find a heat sink that has thermal resistance of 4.76 °C/W or less. A Wakefield 621-K will be fine, it has a thermal resistance of 4.2 °C/W.

Thermal analysis



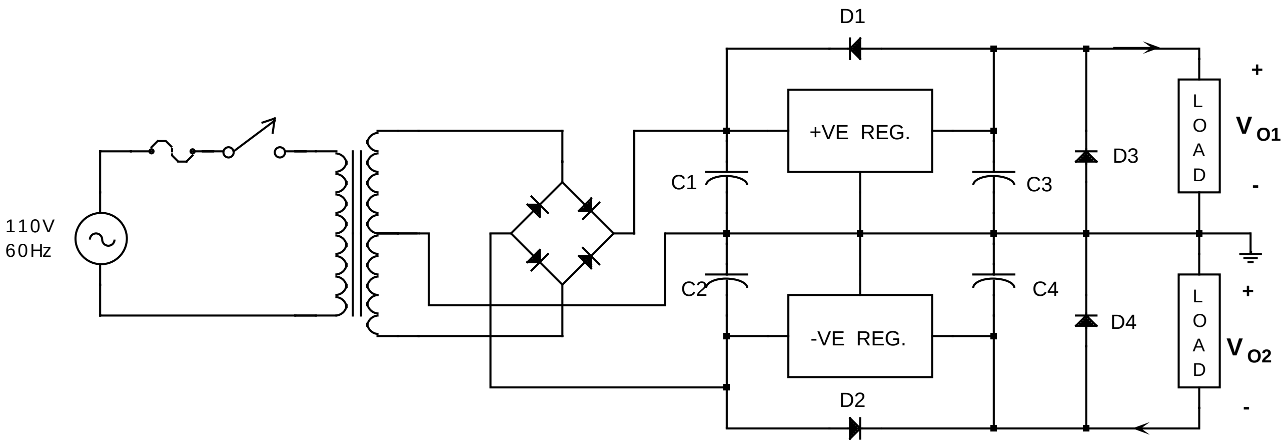
$T_{J\ max}$ for T_A=25°C and P_{REG} = 7.8W is

$T_{J\ max}$ = 25 + 7.8 (2.3+0.1+4.2) = 76.5°C

The heat sink temperature is

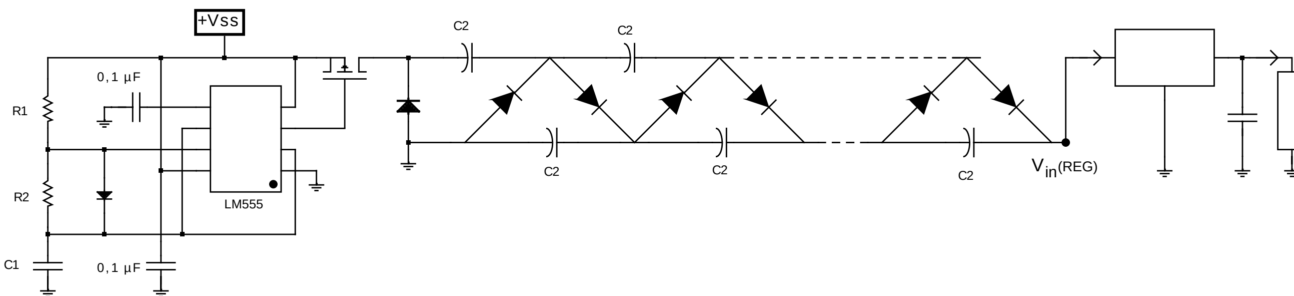
T_S = 25 + 4.2 * 7.8 = 57.8°C (HOT!)

DUAL SUPPLY WITH GROUNDED OUTPUTS



Diodes D1 through D4 are for protection purposes. Calculation of the maximum current levels in the diodes and the transformer is different than with a single supply and should be done with a good circuit simulator. For multiple output voltages one can also use several isolated secondary windings.

HIGH VOLTAGE OUTPUT FROM EXISTING LOW-VOLTAGE SOURCE



$$C_{EQ} \approx C_2 \,/\, 0{,}5N \qquad \Delta V_{in(PP)} = \frac{\Delta Q}{C_{EQ}} = \frac{k\, I_L \Delta t}{C_{EQ}} = \frac{k\; N \times I_L}{2\, C_2 F_{RIP}} \qquad V_{in(reg)} = f\left(V_{SS}, C_2, N, I_L\right)$$

where k is a constant that depends on N, C_2 F and I_L . N is the number of capacitors.

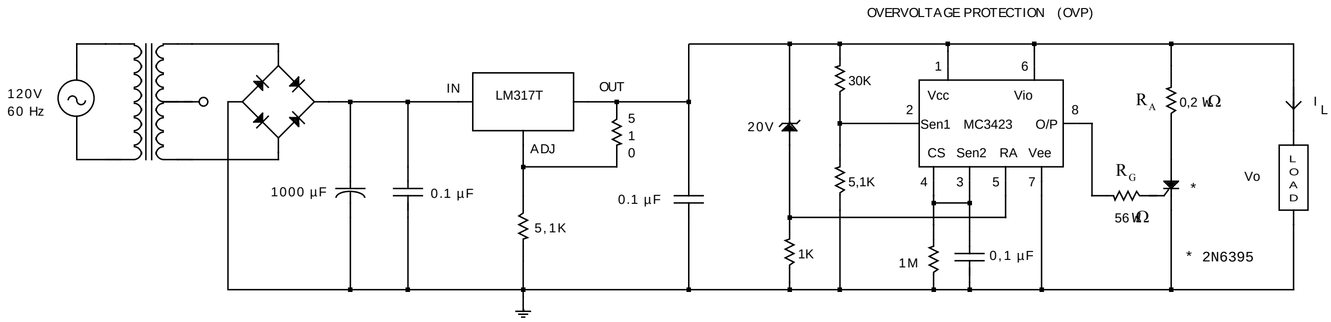
If the 555 frequency is too high, the power MOSFET may not be switched fast enough therefore a high-speed MOSFET driver should be inserted between the 555 O/P and the gate of the MOSFET. As the frequency increases, smaller capacitors can be used for the same amount of ripple at V_{in}.

For an integrated switched-capacitor voltage doubler, refer to National's LM766X series.

Another solution for boosting DC voltage is to use a switching regulator, or DC to DC converter, which can be designed from discrete components or bought right off the shelf from various suppliers.

NOTE: Initial transient required to charge all the capacitors is quite long and increases with the number of capacitors. Voltage multiplication only works well with very light loads.

OVERVOLTAGE PROTECTION CIRCUIT



A) Determine the regulated output voltage.
B) Calculate the two trip voltages (typical values) of the OVP circuit and the expected <u>range</u> of delays for each, assuming 10% capacitors and worst case variations of charge current and internal reference voltage of OVP IC.
C) Determine if the 0,2Ω and the 56Ω resistors are suited for the SCR assuming a minimum trigger pulse of 2 µs at OVP IC O/P. Modify resistors if need be.
D) Explain the purpose of the 0,2Ω and the 56Ω resistors.
E) Explain how an SCR can be turned OFF?
F) Explain why a rate of di_A/dt too large can destroy the SCR?
G) Explain why a rate of dV_{AK}/dt too large can self-trigger the SCR?

A) V_{REG} = 14,0V typical

B) $V_{TR1} = I_X$ (5,1K+30K) = 17,9V typical where I_X = 2,6V/5,1K at triggering

$$\frac{I_{CH}}{C} = \frac{\Delta V}{\Delta t} \quad \Rightarrow \quad \Delta t = \frac{C \times \Delta V}{I_{CH}} \qquad \Delta t_{min} = \frac{0,09\mu \times 2,45}{0,3m} = 0,735 \text{ ms} \qquad \Delta t_{min} = \frac{1,1\mu \times 2,75}{0,1m} = 3,025 \text{ ms}$$

$V_{TR2} \approx$ 20V + 1,4V = 21,4V typical , no delay $t_{d2} \approx 0$ µs

$$\text{C)}\, I_{A(max)} = \frac{21,4 - V_{AK(ON)}}{0,2\Omega} = 107\,\text{A max} \rangle \left(I_{TSM} / 2 = 50\,\text{A} \right) \quad \Rightarrow \quad \text{make } R_A \approx \frac{21,4 - V_{AK(ON)}}{50} = 0,428\Omega$$

NOTE: We can also limit the surge current in the SCR by inserting a small series inductor - this has the benefit of lowering the ON state output voltage when the SCR is triggerred because:

$$V_{OUT(ON)} = I_{LIM\,(REG)} \times R_A + V_{AK\,(ON)} \quad \Rightarrow \quad V_{OUT(ON)} \approx V_{AK\,(ON)}$$ without R_A and with small inductor.

$$I_{GT} \approx \frac{17,9 - 2 - 0,7}{56} = 271,4 \text{ mA}$$

The SCR has a maximum gate current of 2A (non-repetitive) $I_{GT\ max}$ is not exceeded.

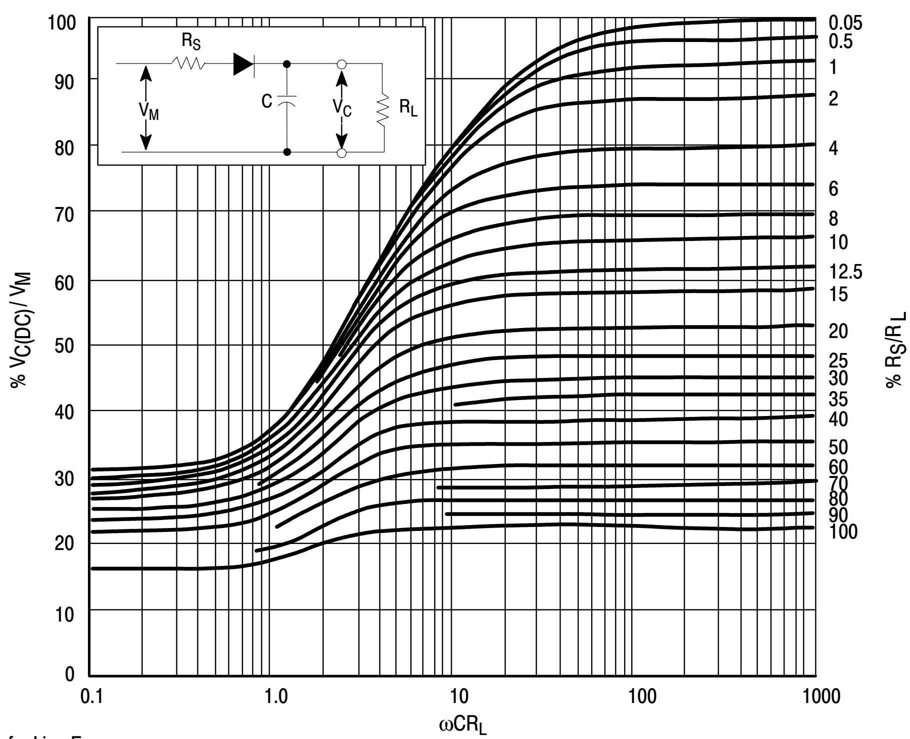
From figure 6 of 2N6395 data sheet we read I_{GT} = 26 mA typical at -40 °C for a 2 µs pulse. According to the I_{GT} spec's, the ratio I_{GTmax}/I_{GTmin} = 30m/5m = 6 for a DC gate trigger current. If we <u>assume</u> the same ratio for a pulsed gate current, we have a worst case I_{GT} max ≈ 5 X 26 mA = 130 mA. The maximum output current of the OVP IC is 300 mA, therefore let I_{GT} = 180mA
and $R_G = (17,9-V_{AK\,(ON)})/180m$ = 99,4 Ω (100Ω std) assuming $V_{AK\,(ON)}$= 0V.

D,E,F and G) See class notes and read MC3423 application information on SCR.

1. Design of Capacitor–Input Filters

The best practical procedure for the design of capacitor–input filters still remains based on the graphical data presented by Schade(1) in 1943. The curves shown in Figures 8–2 through 8–5 give all the required design information for half–wave and full–wave rectifier circuits. Whereas Schade originally also gave curves for the impedance of vacuum–tube rectifiers, the equivalent values for semiconductor diodes must be substituted.

Figure 8–2. Relation of Applied Alternating Peak Voltage to Direct Output Voltage in Half–Wave Capacitor–Input Circuits

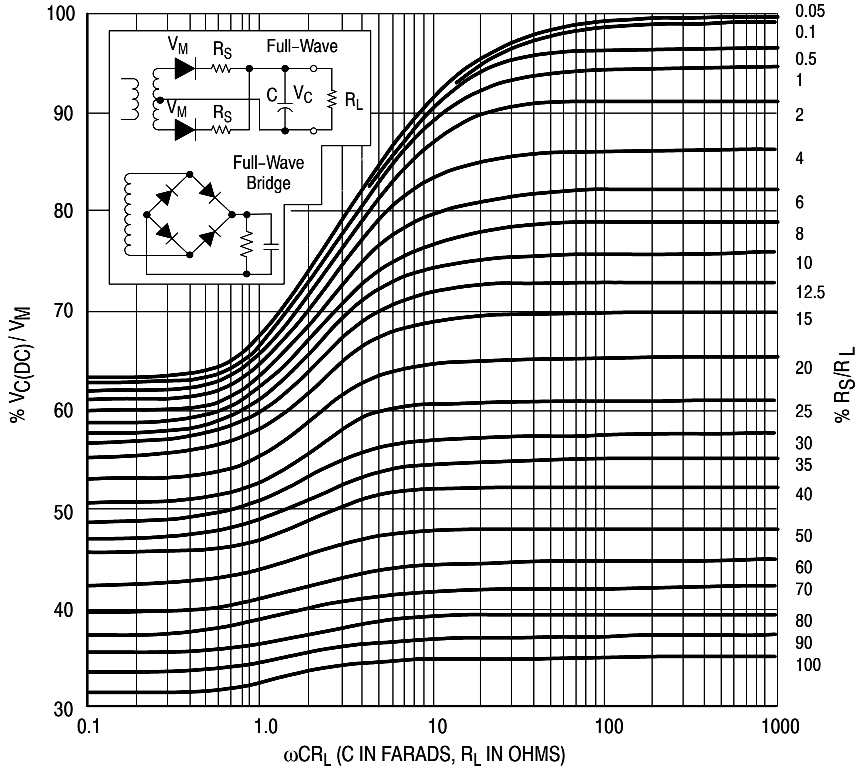


ω = 2 π f, f = Line Frequency
C in Farads
R_L in Ohms

However, the rectifier forward drop often assumes more significance than the dynamic resistance in low–voltage supply applications, as the dynamic resistance can generally be neglected when compared with the sum of the transformer secondary–winding resistance plus the reflected primary–winding resistance. The forward drop may be of considerable importance, however, since it is about 1.0 V, which clearly cannot be ignored in supplies of 12 V or less.

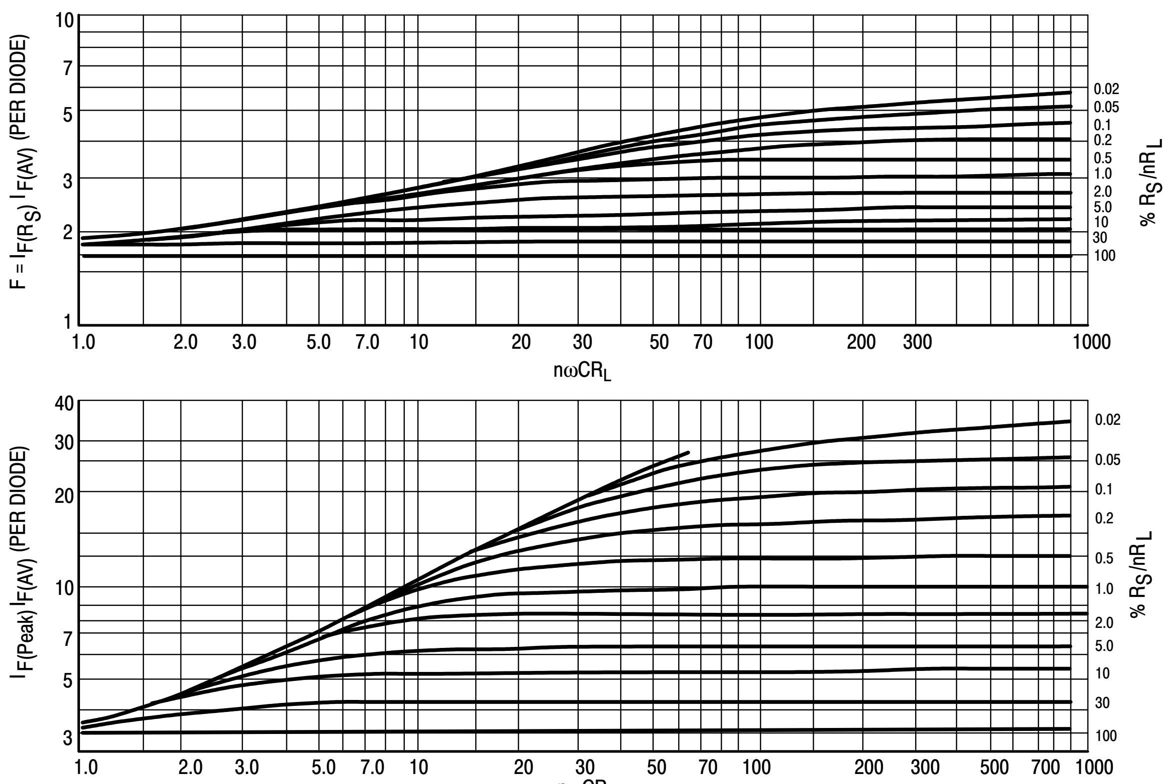
(1) From O. H. Schade, Proc. IRE, Vol. 31, p. 356, 1943.

Figure 8–3. Relation of Applied Alternating Peak Voltage to Direct Output Voltage in Full–Wave Capacitor–Input Circuits



$\omega = 2\pi f$, f = Line Frequency

Figure 8–4. Relation of RMS and Peak–to–Average Diode Current in Capacitor–Input Circuits



n = { 1 for Half–Wave Single–Phase Rectifier Circuits; 2 for Full–Wave Single–Phase Rectifier Circuits }

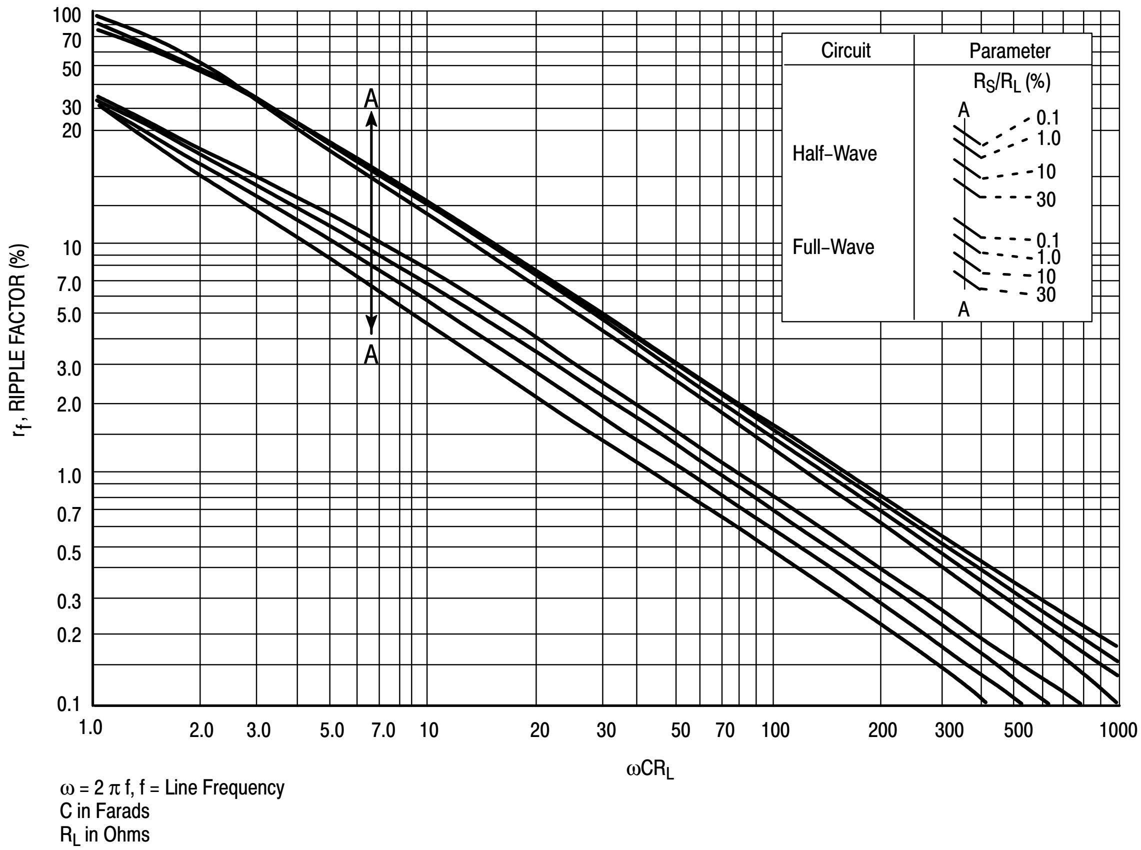
$\omega = 2\pi f$, where f = Line Frequency

C in Farads

R_L in Ohms

R_S = RMS Equivalent Source Resistance

Figure 8–5. Root–Mean–Square Ripple Voltage for Capacitor–Input Circuits



Returning to the above curves, the full–wave circuit will be considered. Figure 8–3 shows that a circuit must operate with $\omega CR_L \geq 10$ in order to hold the voltage reduction to less than 10% and $\omega CR_L \geq 40$ to obtain less than 2.0% reduction. However, it will also be seen that these voltage reduction figures require R_S/R_L, where R_S is now the total series resistance, to be about 0.1% which, if attainable, causes repetitive peak–to–average current ratios from 10 to 17 respectively, as can be seen from Figure 8–4. These ratios can be satisfied by many diodes; however, they may not be able to tolerate the turn–on surge current generated when the input–filter capacitor is discharged and the transformer primary is energized at the peak of the input waveform. The rectifier is then required to pass a surge current determined by the peak secondary voltage less the rectifier forward drop and limited only by the series resistance R_S. In order to control this turn–on surge, additional resistance must often be provided in series with each rectifier. It becomes evident, then, that a compromise must be made between voltage reduction on the one hand and diode surge rating and hence average current–carrying capacity on the other hand. If small voltage reduction, that is good voltage regulation, is required, a much larger diode is necessary than that demanded by the average current rating.

