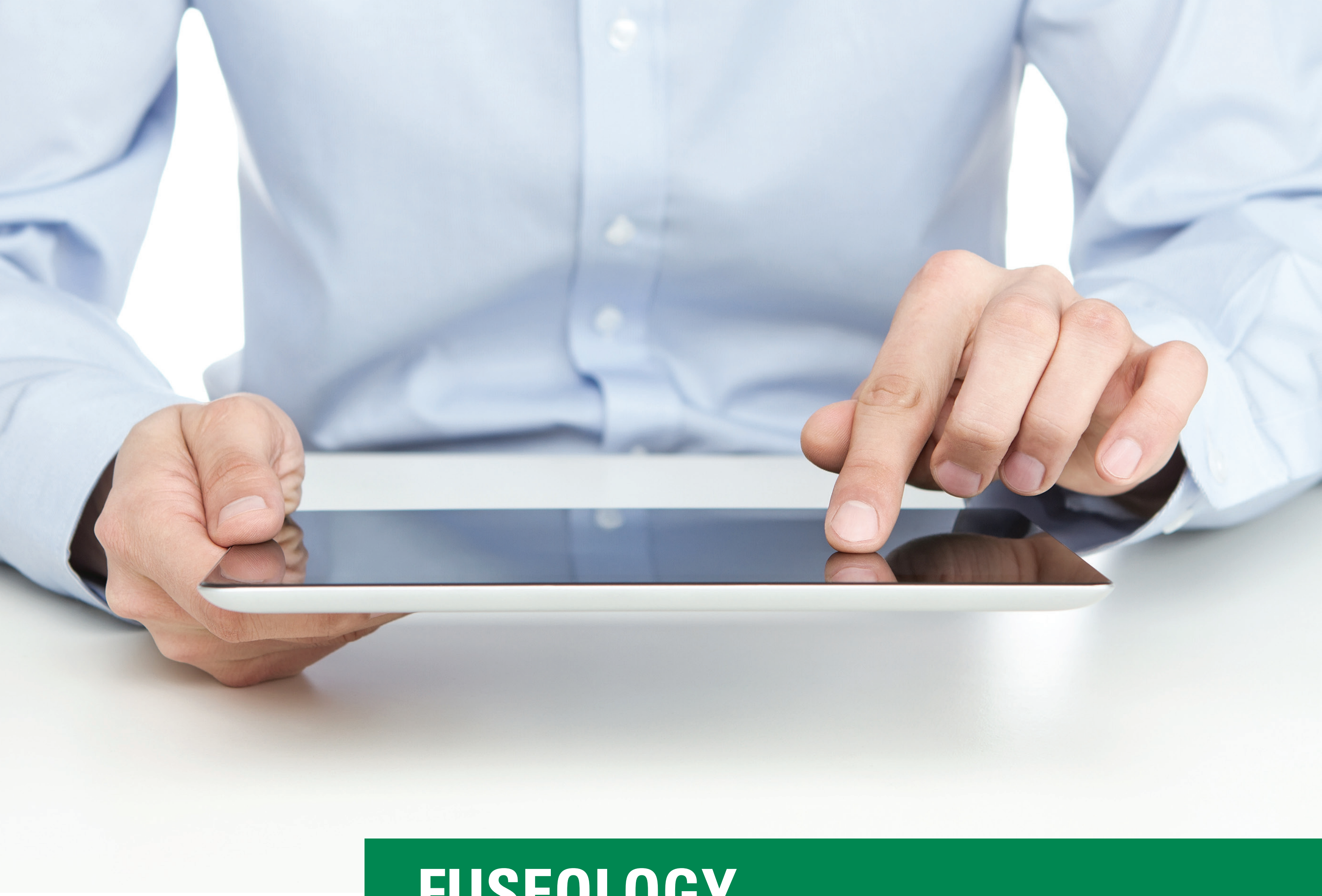


FUSEOLOGY

I. Introduction

The purpose of this Fuseology section is to promote a better understanding of fuses and some of the more 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 a fuse is to provide discrete component or complete circuit protection by reliably melting under overcurrent conditions and thus safely interrupting the flow of current.

II. Types of Overcurrents

An overcurrent is any current which exceeds the ampere rating of wiring, equipment or devices under conditions of use. The term "overcurrent" includes both overloads and short circuits.