Surge Current

The capacitor–input filter allows a large surge to develop, because the reactance of the transformer leakage inductance is rather small. The maximum instantaneous surge current is approximately V_M/R_S and the capacitor charges with a time constant $\tau \approx R_S C_1$. As a rough — but conservative — check, the surge will not damage the diode if V_M/R_S is less than the diode I_{FSM} rating and τ is less than 8.3 ms. It is wise to make R_S as large as possible and not pursue tight voltage regulation; therefore, not only will the surge be reduced but rectifier and transformer ratings will more nearly approach the DC power requirements of the supply.

TRANSFORMER SELECTION GUIDE

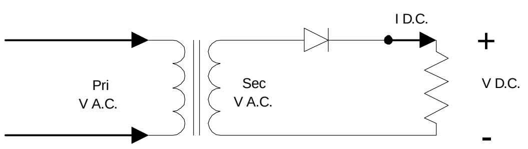
Transformer Voltage: A transformer's secondary A.C. voltage required varies greatly with the type of rectifier chosen and filter arrangement. Use the formulas below as a guide based on the D.C. voltage you require and the rectifier/filter chosen. All A.C. voltage references are R.M.S. Don't forget to take into account losses (not included in this guide), especially diode voltage drop. Leave an adequate safety margin for D.C. regulator voltage requirements and minimum operating line voltage.

Transformer Current Ratings: A transformer's A.C. current rating needs to be recalculated from the D.C. load current. The required current varies with type of rectifier chosen and filter type. Use the formulas below as a guide, shown for common D.C. supplies. Included in the formulas is higher peak to peak capacitor charging current in the filter.

Rectifier Selection Notes: When selecting rectifiers remember, average current in a full wave circuit is .5 x I D.C. per diode. In a half wave circuit, average current is equal to I D.C. per diode. A rating at least twice the output current is recommended to cover turn on surge. In full wave circuits, the reverse voltage rating should be in excess of 1.4 x V A.C. In half wave circuits, the reverse voltage rating should be in excess of 2.8 x V A.C.

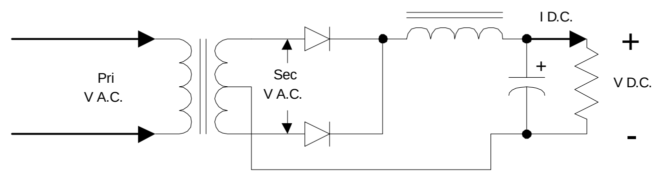
Capacitor Selection Notes: When choosing capacitor voltage, allowances should be made for D.C. voltage rise due to transformer regulation. Remember, RMS ripple current in a filter capacitor can be 2 to 3 times D.C. load current. Capacitor life is greatly increased by reducing it's temperature via less RMS current or reduced ambient temperature.

HALF WAVE Resistive Load



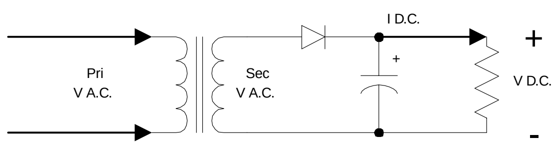
V D.C. = 0.45 X Sec. V A.C.
I D.C. = 0.64 X Sec. I A.C.

FULL WAVE Choke Input Load



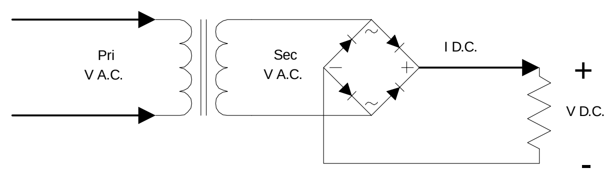
V (Peak) D.C. = 0.45 X Sec. V A.C.
V (Avg) D.C. = 0.45 X Sec. V A.C.
I D.C. = 1.54 X Sec. I A.C.

HALF WAVE Capacitor Input Load



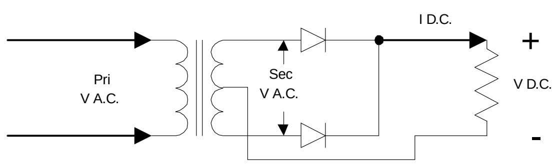
V (Peak) D.C. = 1.41 X Sec. V A.C.
V (Avg) D.C. = 0.90 X Sec. V A.C.
I D.C. = 0.28 X Sec. I A.C.

FULL WAVE BRIDGE Resistive Load



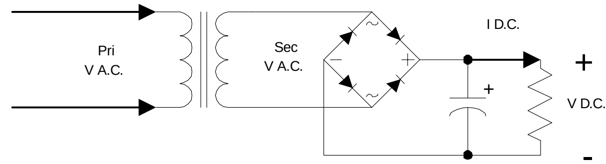
V D.C. = 0.90 X Sec. V A.C.
I D.C. = 0.90 X Sec. I A.C.

FULL WAVE Resistive Load



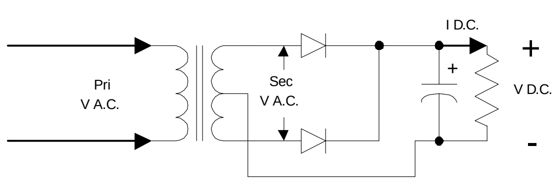
V D.C. = 0.45 X Sec. V A.C.
I D.C. = 1.27 X Sec. I A.C.

FULL WAVE BRIDGE Capacitor Input Load



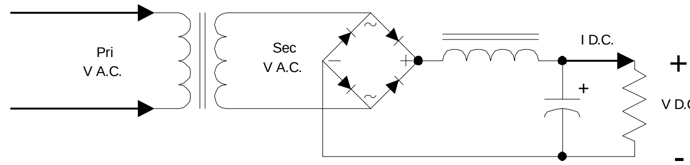
V (Peak) D.C. = 1.41 X Sec. V A.C.
V (Avg) D.C. = 0.90 X Sec. V A.C.
I D.C. = 0.62 X Sec. I A.C.

FULL WAVE Capacitor Input Load



V (Peak) D.C. = 0.71 X Sec. V A.C.
V (Avg) D.C. = 0.45 X Sec. V A.C.
I D.C. = 1.00 X Sec. I A.C.

FULL WAVE BRIDGE Choke Input Load



V (Peak) D.C. = 0.90 X Sec. V A.C.
V (Avg) D.C. = 0.90 X Sec. V A.C.
I D.C. = 0.94 X Sec. I A.C.

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- High insulation - Hipot of 2,500V RMS.
- Class B insulation - 130 degrees C.
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Cat. No. Single Pri. 115V	Cat. No. Dual Pri. 115/230V	Size VA	Secondary (RMS)	
			Series	Parallel
164D10	162D10	1.1	10V C.T. @ .11A	5V @ .22A
164E10	162E10	2.4	10V C.T. @ .25A	5V @ .5A
164F10	162F10	6.0	10V C.T. @ .6A	5V @ 1.2A
164G10	162G10	12.0	10V C.T. @ 1.2A	5V @ 2.4A
164H10	162H10	20.0	10V C.T. @ 2A	5V @ 4.0A
164J10	162J10	36.0	10V C.T. @ 3.6A	5V @ 7.2A
164D12	162D12	1.1	12.6V C.T. @ .09A	6.3V @ .18A
164E12	162E12	2.4	12.6V C.T. @ .2A	6.3V @ .4A
164F12	162F12	6.0	12.6V C.T. @ .5A	6.3V @ 1.0A
164G12	162G12	12.0	12.6V C.T. @ 1.0A	6.3V @ 2.0A
164H12	162H12	20.0	12.6V C.T. @ 1.6A	6.3V @ 3.2A
164J12	162J12	36.0	12.6V C.T. @ 2.85A	6.3V @ 5.7A
164D16	162D16	1.1	16V C.T. @ .07A	8V @ .14A
164E16	162E16	2.4	16V C.T. @ .15A	8V @ .3A
164F16	162F16	6.0	16V C.T. @ .4A	8V @ .8A
164G16	162G16	12.0	16V C.T. @ .8A	8V @ 1.6A
164H16	162H16	20.0	16V C.T. @ 1.25A	8V @ 2.5A
164J16	162J16	36.0	16V C.T. @ 2.25A	8V @ 4.5A
164D20	162D20	1.1	20V C.T. @ .055A	10V @ .11A
164E20	162E20	2.4	20V C.T. @ .12A	10V @ .24A
164F20	162F20	6.0	20V C.T. @ .3A	10V @ .6A
164G20	162G20	12.0	20V C.T. @ .6A	10V @ 1.2A
164H20	162H20	20.0	20V C.T. @ 1A	10V @ 2.0A
164J20	162J20	36.0	20V C.T. @ 1.8A	10V @ 3.6A
164D24	162D24	1.1	24V C.T. @ .045A	12V @ .09A
164E24	162E24	2.4	24V C.T. @ .1A	12V @ .2A
164F24	162F24	6.0	24V C.T. @ .25A	12V @ .5A
164G24	162G24	12.0	24V C.T. @ .5A	12V @ 1.0A
164H24	162H24	20.0	24V C.T. @ .8A	12V @ 1.6A
164J24	162J24	36.0	24V C.T. @ 1.5A	12V @ 3.0A
164D28	162D28	1.1	28V C.T. @ .04A	14V @ .08A
164E28	162E28	2.4	28V C.T. @ .085A	14V @ .17A
164F28	162F28	6.0	28V C.T. @ .2A	14V @ .4A
164G28	162G28	12.0	28V C.T. @ .42A	14V @ .84A
164H28	162H28	20.0	28V C.T. @ .7A	14V @ 1.4A
164J28	162J28	36.0	28V C.T. @ 1.3A	14V @ 2.6A
164D36	162D36	1.1	36V C.T. @ .03A	18V @ .06A
164E36	162E36	2.4	36V C.T. @ .065A	18V @ .13A
164F36	162F36	6.0	36V C.T. @ .17A	18V @ .34A
164G36	162G36	12.0	36V C.T. @ .35A	18V @ . 7A
164H36	162H36	20.0	36V C.T. @ .55A	18V @ 1.1A
164J36	162J36	36.0	36V C.T. @ 1A	18V @ 2.0A
164D48	162D48	1.1	48V C.T. @ .023A	24V @ .046A
164E48	162E48	2.4	48V C.T. @ .05A	24V @ .1A
164F48	162F48	6.0	48V C.T. @ .125A	24V @ .25A
164G48	162G48	12.0	48V C.T. @ .25A	24V @ .5A
164H48	162H48	20.0	48V C.T. @ .4A	24V @ .8A
164J48	162J48	36.0	48V C.T. @ .75A	24V @ 1.5A
164D56	162D56	1.1	56V C.T. @ .02A	28V @ .04A
164E56	162E56	2.4	56V C.T. @ .045A	28V @ .09A
164F56	162F56	6.0	56V C.T. @ .11A	28V @ .22A
164G56	162G56	12.0	56V C.T. @ .22A	28V @ .44A
164H56	162H56	20.0	56V C.T. @ .35A	28V @ .7A
164J56	162J56	36.0	56V C.T. @ .65A	28V @ 1.3A
164D120	162D120	1.1	120V C.T. @ .01A	60V @ .02A
164E120	162E120	2.4	120V C.T. @ .02A	60V @ .04A
164F120	162F120	6.0	120V C.T. @ .05A	60V @ .1A
164G120	162G120	12.0	120V C.T. @ .1A	60V @ .2A
164H120	162H120	20.0	120V C.T. @ .16A	60V @ .32A
164J120	162J120	36.0	120V C.T. @ .3A	60V @ .6A

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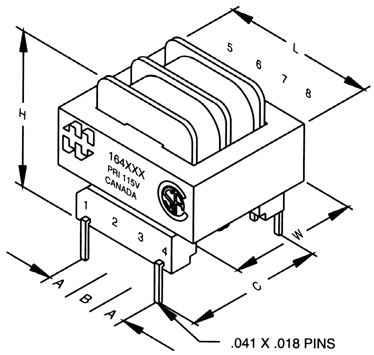
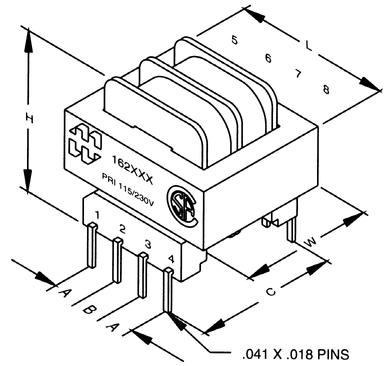
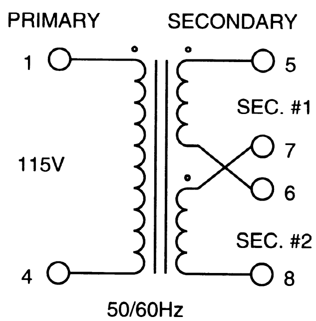
Single Primary - 164 Series



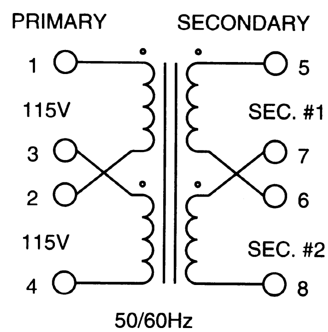
Dual Primary - 162 Series



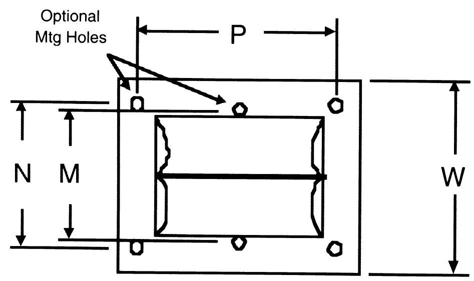
Single Primary - 164 Series Schematic



Dual Primary - 162 Series Schematic



164 & 162 Series - Common Mounting Hole Drawing
(6, 12, 20 & 36 VA units)



Top View

164 & 162 Series Common Dimension Table

(VA) Size	L	W	H	A	B	C	M	N	P	Mtg. Screw	lbs.
1.1	1 3/8	1 1/8	1 15/16	.25	.25	1.20	--	--	--	--	0.17
2.4	1 3/8	1 1/8	1 3/16	.25	.25	1.20	--	--	--	--	0.25
6	1 5/8	1 5/16	1 5/16	.25	.35	1.28	1 1/16	--	--	#4	0.44
12	1 7/8	1 9/16	1 1/2	.30	.40	1.41	1 1/4	--	--	#4	0.70
20	2 1/4	1 7/8	1 7/16	.30	.40	1.60	1 1/2	--	--	#4	0.80
36	2 5/8	2 3/16	1 9/16	.40	.40	1.85	--	1 3/4	2 3/16	#6	1.10

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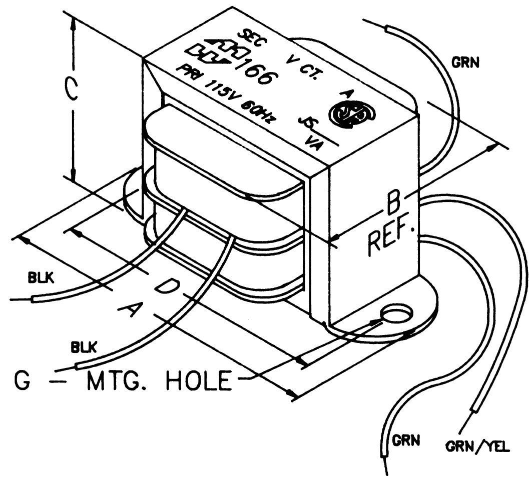
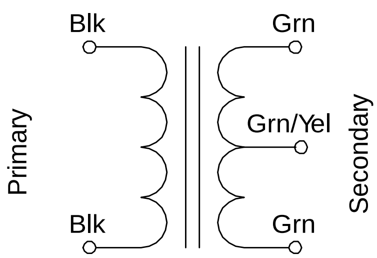
- Hi-Pot test of 2,000V RMS.
- UL listed (# E50394) & CSA certified (# LR3902).



Transformer Schematic



Dimension Table

Mtg. Style	Dimensions A	B	C	D	Mtg. Hole
C0H	1.35	0.69	0.69	1.06	.125
C1H	1.63	0.88	0.81	1.38	.125
C2H	2.06	1.25	1.19	1.75	.187
C3H	2.06	1.38	1.19	1.75	.187
C4H	2.38	1.38	1.38	2.00	.187
C5H	2.38	1.50	1.38	2.00	.187
C6H	2.81	1.50	1.69	2.38	.187
C7H	2.81	1.63	1.69	2.38	.187
C8H	3.25	1.63	2.00	2.81	.187
C9H	3.25	1.75	2.00	2.81	.187
C10H	3.25	2.00	2.00	2.81	.187
C11H	3.69	1.88	2.31	3.13	.187
C12H	3.69	2.00	2.31	3.13	.187
C13H	3.69	2.13	2.31	3.13	.187
C14H	4.03	2.25	2.63	3.56	.187
C15H	4.03	2.50	2.63	3.56	.187
C16H	4.50	2.50	2.88	4.00	.203

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Primary 115 VAC 60 Hz.

Cat. No.	Secondary (RMS)		Dim. Ref.
	VAC	Amps	
166F2	2.5ct	0.25	C2H
166G2	2.5ct	0.50	C2H
166J2	2.5ct	1.00	C3H
166K2	2.5ct	1.50	C4H
166L2	2.5ct	2.50	C6H
166M2	2.5ct	3.00	C6H
166Q2	2.5ct	6.00	C8H
166S2	2.5ct	10.00	C12H
166F5	5.0ct	0.25	C2H
166G5	5.0ct	0.50	C3H
166J5	5.0ct	1.00	C5H
166L5	5.0ct	2.00	C7H
166MS	5.0ct	3.00	C9H
166R5	5.0ct	8.00	C12H
166RS	5.0ct	8.00	C16H
166S5	5.0ct	10.00	C13H
166U5	5.0ct	15.00	C14H
166V5	5.0ct	20.00	C16H
166E6	6.3ct	0.15	C2H
166F6	6.3ct	0.30	C3H
166G6	6.3ct	0.60	C4H
166J6	6.3ct	1.00	C6H
166K6	6.3ct	1.20	C6H
166L6	6.3ct	2.00	C7H
166N6	6.3ct	4.00	C9H
166Q6	6.3ct	6.00	C12H
166S6	6.3ct	10.00	C14H
166G7	7.0ct	0.70	C5H
166U7	7.5ct	15.00	C16H
166G8	8.0ct	0.50	C4H
166J8	8.5ct	1.00	C6H
166L8	8.5ct	2.00	C8H
166M8	8.5ct	3.00	C9H
166N8	8.5ct	4.00	C10H
166G9	9.0ct	0.50	C4H
166F10	10.0ct	0.30	C3H
166G10	10.0ct	0.50	C5H
166J10	10.0ct	1.00	C7H
166L10	10.0ct	2.00	C9H
166M10	10.0ct	3.00	C10H
166N10	10.0ct	4.00	C12H
166P10	10.0ct	5.00	C13H
166R10	10.0ct	8.00	C15H
166S10	10.0ct	10.00	C16H
166P11	11.0ct	5.00	C13H
166S11	11.0ct	10.00	C16H
166C12	6.3/12.6ct	.1/.05	C2H
166E12	12.0ct	0.15	C3H
166K12	12.0ct	1.20	C8H
166F12	12.6ct	0.30	C4H
166G12	12.6ct	0.50	C6H
166J12	12.6ct	1.00	C7H
166L12	12.6ct	2.50	C10H
166N12	12.6ct	4.00	C13H
166Q12	12.6ct	6.00	C14H
166R12	12.6ct	8.00	C16H
166E14	14.0ct	0.15	C3H
166G14	14.0ct	0.50	C6H

Primary 115 VAC 60 Hz.