A. Overloads

An overload is an overcurrent which is confined to normal current paths. An overload occurs when the current exceeds the value for which the wires or equipment are rated. This can happen when too many devices are connected to the circuit, or when a device connected to the circuit malfunctions in a way that causes it to draw higher than normal current, usually in the range of one to six times normal current. Sustained overloads eventually overheat circuit components. Therefore, fuses must open circuits experiencing sustained overloads before damage occurs.

B. Short Circuits

A short circuit is current out of its normal path. It occurs when accident or malfunction creates an unintended path for the electricity to flow from the battery or alternator to ground. This shorter, more direct path to ground bypasses the resistance normally offered by the wiring and devices connected to the circuit. With virtually no resistance left to impede current flow, the voltage forces higher and higher current to flow through the wires to the point of the short. Under such a condition, the current will quickly build to such a high level that the heat generated can cause insulation to burn and equipment to be damaged unless the circuit is opened through the use of a fuse.

III. Fuse Selection Parameters

Since overcurrent protection is crucial to reliable electrical system operation and safety, fuse selection and application should be carefully considered. When selecting fuses, the following parameters should be evaluated:

A. Voltage Rating

The voltage rating, as marked on a fuse, indicates the maximum voltage of the circuit for which the fuse is designed to operate safely in the event of an overcurrent. Therefore, the fuse's voltage rating must equal or exceed the available circuit voltage where the fuse will be installed. System voltage exceeding the fuse's rated voltage may result in fuse damage. The voltage rating is 32 volts DC for the MINI®, MAXI®, ATO®, MIDI®, MEGA®, and CABLEPRO® Fuses.

B. Interrupting Rating

The interrupting rating (also known as breaking capacity or short circuit rating) is the maximum current, as stated by the manufacturer, which the fuse can safely interrupt at rated voltage. During a fault or short circuit condition, a fuse may receive an instantaneous current many times greater than its normal operating current. Safe operation requires that the fuse remain intact (no body rupture) and clear the circuit. The interrupting rating is 1000A @ 32 volts DC for the MINI®, MAXI®, ATO®, JCASE®, and MIDI® Fuses, and 2000A @ 32 volts DC for the MEGA® and CABLEPRO® Fuses.

C. Time-Current Characteristics

A fuse's time-current characteristics determine how fast it responds to different overcurrents. All fuses have inverse time-current characteristics, so opening time decreases as overcurrents increase. Time-current characteristics are presented graphically on standardized "log-log" paper. Figure 1 is a sample time-current curve for the MAXI Fuse series for fuses rated 20-60A. Current values increase from left to right, and time increases from bottom to top. The average melting time for any current can be determined from the curve. For example, from Figure 1 it can be determined that a 20A MAXI Fuse experiencing an overload of 100A will open in about 0.5 seconds. At 40A, the same 20A MAXI Fuse would open in about 9 seconds.

Time-current curves are also used to compare fuses of the same series but of different current ratings. Suppose it was desired to compare the opening times of 20A and 60A MAXI Fuses at an overload of 100A. From the curve in Figure 1, one can see that the 20A fuse opens in about 0.5 seconds at 100 amps, whereas the 60A fuse does not open until about 50 seconds.

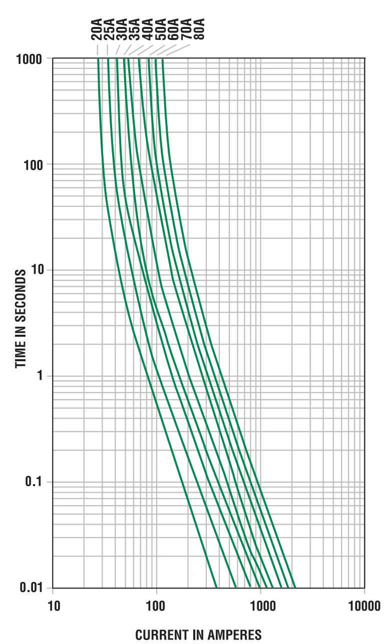


Figure 1: Average Melting-Current Curve for the MAXI Fuse Series (20-60A)

It is important to note that time-current curves give only average melting times and are presented as a design aid but are not considered as part of the fuse specifications.