Cat. No.	Secondary (RMS)		Dim. Ref.
	VAC	Amps	
166J14	14.0ct	1.00	C7H
166L14	14.0ct	2.00	C10H
166Q14	14.0ct	6.00	C15H
166F16	16.0ct	0.25	C4H
166G16	16.0ct	0.50	C6H
166J16	16.0ct	1.00	C8H
166L16	16.0ct	2.20	C10H
166M16	16.0ct	3.00	C13H
166B18	9.0/18.0ct	.06/.03	C2H
166K18	18.0ct	1.50	C9H
166M18	18.0ct	3.00	C13H
166P18	18.0ct	5.00	C15H
166D20	20.0ct	0.1	C3H
166E20	20.0ct	0.15	C3H
166F20	20.0ct	0.30	C5H
166G20	20.0ct	0.50	C7H
166J20	20.0ct	1.00	C9H
166L20	20.0ct	2.00	C11H
166L22	22.0ct	2.00	C13H
166A24	12.6/25.2ct	.05/.025	C2H
166C24	24.0ct	.085	C3H
166L24	24.0ct	2.00	C13H
166N24	24.0ct	4.00	C16H
166D25	25.0ct	0.10	C3H
166E25	25.0ct	0.15	C4H
166F25	25.0ct	0.30	C6H
166G25	25.0ct	0.50	C7H
166J25	25.0ct	1.0	C9H
166K25	25.0ct	1.5	C11H
166L25	25.0ct	2.00	C13H
166M25	25.0ct	3.00	C14H
166F28	28.0ct	0.25	C6H
166G28	28.0ct	0.50	C7H
166J28	28.0ct	1.00	C10H
166L28	28.0ct	2.00	C13H
166E30	30.0ct	0.15	C4H
166F30	30.0ct	0.25	C6H
166G30	30.0ct	0.50	C8H
166J33	33.0ct	1.00	C10H
166K35	35.0ct	1.50	C13H
166E36	36.0ct	0.15	C5H
166F36	36.0ct	0.30	C7H
166G36	36.0ct	0.50	C8H
166J36	36.0ct	1.00	C11H
166L42	42.0ct	2.00	C15H
166E44	44.0ct	0.15	C6H
166F44	44.0ct	0.25	C7H
166G44	44.0ct	0.50	C9H
166J44	44.0ct	1.00	C12H
166C50	50.0ct	0.075	C4H
166F50	50.0ct	0.30	C8H
166G50	50.0ct	0.50	C9H
166J50	50.0ct	1.00	C13H
166L50	50.0ct	2.00	C16H
166G60	60.0ct	0.50	C10H
166G80	80.0ct	0.50	C11H
166G100	100.0ct	0.50	C13H
166F120	120.0ct	0.30	C11H

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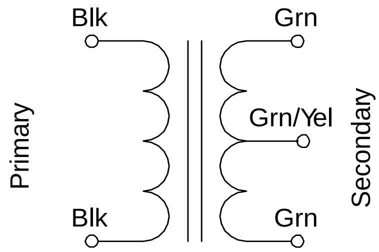
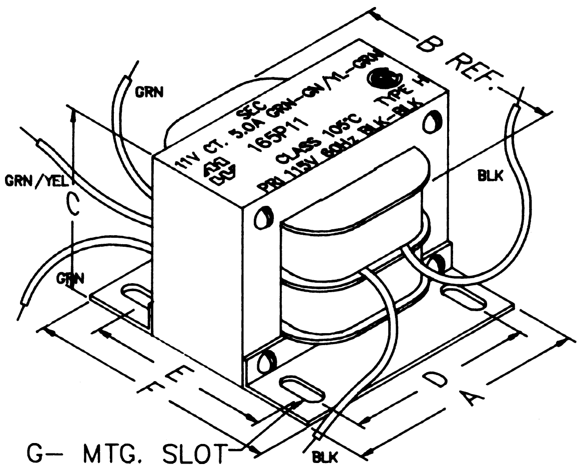
Transformer Schematic





HIGH CURRENT - OPEN FRAME FILAMENT & L.V. RECTIFIER USE TRANSFORMERS

- Primary 115 VAC, 60 Hz.
- All secondaries center tapped, VAC (RMS)
- Open style, 4 hole frame chassis mount.
- Minimum 6" long leads or copper tabs with holes.
- Dual bobbin design - no electrostatic shield required.
- Class B insulation (130 degrees, C).
- Hi-Pot test of 2,000V RMS.
- UL listed (# E50394)& CSA certified (# LR3902).

Dimension Table

Mtg. Style	Dimensions A	B	C	D	E	F	Mtg. Slot
H7	3.00	3.25	2.56	2.50	3.25	4.00	.22x.56
H9	3.75	2.63	3.13	3.13	2.50	3.25	.22x.56
H10	3.75	3.13	3.13	3.13	2.75	3.50	.22x.56
H12	3.75	3.63	3.13	3.13	3.25	4.00	.22x.56
H16	4.50	3.88	3.75	3.75	2.75	3.50	.28x.56
H18	4.50	4.38	3.75	3.75	3.25	4.00	.28x.56
H19	4.50	4.38	3.75	3.75	3.75	4.50	.28x.56

Selection Table

Primary 115 VAC 60 Hz.

Cat. No.	Secondary (RMS) VAC	Amps	Dim. Ref.
165Z3	3.0ct	50	H10
165X5	5.0ct	30	H9
165V7	7.5ct	21	H9
165V10	10.0ct	20	H10
165U11	11.0ct	15	H9
165S12	12.6ct	10	H7
165V12	12.6ct	20	H12
165S18	18.0ct	10	H10
165U18	18.0ct	15	H16
165V18	18.0ct	20	H18
165T22	22.0ct	12	H16
165V22	22.0ct	20	H19
165P25	25.0ct	5	H7
165S25	25.0ct	10	H12
165P30	30.0ct	5	H7
165S30	30.0ct	10	H16
165P60	60.0ct	5	H16
165N80	80.0ct	4	H18

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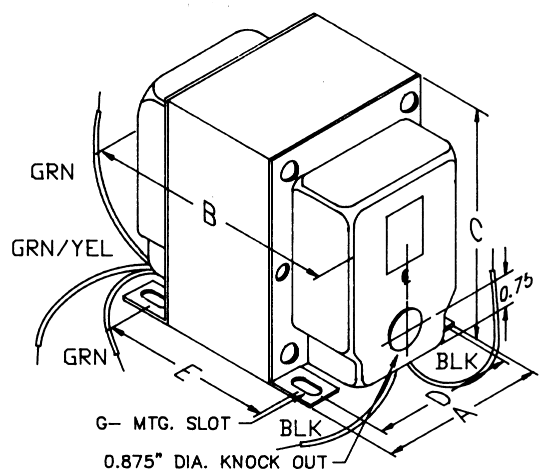
Power



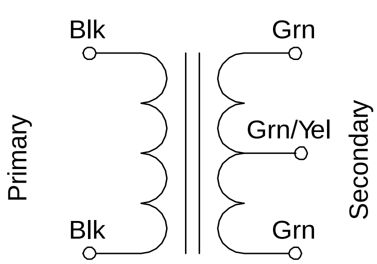
ENCLOSED FILAMENT & L.V. RECTIFIER USE TRANSFORMERS

- Primary 115 VAC, 60 Hz.
- All secondaries center tapped, VAC (RMS)
- Enclosed, 4 hole chassis mount.
- Minimum 6" long leads.
- Dual bobbin design - no electrostatic shield required.
- Class B insulation (130 degrees C).
- Hi-Pot test of 2,000V RMS.
- UL listed (# E50394) & CSA certified (# LR3902).

Dimension Table

Mtg. Style	Dimensions A	B	C	D	E	G-Mtg. Slot
X1	1.88	2.19	2.50	1.50	1.31	.19 X .31
X2	1.88	2.44	2.50	1.50	1.56	.19 X .31
X3	2.19	2.38	2.63	1.75	1.31	.19 X .25
X4	2.19	2.50	2.63	1.75	1.44	.19 X .25
X5	2.19	2.63	2.63	1.75	1.56	.19 X .25
X6	2.50	2.75	3.06	2.00	1.69	.203 X .38
X7	2.50	3.00	3.06	2.00	1.94	.203 X .38
X8	2.50	3.25	3.06	2.00	2.19	.203 X .38
X9	2.50	3.75	3.06	2.00	2.69	.203 X .38
X10	3.13	3.50	3.81	2.50	2.19	.203 X .38
X11	3.13	3.75	3.81	2.50	2.44	.203 X .38
X13	3.75	4.00	4.56	3.00	2.81	.203 X .38
X14	3.75	4.50	4.56	3.00	3.31	.203 X .38
X15	3.75	5.00	4.56	3.00	3.81	.203 X .38
X16	3.75	5.50	4.56	3.00	4.31	.203 X .38

Transformer Schematic



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Selection Tables

Primary 115 VAC 60 Hz.

Cat. No.	Secondary (RMS)		Dim. Ref.
	VAC	Amps	
167M5	5.0ct	3	X1
167Q5	5.0ct	6	X2
167R5	5.0ct	8	X4
167S5	5.0ct	10	X5
167U5	5.0ct	15	X6
167V5	5.0ct	20	X8
167X5	5.0ct	30	X10
167N6	6.3ct	4	X2
167Q6	6.3ct	6	X3
167R6	6.3ct	8	X5
167S6	6.3ct	10	X6
167T6	6.3ct	12	X6
167U6	6.3ct	16	X8
167U7	7.5ct	15	X8
167V7	7.5ct	21	X10
167N10	10.0ct	4	X4
167P10	10.0ct	5	X5
167R10	10.0ct	8	X7
167S10	10.0ct	10	X8
167P11	11.0ct	5	X6
167S11	11.0ct	10	X8
167U11	11.0ct	15	X10
167L12	12.6ct	2.5	X2
167N12	12.6ct	4	X5
167Q12	12.6ct	6	X6
167R12	12.6ct	8	X8
167S12	12.6ct	10	X9
167V12	12.6ct	20	X13
167N14	14.0ct	4	X6
167Q14	14.0ct	6	X7
167M16	16.0ct	3	X5
167P16	16.0ct	5	X7
167M18	18.0ct	3	X6
167P18	18.0ct	5	X7
167S18	18.0ct	10	X11
167U18	18.0ct	15	X13
167V18	18.0ct	20	X14
167M20	20.0ct	3	X6
167P20	20.0ct	5	X8
167U20	20.0ct	16	X14
167T22	22.0ct	12	X13
167V22	22.0ct	20	X15
167L24	24.0ct	2	X5

Primary 115 VAC 60 Hz.

Cat. No.	Secondary (RMS)		Dim. Ref.
	VAC	Amps	
167J25	25.0ct	1	X2
167K25	25.0ct	1.5	X3
167M25	25.0ct	3	X6
167N25	25.0ct	4	X8
167P25	25.0ct	5	X9
167S25	25.0ct	10	X13
167J28	28.0ct	1	X2
167L28	28.0ct	2	X6
167M28	28.0ct	3	X7
167K30	30.0ct	1.5	X4
167M30	30.0ct	3	X7
167P30	30.0ct	5	X10
167S30	30.0ct	10	X13
167J33	33.0ct	1	X2
167J36	36.0ct	1	X3
167L36	36.0ct	2	X6
167M36	36.0ct	3	X8
167P36	36.0ct	5	X11
167R36	36.0ct	8	X13
167T36	36.0ct	12	X15
167L44	44.0ct	2	X7
167J50	50.0ct	1	X5
167L50	50.0ct	2	X8
167P50	50.0ct	5	X13
167G55	55.0ct	0.5	X2
167J55	55.0ct	1	X6
167L55	55.0ct	2	X8
167G60	60.0ct	0.5	X2
167J60	60.0ct	1	X6
167L60	60.0ct	2	X9
167M60	60.0ct	3	X11
167P60	60.0ct	5	X13
167S64	64.0ct	10	X16
167L70	70.0ct	2	X9
167N70	70.0ct	4	X13
167G80	80.0ct	0.5	X4
167J80	80.0ct	1	X7
167L80	80.0ct	2	X10
167N80	80.0ct	4	X14
167G100	100.0ct	0.5	X5
167J100	100.0ct	1	X8
167P100	100.0ct	5	X16
167G120	120.0ct	0.5	X6
167H200	200.0ct	0.87	X11

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The application guidelines and product data in this guide are intended to provide technical information that will help with application design. Since these are only a few of the contributing parameters, application testing is strongly recommended and should be used to verify performance in the circuit/application. In the absence of special requirements, Littelfuse reserves the right to make appropriate changes in design, process, and manufacturing location without notice.

The purpose of the Fuseology Section is to promote a better understanding of both fuses and common application details. The fuses to be considered are current sensitive devices which are designed as the intentional weak link in the electrical circuit. The function of the fuse is to provide protection of discrete components, or of complete circuits, by reliably melting under current overload conditions. This fuseology section will cover some important facts about fuses, selection considerations, and standards.

FUSE FACTS

The following fuse parameters or application concepts should be well understood in order to properly select a fuse for a given application.

AMBIENT TEMPERATURE: Refers to the temperature of the air immediately surrounding the fuse and is not to be confused with "room temperature." The fuse ambient temperature is appreciably higher in many cases, because it is enclosed (as in a panel mount fuseholder) or mounted near other heat producing components, such as resistors, transformers, etc.

BREAKING CAPACITY: See Interrupting Rating.

CURRENT RATING: The nominal amperage value marked on the fuse. It is established by the manufacturer as a value of current which the fuse can be loaded to, based on a controlled set of test conditions (See RERATING).

Catalog Fuse part numbers include series identification and amperage ratings. Refer to the FUSE SELECTION GUIDE section for guidance on making the proper choice.

RERATING: For 25°C ambient temperatures, it is recommended that fuses be operated at no more than 75% of the nominal current rating established using the controlled test conditions. These test conditions are part of UL/CSA/ANCE (Mexico) 248-14 "Fuses for Supplementary Overcurrent Protection," whose primary objective is to specify common test standards necessary for the continued control of manufactured items intended for protection against fire, etc. Some common variations of these standards include: fully enclosed fuseholders, high contact resistances, air movement, transient spikes, and changes in connecting cable size (diameter and length). Fuses are essentially temperature-sensitive devices. Even small variations from the controlled test conditions can greatly affect the predicted life of a fuse when it is loaded to its nominal value, usually expressed as 100% of rating.

The circuit design engineer should clearly understand that the purpose of these controlled test conditions is to enable fuse manufacturers to maintain unified performance standards for their products, and he must account for the variable conditions of his application. To compensate for these variables, the circuit design engineer who is designing for trouble-free, long-life fuse protection in his equipment generally loads his fuse not more than 75% of the nominal rating listed by the manufacturer, keeping in mind that overload and short circuit protection must be adequately provided for.

The fuses under discussion are temperature-sensitive devices whose ratings have been established in a 25°C ambient. The fuse temperature generated by the current passing through the fuse increases or decreases with ambient temperature change.

The ambient temperature chart in the FUSE SELECTION GUIDE section illustrates the effect that ambient temperature has on the nominal current rating of a fuse. Most traditional Slo-Blo® Fuse designs use lower melting temperature materials and are, therefore, more sensitive to ambient temperature changes.

DIMENSIONS: Unless otherwise specified, dimensions are in inches. The fuses in this catalog range in size from the approx. 0603 chip size (.063"L x .031"W x .018"H) up to the 5 AG, also commonly known as a "MIDGET" fuse (13/32" dia. x 1½" length). As new products were developed throughout the years, fuse sizes evolved to fill the various electrical circuit protection needs. The first fuses were simple, open-wire devices, followed in the 1890's by Edison's enclosure of thin wire in a lamp base to make the first plug fuse. By 1904, Underwriters Laboratories had established size and rating specifications to meet safety standards. The renewable type fuses and automotive fuses appeared in 1914, and in 1927 Littelfuse started making very low amperage fuses for the budding electronics industry.

The fuse sizes in the chart below began with the early "Automobile Glass" fuses, thus the term "AG". The numbers were applied chronologically as different manufacturers started making a new size: "3AG," for example, was the third size placed on the market. Other non-glass fuse sizes and constructions were determined by functional requirements, but they still retained the length or diameter dimensions of the glass fuses. Their designation was modified to AB in place of AG, indicating that the outer tube was constructed from Bakelite, fibre, ceramic, or a similar material other than glass. The largest size fuse shown in the chart is the 5AG, or "MIDGET," a name adopted from its use by the electrical industry and the National Electrical Code range which normally recognizes fuses of 9/16" x 2" as the smallest standard fuse in use.

FUSE SIZES

SIZE	DIAMETER (Inches)		LENGTH (Inches)	
1AG	1/4	.250	5/8	.625
2AG	—	.177	—	.588
3AG	1/4	.250	1¼	1.25
4AG	9/32	.281	1¼	1.25
5AG	13/32	.406	1½	1.50
7AG	1/4	.250	7/8	.875
8AG	1/4	.250	1	1

TOLERANCES: The dimensions shown in this catalog are nominal. Unless otherwise specified, tolerances are applied as follows:

± .010" for dimensions to 2 decimal places.
± .005" for dimensions to 3 decimal places.

The factory should be contacted concerning metric system and fractional tolerances. Tolerances do not apply to lead lengths.

FUSE CHARACTERISTICS: The characteristic of a fuse design refers to how rapidly the fuse responds to various current overloads. Fuse characteristics can be classified into three general categories: very fast-acting, fast-acting, or Slo-Blo® Fuse. The distinguishing feature of Slo-Blo® fuses is that these fuses have additional thermal inertia designed to tolerate normal initial or start-up overload pulses.

FUSE CONSTRUCTION: Internal construction may vary depending on ampere rating. Fuse photos in this catalog

FUSE FACTS

show typical construction of a particular ampere rating within the fuse series.

FUSEHOLDERS: In many applications, fuses are installed in fuseholders. These fuses and their associated fuseholders are not intended for operation as a "switch" for turning power "on" and "off".

INTERRUPTING RATING: Also known as breaking capacity or short circuit rating, the interrupting rating is the maximum approved current which the fuse can safely interrupt at rated voltage. During a fault or short circuit condition, a fuse may receive an instantaneous overload current many times greater than its normal operating current. Safe operation requires that the fuse remain intact (no explosion or body rupture) and clear the circuit.

Interrupting ratings may vary with fuse design and range from 35 amperes AC for some 250V metric size (5 x 20mm) fuses up to 200,000 amperes AC for the 600V KLK series. Information on other fuse series can be obtained from the factory.

Fuses listed in accordance with UL/CSA/ANCE 248 are required to have an interrupting rating of 10,000 amperes, with some exceptions (See STANDARDS section) which, in many applications, provides a safety factor far in excess of the short circuit currents available.

NUISANCE OPENING: Nuisance opening is most often caused by an incomplete analysis of the circuit under consideration. Of all the "Selection Factors" listed in the FUSE SELECTION GUIDE, special attention must be given to items 1, 3, and 6, namely, normal operating current, ambient temperature, and pulses. For example, one prevalent cause of nuisance opening in conventional power supplies is the failure to adequately consider the fuse's nominal melting I^2t rating. The fuse cannot be selected solely on the basis of normal operating current and ambient temperature. In this application, the fuse's nominal melting I^2t rating must also meet the inrush current requirements created by the input capacitor of the power supply's smoothing filter. The procedure for converting various waveforms into I^2t circuit demand is given in the FUSE SELECTION GUIDE. For trouble-free, long-life fuse protection, it is good design practice to select a fuse such that the I^2t of the waveform is no more than 20% of the nominal melting I^2t rating of the fuse. Refer to the section on PULSES in the FUSE SELECTION GUIDE.

RESISTANCE: The resistance of a fuse is usually an insignificant part of the total circuit resistance. Since the resistance of fractional amperage fuses can be several ohms, this fact should be considered when using them in low-voltage circuits. Actual values can be obtained from the factory. Most fuses are manufactured from materials which have positive temperature coefficients, and, therefore, it is common to refer to cold resistance and hot resistance (voltage drop at rated current), with actual operation being somewhere in between. Cold resistance is the resistance obtained using a measuring current of no more than 10% of the fuse's nominal rated current. Values shown in this publication for cold resistance are nominal and representative. The factory should be consulted if this parameter is critical to the design analysis. Hot resistance is the resistance calculated from the stabilized voltage drop across the fuse, with current equal to the nominal rated current flowing through it.

Resistance data on all of our fuses is available on request. Fuses can be supplied to specified controlled resistance tolerances at additional cost.

SOLDERING RECOMMENDATIONS: Since most fuse constructions incorporate soldered connections, caution should be used when installing those fuses intended to be soldered in place. The application of excessive heat can reflow the solder within the fuse and change its rating. Fuses are heat-sensitive components similar to semi-conductors, and the use of heat sinks during soldering is often recommended.

TEST SAMPLING PLAN: Because compliance with certain specifications requires destructive testing, these tests are selected on a statistical basis for each lot manufactured.

TIME-CURRENT CURVE: The graphical presentation of the fusing characteristic, time-current curves are generally average curves which are presented as a design aid but are not generally considered part of the fuse specification. Time-current curves are extremely useful in defining a fuse, since fuses with the same current rating can be represented by considerably different time-current curves. The fuse specification typically will include a life requirement at 100% of rating and maximum opening times at overload points (usually 135% and 200% of rating). A time-current curve represents average data for the design; however, there may be some differences in the values for any one given production lot. Samples should be tested to verify performance, once the fuse has been selected.

UNDERWRITERS LABORATORIES: Reference to "Listed by Underwriters Laboratories" signifies that the fuses meet the requirements of UL/CSA/ANCE 248 "Fuses for Supplementary Overcurrent Protection". Some 32 volt fuses (automotive) in this catalog are listed under UL Standard 275. Reference to "Recognized under the Component Program of Underwriters Laboratories" signifies that the item is recognized under the component program of Underwriters Laboratories and application approval is required.

VOLTAGE RATING: The voltage rating, as marked on a fuse, indicates that the fuse can be relied upon to safely interrupt its rated short circuit current in a circuit where the voltage is equal to, or less than, its rated voltage. This system of voltage rating is covered by N.E.C. regulations and is a requirement of Underwriters Laboratories as a protection against fire risk. The standard voltage ratings used by fuse manufacturers for most small-dimension and midget fuses are 32, 63, 125, 250 and 600.

In electronic equipment with relatively low output power supplies, with circuit impedance limiting short circuit currents to values of less than ten times the current rating of the fuse, it is common practice to specify fuses with 125 or 250 volt ratings for secondary circuit protection of 500 volts or higher.