The term used in fuse design that describes how rapidly a fuse responds to various overcurrents is the fuse's "characteristics." Automotive fuse characteristics are determined by the fuse's degree of time delay. Initial or start-up pulses are normal for many automotive applications and require fuses to have a time delay designed in to enable them to survive these pulses and still provide protection against prolonged overloads. Fuses such as the MINI® Fuse and ATO® Fuse have a moderate degree of time delay, whereas fuses like the MAXI® Fuse and MEGA® Fuse have a high degree of time delay which enables them to handle high inrush currents like those caused by motor start-ups. Figure 2 compares sample time-current curves of a 30A MINI Fuse to a 30A MAXI Fuse. To see that the MAXI Fuse has more time delay than the MINI Fuse, compare their opening times at an overload of 100A. Despite the fact that the fuses are the same rating, the MINI Fuse opens in about 0.1 seconds while the MAXI Fuse opens in about 2.2 seconds.

When selecting a fuse, the start-up pulse should be defined and then compared to the time-current curve for the fuse.

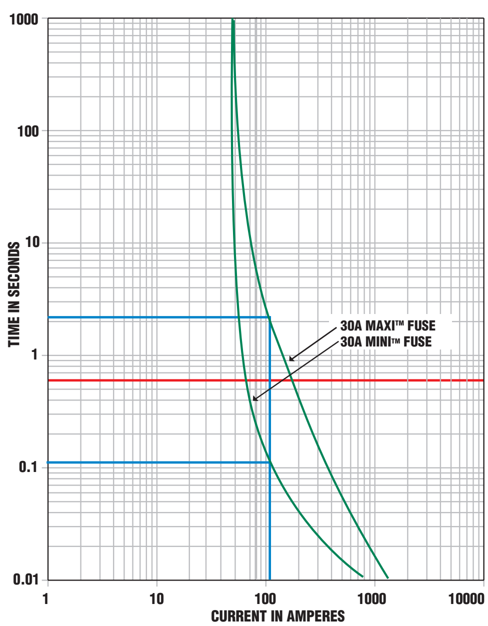


Figure 2: Average Melting-Current Curve Comparing 30A MINI Fuse to 30A MAXI Fuse

D. Current Rating
The current rating is the maximum current which the fuse can continuously carry under specified conditions.

1. Normal Operating Current Based On Rerating

1.1 At Room Temperature
The current rating of a fuse is typically derated 25% for operation at 25˚C to avoid nuisance blowing. This means that the new current carrying capability of the fuse is equal to 75% of its rating.

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.

1.2 At a Different Ambient Temperature
The Rerating curve is based on a voltage drop adjustment at different ambient temperatures.

The current carrying capacity of fuses is affected by changes in ambient temperature.

At higher ambient temperatures, a fuse will respond faster to a given overload. Conversely, at lower ambient temperatures, a fuse will respond slower to a given overload. In addition, the temperature of the fuse increases as the normal operating current approaches or exceeds the rating of the fuse.

Figure 3 is the temperature rerating curve for the MAXI® Fuse.

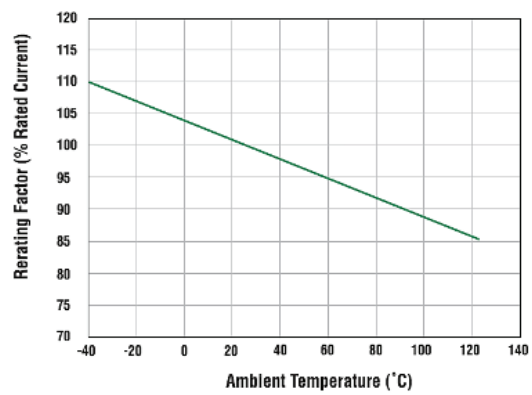


Figure 3: MAXI Temperature Rerating Curve

Suppose there is a normal operating current of 26 amperes in a particular circuit, and the ambient temperature will be 100˚C instead of 25˚C. Which MAXI® Fuse rating should be used? From Figure 3, the percent of rated current to be used at an ambient temperature of 100˚C is 89%, so:

$$\text{Ideal Fuse Rating} = \frac{\textit{Nominal Operating Current}}{\textit{Temp Rerating Factor} \times 0.75}$$

$$\text{Ideal Fuse Rating} = \frac{26\text{A}}{0.89 \times 0.75} = 38.9 \text{ A}$$

Therefore, a next higher fuse rating like 40A or larger should be used.

Please review wire gauge selection at various ambient temperatures in section "IV" of fuseology guide to properly match wire gauge at highest ambient temperature.

2. Normal Operating Current Based On Derating

The Derating curve is based on an individual temperature rise curve.

The Derating curve defines the maximum current load that a component (typically, the fuse melting element) can continuously carry without exceeding its maximum temperature limit.

The maximum admitted temperature of a specific component is strictly correlated to the material (and the plating, if present) of the component itself and expected life time.