As mentioned previously (See RERATING), fuses are sensitive to changes in current, not voltage, maintaining their "status quo" at any voltage from zero to the maximum rating of the fuse. It is not until the fuse element melts and arcing occurs that the circuit voltage and available power become an issue. The safe interruption of the circuit, as it relates to circuit voltage and available power, is discussed in the section on INTERRUPTING RATING.

FUSE FACTS

To summarize, a fuse may be used at any voltage that is less than its voltage rating without detriment to its fusing characteristics. Please contact the factory for applications at voltages greater than the voltage rating.

DERIVATION OF NOMINAL MELTING I^2t: Laboratory tests are conducted on each fuse design to determine the amount of energy required to melt the fusing element. This energy is described as nominal melting I^2t and is expressed as "Ampere Squared Seconds" (A^2 Sec.). A pulse of current is applied to the fuse, and a time measurement is taken for melting to occur. If melting does not occur within a short duration of about 8 milliseconds (0.008 seconds) or less, the level of pulse current is increased. This test procedure is repeated until melting of the fuse element is confined to within about 8 milliseconds. The purpose of this procedure is to assure that the heat created has insufficient time to thermally conduct away from the fuse element. That is, all of the heat energy (I^2t) is used, to cause melting. Once the measurements of current (I) and time (t) are determined, it is a simple matter to calculate melting I^2t. When the melting phase reaches completion, an electrical arc occurs immediately prior to the "opening" of the fuse element. Clearing I^2t = Melting I^2t + arcing I^2t. The nominal I^2t values given in this publication pertain to the melting phase portion of the "clearing" or "opening".

FUSE SELECTION GUIDE

The application guidelines and product data in this guide are intended to provide technical information that will help with application design. Since these are only a few of the contributing parameters, application testing is strongly recommended and should be used to verify performance in the circuit/application.

Many of the factors involved with fuse selection are listed below:

Selection Factors

1. Normal operating current
2. Application voltage (AC or DC)
3. Ambient temperature
4. Overload current and length of time in which the fuse must open.
5. Maximum available fault current
6. Pulses, Surge Currents, Inrush Currents, Start-up Currents, and Circuit Transients
7. Physical size limitations, such as length, diameter, or height
8. Agency Approvals required, such as UL, CSA, VDE, or Military
9. Considerations: mounting type/form factor, ease of removal, axial leads, visual indication, etc.
10. Fuseholder features: clips, mounting block, panel mount, p.c. board mount, R.F.I. shielded, etc.

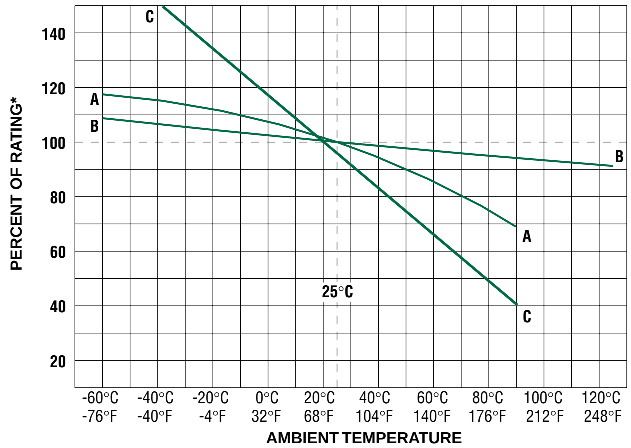
NORMAL OPERATING CURRENT: The current rating of a fuse is typically derated 25% for operation at 25°C to avoid nuisance blowing. For example, a fuse with a current rating of 10A is not usually recommended for operation at more than 7.5A in a 25°C ambient. For additional details, see RERATING in the previous section and AMBIENT TEMPERATURE below.

VOLTAGE: The voltage rating of the fuse must be equal to, or greater than, the available circuit voltage. For exceptions, see VOLTAGE RATING.

AMBIENT TEMPERATURE: The current carrying capacity tests of fuses are performed at 25°C and will be affected by changes in ambient temperature. The higher the ambient temperature, the hotter the fuse will operate, and the shorter its life will be. Conversely, operating at a lower temperature will prolong fuse life. A fuse also runs hotter as the normal operating current approaches or exceeds the rating of the selected fuse. Practical experience indicates fuses at **room temperature** should last indefinitely, if operated at no more than 75% of catalog fuse rating.

CHART SHOWING EFFECT OF AMBIENT TEMPERATURE ON CURRENT-CARRYING CAPACITY (TYPICAL)

KEY TO CHART:
Curve A: Thin-Film Fuses and 313 Series (.010 to .150A)
Curve B: Very Fast-Acting, Fast-Acting, and Spiral Wound Slo-Blo® Fuses
Curve C: Resettable PTC's



*Ambient temperature effects are in addition to the normal derating, see example.

Example: Given a normal operating current of 1.5 amperes in an application using a traditional Slo-Blo® fuse at room temperature, then:

$$\text{Catalog Fuse Rating} = \frac{\text{Normal Operating Current}}{0.75}$$

or

$$\frac{1.5 \text{ Amperes}}{0.75} = 2.0 \text{ Amp Fuse (at 25°C)}$$

FUSE SELECTION GUIDE

Similarly, if that same fuse were operated at a very high ambient temperature of 70°C, additional derating would be necessary. Curve "A" (Traditional Slo-Blo® Fuse) of the ambient temperature chart shows the maximum operating "Percent of Rating" at 70°C to be 80%, in which case;

$$\text{Catalog Fuse Rating} = \frac{\text{Nominal Operating Current}}{0.75 \times \text{Percent of Rating}}$$

or

$$\frac{1.5 \text{ Amperes}}{0.75 \times 0.80} = 2.5 \text{ Amp Fuse (at 70°C)}$$

OVERLOAD CURRENT CONDITION: The current level for which protection is required. Fault conditions may be specified, either in terms of current or, in terms of both current and maximum time the fault can be tolerated before damage occurs. Time-current curves should be consulted to try to match the fuse characteristic to the circuit needs, while keeping in mind that the curves are based on average data.

MAXIMUM FAULT CURRENT: The Interrupting Rating of a fuse must meet or exceed the Maximum Fault Current of the circuit.

PULSES: The general term "pulses" is used in this context to describe the broad category of wave shapes referred to as "surge currents", "start-up currents", "inrush currents", and "transients". Electrical pulse conditions can vary considerably from one application to another. Different fuse constructions may not all react the same to a given pulse condition. Electrical pulses produce thermal cycling and possible mechanical fatigue that could affect the life of the fuse. Initial or start-up pulses are normal for some applications and require the characteristic of a Slo-Blo® fuse. Slo-Blo® fuses incorporate a thermal delay design to enable them to survive normal start-up pulses and still provide protection against prolonged overloads. The start-up pulse should be defined and then compared to the time-current curve and I^2t rating for the fuse. Application testing is recommended to establish the ability of the fuse design to withstand the pulse conditions.

Nominal melting I^2t is a measure of the energy required to melt the fusing element and is expressed as "Ampere Squared Seconds" (A^2 Sec.). This nominal melting I^2t, and the energy it represents (within a time duration of 8 milliseconds [0.008 second] or less and 1 millisecond [0.001 second] or less for thin film fuses), is a value that is constant for each different fusing element. Because every fuse type and rating, as well as its corresponding part number, has a different fusing element, it is necessary to determine the I^2t for each. This I^2t value is a parameter of the fuse itself and is controlled by the element material and the configuration of the fuse element. In addition to selecting fuses on the basis of "Normal Operating Currents", "Derating", and "Ambient Temperature" as discussed earlier, it is also necessary to apply the I^2t design approach. This nominal melting I^2t is not only a constant value for each fuse element design, but it is also independent of temperature and voltage. Most often, the nominal melting I^2t method of fuse selection is applied to those applications in which the fuse must sustain large current pulses of a short duration. These high-energy currents are common in many applications and are described by a variety of terms, such as "surge current", "start-up current", "inrush current", and other similar circuit "transients" that can be classified in the general category of "pulses." Laboratory tests are conducted on each fuse design to determine its nominal melting I^2t rating. The values for I^2t given in this publication are nominal and representative. The factory should be consulted if this parameter is critical to the design analysis. The following example should assist in providing a better understanding of the application of I^2t.

EXAMPLE: Select a 125V, very fast-acting PICO® fuse that is capable of withstanding 100,000 pulses of current (I) of the pulse waveform shown in Figure 1. The normal operating current is 0.75 ampere at an ambient temperature of 25°C.

Step 1 — Refer to Chart I (page #6) and select the appropriate pulse waveform, which is waveform (E) in this example. Place the applicable value for peak pulse current (i_p) and time (t) into the corresponding formula for waveshape (E), and calculate the result, as shown:

$$I^2t = \frac{1}{5}(i_p)^2t$$

$$= \frac{1}{5} \times 8^2 \times .004 = 0.0512 \ A^2 \text{ Sec.}$$

This value is referred to as the "Pulse I^2t".

Step 2 — Determine the required value of Nominal Melting I^2t by referring to Chart II (page 6). A figure of 22% is shown in Chart II for 100,000 occurrences of the Pulse I^2t calculated in Step 1. This Pulse I^2t is converted to its required value of Nominal Melting I^2t as follows:

Nom. Melt I^2t = Pulse $I^2t/.22$
= $0.0512/.22 = 0.2327 \ A^2$ Sec.

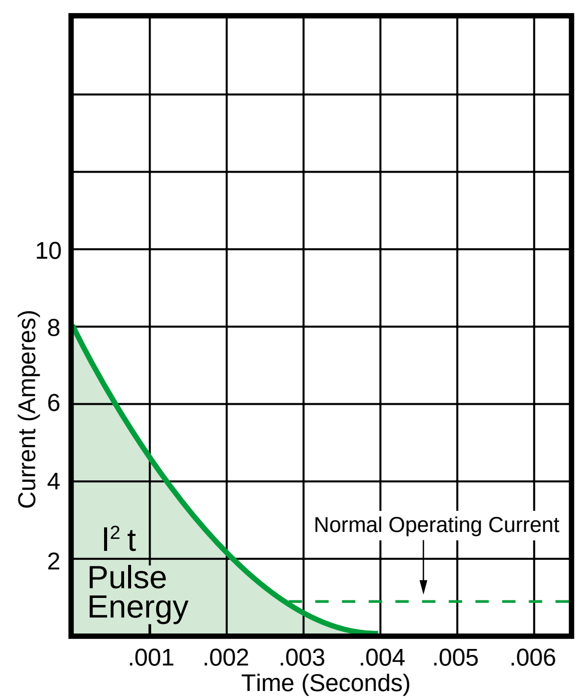
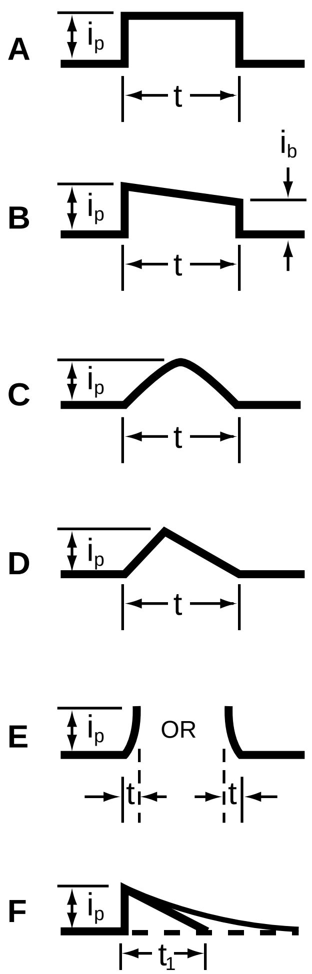


Figure 1

FUSE SELECTION GUIDE

CHART I

WAVESHAPES	FORMULAS
A	$i = k$ $I^2t = i_p^2\,t$
B	$i = i_p - kt$ $I^2t = (1/3)(i_p^2 + i_p i_b + i_b^2)\,t$
C	$i = i_p \sin t$ $I^2t = (1/2)\,i_p^2\,t$
D	$I^2t = (1/3)\,i_p^2\,t$
E	$i = kt^2$ OR $i = i_p(1-kt)^2$ $I^2t = (1/5)\,i_p^2\,t$
F	$i = i_p e^{-kt}$) $I^2t \cong (1/2)\,i_p^2\,t_1$



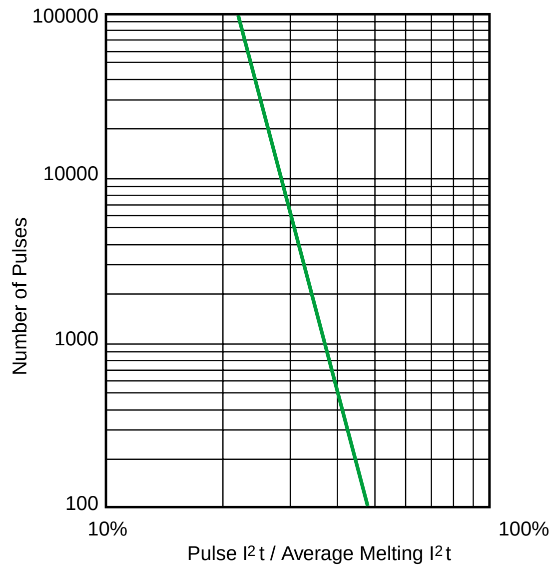
Step 3 — Examine the I^2t rating data for the PICO® II, 125V, very fast-acting fuse. The part number 251001, 1 ampere design is rated at 0.256 A^2 Sec., which is the minimum fuse rating that will accommodate the 0.2327 A^2 Sec. value calculated in Step 2. This 1 ampere fuse will also accommodate the specified 0.75 ampere normal operating current, when a 25% derating factor is applied to the 1 ampere rating, as previously described.

TESTING: The above factors should be considered in selecting a fuse for a given application. The next step is to verify the selection by requesting samples for testing in the actual circuit. Before evaluating the samples, make sure the fuse is properly mounted with good electrical connections, using adequately sized wires or traces. The testing should include life tests under normal conditions and overload tests under fault conditions, to ensure that the fuse will operate properly in the circuit.

CHART II

PULSE CYCLE WITHSTAND CAPABILITY

100,000 Pulses	Pulse I^2t = 22% of Nominal Melting I^2t
10,000 Pulses	Pulse I^2t = 29% of Nominal Melting I^2t
1,000 Pulses	Pulse I^2t = 38% of Nominal Melting I^2t
100 Pulses	Pulse I^2t = 48% of Nominal Melting I^2t



Note: Adequate time (10 seconds) must exist between pulse events to allow heat from the previous event to dissipate.

FUSEHOLDER SELECTION GUIDE

RERATING: For 25°C ambient temperatures, it is recommended that fuseholders be operated at no more than 60% of the nominal current rating established using the controlled test conditions specified by Underwriters Laboratories. The primary objective of these UL test conditions is to specify common test standards necessary for the continued control of manufactured items intended for protection against fire, etc. A copper dummy fuse is inserted in the fuseholder by Underwriters Laboratories, and then the current is increased until a certain temperature rise occurs. The majority of the heat is produced by the contact resistance of the fuseholder clips. This value of current is considered to be the rated current of the fuseholder, expressed as 100% of rating. Some of the more common, everyday applications may differ from these UL test conditions as follows: fully enclosed fuseholders, high contact resistance, air movement, transient spikes, and changes in connecting cable size (diameter and length). Even small variations from the controlled test conditions can greatly affect the ratings of the fuseholder. For this reason, it is recommended that fuseholders be derated by 40% (operated at no more than 60% of the nominal current rating established using the Underwriter Laboratories test conditions, as stated above).

Littelfuse is at your service to help solve your electrical protection problems. When contacting Littelfuse sales engineers, please have all the requirements of your applications available. Requests for quotes or assistance in designing or selecting special types of circuit protection components for your particular applications are also welcome.

In the absence of special requirements, Littelfuse reserves the right to make appropriate changes in design, process, and manufacturing location without prior notice.

STANDARDS

Fuse ratings and other performance criteria are evaluated under laboratory conditions **and acceptance criteria**, as defined in one or more of the various fuse standards. It is important to understand these standards so that the fuse can be properly applied to circuit protection applications.

UL/CSA/ANCE (Mexico) 248-14 FUSES FOR SUPPLEMENTARY OVERCURRENT PROTECTION (600 Volts, Maximum) (Previously UL 198G and CSA C22.2, No. 59)

UL LISTED

A UL Listed fuse meets all the requirements of the UL/CSA 248-14 Standard. Following are some of the requirements.

UL ampere rating tests are conducted at 100%, 135%, and 200% of rated current. The fuse must carry 110% of its ampere rating and must stabilize at a temperature that does not exceed a 75°C rise at 100%.

The fuse must open at 135% of rated current within one hour. It also must open at 200% of rated current within 2 minutes for 0-30 ampere ratings and 4 minutes for 35-60 ampere ratings.

The interrupting rating of a UL Listed fuse is 10,000 amperes AC minimum at 125 volts. Fuses rated at 250 volts may be listed as interrupting 10,000 amperes at 125 volts and, at least, the minimum values shown below at 250 volts.

Ampere Rating of Fuse	Interrupting Rating In Amperes	Voltage Rating
0 to 1	35	250 VAC
1.1 to 3.5	100	250 VAC
3.6 to 10	200	250 VAC
10.1 to 15	750	250 VAC
15.1 to 30	1500	250 VAC

Recognized Under the Component Program of Underwriters Laboratories

The Recognized Components Program of UL is different from UL Listing. UL will test a fuse to a specification requested by the manufacturer. The test points can be different from the UL Listed requirements if the fuse has been designed for a specific application. Application approval is required by UL for fuses recognized under the Component Program.

UL 275 AUTOMOTIVE GLASS TUBE FUSES (32 Volts)

UL Listed

UL ampere ratings tests are conducted at 110%, 135%, and 200%. Interrupting rating tests are not required.

CSA Certification

CSA Certification in Canada is equivalent to UL Listing in the United States.

The Component Acceptance Program of CSA is equivalent to the Recognition Program at UL. This CSA Program allows the manufacturer to declare a specification. CSA then verifies the test results.

MITI APPROVAL

MITI® approval in Japan is similar to UL Recognition in the United States.
MITI® has its own design standard and characteristics.

INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC)

Publication 60127, Sheet 1, 2, 3, 5, 6 (250 Volts)

The IEC organization is different from UL and CSA, since IEC only writes specifications and does not certify. UL and CSA write the specifications, are responsible for testing, and give certification.

Certification to IEC specifications are given by such organizations as SEMKO (Swedish Institute of Testing and Approvals of Electrical Equipment) Ⓢ and BSI (British Standards Institute ▽, as well as UL and CSA.

IEC Publication 60127 defines three breaking capacity levels (interrupting rating). Low breaking capacity fuses must pass a test of 35 amperes or ten times rated current, whichever is greater, while enhanced breaking capacity fuses must pass a test of 150 amperes and finally high breaking capacity fuses must pass a test of 1500 amperes.

Sheet 1 – Type F Quick Acting, High Breaking Capacity
Sheet 2 – Type F Quick Acting, Low Breaking Capacity
Sheet 3 – Type T Time Lag, Low Breaking Capacity
Sheet 5 – Type T Time Lag, High Breaking Capacity
Sheet 6 – Type T Time Lag, Enhanced Breaking Capacity

The letters ‘F’ and ‘T’ represent the time-current characteristic of the fast-acting and time delay fuses. One of these letters will be marked on the end cap of the fuse.

UL/CSA/ANCE (Mexico) 248-14 vs. IEC 60127 FUSE OPENING TIMES (UL/CSA/ANCE (Mexico) 248-14 Was Previously UL 198G and CSA 22.2, No. 59) vs. MITI®

Percent of Rating	UL & CSA STD 248-14	IEC TYPE F Sheet 1 (*)	IEC Type F Sheet 2 (*)	IEC Type T Sheet 3 & 4 (*)	IEC Type T Sheet 5 (*)	MITI ®
110	4 Hr. Min.	—	—	—	—	
130	—	—	—	—	—	1Hr. Min.
135	60 Minutes Max.	—	—	—	—	
150	—	60 Minutes Min.	60 Minutes Min.	60 Minutes Min.	60 Minutes Min.	
160	—	—	—	—	—	1 Hr. Max.
200	2 Minutes Max.	—	—	—	—	2 Minutes Max.
210	—	30 Minutes Max.	30 Minutes Max.	2 Minutes Max.	30 Minutes Max.	

(*) Note: The IEC Specification is only written up to 6.3A, any components above these ratings are not recognized by the IEC (although the fuses may have those opening characteristics).

IEC also has requirements at 275%, 400% and 1000%; however, the chart is used to show that fuses with the same ampere rating made to different specifications are not interchangeable. According to the IEC 60127 Standard, a one ampere-rated fuse can be operated at one ampere. A one ampere-rated fuse made to UL/CSA/ANCE 248-14 should not be operated at more than .75 ampere (25% derated — See RERATING section of FUSEOLOGY).

MITI® covers only one characteristic i.e. there are no ‘delay’ definitions on other performance variants.

STANDARDS AND PACKAGING INFORMATION

Publication IEC 60127-4
(Universal Modular Fuse-Links [UMF])

This part of IEC 60127 covers both PCB through-hole and surface mount fuses. This standard covers fuses rated 32, 63, 125, and 250 volts. This standard will be accepted by UL/CSA making it the first global fuse standard. This specification uses different fusing gates than IEC 60127-2; the gates used here are 125%, 200%, and 1000%.

The fuses must not open in less than one hour at 125% of rated current and open within two minutes at 200% of rated current. The 1000% overload is used to determine the fuse characteristic. The time for each rating is listed below.

Type FF: Less than 0.001 sec.
Type F: From 0.001 - 0.01 sec.
Type T: From 0.01 - 0.1 sec.
Type TT: From 0.1 - 1.00 sec.

These characteristics correlate to the terminology used in IEC 60127-1.

Breaking capacity (interrupting rating) varies based on volt age rating. Parts rated at 32 & 63 volts must pass a test of 35 amperes or ten times rated current, whichever is greater.Parts rated at 125 volts must pass a test of 50 amperes or ten times rated current, whichever is greater. Parts rated at 250 volts are further defined as either low, intermediate or high breaking. The low breaking capacity fuses must pass a test of 100 amperes or ten times rated current, while intermediate breaking capacity fuses must pass a test of 500 amperes and, finally, high breaking capacity fuses must pass a test of 1500 amperes.

Packaging Suffixes

A/X = 1 unit per bag
V = 5 units per box
T = 10 units per box
H = 100 units per box
U = 500 units per box
M = 1000 units per box
P = 2000 units per box
W = 3000 units per box
N = 5000 units per box
R = Taped & reeled fuses
M1 = Taped & reeled. Spacing = 4 mm. 1000 pieces per reel
MT1 = Taped & reeled. Spacing = 2.062 inches (52.4 mm) 1000 pieces per reel
MT2 = Taped & reeled. Spacing = 2.50 inches (63.5 mm) 1000 pieces per reel
MT3 = Taped & reeled. Spacing = 2.874 inches (73 mm) 1000 pieces per reel

NT1 = Taped & reeled. Spacing = 2.062 inches (52.4 mm) 5000 pieces per reel
NT2 = Taped & reeled. Spacing = 2.50 inches (63.5 mm) 5000 pieces per reel
NT3 = Taped & reeled. Spacing = 2.874 inches (73 mm) 5000 pieces per reel

Tx = Taped & reeled. Spacing to be determined.

MILITARY/FEDERAL STANDARDS
See Table of Contents for Military Product Section.

Fuses and holders approved to the following Military specifications are on the Qualified Products List (QPL) for that specification.

MIL-PRF-15160 and MIL-PRF-23419

These specifications govern the construction and performance of fuses suitable primarily for military electronic applications.

MIL-PRF-19207

This specification governs the construction and performance of fuseholders suitable for military applications.

DESC Drawing #87108

This drawing governs the construction and performance of .177" x .570" (2AG size) cartridge fuses and axial lead versions suitable for military applications. DESC #87108 designation is included in the fuse end cap marking.

FEDERAL SPECIFICATION W-F-1814

This specification governs the construction and performance of fuses with high interrupting ratings that are approved for federal applications. Fuses approved to these specifications are on the Federal Qualified Products List.

Write to the following agencies for additional information on standards, approvals, or copies of the specifications.

Underwriters Laboratories Inc. (UL)
333 Pfingsten Road
Northbrook, IL 60062
Att: Publications Stock

Canadian Standards Association (CSA)
178 Rexdale Boulevard
Rexdale, Ontario, Canada M9W 1R3
Att: Standard Sales

International Electrotechnical Commission (IEC)
3, Rue de Varembe
1211 Geneva 20
Switzerland
Att: Sales Department

Naval Publications and Military Standards Form Center (for Military and Federal Standards)
5801 Tabor Avenue
Philadelphia, PA 19120
Att: Commanding Officer

Defense Supply Center Columbus (DSSC)
3990 East Broad Street
Columbus, OH 43216-5000

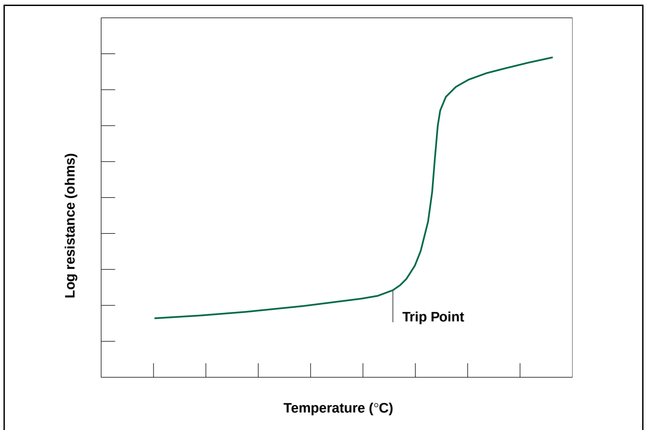
Ministry of International Trade and Industry (MITI)
Kasumigaseki
Chi-Youda-Ku
Tokyo 100, Japan

PTC FACTS

Overcurrent circuit protection can be accomplished with the use of either a traditional fuse or the more recently developed resettable PTC. Both devices function by reacting to the heat generated by the excessive current flow in the circuit. The fuse melts open, interrupting the current flow, and the PTC changes from a low resistance to a high resistance to limit current flow. Understanding the differences in performance between the two types of devices will make the best circuit protection choice easier.

The most obvious difference is that the PTC is *resettable.* The general procedure for resetting after an overload has occurred is to remove power and allow the device to cool down. There are several other operating characteristics that differentiate the two types of products. The terminology used for PTCs is often similar but not the same as for fuses. Two parameters that fall into this category are leakage current and interrupting rating.

LEAKAGE CURRENT: The PTC is said to have “tripped” when it has transitioned from the low resistance state to the high resistance state due to an overload.



Protection is accomplished by limiting the current flow to some *leakage* level. Leakage current can range from less than a hundred milliamps at rated voltage up to a few hundred milliamps at lower voltages. The fuse on the other hand completely interrupts the current flow and this open circuit results in “0” leakage current when subjected to an overload.

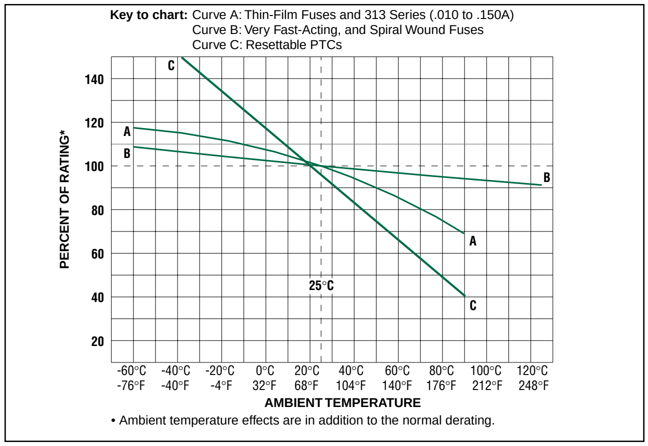
INTERRUPTING RATING: The PTC is rated for a maximum short circuit current at rated voltage. This fault current level is the maximum current that the device can withstand but the PTC will not actually interrupt the current flow (see LEAKAGE CURRENT above). A typical PTC short circuit rating is 40A. Fuses do in fact interrupt the current flow in response to the overload and the range of interrupting ratings goes from hundreds of amperes up to 10,000 amperes at rated voltage.

The circuit parameters may dictate the component choice based on typical device rating differences.

VOLTAGE RATING: General use PTCs are not rated above 60V while fuses are rated up to 600V.

CURRENT RATING: The operating current rating for PTCs can be up to 11A while the maximum level for fuses can exceed 20A.

TEMPERATURE RATING: The useful upper limit for a PTC is generally 85°C while the maximum operating temperature for fuses is 125°C. The following temperature derating curves that compare PTCs to fuses illustrate that more derating is required for a PTC at a given temperature.



Additional operating characteristics can be reviewed by the circuit designer in making the decision to choose a PTC or a fuse for overcurrent protection.

AGENCY APPROVALS: PTCs are Recognized under the Component Program of Underwriters Laboratories to UL Thermistor Standard 1434. The devices have also been certified under the CSA Component Acceptance Program. Approvals for fuses include Recognition under the Component Program of Underwriters Laboratories and the CSA Component Acceptance Program. In addition, many fuses are available with full “Listing” in accordance with the new Supplementary Fuse Standard UL/CSA/ANCE (Mexico) 248-14.

RESISTANCE: Reviewing product specifications indicates that similarly rated PTCs have about twice (sometimes more) the resistance of fuses.

TIME-CURRENT CHARACTERISTIC: Comparing the time-current curves of PTCs to time-current curves of fuses show that the speed of response for a PTC is similar to the time delay of a Slo-Blo® fuse.

SUMMARY: Many of the issues discussed become a matter of preference, but there is an important area of application where the use of resettable PTCs is becoming a requirement. Much of the design work for personal computers and peripheral devices is strongly influenced by *Microsoft and Intel System Design Guide* which states that “Using a fuse that must be replaced each time an overcurrent condition occurs is unacceptable.” And the *Plug and Play SCSI* (Small Computer Systems Interface) Specification for this large market includes a statement that “. . . must provide a self-resetting device to limit the maximum amount of current sourced”.

The PTC / fuse discussion provides some insight as to when PTCs may be the appropriate choice for providing overcurrent circuit protection. A selection guide worksheet appears on the following page as an aid in choosing the best circuit protection component.

SELECTION GUIDE WORKSHEET

1. Define the circuit operating parameters.

Complete the following form:

Normal operating current in amperes: ______________________

Normal operating voltage in volts: ______________________

Maximum interrupt current: (see page 3) ______________________

Ambient Temperature/Rerating: (see page 4) ______________________

Typical overload current: ______________________

Required opening time at specified overload: ______________________

Transient pulses expected: (see page 5) ______________________

Resettable or one-time: ______________________

Agency Approvals: ______________________

Mounting type/form factor: ______________________

Typical resistance (in circuit): ______________________

2. Select the proper circuit protection component.

LITTELFUSE CIRCUIT PROTECTION COMPARISON TABLE:

	Surface Mount PTC (Pg. 22-25)	30V PTC Leaded (Pg. 26-27)	60V PTC Leaded (Pg. 28-29)	'0603' SMF (Pg. 34-35)	'1206' SMF (Pg. 33, 36)
Operating Current Range	0.300 - 2.6A	0.900 - 9A	0.100 - 3.75A	0.250 - 5A	0.125 - 7A
Maximum Voltage (*)	60V	30V	60V	32V	125V
Maximum Interrupting Rating (**)	40A	40A	40A	50A	50A
Temperature Range	–40°C to 85°C	–40°C to 85°C	–40°C to 85°C	–55°C to 125°C	–55°C to 125°C
Thermal Rerating	Medium	Medium	Medium	Low	Low
Opening time at 200% I_N (***)	Slow	Slow	Slow	Fast	Fast to Medium
Transient Withstand	Low	Low	Low	Low	Low
Resistance	Medium	Low to Medium	Medium	Low	Low
Agency Approvals	UL, CSA, TUV	UL, CSA, TUV	UL CSA, TUV	UL, CSA	UL, CSA
Operational Uses	Multiple	Multiple	Multiple	One Time	One Time
Mounting/Form Factor	Surface Mount	Leaded	Leaded	Surface Mount	Surface Mount

(*) Maximum operating voltage in the series, parts may be used at voltages equal to or less than this value.
(**) Maximum interrupting rating at specified voltage which may be less than maximum operating voltage.
(***) Opening time is in relation to other forms of protection. A fast device will typically operate within three seconds at 200% of rated current.

SELECTION GUIDE WORKSHEET

3. Determine the opening time at fault.

Consult the Time-Current (T-C) Curve to determine if the selected part will operate within the constraints of your application. If the device opens too soon, the application may experience nuisance operation. If the device does not open soon enough, the overcurrent may damage downstream components.

To determine the opening time for the chosen device, locate the overload current on the X-axis of the appropriate T-C Curve and follow its line up to its intersection with the curve. At this point read the time listed on the Y-axis. This is the average opening time for that device. If your overload current falls to the right of the curve the device will open. If the overload current is to the left of the curve the device will not operate.

4. Verify ambient operating parameters.

Ensure that the application voltage is less than or equal to the device's rated voltage and that the operating temperature limits are within those specified by the device.

5. Verify the device's dimensions.

Using the information from the Designer's Guide page, compare the maximum dimensions of the device to the space available in the application.

LITTELFUSE CIRCUIT PROTECTION COMPARISON TABLE:

	Nano2® SMF Fuse (Pg. 40-41)	PICO® II Fuse (Pg. 48-51)	2AGs (Pg. 55-57)	5x20mm (Pg. 62-70)	3AGs/3ABs (Pg. 58-61,71)	Midgets (Pg 76-84)
Operating Current Range	0.062 - 15A	0.062 - 15A	0.100 - 10A	0.032 - 15A	0.010 - 35A	0.100 - 30A
Maximum Voltage (*)	125V	250V	250V	250V	250V	600V
Maximum Interrupting Rating (**)	50A	50A	10,000A	10,000A	10,000A	200,000A
Temperature Range	–55°C to 125°C	–55°C to 125°C	–55°C to 125°C	–55°C to 125°C	–55°C to 125°C	–55°C to 125°C
Thermal Rerating	Low	Low	Low	Low	Low	Low
Opening time at 200% I_N (***)	Fast to Medium	Fast to Medium	Fast to Medium	Fast to Slow	Fast to Slow	Fast to Slow
Transient Withstand	Low to Medium	Low to Medium	Low to High	Low to High	Low to High	Low to High
Resistance	Low	Low	Low	Low	Low	Low
Agency Approvals	UL, CSA, MITI	UL, CSA, MITI	UL, CSA, MITI	CSA, BSI, VDE, MITI, SEMKO, UL	UL, CSA, MITI	UL, CSA
Operational Uses	One Time	One Time	One Time	One Time	One Time	One Time
Mounting/Form Factor	Surface Mount	Leaded	Leaded or Cartridge	Leaded or Cartridge	Leaded or Cartridge	Cartridge

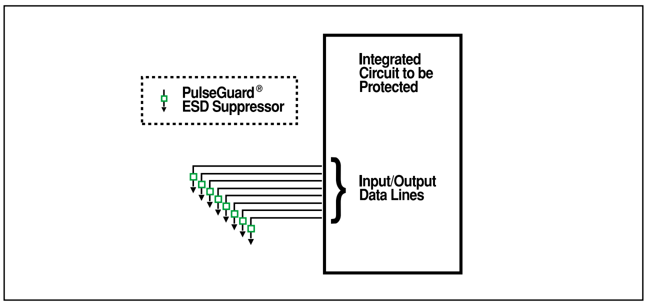
(*) Maximum operating voltage in the series, parts may be used at voltages equal to or less than this value.
(**) Maximum interrupting rating at specified voltage which may be less than maximum operating voltage.
(***) Opening time is in relation to other forms of protection. A fast device will typically operate within three seconds at 200% of rated current.

PulseGuard® Suppressors

ESD Suppressor FACTS

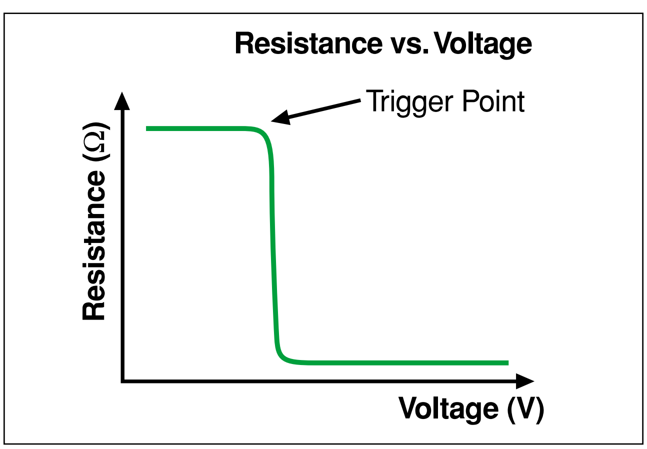
Electronic devices that rely on integrated circuitry are becoming more sensitive to the threats of electrostatic discharge (ESD) transient overvoltage events. Using the input/output communication ports as entryways, ESD pulses are able to pass from the outside of the electronic equipment to the I/O pins of the integrated circuit (IC) chips inside. The ESD transients are generated by people and transferred to the equipment during normal operation and maintenance.

IC's are typically manufactured to withstand ESD events up to 2,000 volts; however, ESD events often occur at levels exceeding 15,000 volts. Because of this protection discrepancy, reliability of the electronic equipment is compromised. The solution to this problem is to supplement the on-chip protection against ESD events by installing ESD suppressing components in parallel with the input/ output communications lines as shown below.



Protection is provided by the PulseGuard suppressor as it transitions from a high resistance state to a low resistance state. In the "off" state, the high resistance causes the part to be electrically transparent to the circuit. After being triggered, the ESD protector shifts to the "on" state, becomes conductive, and shunts the ESD pulse from the signal line to ground. The amount of voltage that the system experiences due to ESD is thus minimized. After the ESD energy is dissipated, the PulseGuard suppressor "resets" itself to the high resistance "off" state.

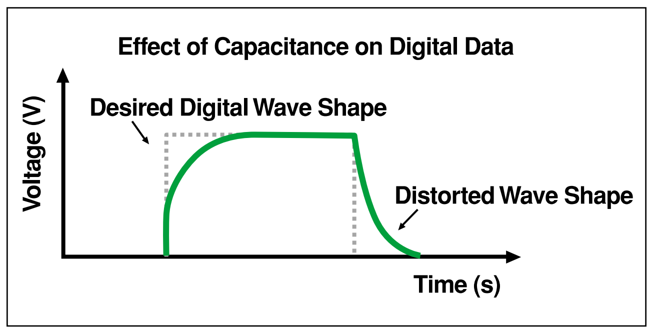
A factor that complicates the protection of data communication lines is that signal transmission rates are increasing continuously. The information age has mandated the need for more communication links between electronic systems, causing an associated explosion in the magnitude of data that must be handled. Data transmission rates, by necessity, have increased and will continue to increase.



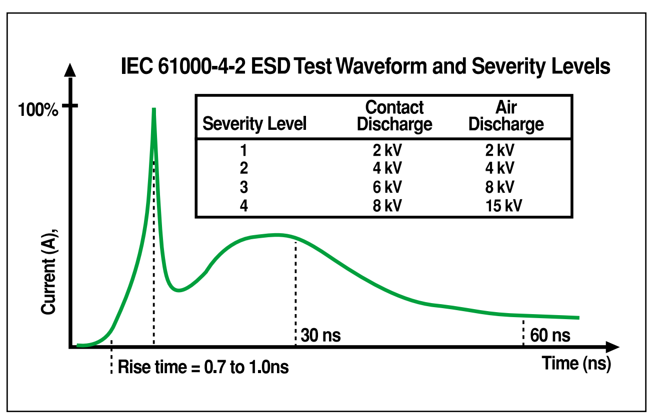
As the transmission rate of data increases, the inherent capacitance of the ESD suppressor becomes an issue. Capacitance will cause degradation to the signals that are passing along the data line. PulseGuard suppressors have less than 1 pF of capacitance and will not affect the signals. Typical effects on the data waveshape can be seen below.

For those applications where the speed of the data streams is approximately 100MHz or less, Littelfuse also offers electroceramic and silicon products for ESD protection. The MultiLayer Varistor (MLV) devices should be used to protect data lines where the speed of the signal is approximately 100MHz or less. The SP series contains the SP720, SP721, SP723, and SP724 devices. Both of these product families also provide protection against Electrical Fast Transients (EFT's) and have limited surge (8x20 µs) capabilities.

As an example, the SP724 would be the ideal solution for USB1.1 data lines, which transmit data up to speeds of 12 Mbps. The new USB2.0 serial bus will be able to transmit data at speeds up to 480 Mbps. For that application, the PulseGuard product would be the ideal solution.



Aside from reliability, the IEC 61000-4-2 test specification is an important design consideration. Created by the International Electrotechnical Commission (IEC), this specification provides the definition of the ESD waveform, severity levels, and the methodologies that are used to test the ability of electronic equipment to survive multiple ESD events. The following chart includes the waveshape and voltage level information relating to this specification.



Severity Level	Contact Discharge	Air Discharge
1	2 kV	2 kV
2	4 kV	4 kV
3	6 kV	8 kV
4	8 kV	15 kV

PulseGuard® Suppressors

ESD Suppressor FACTS

Currently, electronic equipment manufacturers are required to certify that their equipment can survive testing to the IEC standard if they are selling that equipment into the European Union. Non-compliance is a prosecutable offense. Compliance is voluntary in the United States. Use of Pulse-Guard ESD suppressors will help our customers to meet this important specification.

LEAKAGE CURRENT: Until the PulseGuard suppressor transitions to the “on” state, it is electrically transparent to the circuit. Leakage current passing through the device is less than .1 µA.

INTERRUPTING RATING: ESD suppressors are not rated as current-breaking devices; however, PulseGuard suppressors are able to withstand the 45A that are present during worst case ESD discharges.

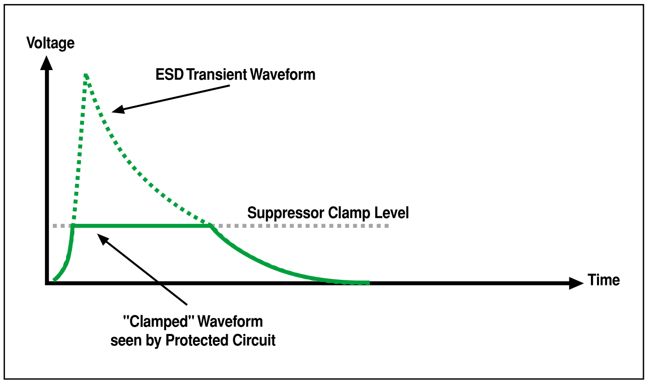
VOLTAGE RATING: PulseGuard suppressors are rated for use in operating environments up to 24 VDC.

TEMPERATURE RATING: The operating temperature range is –65°C to +125°C. These devices do not operate as a result of thermal action; therefore, there is no derating necessary.