The derating curve is deduced from the temperature rise of the component when it is crossed by a certain current: the higher is the current, the higher is the temperature reached. This is reached as a result of the Joule effect.

Derating curve graphs are calculated with a safety temperature margin of 20%

Main characteristics of the derating curve:

- It is specific for each single fuse rating of a fuse series (MINI®, MEGA®, ZCASE®…);
- It is affected by the ambient temperature surrounding of the component;
- It is affected by the system set-up (connections, wires size etc..)

Figure 4 is an example of a Derating curve for a MAXI® 40 A fuse element.

The following example shows how to use such a curve.

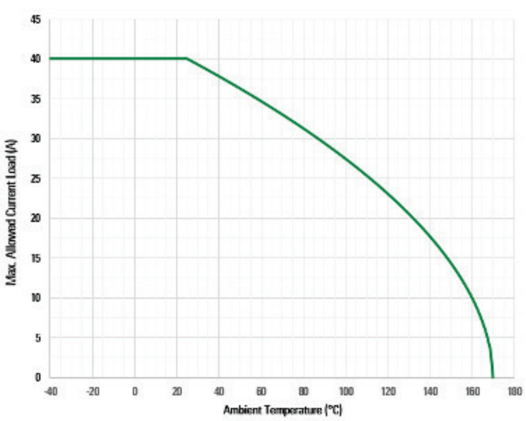


Figure 4: MAXI fuse 40 A Derating Curve

Suppose to have this fuse operating at an ambient temperature of 100 °C.

Which is the current capability of the fuse?

From Figure 4, the maximum current that the fuse can bear at 100 °C is 27.5 A.

3. Comparison between rerating and derating curve

Let's try to obtain the same information using both curves, considering again a MAXI® fuse 40 A and an ambient temperature of 100 °C.

In the previous point 2 we already defined that – according to the Derating Curve (Figure 4) - a MAXI® fuse 40 A can bear 27.5 A at a temperature of 100 °C.

Doing the same calculation using the Rerating curve (Figure 3), we'll obtain:

Fuse rating x Temp rerating factor x0.75 = 40 A x 0.89 x 0.75 = 26.7 A

Littelfuse® recomendation is to use the rerating rule as a first and quick method to identify the most suitable fuse rating based on the current load of a specific circuit.

The Derating curve allows to have a more precise information about the maximum current capability of every single fuse* (or any other component in the circuit) in relation to the ambient temperature.

*Derating curves may change depending on the final condition of the application (terminals characteristics, wire size etc..). Please ask Littelfuse® for more information.

E. Transient Overcurrent Considerations

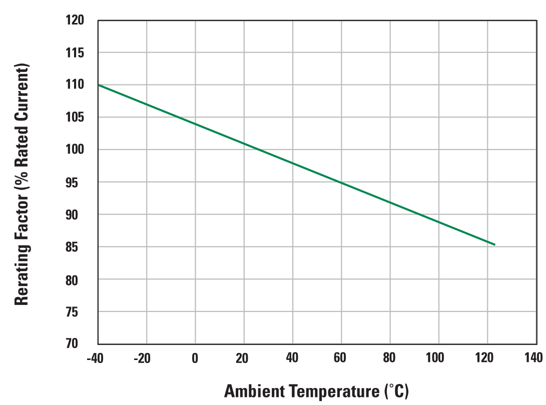


Figure 5: MINI Auto Fuse 297 Series Temperature Rerating Curve

Transient pulses of inrush current are commonplace in vehicle electrical systems. The transient overcurrent pulses affect the life of automotive fuses.

1. **I²t**

   I^2t is an expression of the available thermal energy resulting from current flow. With regard to fuses, the term is usually expressed as melting, arcing, and total clearing I^2t. The units for I^2t are expressed in ampere-squared-seconds [A^2s].

   Melting I2t: the thermal energy required to melt a specific fuse element.

   Arcing I2t: the thermal energy passed by a fuse during the arcing time. The magnitude of arcing I^2t is a function of the available voltage and stored energy in the circuit.

   Total Clearing I2t: the thermal energy through the fuse from overcurrent inception until current is completely interrupted. Total clearing I^2t = (melting I^2t) + (arcing I^2t).

   I^2t has two important applications to fuse selection. The first is pulse cycle withstand capability and the second is selective coordination.

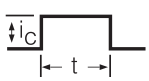
2. **Pulse Cycle Withstand Capability**

   Electrical pulses produce thermal cycling and possible mechanical fatigue that could affect the life of the fuse.