AGENCY APPROVALS: At this time, there are no applicable standards for ESD suppressor components. Nonetheless, PulseGuard suppressors have been subjected to all levels of severity of the IEC 61000-4-2 test specification using both the Contact Discharge and Air Discharge injection methods. In all cases, clamping of the ESD transient is provided.

RESISTANCE: While in the “off” state, the suppressors remain electrically transparent to the circuit. The measured resistance of the suppressors is 10 MΩ, or greater.

TIME-VOLTAGE CHARACTERISTIC: Because the magnitude of the voltage and the time duration vary with the individual ESD event, a general form of this curve is shown below.



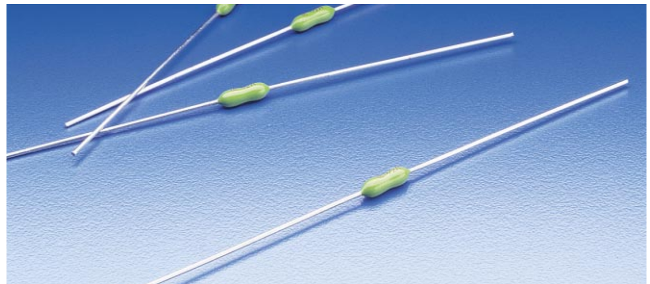
SUMMARY: The decision to use the surface mount suppressor or the connector array suppressor is left to the individual application. The ideal location is at the connector site, so that the ESD pulse is shunted to ground before the pulse enters the body of the electronic equipment. However, protection against the ESD threat will also be realized if the surface mount PulseGuard suppressors are installed as close as possible to the source of ESD. That is, on the PC board behind the connector so that the suppressor is the first device encountered by the ESD pulse after it passes through the connector.

SUBMINIATURE

PICO® II Very Fast-Acting Type Fuse

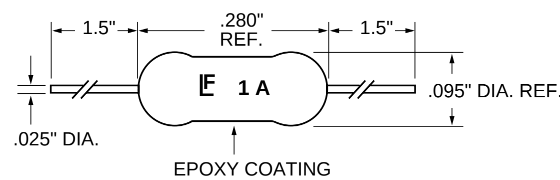
QPL

The PICO® II very fast-acting fuse is designed to meet an extensive array of performance characteristics in a space-saving subminiature package.



ELECTRICAL CHARACTERISTICS:

% of Ampere Rating	Ampere Rating	Opening Time
100%	1/16–15	4 hours, **Min**imum
200%	1/16–7	1 second, **Max**imum
	10	3 seconds, **Max**imum
	12–15	10 seconds, **Max**imum



NOTE: .025" diameter for 1/16–10A, .032" diameter for 12 –15A.

AGENCY APPROVALS: Recognized under the Components Program of Underwriters Laboratories and Certified by CSA. Approved by MITI from 1 through 5 amperes.

AGENCY FILE NUMBERS: UL E10480, CSA LR 29862.

REFERENCE TO MIL SPEC: Available in Military QPL type FM10, conforming to MIL-PRF-23419. To order, change **251** to **253** as shown below.

INTERRUPTING RATINGS:
300 amperes at rated voltage VDC.
50 amperes at rated voltage VAC.

ENVIRONMENTAL SPECIFICATIONS:
Operating Temperature: –55°C to 125°C.
Shock: MIL-STD-202, Method 213, Test Condition I (100 G's peak for 6 milliseconds).
Vibration: MIL-STD-202, Method 201 (10–55 Hz); Method 204, Test Condition C (55–2000 Hz at 10 G's Peak).
Moisture Resistance: MIL-STD-202, Method 106.

PHYSICAL SPECIFICATIONS:
Materials: Encapsulated, Epoxy-Coated Body; Solder Coated Copper Wire Leads.
Flammability Rating: UL 94V0
Soldering Parameters:
Wave Solder — 260°C, 10 seconds maximum.
Solderability: MIL-STD-202, Method 208.
Lead Pull Force: MIL-STD-202, Method 211, Test Condition A (will withstand a 7 lb. axial pull test).

PACKAGING SPECIFICATIONS: Tape and Reel per EIA-296; T1: 2.062" (52.4mm) taped spacing; 5,000 per reel.
Option: Radial Lead Version; 0.4" lead spacing; to order, change **251** to **252**.

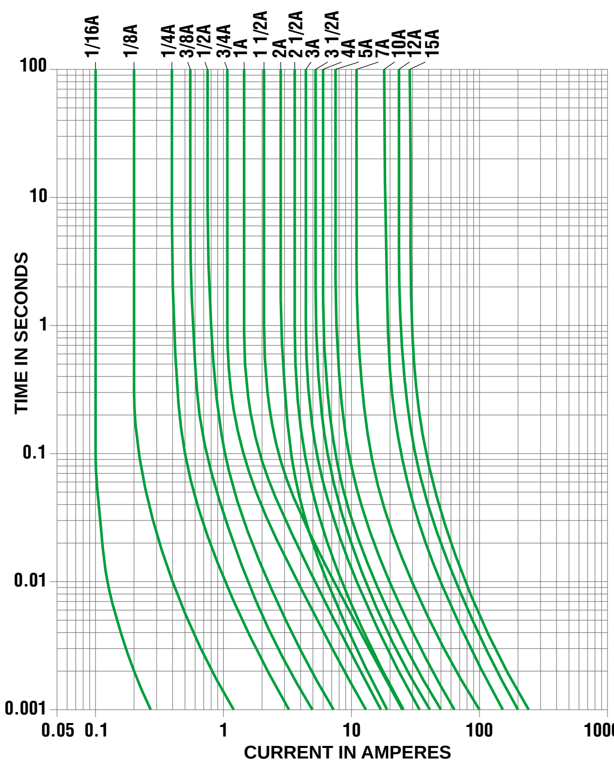
PATENTED

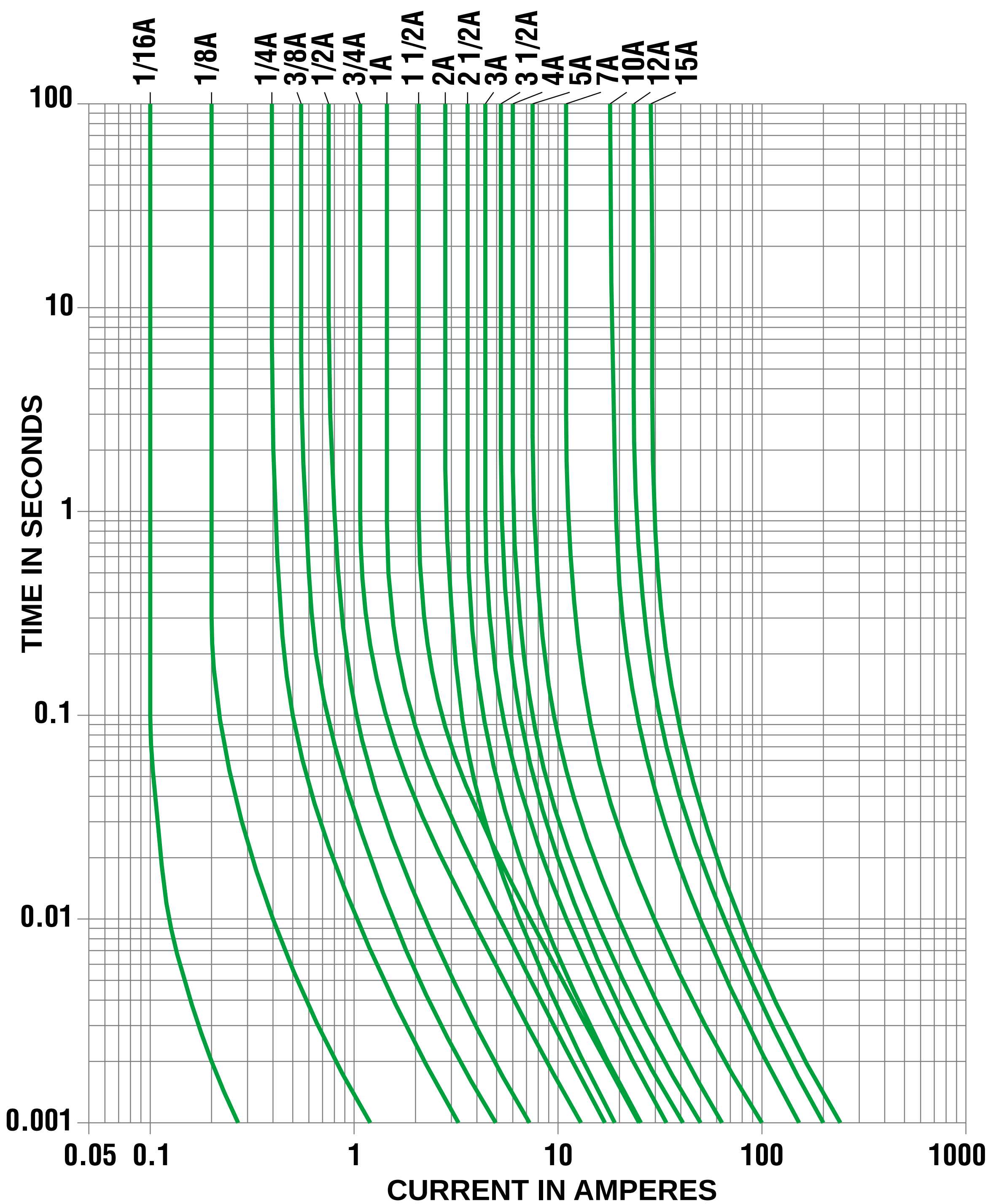
ORDERING INFORMATION:

Std. Type Catalog Number	Mil. Type Catalog Number	Ampere Rating	Voltage Rating	Nominal Resistance Cold Ohms	Nominal Melting I²t A² Sec.
R251.062	**R253**.062	1/16	125	7.0	0.000113
R251.125	**R253**.125	1/8	125	1.70	0.00174
R251.250	**R253**.250	1/4	125	0.665	0.0116
R251.375	**R253**.375	3/8	125	0.395	0.0296
R251.500	**R253**.500	1/2	125	0.280	0.0598
R251.750	**R253**.750	3/4	125	0.175	0.153
R251 001	**R253** 001	1	125	0.128	0.256
R251 01.5	**R253** 01.5	1 1/2	125	0.0823	0.587
R251 002	**R253** 002	2	125	0.0473	0.405
R251 02.5		2 1/2	125	0.0360	0.721
R251 003	**R253** 003	3	125	0.0290	1.19
R251 03.5		3 1/2	125	0.0240	1.58
R251 004	**R253** 004	4	125	0.0204	2.45
R251 005	**R253** 005	5	125	0.0155	4.14
R251 007	**R253** 007	7	125	0.0105	10.4
R251 010	**R253** 010	10	125	0.00705	25.5
R251 012		12	32	0.0055	45.2
R251 015	**R253** 015	15	32	0.00446	68.8

Note: Higher Ampere Ratings Available.
Contact Technical Assistance for Details

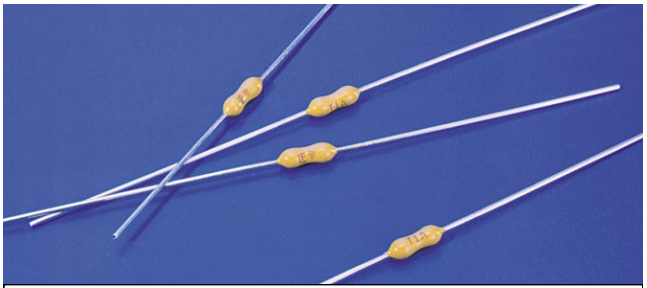
Average Time Current Curves




1/16A
1/8A
1/4A
3/8A
1/2A
3/4A
1A
1 1/2A
2A
2 1/2A
3A
3 1/2A
4A
5A
7A
10A
12A
15A
100
10
1
0.1
0.01
0.001
TIME IN SECONDS
0.05
0.1
1
10
100
1000
CURRENT IN AMPERES

SUBMINIATURE

PICO® II Time Lag Type Fuse 471 Series



- The PICO® II time-lag fuse is designed for applications that require moderate inrush withstand.
- For additional inrush withstand, consult the 473 Series.

ELECTRICAL CHARACTERISTICS:

% of Ampere Rating	Opening Time
100%	4 hours, **Min**imum
200%	120 seconds, **Max.**

AGENCY APPROVALS: Recognized under the Components Program of Underwriters Laboratories and Certified by CSA. Approved by MITI from 1 through 5 amperes.

AGENCY FILE NUMBERS: UL E10480, CSA LR 29862.

INTERRUPTING RATINGS:
50 amperes at 125 VAC and VDC.

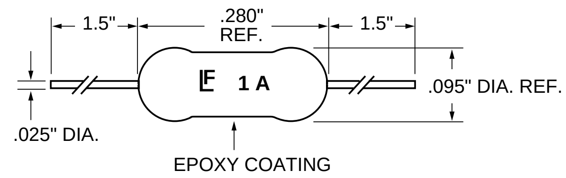
ENVIRONMENTAL SPECIFICATIONS:
Operating Temperature: –55°C to 125°C.
Shock: MIL-STD-202, Method 213, Test Condition I (100 G's peak for 6 milliseconds).
Vibration: MIL-STD-202, Method 201 (10–55 Hz); Method 204, Test Condition C (55–2000 Hz at 10 G's Peak).
Moisture Resistance: MIL-STD-202, Method 106.

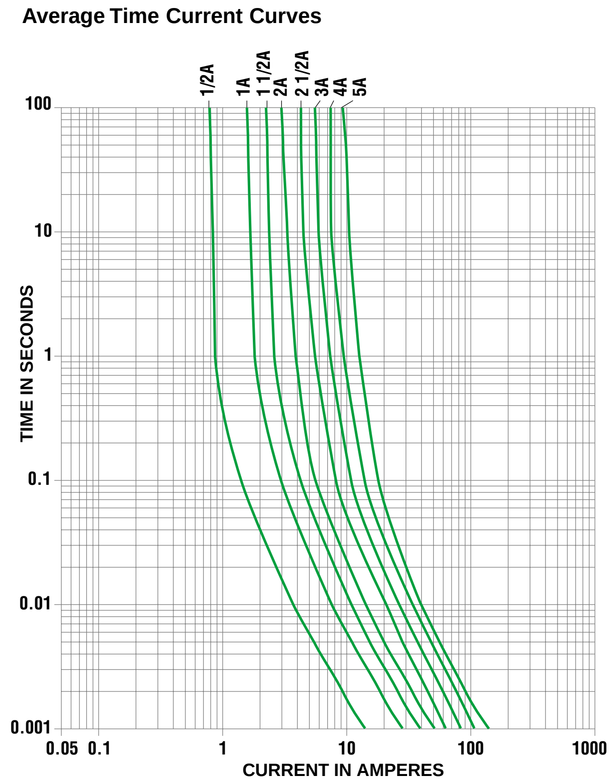
PHYSICAL SPECIFICATIONS:
Materials: Encapsulated, Epoxy-Coated Body; Solder Coated Copper Wire Leads.
Flammability Rating: UL 94V0
Soldering Parameters:
Wave Solder — 260°C, 10 seconds maximum.
Solderability: MIL-STD-202, Method 208.
Lead Pull Force: MIL-STD-202, Method 211, Test Condition A (will withstand a 7 lb. axial pull test).

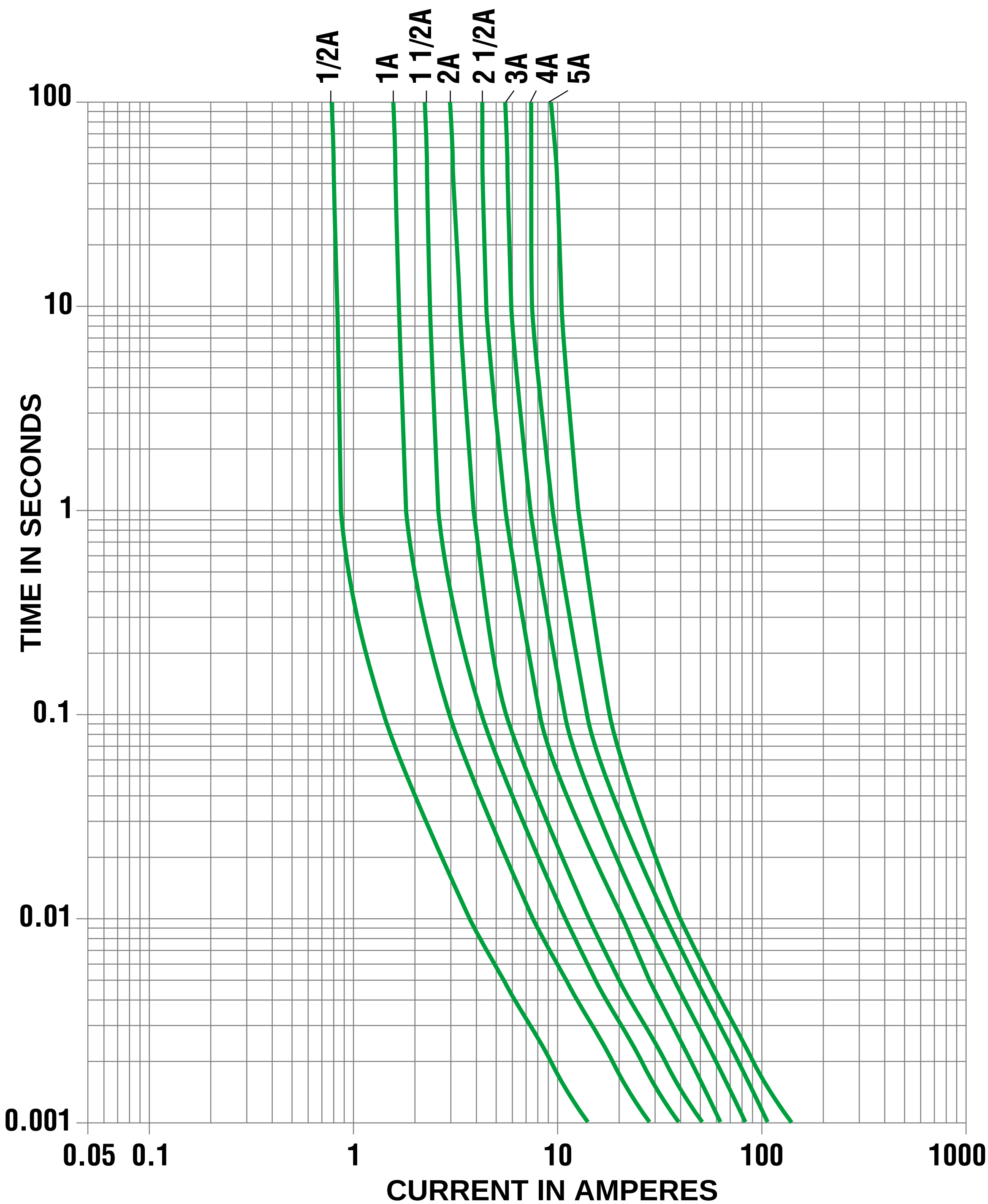
PACKAGING SPECIFICATIONS: Tape and Reel per EIA-296; 5,000 per reel.

ORDERING INFORMATION:

Catalog Number	Ampere Rating	Voltage Rating	Nominal Resistance Cold Ohms	Nominal Melting I²t A² Sec.
0471.500	1/2	125	0.189	0.159
0471 001.	1	125	0.085	0.722
0471 01.5	1¹/₂	125	0.054	1.610
0471 002.	2	125	0.039	2.500
0471 02.5	2¹/₂	125	0.030	4.390
0471 003.	3	125	0.023	6.960
0471 004.	4	125	0.012	10.600
0471 005.	5	125	0.008	15.400

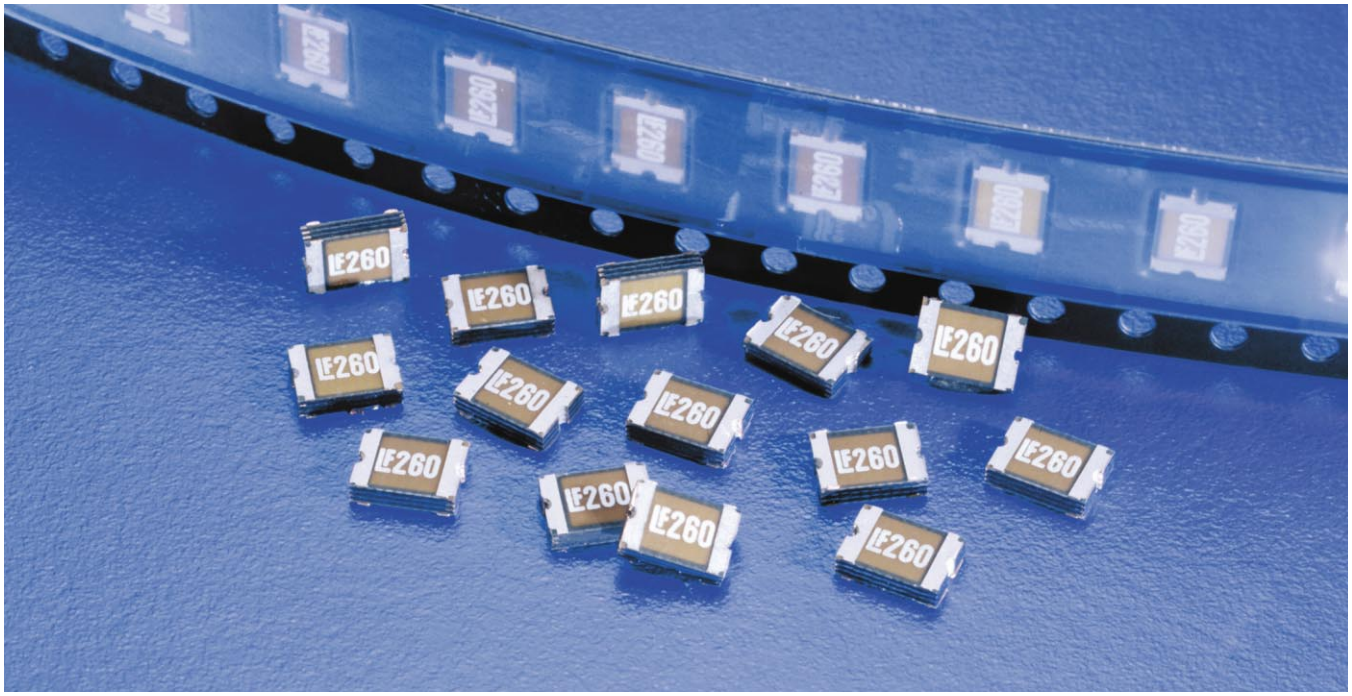





1/2A
1A
1 1/2A
2A
2 1/2A
3A
4A
5A
100
10
1
0.1
0.01
0.001
TIME IN SECONDS
0.05
0.1
1
10
100
1000
CURRENT IN AMPERES

SURFACE MOUNT PTC

1812L Series



PHYSICAL SPECIFICATIONS:

Terminal Material: Tin-Lead Plated Copper

Solderability: Meets EIA specification RS186-9E and IPC/EIA J-STD-002, and IPC/EIA J-STD-001.

Device Labeling: Device is marked with LF and amperage rating.

Packaging: 12mm tape and reel carrier per EIA 481 Standard.
Standard reel quantity: 2,000 devices on 7" reel (PRT Suffix).
Optional reel quantity: 8,000 devices on 13" reel (ZRT Suffix).

AGENCY APPROVALS: UL, CSA, TUV approved.

ENVIRONMENTAL SPECIFICATIONS:

Passive Aging: 85°C, 1000 Hours.

Humidity Aging: 85°C, 85% R.H., 100 hours.

Thermal Shock: 85°C / –40°C, 20 times.

Vibration: MIL-STD 202, Method 201, MIL-STD-883, Method 2007.

Mechanical Shock: MIL-STD-202, Method 213 test condition I (100 g's, 6 sec.).

Solvent Resistance: MIL-STD-202, Method 215.

Operating/Storage Temperature: –40°C to 85°C
Device should remain in sealed bags prior to use.

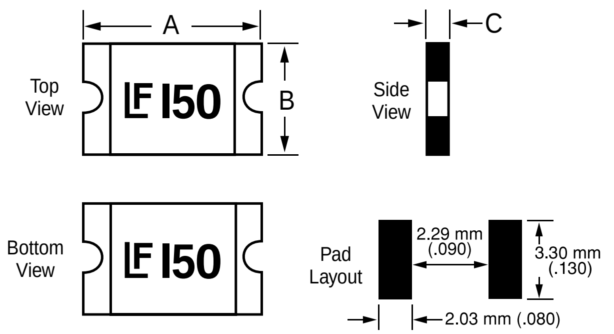
Temperature Rerating:

Part Number	Ambient Temperature									
	-40°C	-20°C	0°C	20°C	40°C	50°C	60°C	70°C	80°C	85°C
	Hold Current (A)									
1812L050	0.65	0.61	0.57	0.50	0.46	0.44	0.41	0.39	0.37	0.35
1812L075	0.98	0.91	0.83	0.75	0.69	0.65	0.62	0.58	0.54	0.53
1812L110	1.44	1.33	1.22	1.10	1.01	0.96	0.90	0.85	0.80	0.77
1812L125	1.63	1.51	1.41	1.25	1.15	1.09	1.03	0.96	0.91	0.88
1812L150	1.96	1.81	1.67	1.50	1.38	1.30	1.23	1.16	1.09	1.05
1812L200	3.02	2.68	2.33	2.00	1.66	1.49	1.32	1.15	0.99	0.82
1812L260	3.92	3.48	3.04	2.60	2.16	1.94	1.72	1.50	1.28	1.06

SURFACE MOUNT PTC

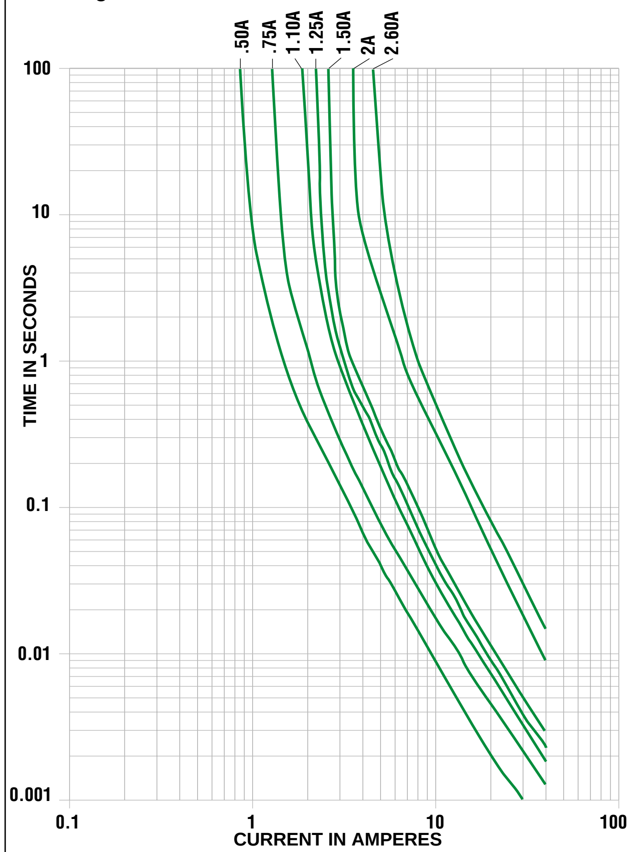
1812L Series

Dimensions (Inches) **Recommended Pad Layout (Inches)**
All dimensions are nominal.



Devices can be reflow or wave soldered.

Average Time Current Curves



Dimensions:

1812L 050-150	A	B	C
Min. [mm (in.)]	4.32(.170)	3.00(.118)	0.53(.021)
Max. [mm (in.)]	4.62(.182)	3.30(.130)	0.69(.028)

Dimensions:

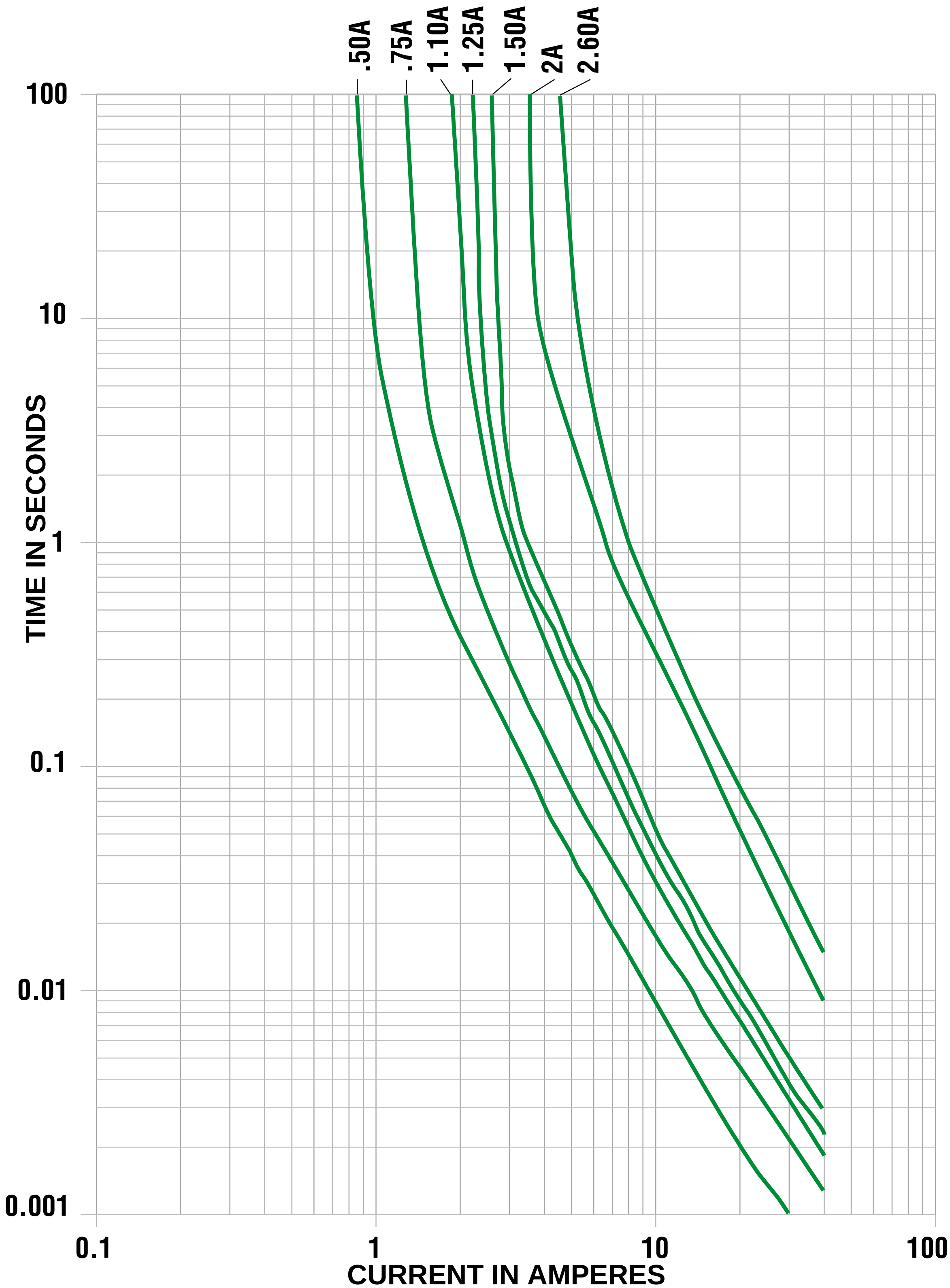
1812L 200-260	A	B	C
Min. [mm (in.)]	4.32(.170)	3.00(.118)	1.01(.040)
Max. [mm (in.)]	4.62(.182)	3.30(.130)	1.45(.057)

Electrical Characteristics:

Part Number	I_{hold} (A)	I_{trip} (A)	V_{max} (Vdc)	I_{max} (A)	P_d max. (W)	Maximum Time To Trip Current (A)	Maximum Time To Trip Time (Sec)	Resistance R_{IL} (Ω)	Resistance R_{AT} (Ω)
1812L050	0.50	1.00	15.0	40	0.8	8.0	0.15	0.100	1.000
1812L075	0.75	1.50	13.2	40	0.8	8.0	0.30	0.075	0.420
1812L110	1.10	2.20	6.0	40	0.8	8.0	0.30	0.040	0.226
1812L125	1.25	2.50	6.0	40	0.8	8.0	0.25	0.045	0.184
1812L150	1.50	3.00	6.0	40	0.8	8.0	0.30	0.040	0.137
NEW 1812L200	2.00	4.00	6.0	40	0.8	8.0	2.50	Call for Data	Call for Data
NEW 1812L260	2.60	5.20	6.0	40	0.8	8.0	2.50	0.01	0.050

I_{hold} = Hold Current: maximum current device will sustain for 4 hours without tripping in 20°C still air.
I_{trip} = Trip Current: minimum current at which the device will trip in 20°C still air.
V_{max} = Maximum voltage device can withstand without damage at rated current (I_{max})
I_{max} = Maximum fault current device can withstand without damage at rated voltage (V_{max})
P_d = Power dissipated from device when in the tripped state at 20°C still air.
R_{IL} = Minimum resistance of device in initial (un-soldered) state.
R_{AT} = Maximum measured resistance in the non-tripped state 1 hour after reflow with reflow conditions of 260°C for 20 sec.

CAUTION: Operation beyond the specified ratings may result in damage and possible arcing and flame.


.50A
.75A
1.10A
1.25A
1.50A
2A
2.60A
100
10
1
0.1
0.01
0.001
TIME IN SECONDS
0.1
1
10
100
CURRENT IN AMPERES

MC3423

Overvoltage Crowbar Sensing Circuit

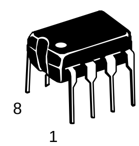
This overvoltage protection circuit (OVP) protects sensitive electronic circuitry from overvoltage transients or regulator failures when used in conjunction with an external "crowbar" SCR. The device senses the overvoltage condition and quickly "crowbars" or short circuits the supply, forcing the supply into current limiting or opening the fuse or circuit breaker.

The protection voltage threshold is adjustable and the MC3423 can be programmed for minimum duration of overvoltage condition before tripping, thus supplying noise immunity.

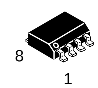
The MC3423 is essentially a "two terminal" system, therefore it can be used with either positive or negative supplies.

OVERVOLTAGE SENSING CIRCUIT

SEMICONDUCTOR TECHNICAL DATA



P1 SUFFIX
PLASTIC PACKAGE
CASE 626

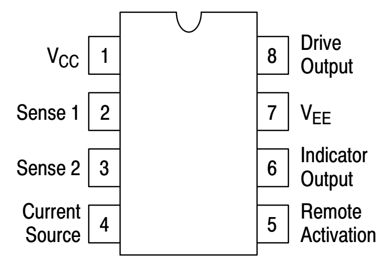


D SUFFIX
PLASTIC PACKAGE
CASE 751
(SOP–8)

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Differential Power Supply Voltage	$V_{CC}–V_{EE}$	40	Vdc
Sense Voltage (1)	V_{Sense1}	6.5	Vdc
Sense Voltage (2)	V_{Sense2}	6.5	Vdc
Remote Activation Input Voltage	V_{act}	7.0	Vdc
Output Current	I_O	300	mA
Operating Ambient Temperature Range	T_A	0 to +70	°C
Operating Junction Temperature	T_J	125	°C
Storage Temperature Range	T_{stg}	–65 to +150	°C

PIN CONNECTIONS

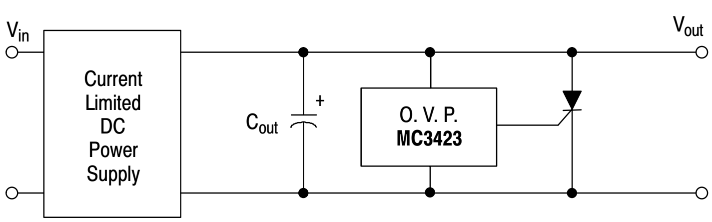


(Top View)

ORDERING INFORMATION

Device	Operating Temperature Range	Package
MC3423D	T_A = 0° to +70°C	SO–8
MC3423P1		Plastic DIP

Simplified Application



ELECTRICAL CHARACTERISTICS (5.0 V ≤ $V_{CC} - V_{EE}$ ≤ 36 V, $T_{low} < T_A$, T_{high}, unless otherwise noted.)

Characteristics	Symbol	Min	Typ	Max	Unit
Supply Voltage Range	$V_{CC}–V_{EE}$	4.5	–	40	Vdc
Output Voltage (I_O = 100 mA)	V_O	V_{CC}–2.2	V_{CC}–1.8	–	Vdc
Indicator Output Voltage ($I_{O(Ind)}$ = 1.6 mA)	V_{OL}(Ind)	–	0.1	0.4	Vdc
Sense Trip Voltage (T_A = 25°C)	V_{Sense1}, V_{Sense2}	2.45	2.6	2.75	Vdc
Temperature Coefficient of V_{Sense1} (Figure 2)	TCV_{S1}	–	0.06	–	%/°C
Remote Activation Input Current					µA
(V_{IH} = 2.0 V, $V_{CC} – V_{EE}$ = 5.0 V)	I_{IH}	–	5.0	40	
(V_{IL} = 0.8 V, $V_{CC} – V_{EE}$ = 5.0 V)	I_{IL}	–	–120	–180	
Source Current	I_{Source}	0.1	0.2	0.3	mA
Output Current Risetime (T_A = 25°C)	t_r	–	400	–	mA/µs
Propagation Delay Time (T_A = 25°C)	t_{pd}	–	0.5	–	µs
Supply Current	I_D	–	6.0	10	mA

NOTES: T_{low} to T_{high} = 0° to +70°C

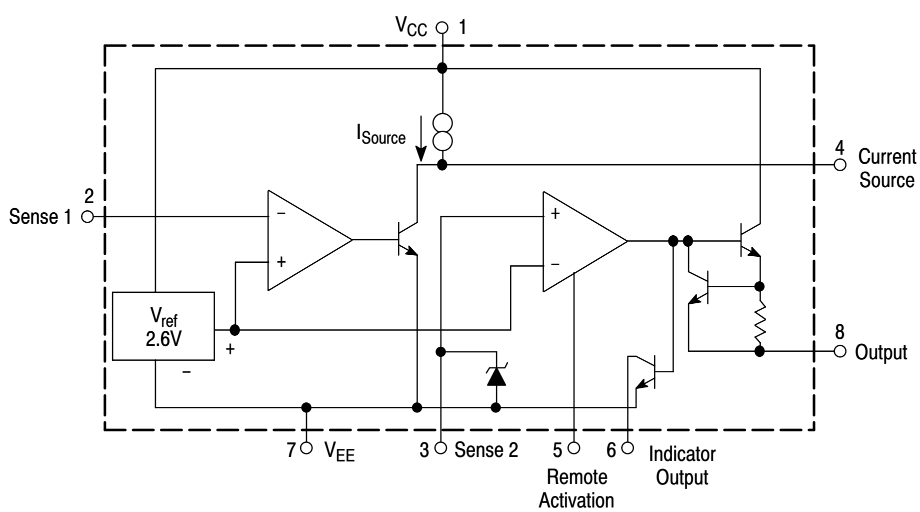
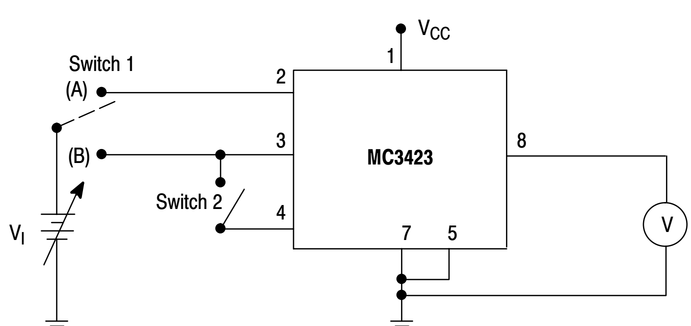


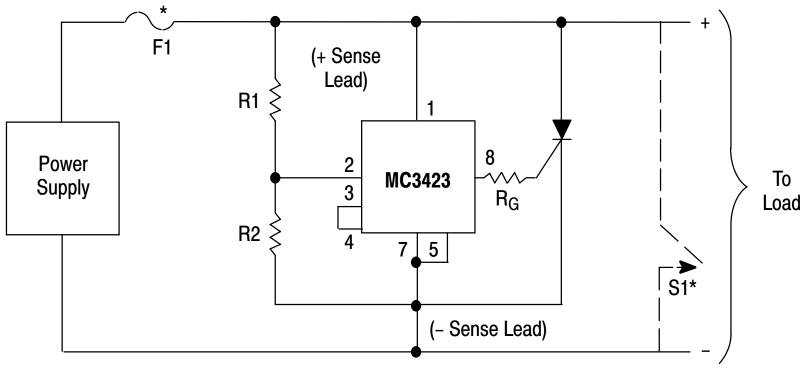
Figure 1. Representative Block Diagram



	Switch 1	Switch 2
$V_{Sense\ 1}$	Position A	Closed
$V_{Sense\ 2}$	Position B	Open

Ramp V_I until output goes high; this is the V_{Sense} threshold.

Figure 2. Sense Voltage Test Circuit



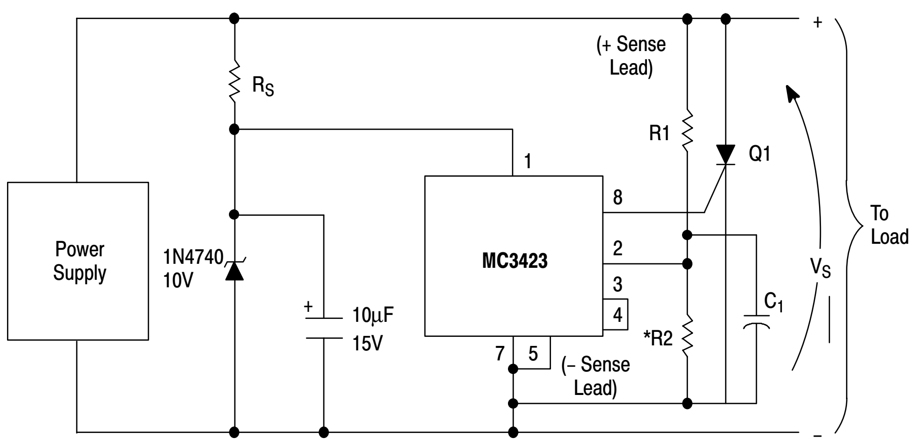
$$V_{trip} = V_{ref}\left(1 + \frac{R1}{R2}\right) \approx 2.6V\left(1 + \frac{R1}{R2}\right)$$

R2 ≤ 10 kΩ for minimum drift

For minimum value of R_G, see Figure 9.

*See text for explanation.