   For this reason, it is important to know the pulse cycle withstand capability of the fuse, which is defined as the number of pulses of a given I^2t value that can be withstood by the fuse without opening, assuming that there is sufficient cool down time between pulses.

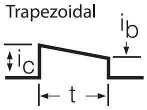
WAVESHAPE — FUNCTION AND VALUE

Square



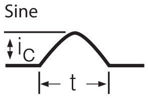
$i = k$
$I^2t = i_C^2t$

Trapezoidal



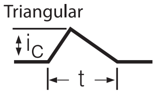
$i = i_C \pm kt$
$I^2t = (1/3)(i_C^2+i_bi_C+i_b^2)t$

Sine



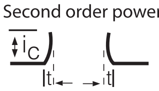
$i = i_C \sin t$
$I^2t = (1/2)i_C^2t$

Triangular



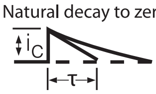
$i = \underline{+}\, kt$
$I^2t = (1/3)i_C^2t$

Second order power



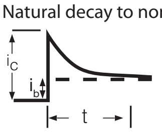
$i = kt^2$
$I^2t = (1/5)i_C^2t$

Natural decay to zero



$i = i_Ce\text{-}t/\tau$
$I^2t = (1/2)i_C^2\,\tau$

Natural decay to non-zero value



$$I^2t= i_b^2t - 2\tau i_b(i_c-i_b)(e^{-t/\tau}-1)-\tau/2(i_c-i_b)^2(e^{-2t/\tau}-1)$$

Figure 6: Evaluating the I²t of a Variety of Current Wave Shapes

Figure 6 shows how I^2t of the pulse can be calculated from the graph of the pulse current as a function of time.

Figure 7 is a graph of the pulse cycle withstand capability of blade fuses. Because electrical pulse conditions can vary considerably from one application to another, application testing is recommended to establish the ability of the fuse design to withstand the pulse condition.

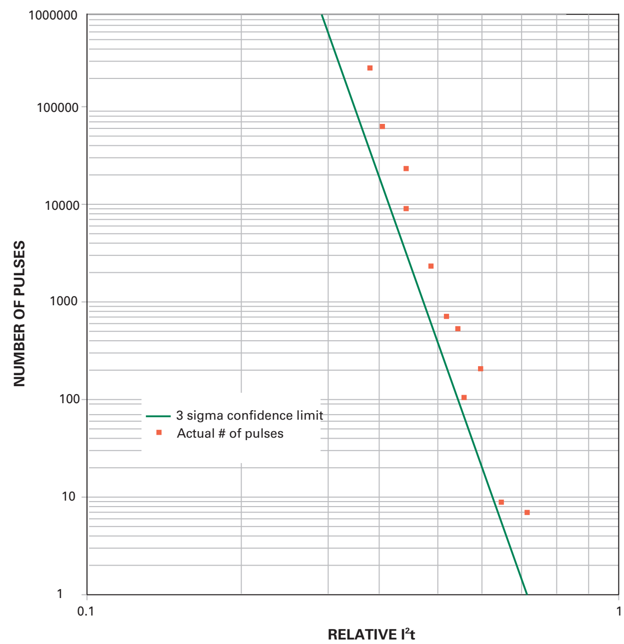


Figure 7: Pulse Cycle Withstand Capability for Blade Fuses

3. **Selective Coordination**

   In a selectively coordinated system, only the fuse immediately on the line side of an overcurrent opens. Upstream fuses remain closed and undamaged. All other equipment remains in service, which simplifies locating overloaded equipment or short circuits. In Figure 8, if a short circuit arises behind fuse #1, fuse #1 should open and fuse #2 should stay closed and undamaged. The condition necessary to assure this result is that the minimum melting I^2t of the supply side fuse (fuse #2) must be greater than the total clearing I^2t of the load side fuse (fuse #1). This condition results in the load side fuse opening before the supply side fuse begins to melt. Minimum melting and total clearing I^2t data are given in this catalog.

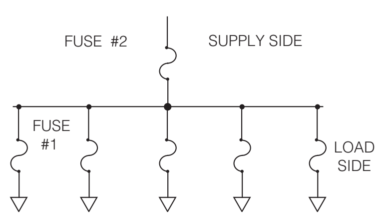


Figure 8: Selective Coordination for Fuses in Series

IV. Voltage Drop Across Terminals

A fuse is only as good as the system in which it is used. One aspect of the electrical system that has considerable effects on the performance of the fuse is the quality of the connection between the fuse and the cable it protects. High voltage drop across the fuse/terminal interface creates additional thermal loading, which in turn causes shifts in the time-current characteristics of the fuse. Table 1 below gives the maximum recommended voltage drop per terminal for automotive fuses. Figure 9 indicates the measurement locations used to determine the voltage drop across the terminal. The voltage drop across the left terminal would be $V_{2\text{-}4}$ and the voltage drop across the right terminal would be $V_{1\text{-}3}$.

Type	Maximum Recommended Voltage Drop Per Terminal [MV] (between points 1-3 or 2-4)
ATO® FUSE	30
MINI® FUSE	30
MAXI® FUSE	30
MEGA® FUSE	15

Table 1: Maximum Recommended Voltage Drop per Terminal

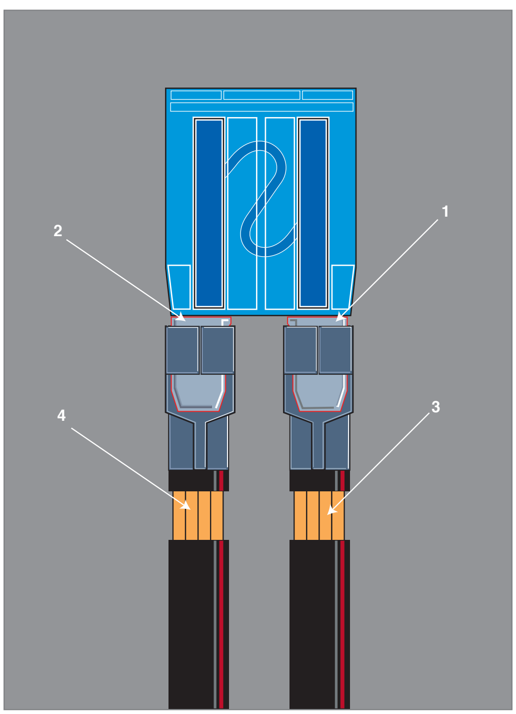


Figure 9: Measurement Locations along the Fuse/Terminal/Cable System Used to Determaine the Voltage Drop across the Terminal

V. Diffusion

Diffusion Pill Technology is a mixing of molecules, atoms or crystals in the solid, liquid or gaseous state. Diffusion Pill Technology is often used in the design of fuses for automotive, electronic and industrial fuse applications.

"M-effect" is the method of diffusing one metal into another to form a new alloy with a lower melting point. Littelfuse uses the "M-effect" to produce three very desirable characteristics in fuse designs: lower melting temperature, time delay, and lower voltage drop.

By affixing a diffusion pill tin to the element, the melting temperature is decreased. This decrease in melting temperature reduces the fuse rating. In order to reestablish its original rating the fuse elements' cross section needs to increase. An increase in cross section increases the blow time at higher overload condition. A higher degree of time delay enables a fuse to withstand higher current inrush pulses. This increase in cross section reduces the overall fuse resistance and voltage drop.

VI. Match Wire Gauge to Fuse

In order to protect wiring under all overload and short circuit conditions, it is necessary to standardize the fuse and wire selection process.

Fuses have controlled opening characteristics, and each wire gauge has its respective current carrying capacity. Fuses need to be selected to always protect the wire insulation from damage.

In the selection of wire gauge at various ambient temperatures, it is important to consider the worst case or highest ambient temperature for the application. Wires derate to a much higher degree than fuses, because wire insulation temperature capability is affected much more severely.

Maximum Recommended Continuous Current

Wire Size		Max Continuous Current (A)				
		At 25°C		At 80°C		At 105°C
mm²	Gage No.	GXL (1)	GPT (2)	GXL (1)	GPT (2)	GXL (1)
0.3		15	10	11	4	9
0.5	20	21	15	16	6	13
0.75		27	21	20	7	17
0.8	18	31	22	23	7	19
1	16	33	23	25	9	20
1.5		43	30	33	12	27
2	14	50	36	37	14	32
2.5		60	42	45	15	38
3	12	68	47	51	18	42
4		80	56	61	22	50
5	10	90	65	68	23	58
6		103	73	78	28	64
8	8	125	87	96	30	79
10		146	103	111	40	90
13	6	170	120	129	47	105
19	4	221	156	166	61	137

(1) = General purpose cross link polyethylene insulation wire with a maximum insulation temperature of 155˚C.
(2) = General purpose thermoplastic insulation wire with a maximum insulation temperature of 90˚C.