Figure 3. Basic Circuit Configuration



$$C_1 > \frac{R_S}{R_1R_2}\,(R_1 + R_2)\ 10\mu F$$

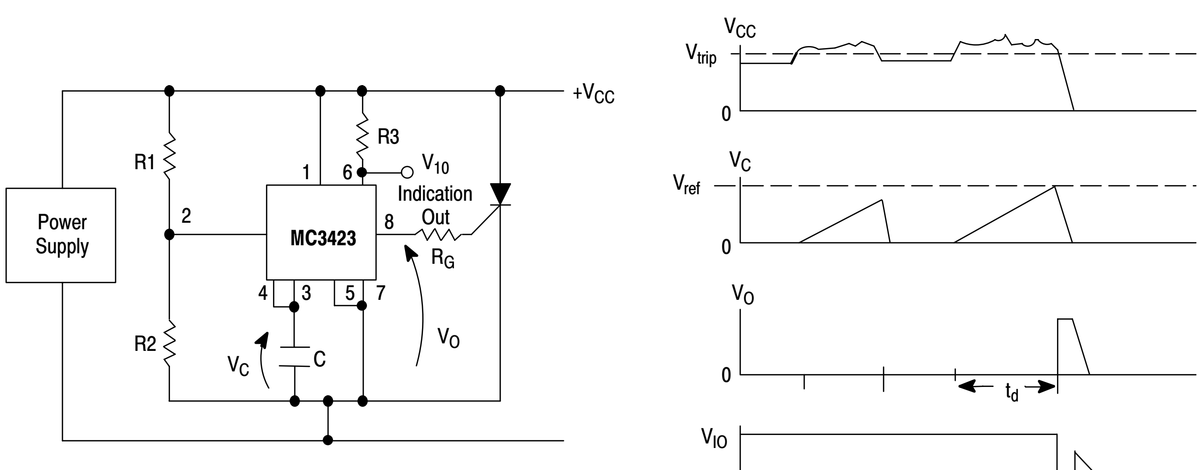
$$R_S = \left(\frac{VS \quad 10}{25}\right)k\Omega$$

$$V_{trip} = V_{ref}\left(1 + \frac{R1}{R2}\right) \approx 2.6V\left(1 + \frac{R1}{R2}\right)$$

*R2 ≤ 10 kΩ

Q1: $V_S \le 50$ V; 2N6504 or equivalent
$V_S \le 100$ V; 2N6505 or equivalent
$V_S \le 200$ V; 2N6506 or equivalent
$V_S \le 400$ V; 2N6507 or equivalent
$V_S \le 600$ V; 2N6508 or equivalent
$V_S \le 800$ V; 2N6509 or equivalent

Figure 4. Circuit Configuration for Supply Voltage Above 36 V



$$R3 \ge \frac{V_{trip}}{10\ mA}$$

$$t_d = \frac{V_{ref}}{I_{source}} \times C \approx 12 \times 10^3 \ C$$

(See Figure 10)

Figure 5. Basic Configuration for Programmable Duration of Overvoltage Condition Before Trip

APPLICATION INFORMATION

Basic Circuit Configuration

The basic circuit configuration of the MC3423 OVP is shown in Figure 3 for supply voltages from 4.5 V to 36 V, and in Figure 4 for trip voltages above 36 V. The threshold or trip voltage at which the MC3423 will trigger and supply gate drive to the crowbar SCR, Q1, is determined by the selection of R1 and R2. Their values can be determined by the equation given in Figures 3 and 4, or by the graph shown in Figure 8. The minimum value of the gate current limiting resistor, R_G, is given in Figure 9. Using this value of R_G, the SCR, Q1, will receive the greatest gate current possible without damaging the MC3423. If lower output currents are required, R_G can be increased in value. The switch, S1, shown in Figure 3 may be used to reset the crowbar. Otherwise, the power supply, across which the SCR is connected, must be shut down to reset the crowbar. If a non current–limited supply is used, a fuse or circuit breaker, F1, should be used to protect the SCR and/or the load.

The circuit configurations shown in Figures 3 and 4 will have a typical propagating delay of 1.0 µs. If faster operation is desired, Pin 3 may be connected to Pin 2 with Pin 4 left floating. This will result in decreasing the propagating delay to approximately 0.5 µs at the expense of a slightly increased TC for the trip voltage value.

Configuration for Programmable Minimum Duration of Overvoltage Condition Before Tripping

In many instances, the MC3423 OVP will be used in a noise environment. To prevent false tripping of the OVP circuit by noise which would not normally harm the load, MC3423 has a programmable delay feature. To implement this feature, the circuit configuration of Figure 5 is used. In this configuration, a capacitor is connected from Pin 3 to V_{EE}. The value of this capacitor determines the minimum duration of the overvoltage condition which is necessary to trip the OVP. The value of C can be found from Figure 10. The circuit operates in the following manner: When V_{CC} rises above the trip point set by R1 and R2, an internal current source (Pin 4) begins charging the capacitor, C, connected to Pin 3. If the overvoltage condition disappears before this occurs, the capacitor is discharged at a rate $\cong$ 10 times faster than the charging rate, resetting the timing feature until the next overvoltage condition occurs.

Occasionally, it is desired that immediate crowbarring of the supply occur when a high overvoltage condition occurs, while retaining the false tripping immunity of Figure 5. In this case, the circuit of Figure 6 can be used. The circuit will operate as previously described for small overvoltages, but will immediately trip if the power supply voltage exceeds V_{Z1} + 1.4 V.

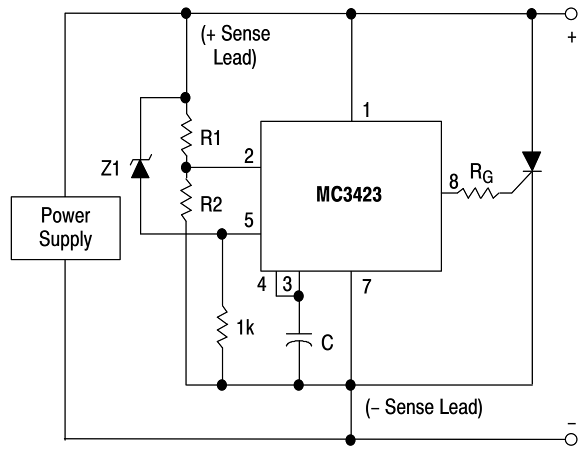


Figure 6. Configuration for Programmable Duration of Overvoltage Condition Before Trip/With Immediate Trip at High Overvoltages

Additional Features

1. Activation Indication Output

An additional output for use as an indicator of OVP activation is provided by the MC3423. This output is an open collector transistor which saturates when the OVP is activated. In addition, it can be used to clock an edge triggered flip–flop whose output inhibits or shuts down the power supply when the OVP trips. This reduces or eliminates the heatsinking requirements for the crowbar SCR.

2. Remote Activation Input

Another feature of the MC3423 is its remote activation input, Pin 5. If the voltage on this CMOS/TTL compatible input is held below 0.8 V, the MC3423 operates normally. However, if it is raised to a voltage above 2.0 V, the OVP output is activated independent of whether or not an overvoltage condition is present. It should be noted that Pin 5 has an internal pull–up current source. This feature can be used to accomplish an orderly and sequenced shutdown of system power supplies during a system fault condition. In addition, the activation indication output of one MC3423 can be used to activate another MC3423 if a single transistor inverter is used to interface the former’s indication output to the latter’s remote activation input, as shown in Figure 7. In this circuit, the indication output (Pin 6) of the MC3423 on power supply 1 is used to activate the MC3423 associated with power supply 2. Q1 is any small PNP with adequate voltage rating.

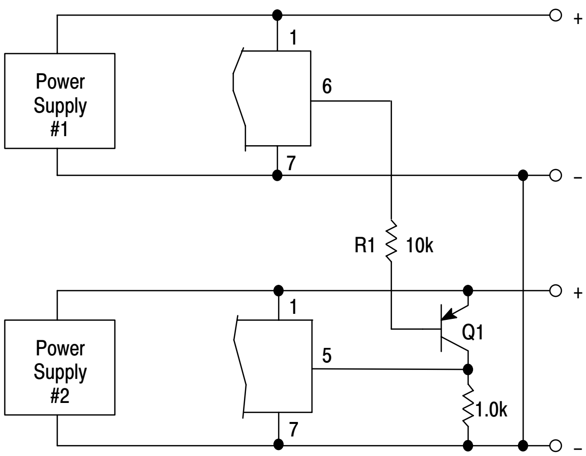


Figure 7. Circuit Configuration for Activating One MC3423 from Another

Note that both supplies have their negative output leads tied together (i.e., both are positive supplies). If their positive leads are common (two negative supplies) the emitter of Q1 would be moved to the positive lead of supply 1 and R1 would therefore have to be resized to deliver the appropriate drive to Q1.

Crowbar SCR Considerations

Referring to Figure 11, it can be seen that the crowbar SCR, when activated, is subject to a large current surge from the output capacitance, C_{out}. This capacitance consists of the power supply output caps, the load's decoupling caps, and in the case of Figure 11A, the supply's input filter caps. This surge current is illustrated in Figure 12, and can cause SCR failure or degradation by any one of three mechanisms: di/dt, absolute peak surge, or I^2t. The interrelationship of these failure methods and the breadth of the applications make specification of the SCR by the semiconductor manufacturer difficult and expensive. Therefore, the designer must empirically determine the SCR and circuit elements which result in reliable and effective OVP operation. However, an understanding of the factors which influence the SCR's di/dt and surge capabilities simplifies this task.

di/dt

As the gate region of the SCR is driven on, its area of conduction takes a finite amount of time to grow, starting as a very small region and gradually spreading. Since the anode current flows through this turned–on gate region, very high current densities can occur in the gate region if high anode currents appear quickly (di/dt). This can result in immediate destruction of the SCR or gradual degradation of its forward blocking voltage capabilities – depending on the severity of the occasion.

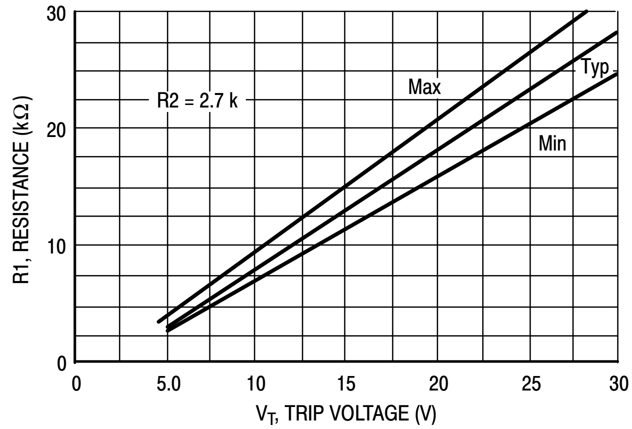


Figure 8. R1 versus Trip Voltage

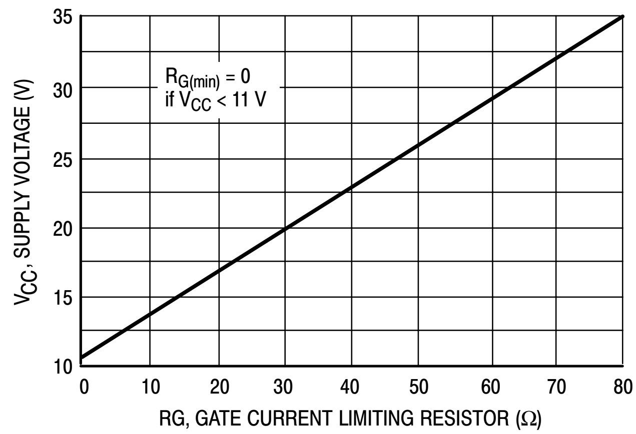


Figure 9. Minimum R_G versus Supply Voltage

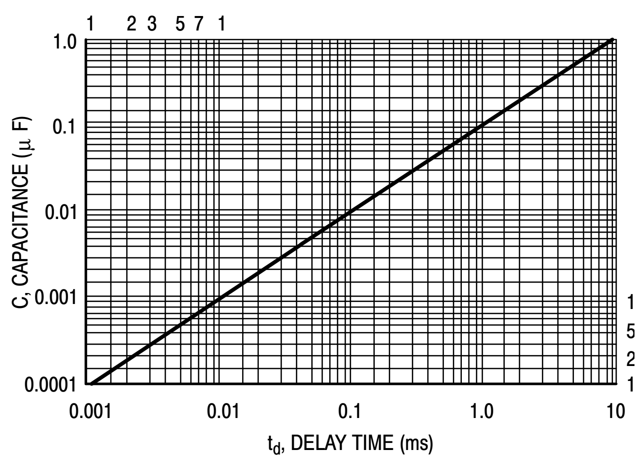


Figure 10. Capacitance versus Minimum Overvoltage Duration

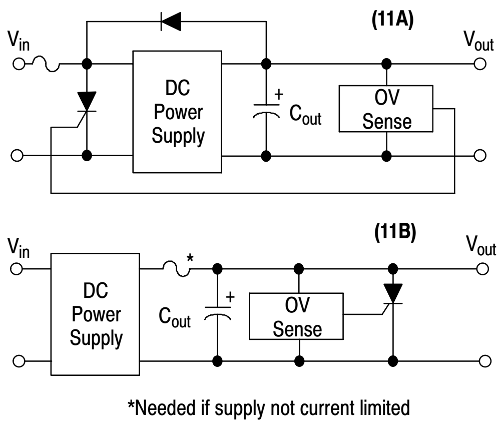


Figure 11. Typical Crowbar OVP Circuit Configurations

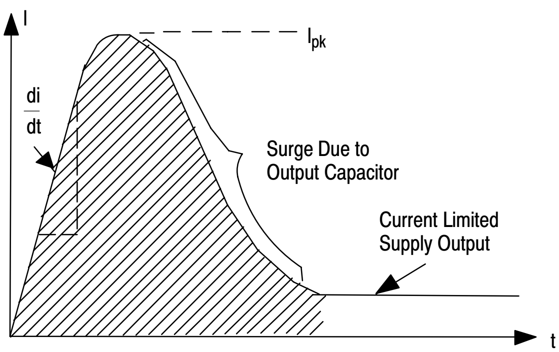


Figure 12. Crowbar SCR Surge Current Waveform

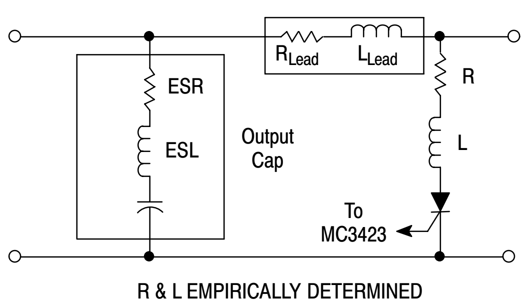


Figure 13. Circuit Elements Affecting SCR Surge and di/dt

The usual design compromise then is to use a garden variety fuse (3AG or 3AB style) which cannot be relied on to blow before the thyristor does, and trust that if the SCR does fail, it will fail short circuit. In the majority of the designs, this will be the case, though this is difficult to guarantee. Of course, a sufficiently high surge will cause an open. These comments also apply to the fuse in Figure 11B.

The value of di/dt that an SCR can safely handle is influenced by its construction and the characteristics of the gate drive signal. A center–gate–fire SCR has more di/dt capability than a corner–gate–fire type, and heavily overdriving (3 to 5 times I_{GT}) the SCR gate with a fast <1.0 µs rise time signal will maximize its di/dt capability. A typical maximum number in phase control SCRs of less than 50 A(RMS) rating might be 200 A/µs, assuming a gate current of five times I_{GT} and < 1.0 µs rise time. If having done this, a di/dt problem is seen to still exist, the designer can also decrease the di/dt of the current waveform by adding inductance in series with the SCR, as shown in Figure 13. Of course, this reduces the circuit's ability to rapidly reduce the DC bus voltage and a tradeoff must be made between speedy voltage reduction and di/dt.

Surge Current

If the peak current and/or the duration of the surge is excessive, immediate destruction due to device overheating will result. The surge capability of the SCR is directly proportional to its die area. If the surge current cannot be reduced (by adding series resistance – see Figure 13) to a safe level which is consistent with the systems requirements for speedy bus voltage reduction, the designer must use a higher current SCR. This may result in the average current capability of the SCR exceeding the steady state current requirements imposed by the DC power supply.

A WORD ABOUT FUSING

Before leaving the subject of the crowbar SCR, a few words about fuse protection are in order. Referring back to Figure 11A, it will be seen that a fuse is necessary if the power supply to be protected is not output current limited. This fuse is not meant to prevent SCR failure but rather to prevent a fire!

In order to protect the SCR, the fuse would have to possess an I^2t rating less than that of the SCR and yet have a high enough continuous current rating to survive normal supply output currents. In addition, it must be capable of successfully clearing the high short circuit currents from the supply. Such a fuse as this is quite expensive, and may not even be available.

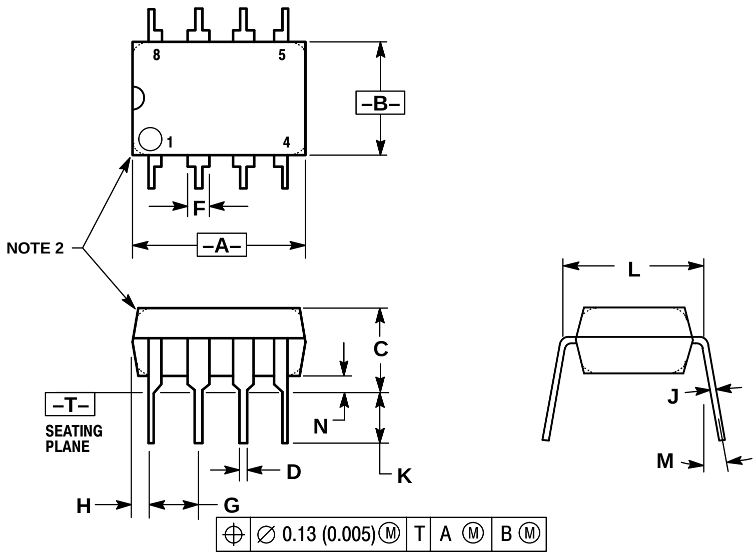
CROWBAR SCR SELECTION GUIDE

As an aid in selecting an SCR for crowbar use, the following selection guide is presented.

Device	I_{RMS}	I_{FSM}	Package
2N6400 Series	16 A	160 A	TO–220 Plastic
2N6504 Series	25 A	160 A	TO–220 Plastic
2N1842 Series	16 A	125 A	Metal Stud
2N2573 Series	25 A	260 A	Metal TO–3 Type
2N681 Series	25 A	200 A	Metal Stud
MCR3935–1 Series	35 A	350 A	Metal Stud
MCR81–5 Series	80 A	1000 A	Metal Stud

PACKAGE DIMENSIONS

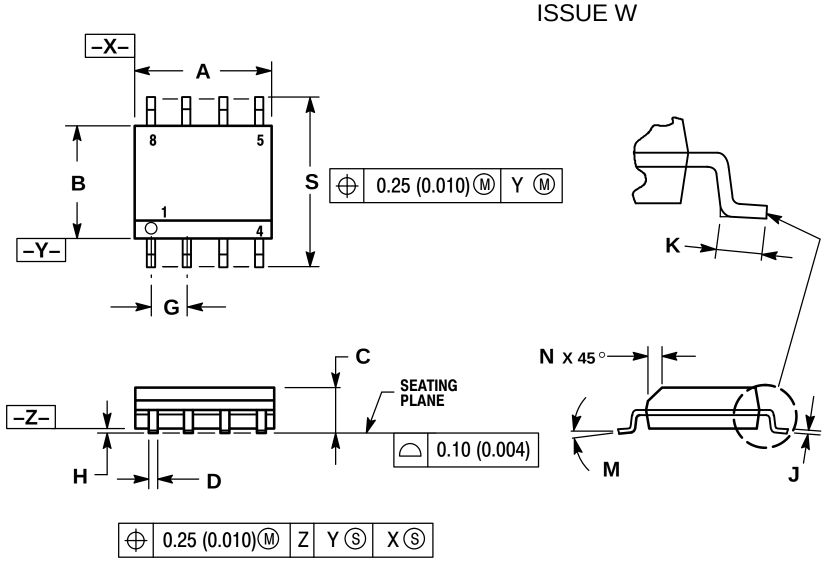
P1 SUFFIX
PLASTIC PACKAGE
CASE 626–05
ISSUE L



NOTES:
1. DIMENSION L TO CENTER OF LEAD WHEN FORMED PARALLEL.
2. PACKAGE CONTOUR OPTIONAL (ROUND OR SQUARE CORNERS).
3. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	9.40	10.16	0.370	0.400
B	6.10	6.60	0.240	0.260
C	3.94	4.45	0.155	0.175
D	0.38	0.51	0.015	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
H	0.76	1.27	0.030	0.050
J	0.20	0.30	0.008	0.012
K	2.92	3.43	0.115	0.135
L	7.62 BSC		0.300 BSC	
M	---	10°	---	10°
N	0.76	1.01	0.030	0.040

D SUFFIX
PLASTIC PACKAGE
CASE 751–07
(SOP–8)
ISSUE W



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 (0.005) TOTAL IN EXCESS OF THE D DIMENSION AT MAXIMUM MATERIAL CONDITION.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	4.80	5.00	0.189	0.197
B	3.80	4.00	0.150	0.157
C	1.35	1.75	0.053	0.069
D	0.33	0.51	0.013	0.020
G	1.27 BSC		0.050 BSC	
H	0.10	0.25	0.004	0.010
J	0.19	0.25	0.007	0.010
K	0.40	1.27	0.016	0.050
M	0°	8°	0°	8°
N	0.25	0.50	0.010	0.020
S	5.80	6.20	0.228	0.244